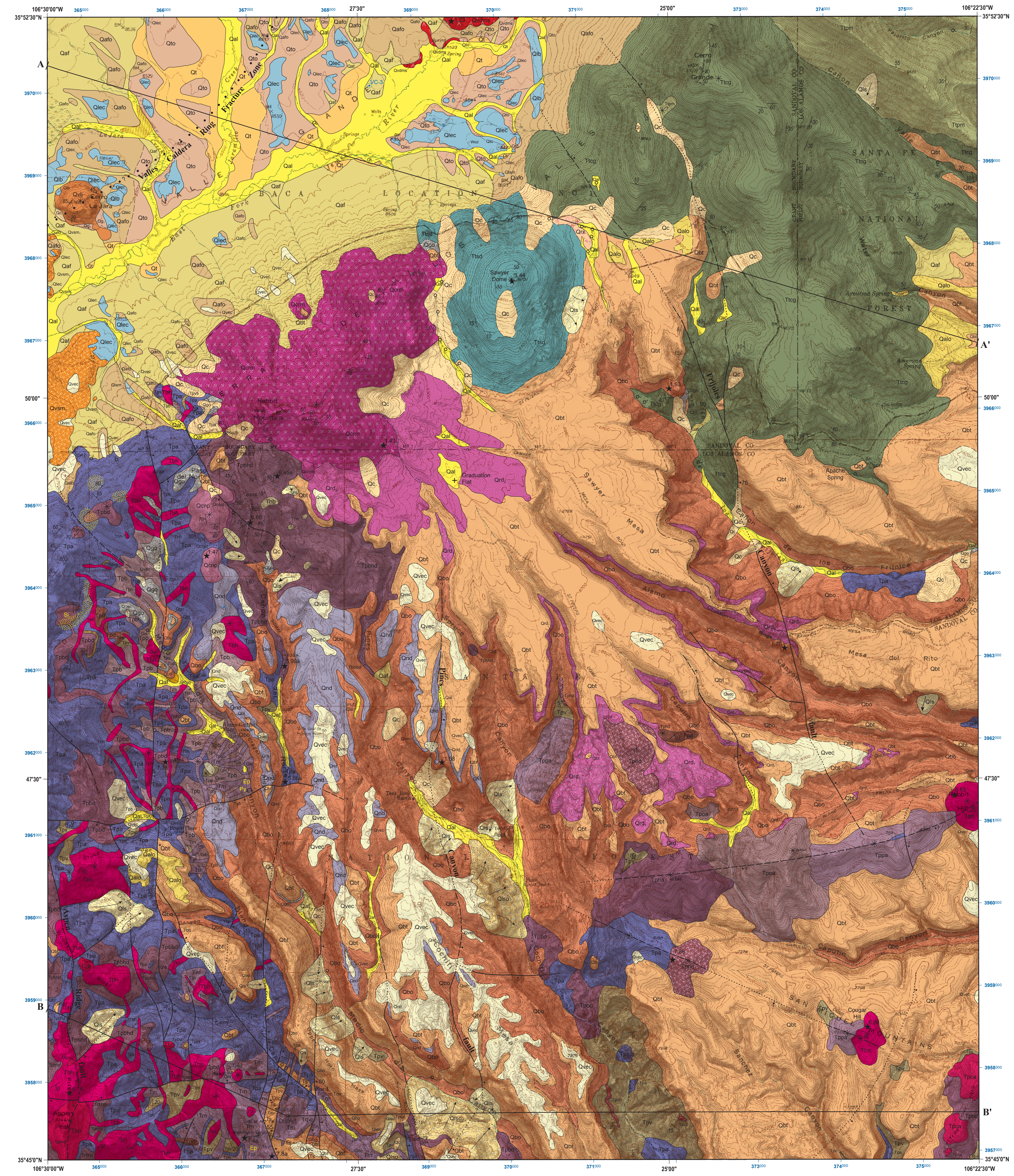
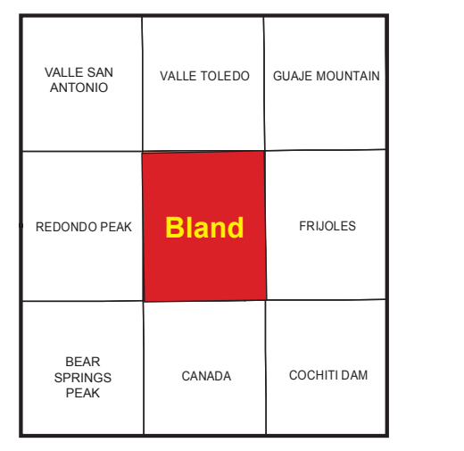
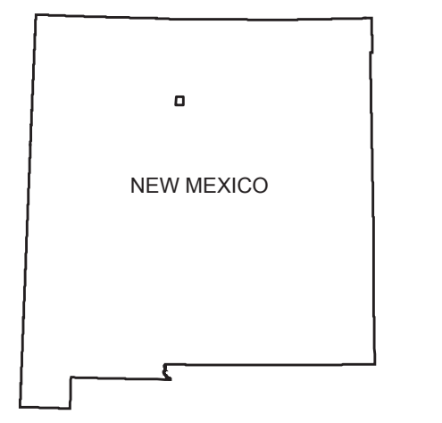
NEW MEXICO BUREAU OF GEOLOGY AND MINERAL RESOURCES A DIVISION OF NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY

NMBGMR Open-file Geologic Map 112
Last Modified September 2012

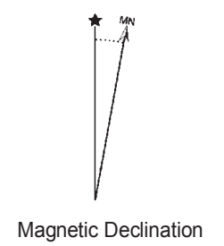


Base from U.S.Geological Survey 1953, from photographs taken 1947,
revised from photographs taken1975. Map edited in 1977.
1927 North American datum, UTM projection -- zone 13N
1000- meter Universal Transverse Mercator grid, zone 13, shown in blue tics.





