Preliminary Geologic Map of the Redondo Peak Quadrangle, Sandoval County, New Mexico

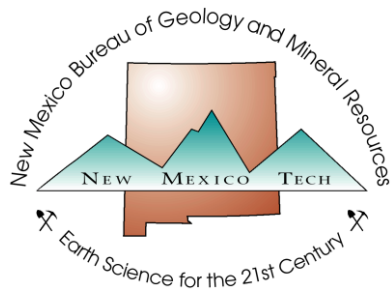By

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REDONDO PEAK 7.5-MINUTE QUADRANGLE,
SANDOVAL COUNTY, NEW MEXICO

1:24,000

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INTRODUCTION

The Redondo Peak 7.5 minute quadrangle is in Sandoval County and straddles the southern rim of the Valles caldera in the Jemez Mountains, New Mexico (Fig. 1). Topographically, the quadrangle is bounded by Redondo Peak on the north, the Banco Bonito plateau and Cat Mesa on the west, Valle Grande on the northeast, and a series of north-trending canyons and ridges to the south and southeast (San Juan Canyon, Peralta Ridge, etc.). Geologically, the quadrangle consists of three domains: the resurgent dome of Valles caldera in the north; the southern moat of Valles caldera in the center; and a part of the Jemez Mountains volcanic field to the south. Each domain has unique geology as described below. The relatively new Valles Caldera National Preserve occupies the northern half of the quadrangle. Before 2000, the Preserve belonged to the Baca Land and Cattle Company of Abilene, Texas. Access to the Preserve is restricted and must be obtained through the headquarters in Los Alamos, about 30 miles to the east. The southern half of the quadrangle is part of the Santa Fe National Forest. Small but significant private lands occur in the Vallecitos de los Indios area south of New Mexico Highway 4 and east and west of Forest Service road 10, and in scattered areas within forest service lands. Most areas of the quadrangle can be visited by dirt roads. The southeast corner of the quadrangle is rather remote and is best accessed by trails.

The quadrangle was once home to pre-Columbian Indian cultures (Paleo-Indian, Archaic, and ancestral Puebloan), Spanish land grants, homesteads and scattered ranches. In 1860 the Baca #1 land grant incorporating the present Valles Caldera National Preserve was given to the heirs of Luis Maria Cabeza de Vaca by passage of an act to settle disputed land claims in the Territory of New Mexico (Martin, 2003). Frank Bond purchased the "Baca" in 1926 and his heirs sold it to the Baca Land and Cattle Company (James P. Dunnigan) in 1962. Presently, the Preserve is managed for limited public recreation, and for elk hunting, cattle grazing, fishing, and scientific study. Timber is harvested and pumice is mined on National Forest lands. Geothermal energy was explored but not developed on both Preserve and National Forest lands in the 1960s to 1980s. Due to presence of the Bland gold mining district to the east, precious metal exploration has been conducted sporadically on National Forest lands from the late 1800s to the present, but no successful metallic mines have been established on the quadrangle.

The objectives of the present study are to provide detailed geologic mapping for the Valles Caldera National Preserve and to contribute quadrangle maps for the New Mexico State Map Program. The geology of the quadrangle was primarily mapped in the summer and fall months of 2003 and 2004. 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 NM State Map quadrangles have been published by Goff et al. (2002), Kempter and Kelley (2002), Osburn et al. (2002), and Kelley et al. (2003).

ACKNOWLEDGMENTS

STRATIGRAPHY

The oldest rock units in the Redondo Peak quadrangle (see Correlation Chart, Fig. 2) are exposed in the East Fork Jemez River canyon on the west central side of the map and consist of Permian red beds (Abo and Yeso Formations; Glorieta Sandstone) overlain by poorly exposed Triassic sandstone, siltstone, conglomerate, and limestone of the Moenkopi Formation and the Chinle Group (Kelley et al., 2003). These rocks are overlain by poorly exposed, non-indurated Miocene Santa Fe Group sandstone and andesite of the Keres Group. Large landslides, talus and colluvium hide much of the exposures in this area.

A few kilometers to the south, in San Juan Canyon, Keres Group rocks overlie early Miocene strata of the Abiquiu Formation and sandstone of the mid-Miocene Santa Fe Group. Relations between the Abiquiu and the Santa Fe are not exposed. Thus, it is possible that the uppermost Abiquiu rocks shown on the map grade into Santa Fe Group rocks. Several north-trending faults cut San Juan Canyon and Santa Fe sandstones appear

beneath mafic rocks of the Keres Group as faulting steps to the east. This area is extensively hidden by several large landslides because both Abiquiu and Santa Fe sandstones are relatively non-indurated and slump easily. An $Ar^{40/39}$ date on an olivine basalt lava overlying the Santa Fe and Abiquiu rocks in this area is 9.45 ± 0.07 Ma (W. McIntosh and L. Peters, NMBGMR).

Volcanic and volcaniclastic rocks of the Keres Group occur throughout the southern geologic domain of the quadrangle. Ages range from 13 to 6 Ma (Gardner and Goff, 1984; Gardner et al., 1986). The Keres Group consists of basaltic to rhyolitic rocks occurring primarily as flows and domes, with subordinate pyroclastic rocks. Generally speaking, the unit grades upwards from basalt and subordinate basaltic andesite into two-pyroxene andesite and dacite, all of the Paliza Canyon Formation. However, exposures of interbedded basalt and andesite flows are well exposed on the eastern slopes of Los Griegos. The distinctive hornblende dacite capping Los Griegos was dated by $Ar^{40/39}$ at 8.71 ± 0.66 Ma (W. McIntosh and L. Peters, NMBGMR). Three $Ar^{40/39}$ dates on andesites near the summits of Cerro Pelado and Peralta Ridge range from 8.78 to 9.44 Ma (Justet, 2003). Additionally, relations of andesite interbedded with the distinctive biotite-hornblende dacite of Cerro del Pino (9.42 ± 0.22 Ma, Justet, 2003) are exposed just north of Cerro del Pino, on the east side of Cerro Pelado ridge, along Peralta Ridge and in Peralta Canyon. Other dacites of the Keres Group intrude or overlie andesite.

