

Preliminary Geologic Map of the Cerro Pelon Quadrangle, Cibola and McKinley Counties, New Mexico

By

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Open-file Digital Geologic Map OF-GM 202

Scale 1:24,000

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PRELIMINARY GEOLOGIC MAP OF THE CERRO PELON QUADRANGLE, CIBOLA AND McKINLEY COUNTIES, NEW MEXICO

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Cover Photo: Spectacular tent rocks and cliffs of alternating pyroclastic fall, flow and surge deposits exposed in upper San Mateo Canyon, Cerro Pelón Quadrangle. These tephra are at least 110 m thick and are part of unit Tvst described below (photo by S.A. Kelley).

INTRODUCTION

Cerro Pelón quadrangle lies on the north flank of Mount Taylor, an extinct composite volcano in west central New Mexico (Hunt, 1938), and is located roughly 25 km northeast of Grants, New Mexico (Fig. 1). The landscape is dominated by a volcanic highland to elevations of 3325 m (10,900 ft) in the southwest and south, which is flanked by lava flows and cinder cones of Mesa Chivato to the north and San Mateo Canyon to the northwest. Forest Service roads 51, 239, 451, 453, 456, and 555 provide access to most parts of the quadrangle. The U.S. Forest Service owns most land in the quadrangle. Exceptions are the Lee and Elkins Ranches in the southeast part of the quadrangle, a thin strip of the Bartolome Fernandez Land Grant in the northwest corner of the quadrangle, a small piece of the San Mateo Springs Grant in lower San Mateo Canyon, and the tiny San Mateo Springs Tract No 2 landholding south of Mesa La Cuchilla. Because of the recent rise in uranium prices, much of the San Mateo Canyon region including the mesa west of the canyon contains revived mineral claims and many new fences partially restricting access. Most of the land is used for ranching, recreation, and hunting. We found relatively scant evidence that pre-Columbian inhabitants lived in the quadrangle.

Hunt (1938) produced the first geologic map of the region and pointed out the spatial association between the Mount Taylor stratovolcano and surrounding mafic lavas and cinder cones. Sears et al. (1941) described transgressive-regressive depositional relations in Upper Cretaceous sedimentary rocks beneath Mount Taylor. Geologic mapping of 1:24,000 quadrangles began in the 1960s, mainly supporting the regional uranium boom (e.g., Moench, 1963; Moench and Schlee, 1967; Lipman et al., 1979). Crumpler (1980a, 1980b) mapped a portion of Mesa Chivato about 10 kilometers north of Cerro Pelón quadrangle and analyzed many of the lavas, cones and domes. Crumpler (1982, Fig. 4) also published a geologic sketch map of the summit of Mount Taylor. Perry et al. (1990) published a more detailed geologic map of the summit and southwest flank of the volcanic complex. Dillinger (1990) produced a 1:100,000-scale map of the region to support coal investigations. The geochemistry and age of Mount Taylor and Mesa Chivato volcanic products has been investigated in numerous reports (Baker and Ridley, 1970; Lipman and Moench, 1972; Crumpler, 1982; Perry et al., 1990; Shackley, 1998).

ACKNOWLEDGEMENTS

Buddy Elkins graciously provided access to the Elkins Ranch and Harry Lee, Jr. granted access to the Lee Ranch. The State Map Program jointly supported by the U.S. Geological Survey and the New Mexico Bureau of Geology and Mineral Resources funded this geologic map. We thank J. Michael Timmons (NMBG&MR) for logistical and tactical support and Larry Crumpler (New Mexico Natural History Museum) for discussions on the volcanology, Amy Trivett helped us identify and scan well logs housed in the Library of Subsurface Data at the New Mexico Bureau of Geology and Mineral Resources. We thank Ginger McLemore and Rusty Riese for discussions about the uranium logs and uranium prospects and thank Kelsey Seals for her diligent cartographic skills producing the final map. Fieldwork was conducted by standard methods (topographic maps, air photography, binoculars, rock hammers, hand lenses, GPS devices, brunton compasses, four-wheel drive trucks, and boot leather) on all lands.

GEOLOGY

The Cerro Pelón quadrangle is underlain by a thick, widespread sequence of folded, domed and faulted upper Cretaceous rocks of the southern Colorado Plateau (Figs. 2, 3) having an aggregate

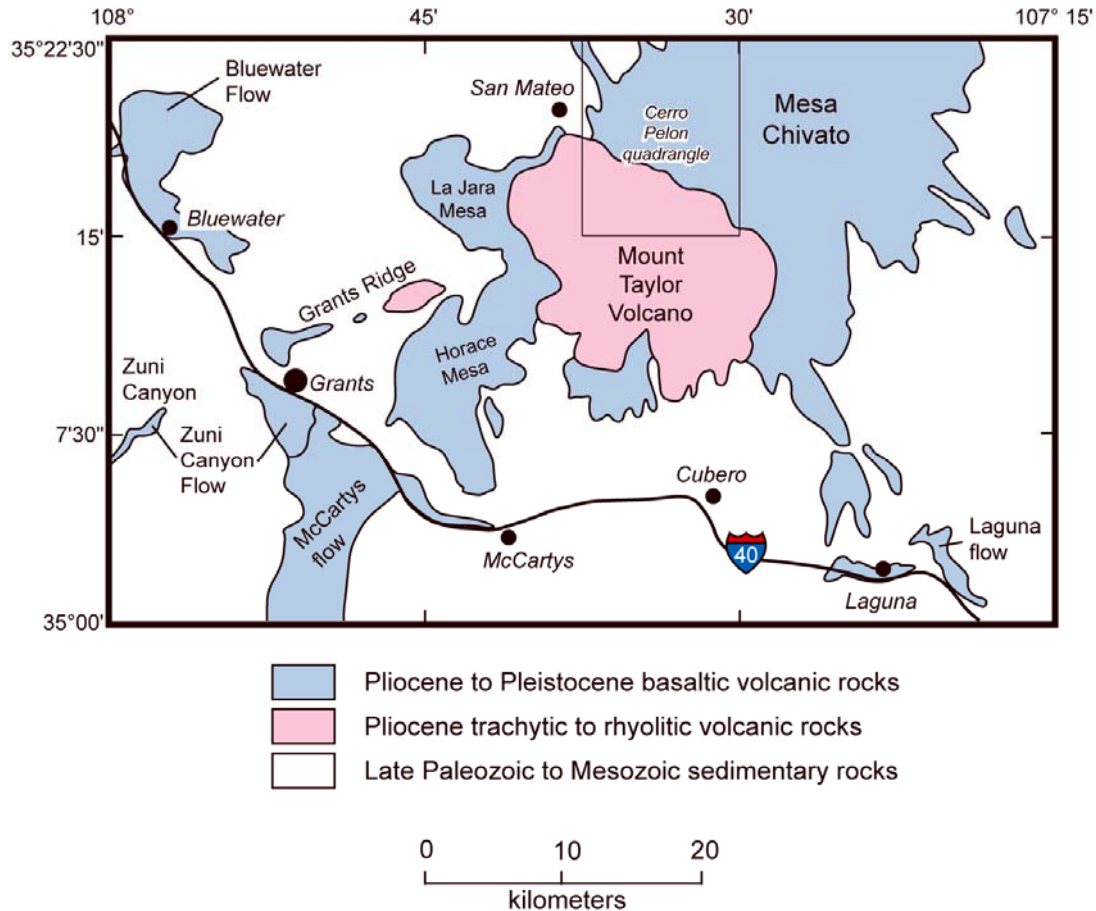


Figure 1: Map showing location of Cerro Pelón quadrangle and important physiographic features with respect to Mount Taylor Volcano.

thickness of 1070 m (3500 ft). Our mapping utilizes the style and terminology of Hunt (1938) and Lipman et al. (1979). The upper Cretaceous section (Fig. 4) is a regressive sequence, recording a gradual transition from open marine conditions (Mancos Shale) to a marginal marine (Gallup Sandstone, Stray and Dalton Sandstone members of the Crevasse Canyon Formation) and deltaic (Dilco and Gibson Coal members of the Crevasse Canyon Formation) setting. The Point Lookout Sandstone, exposed to the west of the quadrangle, was deposited during a marine transgression. The Menefee Formation, the only Cretaceous unit exposed at the surface beneath the volcanic rocks on the quadrangle, was deposited in a coastal plain setting during a regressive to transgressive cycle. The Menefee Formation is made up of two members: the older Cleary Coal Member and the younger Allison (barren) Member. Fluvial sandstone and shale of the Allison Member dominate the Cretaceous exposures on the Cerro Pelón quadrangle (Figure 4); only one or two lenses of coal were observed in the northwestern corner of the quadrangle.

The upper Cretaceous sequence in the Mount Taylor region was folded, uplifted and eroded in early to mid Tertiary time forming part of the greater Colorado Plateau. During the last 25 Myr, a structural transition zone has developed between the Colorado Plateau and an extensional zone called the Rio Grande rift. Cretaceous rocks were partially eroded during a period of base level stability and pedimentation in west central New Mexico that lasted from approximately 4 to 2.5 Ma. The Mt. Taylor volcanics were erupted onto this pediment surface.

