Preliminary Geologic Map of the Valle Toledo Quadrangle, Sandoval and Los Alamos Counties, New Mexico.

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Scale 1:24,000

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New Mexico Bureau of Geology and Mineral Resources
801 Leroy Place, Socorro, New Mexico, 87801-4796

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GEOLOGIC MAP OF THE VALLE TOLEDO 7.5-MINUTE QUADRANGLE, SANDOVAL AND LOS ALAMOS COUNTIES, NEW MEXICO

1:24,000

By

Jamie N. Gardner[1], Fraser Goff[2], Steve L. Reneau[3], M. Magdalena Sandoval[2], Paul G. Drakos[4], Danny Katzman[3], and Cathy J. Goff[5]

[1]14170 NM-4, Jemez Springs, NM 87025
[2]Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131
[3]EES-9, MS D452, Los Alamos National Laboratory, Los Alamos, NM 87545
[4]Glorieta Geoscience, Inc., 1723 Second St., Santa Fe, NM 87505
[5]Independent Consultant, 5515 Quemazon, Los Alamos, NM 87544

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DISCUSSION

Introduction

Most of the Valle Toledo 7.5-minute quadrangle is in Sandoval County, but the eastern edge captures the northwest part of Los Alamos County. The Valles Caldera National Preserve covers about 85% of the quadrangle with the remaining lands being parts of the Santa Fe National Forest and Santa Clara Pueblo. The topography is mountainous, with beautiful intervening valleys, and altitudes range from just below 8540 feet in upper Valle Grande on the southern edge of the quadrangle to over 10,920 feet at Cerro Toledo on the northern edge of the quadrangle. At least thirteen summits have altitudes over 10,000 feet. The quadrangle is bounded by the Sierra de los Valles on the east, Santa Clara Canyon on northeast, Sierra de Toledo on the north, and Valle Grande on the south. The headwaters of three important perennial streams occur within the area of the Valle Toledo quadrangle: both San Antonio Creek and East Fork Jemez River have headwaters just southeast of the center of the quadrangle in Valle de los Posos and upper Valle Grande, respectively, and Santa Clara Creek's headwaters are just east of Cerro Toledo.

Because of the high altitude of the Valle Toledo quadrangle, ancient peoples apparently did not make permanent homes in the map area; however, we observed evidence for seasonal hunting camps in many of the valleys. Additionally, ancient obsidian quarry sites are abundant around Cerro del Medio, and lithic scatters of obsidian flakes totally blanket some areas. Since prehistoric times land use has been mainly for seasonal grazing of cattle and sheep; in fact early Twentieth Century shepherd graffiti is abundant in some aspen stands. Most of the map area formed the northeast corner of Baca Location #1, originally established as a Spanish land grant in 1860 (Martin, 2003). Obtained by Frank Bond of Española in 1926, the "Baca" was later sold to James P. Dunigan and the Baca Land and Cattle Company in 1962. Extensive logging operations persisted in the map area until the 1960s, with some areas being seriously decimated, but from 1962 until 2000 the Baca Ranch was mainly a cattle operation with additional proceeds derived from elk hunts and geothermal exploration leases. With the Valles Caldera Preservation Act in 2000, the federal government purchased the Baca Ranch and most of it became the Valles Caldera National Preserve. The Preserve is managed for limited grazing, scientific studies, and recreational activities, such as hiking, biking, cross country skiing, fishing, and elk hunting.

Geology of the Valles-Toledo caldera complex dominates the Valle Toledo quadrangle. Two voluminous and explosive eruptions of Bandelier Tuff occurred at about 1.6 and 1.2 Ma forming the Toledo and Valles calderas, respectively (Self et al., 1986; Izett and Obradovich, 1994; Spell et al., 1996; Phillips et al., 2007). In many places the two calderas are spatially coincident, with the younger Valles caldera obliterating most evidence of the older Toledo caldera; however, the Valle Toledo quadrangle is one area where structural distinctions between the two calderas can be inferred. With this framework, the geology of the Valle Toledo quadrangle can be divided into several distinct environments: the caldera complex walls, composed of Tertiary volcanic rocks and sedimentary deposits, in the northwest and northeast corners of the quadrangle and along the eastern edge of the map; the Toledo caldera ring fracture and Toledo Embayment, marked by post-caldera rhyolite domes and flows, plugs of Tertiary dacite, and ponded Bandelier Tuff in roughly the northeastern half of the quadrangle; part of the resurgent dome of Valles caldera with early caldera-fill deposits and immediately post-caldera volcanics in the southwest corner of the map; the Valles caldera ring fracture marked by a swath of post-caldera rhyolite domes, flows, and minor pyroclastic deposits across the roughly southwestern half of the quadrangle; and, the intermountain valleys which hosted post-caldera lakes and alluvial systems.

This map is the result of a collaborative project among Los Alamos National Laboratory, New Mexico Bureau of Geology and Mineral Resources, and Valles Caldera National Preserve, with the purpose of creating 1:24000-scale geologic maps of the caldera as a basis for resource management, scientific studies, and interpretive materials. Additionally, the project contributes geologic quadrangle maps to the STATEMAP Program. Mapping of this quadrangle was done in 1981 and in 2002, 2003, and 2005. Gardner and Goff (1996) presented the results of the 1981 mapping, some of which was remapped as part of the current effort. Regional geology and stratigraphy have been previously published by Griggs (1964), Bailey et al. (1969), Smith et al. (1970), Kelley (1978), Gardner (1985), Gardner and Goff (1984) and Gardner et al. (1986). Adjacent and nearby geologic maps have been published by Goff et al. (1990; 2002; 2006a; 2006b), Kempter and Kelley (2002), Kempter et al., (2004; 2005), and Lawrence et al., (2004).

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Stratigraphy

The Valle Toledo quadrangle offers an abundance of geologically young rocks, with about 75% of the map area covered with Quaternary units, most of which are 1.25 million years old and younger. Outside of blocks in the caldera collapse breccia unit (Qxbo), the oldest exposed volcanic rocks are andesites, estimated to be roughly 8 to 10 million years old, of the Paliza Canyon Formation, exposed in the northwest corner of the quadrangle and in Santa Clara Canyon on the northeast edge of the map. In the northwest corner, the andesites are overlain by a thick sequence of interbedded arkosic sandstone, volcaniclastic deposits, and dacites. The bottom of the sequence contains rocks of clear Paliza Canyon affinity, and the top has rocks that are clearly La Grulla Formation dacites (see Goff et al., 2011 for list of stratigraphic changes). Problematic are intermediate composition volcanics in the middle. Further dating of units in this sequence will be difficult because hydrothermal alteration is intense and pervasive; however, further work is warranted because this area may reveal important relations among Paliza Canyon volcanic and volcaniclastic units, Santa Fe Group sediments, Puye Formation, and La Grulla Formation. The sequence appears to be largely conformable from bottom to top. Gardner and Goff (1996) point out that unit Tscu represents basin-fill deposits at the eastern margin of the volcanic field, revealing the interbedding of arkosic sandstones with proximal volcanic and volcaniclastic material. Bearhead Rhyolite intrudes the sedimentary and intermediate composition volcanic sequence and is responsible for the widespread alteration. The alteration, it should be noted, affects the lowermost La Grulla dacites. Individual dikes and intrusive bodies of Bearhead Rhyolite are difficult to map because of intense alteration and poor exposures; some are depicted, some with exaggeration, on the map, but there are many more that could not be mapped.