QUADRANGLE LOCATION



Magnetic Declination
September 2005
9º 55' East
At Map Center

1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929

Mapping of this quadrangle was funded by a matching-funds grant from the STATEMAP program of the National Cooperative Geologic Mapping Act, administered by the U. S. Geological Survey, and by the New Mexico Bureau of Geology and Mineral Resources, (Dr. Peter A. Scholle, *Director and State Geologist* , Dr. J. Michael Timmons, *Geologic Mapping Program Manager*).

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New Mexico Bureau of Geology and Mineral Resources
Open-file Geologic Map 112

Geologic map of the Bland quadrangle, Los Alamos and Sandoval Counties, New Mexico.

May 2006

by
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MAP SYMBOLS

A ├──┤ A' Location of geologic cross section.

─── - - - · · Geologic contact. Solid where exposed or known, dashed where approximately known, queried where uncertain.

55 ─┴─●─ ─ ─ · · · Normal fault, ball-and-bar on downthrown side. Solid where exposed, dashed where approximately known, dotted where concealed.

3 Strike and dip of inclined bedding.

30 Strike and dip of volcanic foliation.

✳ Volcanic vent. Queried where uncertain.

↓ ↘ Landslide. Arrow shows direction of movement.

∽ Cold spring.

★ 8.66a Location of radiometric-dated sample (age in Ma; "a" indicates altered rock sample)

⊙ Well.

∿∿ Alteration associated with fault shear.

▨ Localized geochemical alteration.

Alteration Products:

Ep Vug/vein epidote Si Quartz/chalcedony

Py Abundant pyrite.

COMMENTS TO MAP USERS

A geologic map displays information on the distribution, nature, orientation, and age relationships of rock and deposits and the occurrence of structural features. Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic quadrangle map may be based on any of the following: reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist(s). Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown.

Cross sections are constructed based upon the interpretations of the author made from geologic mapping, and available geophysical, and subsurface (drillhole) data. Cross-sections should be used as an aid to understanding the general geologic framework of the map area, and not be the sole source of information for use in locating or designing wells, buildings, roads, or other man-made structures.

The map has not been reviewed according to New Mexico Bureau of Geology and Mineral Resources standards. The contents of the report and map should not be considered final and complete until reviewed and published by the New Mexico Bureau of Geology and Mineral Resources. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of New Mexico, or the U.S. Government.

DESCRIPTION OF MAP 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), Gardner *et al.* (2010), and this map. 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).

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

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

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

Qaf **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 may be difficult to distinguish from older alluvial fans (described below); deposits in the Valle Grande are younger than the 50 to 60 kyr El Cajete pumice; 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.

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.

Qalo **Older alluvium —** Older deposits of gravel, sand and silt that largely pre-date incision of canyons on the Pajarito Plateau; gravels consist of volcanic fragments, particularly porphyritic dacite, andesite, and welded ignimbrite, from sources in Sierra de los Valles to the west; underlies El Cajete pumice, younger alluvial fans and younger landslides; roughly contemporaneous with older alluvial fan deposits and landslides; overlies Tshirege Member, Bandelier Tuff and dacite of Cerro Grande; maximum exposed thickness about 6 m.

Qto **Older terrace gravel —** Older alluvial deposits of gravel, sand and silt that overlie deposits of the South Mountain lake within Valle Grande; gravels consist of volcanic fragments, particularly dacite, andesite, rhyolite, obsidian and welded ignimbrite from surrounding mountains; underlies El Cajete pumice, younger alluvial fans and younger landslides; roughly contemporaneous with older alluvial fan deposits; maximum exposed thickness about 6 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; 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 Qg_1; age ≤552 ka (Fawcett *et al.*, 2005); maximum drilled thickness in Valle Grande is about 95 m (Conover *et al.*, 1963); drilled thickness in VC-3 core hole in eastern Valle Grande is 76 m.

Qg1 **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 (Goff *et al.*, 2005); 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; Qg_1 underlies the South Mountain rhyolite (*Qvsm*) and Cerro La Jara rhyolite (*Qvlj*) and is composed primarily of gravels containing Bandelier Tuff, aphyric rhyolite, precaldera volcanics and rare Permian fragments where exposed west of map area; thickness beneath Valle Grande unknown.

Qvs **Post-collapse lacustrine and alluvial deposits (cross section A-A' only)** — Intracaldera sediments post-dating formation of Valles caldera; consists of 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 (Goff *et al.*, 2005); beds generally display zeolitic or less commonly acid sulfate alteration; underlies and/or interbedded with *Qdf*; overlies *Qbt*; thickness beneath Valle Grande is speculative.

Qdf **Post-collapse debris flow, landslide, and colluvial deposits (cross section A-A' only)** — Intracaldera sediments post-dating formation of Valles caldera; consists of 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; formed during rapid slumping and erosion of Valles caldera walls, erosion of exposed megabreccia blocks, 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 and cobbles on landscape; presumably underlies most other units in the Valle Grande; exposed only around the south flank of Cerro La Jara, possibly due to intrusion of rhyolite through Valle Grande sediments; maximum exposed thickness is 5 m; thickness beneath Valle Grande is speculative.