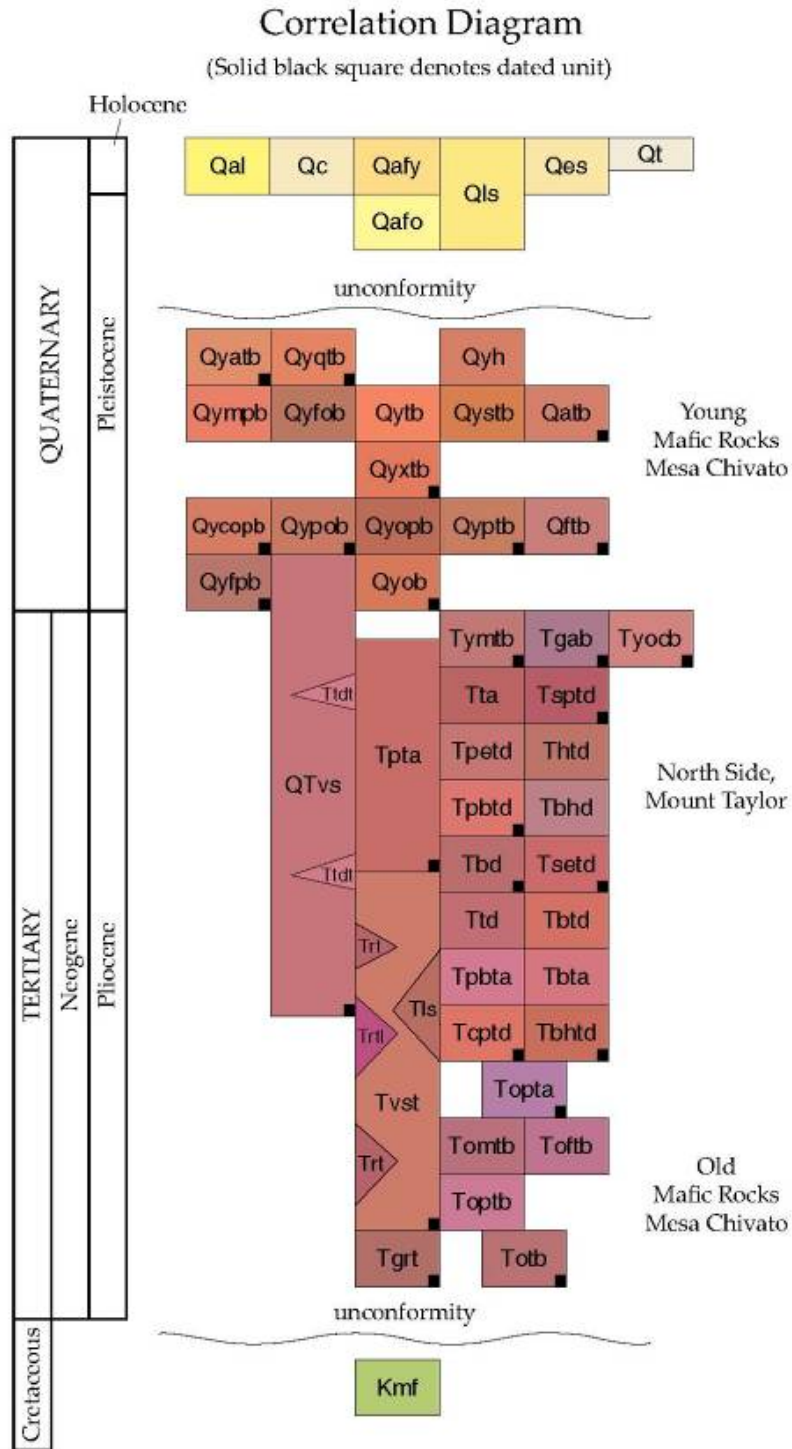


Figure 2: Correlation chart of geologic units mapped during this investigation.

Bryan and McCann (1938) suggested that the erosion surface underlying Mt. Taylor was correlative with the Ortiz surface located in the Rio Grande rift. Beginning in the early Pliocene (roughly 3.8 Ma), volcanism ensued in the region eventually forming a composite intermediate composition stratovolcano at Mount Taylor, flanked by mesas covered with basaltic lavas and cinder cones.

This volcanism more or less ceased at about 1.25 Ma. Since that time, erosion has cut broad basins and shallow canyons into the terrain. The regional Pliocene pediment surface is preserved only where it is capped by basalt flows, such as on Mesa Chivato.

Subsurface stratigraphy Cerro Pelon quadrangle

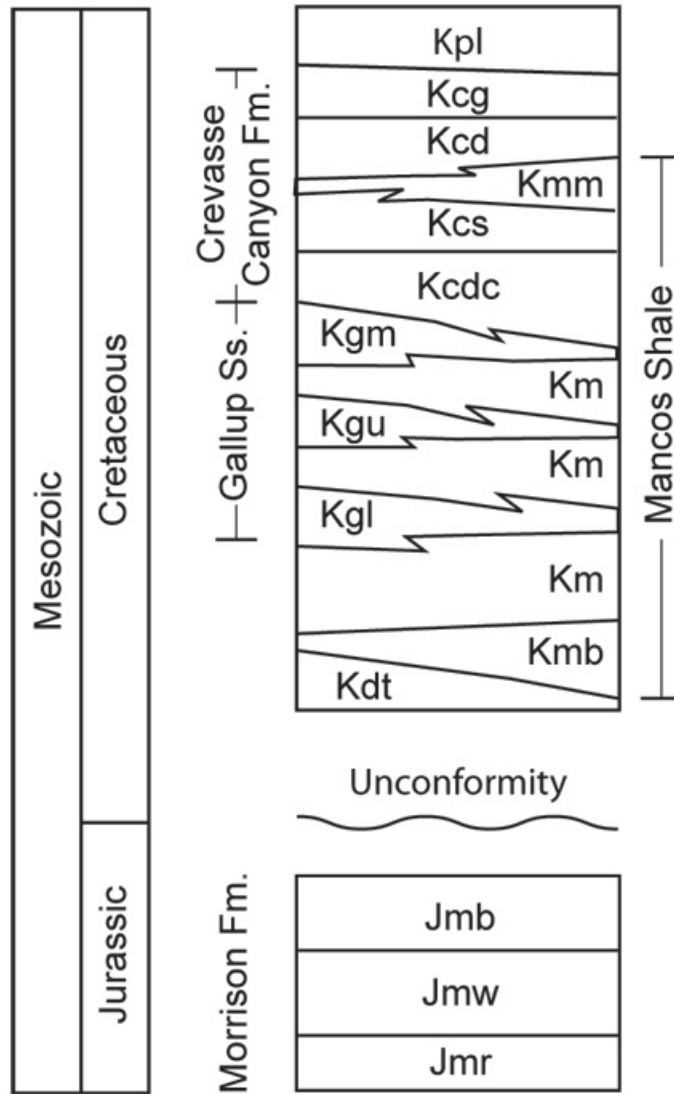


Figure 3: Subsurface stratigraphy of Cerro Pelón quadrangle through Morrison Formation.

Weakly cemented sedimentary rocks are discontinuously preserved above the Cretaceous units and below the oldest volcanic rocks in the northwestern part of the Cerro Pelón quadrangle and on the northwest side of the mesa north of La Mosca tank on the San Mateo quadrangle. This unit is too thin to show on the geologic map. The sediments are found below the oldest basalt in San Miguel Canyon along the north edge of the quadrangle. Here, conglomeratic sandstone with lenses of black, yellow, and gray chert pebbles grades up into a very fine-grained to fine-grained sandstone with moderate sorting. The sand grains are generally angular, but there are a few larger well-rounded grains. At one place along this escarpment, reworked aphyric pumice likely derived from Grants Ridge Tuff is included in the sandstone below the oldest basalt flow in this area.

The chert pebble conglomeratic sandstone is also preserved below the Grants Ridge Tuff on La Cuchilla Mesa in the northwestern corner of the Cerro Pelón quadrangle; the exposures are poor, but chert pebble float is common. The sediment is well exposed on the northwest side of the mesa north of La Mosca tank on the San Mateo quadrangle (Fig. 5). The spotty preservation of this unit appears to mark the course of a Pliocene stream carrying chert reworked out of older Mesozoic units.



Figure 4: Ledges of pink to tan Grants Ridge Tuff and overlying volcaniclastic sandstone sit on golden brown sandstone of the Cretaceous Menefee Formation in Marquez Canyon. Black to gray shale of the Menefee Formation forms the slope below the sandstone.

Crumpler (1980a, 1980b) and Perry et al. (1990) provide the most recent descriptions of the magmatic evolution of the Mount Taylor volcanic field (MTVF) and Mesa Chivato. Volcanism in the Cerro Pelón quadrangle probably commenced with emplacement of the Grant's Ridge tuff

(3.26 ± 0.20 Ma) erupted from the rhyolite center of Grant's Ridge, about 20 km SW of the quadrangle. The pyroclastic deposits (pyroclastic fall, flow and surge) are white to pale pink in color (Figure 4) and form a discontinuous band at or near the base of mafic flows beneath most mesas west of the quadrangle. The beds also contain a suite of characteristic lithic fragments (aphyric obsidian, chert, and Precambrian granitoids) that allows identification and mapping of the pyroclastic beds through covered terrain. The tuff forms a thin, poorly exposed layer beneath the west side of Mesa La Cuchilla but appears to be cut out by erosion throughout most of San Mateo Canyon. Elsewhere in the quadrangle, Grant's Ridge tuff is removed by erosion (west and northwest), buried beneath younger volcanic units, or never deposited (east and northeast)



Figure 5: Photo of chert pebble conglomerate in weathered top of Menefee Formation below fall deposit of Grants Ridge Tuff on San Mateo quadrangle just west of map area.

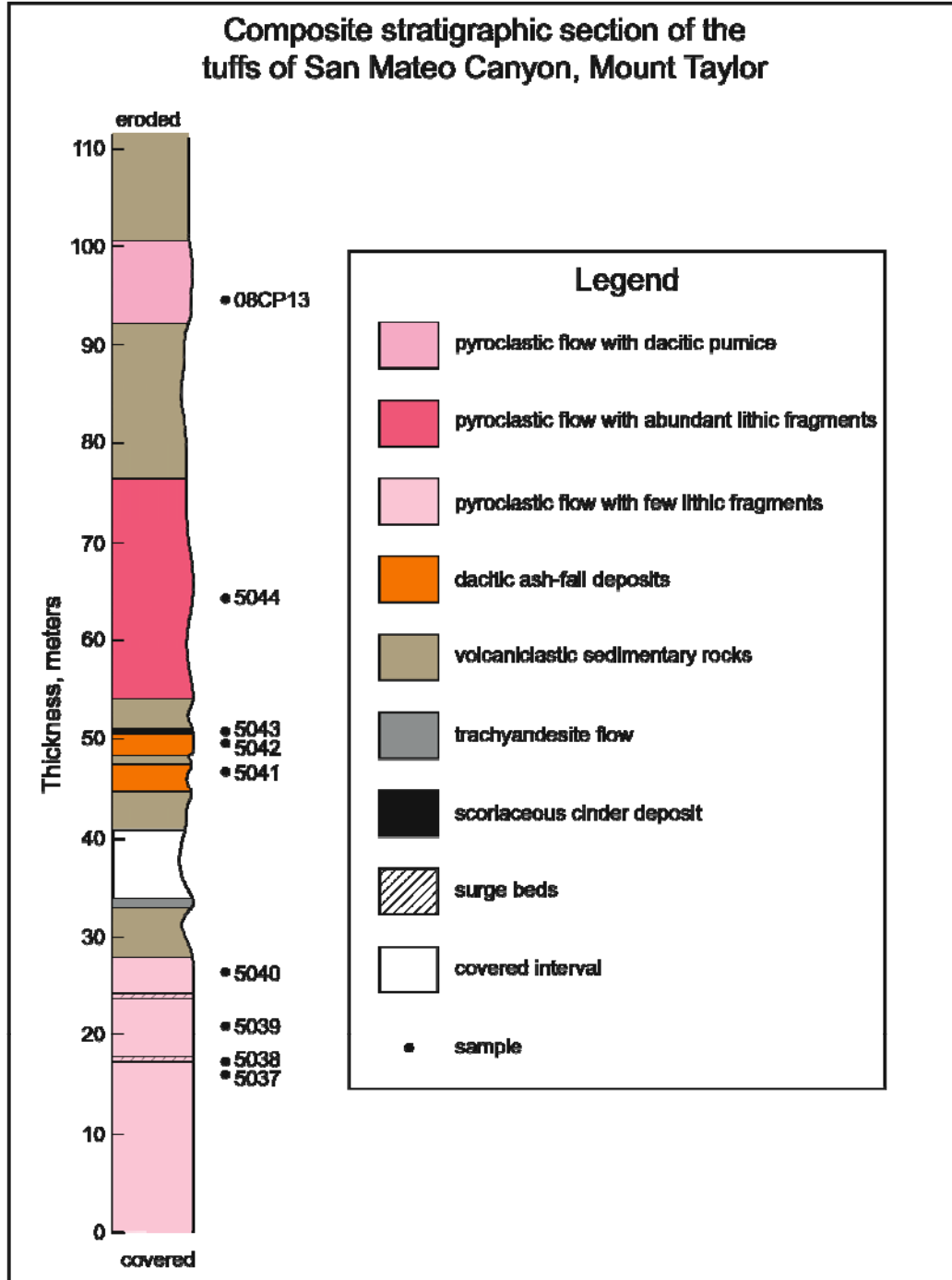


Figure 6: Composite section of the tuffs of San Mateo Canyon (see Appendix 1).