The La Grulla Formation consists of dacitic domes, flows, and plugs that overlie, for the most part, or intrude (?) the older rocks. The rhyodacite on the north caldera rim

(Tgbhd), however, is intruded by Bearhead Rhyolite and affected by the associated hydrothermal alteration, and has an age of 7.42 ± 0.05 Ma. Tschicoma Formation dacites form the northeastern and eastern rims of the caldera complex in the quadrangle, and a northeast-trending chain of three plugs in the Toledo Embayment. Two of these plugs, Cerro Rubio and the hill just north of it, were originally interpreted to have erupted immediately prior to (Ttcr) and immediately following (Ttcd) eruption of the Tshirege Member of the Bandelier Tuff (Smith et al., 1970; Smith, 1979). Work in the 1980s indicated, however, that both of the plugs were older than either member of the Bandelier Tuff, and that temporally and geochemically the plugs are part of the Tschicoma Formation (Heiken et al., 1986; Self et al., 1986; Stix et al., 1988; Gardner et al., 2010). Additionally, outcrops of Tshirege Member occur on top of the plugs.

Approximately 400 km^3 of the Otowi Member of the Bandelier Tuff were erupted during formation of the Toledo caldera at about 1.6 Ma. Otowi tuffs are not exposed in the map area, but are shown on the cross-sections because numerous drilling projects have revealed a thick sequence of caldera-fill Otowi Member (Goff and Gardner, 1994). From about 1.6 to about 1.25 Ma rhyolites erupted as domes, lavas, and pyroclastic flows and falls from both the Toledo caldera ring fracture and outside of it. These units make up the Valle Toledo Member of the Cerro Toledo Formation (Gardner et al., 2010; Goff et al., 2011). An arc of these domes, including the Los Posos and Trasquilar domes in the Valle Toledo quadrangle, was originally assigned to the Valles Rhyolite (Smith et al., 1970), but later dating and petrologic work indicated they are part of the Cerro Toledo Formation. The revised stratigraphic assignment of these domes was part of what contributed to the recognition of and the re-definition of the position of the Toledo caldera (Heiken et al., 1986; Self et al., 1986).

A second episode of enormous eruptions of rhyolitic Bandelier Tuff, this time the Tshirege Member at about 1.25 Ma, accompanied development of the Valles caldera. Almost immediately following caldera formation, structural upheaval of the caldera floor, preceded and in part accompanied by small volume volcanism representing the earliest eruptions of the Valles Rhyolite, formed the resurgent dome of Valles caldera. The Valle Toledo quadrangle only catches a small part of the northeastern portion of the resurgent dome, but the tilting on the flank of the resurgent structure is particularly evident at Cerro Piñon (southwest end of cross-section B-B’). Valles Rhyolite continued to be erupted with the earliest post-resurgence date of 1.229 Ma (Phillips et al., 2007) at Cerro del Medio. After possibly more than 80 thousand years of volcanism building the Cerro del Medio dome and flow complex (Gardner et al., 2007), the focus of activity generally migrated counterclockwise through the caldera moat, forming Cerro del Abrigo and Cerro Santa Rosa from about 0.97 to 0.80 Ma. Valles Rhyolite volcanism continued in the neighboring quadrangles to the west, southwest, and south (Valle San Antonio, Redondo Peak, and Bland quadrangles).

Alluvial, lacustrine, and colluvial systems developed, overlapping with and post-dating Valles Rhyolite volcanism (units Qmso, Qafo, Ql, and Qto). Older mass wasting events (Qlso) on the flanks of some domes and the caldera walls also occurred during roughly the same time period. At about 0.5 Ma, lakes existed in the Valle Toledo and Valle

Grande from eruptions of moat rhyolites into creeks downstream of these valleys (San Antonio Mountain and South Mountain, respectively). In the late Pleistocene the youngest caldera-hosted lake developed with the eruption of El Cajete damming the East Fork Jemez River drainage (Reneau et al., 2007). Deposits and landforms of this youngest lake are found in the southwest part of the quadrangle (units Qlec and Qlb, as well as a shoreline cut on older fans, Qafo). Also likely in the late Pleistocene, boulder fields (Qrx) developed mostly on north- and west-facing slopes of the domes and caldera walls. At least some of these boulder fields are periglacial features (Blagbrough, 1994).

Structure and Tectonics

Structurally, the Valle Toledo quadrangle includes part of the resurgent dome of Valles caldera, a Miocene margin of the Rio Grande rift, portions of the inferred ring fracture systems of both the Toledo and Valles calderas, the Toledo embayment, and a number of faults.

A strong northeastern-trending structural grain, locally coincident with the Jemez lineament, is evident in the caldera region. This structural grain is expressed as the Jemez fault zone, faults on the resurgent dome, the Toledo Embayment elongation of the caldera depression, the Santa Clara Canyon fault zone, and the Embudo fault zone. Additionally, geophysical data indicate that deep caldera structure is dominated by northeast-trending fault bounded blocks (Goff et al., 1989). Aldrich and Dethier (1990) presented evidence that the Embudo fault zone and northeast-trending ancestral Santa Clara Canyon drainage have existed since middle Miocene time. The sequence of rift-fill sediments with interbedded volcanics, north of Trasquilar dome, thickens to the east and becomes more dominantly sedimentary to the east. These relations lead Gardner and Goff (1996) to the conclusion that some vestige of the Toledo Embayment has existed as a structural tough or rift basin in the past, and that the embayment area has a long history of structurally influenced sedimentation and fluvial incision. While north-trending faults to the west of the map area were part of the >13 to 6 Ma western margin of the Rio Grande rift (Gardner and Goff, 1984), major northeast-trending rift structure or structures must have existed in the area now obscured by the embayment. The northeast-trending faults that cut Cerro Rubio and the Santa Rosa and Trasquilar domes are likely remnants of this structural zone.

As discussed above, the arc of domes, including the Los Posos and Trasquilar domes in the Valle Toledo quadrangle, and Warm Springs dome in the Valle San Antonio quadrangle, was originally assigned to the Valles Rhyolite (Smith et al., 1970), but later dating and petrologic work indicated they are part of the Cerro Toledo Formation. The revised stratigraphic assignment of these domes was part of what contributed to the recognition of and the re-definition of the position of the Toledo caldera ring fracture system (Heiken et al., 1986; Self et al., 1986). This, however, left the Toledo embayment to be a bit of an enigma, and origins of the embayment were the subject of some speculation (Heiken et al., 1986; Self et al., 1986; Goff et al., 1989; Turbeville et al., 1989; etc.).

Considering timing constraints, the structural and tectonic history of the area, and field relations, Gardner and Goff (1996) concluded that the depression of the Toledo Embayment must have formed during collapse of the Toledo caldera. While the main ring fracture zone of the Toledo caldera is marked by the arc of the Los Posos and Trasquilar domes in the map area, clearly the embayment is part of the Toledo caldera by virtue of age of its formation and the concentration of Valle Toledo Member rhyolite domes in it. Gardner and Goff (1996) argued that the Toledo (Otowi) magma chamber was slightly elongated to the northeast along "regional faults," which, given the discussion above must have been major rift-related structures. When the magma chamber was sufficiently evacuated, collapse occurred on both the Toledo ring fracture system and the northeast-trending structures.