Qgo **Older gravels** — Sediments interbedded with the upper and lower Bandelier Tuff south and east of the caldera margin; consists primarily of dark gray to buff gravel, fluvial and minor debris flow deposits; clasts consist of precaldera volcanic rocks, aphyric obsidian attributed to Rabbit Mountain or Del Norte Pass domes, and welded to silicified Bandelier Tuff; exposures are often poor; without stratigraphic or spatial control, unit is difficult to distinguish from *Tpv* or *Qdf* if no Bandelier Tuff or obsidian clasts are present; maximum exposed thickness is 25 m.

Tewa Group

Qvec **El Cajete pyroclastic beds (Valles Rhyolite)** — 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; Gardner *et al.*, 2010); 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; 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 20 m in valleys of the southeastern map area; thins on mesa tops and hills forming scant exposures too thin or small to map.

Qvsm1 **South Mountain rhyolite (Valles Rhyolite)** — 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; erupted from South Mountain west of map area; consists of four main flow units (oldest to youngest $Qvsm_1$ to $Qvsm_4$; Goff *et al.*, 2005) but only $Qvsm_1$ occurs in map area; fills valley in southwestern Valle Grande; underlies El Cajete pumice and various sedimentary deposits in Valle Grande; overlies Qg_1 sedimentary deposits; $^{40}Ar/^{39}Ar$ age is 0.52 ± 0.01 Ma (Spell and Harrison, 1993); maximum exposed thickness about 30 m along East Fork, Jemez River.

Qvlj **Cerro La Jara rhyolite (Valles Rhyolite)** — Dome of flow-banded, massive to slightly vesicular rhyolite lava that closely resembles South Mountain rhyolite in mineralogy; probably originates from same magma batch as South Mountain; intrudes through early caldera fill debris flow deposits; flanked by El Cajete lake and beach deposits on east and by various alluvial fan deposits on other sides; $^{40}Ar/^{39}Ar$ age is 0.53 ± 0.01 Ma (Spell and Harrison, 1993); maximum exposed thickness about 75 m.

Qvdms **Cerro Del Medio rhyolite (Valles Rhyolite)** — Large dome and flow complex of aphyric obsidian to slightly porphyritic, flow-banded rhyolite; flow exposed in map area is one of the older flows erupted from the complex; contains sparse phenocrysts of quartz, sanidine, biotite ± hypersthene; flow is locally vesicular, spherulitic and devitrified; underlies alluvial deposits in Valle Grande; base of unit not exposed; most recent $^{40}Ar/^{39}Ar$ age on sample just north of map area is 1.229 ± 0.017 Ma (Phillips, 2004); maximum exposed thickness in map area is about 35 m.

Qrd2 **Rabbit Mountain debris flow deposits** — Two debris flow deposits overlying the upper Bandelier Tuff immediately south of Rabbit Mountain; general features resemble those of Qrd_1 except the matrix is not as ash-rich and is not sintered; overlain by colluvium and El Cajete pumice; maximum exposed thickness is about 60 m.

Qbt **Upper 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.*, 1997); 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. Locally displays a thin (<2 m) laminated, pumice fall (Tsankawi Pumice) and surge deposit at base of unit that contains roughly 1% of hornblende dacite pumice (Bailey *et al.*, 1969) but this deposit is very thin or absent within map area. Locally contains accidental lithic fragments of older country rock entrained during venting and pyroclastic flow. *Qbt* forms upper surface of western Pajarito Plateau in central and southeastern map area; originated from catastrophic eruptions that formed Valles caldera. Most recent $^{40}Ar/^{39}Ar$ age is 1.25 ± 0.01 Ma (Phillips, 2004); maximum observed thickness is over 260 m in upper Frijoles Canyon.

Qrd1 **Rabbit Mountain glowing avalanche deposits** — White to pale gray debris flows formed by multiple failures of the Rabbit Mountain dome; Qrd_1 forms southeast-trending tongue of chaotic debris over 5 km long and 3 km wide that occurs between the Tshirege and Otowi Members of the Bandelier Tuff; exposures on Obsidian Ridge reveal at least three pulses in the avalanche deposit; sintered textured indicates failure of Rabbit Mountain while dome was still hot; surface of deposit is hummocky; deposit is matrix supported; matrix is extremely ashy; fragments consist of fine sand to large boulders; fragments consist primarily of devitrified massive to flow-banded rhyolite and subordinate obsidian; contains sparse fragments of welded Bandelier Tuff; also contains sparse fragments of biotite-hornblende dacite from dome and flow complex on the southwest shoulder of Rabbit Mountain; maximum exposed thickness is about 40 m.

Qcrm Qcrmt **Rabbit Mountain rhyolite (Valle Toledo Member)** — Large dome with thick flows and flow breccias of black, aphyric to sparsely phyric obsidian to white, devitrified rhyolite; contains sparse visible phenocrysts of quartz, sanidine, and biotite; displays some spherulitic flow banding; displays zones of lithophysae and miarolitic cavities along summit ridges; dome has suffered several episodes of collapse to the north, south, and southeast; actual vent area is probably north of location shown on map having collapsed northward before or during formation of Valles caldera; small exposure of associated, bedded tuff (*Qcrmt*) occurs southwest of dome; K-Ar date of *Qcrm* is 1.43 ± 0.04 Ma (Goff *et al.*, 1990); $^{40}Ar/^{39}Ar$ age is 1.428 ± 0.007 Ma (Peters and McIntosh, 2001, unpublished); maximum exposed thickness is about 410 m.