Emplacement of Grant's Ridge tuff was apparently followed by eruption of an aphyric basaltic lava (unit Totb) exposed on the south edge of San Lucas Valley in the northwest part of the quadrangle (about 3.25 Ma). This lava can be traced eastwards to an eroded, dike-intruded cinder cone (Hill 8317) near the north-central edge of the quadrangle. The east margin of a coarse,

plagioclase-phyric basaltic trachyandesite flow (unit Topta, 2.86 ± 0.04 Ma) is interbedded with volcanoclastic rocks on the west margin of the quadrangle. Other older mafic lavas and cinder cones exposed on the quadrangle have yet to be dated.

The bulk of Mount Taylor formed between about 3.3 and 2.5 Ma (Perry et al., 1990). By about 3.1 Ma several pyroclastic units were erupted from rhyolitic centers now exposed within the Mt. Taylor amphitheater. One of the fall deposits collected just west of Cerro Pelón quadrangle is dated at 3.08 Ma (see McCraw et al., 2009 for stratigraphic section of older tephra) and is probably equivalent to rhyolitic tephra deposited in lower San Mateo Canyon (cover photo).

More than 110 m of ignimbrite, volcanoclastic sediment, ash-fall tephra, and minor trachyandesite flows are preserved in western San Mateo Canyon (Fig. 6). The two lower tuffs are continuously exposed in San Mateo Canyon and the uppermost tuff is discontinuously exposed. The tuffs are also present in Marquez and Marcua Canyons and the upper part of the succession may extend to the north central part of the quadrangle. The oldest pyroclastic flow is at least 25 m thick toward the west end of San Mateo Canyon and appears to thin to the east. The oldest ignimbrite is white and contains few lithic fragments. The pumice is crystal-poor. This ignimbrite may correlate to a tuff, informally referred to as the tuff of Water Canyon, exposed along the southeastern wall of



Figure 7: La Mosca summit (NW amphitheater margin of Mt. Taylor) photographed from upper La Mosca Canyon after light snowfall in October 2008. Note the cluster of microwave towers on the summit. La Mosca is composed of porphyritic biotite trachydacite flows and sheeted intrusive rocks (Tpbd, 2.71 Ma) overlying and cutting porphyritic trachyandesite and trachydacite lavas.

Mt. Taylor amphitheater (Osburn et al., 2010). The $^{40}\text{Ar}/^{39}\text{Ar}$ sanidine age of the tuff of Water Canyon is 2.87 ± 0.04 Ma (W.C. McIntosh, unpublished data). A period of erosion caused incision of deep channels in the oldest ignimbrite and volcanoclastic sediments later filled the channels. During this time interval, a thin trachyandesite flow erupted from an unknown source and 2- to 3-m-thick dacitic ash-fall tephras blanketed the landscape. This succession is overlain by a remarkable lithic-rich trachydacitic tuff that contains an interval of mingled pumice lapilli near the middle of the unit. This unit is unique in the Mt. Taylor region and its presence raises the possibility that a previously unrecognized but buried (?) vent is located on the northwest side of Mt. Taylor. Again, an episode of erosion cut deep channels in the lithic-rich ignimbrite and volcanoclastic conglomeratic sandstone and conglomerate with reworked trachydacite pumices filled the channels in the lithic-rich tuff. Finally, a discontinuously exposed trachydacitic ignimbrite, which has a $^{40}\text{Ar}/^{39}\text{Ar}$ plagioclase age of 2.79 ± 0.09 Ma derived from pumice clasts within the ignimbrite in Salazar Canyon (W.C. McIntosh, unpublished data) was erupted, then buried by volcanoclastic sediments. The youngest trachydacite ignimbrites exposed on the NW side of Mount Taylor resemble those south of Mt Taylor now dated at 2.71 ± 0.06 Ma (Goff et al., 2008).



Figure 8: Eroded cinder cone of Cerro Pelón (1.26 ± 0.19 Ma) photographed from the northwest in October 2008. A prominent dike is exposed in the west (left) side of the cone.

The oldest evolved lavas in the Cerro Pelón quadrangle are a coarse porphyritic trachydacite (Tcptd) exposed in the SW corner of the quadrangle, a porphyritic biotite trachyandesite (Tpbta) exposed near the south-central margin of the quadrangle, and a thick sequence of sugary enclave trachydacite (Tsetd) at Cerro Venada, north of La Mosca summit. Volcanoclastic sediments shed

off the Mount Taylor edifice overlie and surround these lavas. Subsequent emplacement of overlying trachydacite and trachyandesite lavas, domes and dikes are dated at 2.77 to 2.48 Ma (Fig. 7). For example, the coarse porphyritic “Spud Patch” trachydacite is 2.53 ± 0.06 Ma. These intermediate composition units intrude, interfinger with and overlie the volcanoclastic sediments.

Although construction of Mount Taylor ceased at about 2.5 Ma, mafic volcanism continued around the margins of the volcano (Goff et al., 2008; McCraw et al., 2009; Osborn et al., 2010). On Cerro Pelón quadrangle intermediate composition flows and volcanoclastic sediments are overlain by an impressive sequence of younger trachybasalt flows and cones. One of the oldest flows of this group (Qyptb, 2.30 ± 0.13 Ma) overlies tuffaceous sediments (Tvst) near the north edge of the quadrangle. Five of the larger and more extensive flows (Qyxtb) contain small xenoliths of mantle peridotite and gabbro, and rare xenoliths of Precambrian rocks and Cretaceous sandstone. Three of these five units are dated at 1.85 ± 0.05 to 1.74 ± 0.03 Ma but they are overlain by many other mafic flows. The youngest eruption in the quadrangle apparently occurred at the Cerro Pelón area, a cluster of three mafic cinder cones. The age of the aphyric trachybasalt erupted from Cerro Pelón proper is 1.26 ± 0.19 Ma (Fig. 8).

Several researchers beginning with Hunt (1938) have stated that earliest Mount Taylor eruptions are compositionally evolved (rhyolite) but become progressively more intermediate in

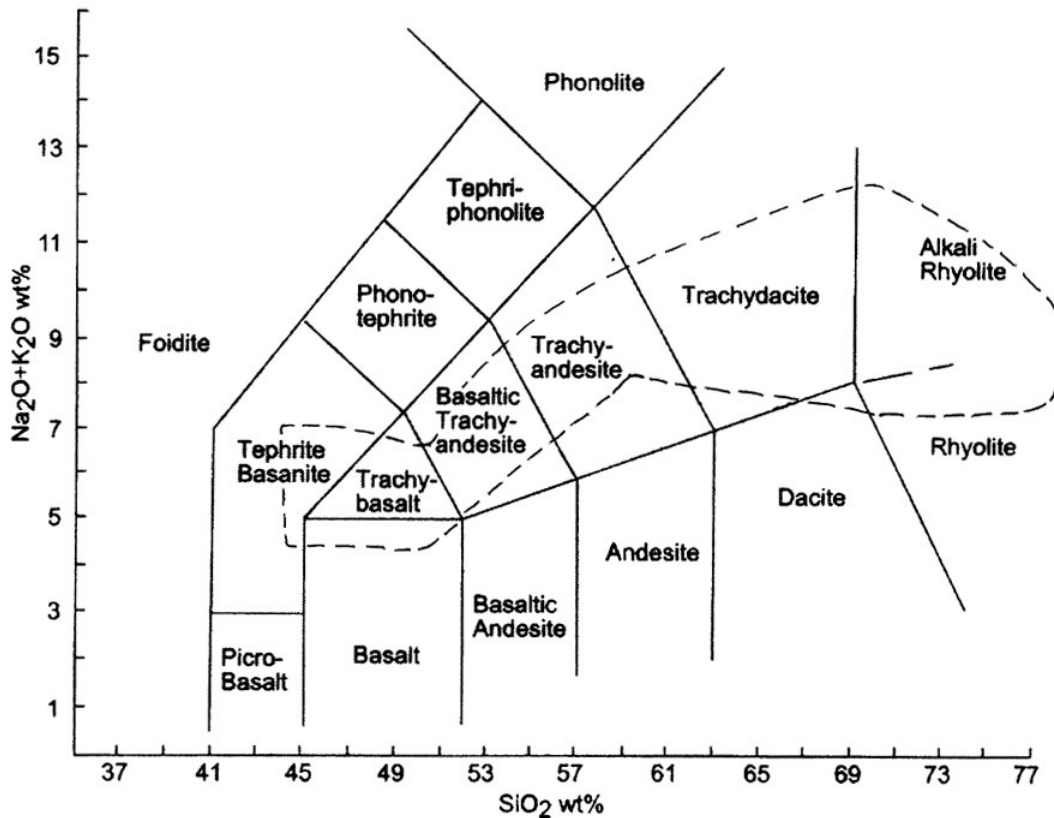


Figure 9: Plot of $Na_2O + K_2O$ versus SiO_2 showing the rock classification scheme of La Bas et al. (1986) and dashed line encompassing published chemical analyses from the Mount Taylor volcanic field. Most volcanic rocks are slightly alkalic; thus basalts (hawaiites) are named trachybasalt, latites (muegerites) are named trachyandesite, etc. The only rocks whose names are unaffected by this scheme are the rhyolites and basanites (from Goff et al., 2008).

composition with time (trachyandesite). Our mapping has identified many exceptions to this generalized trend, in which trachyandesite lavas are interbedded with early trachydacite flows, but our evaluation of this previous concept is not yet complete.