A small exposure of hydrothermally altered Canovas Canyon rhyolite tuff underlying andesite occurs on the southern edge of the map in Peralta Canyon. Relations of this tuff with Paliza Canyon basalt are not known. Plugs, dikes, flows, and minor pyroclastic rocks of Bearhead Rhyolite intrude and overlie other rocks of the Keres Group. The faulted Bearhead Rhyolite plug south of Cerro Pelado, which was previously unrecognized (Smith eat al., 1970), was dated by $Ar^{40/39}$ at 7.62 ± 0.44 Ma (obsidian) and 7.83 ± 0.26 Ma (devitrified lava) (W. McIntosh and L. Peters, NMBGMR). The unnamed dome complex of Bearhead Rhyolite in upper San Juan Canyon has an $Ar^{40/39}$ date of 6.38 ± 0.09 Ma (Justet, 1996).

Volcanic rocks of the Keres Group are interbedded and overlain by volcaniclastic debris flow and fluvial deposits, partially equivalent to the Cochiti Formation (Bailey et al., 1969; Gardner et al., 1986; Smith and Lavine, 1996). These deposits are found within restricted areas in San Juan and Peralta Canyons. Deposits overlying Paliza Canyon and Bearhead units are exposed in uppermost San Juan Canyon west of Cerro Pelado. The upper age limit of these deposits is unknown but may extend into Pliocene time. These volcaniclastic rocks are difficult to distinguish from Older Gravels, a unit that is essentially synchronous with the upper and lower Bandelier tuffs. The two units have similar provenance but Older Gravels do contain cobbles of the Bandelier tuffs.

The lower Bandelier Tuff (Otowi Member) formed at c.a. 1.6 Ma during explosive formation of the Toledo caldera (Smith et al., 1970; Izett and Obradovich, 1994; Spell et al., 1996; Phillips, 2004). Excellent exposures of lower Bandelier ignimbrite sheets occur at the Cat Mesa area in the southwestern part of the map. An excellent exposure of the

Guaje pumice fall occurs beneath the Otowi Member along an abandoned dirt road on the west wall of San Juan Canyon. The lower Bandelier overlies rocks of the Keres Group.

The upper Bandelier Tuff (Tshirege Member) formed 1.25±0.01 Ma during explosive formation of the Valles Caldera (Smith et al., 1970; Phillips, 2004). The upper Bandelier forms small isolated canyon-filling outcrops in Peralta and Paliza Canyons and forms the bulk of the resurgent dome within Valles caldera. A thin 1-m exposure of the Tsankawi pumice fall deposit occurs between the Otowi and Tshirege members on the west side of Peralta Canyon. This general area also contains two outcrops of Older Gravels overlying the Tshirege Member.

The famous resurgent dome of Valles Caldera (Smith and Bailey, 1968) occurs on the northern margin of the quadrangle. Geologic relations are best exposed along fault scarps in Redondo Creek and on the southern edges of Redondo Peak and Redondo Border. The resurgent dome is composed primarily of densely welded, intracaldera Upper Bandelier Tuff. The thickness of Upper Bandelier is 1012 m in well Baca-12 (see cross section A-A'; Nielson and Hulen, 1984). Three blocks of caldera collapse breccia ("megabreccia" of Lipman, 1976) are immersed in the Upper Bandelier Tuff along Redondo Border. Within the quadrangle, these breccias consist entirely of andesitic rocks, presumably of the Keres Group. Further north, the collapse breccias consist of Pennsylvanian through Quaternary rocks (Goff et al., 2003).

The Upper Bandelier Tuff of the resurgent dome is overlain by debris flows, fluvial and lacustrine rocks, and by interbedded porphyritic lavas and lithic-rich tuffs of the Deer Canyon Rhyolite. A recent date on a thin rhyolite lava from the south slope of Redondo Border is 1.25±0.02 Ma, indistinguishable from the age of the Upper Bandelier Tuff (W. McIntosh, unpublished data). Similar ages were obtained from other sites of Deer Canyon Rhyolite to the north (Phillips, 2004).

The southern moat of Valles caldera is filled with an alternating sequence of rhyolitic rocks and volcaniclastic sediments that documents several periods of incision and blockage of the ancestral East Fork Jemez River. A layer of fluvial and minor lacustrine rocks (unit Qg1) overlies andesite and redbeds, and underlies porphyritic lava of South Mountain rhyolite (0.52±0.01 Ma; Spell and Harrison, 1993) in ravines west of Jemez Falls. This lava flow also overlies an older landslide complex on the south side of the river. Another layer of sediments (Qg2) overlies South Mountain rhyolite in several areas upstream and east of Jemez falls and in the VC-1 corehole (Gardner et al., 1987). This layer is overlain by fall deposits of the El Cajete pumice and ignimbrites of the Battleship Rock tuff (about 50 to 60 ka; Toyoda et al., 1995; Reneau et al., 1996). A third layer composed of volcanic debris flows and gravelly alluvium (Qg3) overlies pyroclastic units of Battleship Rock and El Cajete in the area just north and east of Jemez Falls. This layer is discontinuously exposed beneath the west and north edges of the overlying Banco Bonito rhyolite (about 40 ka; Ogoh et al., 1993; Phillips et al., 1997). Layer Qg2 may be partly contemporaneous with lacustrine deposits exposed in and buried beneath Valle Grande, associated with a South Mountain rhyolite dam (Conover et al., 1963; Griggs, 1964; Reneau et al., 2004; Fawcett et al., 2004) whereas layer Qg3 may be partly

contemporaneous with younger lacustrine deposits in Valle Grande associated with an El Cajete pumice dam (Reneau et al., 2004).

STRUCTURE AND TECTONICS

The Redondo Peak quadrangle straddles the southern boundary of the Valles caldera, separating the Cañada de Cochiti fault zone (CFZ) in the south from cross cutting, caldera-related structures in the north. The CFZ is "a broad swath of north-trending normal faults that cuts the Keres Group rocks in the southern Jemez Mountains" (Gardner, 1985). The CFZ represented the western boundary of the Española Basin of the Rio Grande rift from about 11 to 4 Ma (Gardner et al., 1986). Most of the larger faults within the fault zone (Cerro del Pino, Paliza Canyon, Peralta Canyon) have down to the east displacement and major fault blocks are tilted noticeably to the west. Exceptions are the down to the west fault in lower San Juan Canyon and the fault along the axis of Aspen Ridge. There is apparently more than 500 m of cumulative vertical offset across the entire fault zone (Gardner, 1985; Gardner et al., 1986). In addition, a set of less-pronounced, west trending faults a varying displacement cuts across the grain of the major north-trending blocks.