With eruption of the Tshirege Member of the Bandelier Tuff, the Valles caldera developed with the main ring fracture, as inferred from the positions of post-caldera domes, distinctly inboard of the Toledo caldera ring fracture in the Valle Toledo quadrangle. Additionally, based on the plan shape of the Valles caldera, the northeast-trending structural grain did not influence magma chamber shape. As mentioned above, however, the northeast-trending structural grain is pronounced in deep caldera structure (Goff et al., 1989), consisting of large northeast-trending fault blocks surrounded by the ring fracture faults.

Structural upheaval of the floor of Valles caldera occurred within a few tens of thousands of years of caldera formation (Phillips, 2004; Phillips et al., 2007). The southwest corner of the Valle Toledo quadrangle captures a small part of this upheaval as the northeast tip of the resurgent dome. The tilting of units caused by resurgent doming is particularly evident at Cerro Piñon (southwest end of cross-section B-B'). The map area only includes a few of the numerous faults that developed during resurgent doming, and these are east-southeast-trending normal faults at the southwest edge of the quadrangle.

Several faults with significant displacements on Tschicoma dacites occur on the east side of the quadrangle. The north-trending faults may be related to the Pajarito fault system, farther to the east, but age relations and structural connections remain unclear. One fault just north of Pajarito Mountain exhibits an east-southeastern trend, similar to the faults of the resurgent dome on the west side of the quadrangle.

Hydrothermal Alteration

There are two zones of hydrothermal alteration, each representing separate events, in the quadrangle: alteration in the north caldera wall and alteration on the resurgent dome. The new mapping has provided some revelations regarding hydrothermal activity in the basin-fill sediments and volcanic rocks west of the Toledo Embayment within the north caldera wall. Intrusion of many Bearhead rhyolite bodies (described above) has resulted in rather widespread silicification accompanied by clays, pyrite and iron oxides. Detailed work has not been done on the alteration assemblages but we suspect that smectite, kaolinite, and possibly illite-smectite are variably developed. Iron oxides include substantial limonite, goethite, and locally hematite forming bright orange to brick red outcrops. Other sulfides besides pyrite have not yet been identified.

The alteration is particularly common along contacts with the rhyolite. Smaller rhyolite bodies are so pervasively altered that virtually no original textures remain, and only shattered, druzy quartz and chalcedony are present. Where the rhyolite intrudes sedimentary rocks, the alteration is so complete that commonly the contact between rhyolite and sandstone is obscure. Quartz veins, some with open fractures, also cut some altered zones. Chlorite may be present in some of the andesitic rocks but is not present in the rhyolites or sedimentary rocks. Some of the coarser sediments are so thoroughly cemented by hematite that they look like ironstones. As mentioned above, the alteration appears to be younger than early La Grulla volcanism because some rhyolite bodies cut La Grulla rocks that show alteration only in proximity to the rhyolites. Thus this alteration appears to be related to the rhyolite intrusions, about 5 to 7 Ma.

On the resurgent dome, we have identified widespread zeolite, clay, and silica alteration products in lacustrine deposits, interbedded Deer Canyon rhyolite lavas and tuffs, and uppermost Bandelier Tuff on the resurgent dome (Chipera et al., 2007; Goff et al., 2007). Where found, the zeolite alteration only affects the upper 10 m or so of the Bandelier Tuff and is localized. It does not affect the entire resurgent dome. The primary zeolites are clinoptilolite and mordenite. Clinoptilolite is most common in the sediments while mordenite is most common in the lavas and tuffs.

Localized silicification occurs along some faults of the resurgent dome, quite distant from active hydrothermal area in the Redondo Creek graben (southwest of the map area). The alteration rarely consists of massive quartz replacement of Bandelier Tuff and other rocks up to 1.5 m surrounding the faults, but more commonly consists of quartz to opal deposition in gouge zones about 0.5 m wide. The silicification may be associated with Fe-oxide staining, particularly in the opal. This fault-controlled silicification may represent conduits for rising hydrothermal fluids during the growth of the resurgent dome.

DESCRIPTIONS OF UNITS

Note: Descriptions of map units are listed in approximate order of increasing age. Formal stratigraphic names are described in Griggs (1964) and Bailey et al. (1969) with usage revised in Gardner et al. (1986), Goff et al. (1990), Goff and Gardner (2004), and Gardner et al. (2010). Field names of volcanic rocks are based on hand specimens and petrography and may differ from names based on chemical classifications (Wolff et al., 2005). Significant changes in regional stratigraphy and nomenclature have occurred in this area since this map was first compiled and are described in the ***Geologic Map of the Valles caldera, Jemez Mountains, New Mexico*** (Goff et al., 2011).

Quaternary Deposits

Qal **Alluvium—**Deposits of gravel, sand and silt in canyon bottoms; locally includes stream terraces and canyon wall colluvium; mostly Holocene in age; maximum thickness exceeds 15 m.

Qc **Colluvium—**Poorly sorted slope wash and talus deposits from local sources; mapped only where extensive or where covering critical relations; unit is commonly gradational into *Qafo*; mostly Holocene and Pleistocene in age; thickness can locally exceed 15 m.

Qaf **Alluvial fans—**Fan-shaped deposits of coarse to fine gravel, sand, silt, and clay along tributary drainages, at the mouths of valleys and in the Valle Grande; maximum exposed thickness about 15 m.

Qt **Younger stream terraces**—Deposits of sand, gravel, and silt that underlie young terraces bordering present streams; inferred to be largely Holocene or late Pleistocene in age; maximum thickness uncertain.

Qls **Landslides—**Unsorted debris, slumps, or block slides partially to completely intact, that have moved down slope; slumps and block slides usually display some rotation relative to their failure plane; thickness varies considerably depending on the size and nature of the landslide.

Qlec/Qlb **El Cajete lake deposits—**Deposits of reworked El Cajete pumice and coarse sand in Valle Grande; Qlec occurs below the upper level of a lake formed when deposits of El Cajete pumice dammed the East Fork Jemez River (Reneau et al., 2004, 2007); may include some primary El Cajete fall deposits that were buried by the lake; Qlb designates constructional landforms along and near the margin of the lake, including beach ridges and spits; age about 50 to 60 ka; maximum thickness about 4 m.

Qrx **Boulder fields**—Areas covered with dark grey to dark brown, large (up to 3 m) boulders derived from subjacent rock units; generally devoid of vegetation; many appear to be rock glaciers, exhibiting flowage features such as arcuate pressure ridges (Blagbrough, 1994); thickness unknown.

Qto **Older stream terraces—**Deposits of gravel, sand, silt, and clay below higher stream terraces along the margins of present streams and basins; overlies *Qdf*, *Ql*, Valles Rhyolite and Cerro Toledo Formation; underlies *Qlec* in Valle Grande; maximum thickness at least 5 m.

Qlso **Older landslides—**Older slide deposits that are overlain by older terrace gravels (*Qto*); maximum exposed thickness about 25 m.