Volcanic rocks in the Mount Taylor area are slightly alkalic. Few units contain primary quartz, although many of the mafic lavas contain quartz xenocrysts. Previous workers in this region have variously classified the majority of volcanic rocks as basalt-andesite-rhyolite to hawaiite-latitude-trachyte-rhyolite (e.g., Baker and Ridley, 1970; Lipman and Moench, 1972; Crumpler, 1980a; 1980b; Perry et al., 1990). For this map, we are using the widely accepted classification scheme of La Bas et al. (1986) and previously published chemical analyses to rename the volcanic units (Fig. 9). Thus, the alkali basalts (hawaiites) are called trachybasalts, basaltic andesites (muegerites) are called basaltic trachyandesites, andesites (latites) are named trachyandesites, and quartz latites are called trachydacite. The only volcanic rocks with no name changes are the rhyolites and basanites.

STRUCTURE

Practically all Cretaceous rocks are covered by Plio-Pleistocene volcanic and volcanoclastic rocks on Cerro Pelón quadrangle. However, Mount Taylor is on southeastern margin of the Laramide-age San Juan Basin and is on the western flank of the northeast-striking McCarty syncline of Hunt (1938). An east-dipping monoclinical ridge in the northwestern part of the Lobo Springs quadrangle marks the western edge of the McCarty syncline (Goff et al., 2008; McCraw et al., 2009). The effect of this monoclinical ridge is to drop the Mesozoic rocks a thousand meters or more beneath Mount Taylor and Cerro Pelón quadrangle. Several low amplitude folds that strike NW to NE in the Lobo Canyon area, southwest of our quadrangle are superimposed on the large-scale synclinal structure. These folds do not affect the overlying volcanic rocks and are presumably Laramide in age.

We previously described Pliocene magmatic deformation of Mesozoic strata in the San Fidel and Devil Canyon domes in Lobo Springs quadrangle (Goff et al., 2008). This deformation was first recognized by Hunt (1938). The domes are apparently caused by shallow intrusion of trachybasalt magmas, possibly forming small laccoliths or sills, and we found a small gabbro plug and gabbro xenoliths in cinder cone deposits within the general region of the two domes (Goff et al., 2008). Within Cerro Pelón quadrangle, we have not identified similar domal structures. However, we have found what appears to be a shallow gabbroic sill (unit Tgab) beneath an eroded cinder cone (unit Typtc – cone east of Cerro Osha). Also, one flow in the north central part of the quadrangle contains relatively abundant gabbro xenoliths (unit Qyptb). Finally, a curious, faulted window of uplifted volcanoclastic rocks (QTvs) occurs in the center of the quadrangle that may result from shallow intrusion of mafic magmas.

Most faults in the Cerro Pelón quadrangle are normal faults having a north to northeast trend probably responding to NW-SE extension along the boundary between the Colorado Plateau and Rio Grande rift tectonic provinces (Baldrige et al., 1983; Aldrich and Laughlin, 1984). However, there are a couple of exceptions, the most notable of which is the NW-trending fault that strikes toward the San Lucas valley in the northwest part of the quadrangle. East-west striking faults are common in Marquez and Marcua canyons; the NE-striking Lagunita Tank fault appears to intersect the E-W striking fault zone in this area.

A surprising number of eroded cinder cones contain remnant dikes. Most dikes have an east to northeast trend apparently intruding into weak zones created by the regional tectonic fabric. There is also a group of three relatively young cinder cones (units Qytc and Qyfoc) in the center of the quadrangle that lie on a perfect northeast trend. Presumably, these cones are underlain by a dike system intruding a NE-trending fracture or fault.

HYDROTHERMAL ALTERATION

Weak hydrothermal alteration is found in many of the trachydacite and trachyandesite units on the southern margin of the quadrangle. Generally, the alteration is pale red to pink in color and consists of combinations of clay, silica, carbonate and Fe-oxides found in fractures, cavities and vugs. We found no evidence for significant hot spring activity or subjacent deposition of epithermal ore deposits.

CROSS SECTIONS AND URANIUM EXPLORATION WELLS

Two east-west trending cross sections across Cerro Pelón quadrangle accompany the map. The cross sections utilize published information and the cross sections presented in Goff et al. (2008) and McCraw et al. (2009). Our cross section endpoints are

A = 107°37'30" & 3912000; A' = 107°30'0" & 3912180
B = 107°37'30" & 3904560; B' = 107°30'0" & 3905280 (UTM NAD27)

and, on the west (at endpoints A and B), they match the eastern cross section endpoints (A' and B') on the adjacent San Mateo quadrangle.

Significantly, the western end of cross section A-A' utilizes uranium exploration drill hole data and cross sections presented in Reise (1977). More than 100 wells were drilled on the western side of southern Mesa Cuchilla during the Grants uranium boom of the late 1970s to mid 1980s and the data from these wells provide exceptional upper Jurassic stratigraphy. Several of Reise's section lines are drawn on the geologic map and five of the sections are reproduced in Appendix 2, scaled to 1:24,000.

Drill holes in this area targeted the uranium-rich Westwater Canyon Member of the Morrison Formation and the contact with the underlying Recapture Member, which occurs at depths of roughly 4250 feet amsl, or roughly 4000 feet below the top of southern Mesa Cuchilla. As a result, the Jurassic-Cretaceous boundary is accurately known (i.e., the boundary between lowermost Cretaceous Dakota Sandstone and uppermost Jurassic Morrison Formation) and the subdivision of members within uppermost Morrison is also accurately known. This information is reflected in cross sections A-A' and B-B' and we consider the J-K boundary to be quite accurate on the western half of cross section A-A'.

Because of the very complex interfingering relations in Jurassic sands and shales, we have lumped the Brushy Basin and Westwater Canyon units as one layer in our cross sections. Along cross section A-A', the Brushy Basin Member varies from 65 to 125 feet thick and the Westwater Canyon Member is 130 to 260 feet thick, generally thickening to the east (see cross sections of Reise, 1977). From north to south, the Brushy Basin varies from 90 feet thick (at the Lagunita

Fault) to 130 feet thick near east end of section H (Appendix 2), while the Westwater Canyon remains relatively uniform (170 ± 10 feet) over this interval.

The thickness of Dakota Sandstone shown in the Reise cross sections (60 to 80 feet thick) is considerably thinner than depicted in the cross sections of Goff et al. (2008) and McCraw et al. (2009) and is considerably thinner than the indicated thickness of Dakota Sandstone in the Marquez Ranch and Grants areas as compiled by Owen and Owen (2003, Fig. 1). The later authors show that the aggregate thickness of Dakota including intertongues of Mancos Shale is roughly 300 feet in the map area. Apparently, the Reise sections show only the basal sand of the Dakota, the lower Oak Canyon Member. Consequently, the thickness of Dakota in our cross sections is adjusted upward to about 300 feet (roughly 90 m) compared to Reise (1977). From these data and our analysis of Dakota unit thickness, it is our opinion that the J-K boundary on the eastern end of section A-A' of McCraw et al. (2009) is slightly too high.

Another stratigraphic feature revealed in Owen and Owen (2003) is the unconformable relation at the J-K boundary and slight westward dip of the Morrison Formation. As a result, the uppermost Morrison (Jackpile Member) is missing in the subsurface within Cerro Pelón quad and the underlying Brushy Basin Member thickens slightly to the east (Reise, 1977, 1980; Owen and Owen, 2003).

The sections of McCraw et al (2009) show the Gibson Coal unit having a thickness of about 360 feet in the San Mateo quadrangle. However, Goff et al indicate that the Gibson Coal is as much as 1100 feet thick in the Lobo Canyon area to the south. For the sake of continuity, cross section A-A' uses the thickness of McCraw et al (2009) but the thickness of Gibson Coal increases to the south as shown on section B-B'. We recognize that there is probably a need to obtain better data on thickness variations for the Gibson Coal in this region.

The Reise (1977) sections show two other important stratigraphic features: first, a very gentle rise of the J-K boundary toward the east and second, a pronounced rise of the J-K boundary to the south toward the summit of Mount Taylor, especially between Reise cross sections O-O' and H-H' (Appendix 2). The second feature is portrayed by Reise (1977) as a sharp upwarp in the J-K section that begins just south of O-O'. The pronounced rise of the J-K boundary is projected into the western end of our section B-B' at an elevation of roughly 5900 feet amsl. Because Cretaceous rocks are not exposed throughout the southern and eastern parts of Cerro Pelón quadrangle and we could find no well data for these areas, subsurface stratigraphy on eastern A-A' and B-B' is somewhat speculative.

Reise also shows 80 to 100 feet of down-to-the-south displacement in the J-K boundary along the Lagunita Fault, with offset increasing to the east. This fault trends to the northeast and offsets young trachybasalt (Qyxtb, 1.8 Ma) by about 30 feet in the upper east wall of San Mateo Canyon. Thus, the Lagunita Fault became active before this lava was erupted.

DESCRIPTION OF MAP UNITS

Note: Descriptions of map units are listed in approximate order of increasing age. Formal stratigraphic names of Cretaceous units are described by Sears et al. (1941), Lipman et al., (1979), and Dillinger (1990). Field identification of volcanic rocks is based on hand specimens, petrography and chemical data published by Hunt (1938), Baker and Ridley (1970), Lipman and Moench (1972), Lipman and Mehnert (1979), Crumpler (1980a, 1980b, 1982), and Perry et al. (1990). The names of volcanic units are based on the above chemical data and the alkali-silica

diagram of Le Bas et al. (1986). See Goff et al., 2008 for a contemporary description of the rocks and geology in the Mount Taylor area.

Quaternary

- Qal** **Alluvium**—Deposits of sand, gravel and silt in main valley bottoms; locally includes stream terraces, alluvial fans, and canyon wall colluvium; valley floor alluvium is typically finer-grained, silt and sand dominated deposits with interbedded gravel beds, whereas low terrace deposits are predominantly sand and gravel. Qal is mostly Holocene in age; maximum thickness of various alluvium deposits is uncertain but may exceed 15 m.
- Qc (Qco)** **Colluvium**—Poorly sorted slope wash and mass wasting deposits from local sources; mapped only where extensive or where covering critical relations; thickness can locally exceed 15 m.
- Qes** **Eolian deposits**—Windblown and sheet wash deposits of silt and fine sand 0.2 to greater than 1 m thick on various mesas.
- Qt** **Terrace deposits**—Deposits of sandy pebble to boulder size gravel underlying terrace surfaces located approximately 5 to 15 m above local base level; mapped only in upper Salazar Canyon; deposits are only a few meters thick.
- Qls** **Landslides**—Poorly sorted debris that has moved chaotically down steep slopes; 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; ages vary from Holocene to mid- to late-Pleistocene; thicknesses vary considerably depending on the size and nature of the landslide.
- Qaf** **Alluvial fans**—Typically fan-shaped deposits of coarse to fine gravel and sand, silt, and clay within and at the mouths of valleys; associated with present drainages and usually not incised; grades into alluvial deposits along main channels; probably Holocene to middle Pleistocene in age; occasionally subdivided into young (**Qafy**) and old (**Qafo**) fans; maximum exposed thickness about 15 m.