The CFZ was very active during Keres Group time because volcanic and volcaniclastic deposits thicken to the east across the zone (Gardner, 1985; Gardner and Goff, 1984). It is probable that some of the major faults were active during early evolution of the Rio Grande rift because the Abiquiu Formation (early Miocene to Oligocene?) disappears eastward whereas and the apparent thickness of the later Santa Fe Group increases in the same direction. Although most faulting was completed prior to eruption of Bearhead Rhyolite (6 to 7 Ma), rhyolite intrusives clearly utilized the fault zone as conduits and rhyolite units are offset as much as 30 m along some of the faults. There is also a strong correlation between hydrothermal phenomena (alteration, brecciation, and veining) and many faults, particularly in uppermost Paliza Canyon and along the entire length of Peralta Canyon and Aspen Ridge. This hydrothermal activity lasted from roughly 8 to 5.6 Ma (WoldeGabriel and Goff, 1989). Additionally, there are several locations where displacements of ≤10 m are observable in the Bandelier tuffs. Thus, although the CFZ was most active in Miocene time, minor faulting has continued to at least 1.2 Ma.

Faulting caused by development of the Valles caldera and slightly earlier Toledo caldera is quite different from rift-related faulting along the CFZ. Collapse of these calderas during evacuation of roughly 600 to 700 km^3 of Bandelier magmas (Smith and Bailey, 1966; 1968) resulted in dramatic down-to-the north displacement along an arcuate fault zone of the south caldera wall. Faults within this zone are not exposed because they are buried beneath a thick section of post-caldera moat rhyolites and intra-caldera sediments. Maximum displacement on Precambrian basement is on the order of several kilometers based on gravity and drill hole data with displacement increasing toward the eastern sector of the caldera beneath Valle Grande (Goff et al., 1989). The position of this structural boundary of the caldera (the ring-fracture zone of Smith et al., 1961) is inferred by the arcuate locations of the South Mountain dome, El Cajete crater, and Banco Bonito vent. Slumping of the south caldera wall during and after caldera formation has extended

the topographic rim well beyond the limit of the structural boundary (Smith and Bailey, 1968; Lipman, 2000). Some landslides are still observable along the topographic rim although they are mostly mantled with fall deposits of El Cajete pumice. We could find no faults within the southern caldera moat, indicating that little if any displacement has occurred during the last 0.5 Ma.

Growth of the Valles resurgent dome presents yet another structural style (Smith and Bailey, 1968). Within the quadrangle the resurgent dome consists of the southern segments of Redondo Peak and Redondo Border. Maximum uplift of caldera-fill ignimbrite and overlying rocks is at least 1000 m resulting in development of a medial (or keystone) graben now occupied by Redondo Creek. The elongation of the resurgent dome and the trend of the graben are northeast, on strike with the Jemez fault zone (JFZ) to the southwest. The JFZ is a structure of the Rio Grande rift; thus the resurgent dome has utilized pre-existing rift structure for growth (Goff et al., 1989). The margins of the resurgent dome segments are broken by a multitude of large and small faults. This faulting is better expressed on the less-uplifted Redondo Border block where early post-caldera eruptive and sedimentary units are better preserved. The crest of Redondo Peak is virtually stripped of all early post-caldera rocks and the flanks are extensively covered by talus and landslide deposits, hiding the exact position of many faults. Where observable, many faults within the resurgent dome display extensive development of gouge, breccia, and silicification. In addition, early post-caldera lavas and tuffs of Deer Canyon Rhyolite, and interbedded debris flow and lacustrine deposits show steep dips and contrasting thicknesses on adjacent fault blocks suggesting that much of the resurgence occurred early in the caldera history (Smith et al., 1968; Goff et al., 2003). Based on new $Ar^{40/39}$ ages obtained by Phillips (2004), resurgence occurred only 27±27 ka after caldera formation.

HYDROTHERMAL ALTERATION

Pervasive hydrothermal alteration occurs within rocks of the Keres Group in the southeastern part of the quadrangle and is most evident near or along faults. Typically, the alteration is defined by green, red, white, and yellow colors overprinting the usual gray, pink, and black colors of basaltic to rhyolitic flows. Low-grade alteration consists primarily of silica (opal and chalcedony), calcite, Fe-rich smectite, and Fe-oxides replacing the groundmass minerals and phenocrysts. As rank of alteration increases, zeolite, quartz, illite, chlorite, secondary feldspar, hematite, pyrite, and epidote become more common and replacement of the volcanic host is more thorough. Bright green epidote is easily seen in basaltic rocks opposite the Las Conches campground on NM Highway 4 where vugs are filled with epidote, quartz and calcite. Zeolite fibers form sprays growing from altered vesicles in the faulted andesites along Peralta Canyon. A sample fiber was identified as mordenite by XRD. Three patches of hydrothermal breccia (mosaic breccia) were mapped along the Aspen Ridge fault. These patches consist of highly altered andesitic rocks in a silicified, fine-grained matrix. Small quartz and calcite veins are found along many of the faults. A zone of quartz veining perhaps 200 to 300 m long was mapped as a separate unit along the Aspen Ridge Fault. From laboratory measurements and investigations of active geothermal systems, presence of epidote

indicates paleo hydrothermal temperatures were at least 220°C in some areas (Hochstein, 1982, p. 89). WoldeGabriel (1990) noted that alteration of mafic and intermediate composition volcanics in the Keres Group began as early as 8.2 Ma and is best expressed in the northern and southern ring-fracture zones of Valles caldera. Within the Redondo Peak quadrangle, alteration intensity and rank increases in the direction of the Cochiti gold mining district where paleo temperatures reached 195 to 375°C (Wronkiewicz et al., 1984). Epithermal activity in the Cochiti district was dated at 6.5 to 5.6 Ma by WoldeGabriel and Goff (1989). The distribution of alteration and the dates indicate that much of the alteration in the quadrangle was caused by intrusion of the Bearhead Rhyolite into the Canada de Cochiti fault zone (Gardner et al., 1986).