Qafo **Older alluvial fans—**Older deposits of coarse to fine gravel and sand derived mostly from the volcanic domes, resurgent dome, and caldera walls; in Valle Grande these fans represent alluvial systems established earlier than the El Cajete pumice and associated lacustrine deposits *(Qlec, Qlb);* in Valle Toledo these fans overlie and interfinger with *Qto* and overlie *Qlso*; portions of fans are still active; contact with *Qc*, particularly around flanks of volcanic domes, is gradational; thickness is unknown.

Ql **Lacustrine deposits of Valle Toledo and upper Valle Grande**—Finely laminated to thickly bedded deposits of clay, silt, and very fine sand, derived by erosion of surrounding rock units, and deposited in lakes; locally includes coarser sand and gravel near shoreline; deposits commonly tuffaceous, and diatomaceous facies occur; overlies older alluvial fans (*Qafo*) and older landslides (*Qlso*); underlies older terrace gravels (*Qto*); maximum exposed thickness about 6 m.

Qmso **Older sedimentary deposits of northern caldera—**Debris flow, landslide, and minor fluvial deposits that resemble early caldera fill sediments (*Qdf*, described below) but which also contain fragments of lava and pumice from Cerro del Medio rhyolites; age about 1.2 to 0.9 Myr; maximum exposed thickness about 25 m.

Qalo **Older alluvium—**Gravel, sand, and silt generally overlying the Tshirege Member, Bandelier Tuff on the rim and flanks of Valles caldera; largely pre-date incision of canyons in surrounding plateaus and highlands; gravels consist primarily of volcanic fragments from sources near the deposits and possibly from within the caldera; 20-m-thick lobe of Qalo overlying Tgbhd and Qcnr consists primarily of white to pale gray debris flows containing mostly fragments of rhyodacite and rhyolite in a poorly exposed sandy matrix. Roughly contemporaneous in age to north caldera sediments (Qmso) and early caldera debris flows (Qdf).; maximum exposed thickness about 15 m.

TEWA GROUP (Pleistocene)

Valles Caldera

Qvsr/Qvsrt **Cerro Santa Rosa Member (Valles Rhyolite)—**(Note on terminology: this entire dome complex was originally referred to as Cerro Santa Rosa [for example, Doell et al., 1968; Smith et al., 1970] and this terminology remains entrenched in the literature [for example, Spell and Harrison, 1993; Singer and Brown, 2002]. We retain this usage, but, unfortunately, recently revised topographic maps restrict the name Cerro Santa Rosa to what we map as *Qvsr*$_2$, and label the entire chain of domes including the Santa Rosa complex and Trasquilar dome [*Qctq*] “Cerros de Trasquilar.”) Two domes and flows of petrographically and chemically similar, but temporally and magnetically dissimilar, rhyolite. *Qvsr*$_2$: Dome of white, porphyritic rhyolite with 15 to 20 % phenocrysts (up to 4 mm) of abundant pink quartz, subordinate sanidine, and trace biotite euhedra; groundmass glassy and pumiceous; outcrops massive to flow banded; dated by $^{40}Ar/^{39}Ar$ at 0.787 Ma +/- 0.015 (one sigma error, Spell and Harrison, 1993); maximum thickness about 150 m. *$Qvsr_1$*: White to grey dome and flows of porphyritic rhyolite with 10 to 15 % fine (1 to 2 mm) to coarse (4mm) phenocrysts of abundant quartz, subordinate sanidine, and sparse, small biotite; groundmass glassy and pumiceous; dome exhibits a breccia apron around summit; west flank of unit, on the Valle San Antonio quadrangle, includes petrographically similar flows, with chatoyant sanidine, that may be of different age; dated by $^{40}Ar/^{39}Ar$ at 0.914 Ma +/- 0.004 (one sigma error, Spell and Harrison, 1993) and 0.936 +/- 0.008 (two sigma error, Singer and Brown, 2002); maximum thickness over 240 m on the Valle San Antonio quadrangle. *Qvsrt*: Poorly exposed deposit of gray lithic-rich pumice forming rounded hill east of *$Qvsr_1$*; may be equivalent in age to Santa Rosa ignimbrite exposed to west of dome (0.91 Ma; Goff et al., 2006, 2011); maximum thickness about 75 m.

$Qvda_x$ **Cerro del Abrigo Member (Valles Rhyolite)--**Complex of four dome and flow sequences of finely porphyritic rhyolite with subtle petrographic variations. Spell and Harrison (1993) give a composite $^{40}Ar/^{39}Ar$ date of 0.973 Ma +/- 0.010 for the entire complex. *$Qvda_4$*: white to grey devitrified rhyolite with 10% felsic phenocrysts (about 1 mm) of dominantly sanidine with subordinate amounts of quartz and plagioclase; quartz occurs as both euhedral and embayed forms; trace biotite and hornblende and sparse glomerocrysts of felsic phases, biotite, and magnetite; maximum exposed thickness about 255 m. *$Qvda_3$*: white to grey devitrified rhyolite with 15% relatively large (2-4 mm) phenocrysts of dominantly sanidine and lesser amounts of plagioclase; pale pink quartz is sparse, large (3-4 mm), and embayed; sparse 2 mm biotite and extremely rare hornblende; sparse opaque phases; maximum exposed thickness about 245 m. *$Qvda_2$*: white perlitic rhyolite with 10% felsic phenocrysts (1-2 mm) of dominantly sanidine with subordinate plagioclase; biotite and embayed, pale pink quartz are sparse and relatively large (about 1 mm); sparse opaques; trace tiny (0.1 mm) hornblende; maximum exposed thickness about 405 m. *$Qvda_1$*: apron of white perlitic rhyolite exposed on erosional platforms on south side of dome complex; porphyritic with 20% felsic phenocrysts (2 mm) of dominantly sanidine and subordinate plagioclase and embayed, pale pink quartz; sparse partial bipyrimidal forms of quartz; biotite up to 1%; trace hornblende; glomerocrysts of sanidine +/- plagioclase +/- biotite +/-quartz; maximum exposed thickness about 65 m.

