Geologic Map of the Socorro Quadrangle, Socorro County, New Mexico

By

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June, 1999

New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 034

Scale 1:24,000

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Socorro 7.5′ Quadrangle
OF-DM 34

GEOLOGIC MAP OF SOCORRO QUADRANGLE, SOCORRO COUNTY, NEW MEXICO

by
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COMMENTS TO MAP USERS

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This quadrangle map has been Open-Filed in order to make it available as soon as possible. The map has not been reviewed according to NMBMMR standards, and due to the ongoing nature of work in the area, revision of this map is likely. As such, dates of revision are listed in the upper right corner of the map and on the accompanying report. ***The contents of the report and map should not be considered final and complete until it is published by the NMBMMR.***

A geologic map graphically displays information on the distribution, nature, orientation, and age relationships of rock and surficial units and the occurrence of structural features such as faults and folds. Geologic contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic map are based on field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation.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. Significant portions of the study area may have been mapped at scales smaller than the final map; therefore, the user should be aware of potentially significant variations in map detail. 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 everywhere.

Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. The information provided on this map cannot be substituted for site-specific geologic, hydrogeologic, or geotechnical investigations. The use of this map to precisely locate buildings relative to the geological substrate is not recommended without site-specific studies conducted by qualified earth-science professionals.

The cross-sections in this report are constructed based on surficial geology, and where available, subsurface and geophysical data. The cross sections are interpretive and should be used as an aid to understand the geologic framework and not used as the sole source of data in locating or designing wells, buildings, roads, or other structures.

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DESCRIPTIONOF MAP UNITS: SOCORRO 7.5′ QUADRANGLE

POST-SANTA FE GROUP UNITS

af — Artificial fill (uppermost Holocene)— Mostly represents compacted fill as roadway subgrades along Interstate 25, also represents irrigation levees, and the flood control diversion west of Socorro. Includes waste rock piles near Highway 60. Thickness 0–12 m.

Qac — Active channel of Rio Grande (recent)—Sand, gravel and minor mud of active Rio Grande channel. Thickness probably 0–9 m.

Qvy — Younger valley alluvium, piedmont facies (Holocene to uppermost Pleistocene) — Active channel, low terrace and alluvial-fan deposits of tributary arroyos. Consists of poorly sorted, nonindurated, volcanic-rich gravel, sand, silt, and clay. Associated with low graded surfaces formed during last major episode of valley entrenchment and backfilling. Thickness 0–30 m.

Qvyf — Younger valley fill, axial-fluvial facies (Holocene to uppermost Pleistocene) — Floodplain deposits of Rio Grande; consists mostly of clay to sand. Grades to well sorted gravel at basal scour surface as much as 30 m below floodplain (McGrath and Hawley, 1987). Intertongues with Qvy. Thickness 0–30 m.

Qe — Eolian deposits (Holocene) — Light gray, fine grained, well sorted sand; locally caps older alluvial and terrace surfaces. Thickness 0–5 m.

Qca Colluvium and alluvium, undifferentiated (Holocene to Middle Pleistocene) — Talus and colluvium on steep to moderate slopes in the Socorro Mountains. Also, gravelly slope wash on erosion surfaces cut in poorly consolidated upper Cenozoic deposits in Socorro Basin. Gravelly colluvium is typically shown where it masks ancestral Rio Grande deposits (QTsf). Includes rock avalance deposits on east face of Socorro Peak. Widespread colluvial veneers on dissected piedmont slopes in the Socorro Basin are generally not delineated. Usually 0.3-3 m. thick, locally as much as 10 m. thick.

Qls Landslide deposits and colluvium (upper Pleistocene to middle Pleistocene). Includes numerous toreva-type (rotated) slide blocks of lava (Tsr, Tsd, Tbsc) that have slipped down slope on underlying Popotosa playa deposits (Tpp). Suffix in parenthesis indicates composition of slide blocks (b=basalt, d=dacite, r=rhyolite). Slide blocks and mudstones are mantled by abundant colluvium. Includes small mud flows and minor alluvium. Most slide areas are relatively stable or inactive. Landslides are widespread northwest and southwest of Socorro Peak, also around Black Mountain. Characterized by hummocky topography. Thickness of lava slide blocks is as much as 90 m.

Qp Fill of small closed basins (playas) in landslide terrance (middle to upper Pleistocene)—Unconsolidated mud, silt and sand; generally flat lying locally dissected by recent rivulets. Probably less than 10 m thick in most smaller basins.

Qvo Older valley alluvium, piedmont facies (middle to upper Pleistocene) — Inset terrace and alluvial-fan deposits of tributary arroyos associated with five episodes of valley entrenchment and backfilling. From oldest to youngest, graded surfaces associated with these alluvial deposits project: 64–70 m (Qvo1), 43–52 m (Qvo2), 30–40 m (Qvo3), 15–21 m (Qvo4) and 6–9 m (Qvo5) above modern drainages and the Rio Grande floodplain. Consists of poorly to moderately sorted, bouldery to cobbly, volcanic-rich gravel, gravelly sand and muddy silts. Generally reddish orange to reddish brown, locally light brown to tan in color. Mostly nonindurated, however, uppermost beds beneath graded surfaces are variably cemented by pedogenic carbonate horizons (c) approximately 0.6 m to 0.1 m thick. Tentative correlation with Quaternary alluvial units in the San Acacia and Las Cruces areas (based on projected height above Rio Grande) suggest these deposits range in age from about 250,000 years to 25,000 years old (Machette, 1978). Thickness 0–12 m, average thickness 6–9 m.

Qvof Older valley fill, fluvial facies and minor piedmont facies (upper Pleistocene) — Complexly intertonguing axial-river deposits (older Rio Grande) and distal alluvial-fan deposits of tributary arroyos. Locally divided into older (Qvof2) and younger (Qvof3) units based on lateral continuity with older piedmont deposits (Qvo2 and Qvo3). Consists of light gray to light yellowish brown, well sorted, fluvial sands and gravels (transport to south), interbedded with reddish orange, poorly sorted, sandy to cobbly, volcanic-rich gravels (transport to east), and red-silty mudstones. Well rounded to subrounded quartzite, granite and metamorphic rock pebbles are typical of the axial-river deposits. However, lenses of locally derived volcanic cobbles (reworked piedmont facies) are also present in axial-river deposits. Facies boundary with Qvo placed at approximate western limit (crosses on map) of axial river beds that commonly *overlie* volcanic-rich piedmont-facies gravels. As much as 12 m thick.

Qpu Piedmont deposits undifferentiated (upper to lower Pleistocene) — Coarse debris flows and poorly sorted volcanic-rich gravels, sand and muds, deposited on small alluvial fans derived from small catchment areas on the east flank of the Socorro Peak Contains buried soils similar to those in QTsp; not demonstrated to intertongue with QTsf. Probably represents locally continuous aggradation, equivalent to QTsp and older Qvo deposits. Base not exposed, minimum thickness 30–60 m. Includes remnant of high-level terrace, as much as 9 m thick, within the northern Chupadera Mountains.

SANTA FE GROUP

Intermontane basin fill of the Rio Grande rift. As redefined by Machette, 1978, includes the Pliocene and Pleistocene valley fill of the Sierra Ladrones Formation (of Machette, 1978), and Miocene bolson fill of the Popotosa Formation, named by Denny, 1940. Also includes intercalated volcanic units such as the Socorro Peak Rhyolite, rhyolitic ash-falls, and local basalt flows (Osburn and Chapin, 1983).