Volcanic Rocks of Mount Taylor, Southern Mesa Chivato and Vicinity

- Qyatb** **Younger very aphyric trachybasalt**—Youngest cone and flows erupted from the Cerro Pelón complex; consist of blue-gray to black, fine-grained hawaiite and red to black cinder deposits (**Qyate**) having very tiny sparse olivine phenocrysts and sparse quartz xenocrysts in intersertal to slightly vesicular groundmass. Microphenocrysts consist of plagioclase, clinopyroxene, minor olivine, opaque oxides and very tiny, sparse titaniferous biotite in glass. Cone contains two dikes (**Qyate**) the most prominent of which trends northwest. Flows overlie units Tbd, Qytb, Tyntb, QTvs and Thta. Sample of flow west of cone has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 1.26 ± 0.19 Ma. Flows are ≤ 30 m thick.
- Qyqtb** **Younger quartz-bearing trachybasalt**—Two cone and flow complexes. The southern complex consists of black to gray, fine-grained hawaiite and red to black cinder deposits (**Qyqtc**) having sparse olivine phenocrysts and extremely rare quartz xenocrysts. Cone and flow apparently underlie unit Qyatb but overlie unit Tyntb in Cerro Pelón complex. Flows extend to NE along Seboyetita Creek. The northern complex consists of gray, medium-grained hawaiite and black to red cinder deposits (**Qyqtc**) containing small olivine phenocrysts and sparse

quartz xenocrysts in intersertal groundmass. Microphenocrysts consist of plagioclase, clinopyroxene, olivine, orthopyroxene and opaque oxides in glass. Flow apparently originates from summit of cinder cone. Flow apparently overlies unit Qyptb immediately to east and unit Qyxtb to west. Flow overlies unit QTvs. Lava from southern flow has $^{40}\text{Ar}/^{39}\text{Ar}$ date of 1.53 ± 0.07 Ma. Maximum exposed thickness of flows is ≤ 35 m.

- Qyh** **Younger medium-grained trachybasalt**—Cone and flow complex straddling upper Spud Patch Canyon in SW part of quadrangle; consists of gray to black flows and red to black cinder deposits (**Qyhc**) of hawaiite containing sparse phenocrysts of plagioclase, rare phenocrysts of black augite and sparse xenocrysts of quartz in dense, medium-grained trachytic groundmass; several short, north-trending dikes (**Qyhd**) are exposed in canyon wall east of cinder cone; overlies unit Qyxtb; unit not dated; maximum exposed thickness about 80 m.
- Qatb** **Younger aphyric trachybasalt**—Cone and flow complex between American and Colorado canyons in south-central quadrangle; consists of dark gray flows and black to red cinder deposits (**Qate**) of basalt with rare phenocrysts of plagioclase, tiny olivine, and rare quartz xenocrysts; cone deposits contain beautiful assortment of spindle bombs; overlies units Qytb, Qyxtb and QTvs; dense bomb from cone has $^{40}\text{Ar}/^{39}\text{Ar}$ date of 1.76 ± 0.05 Ma; maximum observed thickness about 60 m.
- Qympb** **Younger medium-grained plagioclase trachybasalt**—Gray to black flows and red to black cinder deposits (**Qympc**) of medium-grained basalt containing small, platy, interlocking microphenocrysts of plagioclase and tiny microphenocrysts of olivine and clinopyroxene; cinders contain rare fragments of Cretaceous sandstone; cone has young, conical shape; overlies Qyopb. Unit is not dated. Maximum observed thickness is about 60 m.
- Qyfob** **Younger fine-grained olivine trachybasalt**—Single cone and flow complex in south central quadrangle east of American Canyon; consists of dark gray flow and black to red cinder deposits (**Qyfoc**) of fine-grained basalt with abundant tiny phenocrysts of olivine; small closed depression on NE side of cone may be lava vent; overlies units Qytb and Tyocb; unit is not dated; maximum exposed thickness is ≤ 50 m.
- Qytb** **Younger trachybasalt**—Three cone and flow complexes in south central quadrangle east of American Canyon, which includes Cerro Osha. Consists of black to dark gray lavas and black to red cinder deposits (**Qytc**) of relatively aphyric basalt with rare, very tiny phenocrysts of plagioclase \pm olivine; two northern cones contain NE-trending dikes (**Qytd**); overlies units Qyptb, Thta, QTvs and Tyocb; overlain by Qyfob. The unit Qytb also includes a sequence of flows in NE corner of quadrangle that overlie Qycopb and apparently overlie Qftb. Various units are not dated and flows are ≤ 60 m thick.
- Qystb** **Younger spotted trachybasalt**—Gray to black lava flows and red to black cinder deposits (**Qyste**) of distinctive, spotted hawaiite containing rare phenocrysts of plagioclase ≤ 1 cm long, and rare tiny phenocrysts of olivine. The spots appear to be clots of plagioclase microphenocrysts aligned parallel to flow foliations. Overlies Qyfpb, Qyopb, Qypob, Tymtb and Tyocb. Unit is not dated. Maximum observed thickness is about 120 m.

- Qyxtb** **Younger xenocrystal trachybasalt**—Five cinder cone and flow complexes in southern and eastern map area consisting of black to gray, medium- to fine-grained hawaiiite and red to black cinder deposits (**Qyxte**) having very sparse phenocrysts of olivine, plagioclase, and augite and very rare xenoliths of mantle peridotite and extremely rare fragments of gabbro. Some specimens contain rare quartz xenocrysts; cinder deposits may contain bombs of trachyandesite, trachydacite, and Cretaceous sandstone. Two cones contain NE-trending dikes (**Qyxtd**). Lavas flowed to east, north and west. Flows overlie units Tpetd, Toptb, QTvs, Tvst, Tsptd, and Trt. Flows underlie Qyh, Qatb, and Qyqtb. Flow from cone near SW edge of map has $^{40}\text{Ar}/^{39}\text{Ar}$ date of 1.74 ± 0.03 Ma (McCraw et al., 2009). Flow on Mesa La Cuchilla in NW corner of map has $^{40}\text{Ar}/^{39}\text{Ar}$ date of 1.79 ± 0.05 Ma. Flow from cone in SE part of map has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 1.85 ± 0.06 Ma. Maximum thickness of flows is ≤ 60 m.
- Qyopb** **Younger olivine plagioclase trachybasalt**—Two cinder cone and flow complexes in central and eastern parts of quadrangle consisting of gray to black, slightly porphyritic lavas and red to black cinder deposits (**Qyopc**); both cones contain NE-trending dikes (**Qyopd**). Specimens are relatively aphyric containing tiny rare phenocrysts of olivine \pm clinopyroxene, and sparse small phenocrysts of plagioclase. The more northerly of the two cones contains rare fragments of gabbro and Cretaceous sandstone. Overlies Qyptb, Qypob, and QTvs; underlies Qytb, Qyfpb and Qystb. Unit is not dated. Maximum observed thickness is about 60 m.
- Qftb** **Younger fine-grained plagioclase trachybasalt**— Light gray flows of aphyric, aphanitic trachybasalt containing a felted groundmass of very fine-grained plagioclase, clinopyroxene, and minor olivine. Flows originate from unidentified source ENE of the quadrangle. Overlies Qycopb and Qyob; apparently underlies Qytb. Sample of flow has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.28 ± 0.07 Ma. Maximum observed thickness is about 10 m.
- Qycopb** **Younger porphyritic pyroxene olivine basalt**—Gray to black flows of very distinctive, speckled, medium to coarse-grained porphyritic basalt containing abundant phenocrysts (5-15%) of anhedral to resorbed black clinopyroxene (≤ 4 mm), green anhedral olivine (≤ 5 mm) and clear to white, zoned subhedral plagioclase (≤ 5 mm). Olivine is commonly iddingsitized and frequently rimmed or intergrown with clinopyroxene. Specimens generally contain a trace amount of xenocrystic quartz. Overlies Tvst and Qyob; underlies Qftb and Qytb; source is east of quadrangle. Sample of flow has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.31 ± 0.06 Ma. Maximum observed thickness is about 30 m.
- Qypob** **Younger plagioclase olivine trachybasalt**—Gray to black flows and red to black cinder deposits (**Qypoc**) of distinctive, medium-grained basalt containing abundant white, blocky plagioclase (≤ 4 mm), pale green anhedral olivine (≤ 3 mm) and sparse black clinopyroxene (≤ 1 mm) phenocrysts. The olivine is commonly iddingsitized. Large cone contains two, long NNE-trending dikes (**Qypod**) composed of finer grained but petrographically similar trachybasalt. Overlies Tvst, Qyob and Qyptb; underlies Qyopb and Qympb. Sample of flow has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.29 ± 0.06 Ma. Maximum exposed thickness is about 100 m.
- Qyptb** **Younger gabbro-bearing plagioclase trachybasalt**—Gray, medium to fine-grained hawaiiite and black to red cinder deposits (**Qypte**) containing sparse small phenocrysts of plagioclase and black clinopyroxene; contains rare, resorbed

quartz xenocrysts (≤ 10 mm), and locally abundant, resorbed gabbroic (plagioclase plus clinopyroxene) xenoliths (≤ 20 mm). Two small puddles of lava occur within the cone complex in center of quadrangle; a northeast trending slope of unit QTvs is exposed within the flows; cone and flows apparently underlie unit Qyqtb to west and underlie units Qyopb and Qypob to east; overlies unit Tvst; sample of lava from the cone complex has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.30 ± 0.13 Ma; maximum exposed thickness of flows is < 25 m.

Qyob **Younger olivine trachybasalt**—Gray to black flows and red to black cinder deposits (**Qyoc**) of fine-grained basalt containing 2-4% resorbed olivine phenocrysts (≤ 5 mm) of uniquely translucent green color. The olivine is commonly iddingsitized. Felted groundmass contains abundant plagioclase and olivine microphenocrysts. The cone contains a NNE-trending dike (**Qyod**). Specimens on the cone are finer grained and also contain conspicuous resorbed plagioclase and clinopyroxene megacrysts. Overlies Tvst and apparently Totb; underlies Qypob, Qftb and Qycopb. Sample of flow has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.18 ± 0.06 Ma, but age seems too young to fit stratigraphy and dates of other units. Maximum observed thickness is about 70 m.

Qyfpb **Younger fine plagioclase trachybasalt**—Gray, medium- to fine-grained basalt and black to red cinder deposits (**Qyfpc**) having sparse tiny plagioclase and rare tiny olivine phenocrysts. Lava specimens often have felted appearance. Eroded cone, which lies immediately east of Cerro Osha overlies layer of poorly exposed gabbro (Tgab). Dike of **Qyfpd** cuts flow just south of cone. Overlies Tyoch; underlies Qytb, Qystb and Qyqtb. Sample of dense bomb fragment in cone has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.37 ± 0.14 Ma. Maximum exposed thickness in cone is about 150 m.