$Qvdm_x$ **Cerro del Medio Member (Valles Rhyolite)—**Dome and flow complex of at least six distinctive phases of rhyolitic activity; includes pyroclastic fall deposits (*Qvdmt*) on north flank of Cerro del Medio and pyroclastic flows on the Valle San Antonio quadrangle. Stratigraphic relations and dates among the three oldest flow lobes do not permit discrimination of their sequence; thus, they are designated north, west, and south ($Qvdm_n$, $Qvdm_w$, and $Qvdm_s$, respectively). The sequence of eruption of the three youngest phases is clear from field relations, and, thus these units are designated from oldest to youngest $Qvdm_4$, $Qvdm_5$, and $Qvdm_6$. Spell and Harrison (1993) gave a composite $^{40}Ar/^{39}Ar$ date of 1.133 Ma +/- 0.011 (one sigma error) for the entire Cerro del Medio complex. However, detailed work by Phillips (2004, unpub.) has yielded very high precision dates on $Qvdm_s$ and $Qvdm_4$ that indicate the Cerro del Medio eruptions up through $Qvdm_4$ spanned at least 40,000 to 80,000 years, and that more dating of the complex could be fruitful. *Qvdmt*: white to grey, crudely bedded pumice fall deposit with cognate pyroclasts up to 20 cm; unit commonly has strong pedogenic overprint and is extensively colluviated; pumice pyroclasts are sparsely phyric with sanidine laths and glomerocrysts of sanidine plus opaques; sanidines are weakly zoned and inclusion-free; unit is likely associated with eruption of $Qvdm_6$ based on petrographic similarities; thickness uncertain due to blanketing nature of deposit, but is at least 4 meters maximum thickness. $Qvdm_6$: massive, devitrified, grey, pumiceous rhyolite flow with about 5% small (<2 mm) phenocrysts of sanidine laths and glomerocrysts of sanidine plus opaques; sanidines are weakly zoned and largely inclusion-free; vent and associated breccia are near the topographically highest point on Cerro del Medio; maximum exposed thickness about 45 m. $Qvdm_5$: upheaved dome of vitrophyric to devitrified rhyolite; locally flow banded; sparsely phyric with 1-3% sanidine phenocrysts in blocky and lath-shaped forms; phenocrysts are moderately zoned and some exhibit cores and zones riddled with inclusions (mostly glass); sparse opaque phases; extremely rare clinopyroxene and zircon; margins of unit near contacts with older units, where well-exposed, are vertically foliated breccia with elongate clasts, oriented parallel to the contact, set in a very fine grained matrix; maximum exposed thickness about 215 m. $Qvdm_4$: massive, brown to black, aphyric obsidian flow; flow banded and devitrified around unit margins; obsidian from this unit is so clean and free of inclusions and crystals that it was a highly desired material for tool and point making for ancient peoples; ancient quarry sites are common within the unit and lithic scatters include exotic rocks, such as rounded quartzite cobbles from axial river deposits near the Rio Grande, that were used as hammer stones; ancient peoples quarried the obsidian from this unit for so many millennia that there are very few true outcrops left; maximum exposed thickness about 260 m. Phillips (unpub.) has $^{40}Ar/^{39}Ar$ data that suggest 1.169 Ma +/- 0.005 (two sigma error) is a good age estimate for $Qvdm_4$, consistent with a previous $^{40}Ar/^{39}Ar$ date of 1.161 Ma +/- 0.010 on this unit (Izett and Obradovich, 1994). $Qvdm_n$: grey to light brown, pumiceous, flowbanded, glassy to devitrified rhyolite; sparsely phyric with about 5% phenocrysts of sanidine and glomerocrysts of sanidine plus opaques; some sanidine phenocrysts are strongly zoned; rare clinopyroxene; maximum exposed thickness about 30 m. *Qvdm*$_w$: light brown to black, obsidian flow; locally devitrified and flow banded; nearly apyric with <1% small (<0.3 mm) sanidine and very sparse magnetite; maximum exposed thickness about 120 m. Izett and Obradovich (1994) dated this unit at 1.207 Ma +/- 0.017. *Qvdm*$_s$: grey to light brown, flow banded, sparsely porphyritic, devitrified rhyolite; approximately 5% phenocrysts of sanidine and glomerocrysts of sanidine; sparse hornblende and embayed quartz; rare plagioclase; maximum exposed thickness about 75 m. Phillips (2004) and Phillips et al. (2007) dated *Qvdm*$_s$ by $^{40}Ar/^{39}Ar$ at 1.229 Ma +/- 0.017.

Qdf **Early caldera fill; alluvial, debris flow, landslide, and colluvial deposits—**Dark gray to buff, matrix-supported beds containing fine silt to boulders of various early post-caldera rhyolites, Bandelier Tuff, precaldera volcanic rocks, Miocene to Permian sandstone, Pennsylvanian limestone and Precambrian crystalline rocks; unit contains fluvial sand and gravel deposits; cobbles of older lithologies are more abundant in the lower beds; upper beds generally contain more precaldera volcanic rocks; rare beds contain mostly Bandelier Tuff; formed during rapid slumping and erosion of caldera walls, erosion of exposed megabreccia blocks (e.g., *Qxbo*), and erosion of previously formed beds during uplift of the resurgent dome; finer-grained matrix is generally not exposed; weathering produces a lag of boulders on landscape; lower part of unit displays extensive, low-grade hydrothermal alteration; fault relations in this unit are often difficult to determine; interbedded with and overlies all other units on resurgent dome; maximum exposed thickness in map area is 50 m.

Qdc **Deer Canyon Member, lava unit (Valles Rhyolite)—**Massive, gray to pale pink, aphyric rhyolite lavas usually containing tiny phenocrysts of sanidine and quartz (Bailey et al., 1969); some sanidine is chatoyant; groundmass is generally silicified; flow breccias are often opalized and iron-stained; most exposures are highly deformed by uplift and faulting on the resurgent dome of Valles caldera; many exposures show extensive zeolitic alteration; overlies Deer Canyon tuffs (*Qdct*); interbedded with *Qdf* and generally overlies *Qvs*; overlies Bandelier Tuff; ages of three flows range from 1.28 to 1.25 Ma (Phillips et al., 2007); maximum exposed thickness about 40 m.

Qdct **Deer Canyon Member, tuff unit (Valles Rhyolite)—**White to cream to pale buff lithic-rich rhyolitic tuffs; pumice fragments usually contain phenocrysts of quartz and sanidine; lithic fragments generally consist of Bandelier Tuff and precaldera volcanics; tuff beds usually deformed by faulting; beds often extensively altered to zeolites, silica, Fe-oxides, and clay (Chipera et al., 2007); beds occasionally graded; beds occasionally contain accretionary lapilli and hydromagmatic surge; interbedded with

Qdc, *Qdf*, and *Qvs*; overlies *Qbt*; ages of five tuffs range from 1.27 to 1.23 Ma (Phillips et al., 2007); maximum exposed thickness about 30 m.

Qvs **Early caldera fill lacustrine and fluvial deposits (shown on cross-sections only)—**White to buff, laminated to thinly bedded, diatomaceous mudstone and siltstone, and generally white to gray to tan cross bedded to normally graded sandstone and conglomerate; sandstone and conglomerate beds contain mostly fragments of rhyolite pumice, tuff and lava but also contain some grains of precaldera volcanics, Miocene to Permian sandstone, and Precambrian crystalline fragments; some beds contain ripple marks, flute casts and plane laminations and could be deltaic deposits near margins of initial caldera lakes; beds generally display zeolitic or less commonly acid sulfate alteration; beds generally deformed by uplift of resurgent dome; usually underlies *Qdc* and *Qdct*; interbedded with *Qdf*; overlies *Qbt*; maximum exposed thickness about 20 m on the Redondo Peak quadrangle.

Qxbo **Caldera collapse breccia—**Caldera-wall landslide breccias (megabreccias) that accumulate synchronously during caldera formation (Lipman, 1976); incorporated in and interbedded with intracaldera Tshirege Member of the Bandelier Tuff; individual blocks mapped if more than 30 m across; within Valle Toledo quadrangle, this unit consists primarily of silicified and brecciated, brownish-red, Otowi Member of the Bandelier Tuff (Qxbo) with phenocrysts of quartz and sanidine; the origin of the brecciated texture is not obvious; other blocks of megabreccia may occur within the map area but are difficult to distinguish from *Qdf* because of poor exposures; generally show baking and odd disaggregation textures around margins if contacts with enclosing *Qbt* are preserved; maximum exposed thickness is highly variable; not shown in cross sections for clarity.