Qlc
QTsl Sierra Ladrones Formation (lower Pleistocene to lower Pliocene) — Late-stage

Tsl basin fill of the Rio Grande valley characterized by an axial-river facies (ancestral Rio Grande) and intertonguing piedmont facies (large alluvial fans) derived from adjacent mountain ranges. Capped by Las Cañas geomorphic surface (Qlc) of McGrath and Hawley, 1987. As mapped here, younger piedmont facies (QTslp upper member) and older piedmont facies (lower member, Tslp) locally lie in angular unconformity on tilted Popotosa beds at the basin margin. Also, the younger piedmont facies (QTslp) is locally inset against or disconformably overlies the older piedmont facies (Tslp). The base of the younger axial-river facies (QTslf) is not exposed here. Maximum thickness of Sierra Ladrones Formation probably 300–400 m.

Qlc Las Cañas geomorphic surface of McGrath and Hawley, 1987 (lower Pleistocene). Erosional remnants of geomorphic surface representing maximum level of aggradation of late Cenozoic basin fill along the Rio Grande valley near Socorro. Defines top of Santa Fe Group and Sierra Ladrones Formation where present. Characterized by discontinuously exposed laminar calcrete as much as 2 m thick. Locally mantled with thin desert pavement or dark red argillic horizon. Projects 80 to 100 m above modern Rio Grande. Correlation with geomorphic surface in type area, east of the Rio Grande, is based on similar landscape position and soil development. Tenatively correlated with the lower La Mesa surface of Las Cruces area, which has recently been dated at 0.73–0.9 Ma (Mack and others, 1993).

QTslp Sierra Ladrones Formation, upper piedmont facies (lower Pleistocene to upper Pliocene) — Alluvial-fan deposits below Las Cañas surface (Qlc) of McGrath and

Hawley, 1987. From south to north, large, low-gradient alluvial fans (paleoslopes of 100–140 ft/mi) emanate from Socorro Canyon, and Nogal Canyon. Distinctive volcanic clasts demonstrate that both were fed by large canyons in the eastern Magdalena Mountains, namely Six Mile Canyon and Water Canyon. Consists of reddish orange to reddish brown, poorly consolidated, volcanic-rich, boulder to cobble conglomerates, conglomeratic sandstones, muddy sandstones, and silty mudstones; generally fining to the east. Buried calcic soil horizons (bc) are common within the piedmont facies. Maximum thickness of upper piedmont facies, is estimated to be about 140 m. West of the Socorro Canyon fault, on a structurally higher blocks, the uppermost piedmont facies is about 6–12 m thick.

QTslf Sierra Ladrones Formation, upper member, axial-fluvial facies (lower Pleistocene to upper Pliocene) — Axial river deposits of the ancestral Rio Grande, and minor intertonguing distal piedmont-slope deposits. QTsf–QTsp facies boundary is placed at *western* (mountainward) limit of well sorted, light-gray to pale yellowish brown, quartz-rich river sands or pebbly gravels. Piedmont facies gravels that locally *cap* the fluvial facies (east of the facies boundary) are delineated as QTsp on the map. Axial river sands and gravels are usually non indurated. Pebbly gravel lenses typically contain well-rounded to subrounded clasts of quartzite, chert, granite, metamorphic rocks, and various volcanic rocks (a few recycled from local piedmont facies). Lenses of rhyolitic pumice (r) are also locally present. River sands often fine upwards into red or greenish gray, poorly indurated, mudstones that probably represent floodplain deposits or abandoned channel fills. Water-laid rhyolitic ash beds (a), apparently derived from eruptions in the Jemez Mountains (Dunbar and others, 1996), locally overlie floodplain mudstones near the western limit of the axial-river facies. Base of Pleistocene axial-river facies is not exposed in the Socorro quadrangle. Possibly 200 m thick near down faulted axis of Socorro Basin.

Tbsc Basalt of Socorro Canyon (lower Pliocene)—Dark gray, massive to vesicular, olivine basalt flows. Contains 1-2% fine-grained (1–2mm) yellowish brown phenocrystic olivine and sparse to rare glomenophenocrysts of plagioclase. Erupted from NNE trending fissure vent near salient on south side of Black Mountain (Mesa). Stack of three flows here is 18–21 m thick; thin zones of reddish scoria and agglomerates occur between flows near the vent. Average thickness this single- to multiple- flow unit is 6–9 m. Unit flowed down easterly paleoslope of ancestral Socorro/Six Mile Canyon; as indicated by local interbedded relationship with Tsp conglomerates that contain unique clasts from the NE Magdalena Mountains. Unit may be down faulted into subsurface east of the Socorro Canyon fault zone. Apparent eruption age from four $^{40}Ar/^{39}Ar$ analyses (Table 1) is 3.73± 0.1 Ma (Table 1). Chemical analysis indicates this unit is a tholeiitic basalt containing about 49.5–50.0% SiO_2 (Baldridge et. al., 1989).

Tslp Sierra Ladrones Formation, lower member, piedmont facies (lower to upper Pliocene) — Easterly transported piedmont-slope deposits. Consists of poor to moderately indurated, light brown to pale reddish brown, conglomeratic sandstones with abundant locally derived volcanic clasts and rare dark red clasts of jasperoidal cemented (potassium metasomatized) lower Popotosa Formation (Tpfm). Lies conformably on fluvial-fan transition facies (Tslt) near Grefco Mine and south of Nogal Canyon. Locally overlain by middle Pliocene basalt of Socorro Canyon (Tbsc) in area southeast of Grefco Mine. Conglomerates SE of Grefco Mine contain rare cobbles of upper Lemitar Tuff with large mafic clots; these unique cobbles must have come from the NE Magdalena Mountains via ancestral Six Mile Canyon. Further west a younger channel deposit of ancestral Six Mile Canyon overlies and is slightly inset into the basalt of Socorro Canyon, which caps Black Mtn. Maximum exposed thickness is 120 m. Thickness range 0–120 m.

Tslt Sierra Ladrones Formation, lower member, fluvial-fan transition facies (lower Pliocene) — Light gray to yellowish brown, well sorted, fine to medium-grained, moderately quartz-rich sand and sandstone, with a few thin beds of volcanic-pebble conglomerate, mudstone-clast conglomerates, and red or pale green mudstone. Black heavy-mineral laminations are common in the well sorted, sand beds. Calcite cemented conglomerate and sandstones more common toward base. Well sorted fine-grained sands contain about 60 percent monocrystalline quartz, 20 percent feldspar (microcline and non volcanic plagioclase), and 20 percent volcanic lithic fragments. Considering their location, these relatively arkosic and volcanic-poor sandstones may represent the distal portion of a large fluvial fan emanating from the Water Canyon area of the Magdalena Mountains. Much of the non volcanic quartz may have been recycled(?) from the upper buff member (Tpfb) of the Popotosa Fm. Transition unit is well exposed in a deep ravine on the northeast flank of Socorro Peak, and in small exposures below Tbsc near the Grefco Mine. Easterly paleocurrents and rare pebbles or small cobbles of well indurated (K-metasomatized) lower Popotosa Formation (Tpfn) in the Socorro Peak exposures indicate this fluvial unit is partly recycled from uplifted lower Popotosa beds in the Magdalena Mountains. Pale red mudstones become more abundant to east and northeast where this unit (Tslt) appears to grade into overbank facies of ancestral Rio Grande (Tsfo). Unit probably marks transition from closed basin to axial river deposition, possibly in response to a wetter climate. Transition unit was probably inset against Popotosa playa beds and Miocene lavas on flanks of Socorro Peak. Unit is as much as 300 m thick on northeast flank of Socorro Peak. Tributary streams most likely flowed around lavas capping Socorro Peak, thus this unit is probably absent due east of Socorro Peak.

Tslo Sierra Ladrones Formation, lower member, overbank facies (lower to upper Pliocene)—Reddish brown to light brown poorly indurated, non-gypsiferous mudstones silt and minor sand. Grades upward and westward into distal fluvial fan facies (Tslt). North of Nogal Arroyo this fine grained unit appeared to unconformably overlie strongly east titled maroon gypsiferous mudstones of the Popotosa playa facies (Tpp) and an interbedded dacitic ashbed (Tsndt). Unit may be as much as 60 m thick. Tsfo and Tslt appear to grade eastward and upward into quartzite-bearing older axial river deposits (Tslf) just west of the Socorro Canyon fault.