Two styles of alteration are observed in the rocks of the Valles resurgent dome. The first style consists of pale greenish-white to yellowish-white amorphous silica, opal, smectite, Fe-oxides, and zeolite (clinoptilolite and mordenite) most prevalent in uppermost Bandelier Tuff, Deer Canyon tuff and associated lacustrine rocks but occasionally seen in Deer Canyon lavas and lower exposures of intracaldera debris flow deposits. Presumably, secondary feldspars are present but presence of these phases has not been confirmed. Original textures are not disturbed but in thin section the alteration has caused devitrification of the groundmass and pumice shards in the rocks. The zeolitic alteration is not enhanced along faults but forms a pervasive layer as much as 20 m thick throughout the lower flanks of the resurgent dome. This alteration was caused by the first intracaldera lake, which was probably neutral to slightly alkaline in pH character (Goff et al., 2003).

The second style of alteration on the resurgent dome is hydrothermal in character and is fault controlled, particularly along northeast-trending faults near the Redondo Creek graben. It consists of opal, chalcedony and quartz as veins and stockwork fillings in gouge and breccia zones that are occasionally shades of orange, yellow, and red. Associated minerals include Fe-oxides, illite, adularia, alunite, and pyrite. This alteration was caused by the high-temperature geothermal system (≤300°C) circulating within various sectors of Valles caldera during the last 1.25 Ma (Hulen and Nielson, 1986; WoldeGabriel and Goff, 1989; Goff and Gardner, 1994). Just north of the quadrangle an acidic cap zone to the current system is expressed as weak, sub-boiling fumaroles associated with amorphous silica, opal, pyrite, sulfur, kaolinite, Fe-oxides, alunite, jarosite, gypsum, and unusual sulfate minerals (Charles et al., 1986; Goff and Janik, 2000). Very little secondary calcite is found in surface rocks on the resurgent dome because most are calcium deficient. Vein calcite, anhydrite, epidote and high temperature, Ca-rich zeolite (wairakite) are common deeper within the system where hydrothermal fluids have access to Ca-bearing, pre-caldera volcanic rocks and underlying Paleozoic carbonate strata.

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FIGURE CAPTIONS

Figure 1: Map of Redondo Peak quadrangle showing locations of Valles caldera, the south rim of the caldera, major physiographic features and the three geologic domains; from north to south, resurgent dome, southern moat, and southern Jemez Mountains.

Figure 2: Correlation chart of Redondo Peak quadrangle showing stratigraphic position of geologic map units, their geologic ages, map units within the three geologic domains of the map, and units with dates.

DESCRIPTION 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), Goff *et al.* (2007), Gardner *et al.* (2010), and Goff *et al.* (2011). 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). Minor yet significant changes in regional stratigraphy and nomenclature have occurred here 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).

Qdi   **Disturbed Areas**—Anthropogenically disturbed areas; consists of underlying rock units at each area; unit mapped only where extensive at pumice mines and well pads; not shown in correlation chart; maximum thickness more than 10 m but usually less than 3 m.

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 contacts or fault relations; mostly Holocene and Pleistocene in age; thickness can locally exceed 10 m.

Qt   **Terrace gravel**—Slightly older alluvium that lies along the margins of present streams and basins; now undergoing erosion; mapped in only a few locations; maximum thickness as much as 15 m.

Qaf, Qafu   **Alluvial fans**—Fan-shaped deposits of coarse to fine gravel and sand at the mouths of valleys and in the Valle Grande; some fan deposits (Qafu) may be difficult to distinguish from older alluvial fans (described below); maximum exposed thickness about 15 m.

Qls   **Landslides**—Unsorted debris that has moved chaotically down steep slopes, or 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.

Qalo   **Older alluvium**—Deposits of gravel, sand and silt that are overlain by alluvial fans; includes bog deposits north of Banco Bonito rhyolite near area where Redondo Creek emerges from the resurgent dome; age varies; estimated thickness unknown.

Qlec, Qlb   **El Cajete lake deposits**—Deposits of reworked El Cajete pumice and coarse sand in the Valle Grande; Qlec occurs below the upper level of a lake formed when deposits of the El Cajete pumice dammed the East Fork Jemez River (Reneau et al., 2004); 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 exposed thickness about 4 m.

Qafo   **Older alluvial fans**—Fan deposits of coarse to fine gravel and sand in the Valle Grande and elsewhere that are older than the El Cajete pumice or

contemporaneous lacustrine units; maximum exposed thickness is unknown.

Qlso   **Older landslides**—Older slide deposits that are overlain by El Cajete pumice or (rarely) by the Tshirege Member of the Bandelier Tuff; latter examples occur in San Juan Canyon in southwest part of the map; maximum exposed thickness about 25 m.

Qlsm   **South Mountain lake deposits**—Laminated to bedded, diatomaceous silty clay and mudstone; minor siltstone and sandstone; found in Valle Grande (Conover et al., 1963; Griggs, 1964; Reneau et al., 2004; Fawcett et al., 2004); lake formed when South Mountain rhyolite dammed drainage of the East Fork Jemez River (Reneau et al., 2004); possibly interbedded with older alluvial fan deposits (Qafo); overlies sedimentary deposits time equivalent to Qg1; age ≤520 ka; maximum drilled thickness in Valle Grande is about 95 m (Conover et al., 1963; Fawcett et al., 2011); drilled thickness in VC-3 core hole east of Redondo Peak quadrangle is 76 m.