Qbt **Bandelier Tuff, Tshirege Member—**Multiple flows of white to orange to dark gray densely welded to non-welded rhyolitic ash-flow tuff (ignimbrite); 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., 1997); in more welded portions, sanidine typically displays blue iridescence. Upper flow units generally more welded than lower ones. Intracaldera flow units are highly welded with well-developed fiamme and rare vitrophyre. Locally contains a thin (<2 m) laminated, pumice fall and surge deposit at base of unit (Tsankawi Pumice) that contains roughly 1% of hornblende dacite pumice (Bailey et al., 1969). Locally contains accidental lithic fragments of older country rock entrained during venting and pyroclastic flow. Qbt is major unit of the Valles caldera resurgent dome; forms inconspicuous canyon-filling outliers on pre-existing volcanic topography south and east of the caldera and in the Toledo embayment; erupted during formation of the Valles caldera. Most recent $^{40}Ar/^{39}Ar$ age is 1.25±0.01 Ma (Phillips, 2004; Phillips et al., 2007); maximum observed thickness within caldera over 900 m.

CERRO TOLEDO FORMATION (Pleistocene)

Qcpc **Gravel and sandstone (Pueblo Canyon Member)—**Thin deposit of primarily Tschicoma Formation-derived gravels in lower northeast wall of Valles caldera (Goff et al., 2011); sandy matrix very poorly exposed; underlies *Qbt*; overlies rhyodacite of *Ttrc*; maximum exposed thickness about 15 m.

Toledo Embayment

Qcrt **Rhyolite tuff (Valle Toledo Member)—**Two areas of white to gray to black, partially to densely welded, nearly aphyric, rhyolitic tuff; many fragments are vesicular and show flow banding and spherulitic texture; other fragments resemble welded fiamme in pyroclastic flows; microphenocrysts consist of sparse quartz, sanidine, biotite and rare clinopyroxene; tuffs apparently fill the vents for the pyroclastic eruptions; east exposure contains core of aphyric rhyolite lava (*Qcr*); intrudes *Qcr* and *Ttcd*; overlain by *Qbt*; K-Ar age of west exposure (Pinnacle Peak) is 1.20 ± 0.02 Ma (Stix et al., 1988); maximum exposed thickness is roughly 200 m.

Qcr **Aphyric rhyolite (Valle Toledo Member)—**Two dome and flow complexes and two small intrusive bodies of white to gray to black, flow-banded rhyolite; obsidian phases are completely aphyric; devitrified phases contain spherulites and very sparse microphenocrysts of quartz, sanidine, and biotite; locally displays bread crust textures; flow bands are locally oxidized to reddish color; intrudes *Ttcr* and *Qcrt*; overlain by *Qbt*; K-Ar age of dome west of dacite north of Cerro Rubio (*Ttcd*) is 1.33 ± 0.02 Ma (Stix et al., 1988); maximum exposed thickness is 365 m.

Qcs **Sierra de Toledo rhyolite (Valle Toledo Member)—**White to gray, flow-banded, sparsely porphyritic rhyolite with roughly 5% phenocrysts of quartz, sanidine, biotite, and tiny magnetite; sanidine is often chatoyant blue; most samples are devitrified, platy and spherulitic; commonly exhibits bread crust textures; apparently overlies *Qcr*; overlies *Qcwp*; overlain by *Qbt*; possibly originates from two vents; $^{40}Ar/^{39}Ar$ ages of two samples range from 1.34 to 1.38 Ma (Spell et al., 1996); maximum exposed thickness is 365 m.

Qctr **Turkey Ridge rhyolite (Valle Toledo Member)—**White to gray, flow-banded, porphyritic rhyolite with roughly 7% phenocrysts of quartz, sanidine, biotite, and magnetite; sanidine is commonly large and chatoyant; most samples are devitrified, platy and spherulitic; commonly exhibits bread crust textures; overlies *Qci*; overlain by *Qcs* and *Qbt*; has one vent along axis of ridge; $^{40}Ar/^{39}Ar$ age is 1.34 ± 0.02 Ma (Spell et al., 1996); maximum exposed thickness is 490 m.

Qct **Cerro Toledo rhyolite (Valle Toledo Member)—**White to gray, flow-banded, aphyric rhyolite with microlites of quartz, sanidine, biotite; obsidian phase is completely aphyric; rarely contains spherulites and bread crust textures; overlies *Qci* and apparently underlies *Qctr*; underlies *Qbt*; originates from two vents; K-Ar date on Cerro Toledo proper is 1.38 ± 0.05 Ma (Stix et al., 1988); maximum exposed thickness is 520 m.

Qci **Indian Point rhyolite (Valle Toledo Member)—**White to gray, flow-banded, sparsely porphyritic rhyolite with about 3% phenocrysts of quartz and sanidine; biotite is extremely rare; most samples are devitrified and spherulitic; underlies *Qctr* and *Qct*; originates from single vent; $^{40}Ar/^{39}Ar$ age is 1.46 ± 0.01 Ma (Spell et al., 1996); maximum exposed thickness is 410 m.

Qcnr **North caldera rim intrusion—**Flow-banded, sparsely porphyritic rhyolitic intrusive body and minor lava having phenocrysts of quartz, sanidine, and biotite; intrudes *Tgbhd*, *Tpbd*, and *Tscu*; overlain by *Qalo*; $^{40}Ar/^{39}Ar$ age is 1.61 ± 0.03 Ma (Goff et al., 2011); maximum exposed thickness is 50 m.

Toledo Caldera

Qctq **Cerro Trasquilar rhyolite (Valle Toledo Member)—**White to gray to black, flow-banded to massive, sparsely porphyritic rhyolite with tiny phenocrysts of quartz, sanidine, clinopyroxene, opaque oxides and rare biotite; glassy samples usually show perlitic textures; devitrified samples are often spherulitic; flow-banded samples are commonly oxidized to red and orange colors; overlies and intrudes *Tscu* and *Tpa*; underlies *Ql*; erupted from a single vent; $^{40}Ar/^{39}Ar$ age is 1.36 ± 0.01 Ma (Spell et al., 1996); maximum exposed thickness is 225 m.

Qcep **East Los Posos rhyolite (Valle Toledo Member)—**White to gray, flow-banded to massive porphyritic rhyolite with 5% phenocrysts of quartz, sanidine, biotite, hornblende, opaque oxides; rarely contains black glassy groundmass; most samples are devitrified and spherulitic; flow-banded samples often display red to orange oxidation; erupted from a single vent; $^{40}Ar/^{39}Ar$ age is 1.45 ± 0.01 Ma (Spell et al., 1996); maximum exposed thickness is 165 m.

Qcwp **West Los Posos rhyolite (Valle Toledo Member)—**White to gray to black, flow-banded to massive porphyritic rhyolite with 5% phenocrysts of quartz, sanidine, plagioclase, biotite and opaque oxides; commonly contains relict black glass in a spherulitic, flow-banded groundmass; most samples are devitrified; underlies *Qcs* and *Qbt*; erupted from a single vent; $^{40}Ar/^{39}Ar$ age is 1.54 ± 0.01 Ma (Spell et al., 1996); maximum exposed thickness is 370 m.