Tslf Sierra Ladrones Formation, lower member, axial river facies (lower to upper Pliocene)—Light brownish gray to pinkish gray sandstone and conglomeratic sandstone with abundant volcanic clasts and a distinctive minor component of well rounded quartzite clasts. Fine to coarse grained sands, tabular to trough cross bedded, locally moderately indurated with calcite cement. Exposures in wall of Nogal Canyon locally contain silicified logs. Locally well exposed in west half of section 20 north of Nogal Canyon and in down faulted sliver east of Grefco mine. Latter exposure contains minor granitic clasts. Axes of trough ross beds indicate southerly paleo low Maybe as much as 300–400 m thick east of the Socorro Canyon fault.

Tp Popotosa Formation (lower to upper Miocene)—Intermontane bolson fill deposits of early Rio Grande rift grabens and half grabens. Defined by Denny, 1940, and redefined by Machette, 1978. Can locally be divided into lower red and gray fanglomerate facies (Tpfr and Tpfg) which predate basaltic to dacitic volcanism of late Miocene age (ca 9.8–9.5 Ma) in the Socorro Peak area. Further north the lower red fanglomerates contain rhyolitic ash beds deposited at about 15 Ma (Cather, et al 1994). Upper Popotosa Formation consists mostly of maroon gypsiferous mudstones assigned to the playa facies of the Popotosa Fm (Tpp). Buff conglomeratic sandstones (Tpfb) derived from the west; and pale red to pinkish conglomeratic sandstones (Tpfp) derived from the east, locally intertongue with the playa facies. Undivided Popotosa Formation is shown in cross section only. Probably as much as 900–1500 m thick under western flank of Socorro Basin.

Tpfr Basal red fanglomerate facies (lower to middle Miocene; potassium metasomatized in upper Miocene time)—Medium reddish brown to dark red volcanic-rich alluvial conglomerates and debris flows. Clast compositions and imbrications generally indicate northerly transport. Eroded from fault blocks of underlying Luis Lopez Formation (andesite to rhyolite lavas) and regional tuffs (mostly Thm, Tlu and Tsc). Dark red color and moderate to extreme degree of induration is derived from jaisperoidal silica cement, which is associated with potassium metasomatism of late Miocene age (Dunbar et al, 1994; Chamberlin and Eggleston, 1996). Metasomatized fanglomerates locally interfinger with gray and greenish gray fanglomerates on east face of Socorro Peak (Tpfg). Depositional contacts are locally crossed by alteration (metasomatism) boundaries. Basal fanglomerates were eroded from Miocene early rift fault blocks; an angular unconformity of 10–25 degrees is commonly evident at the base of the lower Popotosa Formation. Unit fills north-trending strike valleys in southern Lemitar Mountains. Monolithic colluvial breccias (triangle symbol), derived from subjacent volcanic units are common at the base of the lower Popotosa Formation. Thickness of wedge-shaped fills are highly variable, from 0–300 m.

Tpfg Basal gray fanglomerate facies—lower to middle Miocene. Light gray to light purplish gray and greenish gray (weakly altered) volcanic rich conglomerates and conglomeratic sandstones. Locally includes light purplish gray sandstones and mudstones representing minor lacustrine facies in area south of M-Mountain (not mapped separately). Clasts of light gray crystal-poor ignimbrites and purplish basaltic andesites are dominant; clast imbrications indicate westerly paleocurrents.

Blusih green, celadonitic zones appear to occur adjacent to metasomatism boundaries (ie. red well indurated fanglomerates). Gray conglomeratic sandstones about 1 km SE of M Mtn contain numerous small jasperoid and barite veinlets; thus indicating that they also predate the alternation/metasomatism event. Monolithic colluvial breccias (triangle symbol), are common at the base of the lower Popotosa Formation. 0–300 m thick.

Tpp Medial to upper playa facies (upper Miocene)—Mostly red or maroon claystone with minor greenish claystone and thin bedded buff to light gray siltstones to fine-grained sandstones. Thin beds of gypsum are common in well exposed section west of Kelly Ranch; selenitic veinlets are also widespread in this unit. Claystones are poorly indurated and commonly masked by landslide deposits (Qls) and colluvium (Qac) where they underlie steeper slopes on west flank of Socorro Peak. Playa deposits near Kelly Ranch are interbedded with and grade north-westward into buff conglomeratic sandstones (Tpfb). Near the Grefco mine playa mudstones interfinger with pale red conglomeratic sandstones derived from the east side of the Socorro Basin (Tpfp). Playa deposits appear to disconformably overlie red fanglomerate facies, (Tpfr), and older volcanic rocks in the northern Chupadera Mountains. Near the unconformity playa deposits locally grade down into thin interval (<10 m) of red muddy conglomerates, which are not differentiated on this map. Playa deposits contain lavas and ash beds ranging from 9.8 to 7.8 Ma. West of the quadrangle, younger playa deposits locally underlie the flanks of Sedillo Hill which is capped by a trachyandesite lava flow dated at 6.88 ± 0.02 Ma (W. C. McIntosh, written commun.). Minimum unfaulted thickness west of Kelly Ranch is 390 m; estimated maximum thickness is 750 m.

Tpfb Medial buff conglomeratic sandstone facies (upper Miocene). Pale brownish yellow (buff) conglomeratic sandstones and quartzo-feldspathic sandstones. Characterized by sparse to moderately abundant subrounded clasts of hydrothermally altered crystal-poor rhyolites. Altered clasts are yellowish brown to gray and speckled with small dots of yellow brown goethite, probably after pyrite. Clast compositions and easterly paleocurrent observations suggest the facies represents a distal alluvial fan or braided channel deposit shed from the Magdalena area about 15 km to west. Unit intertongues with and grades upwards into thick playa facies section in area about 5 km SW of Kelly Ranch; estimated thickness here is about 420 m. Locally contains the basalt of Kelly Ranch dated at 9.77 Ma.

Tpfp Upper pale red conglomeratic sandstone facies (upper Miocene). Pale red to pale reddish orange conglomeratic sandstones; well exposed NE of the Grefco perlite mine. Volcanic clasts are dominant, but unit also contains rare pebbles at dark red finely laminated siltstone and fine grained sandstone, lithologically similar to the Permian Abo Formation. This pale red conglomeratic facies most likely represents distal alluvial fan deposits derived from Las Cañas uplift on the eastern side of the Socorro Basin. If so, this late Miocene unit facies must predate the ancestral Rio Grande. Tpfp conformably overlies tuffs (Tsrt2) erupted from the Grefco vent area at about 7.85 Ma. Pale red conglomeratic sandstones also intertongue with gray perlitic sandstones (Tpsr) that were locally shed to the northeast off the glassy lava dome. Further west these units intertongue with playa facies claystones. Maximum exposed thickness is 60–90 m.

Tpsr Perlitic sandstone facies (late Miocene). Light gray vitrophyric sandstones and conglomeratic sandstones locally shed from the flanks of the glassy rhyolitic lava dome that now hosts the Grefco perlite mine. Alluvial apron surrounding lava dome is about 30–75 m thick and directly overlies bedded tuffs related to initial pyroclastic eruptions from the Grefco vent.