Qg1–Qg3   **Sedimentary deposits of southern caldera moat**—Various deposits of alluvium, colluvium, debris flows and minor lacustrine beds interbedded with lavas and pyroclastic rocks in the southern moat of Valles caldera; formed during at least three episodes of incision and blockage of the ancestral East Fork of the Jemez River and tributaries; generally poorly exposed; identified mostly by stratigraphic position; Qg1 underlies the South Mountain rhyolite (Qsm) and is primarily gravels containing Bandelier Tuff, aphyric rhyolite, precaldera volcanics and rare Permian fragments; contains diatomaceous lacustrine beds just downstream of Jemez Falls; Qg2 overlies Qsm but underlies Qec and Qbr; Qg2 contains fragments of Bandelier Tuff and precaldera volcanics near southeast edge of South Mountain; also contains fragments of Qsm further to west; displays extensive low-temperature hydrothermal alteration in VC-1 corehole; Qg3 underlies Qbb but overlies Qec and Qbr; contains fragments of Bandelier Tuff, precaldera volcanics, Permian redbeds, Pennsylvanian limestone and Precambrian crystalline rocks in western exposures; also contains large blocks of glassy rhyolite in area south of El Cajete vent but north of Jemez Falls campground; maximum exposed thickness about 40 m.

Qvs   **Early caldera fill lacustrine and fluvial deposits**—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.

Qdf   **Early caldera fill debris flow, landslide, and colluvium deposits**—Dark gray to buff, matrix-supported beds containing fine silt to boulders of various early caldera rhyolites, Bandelier Tuff, precaldera volcanics, Miocene to Permian sandstone, Pennsylvanian limestone and Precambrian crystalline rocks; unit contains minor fluvial deposits; older lithologies are more abundant in the lower beds; upper beds generally contain more precaldera volcanics; rare beds contain mostly Bandelier Tuff; formed during rapid slumping and erosion of caldera walls, erosion of exposed megabreccia blocks (Qx), 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 observe; interbedded with and overlies all other units on resurgent dome; maximum exposed thickness in map area is 50 m.

Qgo   **Older Gravels**—Dark gray to buff gravel and debris flow deposits interbedded with the Tshirege Member of the Bandelier Tuff south of the caldera margin; consists primarily of precaldera volcanic rocks and Bandelier Tuff; exposures are small and usually poor; without stratigraphic control, unit is difficult to distinguish from Tpv if no Bandelier Tuff clasts are present; maximum exposed thickness is 25 m.

Tewa Group (Pleistocene)
Valles Rhyolite
East Fork Member

Qvb   **Banco Bonito rhyolite**—Thick viscous lava flows that contain phenocrysts of plagioclase, quartz, biotite, hornblende, clinopyroxene and rare sanidine in a black glassy to gray devitrified groundmass; contains some quartz with clinopyroxene reaction rims; top of unit is pumiceous; erupted from vent at east end of Banco Bonito ridge in north central map area; fills three deep, west- to northwest-trending paleocanyons cut into the Battleship Rock ignimbrite in southwestern moat of Valles caldera; consists of at least two thick flow units (Manley and Fink, 1987; Gardner et al., 1987); upper surface of unit preserves pressure ridges and valleys with up to 10 m of relief; overlies discontinuous sedimentary and pyroclastic deposits; unit dated at 37 to 45 ka (Ogoh et al., 1993; Phillips et al., 1997) but age still has uncertainties (Lepper and Goff, 2007); maximum exposed thickness roughly 140 m.

Qvcr   **VC-1 rhyolite (only on cross section A-A')**—Black flow banded lava containing sparse phenocrysts of plagioclase, quartz, biotite,

clinopyroxene, hornblende and rare sanidine in very glassy to perlitic matrix; has unusual prismatic fracturing; found only in VC-1 corehole where it is 19 m thick (Gardner et al., 1987; Goff and Gardner, 1994); underlies 14 m of pumice, fragmented ignimbrite and sediments now correlated with unit Qg3 sedimentary rocks of southwest moat; separated from underlying Qbr by 0.1 m of sediment baked orange by VC-1 rhyolite; apparently filling shallow paleovalley in southern moat; vent area not known but probably near Banco Bonito and El Cajete vents; may be equivalent to large glassy rhyolite blocks found in uppermost beds of El Cajete pyroclastic beds (Wolff et al. 1996); age not resolved but probably around 50 ka.

Qvbr   **Battleship Rock ignimbrite**—Ash flow tuff sheets (ignimbrites) consisting of rhyolitic pumice, lithic clasts, crystal fragments, glass shards, and volcanic ash; pumice contains phenocrysts of plagioclase, quartz, biotite, hornblende, clinopyroxene, and rare sanidine; may be densely welded and have conspicuous fiamme; erupted from E1 Cajete crater in north central map area; consists of at least three flow units in VC-1 corehole; consists of many smaller ignimbrites interbedded with the upper part of the El Cajete pyroclastic beds; mostly filled paleocanyons in southwestern moat of Valles caldera; underlies Banco Bonito Flow and various sedimentary deposits; overlies South Mountain rhyolite and various sedimentary deposits; estimated age is 50 to 60 ka (Toyoda et al., 1995; Reneau et al., 1996); maximum exposed thickness about 30 m.

Qvec   **El Cajete pyroclastic beds** —White to tan, moderately sorted, pyroclastic fall deposits of vesicular rhyolite; pumice clasts contain sparse phenocrysts of plagioclase, quartz, and biotite with rare microphenocrysts of hornblende and clinopyroxene; some clasts contain resorbed quartz with pale green, clinopyroxene reaction rims; originated from El Cajete crater (Bailey et al., 1969; Smith et al., 1970; Gardner et al., 1986; Self et al., 1988; Wolff et al., 1996); maximum diameter of clasts is about 50 cm near vent but clast size diminishes away from source; contains relatively abundant lithic clasts of Bandelier Tuff and precaldera volcanic rocks but rare Paleozoic and Precambrian rocks; also contains blocks of black glassy rhyolite near vent; includes pyroclastic surge deposits in near-vent areas; underlies Banco Bonito Flow and various sedimentary deposits; upper part of unit includes thin ignimbrites of Battleship Rock; overlies South Mountain rhyolite and various sedimentary deposits; unit dated at about 50 to 60 ka (Toyoda et al., 1995; Reneau et al., 1996); unit extensively reworked by erosion, collecting on south and east facing slopes; maximum exposed thickness about 70 m in vent area and as much as 50 m in valleys of the southern map area; thins on mesa tops and hills forming scant exposures too thin or small to map.