Qbo **Bandelier Tuff, Otowi Member (shown on cross-sections only)—**White to pale pink to orange, generally poorly welded rhyolitic ash-flow tuff; pumice and matrix contains abundant phenocrysts of sanidine and quartz, and sparse mafic microphenocrysts; sanidine may display a blue iridescence; contains abundant accidental lithic fragments; consists of multiple flow units in a compound cooling unit; contains a stratified pyroclastic fall and surge deposits at base (Guaje Pumice); outflow sheets of *Qbo* discontinuously fill rugged topography on a volcanic surface of pre-Toledo caldera age; very difficult to distinguish from the Tshirege Member of Bandelier Tuff in hand samples and thin sections; 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; originated from catastrophic eruptions that formed Toledo caldera; $^{40}Ar/^{39}Ar$ ages 1.61 ± 0.01 to 1.62 ± 0.04 Ma (Izett and Obradovich, 1994; Spell et al., 1996); maximum exposed thickness on the Redondo Peak quadrangle about 60 m.

Quaternary-Tertiary Deposits

QTp **Puye Formation—**Thin deposit of poorly exposed gravel exposed above northeast wall of upper Quemazon Canyon; apparently underlies Ttqc but overlies Ttrc; sandy matrix poorly preserved; thickness about 6 m.

Tertiary Deposits

KERES GROUP (Pliocene-Miocene)

Tschicoma Formation (Pliocene)

Ttqc **Upper Quemazon Canyon dacite—**Bluish-gray to pinkish-gray, flow-banded to massive, porphyritic dacite with 3% phenocrysts of large plagioclase and small resorbed quartz in a trachytic groundmass of plagioclase, orthopyroxene, clinopyroxene, biotite and opaque oxides; overlies *QTp* and *Ttrc*; erupted on topographic margin of Toledo caldera from now-eroded vent; erupted lava flowed to west; $^{40}Ar/^{39}Ar$ age is 2.92 ± 0.05 Ma; maximum exposed thickness is roughly 65 m.

Ttpm **Pajarito Mountain dacite—**Dome and flow complex of blue-gray to pale pink, massive to sheeted, porphyritic dacite containing phenocrysts of plagioclase, hypersthene, clinopyroxene, rare oxidized biotite and opaque oxides in a devitrified groundmass; contains clots of complexly zoned plagioclase and sparse clots of two pyroxenes; thick flows contain intervals of flow breccia; unit forms a volcanic center probably consisting of several eruptive events; source is Pajarito Mountain northeast of map area on the Guaje Mountain quadrangle; overlies hornblende dacite of Cerro Grande (*Ttcg*); locally underlies Tshirege Member of the Bandelier Tuff (*Qbt*); $^{40}Ar/^{39}Ar$ ages on widely separated samples range from 3.1 to 2.9 Ma (Broxton et al., 2007); maximum exposed thickness is about 365 m.

Ttcb **Caballo Mountain dacite (Tschicoma Formation)—**Dome and flow complex of dark gray to purple-red, massive to sheeted, porphyritic dacite containing large phenocrysts of plagioclase in a trachytic groundmass of plagioclase, clinopyroxene, rare rounded quartz, opaque oxides and oxidized biotite; contains plagioclase-clinopyroxene clots; contains minor flow breccia; source is Caballo Mountain just east of map area; may contain multiple eruptive units; overlies *Ttrc* and *Ttd*; $^{40}Ar/^{39}Ar$ age is 3.06 ± 0.15 Ma (Broxton et al., 2007); maximum exposed thickness about 200 m.

Ttcg **Cerro Grande dacite—**Extensive dome and flow complex of light to dark gray to pale pink, massive to sheeted porphyritic dacite containing phenocrysts of plagioclase, hypersthene, and conspicuous hornblende; the latter two phases commonly show oxidized rims and may be difficult to see in hand sample; contains microphenocrysts of plagioclase, hypersthene and clinopyroxene, and clots of hornblende, hypersthene, plagioclase, and opaque minerals; thick flows contain intervals of flow breccia; source is Cerro Grande in northeast map area; unit forms a volcanic center apparently consisting of several eruptive events; underlies *Ttpm* and Tshirege Member, Bandelier Tuff (Qbt); dates on widely separated samples range from 3.8 to 3.1 Ma (Dalrymple et al., 1967; Broxton et al., 2007); maximum exposed thickness is about 750 m.

Ttcr **Cerro Rubio dacite—**Gray to pink to black, massive to sheeted, fine-grained shallow intrusive dacite with phenocryst assemblage similar to plug *Ttcd* (described below; see Gardner et al., 2010 for stratigraphic change of this unit); contains glassy material near top and upper flanks; intruded by *Qcr* and overlain by *Qbt*; K-Ar age is 3.56 ± 0.36 Ma (Stix et al., 1988); maximum exposed thickness is 440 m.

Ttcd **Dacite north of Cerro Rubio—**White to gray, massive to sheeted, fine-grained dacite plug with small phenocrysts of plagioclase, hornblende, orthopyroxene, sparse biotite and rare quartz in a devitrified groundmass of containing microlites of plagioclase; contains some columnar jointing around margins and top of unit; appears to be a plug with hypabyssal texture; intruded by *Qcr* and *Qcrt*; overlain by *Qbt*; $^{40}Ar/^{39}Ar$ age is 4.21 ± 0.12 Ma (Goff et al., 2011); maximum exposed thickness is 365 m.

Ttsc **Santa Clara Canyon dacite—**Faulted, plug-like, circular body along south side of Santa Clara Canyon near east edge of map; consists of gray, massive to sheeted, porphyritic dacite containing phenocrysts of plagioclase, sanidine, hornblende, biotite, and sparse resorbed quartz in trachytic, glassy to devitrified groundmass with microlites of plagioclase, sanidine, hornblende, biotite, orthopyroxene and opaque oxides; plagioclase is fritted, resorbed, and complexly zoned; contains clots of plagioclase-hornblende; relations with other Tschicoma units uncertain but resembles *Ttcd* and *Ttcr* in petrography; underlies *Qbt*; unit not dated; maximum exposed thickness is 160 m.

Ttpd **Tschicoma Peak area dacite and rhyodacite, undivided—**Gray to pale pink to pale blue, massive to sheeted flows of dacite and rhyodacite exposed in the walls of Santa Clara Canyon in northeast sector of map; flows are generally highly porphyritic containing phenocrysts of plagioclase, pyroxene and opaque oxides ± quartz ± sanidine ± biotite ± hornblende in a trachytic groundmass; overlies *Tpa* and underlies *Qbt*; sources of various flows unknown; may be equivalent to dacitic flows vented near Tschicoma Peak just north of map area (4.46 to 3.57 Ma; (Kempter et al., 2007) or to flows exposed in the walls of Santa Clara Canyon just east of map area (3.91 to 3.79 Ma; WoldeGabriel et al., 2006); maximum exposed thickness is about 565 m.