VOLCANIC ROCK UNITS INTERBEDDED IN POPOTOSA FORMATION

Tbb basalt of Bear Canyon (upper Miocene)—Thin basalt flow intercalated with playa deposits of the upper Popotosa Formation in the northern Chupadera Mountains. Black, dense, fine grained (saccaroidal) basalt with a well developed ophitic texture. Basal flow breccia generally not observed, but amygdaloidal vesicular zones are occasionally present. A groundmass separate from "Shrine Valley" (580 m S. of Socorro quadrangle) has yielded an $^{40}Ar/^{39}Ar$ age of 8.68 ± 0.11 Ma which is analytically equivalent to lithologically similar basalt flows in the upper piedmont facies of the southern Chupadera Mountains (Chamberlin and Eggleston, 1996). Field relationships in the Molino Peak quadrangle would allow the basalt of Bear Canyon (Tpbb) to be the thinner downslope basin floor equivalent and distal margin of the basalt of Broken Tank of Osburn and others, 1981. Chemical analyses indicate this is a trachybasalt (ie. alkalic basalt) containing about 49% SiO_2. Thickness 0–10 m.

Ts Socorro Peak Rhyolite: cluster of Late Miocene silicic lava domes centered near Socorro Peak (Osburn and Chapin, 1983). Individual lava domes range in composition from hornblende dacite (69–70% SiO_2) to hornblende-biotite rhyodacite (70–73% SiO_2) to high silica-rhyolite (75–77% SiO_2) Bobrow, 1983. Dacitic domes are stratigraphically the oldest, rhyodacites are slightly younger, and rhyolites are associated with 4 younger eruptive centers. The more southerly eruptive centers for dacites and rhyolites appear to be the most siliceous. Pumiceous ash beds and bedded tuffs of dacitic to rhyolitic composition are locally mapped as tephra facies (t) of the Socorro Peak rhyolitic that are interbedded in the Popotosa Formation. Most of these undated tuffs are reasonably well correlated with their cogenetic lava dome. Tuffs, lavas and associated shallow intrusions (Tid, Tir) are informally subdivided into three members: 1) early dacites, 2) medial rhyodacites, and 3) rhyolites of 4 different eruptive centers ranging in age from 8.8 to 7.0 Ma.

Tsd/Tsdt Dacite Member of Socorro Peak Rhyolite (upper Miocene)—Mostly medium gray to reddish brown dacitic porphyry lavas containing about 10 percent fine to medium grained phenocrysts of plagioclase and minor hornblende; biotite if present is rare (<0.5%). Medium-grained plagioclase phenocrysts are strongly resorbed and distinctly less abundant than fine-grained plagioclase phenocrysts. Dacite lava domes and associated shallow necks define two distinct NNW trending intrusive belts. The eastern belt extends from Nogal Canyon ("Stonewall" and "Smooth" domes) southward to M Mountain and to the east side of Blue Canyon. Down-faulted dacitic lavas and tuffs on east face of Socorro Peak (Merritt Mine) were probably erupted from the pointed neck (Tid) about 1 km SSE of M Mountain. The second belt extends southward from "Buried" Mesa to "6001" Mesa and to a eroded neck west of the Grefco perlite mine. Many of these dacitic flows appear to represent originally flat topped, cake-like tortas. A dacitic pumiceous agglomerate (Tsdt) locally underlies the lava erupted from the vent on the north flank of M-Mountain. This flat topped flow is tilted about 50° to the west. Its original flat top is well preserved and defined by the overlying rhyodacitic lava (Tsrd) erupted from the vent at "Radar Peak." Another flat-topped dacite south of Blue Canyon, tilted about 20 degrees to the east, is conformably overlain by the 8.66 Ma rhyolite of Signal Flag Hill. In contrast the flat topped dacite flow at 6001 Mesa is essentially horizontal and well developed columnar joints in the lava are nearly vertical. The dacite at M Mountain has yielded an apparently spurious $^{40}Ar/^{39}Ar$ age of 11.56 ± 0.9 Ma from biotite (see Fig. 1). Dacite lavas in the Socorro Peak area are younger than the basalt of Kelly Ranch (9.77 Ma) and older than the rhyolite at Signal Flag Hill (8.66 Ma). They are tentatively estimated to be about 9.6 million years old (see Fig. 1). Individual dacitic flows average about 60–120 m in thickness. Thickness range: 0–120 m.

Tsrd/Tsrdt Rhyodacite Member of Socorro Peak Rhyolite (upper Miocene)—Mostly pale red to light gray rhyodacite poorphyry lavas containing about 10 percent fine to medium grained phenocrysts of plagioclase with minor hornblende and biotite (subequal).

Larger plagioclase phenocrysts are strongly resorbed and hornblende commonly shows a magmatic reaction to form biotite. Individual flows at Radar Peak and Strawberry Peak (just NW of Socorro quad) appear to be compositionally zoned (69.8–71.1% SiO_2) from dacite to low silica rhyolite (Bobrow, 1983); hence the compositional name is rhyodacite. Small outcrops of rhyodacitic tephra (Tsrdt) help define the base of the flow at Radar Peak. A relatively biotite-rich rhyodacitic tephra (Tsrdt) within playa deposits (Tpp) 3 km west of Kelly Ranch is most likely related to the dome at Strawberry Peak or possibly the Radar Peak dome. Biotite from the flow at Radar Peak has yielded an $^{40}Ar/^{39}Ar$ age of 9.51 ± 0.06 Ma, which appears to be in agreement with other dated units nearby (see Fig. 1). The rhyodacite flow at "Radar Peak" overlaps the west margin of the older dacite flow of "M Mountain." Maximum thickness of the Radar Peak flow is about 90-120 m. Thickness range 0-120 m.

Tsr__ Rhyolite member of Socorro Peak Rhyolite; erupted from 4 distinct centers at "Signal Flag Hill," Grefco Mine, "Jejenes Hill" (just west of quadrangle boundary) and "Tripod Peak."

Tsr1 Rholite lava dome, peripheral flows and tuffs at signal Flag Hill (upper Miocene)—Light gray to light brownish gray to pale red, moderately phenocrysts-rich (15-20%), flow-banded, high-silica rhyolite lava (75–76% SiO_2). Lavas contain medium grained phenocrysts of sanidine, plagioclase, quartz and minor biotite. Lava dome was probably erupted from north-trending fissure vent. North end of dome is spectacularly exposed in 45 m high cliff on north side of Signal Flag Hill (south wall of Blue Canyon). Pasty internal flow structure of the rhyolite lava dome is very well exposed in this escarpment created by detachment of a Pleistocene slump lock, which slid into Blue Canyon. Flows east of vent locally overlap older dacite torta (Tsd); west of vent basal tuffs appear to overlie playa deposits (Tpp). Map relationships suggest a narrow keystone graben formed in the vent area prior to eruption. Sanidine from Signal Flag Hill yields an $^{40}Ar/^{39}Ar$ age of 8.66 ± 0.05 Ma (Table 1). Maximum thickness of faulted and eroded lava dome complex is about 60–90 m.

Tsr2
Tsrt2

Rhyolite lava dome and associated tuffs at Grefco Perlite Mine (upper Miocene)—Mostly light gray, glassy, flow banded, phenocryst-poor high-silica rhyolite lava (76–77% SiO_2). Contains less than 1% fine grained phenocrysts of sanidine and plagioclase with traces of quartz and biotite. Original microvesicular obsidian lava has been uniformity altered (hydrated) to commercial quality perlite over last 7 million years (Chamberlin and Barker, 1996). Very rare micronodules of obsidian in the granular perlite attest to its secondary low-temperature origin. Small dome about 1 km across displays unusually glassy core at least 90 m thick; a granophyric felsite zone is present on the northeast flank of the dome. Cogenetic bedded tuff and tuff breccia (Tsrt2) is locally well exposed in fault blocks on west and north side of dome. Tuff breccia 0.7 km N of dome contains blocks and slabs of red claystone (older Tpp) as much as 1 m long. Phenocryst- poor tuff (Tsrt2) overlaps south margin of phenocryst-rich rhyolite lava (Tsr1) and other playa deposits (Tpp) about 1 km north of Socorro spring. See Chamberlin and Barker, 1996, for details of the eruptive history of this world class perlite deposit. Inferred vent lies under central portion of lava dome, near northwest corner of main pit area zoom NW of grizzly). East margin of lava dome has been truncated by east down high-angle normal fault. North margin of lava dome remains partly buried by sedimentary facies of the upper Popotosa Formation (Tpsr, Tpfp and Tpp). Sample from the main pit area yields an $^{40}Ar^{39}Ar$ age of 7.85 ± 0.03 Ma from sanidine (Table 1). Faulting and incomplete exhumation complicate thickness estimate; maximum thickness of lava dome probably 90–120 m. Tuff ranges from 0–30 m.