Tertiary (Pliocene)

QTvs **Volcaniclastic sedimentary rocks**—Gray to tan to white debris flows, fluvial deposits and interbedded tuffs (**Tvst**) shed from the Mount Taylor stratovolcano during growth. Debris flow component is most abundant near source (south and southwest parts of quadrangle) and consists primarily of boulders and cobbles of angular to subangular trachydacite and trachyandesite in a volcanic sand matrix. Boulders form a lag deposit on surface of debris flows. Fluvial component contains rounded to subrounded cobbles including a higher proportion of basaltic clasts, especially to north. Tuffs consist mostly of thin beds and lenses of fall deposits with vesiculated pumice having phenocrysts of plagioclase, clinopyroxene \pm hornblende \pm biotite. Underlies a multitude of mafic flows and cones north of Mt. Taylor and in this extends into the Quaternary; underlies several intermediate composition flows and domes on upper north flank of Mt. Taylor. Overlies a few older, often poorly exposed trachybasalts and intermediate composition rocks throughout the quadrangle; overlies Cretaceous Menefee Formation in lower San Mateo Canyon. Maximum exposed thickness is > 200 m.

Tsptd **Porphyritic “Spud Patch” trachydacite**—Composed of two map units. The basal unit (**Tsptdl**) is gray, porphyritic, glassy lava with 15-20% phenocrysts of plagioclase, pyroxene, hornblende and biotite with angular to rounded enclaves. The basal unit weathers to an orange-brown color and forms prominent cliffs. The basal unit is overlain by light gray porphyritic trachydacite (**Tsptds**) having phenocrysts of plagioclase, pyroxene, hornblende and biotite, and angular to subrounded enclaves of reddish gray lava set in a sugary matrix. The upper unit weathers to an orange-brown color and erodes into spires. The upper unit of the

Spud Patch flow thickens to the north. The contact between the two units is gradational over 1 to 2 m. Contains plagioclase-clinopyroxene-biotite enclaves. The enclaves have a lower phenocryst content (<10%) compared to the matrix. Plagioclase, minor Kspar, clinopyroxene, orthopyroxene, oxidized hornblende and biotite, and opaque oxides have been identified petrographically. Texture is porphyritic, hyalopilitic, and devitrified. Microphenocrysts consist of plagioclase and minor clinopyroxene. Overlies QTvs. Vent for “Spud Patch” lavas is apparently eroded away. Lower unit of Tsptd has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.53 ± 0.06 Ma. Maximum exposed thickness roughly 200 m.

- Tymtb** **Younger megacrystal trachybasalt**—Two cinder cone and flow complexes. One complex constitutes the oldest flow and cone within the Cerro Pelón area in south central portion of quadrangle; consists of black to gray, fine-grained hawaiite and red to black cinder deposits (**Tymtc**) having rare megacrysts of augite and olivine. Partially eroded cone contains two northeast trending dikes (**Tymtd**). Texture is intersertal to slightly trachytic. Microphenocrysts consist of plagioclase, clinopyroxene, minor olivine and opaque oxides in glass. Overlies units Tbtb and Tbtb. Second complex sits near east central edge of map and consists of a single small flow of gray, fine-grained hawaiite and black to red cinder deposits (Tymtc) containing megacrysts of augite and olivine. Lava in Cerro Pelón area has $^{40}\text{Ar}/^{39}\text{Ar}$ date of 2.64 ± 0.10 Ma. Thickness of flows is <30 m.
- Tyocb** **Younger olivine-rich basalt**—Black to gray basalt with conspicuous olivine, plagioclase and clinopyroxene phenocrysts. Texture is intersertal. Groundmass contains plagioclase, olivine, augite, opaque oxides, and glass. Olivine shows iddingsite alteration. Flows originate from eroded, poorly exposed cone of red to black cinders (**Tyoc**) northeast of Cerro Osha, cut by NNE-trending dike (**Tyocd**). Overlies Tbtb; underlies Qytb, Qyfob and Qyfpb; cut by dike of Qyfpd. Sample of flow northwest of cone has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.67 ± 0.12 Ma. Maximum exposed thickness is about 50 m.
- Tgab** **Gabbro**—Gray, fine-grained gabbro containing about 70% plagioclase, 30% black, blocky clinopyroxene and rare tiny olivine; forms layer on lower north side of cone (Qytpc) described above but may be a shallow sill or crystallized core of **Tyocb**. $^{40}\text{Ar}/^{39}\text{Ar}$ age is 2.68 ± 0.07 Ma; maximum exposed thickness roughly 25 m.
- Tta** **Trachyandesite**—Vent and short flow of gray to black, porphyritic lava in the southern quadrangle. Phenocrysts consist of resorbed plagioclase, oxidized clinopyroxene, hypersthene \pm rare olivine and magnetite in a pilotaxitic groundmass containing microphenocrysts of plagioclase, clinopyroxene, apatite, opaque oxides, and devitrified glass. Specimens show minor Fe-oxide alteration. Overlies unit Tbtb in southern part of map. Flow not dated. Exposed thickness is ≤ 100 m.
- Thtd** **Hornblende trachydacite**—Massive to sheeted flow of porphyritic trachydacite containing phenocrysts of plagioclase, clinopyroxene, and minor hornblende; overlies older plagioclase basalt (Toptb) near SW corner of map. Also overlies volcanoclastic sedimentary deposits (QTvs) and units Tbtb and Tbtb. Flow not dated. Exposed thickness is nearly 200 m.
- Tpbtb** **Porphyritic biotite trachydacite**—Gray to yellow brown, massive to sheeted, porphyritic trachydacite lavas containing phenocrysts of Kspar, plagioclase,

clinopyroxene, and biotite in granular to trachytic, devitrified groundmass. Microphenocrysts consist of Kspar, plagioclase and opaque oxides. Contains rare orthopyroxene with clinopyroxene jackets; contains rare enclaves of plagioclase-pyroxene-biotite. Unit contains prominent, NNW-trending plug (and dike?) complex (**Tpbt**) of strongly foliated and sheeted trachydacite atop which are several microwave towers (**Mosca Peak**). Overlies units Tpta, Tbta, QTvs, Tbtac and Tsetd. Sample of intrusion has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.71 ± 0.03 Ma. Maximum exposed thickness about 500 m.

- Tbhd** **Porphyritic biotite hornblende trachydacite**—Gray to reddish gray, massive to sheeted, porphyritic trachydacite lavas containing phenocrysts of plagioclase (some sieved), clinopyroxene, biotite, hornblende, rare quartz, rare Kspar, and opaque oxides in a trachytic to hyalopilitic, devitrified groundmass; microphenocrysts consist of tiny plagioclase, sparse clinopyroxene and opaque oxides. At least two N-trending dikes of this unit are exposed in north amphitheater wall on south edge of quadrangle. Overlies units Tpta and Tbt; underlies small eruption of Tta. Unit is not dated. Maximum exposed thickness about 335 m.
- Tbd** **Porphyritic biotite trachydacite**—Gray to yellow brown, massive to sheeted, porphyritic trachydacite lavas containing phenocrysts of Kspar, clinopyroxene, rare quartz, oxidized biotite, sparse oxidized hornblende and opaque oxides in intergranular, devitrified groundmass; microphenocrysts consist of Kspar, quartz and opaque oxides. Overlies units Tbt and QTvs; overlain by unit Qyatb; unit not dated; maximum exposed thickness about 350 m.
- Tptba** **Porphyritic basaltic trachyandesite**—Gray to tan, massive, porphyritic basaltic trachyandesite lavas containing phenocrysts of clinopyroxene, plagioclase and rare olivine; overlies and intrudes Tbt; unit not dated; maximum observed thickness about 110 m.
- Tpta** **Porphyritic trachyandesite, undivided**—Brownish gray to black, massive to sheeted, porphyritic lavas having phenocrysts of plagioclase, clinopyroxene, rare olivine, and opaque oxides in an intersertal to slightly vesicular groundmass; microphenocrysts consist of plagioclase, clinopyroxene, and opaque oxides in devitrified glass; plagioclase is complexly zoned and sieved; displays minor clay and Fe-oxide alteration. Underlies units Tpbtd, interbedded with Tbhd, overlies Tbt, intruded by Tcptd. Sample of lava from amphitheater rim has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.63 ± 0.07 Ma; maximum exposed thickness about 330 m.
- Tbtd** **Slightly porphyritic biotite trachydacite**—Multiple, often platy flows of pale gray slightly porphyritic lavas occurring along the south margin of the quadrangle; contains 2-4% phenocrysts of small, blocky plagioclase, biotite, and clinopyroxene. Underlies Tpbtd, Tbd and Tymtb; interbedded in Tpta; intruded by Tbhd and Tpbdi; overlies QTvs and Tpbta. Unit is not dated. Maximum observed thickness is about 215 m.
- Tpetd** **Porphyritic enclave-bearing trachydacite**—Thick, multiple flows of dark gray to tan porphyritic lavas having conspicuous enclaves up to 50 cm in diameter, especially in the lower flows. Lava contains phenocrysts of large potassium feldspar, plagioclase, clinopyroxene, orthopyroxene and biotite in an intergranular to hyalopilitic groundmass of plagioclase, potassium feldspar, clinopyroxene and devitrified glass. Groundmass contains sparse phenocrysts (?) of quartz. Enclaves consist of potassium feldspar, plagioclase, clinopyroxene,

orthopyroxene, magnetite, and vesiculated glass. Underlies Qyxtb, Thtd and QTvs; overlies Tcptd. Flow just west of quadrangle boundary has $^{40}\text{Ar}/^{39}\text{Ar}$ date of 2.68 ± 0.09 Ma. Maximum exposed thickness about 250 m.