Ttrc **Rendija Canyon rhyodacite—**Dome and flow complex of gray to pale pink, massive to sheeted, highly porphyritic rhyodacite with phenocrysts of quartz, sanidine, complexly zoned and fritted plagioclase, hornblende and biotite in a trachytic groundmass of plagioclase, hornblende, orthopyroxene, biotite, opaque oxides and apatite; quartz is conspicuous, pale pink and resorbed; hornblende and biotite commonly oxidized; sanidine content varies considerably (Warren, 2005, unpub.); probably represents a volcanic center with several eruptive events; probable vent occurs on northwest-trending ridge south of Quemazon Canyon where frothy, vesicular lava is locally oxidized to orange; possible vent occurs on east edge of map north of Pipeline Road as white, pumiceous, finer-grained rhyodacite; underlies *Ttcb, Ttpm, Ttqc* and *Qbt*; probably underlies *Ttpd* and *Ttcg*; overlies Paliza Canyon Formation andesite (*Tpa*) in Los Alamos Canyon to east in the Guaje Mountain quadrangle; dates on widely separated samples range from 5.36 to 3.50 Ma (Goff et al., 1989; Broxton et al., 2007; Goff et al., 2011); maximum exposed thickness approximately 500 m.

Bearhead Rhyolite (Pliocene? – Miocene)

Tbh **Bearhead intrusive rocks—**White to gray to pale orange dikes, plugs and flows (?) of slightly porphyritic, devitrified to completely silicified rhyolite containing sparse phenocrysts of quartz, sanidine, plagioclase, biotite and opaque oxides in a groundmass containing abundant microlites of feldspar and biotite; rhyolite is rarely flow-banded; dikes may display complicated intrusive relations with country rocks; widths of individual dikes shown on map are commonly exaggerated to be shown at 1:24,000, and may consist of many smaller sub-parallel dikes; pervasive, hydrothermal alteration consists primarily of quartz, chalcedony and/or opal, illite, Fe and Mn oxides, pyrite and possibly other sulfides, alunite, jarosite and gypsum (Goff et al., 2011); intrudes other Keres Group rocks, Tertiary sedimentary rocks (*Tscu*) and La Grulla Formation rhyodacite (*Tgbhd*); probably equivalent to the early and intermediate rhyolite of Loeffler et al. (1988) dated at 7.5 to 5.8 Ma located north of the map area; $^{40}Ar/^{39}Ar$ age of dike west of Rito de los Indios is 4.81 ± 0.03 Ma; dates on various Bearhead units in southern Jemez Mountains range from about 6.0 to 7.2 Ma (Gardner et al., 1986; Goff et al., 1990; Justet, 1996); maximum observed thickness about 100 m.

La Grulla Formation (Miocene)

Tgbhd **Porphyritic biotite, hornblende rhyodacite—**Gray to pale pink, massive to sheeted porphyritic rhyodacite with phenocrysts of sanidine, plagioclase, resorbed quartz, biotite, hornblende, clinopyroxene, orthopyroxene and opaque oxides in a groundmass containing microlites of plagioclase, pyroxene, and opaque oxides; hornblende and biotite are commonly oxidized; contains rare iddingsitized olivine crystals; contains plagioclase-pyroxene-biotite clots; groundmass is trachytic; most samples are devitrified; overlies *Tga*, *Tscu*, and *Tpbd*; intruded by *Tbh* and displays hydrothermal alteration to silica, clay, chlorite and Fe-oxides near intrusive contacts; vent area not known but probably originates from north to northwest; $^{40}Ar/^{39}Ar$ age is 7.42 ± 0.05 Ma (Goff et al., 2011); maximum exposed thickness is about 135 m.

Tga **Porphyritic andesite and dacite, undivided—**Massive to sheeted, porphyritic lavas with phenocrysts of plagioclase, biotite, clinopyroxene, orthopyroxene, and opaque oxides; may contain plagioclase-pyroxene-biotite clots; erupted from multiple vents; found only in extreme northeast corner of quadrangle; overlies Tscu; $^{40}Ar/^{39}Ar$ ages on widely separated samples range from 7.43 to 7.81 Ma (Goff et al., 2011); maximum exposed thickness about 60 m.

Paliza Canyon Formation (Miocene)

Tpbd/Tpbdx **Porphyritic biotite dacite—**Eroded flows of gray, porphyritic dacite with phenocrysts of potassium feldspar, plagioclase, biotite, clinopyroxene, orthopyroxene and rare hornblende in a trachytic groundmass of plagioclase, pyroxene, biotite, and opaque oxides; contains minor clots of plagioclase-pyroxene-biotite; contains thick flow breccia (*Tpbdx*) exposed on north side of fault west of Rito de los Indios; flows are highly variable in thickness suggesting *Tpbd* filled a very irregular paleotopography; many exposures are extensively altered to silica, chlorite, clay and Fe-oxides; underlies *Tgbhd*; interbedded with *Tscu*; overlies *Tpa*; intruded by *Tbh*; vent area unknown but probably originates from northwest; $^{40}Ar/^{39}Ar$ ages range from 7.66 to 7.78 Ma (Goff et al., 2011); maximum exposed thickness near north edge of map is 230 m.

Tpa **Two-pyroxene andesite, undivided—**Flows and flow breccia of andesite from unknown sources; individual units are slightly porphyritic to very porphyritic; flows dense to platy to highly vesicular; fresh units may contain up to 20% phenocrysts of plagioclase, orthopyroxene, and clinopyroxene in an intersertal or slightly trachytic groundmass; groundmass usually contains abundant opaque oxides; plagioclase phenocrysts are commonly fritted and complexly zoned; most specimens contain plagioclase-pyroxene clots ≥1 mm in diameter; some units contain enclaves of plagioclase-pyroxene a few centimeters in diameter; some flows contain minor hornblende and/or biotite; visible alteration varies from slight to extremely intense; alteration generally consists of silica, Fe-oxides, clay ± chlorite ± illite ± pyrite; underlies and is interbedded with *Tscu*; intruded by *Tbh*; vent areas not known but probably lie to the west; andesite exposed in bottom of Santa Clara canyon is dated at 7.88 ± 0.04 Ma (WoldeGabriel et al., 2006); other flows in map area not dated; fresh flows of Tpa in southern Jemez Mountains range from 8.2 to 9.4 Ma (Gardner et al., 1986; Justet, 2003; Goff et al., 2011); maximum exposed thickness about 30 m.

Lobato Basalt (Miocene)

Tlb **Olivine basalt (shown only in cross sections)—**Thin flows of olivine basalt (Smith et al., 1970; Aldrich and Dethier, 1990) interbedded in the Santa Fe Group (Ts). Occurrences in cross sections is speculative but are correlated with similar flows in Santa Clara Canyon west of map area (WoldeGabriel et al., 2006); thickness of individual flows ≤15 m.

SANTA FE GROUP

Chamita Formation (Miocene)

Tscu **Hernandez Member (?)—**Thick sequence (>200 m) of sedimentary deposits, intercalated with older Keres Group rocks; sequence is dominantly arkosic sandstone, but interbeds of pebbly conglomerate, wacke, subangular gravel of intermediate composition volcanics, debris flows, and angular breccias occur; intense silicification is widespread, and deposits are locally altered to iron oxides, clays, and chlorite; *Tscu* is interbedded with *Tpa*, and *Tpbd*; underlies *Tgbhd*; intruded by dikes and plugs of *Tbh*. Assignment of *Tscu* to Chamita Formation is problematic; Gardner and Goff (1996) point out that *Tscu* represents basin-fill deposits at the eastern margin of the volcanic field, revealing interbeds of arkosic sandstones with proximal volcanic and volcaniclastic materials.

Ts **Santa Fe Group, undivided (cross sections only)—**Tan to white to gray sandstone, siltstone and conglomerate; age roughly bracketed between 10 and 20 Ma; thickness highly speculative.

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