Qnd **Del Norte Pass debris avalanche deposit** — White to pale gray debris flows apparently formed by failure of Del Norte Pass rhyolite dome; forms irregular tongue of chaotic debris extending 4 km south-southeast from this dome, primarily south of a prominent ridge of biotite-hornblende dacite; consists of at least two pulses; surface of deposit is hummocky; deposit is matrix supported and matrix is extremely ashy; resembles avalanche deposits of Rabbit Mountain except that obsidian is much less abundant and large blocks of andesite and dacite are much more common; overlies Keres Group rocks near source; occurs between the Tshirege and Otowi Members of the Bandelier Tuff further from source; unit is locally so thick that overlying units of *Qbt* are absent; overlain by El Cajete pumice; maximum exposed thickness is about 60 m.

Qcnp Qcnpt **Paso del Norte rhyolite (Valle Toledo Rhyolite)** — Small dome and flow of white to pale grey devitrified rhyolite with sparse phenocrysts of quartz, sanidine and biotite; displays some spherulitic flow banding; dome has suffered one major episode of collapse to the south during formation of Valles caldera, which apparently denuded the pumiceous and glassy carapace; layer of indurated, slightly altered, lithic-rich tuff (*Qcnpt*) underlies dome on east and southeast; originally mapped as Bearhead Rhyolite (Smith *et al*., 1970) but identified as part of the Cerro Toledo rhyolite by Justet (2003); $^{40}Ar/^{39}Ar$ age of sample from flow south of vent is 1.47 ± 0.04 Ma (Justet, 2003); maximum exposed thickness is about 110 m.

Qbo **Lower 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 (Guaje Pumice; Griggs, 1964) and surge deposit at its base that is very thin or absent in most of the Bland quadrangle; may form tent rocks; *Qbo* discontinuously fills in rugged topography on a volcanic surface of pre-Toledo caldera age; has been extensively to completely removed by erosion in upper Frijoles Canyon, Pines Canyon and Lower Medio Dia Canyon; very difficult to distinguish from non-welded, vitric portions of the upper 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 or beneath intervening deposits of older gravel (*Qgo*); 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); samples of uppermost Otowi just below contacts with Rabbit Mountain and Del Norte Pass debris flow deposits are 1.58 to 1.70 Ma; maximum exposed thickness about 60 m.

Tertiary (Pliocene - Oligocene?) Deposits

Keres Group (Pliocene-Miocene)

Tschicoma Formation (Pliocene)

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, and opaque oxides in a devitrified groundmass; contains clots of complexly zoned plagioclase and occasional 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; small intrusive body of similar dacite southwest of Cerro Grande may be satellite vent to the main eruption; overlies and intrudes 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 (WoldeGabriel, 2001, unpub.); maximum exposed thickness is about 365 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 (usually) 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 of the Bandelier Tuff (*Qbt*); dates on widely separated samples range from 3.8 to 3.1 Ma (Dalrymple et al., 1967; WoldeGabriel, 2001, unpub. data); maximum exposed thickness is about 750 m.

Ttsd **Sawyer Dome dacite —** Dome and flow complex of gray to pale pink, generally massive, porphyritic dacite containing phenocrysts of plagioclase, hypersthene, opaque oxides and conspicuous hornblende up to 4 mm long; contains occasional mafic clots of plagioclase-hornblende up to 10 cm in diameter; underlies dacite of Cerro Grande; underlies Rabbit Mountain Rhyolite and Bandelier Tuff; $^{40}Ar/^{39}Ar$ age is 3.61 ± 0.21 Ma (WoldeGabriel, 2001, unpub. data); maximum exposed thickness is 245 m.

Ttu **Dacite and andesite, undivided (cross section A-A' only) —** Gray to pale pink porphyritic dacite and andesite with phenocrysts of plagioclase, orthopyroxene, clinopyroxene ± hornblende; underlies lower Bandelier Tuff (*Qbo*) and dacite of Sawyer Dome (*Ttsd*); overlies Paliza Canyon andesite (*Tpa*); ages of major domes north of map area roughly 2 to 5 Ma (Goff *et al.*, 2002; Kempter and Kelley, 2002); thickness in cross section is speculative.

Bearhead Rhyolite (Pliocene-Miocene)

Thb Tqv **Hydrothermal breccia and quartz veins** — Relatively small areas of hydrothermal rocks along northwest-trending ridge of dacite south of Rabbit Mountain and along or near fault zones in the Bland area; probably associated with volcanism of the Bearhead Rhyolite but may be related to Keres Group volcanism (Bundy, 1958; Stein, 1983; Goff *et al.*, 2005); Thb consists of relatively circular, vertical pipes of mosaic breccia ≤100 m in diameter containing fragments of altered dacite in a fine-grained, silicified matrix; *Tqv* consists of quartz veins and vein networks up to 50 m wide cutting altered Bearhead Rhyolite and Keres Group volcanic rocks; veins exposed primarily along fault zones in southwest map area; both units have been modified by post-emplacement faulting; veins contain minor adularia, Cu-Pb-Zn sulfides and gold-silver electrum; sulfides extensively altered to oxides, alunite and clay; units are probably between 5.6 and 8.5 Ma (WoldeGabriel and Goff, 1989); vertical thickness of breccia pipes is unknown; vertical extent of veins exceeds 250 m (Bundy, 1958).