Tsr3 Rhyolite lava flow peripheral to "Jejenes Hill" eruptive center (benchmark 6854, Water Canyon quadrangle) (upper Miocene)—Light gray, light brownish gray and pinkish gray, moderately phenocryst-rich (~15%), flow banded, low-silica rhyolite (71–73% SiO_2; Bobrow, 1983). Contains moderately abundant, fine- to medium-grained (0.5–2 mm) phenocrysts of plagioclase, sanidine and biotite with minor quartz (~1%). Moderately eroded lava flow forms low rolling hills to east of their source vent at Jejenes Hill. Equivalent lava just west of quadrangle boundary yields a $^{40}Ar/^{39}Ar$ age of 7.52 ± 0.09 Ma from sanidine (Table 1). Hill at BM 6345 may represent a small domal flow. Boundary with younger flows (Tsr4) from the Tripod Peak center is tentatively inferred along the most incised drainage line that locally separates these petrographically similar lavas. Additional mapping and sampling is warranted to test this tentative boundary. Maximum thickness of flow is about 60–90 m.

Tsr4 Rhyolite lava domes and peripheral flows of "Tripod Peak" eruptive center (upper Miocene)—Light gray, light brownish gray, and pinkish gray, moderately phenocryst rich (~15%), flow banded, low-silica rhyolite (72–73% SiO_2; Bobrow, 1983). Contains moderately abundant fine to medium-grained phenocrysts of plagioclase, sanidine and biotite with minor quartz. Tripod Peak lavas are petrographically similar to slightly older lavas (Tsr3) from the Jejenes Hill center. Flow units of Tripod Peak center yield $^{40}Ar/^{39}Ar$ ages on sanidine of 7.02 ± 0.05 Ma and 7.06 ± 0.03 Ma (Table 1).

Tbk Basalt of Kelly Ranch (upper Miocene)—Medium gray to greenish gray basaltic lavas containing sparse small plagioclase laths (<5%, 1–2 mm), and traces of olivene, often slightly altered to chlorite. Consists of one moderately widespread multiple flow unit that is repeated in several fault blocks west of Kelly Ranch. Three samples from the widespread medial unit yield $^{40}Ar/^{39}Ar$ ages of 9.66 to 9.87 Ma and an average of 9.77 ± 0.06 Ma (Table 1). Minor flows of similar lithology locally occur above and below the medial unit where exposed in fault blocks east of Strawberry Peak (4 km WSW of Kelly Ranch). These undated flows are locally assigned to the upper and lower members of the basalt of Kelly Ranch, Tbku and Tbkl, respectively. Medial flow locally overlies westerly derived distal piedmont facies (Tpfb) near north and west extent of outcrop belt; whereas most of the medial unit is interbedded in playa facies claystones (Tpp). Outcrop patterns and facies relationships suggest the source vent was on the piedmont slope west of the playa (somewhere west of Strawberry Peak). Maximum thickness of stacked flows in medial unit is 30 m. Chemical analyses indicate this is a basaltic trachyandesite (alkalic basaltic andesite) containing about 53% SiO_2 (Chamberlin, 1980). Absent east of Socorro Peak, thickness 0–30 m.

OLIGOCENE VOLCANIC ROCKS OF MOGOLLON-DATIL FIELD:

Tsc South Canyon Tuff (upper Oligocene)—Partially to densely welded, light gray to pale grayish red, phenocryst-poor to moderately phenocryst-rich, pumiceous, high silica rhyolite ignimbrite. Medium grained (1–3 mm) phenocrysts of subequal quartz and sanidine, with traces of biotite and plagioclase; crystals progressively increase upwards from about 5% near partly welded base to as much as 25% near densely welded top (where preserved). Generally lithic poor except near base; light gray pumice (1–5 cm) is moderately abundant (5-15%). Exposure NE of Socorro Peak is strongly brecciated and hydrothermally altered, sanidine here is milky white. Represents remnants of thin outflow sheet erupted from the Mount Withington caldera in the northern San Mateo Mountains (Ferguson, 1991). Mean $^{40}Ar/^{39}Ar$ age is 27.37 ± 0.07 Ma; magnetic polarity is reverse (McIntosh and others, 1991). Correlation here is based on lithology and relative stratigraphic position. As much as 60 m thick in SE Lemitar Mountains, locally wedges out of south of Socorro Peak.

Tlp3 La Jara Peak Basaltic Andesite, upper tongue (upper Oligocene)—In SE Lemitar Mountains, this unit is formed by a thick pile of thin autobrecciated basaltic andesite lava flows. Here it represents as many as 35 individual flows averaging about 3–6 m thick, with a total composite thickness of about 179 m. Individual flows consist of medium gray to grayish red purple, massive to vesicular basaltic andesite lava; they are characterized by moderately abundant (5–10%) fine grained phenocrysts of olivene, which are almost always completely altered to reddish brown iddingsite. Phenocrystic plagioclase is usually absent or very rare. Upper flows in SE Lemitar Mountains are about 10 m thick and locally associated with bedded cinder deposits 2–5 m thick. Calcite commonly fills vesicles and fractures. The La Jara Peak Basaltic Andesite represents a widespread thick pile of alkaline basaltic lavas (mostly trachybasalt to basaltic trachyandesite) that accumulated on the SE margin of the Colorado Plateau (Riley area) in upper Oligocene time. The pile is locally divisable into tongues where thin ash-flow sheets are intercalated with the basaltic pile. Wedge-shaped prisms of basaltic lavas in Lemitar Mountains indicate they were erupted contemporaneously with early extension and domino-style block rotation in the Lemitar Mountains (Chamberlin, 1980, and 1983; Cather, et al, 1994). Minor exposures near Socorro Canyon, about 60 m thick, represent faulted remnants of regional flows that locally crossed into the moat area of the Socorro caldera after it was mostly filled in by the Luis Lopez formation. Older than South Canyon Tuff and younger than Lemitar Tuff. As much as 179 m thick in SE Lemitar Mountains, absent on Socorro Peak.

Tlu
Tll

Lemitar Tuff; upper and lower members (Oligocene)—Compositionally zoned (77 –65 wt% SiO_2), ignimbrite subdivided into a partially to densely welded, light gray, phenocryst-poor (5-15%), rhyolite lower member (T11), and densely welded, dark red, phenocryst-rich (30–45%), rhyodacite to rhyolite upper member (Tlu). Contains sparse to abundant, medium-grained (1-4 mm) phenocrysts of quartz, sanidine, plagioclase, and biotite with traces of augite and sphene. Lower third of upper member is relatively quartz poor (<5%) compared to upper two thirds, which is quartz rich (10–15%). Small (1–3 cm) phenocryst-poor pumice is moderately abundant (3–5%) in lower member. Sparse, phenocryst-rich pumice and small (<2 cm) grayish red "magma blobs" of dacite porphyry are typical in outflow of the upper member. Distribution and thickness trends suggest that the Lemitar Tuff was erupted from a small resurgent caldera in the west central Magdalena Mountains (G. R. Osburn oral commun. 1997; see McIntosh and others, 1991, fig. 29). Lemitar ignimbrite locally appears to pinchout against eastern wall of the older Sawmill Canyon caldera in the Bear Canyon area. Mean $^{40}Ar/^{39}Ar$ age is 28 ± 0.08 Ma; paleomagnetic polarity is normal (McIntosh and others, 1991). Correlation here based on distinctive lithology and stratigraphic position. Narrow horst of upper Lemitar Tuff north of Socorro Canyon is cut by numerous jasperoid veinlets. As much as 60 m thick near Socorro Canyon, absent on Socorro Peak.