Qvsm1–4 **South Mountain Member**—Flow-banded, massive to slightly vesicular rhyolite lava containing phenocrysts of sanidine, plagioclase, quartz,

biotite, hornblende, and clinopyroxene in a pale gray, perlitic to white, devitrified groundmass; rarely glassy; contains very minor pyroclastic deposits at base of flow overlying sedimentary deposit just east of Los Conches campground on NM highway 4; erupted from South Mountain in eastern map area; consists of four main flow units (oldest to youngest Qvsm1 to Qvsm4); fills paleocanyon in southern moat of Valles caldera; contains low-temperature hydrothermal alteration in the VC-1 corehole (Gardner et al., 1987); underlies Battleship Rock ignimbrite, El Cajete pyroclastic beds and various sedimentary deposits; overlies sedimentary deposits and Permian red beds; $^{40}Ar/^{39}Ar$ age is 0.52 ± 0.01 Ma (Spell and Harrison, 1993); maximum exposed thickness about 100 m west of Jemez Falls; at least 450 m thick in vent area.

Qdc　　**Deer Canyon Member, lava unit**—Massive, gray to pale pink, porphyritic rhyolite lavas usually containing abundant phenocrysts of sanidine and quartz (Bailey et al., 1969); sanidine is occasionally chatoyant; fresh samples rarely confused with densely welded Bandelier Tuff; lavas display occasional pepperite and pillow breccia; most exposures are highly deformed by uplift and faulting on the resurgent dome of Valles caldera; many exposures show extensive zeolitic alteration and silicification (Chipera, et al., 2007); usually overlies Deer Canyon tuffs (Qdct) but occasionally interbedded with them; interbedded with Qdf and generally overlies Qvs; overlies Bandelier Tuff; age of thin flow on southwest shoulder of Redondo Border is 1.25 ± 0.02 Ma (W. McIntosh, NMBGMR); maximum exposed thickness about 40 m.

Qdct　　**Deer Canyon Member, tuff unit**—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; maximum exposed thickness about 30 m.

Qx　　**Caldera collapse breccia**—Caldera-wall landslide breccias (megabreccias) that accumulate synchronously during caldera formation (Lipman, 1976); incorporated in and interbedded with intracaldera Bandelier Tuff (Goff et al., 2007); mapped if more than 30 m across; three megabreccia blocks of Miocene andesitic rocks of the Paliza Canyon Formation (?) (Qxp) occur on the southwest shoulder of Redondo Border; other blocks of Qx probably 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 tuff are preserved; maximum exposed thickness is highly variable; not shown in cross section A-A' for clarity.

Qbt   **Bandelier Tuff, Tshirege Member**—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 black clinopyroxene and orthopyroxene and extremely rare microphenocrysts of fayalite (Warshaw and Smith, 1988; Warren et al., 2007); sanidine typically displays blue iridescence; consists of multiple flow units in a compound cooling unit (Smith and Bailey, 1966; Gardner et al., 1986; Broxton and Reneau, 1995; Warren et al., 1997). Upper flow units generally more welded than lower ones. Intracaldera flow units are highly welded with well-developed pumice 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 of the caldera; originated from catastrophic eruptions that formed 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.

Qbo   **Bandelier Tuff, Otowi Member**—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 (Eichelberger and Koch, 1979); consists of multiple flow units in a compound cooling unit; contains a stratified pumice fall and surge deposit at its base (Guaje Pumice; Griggs, 1964); may form tent rocks; Qbo discontinuously fills in rugged topography on a volcanic surface of pre-Toledo caldera age; forms broad plateau covered with Qvec southwest of the caldera margin; very difficult to distinguish from the Tshirege Member of the 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 about 60 m.

Tertiary
Keres Group (Pliocene-Miocene)
Tschicoma Formation (Pliocene)

Ttu   **Dacite and andesite, undivided, only on cross section A-A'**—Gray to pale pink porphyritic dacite and andesite with phenocrysts of plagioclase, orthopyroxene, clinopyroxene ± hornblende; underlies the Otowi Member

of the Bandelier Tuff (Qbo); overlies Paliza Canyon andesite (Tpa); ages of major domes east of map area roughly 2 to 5 Ma (Goff et al., 2002; Kempter and Kelley, 2002); thickness in cross section is speculative; thickness in Sierra de los Valles east of map area exceeds 500 m.

Bearhead Rhyolite

Thb   **Hydrothermal breccia and quartz vein**—Relatively small areas of hydrothermal rocks in north-trending fault zone on Aspen Ridge along southeastern edge of map; probably associated with volcanism of the Bearhead Rhyolite because of close spatial and structural relations but may be related to Keres Group volcanism. Thb consists of relatively circular, vertical pipes of mosaic breccia ≤100 m in diameter containing fragments of altered andesite in a fine-grained, silicified matrix and a poorly exposed lens of quartz veins about 300 m long and 50 m wide cutting altered andesite; both have been modified by faulting; probably between 5.6 and 8.5 Ma (WoldeGabriel and Goff, 1989); vertical thickness is unknown.

Tbh, Tbp   **Rhyolite intrusive rocks (Bearhead Rhyolite)** — White to gray intrusions, domes, and flows of slightly porphyritic to aphyric devitrified rhyolite containing rare phenocrysts of quartz, potassium feldspar, and fresh to altered biotite ± plagioclase; margins of flows may be slightly pumiceous; contains minor flow breccia; margins of intrusions may display chilled contacts with black to gray to pink obsidian, perlite, and banded spherulitic rock; interiors of units are generally flow-banded; associated lithic-rich tuffs occur only in extreme southeast part of map; small, hydrothermally altered plugs and dikes occur along fault zones in southeast map area; intrudes or overlies all other Keres Group rocks; apparently surrounded by Tpv in south-central map area; dates on various Bearhead units range from about 6.0 to 7.2 Ma (Gardner et al., 1986; Goff et al., 1990; Justet, 1996); $^{40}Ar/^{39}Ar$ date on unnamed dome in uppermost San Juan Canyon is 6.38 ± 0.09 Ma (Justet, 1996); maximum observed thickness about 170 m. Two $^{40}Ar/^{39}Ar$ dates on the faulted rhyolite south of Cerro Pelado range from 7.6 to 7.8 Ma (W. McIntosh and L. Peters, NMBGMR).