Tbh Tbp **Rhyolite intrusive rocks (Bearhead Rhyolite)** — White to gray dikes, plugs, sills, domes, and flows of slightly porphyritic to aphyric devitrified rhyolite containing sparse 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; width of individual dikes shown on map are commonly exaggerated and may consist of many smaller sub-parallel dikes; associated lithic-rich tuffs (*Tbp*) occur only in southwest part of map in Aspen Peak area; pervasive, hydrothermally altered plugs and dikes occur throughout west and southwest map area probably emanating from shallow underlying pluton; intrudes or overlies Paliza Canyon Formation rocks; 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 intrusion north of Aspen Peak is 6.76 ± 0.10 Ma; date on Cougar Hill plug is 6.80 ± 0.05; date on Rabbit Hill dome is 6.65 ± 0.03 (Justet, 1996); maximum observed thickness about 170 m.

Paliza Canyon Formation (Miocene)

Tpv **Volcaniclastic deposits —** Black to gray to pale pink to purple-red, highly diverse volcaniclastic unit consisting predominately of sandstones, gravels, lahars, block-and-ash flows, and other debris flows; mostly formed contemporaneously with Paliza Canyon Formation; locally contains hyper concentrated flow and fluvial deposits, cinder and scoria deposits, and pyroclastic fall deposits; contains andesite and dacite flow and flow-breccias too small or thin to map; older deposits display considerable hydrothermal alteration up to presence of epidote; unit has accumulated in small basins, topographic lows, and canyons cut into Paliza Canyon Formation volcanoes; unit generally thickens to south and east toward evolving Rio Grande rift; 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 into the Pliocene (Smith and Lavine, 1996); as defined here, includes both Volcanic Breccia 1 (volcanic sandstone and conglomerate) and Volcanic Breccia 2 (predominately scoria-derived deposits) of Stein (1983) in areas around and north of Bland; largest exposure of *Tpv* occurs in Cochiti Canyon where predominately lahars and block-and-ash flows are interbedded with small andesite and dacite flows, and with dacite tuffs; scoria-rich deposits occur in Bland Canyon, north of Bruce Place, and in areas of upper Medio Dia Canyon; bedded deposits with consistent 15 to 20° dip to east occur in Colle Canyon; exposure of dacite-rich boulder conglomerate occurs beneath upper Bandelier Tuff at southeast tip of Upper Horn Mesa; interbedded and intruded by all types of Keres Group lavas and dikes; intruded by monzonite in Colle Canyon and upper Bland Canyon; underlies Santa Fe Group sandstone in unnamed canyon north of Bland stock; age of *Tpv* in map area is bracketed between roughly 8 and 13 Ma; maximum exposed thickness is about 215 m.

Tpvs **Volcanic sandstone —** Brick red to tan moderately- to well-sorted sandstone containing mostly volcanic fragments, feldspar, mafic minerals, and minor quartz; mapped only where laterally extensive and at least 3 m thick; occurs between lava flow contacts in isolated locations throughout Paliza Canyon Formation.

Tphd **Porphyritic hornblende dacite** — Two eroded dome and flow complexes of gray to pale pink porphyritic dacite in southeast map area; contains phenocrysts of complexly zoned plagioclase and smaller phenocrysts of plagioclase, hornblende, clinopyroxene, opaque minerals ± biotite ± hypersthene ± apatite ± potassium feldspar; may contain clots of plagioclase and mafic minerals; may contain plagioclase-pyroxene-hornblende clots up to 20 cm in diameter; groundmass is glassy to devitrified and commonly trachytic; flows massive to sheeted; $^{40}Ar/^{39}Ar$ age of dome at head of Sanchez Canyon is 7.86 ± 0.14 Ma (Justet, 2003); maximum exposed thickness is 75 m.

Tpbd **Porphyritic biotite dacite** — Eroded domes, flows, dikes and plugs of gray to pale pink dacite having phenocrysts of plagioclase, biotite, clinopyroxene, orthopyroxene ± hornblende in a trachytic groundmass of plagioclase, pyroxene, and opaque oxides; contains complexly zoned and fritted plagioclase phenocrysts up to 15 mm in diameter; contains minor clots of plagioclase and pyroxene; many flows are extensively altered to silica, chlorite, clay, Fe-oxides ± calcite; interbedded with and intrudes andesite in most locations; interbedded with *Tpv* in southeast map area; dike intrudes monzonite west of Bland; intruded by Bearhead Rhyolite; ages of various units in map area unknown; $^{40}Ar/^{39}Ar$ age of flow on ridge top in west-central part of quad is 7.56 ± 0.08 Ma; K-Ar age of dome in upper Bland Canyon just south of map is 9.11 ± 0.19 Ma (Goff et al., 1990); maximum exposed thickness is 140 m.

Tpha **Hornblende andesite** — Gray to black flows, dome, and plug of glassy to devitrified andesite having small phenocrysts of plagioclase, clinopyroxene, oxidized to fresh hornblende ± hypersthene ± rare biotite in a trachytic to nearly intersertal groundmass of plagioclase, clinopyroxene, opaque minerals ± hypersthene ± hornblende; plagioclase may be complexly zoned; may contain plagioclase-pyroxene or plagioclase-hornblende clots; may display flow banding or contain flow breccia; ages of various exposures unknown; maximum exposed thickness about 45 m.