POST COLLAPSE FILL OF SAWMILL CANYON CALDERA

Txs Sawmill Canyon Formation, upper sandstone member (Oligocene)—Volcaniclastic sedimentary deposits mostly derived from the eastern wall of the Sawmill Canyon caldera (Osburn and Chapin, 1983); locally exposed southeast of the Bear Canyon. Fining upward sequence is divided into lower breccia and conglomerate member about 40–50 m thick and an upper sandstone member (Txs) 20–25 m thick. Lower member is exposed just south of Socorro quadrangle (Chamberlin and Eggleston, 1996). Upper member consists of pale red to grayish red, well sorted, fine-grained rhyolitic sandstone with minor conglomeratic beds near the base. Upper sandstone may be partly eolian. Thickness 0–25 m.

Tlp2 La Jara Peak asaltic Andesite, medial tongue in Lemitar Mountains (upper Oligocene)—Iddingsite bearing basaltic andesite lavas very similar to Tlp3 in SE Lemitar Mountains, but stratigraphically older. As many as 40 individual flows with aggregate thickness of about 129 m. Includes 1–2 m thick red conglomeratic sandstone at base. Occurs between Lemitar Tuff and Vicks Peak tuff; top approximately located by projection where overlying Lemitar Tuff locally pinches out. As much as 129 m thick in SE Lemitar Mtns., absent on Socorro Peak.

Tvp Vicks Peak Tuff (Oligocene)—Light gray to pale red, phenocryst poor, densely welded rhyolite ignimbrite. Distinctive aspects include lithophysal zone near base and large pumice lapilli as much as 30 cm long near the top. Contains 1–5 percent phenocrysts of sanidine and sparse quartz. Thin outflow sheet here was erupted from the Nogal Canyon caldera in the southern San Mateo Mountains (Deal and Rhodes, 1976). Mean $^{40}Ar/^{39}Ar$ age is 28.56 ± 0.06 Ma; paleomagnetic polarity is reverse (McIntosh and others, 1991). Correlation here based on lithology and relative stratigraphic position. As much as 51 m thick in SE Lemitar Mountain, absent on Socorro Peak.

Tj La Jencia Tuff (Oligocene)—Light gray, pale red and grayish red, phenocryst poor, rhyolite ignimbrite, characterized by a thick medial zone of very densely welded rheomorphic (flow banded) ignimbrite. Flow-banded core grades to normal eutaxitic ignimbrite near base and top. Contains sparse (3–5%) phenocrysts of sanidine and quartz with traces of plagioclase and biotite. Erupted from the composite Sawmill Canyon-Magdalena caldera in the north central and western Magdalena Mountains (Osburn and Chapin, 1983). Mean $^{40}Ar/^{39}Ar$ age is 28.85 ± 0.04 Ma; paleomagnetic polarity is reverse (McIntosh and others, 1991). Correlation here based on distinctive lithology and relative stratigraphic position. As much as 120 m thick in SE Lemitar Mountains, absent on Socorro Peak.

POST COLLAPSE FILL OF SOCORRO CALDERA

Tz Luis Lopez Formation (Oligocene)—Heterogeneous fill of the Socorro caldera consisting of caldera-wall derived sedimentary rocks, pumiceous lithic-rich ignimbrites, mafic to intermediate lavas, and rhyolitic lavas and tuffs. $^{40}Ar/^{39}Ar$ ages of volcanic units near the bottom and top of the formation, respectively 30.1 ± 0.07 Ma and 28.61 ± 0.17 Ma, indicate that they are premonitory events related to a developing thermomagmatic pulse which culminated in eruption of the La Jencia Tuff from the Sawmill Canyon caldera. Overall distribution and thickness, of the Luis Lopez Fm indicate that it filled a preexisting depression created by eruption of the Hells Mesa Tuff at 32.0 Ma. Local unconformities in the Luis Lopez Formation imply that the Red Canyon horst in the central Chupadera Mountains was uplifted by magma pressure during eruption of the Luis Lopez formation (Chamberlin and

Eggleston, 1996). The general correlation of the three major members within the Luis Lopez Formation, from south to north, is primarily based on lithologic similarity and relative stratigraphic position. Luis Lopez Formation typically lies in moderate angular unconformity (5–12°) on caldera facies Hells Mesa Tuff in the central and southern Chupadera Mountains. Facies relationships of early sedimentary fill in southern Chupadera Mountains imply moderate uplift of a resurgent core shortly after the main caldera forming eruption (Chamberlin and Eggleston, 1996). The Luis Lopez Fm. in northern Chupadera Mountains is about 700 m thick. The east face of Socorro Peak represents a structurally high bench between the northern topographic rim of the Socorro caldera, now buried, and the ring fracture zone located 1–2 km N of Blue Canyon. Here the formation is only 180 m thick.

MEMBERS OF LUIS LOPEZ FORMATION IN NORTHERN CHUPADERA MOUNTAINS AND SOCORRO PEAK AREA:

Tza4 Uppermost andesite member of Luis Lopez Formation (upper Oligocene)—Medium purplish gray to dark gray andesite porphyry; contains 10–15% fine to medium grained phenocrysts of chalky plagioclase and minor altered pyroxene Occurs as erosional remnant of lava flow overlying large ring-fracture lava dome (Tzc) just north of Blue Canyon. Minor unit, assignment to Luis Lopez Fm is arbitrary. Thickness 0–9 m.

Tzc/Tzct Upper rhyolite member of Luis Lopez Fm. and associated tuffs (t); rhyolite of Cook Spring. (upper Oligocene)—Consists of flow banded rhyolite lava domes and cogenetic bedded tuffs emplaced as fall and flow deposits. Lavas and tuffs on the east face of Socorro Peak are phenocryst-poor to moderately phenocryst rich. They contain 5–25%, medium-grained pearly sanidine, altered plagioclase, quartz and traces of biotite; the latter is commonly altered to hematite. These Oligocene lavas and tuffs are potassium metasomatized; plagioclase is commonly replaced by adularia. Phenocrystic quartz is mostly euhedral, only a small fraction shows rounding and resorption. The lithoidal flow banded lavas are usually pale red to light red and occasionally moderate reddish orange to light gray. The large lava dome 2 km SE of Socorro Peak is interpreted as a ring-fracture lava dome on the northeast periphery of the Socorro caldera. Maximum thickness of this domal flow is about 180 m. A cognetic bedded tuff (Tzct), well exposed to the north of this dome, is about 90 m thick. The lapilli-rich tuff contains two thin ash flows, a lithic rich ignimbrite at the base and a 5 m thick densely welded pumiceous tuff about 15 m below the top. Thin densely welded and flow-banded tuffs in the same stratigraphic position are also present in down faulted blocks on the northeast and southeast flank of the large lava dome. These thin rheomorphic tuffs look quite similar to the flow-banded cone of the La Jencia Tuff. Outcrop distribution patterns on the east flank of Socorro Peak indicate 3 or 4 separate eruptive centers for Tzc lavas and tuffs. The small remnant of rhyolite lava 1 km SE of Socorro Peak is clearly feed by a NW striking ring-fracture-like dike that cuts up through the bedded tuff unit. The pale red rhyolite lavas on Socorro Peak generally define the eroded top of the Luis Lopez Fm; they are mostly overlain by lower Popotosa Fm and overlie andesite porphyry (Tza3) of the middle Luis Lopez Formation.