Paliza Canyon Formation (Miocene)

Tpv   **Volcaniclastic Member**—Black to gray to pale pink volcaniclastic unit consisting predominately of gravels, lahars, block and ash flows, and other debris flows; mostly formed contemporaneously with Keres Group but may extend into Pliocene; locally contains hyper concentrated flow and fluvial deposits, cinder deposits, and pyroclastic fall deposits; contains andesite flow-breccias too small or thin to map; unit has accumulated in small basins, topographic lows, and canyons cut into Keres Group volcanoes; unit generally thickens to south and east toward San Juan and

Paliza canyons; most of unit mapped according to the definition of Cochiti Formation described by Bailey et al., (1969) and Gardner et al. (1986) with stratigraphic interpretation extended to Pliocene (Smith and Lavine, 1996); interbedded with Tpb and Tpa in lower San Juan Canyon; interbedded with Tpa and Tpbhd in southern west wall of Peralta Canyon; overlies Tpa, Tphd and Tpbhd on eastern flanks of Cerro Pelado Ridge; apparently surrounds dome of Tbh in south-central map area; age of Tpv is bracketed between roughly 3 and about 13 Ma; maximum exposed thickness about 70 m.

Tpd   **Aphyric dacite**—Greenish gray, flow banded, plug-like body exposed along fault scarp north-northeast of Las Conchas peak; groundmass is very fine grained and trachytic, with sparse microphenocrysts of plagioclase, hornblende, opaque oxides, and possibly potassium feldspar; pervasively altered to chlorite, silica, and clay; margins display intrusion breccia with small blocks and fragments of basalt and andesite in dacite host; maximum exposed thickness about 120 m.

Tpbd   **Porphyritic biotite dacite**—Eroded dome and flows of gray to pale pink dacite having ≤5 % phenocrysts of plagioclase, biotite, and pyroxene in a trachytic groundmass of plagioclase, pyroxene, and opaque oxides; contains complexly zoned and fritted plagioclase phenocrysts ≤10 mm in diameter; contains minor clots of plagioclase and pyroxene; most specimens are extensively altered to silica, chlorite, clay, Fe-oxides and minor calcite; intrudes and overlies andesite in fault zone along southeast side of map; maximum exposed thickness is 160 m.

Tphd   **Porphyritic hornblende dacite**—Eroded flows capping the summits of Las Conchas and Los Griegos (Smith et al., 1970; Gardner, 1985); the latter includes a remnant of a vent; flows overlie andesite; Las Conchas consists of gray to pale pink flow banded dacite containing about 12% phenocrysts of plagioclase, hornblende, orthopyroxene and clinopyroxene in a trachytic groundmass of plagioclase and pyroxene; hornblende is ≤10 mm long and completely oxidized; contains plagioclase-pyroxene clots ≤15 mm in diameter; unit is pervasively altered; groundmass is moderately silicified and cracks contain opal; phenocrysts contain Fe-oxides, silica, calcite, and chlorite; maximum exposed thickness is 50 m; Los Griegos consists of virtually unaltered, gray, flow banded dacite with complexly zoned and fritted plagioclase (8%; ≤15 mm), conspicuous hornblende (6 %; ≤15 mm), and rare ortho- and clinopyroxene phenocrysts in a trachytic groundmass of plagioclase and minor opaques; contains rare clinopyroxene clots ≤2 mm in diameter; $^{40}Ar/^{39}Ar$ date on hornblende from Los Griegos is 8.71 ± 0.66 Ma (W. McIntosh and L. Peters, NMBGMR); maximum exposed thickness is 75 m.

Tpbhd   **Porphyritic biotite, hornblende dacite**—Extensive dome and flow complex filling east-west trending paleocanyon in southern map area (Smith et al., 1970; Gardner, 1985); contains 15% phenocrysts of plagioclase, biotite (≤3 mm), oxyhornblende (≤5 mm), orthopyroxene, and clinopyroxene, in a trachytic groundmass filled with plagioclase and pyroxene microlites; groundmass also contains apatite microphenocrysts up to 0.5 mm long; plagioclase phenocrysts (≤20 mm) are fritted and complexly zoned; contains gray, vesiculated enclaves of plagioclase, pyroxene ± hornblende ± biotite up to 30 cm in diameter; vented from hill east of Cerro del Pino; relatively fresh in west near vent but displays considerable hydrothermal alteration in east, particularly along faults and near canyon bottoms; interbedded with andesite flows (Tpa); Ar $^{40/39}$ age of sample from ridge east of vent is 9.42±0.22 Ma (Justet, 2003); exposed thickness at least 275 m north and west of Cerro del Pino.

Tpa   **Two-pyroxene andesite, undivided**—Domes, flows, flow breccia, spatter deposits, and scoria of andesite from multiple sources; individual units are slightly porphyritic to very porphyritic; flows dense to highly vesicular; tends to be relatively fresh and sometimes glassy in the west to hydrothermally altered in east; typically contains 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; visible alteration generally consists of silica, calcite, Fe-oxides, clay ± chlorite ± zeolite ± pyrite; underlies Tpbd and Tphd; interbedded with Tpv, Tpbhd and Tpb; Cerro Pelado ridge is probably the vent area for many of the flows; black porphyritic andesite along crests of Cerro Pelado and Peralta Ridge have $^{40}Ar/^{39}Ar$ dates of 8.78±0.14 and 8.85±0.17 Ma; platy andesite midway down west flank of Cerro Pelado is dated at 9.44±0.21 Ma (Justet, 2003); maximum exposed thickness over 310 m near Cerro Pelado.