- Tvst** **Tuffs of San Mateo Canyon**—White to gray, bedded tuffs and tephra of rhyolite to trachydacite composition with interbedded volcanoclastic sands and gravels. Tuffs consist of pyroclastic fall and flow deposits no more than 4 m thick. Two of the tuffs are continuously exposed in San Mateo Canyon. The basal rhyolite tuff is lithic poor and probably correlates with a similar looking ignimbrite in Water Canyon, Mount Taylor quadrangle. A tuff near the middle of the San Mateo Canyon sequence contains 10-20% lithics. The lithic fragments consist of trachytic lavas. Tuffs near the top of the sequence are thin and discontinuous, and contain 5-10% lithic fragments. Generally occurs within bottom half of QTvs. Unit as mapped may contain a few meters of Grant's Ridge tuff (Tgrt) at very bottom (see below).
- Ttdt** **Trachydacite tuff**—Light gray to pinkish gray to pale tan pumice and ignimbrite in middle to upper half of QTvs sequence; phenocrysts consist of plagioclase, clinopyroxene, biotite \pm hornblende in a eutaxitic groundmass. Pumice lump from ignimbrite in middle Salazar Canyon on west side of quadrangle has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.79 ± 0.09 Ma. Pumice fall deposit in unit Tvst along FS 239, north edge of map, has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 3.04 ± 0.12 Ma. Maximum exposed thickness is ≤ 15 m.
- Trt/Trtl** **Rhyolite tuff**—White to light gray pumice in bottom of Tvst sequence; phenocrysts consist of potassium feldspar, plagioclase, minor clinopyroxene, quartz, and biotite in a eutaxitic groundmass. Sample from fall deposit just west of the quadrangle has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 3.08 ± 0.20 Ma (McCraw et al., 2009). Maximum exposed thickness is >75 m.
- Tls** **Landslide deposit**—This unsorted unit is mappable in the upper reaches of Marquez Canyon. This deposit consists of angular trachydacitic blocks that are 3-4 m (car-sized) in diameter on top of boulder to cobble sized volcanoclastic debris. The Tertiary landslide is intercalated within the Tvst interval. The deposit is overlain by one of the tephra related to the tuffs of San Mateo Canyon and is topographically above a basalt flow interpreted to be Totb. The landslide is 6 to 12 m thick.
- Ttd** **Trachydacite**—Light gray lava exposed in extreme southwest corner of quadrangle; contains 15 to 20% crystals of biotite, plagioclase, hornblende, and sparse quartz. The plagioclase laths are 2 to 8 mm long. Megacrysts of pyroxene occur in a few outcrops. A 1 to 2 m thick, poorly exposed tephra with pumice lapilli up to 15 cm in diameter is discontinuously preserved at the base of the trachydacite. The lava underlies 1 to 30 m of tuffaceous volcanoclastic sediments (Tvst). Unit is interbedded in QTvs. Unit is not dated and maximum exposed thickness is about 40 m.
- Tbta/Tbtac** **Porphyritic basaltic trachyandesite, undivided**—Gray, massive to sheeted, slightly porphyritic lavas containing phenocrysts of plagioclase, clinopyroxene and olivine in a trachytic to hyalopilitic, devitrified groundmass; microphenocrysts consist of plagioclase, clinopyroxene and opaque oxides; may contain rare quartz xenocrysts; may contain plagioclase-pyroxene-olivine clots; some exposures show minor Fe-oxide oxidation and weathering. Eroded cone of **Tbtac** occurs on ridge to east and may be source of flows. Overlies Toptb and

Tsetd in SW map area; apparently underlies QTvs; underlies Tta, Tpbtd, and Qyatb; units not dated; maximum exposed thickness about 170 m.

Tpbta **Porphyritic biotite trachyandesite**—Flows of dark reddish brown devitrified lava containing phenocrysts of large plagioclase, conspicuous biotite, clinopyroxene and sparse olivine in a massive to slightly trachytic groundmass of plagioclase and clinopyroxene. Overlain by Tbsd, QTvs, Tymtb and Qyqtb. Unit is not dated. Maximum observed thickness is ≥ 160 m.

Tbhtd **Porphyritic biotite hornblende trachydacite**—Small plug of dark brown, glassy to devitrified lava containing phenocrysts of plagioclase (some sieved), Kspar, hornblende, biotite and minor clinopyroxene and orthopyroxene in trachytic to slightly vesiculated groundmass; microphenocrysts consist of plagioclase and minor clinopyroxene; intrudes Toptb; apparently overlapped by Thta; unit not dated; maximum exposed thickness about 100 m.

Tsetd **Sugary enclave trachydacite**—Composed of two mapable units in SW part of quadrangle west of upper San Mateo Canyon. The basal unit (**Tsetdl**) consists of brownish gray, porphyritic, glassy lava with 15-20% phenocrysts of plagioclase, pyroxene, hornblende and biotite with angular to rounded enclaves that are most easily seen on weathered surfaces. The basal unit is overlain by light gray porphyritic trachydacite (**Tsetdu**) having phenocrysts of plagioclase, pyroxene, hornblende, and biotite and angular to subrounded enclaves of reddish gray lava set in a sugary matrix. The contact between the two units is gradational over 1 to 2 m. Plagioclase, minor Kspar, clinopyroxene, hornblende, biotite (the latter three highly oxidized), and opaque oxides are recognized petrographically. Texture is porphyritic, hyalopilitic, and devitrified. Microphenocrysts consist of plagioclase, clinopyroxene, biotite, opaque oxides and noticeable apatite. The enclaves generally have lower phenocryst content than the matrix, consisting of plagioclase, clinopyroxene and biotite. Unit dips steeply to the north. Underlies Tpbtd, Tbtac, and QTvs. Sample of upper flow has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.71 ± 0.06 Ma. Maximum exposed thickness is about 250 m.

Tcptd **Coarse porphyritic trachydacite**—Pale pink to tan, very coarse porphyritic lava containing large (≤ 3 cm) phenocrysts of potassium feldspar. Unit superficially looks like granite and makes a distinctive fine gravelly soil. Smaller phenocrysts consist of magnetite, potassium feldspar, plagioclase, oxidized clinopyroxene, and apatite in a hyalopilitic groundmass of tiny felted plagioclase, potassium feldspar, clinopyroxene, opaque oxides and devitrified glass. Unit shows minor Fe-oxide alteration. Unit underlies Tpted in extreme SW corner of quadrangle. Flow from SE corner of quad has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 2.82 ± 0.08 Ma. Maximum observed thickness is about 80 m.

Topta **Older plagioclase basaltic trachyandesite**—Flows of splotchy white and black porphyritic lavas and containing abundant large (2 cm), often aligned plagioclase phenocrysts. Other phenocrysts consist of clinopyroxene and minor iddingsitized olivine. Groundmass is intersertal and slightly vesicular containing microphenocrysts of plagioclase, iron oxides and devitrified glass. Interbedded in QTvs and Tvst; overlies Trt; underlies Thta and Tpbtd. Flow in lower Salazar Canyon along west central edge of quadrangle has $^{40}\text{Ar}/^{39}\text{Ar}$ date of 2.86 ± 0.04 Ma. Maximum exposed thickness is ≤ 35 m.

Tomtb **Older megacrystal trachybasalt**—Two cone and flow complexes near the east and southeast boundary of the quadrangle that consist of gray to black flows and

red to black cinder deposits (**Tomtc**) of fine-grained trachybasalt; lavas of north complex contain conspicuous large clinopyroxene and olivine phenocrysts, sparse quartz xenocrysts, and rare fragments of Cretaceous sandstone. Eroded cone contains E-trending dike (**Tomtd**); cone and flow appear to be buried by alluvium and surrounding trachybasalt flows; apparently in fault contact with Toftb (described below). Lavas of south complex contain 2-4% phenocrysts of euhedral olivine (≤ 6 mm), black anhedral clinopyroxene (≤ 5 mm), minor plagioclase (≤ 8 mm), and minor quartz xenocrysts (≤ 12 mm); eroded cone is cut by NE-trending dike and surrounded by younger QTvs. Units are not dated. Maximum observed thickness is < 55 m.

- Toftb** **Older plagioclase trachybasalt**—Two cone and flow complexes of gray flows and red to black cinder deposits (**Tofte**) consisting of aphyric, fine-grained hawaiite near east and southeast edge of quadrangle; contains trace zoned euhedral plagioclase, tiny interlocking plates of plagioclase and microphenocrysts of olivine and clinopyroxene. Northern cone is highly eroded and contains three dikes (**Toftd**); cone and flow appear to be buried in alluvium and overlain to the east by Qyxtb. Southern cone contains a NE-trending dike, underlies QTvs and is surrounded from the west by Qyxtb. Units are not dated; maximum observed thickness is ≤ 100 m.
- Toptb** **Older sparsely porphyritic trachybasalt**—Black to gray lava flows with sparse plagioclase and olivine phenocrysts exposed along SW edge of quadrangle. Texture is intersertal and slightly vesicular. Groundmass contains plagioclase, augite, minor olivine, opaque oxides, and glass. Olivine shows iddingsite alteration. Source of flows unknown; overlain by Tta, Tbta and QTvs; intruded by Tbhtd. Unit not dated. Maximum exposed thickness is about 130 m.
- Totb** **Older aphyric trachybasalt**—Gray to black flows and red to black cinder deposits (**Tote**) consisting of aphyric to porphyritic hawaiite. Aphyric specimens contain abundant microphenocrysts of plagioclase and sparse microphenocrysts of olivine and clinopyroxene. Porphyritic flows contain phenocrysts of plagioclase, pyroxene and olivine. Some exposures contain sparse pyroxene clots. The flows form prominent cliffs along south side of San Lucas Valley in NW sector of quadrangle. Eroded cone contains three dikes (**Totd**). Underlies Tvst, Qypob, Qyob and Qyptb; overlies Kmf. Sample of flow NW of cone has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 3.31 ± 0.08 Ma. Sample of flow in NW part of quad has $^{40}\text{Ar}/^{39}\text{Ar}$ age of 3.20 ± 0.05 Ma. Maximum observed thickness is about 60 m.
- Tgrt** **Rhyolite Tuff of Grants Ridge**—White to pale pink, bedded pyroclastic fall, flow and surge deposits; some beds have abundant aphyric obsidian clasts. Most lithics consist of pink to gray Precambrian granite and gneiss, chert, sandstone, limestone and rare basanite. Pumice clasts are glassy to slightly devitrified with very rare phenocrysts of potassium feldspar. Tgrt can be difficult to distinguish from lower pyroclastic units in Tvst above because it is thin and similar in appearance on weathered slopes. Underlies Qyxtb and overlies Kmf along FS 456 in NW edge of quadrangle. Obsidian clast in pyroclastic flow from location SW of quadrangle is dated at 3.26 ± 0.04 Ma (Goff et al., 2008). Maximum observed thickness is about 10 m.

Cretaceous

Mesa Verde Group

Kmf **Menefee Formation**—Interbedded golden to yellow orange, medium to thin bedded sandstone, black to gray to brown shale and siltstone with carbonized wood fragments, and minor coal. The sandstones are composed of well to moderately sorted, very fine- to fine-grained angular to subrounded quartz and lithic grains (litharenite). The sandstone beds are cross-bedded to tabular-bedded to massive. Cross-beds commonly dip east to northeast. The sandstones are variably weakly cemented and well cemented. White silicified logs and wood fragments are common near 261760E 3914530N (UTM zone 13S, NAD27). Maximum exposed thickness about 45 m.

Crevasse Canyon Formation (shown only in cross sections)

Kpl **Point Lookout Sandstone**—Light gray and reddish brown to buff medium to fine-grained cross bedded sandstone. This cliff-forming sandstone caps Jesus Mesa west of map area on San Mateo quadrangle (McCraw et al., 2008). Nodular concretions (approximately 1 cm diameter) and larger (50 cm diameter) hematite concretions are common at the top of the unit. Outside of the map area, this unit is divided into a lower and upper part by the presence of the Satan Tongue of the Mancos Shale, which isn't present locally. The exposed thickness is between 25 and 50 m.