Flow banded rhyolite lavas and tuffs that occur in an equivalent stratigraphic position in the northeastern Chupadera Mountains are relatively phenocryst poor. Light gray lavas and tuffs exposed in road cuts along Highway 60 contain 2–4% fine to medium-grained phenocrysts of plagioclase, sanidine, quartz and minor to rare biotite. Biotite from a thin welded tuff here has yielded a relatively imprecise K-Ar age of 29.4 ± 1.1 Ma (Osburn and Chapin, 1983). Thickness range 0–180 m.

Tzap
Tza3

Upper andesitic member (Oligocene) — Locally divided into a coarsely porphyritic upper flow unit (Tzap) and a lower medium-grained porphyritic flow unit (Tza3). Upper flow unit consists of medium gray to reddish brown andesitic to dacitic lava with abundant (5–20%) phenocrysts of altered plagioclase, pyroxene and minor fresh biotite. Large subhedral to rounded plagioclase phenocrysts (5–15 mm long) are commonly replaced by pink adularia and less commonly by white clay. Northeast striking, coarsely porphyritic dikes and a circular plug near Socorro Canyon represent probable sources for the upper flow unit. Upper flow unit is 0–30 m thick. Lower flow unit (Tza3) consists of dark purplish gray, gray, and reddish brown, medium grained (1–3 mm) andesite porphyry lavas, flow breccias and finely vesicular, near vent, cinder deposits. Massive to platy and locally vesicular lavas contain moderately abundant (5–20%) phenocrysts of altered plagioclase and pyroxene. East margin of a Tza3 vent is locally well exposed in the southwest wall of lower Bear Canyon. Near vertical platy flow structure of another T2a3 vent is also locally exposed in lower Blue Canyon; coeval andesite agglomerates (not mapped separately) are exposed at the NE mouth of Blue Canyon.

Tzt2
Tza2
Tzt1

Middle tuff and lava member (Oligocene) — Subdivided into an upper pumiceous tuff unit (Tzt2), a *locally* intercalated andesite flow unit (Tza2) and a lower pumiceous tuff unit (Tzt1). Upper tuff unit (Tzt2) consists of light brownish gray, poorly welded, pumiceous, lithic-rich rhyolitic ignimbrite. Contains sparse to abundant (5–50%) pebble to cobble size, rounded to angular, lithic fragments of densely welded Hells Mesa Tuff and andesite porphyry. Sparse crystals of sanidine, quartz and biotite in matrix are probably xenocrysts. Approximately 66 m thick on east face of Socorro Peak, may be as much as 300 m thick in northern Chupadera Mountains.

Andesite flow unit (Tza2) is a purplish gray to dark gray, moderately porphyritic to aphanitic, andesite lava flow. Contains sparse, small phenocrysts of plagioclase and pyroxene replaced by metasomatic adularia and Fe oxides, respectively. Platy jointed vent structure, coeval dikes and agglomerates are locally well exposed in walls of upper Socorro Canyon. Associated feeder dikes strike ENE. Maximum thickness at Socorro Canyon is 60 m. This unit is absent at Socorro Peak where Tzt2 rests directly on Tzt1.

Lower tuff unit (Tzt1) consists of light gray, poorly welded, pumiceous, lithic rich, rhyolitic ignimbrite. Andesite porphyry clasts are locally abundant and Hells Mesa Tuff clasts are typically rare to absent. Rare crystals of sanidine and quartz in matrix are probably primary phenocrysts. Sanidine from lower Tzt1 at Black Canyon (2 km south of quadrangle boundary) has yielded a precise $^{40}Ar/^{39}Ar$ age of 30.1 ± 0.07 Ma. Medial tuffs (Tzt2 and Tzt1,) were probably erupted from a now buried vent area within the Sawmill Canyon caldera (Chamberlin and Eggleston, 1996). Tzt1 and Tzt2 are here tentatively correlated with a regional ignimbrite that is generally assigned to the South Crosby Peak Formation (Osburn and Chapin, 1983; Osburn and others, 1993). The basal 30 m of the La Jencia Tuff, as previously mapped in the southeastern Lemitar Mountains (Chamberlin, 1980), is now recognized to be correlative with the lower pumiceous lithic rich tuff (Tzt1) member of the Luis Lopez Formation.

Tzt Lithic –rich tuffs undifferentiated; includes Tzt1 and Tzt2 in small fault blocks on East face of Socorro Peak.

Tzx Basal landslide megabreccia and tuffaceous sandstones member of Luis Lopez Formation (lower Oligocene)—Dark purplish gray to bluish gray heterolithic boulder conglomerate and breccia. Locally exposed on complexly faulted inner topographic wall at north margin of Socorro caldera. This inner topographic wall is defined by Pennsylvanian Madera Limestone disconformably overlain by the landslide mega breccia unit (about 2 km ESE of Socorro Peak). The megabreccia unit contains one large (15 m thick) block of silicified and sheared Madera Limestone. The bouldery conglomerate and breccia surrounding this block contains abundant clasts of micritic limestone, silicified limestone, andesite porphyry and clasts of densely welded pumiceous rhyodacitic tuff (tuff of Granite Mountain). The latter is a quartz-poor, crystal-rich, regional ash-flow unit, which underlies the Hells Mesa Tuff in the Lemitar Mountains. The clasts of tuff of Granite Mountain distinguish this caldera wall breccia from older Spears Formation conglomerates which locally overlie the Madera Limestone in the Lemitar Mountains. The tuff of Granite Mountain clasts demonstrate recycling of pre-caldera (pre-Hells Mesa) rocks at the caldera wall. Light gray to purplish gray andesitic sandstones, as much as 10 m thick, locally occur at the top of the landslide deposits where they are conformably overlain by pumiceous lithic-rich tuff (Tzt1). Maximum exposed thickness of landslide breccia unit is 90 m; unit wedges out abruptly to north where Tzt1 rests directly on Madera Limestone.

ROCKS ASSOCIATED WITH COLLAPSE OF SOCORRO CALDERA

Thm Hells Mesa Tuff (lower Oligocene)—Reddish brown to purplish gray, densely welded, phenocryst-rich (40–50%), quartz-rich, rhyolite ignimbrite. Typically contains abundant medium grained (1–3 mm) phenocrysts of sanidine, plagioclase, quartz and minor biotite. Plagioclase is altered to chalky clay minerals and adularia in association with widespread potassium metasomatism. The 90 m thick exposure in the southeastern Chupadera Mountains represents a relatively thin outflow sheet on the northern margin of the Socorro caldera, which was the source of the Hells Mesa Tuff.

Control points locating the north margin of the large caldera are present at Socorro Peak and at North Baldy, about 15 km to the west in the northern Magdalena Mountains. The southern margin of the caldera is exposed in fault blocks of the southern Chupadera Mountains (Chamberlin and Eggleston, 1996). Intracaldera Hells Mesa Tuff, as much as 2.7 km thick, is inferred to underlie the southwestern half of the Socorro quadrangle between Socorro Peak and the northern Chupadera Mountains (Chamberlin and Eggleston, 1996). Notably the Hells Mesa Tuff is absent on the eroded inner rim of the caldera, where exposed east of Socorro Peak. mean $^{40}Ar/^{39}Ar$ age is 32.06 ± 0.1 Ma; paleomagnetic polarity is reverse. Correlation is based on distinctive lithology and relative stratigraphic position. Thickness range 0–2740 m.

PRE CALDERA ROCKS

ℙm Madera Limestone (Middle Pennsylvanian)—Mostly light to medium gray ledge and cliff forming micritic limestones interbedded with dark gray limy shales and minor sandy limestones. Nodular black chert is common in the micritic limestones. Cliff-forming limestones are medium to thick bedded and moderately fossiliferous (fusulinids, brochiopods, crinoids and corals). Uppermost 30–60 m of limestone, just north of the caldera ring fracture zone is intensely silicified.Yellow brown limonite stains are common on fractures in the flinty silicified limestones. Total exposed thickness on east face of Socorro Peak is 179.4 m (598 ft; Siemers, 1978).