Tpb   **Olivine basalt and basaltic andesite, undivided**—Flows, flow breccia, spatter deposits, and scoria of basalt and subordinate basaltic andesite from multiple sources; most units are slightly porphyritic; flows dense to highly vesicular; tends to be relatively fresh in southwest to highly altered in northeast and east; typical basalt contains 5 % phenocrysts of olivine and plagioclase (≤2 mm) in intersertal groundmass of olivine, clinopyroxene, plagioclase, opaque oxides, and glass; olivine occurs rarely in clots ≤3 mm in diameter; most olivine has high-temperature iddingsite; some flows have diktytaxitic texture; some flows have clinopyroxene phenocrysts; visible alteration consists of silica, calcite, Fe-oxides, clay ± zeolite ± chlorite ± epidote ± pyrite; interbedded with and underlies Tpa; overlies and possibly interbedded with Santa Fe Group (Tsf); overlies

Abiquiu Formation (Tab); ^{40}Ar/^{39}Ar date on basalt east of San Juan Canyon near southwest corner of map is 9.45 ± 0.07 Ma (W. McIntosh and L. Peters, NMBGMR); K-Ar age of hydrothermal clay in altered basalt on NM highway 4 south of Las Conchas is 8.05 ± 0.13 Ma (WoldeGabriel, 1990); maximum exposed thickness about 140 m.

Canovas Canyon Formation (Miocene)

Tcct   **Canovas Canyon rhyolite tuff (Miocene)**—Poorly exposed unit in bottom of Peralta Canyon at southern edge of map; consists of bedded aphyric pumice and lithic fragments of sandstone and mafic volcanics in altered matrix of clay-rich rhyolitic ash; underlies Tpa; relation to Tpb unknown; maximum exposed thickness roughly 35 m.

Santa Fe Group (Miocene)

Ts   **Volcaniclastic deposits**—Poorly exposed pale tan to pink sandstone and dark gray conglomerate; sandstone is generally well-sorted and usually non-indurated; grains are usually well-rounded and consist of weathered mafic volcanic rocks, plagioclase, altered olivine, weathered pyroxene and minor quartz; cement if present is calcite, silica, and Fe-oxides; conglomerate contains basalt and andesite pebbles and cobbles in a sandy matrix; beds too thin to map occur with basalt (Tpb) in area around Las Conches; underlies andesite (Tpa) in upper south wall of East Fork Canyon; underlies basalt in San Juan Canyon north of Cerro del Pino; relations with underlying Abiquiu Formation unclear; maximum observed thickness roughly 60 m; K-Ar date on basalt interbedded with upper Santa Fe Group east of map area is 16.5 ± 1.4 Ma (Gardner and Goff, 1984; Goff et al., 1990).

Abiquiu Formation (Miocene to Oligocene?)

Ta   **Sandstone and siltstone**—White to buff well-bedded sandstone and siltstone; contains grains of rounded to subangular quartz, plagioclase, potassium feldspar, quartzite, and crystalline rocks; contains rare grains of diopside and possible tremolite; cement is commonly opaline; thus beds are sometimes very indurated; calcite and limonite cement less common; well-exposed in San Juan Canyon where it underlies basaltic rocks (Tpb); maximum observed thickness is 120 m; ^{40}Ar/^{39}Ar age on ash bed in upper Abiquiu Formation to southwest is 20.6 ± 0.1 Ma (Osburn et al., 2002).

Triassic

Ћu, Ћcs, Ћm   **Triassic rocks, undivided**—Poorly exposed rocks in middle south wall of East Fork Canyon consisting of three units; the youngest (Ћu) is composed of brick-red to maroon, poorly exposed mudstone and bed of black conglomerate (Salitral shale and Paleo sandstone of the Chinle Group); the middle unit (Ћcs) is composed of gray to yellow-brown coarse sandstone and conglomerate, the latter with distinctive yellow chert clasts (Shinarump Formation of the Chinle Group); and the oldest unit (Ћm) consists of reddish brown micaceous siltstone and thinly bedded sandstone (Moenkopi Formation); underlies Tpa and Tsf; overlies Pu; maximum exposed thickness roughly 40 m.

Permian

Pu   **Permian rocks, undivided**—Well exposed rocks in lower south wall of East Fork Canyon consists of (top to bottom) Glorieta sandstone and the Yeso Formation. Glorieta sandstone consists of white to reddish white, well-sorted, generally plane to cross-bedded quartz arenite with some mica; forms fractured cliffs; Yeso Formation is composed of orange red, well-sorted, medium-grained quartzofeldspathic sandstone and minor siltstone; Abo Formation (only in wells) is made up of brick red to brownish red quartzofeldspathic sandstone, siltstone and mudstone; contains some obvious mica; contains minor conglomerate and limestone; Yeso and Abo are usually indurated in geothermal wells (cross section A-A'), displaying considerable greenish hydrothermal alteration and minor calcite and quartz veining; underlies Tru; contact of Pu with underlying Madera Formation is sharp to gradational depending on location; thickness is 90 m in VC-1 (Goff and Gardner, 1994); thickness is 501 m in Baca-12 (Nielson and Hulen, 1984); maximum exposed thickness in map area roughly 70 m.

Mississippian-Pennsylvanian

MlPu   **Mississippian-Pennsylvanian rocks, undivided (only on cross section A-A')**—Light to dark gray, fossiliferous limestone and micrite with subordinate gray to buff arkose, sandstone, shale and mudstone (Madera Formation); displays considerable hydrothermal alteration, veining, faulting, fracturing and brecciation in geothermal wells (Goff and Gardner, 1994 and references therein); thickness is 390 m in VC-1; thickness is 293 m in Baca-12 (Nielson and Hulen, 1984); the Madera Formation is underlain in VC-1 by 17 m of hydrothermally altered shale, sandstone, conglomerate, and limestone of the Sandia Formation; the Sandia Formation is not identified in Baca-12 but is probably present.

Precambrian

pCu   **Precambrian rocks, undivided (only on cross section A-A')**—Highly variable unit of crystalline rocks throughout Jemez Mountains region (Goff et al., 1989, Table 2); displays minor to severe hydrothermal

alteration; in VC-1 consists of roughly 15 m of gray to green hydrothermally altered, molybdenite-bearing gneiss breccia; alteration minerals are illite-phengite-chlorite-quartz-pyrite-calcite (Hulen and Nielson, 1988; Goff and Gardner, 1994); in Baca-12 consists of 90 m (Nielson and Hulen, 1984) of altered quartz monzonite containing epidote-chlorite-pyrite-actinolite-quartz-calcite; age is 1.62 to 1.44 Ga (Brookins and Laughlin, 1983).