Kcg **Gibson Coal Member**—Interbedded black to brown siltstone, thin to medium bedded tan, golden-yellow, brown, and greenish gray sandstone, and black coal. The sandstone beds are cross-bedded, ranging from trough cross-beds to large-scale, low amplitude planar cross-beds. Petrified wood fragments are common; logs up to 10 cm in diameter and 0.5 m long are locally preserved. The coal beds are generally < 0.5 m thick. The lower contact is gradational with the underlying Dalton Sandstone Member; Maximum exposed thickness to southwest in Lobo Springs quadrangle is roughly 350 m (Goff et al., 2008).

Kcda **Dalton Sandstone Member**—Consists of two prominent sandstone layers, a lower yellowish-orange layer and an upper white layer with an intervening shale bed. The basal sandstone near the contact with the underlying Mulatto Tongue of the Mancos Shale often has thin beds containing abundant pelecypods casts and molds. The upper and lower contacts are gradational with the overlying Gibson Coal Member of the Crevasse Canyon Formation and the underlying Mulatto Tongue of the Mancos Shale. Maximum exposed thickness to southwest in Lobo Springs quadrangle is ≤25 m (Goff et al., 2008).

Kcs **Stray Sandstone Member**—Consists of two prominent reddish-orange sandstone layers with an intervening shale bed. The top of the Stray Sandstone is a thin (<1 m) conglomerate with pebbles to cobbles of quartzite, chert, and quartz. The upper and lower contacts are gradational with the overlying Mulatto Tongue of the Mancos Shale and the underlying Dilco Coal Member of the Crevasse Canyon Formation. Maximum exposed thickness to southwest in Lobo Springs quadrangle is ≤40 m. (Goff et al., 2008).

Kcdi **Dilco Coal Member**—Interbedded black to brown siltstone, thin to medium bedded tan, brown, and olive-green sandstone, and black coal. The sandstones

are cross-bedded to ripple laminated. The coal beds are < 0.5 m thick and are usually in the lower part of the unit. The upper and lower contacts are gradational with the overlying Stray Sandstone of the Crevasse Canyon Formation and the underlying main body of the Gallup Sandstone. Maximum exposed thickness to southwest in Lobo Springs quadrangle is ≤150 m (Goff et al., 2008).

Gallup Sandstone (shown only in cross sections as unit Kg)

Kgm **Main body**—Yellowish gray, white, or golden yellow, medium to thick-bedded, cross-bedded sandstone. Carbonaceous shale is intercalated with the sandstone. Locally contains fossiliferous (*Innocerimid*) beds near the top. Beds are primarily planar-tabular or laminated. The lower contact is gradational with Mancos Shale and the upper contact is gradational with the Dilco Coal Member of the Crevasse Canyon Formation. Maximum exposed thickness to southwest in Lobo Springs quadrangle is ≤25 m (Goff et al., 2008).

Kgu **Upper tongue**—White medium-bedded, cross-bedded to tabular sandstone that is locally capped by well-cemented, fractured, brown-weathering, planar cross-bedded sandstone. The brown sandstone is carbonate cemented; the weakly cemented white sandstone does not react to hydrochloric acid. The upper and lower contacts are gradational with Mancos Shale. Maximum exposed thickness to southwest in Lobo Springs quadrangle is ≤30 m (Goff et al., 2008).

Kgl **Lower tongue**—White medium-bedded, cross-bedded to tabular sandstone that is locally capped by well-cemented, fractured, brown-weathering, planar cross-bedded sandstone. Brown sandstone is carbonate cemented; the weakly cemented white sandstone does not react to hydrochloric acid. The top of unit is locally conglomeratic with sandstone clasts and sharks teeth. The upper and lower contacts are gradational with Mancos Shale. Maximum exposed thickness to southwest in Lobo Springs quadrangle is ≤15 m (Goff et al., 2008).

Mancos Shale (shown only in cross sections)

Kmm **Mulatto Tongue**—Golden yellow, thin-bedded, tabular to ripple-laminated sandstone and black shale. Burrows and scattered pelecypod molds are common in the sandstone beds. Coarse to very coarse sandstone beds near the basal contact with the Stray Sandstone and lenses of conglomerate with well-rounded pebbles of black and white chert and black quartzite are locally present. Upper and lower contacts are gradational with the Dalton and Stray Sandstone members of the Crevasse Canyon Formation. Maximum exposed thickness to southwest in Lobo Springs quadrangle is ≤50 m (Goff et al., 2008).

Km **Main body**—Black to dark brown shale and silty shale intercalated with finely laminated to cross-bedded thinly bedded sandstone. The sandstones are well-sorted, fine-grained quartz arenites. Upper and lower contacts are gradational. Small tongues of Main Mancos are interbedded within the Gallup Sandstone units. Maximum exposed thickness of Main Mancos beneath Gallup Sandstone is ≤50 m. Maximum drilled thickness including Bridge Creek Limestone (described below) is roughly 145 m (Goff et al., 2008, Table 2).

Kmb **Bridge Creek Limestone (combined with Km in cross sections)**—Finely laminated, fossiliferous, light gray limestone interbedded with thin black shale below the Main body of the Mancos Shale. Correlative with the Greenhorn Limestone. Contains abundant invertebrate fossils including *Pycnodonte* aff. *P. kellumi*, *Exogyra levis*, *Plicatula* cf. *P. hydrotheca*, cf. *Caryocorbula* and *Turritella* sp. (Barry Kues, University of New Mexico, personal communication).

Maximum exposed thickness to southwest in Lobo Springs quadrangle is ≤ 25 m (Goff et al., 2008).

Dakota Formation (shown only in cross sections)

Kd **Dakota Formation, undivided**—Alternating sandstones and shales of Dakota Formation and Mancos Shale; Dakota unit identified in uranium well logs (Reise, 1977, 1980) is inferred to be the lower Oak Canyon sandstone Member (about 25 m thick). Aggregate thickness of Dakota is about 100 m in northwestern map area (Owen and Owen, 2003; see also cross sections in Goff et al., 2008 and McCraw et al., 2009).

Jurassic

Morrison Formation (shown only in cross sections)

Jm **Morrison Formation, undivided**—Alternating sandstones and shales identified only in drill holes; as defined here includes Jackpile Member, Brushy Basin Member, Salt Wash Member, Whitewater Member, Recapture Member, and Main Body Bluff Sandstone (see Reise, 1977; Lucas and Zeigler, 2003). Aggregate thickness is ≤ 300 m.

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Appendix 1. Composite Stratigraphic Section of the Tuffs of San Mateo Canyon

Measured October 2009 upsection from unit 1 by Shari Kelley, Fraser Goff, Nelia Dunbar, and Bill McIntosh using an Abney level and Jacob staff. The numerical unit designations were established upsection and are listed in descending stratigraphic order.

Base of the lower part of the section is at 262140 3909983 (UTM zone 13S, NAD 27). Base of the upper part above the trachyandesite flow is at 262103 3909918 (UTM zone 13S, NAD 27).

<u>Unit No.</u>	<u>Thickness (m)</u>	<u>Description</u>
18.	10.5	Poorly exposed volcanoclastic sediments.
17.	8.0	Pyroclastic flow: Massive, no visible breaks, contains swarms of brown (mingled) and white pumice, pumice lapilli <5cm with phenocrysts of biotite and plagioclase; scattered lenses of lithic fragments; ~5-10% lithic fragments, lithic fragments are porphyritic trachytic lavas.
16.	16	Volcanoclastic sedimentary rocks: Primarily tan sandstone with tabular bedding and lenses of conglomerate; occasional upward-fining sequences with boulders at the base and granules at the top. Clasts are rounded to angular porphyritic trachytic lavas; includes lenses of reworked dacitic pumice.
15.	22.5	Pyroclastic flow: Lithic-rich ignimbrite with 10-15% lithic fragments of porphyritic trachytic lava near the base and middle part of the interval; <10% lithic fragments in the upper third of the tuff. The lithic fragments are <0.2 m to 0.4 m in diameter. The tuff contains blocks of pumice up to 0.5 m. Swarms of brown (mingled) and white pumice are common. The pumice lapilli contain rare phenocrysts of plagioclase.
14.	3.1	Volcanoclastic sedimentary rocks: Tan massive to laminated sandy conglomerate; clasts are porphyritic trachytic lava boulders and cobbles up to 0.5 m in diameter; most are 5 to 15 cm. Clasts are rounded to angular; the conglomerate is matrix-supported and contains lenses of rounded dacitic pumice.
13.	0.15	Scoriaceous cinders and black tephra: Dark brown to black cinders and lapilli are <1 cm in diameter with plagioclase phenocrysts.
12.	2.5	Ash-fall deposit: Pumice lapilli up to 10 cm in diameter, most are 3-4 cm across; sequence coarsens upward. Lapilli have phenocrysts of biotite and plagioclase.
11.	0.8	Volcanoclastic sedimentary rocks: Brown laminated to cross-bedded siltstone, sandstone, and reworked pumice.
10.	2.5	Ash-fall deposit: Pumice lapilli up to 3 cm in diameter, coarsening upward sequences. Lapilli have phenocrysts of biotite and plagioclase. Pumice is compacted and mildly altered. Trachytic lava lithic fragments are rare.
9.	7.9	Volcanoclastic sedimentary rocks: Conglomeratic sandstone and conglomerate with angular porphyritic trachytic lava clasts <0.5 m in diameter and rounded dacitic pumice <2 cm in diameter. A red sandstone at the base of the interval may be a paleosol.
8.	5.0	Covered interval: Probably volcanoclastic sedimentary rocks.
7.	1.0	Trachyandesite: Fine-grained, dark brown to black, phenocrysts include <1 mm plagioclase and pyroxene.

6. 5.2 **Volcaniclastic sedimentary rocks:** Conglomeratic sandstone, tabular to cross-bedded, clasts are pebble to boulders of porphyritic trachytic lavas, contains reworked pumice.

5. 3.8 **Lithic-poor pyroclastic flow:** White, massive, base of interval contains little pumice, but becomes more pumice-rich near the top. Crystal-poor pumice lapilli are <1 cm in diameter, rare lithics are < 3 mm in diameter.

4. 0.8 **Surge bed:** Consists mainly of angular lithic fragments that are <2 cm in diameter. Reworked at the top.

3. 5.5 **Lithic-poor pyroclastic flow:** White, contains pumice swarms with lapilli up to 10 cm in diameter; pumice contains more crystals of quartz and plagioclase compared to the units below; lapilli are <1 cm, rare lithics are <3 mm in diameter.

2. 0.5 **Surge bed:** Cross-bedded aphyric pumice lapilli are generally rounded; some are angular. The lithic fragments are <5 cm in diameter and include flow-banded rhyolite and trachytic lava.

1. 17.2 **Lithic-poor pyroclastic flow:** White, massive, no bedding or breaks; laminated at base in exposure by spring, ashy matrix, aphyric to crystal-poor pumice <1 cm, rare lithics are <3 mm in diameter.

Appendix 2: Redrawn cross sections from Reise (1977). See map for cross section locations.

1:24,000 no V.E.