Tppa **Porphyritic andesite** — Gray to black domes and flows of coarsely porphyritic andesite having large phenocrysts of plagioclase and abundant phenocrysts of clinopyroxene and hypersthene in a glassy almost intersertal groundmass of plagioclase, clinopyroxene, hypersthene, and opaque minerals; plagioclase may be complexly zoned; may contain plagioclase-pyroxene clots up to 10 cm in diameter; flows generally sheeted with minor flow breccia; separated from other andesites only in southeast part of map where relations are not obscured by faulting and hydrothermal alteration; flows in map area not dated; K-Ar date of flow at summit of St. Peter's Dome just east of map area is 8.69 ± 0.38 Ma (Goff *et al.*, 1990); maximum observed thickness is about 150 m.

Tpca **Clot-rich andesite** — Extensive dome and flow complex beneath the summit of St. Peter's Dome occurring in extreme southeast corner of map; consists of gray to black porphyritic andesite with abundant distinctive plagioclase-pyroxene clots 2 mm in diameter and phenocrysts of plagioclase, clinopyroxene, and hypersthene in a glassy almost intersertal groundmass; microphenocrysts consist of plagioclase, clinopyroxene, hypersthene, and opaque minerals; flows massive, rarely brecciated or sheeted; unit not dated; maximum observed thickness is about 50 m.

Tpd **Dacite** — Tan to gray to black, flow banded to massive, slightly porphyritic to aphyric dacite lavas, dikes and plug; groundmass is commonly trachytic with phenocrysts of plagioclase and sparse microphenocrysts of plagioclase, clinopyroxene, hypersthene, opaque oxides ± biotite ± hornblende; pervasively altered to chlorite, silica, and clay; intrudes monzonite and andesite in Colle Canyon; ages of various units unknown; maximum exposed thickness about 30 m.

Tpbhd **Porphyritic biotite, hornblende dacite** — Dome and flow complexes and highly faulted flows containing 10 to 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; partially obscured vent occurs beneath southwest flank of Rabbit Mountain; vent for flows east of Bearhead Ridge may occur north of Reid Canyon; fresh outcrops unusual; hydrothermal alteration consists of clay, silica, calcite, Fe-oxides, chlorite ± epidote; interbedded with andesite flows; intruded by Bearhead Rhyolite; $^{40}Ar/^{39}Ar$ age of dome and flow complex south of Rabbit Mountains is 8.66 ± 0.22 Ma; $^{40}Ar/^{39}Ar$ age of similar unit west of map area is 9.42 ± 0.22 Ma (Justet, 2003; Goff et al., 2005); age of pervasive hydrothermal alteration of this unit in upper Del Norte Canyon area is about 6.5 to 6.0 Ma (WoldeGabriel and Goff, 1989); maximum exposed thickness is at least 275 m.

Tpoa **Olivine andesite** — Black to gray dome and flow complex with minor red cinder deposits occurring in southeast map area; consists of slightly porphyritic andesite with phenocrysts of plagioclase, clinopyroxene, and olivine ± hypersthene in a glassy to almost intersertal groundmass; olivine may show both high- and low-temperature iddingsite; may contain sparse plagioclase-pyroxene clots; may contain apatite microphenocrysts; flows massive to sheeted, commonly with vesicular flow tops; apparently intruded by *Tppa* on east and overlain by Tpha on west; age of unit unknown; maximum observed thickness about 70 m.

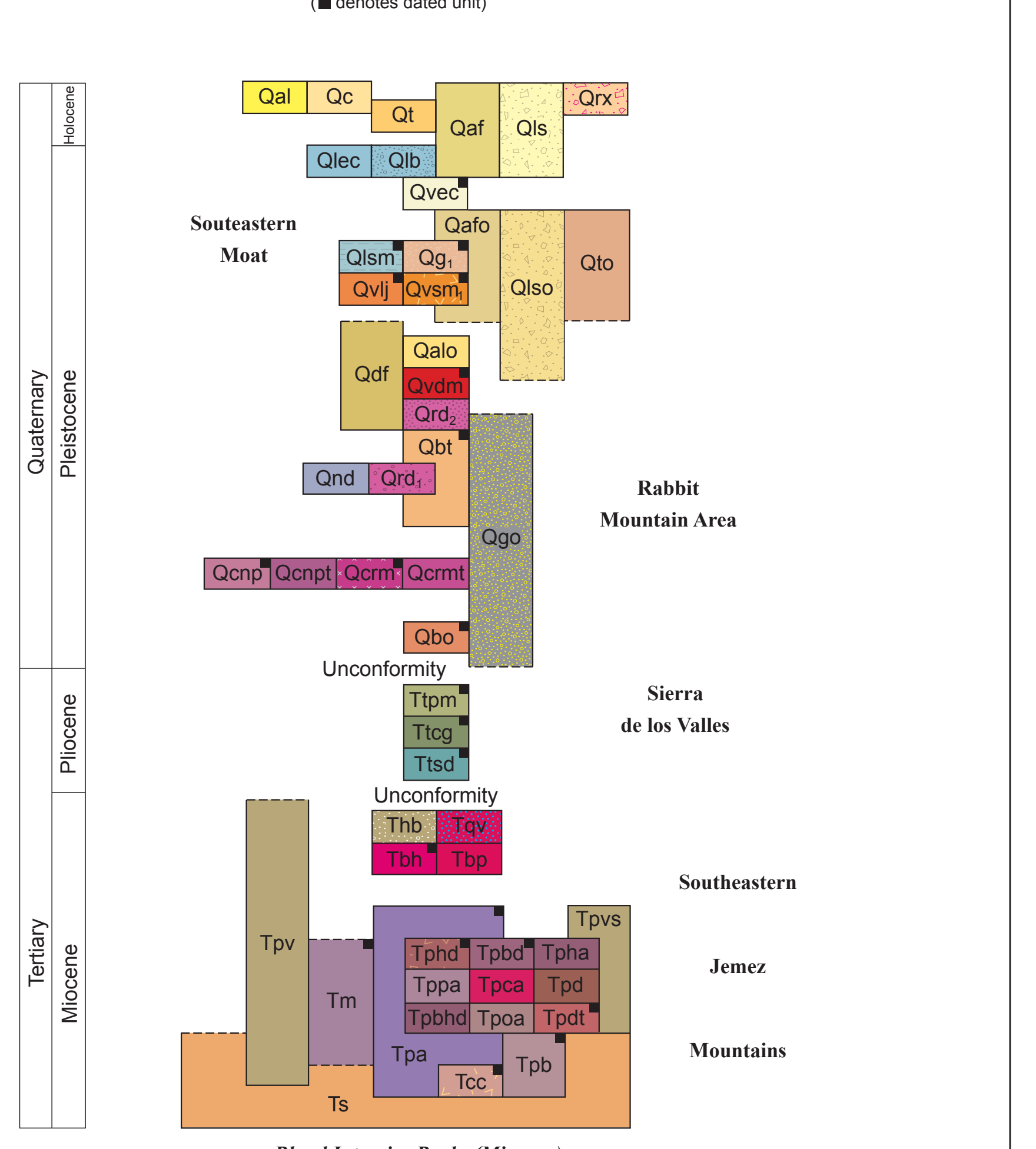
Tpdt **Dacite tuff —** White pyroclastic fall deposits containing pumice, ash, crystals, and lithic fragments commonly found in volcaniclastic deposits of *Tpv*; mapped only where >3 m thick and over a hundred meters in length; phenocrysts in pumice clasts generally contain plagioclase, clinopyroxene, and hypersthene, ± hornblende, ± biotite; beds often slightly silicified; beds are not laterally extensive and pinch out due to erosion; may show reverse or graded bedding; $^{40}Ar/^{39}Ar$ dates of four tuff beds in canyons east of map area range from 9.1 to 9.5 Ma (Lavine *et al.*, 1996); maximum thickness about 10 m but most beds ≤1 m thick and generally too thin or discontinuous to map.

Tpa **Two-pyroxene andesite, undivided** — Domes, flows, flow breccia, spatter deposits, and scoria of andesite from multiple sources; vents are widely scattered; individual units are slightly porphyritic to very porphyritic; flows dense to highly vesicular; tends to be relatively fresh and sometimes glassy in the east to hydrothermally altered in west and southwest; 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 varies from slight to extremely intense; alteration generally consists of silica, calcite, Fe-oxides, clay ± chlorite ± zeolite ± pyrite ± epidote; interbedded with and intrudes most other Paliza Canyon units; overlies basalt in upper Bland Canyon and lower Colle Canyon; intruded by monzonite in lower Colle Canyon and at Bland; units in map area not dated; fresh andesite flows in upper part of unit west of map area range from 8.8 to 9.4 Ma (Goff *et al.*, 2005); maximum exposed thickness about 150 m in upper Medio Dia Canyon.

Tpb **Olivine basalt and basaltic andesite, undivided** — Flows, flow breccia, spatter deposits, and scoria of basalt and subordinate basaltic andesite from multiple sources; one vent (shown within unit *Tpv*) occurs at east end of prominent ridge north of Bruce Place; most units are slightly porphyritic; flows dense to highly vesicular; 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; most flows display variable amounts of hydrothermal alteration consisting of silica, calcite, Fe-oxides, clay ± zeolite ± chlorite ± epidote ± pyrite; interbedded with and underlies *Tpa*; intruded by monzonite in lower Colle Canyon, upper Bland Canyon and central Medio Dia Canyon; units in map area never dated; maximum exposed thickness about 150 m.

CORRELATION OF MAP UNITS

(■ denotes dated unit)



Bland Intrusive Rocks (Miocene)

Tm **Monzonite intrusive bodies** — Dikes, sills, pods, plugs and stocks of crystalline rocks collectively called monzonite (after Bundy, 1958); textures range from coarse-grained, hypidiomorphic granular and seriate to fine-grained, trachytic and porphyritic. Stein (1983) describes the full range of textures, mineralogy and chemical compositions in these intrusives, which range from monzonite to quartz monzonite; apparently a compound stock in the Bland area; primary minerals consist of plagioclase, clinopyroxene, orthopyroxene, potassium feldspar and quartz ± biotite ± hornblende. Alteration is moderate to intense, argillic to propylitic; replacement minerals consist mainly of clays, Fe,Mn-oxides, silica, calcite, illite, chlorite, epidote and pyrite; rank of alteration generally increases toward bottoms of canyons; locally contains cavities of quartz-chlorite-epidote-calcite; larger stock west of Washington Hill contains plexus of unmapped dikes with pronounced north-northwest trend; other stocks and plugs display central core of monzonite from which radiate monzonite dikes; width of single dikes shown on map are usually exaggerated and may consist of up to 20 thin, semi-parallel dikes; vent areas shown on map represent crystallized roots of andesitic to dacitic volcanoes of the Paliza Canyon Formation; monzonite intrudes basalt, andesite, volcaniclastic sediments (*Tpv*) and Santa Fe Group; overlain and intruded by andesite, dacite and Bearhead Rhyolite; K-Ar date on relatively unaltered sample from unspecified location is 11.3 ± 0.3 Ma (Stein, 1983); altered monzonite from main stock has $^{40}Ar/^{39}Ar$ ages of 7.8 to 7.4 Ma; maximum exposed thickness east of Colle Canyon is about 275 m.

Canovas Canyon Formation (Miocene)

Tcc **Canovas Canyon Rhyolite** — Poorly exposed flow of pale greenish-gray, hydrothermally altered rhyolite in bottom of Medio Dia Canyon at Evans-Griffin Place; unit is silicified, containing quartz, feldspar, biotite and possibly hornblende altered to silica, clay, Fe-oxide, illite and chlorite; some specimens contain calcite; underlies basalt; bottom of unit not exposed; maximum exposed thickness about 10 m.

Tcct **Canovas Canyon Rhyolite tuff (cross section B-B' only)** — White to pink pyroclastic fall and pyroclastic flow deposits of the Canovas Canyon Rhyolite (Bailey *et al.*, 1969; Gardner *et al.*, 1986); lowermost unit exposed on east flank of St. Peter's Dome consists of pink, lithic-rich tuff containing abundant fragments of flow-banded rhyolite (informally named the "pink tuff"'); underlies andesite, dacite and volcaniclastic rocks, and overlies the Santa Fe Group on the east side of St. Peter's Dome; age of similar pink tuff in Bear Springs quadrangle is about 9.4 Ma (S. Kelley, unpub. data); maximum observed thickness is about 20 m.

Santa Fe Group (Miocene)

Ts **Sandstone** — White to tan to very pale green feldspathic sandstone; generally medium-grained, well-sorted and well-indurated; grains are mostly subangular to subrounded and consist of roughly 65 to 90% quartz, 5 to 20% feldspar and a variety of other minerals and volcanic rock fragments; much of the quartz is polycrystalline; dark mineral laminations, which may represent bedding are found in scattered locations and have a consistent dip of 15 ± 5° east; feldspar grains are altered to illite and kaolinite (Bundy, 1958); cement consists of variable amounts of chalcedony, calcite, illite, chlorite, limonite, and hematite; near monzonite bodies the quartz grains are partially recrystallized; overlies altered volcaniclastic sediments (*Tpv*) north of Washington Hill; overlies basaltic andesite lava and altered volcanic breccia just south of map area; underlies andesite on northeast wall of lower Bland Canyon; intruded by monzonite stock and dikes in Bland area; underlies and is interbedded with basalt and andesite west of map area (Goff et al., 2005); underlies andesite, dacite, and rhyolite tuff, and overlies Gallisteo Formation in St. Peter's Dome area east of map (Goff et al., 2002); maximum observed thickness roughly 200 m. Age range of unit is roughly 9 to 18 Ma.

Galisteo Formation (Eocene)

Tgs **Sedimentary deposits (cross sections only)** — Orange to tan to brick red beds of well-indurated sandstone, siltstone, arkose, and conglomerate; conglomerate beds may preferentially contain limestone, chert, and granitoid fragments from pebble to boulder size from eroded Paleozoic and Precambrian sources; unit exposed on rotated fault blocks with beds dipping steeply to the west along east flank of St. Peter's Dome (Goff *et al.*, 2002); unconformably underlies the Santa Fe Group; bottom of unit is not exposed; maximum observed thickness is about 200 m; thickness in cross sections is speculative.

Paleozoic Rocks

Permian

Pu **Permian rocks, undivided (cross section A-A' only) —** White to reddish white, well-sorted, generally plane to cross-bedded quartz arenite with some mica (Glorieta Sandstone); orange red, well-sorted, medium-grained quartzofeldspathic sandstone and minor siltstone (Yeso Formation); brick red to brownish red quartzofeldspathic sandstone, siltstone and mudstone; contains some obvious mica; contains minor conglomerate and limestone (Abo Formation); Yeso and Abo are usually indurated beneath the caldera as documented in geothermal wells west of map area (Goff *et al.*, 2005) where they display considerable greenish hydrothermal alteration and minor calcite and quartz veining; contact of *Pu* with underlying Madera Formation is sharp to gradational depending on location; thickness is 501 m in Baca-12 west of map area (Nielson and Hulen, 1984).

Mississippian - Pennsylvanian

MIPu **Mississippian-Pennsylvanian rocks, undivided (cross section A-A' only) —** Light to dark gray, fossiliferous limestone and micrite with subordinate gray to buff arkose, sandstone, shale and mudstone (Madera Formation); may contain hydrothermally altered shale, sandstone, conglomerate, and limestone of the Sandia 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 geothermal wells west of map area (Goff *et al.*, 2005).

Precambrian Rocks

p€u **Precambrian rocks, undivided (cross section A-A' only) —** Highly variable unit of crystalline rocks throughout Jemez Mountains region (Goff *et al.*, 1989, Table 2); displays minor to severe hydrothermal alteration (Goff *et al.*, 2005); age is 1.62 to 1.44 Ga (Brookins and Laughlin, 1983).

REFERENCES

(See accompanying report).

GEOLOGIC CROSS SECTIONS