ℙs Sandia Formation (middle Pennsylvanian)—Dark gray to black, slope-forming carbonaceous shales with minor fossiliferous biomicrites and fine grained quartz ~~oriented~~ arenites are dominate in the upper 63 m. Lower 91 m consists of ledge-and cliff-forming quartz arenites that are dark reddish brown to light gray, fine to coarse grained, massive to cross bedded, feldspathic to miaceous, and mostly medium to thick planar bedded. Arenites contain several 1–2 m thick interbeds of gray siltstone and limy mudstone. Coarse-grained basal arenites disconformably overlie early Protorozoic meta- sedimentary rocks in small window 2 km east of Socorro Peak. Upper contact with Madera Limestone is gradational and generally placed at break in slope to ledge and cliff-forming limestones. Total thickness on east face of Socorro Peak is 154 m (Siemers, 1978).

Xms Meta sedimentary rocks (early Proterozoic)—Dark green argillite and minor narrow bands of fine grained quartzite. The argillite is intensely jointed; north-striking joints are preferentially silicified. Quartzite bands dip about 60 degrees to south. A small dike-like body of fine grained mafic monzonite or granodiorite cuts the argillite about 30 from the west edge of the small pentagonal outcrop. Smith, 1963 reports that Woods Tunnel, a west-trending drift about 45 m below the argillite outcrop, cuts only dark greenish gray equigranular granodiorite. The small dike-like body at the surface maybe an aphopysis of this intrusion. Meta sedimentary basement rocks of similar character in the southern Chupadera Mountains yielded a U-Pb age from zircon of 1659 ± 3 Ma (Bowring and others, 1983). Based on similar lithology and stratigraphic position, metaargillites at Socorro Peak are considered to be of early Proterozoic age.

INTRUSIVE ROCKS

Tir Moderately phenocryst-rich rhyolite neck and dike (upper Miocene) Reddish orange flow banded ryolite porphyry. Steeply foliated neck and narrow dike apophysis cuts Oligocene rhyolite (Tzc) on NE flank of 6001 Mesa. Contains moderately abundant medium-grained phenocrysts of sanidine plagioclase, quartz and biotite. Plagioclase is replaced by chalky clays. Cross cutting relationships and compositional similarities to the nearby upper Miocene lava domes (Tsr1) suggest that this shallow intrusion is cogenetic with the Signal Flag Hill eruptive center of the Socorro Peak Rhyolite.

Tid Hornblende-plagioclase dacite necks and dikes (upper Miocene)—Mostly hydrothermally altered, pale purplish gray, moderately phenocryst-rich, hornblende plagioclase dacite. Forms sharp pointed necks and radial dikes SE of Socorro Peak, where they intrude lower Popotosa fanglomerates (Tpfg and Tpfr). These necks and dikes occur in an intensely altered north-trending fault zone that transects the lower east flank of Socorro Peak. Hornblende prisms in the necks are commonly replaced by pseudomorphs of polycrystalline quartz; plagioclase is commonly replaced by adularia. A small neck-like body of hornblende dacite near Nogal Canyon probably intrudes Popotosa claystones, but contract relationships are obscured by landslides and colluvium. A wide northwest-trending dike-like body of moderately porphyritic hornblende dacite clearly cuts Popotosa claystones (Tpp) in the area west of the Grefco Perlite mine. Correlation of these shallow intrusions with the lower dacite member of the Socorro Peak Rhyolite is based on cross cutting relationships with the Popotosa Formation and textural similarity to dacitic lavas and tuffs that are interbedded with the Popotosa Formation.

Tirz Flow banded rhyolite dikes and sills, in pre-Popotosa rocks (upper Oligocene)—Light pinkish gray to white flow-banded rhyolite dikes and sills with sparse to moderately abundant phenocrysts of quartz, pearly sanidine, chalky plagioclase and rare biotite; the latter is usually replaced by hematite clay. One northwest-trending ring fracture like dike exposed about 1 km SE of Socorro Peak, clearly shows a feeder relationship to the overlying lava flow (Tzc). Similar northwest and north trending rhyolite dikes locally cut lower tuffs of the Luis Lopez Formation on the east face of Socorro Peak. A white flow-banded rhyolite "sill" with sparse quartz and sanidine cuts at a low angle across the lower Madera Formation and upper Sandia Formation. This sill-like body may have been emplaced in minor thrust fault. The sill-like body is repeated by north-trending rift faults of Miocene to Pliocene age. These rhyolite dikes and sills are generally correlated with the upper rhyolite member of the Luis Lopez Formation (Tzc) on the basis of cross cutting relationships, restrictions to pre-Popotosa host rocks and compositional similarity with the rhyolite of Cook Spring.

Tiapz Coarsely porphyritic dikes and plug of andesite to dacitic composition (upper Oligocene)—Medium gray to reddish brown coarsely porphyritic dikes and a circular plug, dikes are locally well exposed in road cuts along Highway 60 in upper Socorro Canyon. These hydrothermally altered or potassium metasomatized dacitic (?) dikes contain moderately abundant (5-15 percent) coarse grained phenocrysts of plagioclase (5–15 mm long) replaced by chalky clays and pinkish adularia, with sparse prisms of pyroxene (?) altered to hematite and minor fresh black biotite. This mineral assemblage is typical of potassium metasomatized rocks. Northeast trending dikes and plug appear to cut older andesite lavas (Tza3) and underlying lithic-rich tuff (Tzt2). Correlation with coarsely porphyritic dacite lava in upper Luis Lopez Formation is based on textural/compositional similarity and similar stratigraphic relationships. The porphyritic plug and flow are both unconformably buried by the lower Popotosa Formation (Tpfr).

Tiaz Sparsely to moderately porphyritic andesite dikes (upper Oligocene)—Pink gray to purplish gray adesitic dikes containing sparse to moderately abundant (3–10%) medium grained phenocrysts of plagioclase altered to white clays and pyroxene altered to humatite. Northeast trending dikes, well exposed in upper Socorro Canyon were probably feeders for texturally similar andesite lavas (Tza3 and Tza2). Dikes cut lithic rich tuffs of the middle Luis Lopez Formation (Tzt2) and are unconformably buried by lower Popotosa Formation (Tpfr).

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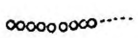
Explanation of Map Symbols: Socorro 7.5′ Quadrangle

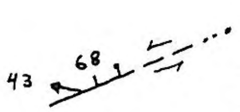
depositional contact, long dashed where approximately located, short dashed where inferred, queried where hypothetical. Direction and angle of dip shown where observed. Note, all alluvial and colluvial contacts are approximately located; they are generally shown as continuous lines to aid map legibility.

unconformity at topographic wall of Oligocene caldera (longer side of hachure toward center of caldera). Dashed where projected under alluvium.

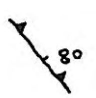


approximate location of facies boundary (piedmont to axial river) in middle Pliocene to Pleistocene basin-fill deposits; dotted where projected under younger deposits. Placed at *western* limit of older quartzite bearing Tslf; of well-sorted axial river sands in the upper Sierra Ladrones Formation (QTslf); and *western* limit of axial river sands in post Santa Fe Group deposits (Qvof).

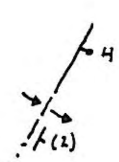
alteration boundary that cuts across bedding. Locally separates well indurated (jasperoidal silica cemented) and potassium metasomatized Popotosa fanglomerate facies (Tpfr) from less indurated, non-metasomatized Popotosa fanglomerate facies (Tpfg).



fault trace, dashed where approximately located, dotted where projected under younger deposit. Ball and bar on downthrown side. Short dash indicates direction and angle of dip. Arrow indicates bearing and plunge of striations or mullions on fault surface. Half arrows indicate apparent lateral component of slip where inferred from combination of stratigraphic offset and orientation of striations on fault surface.

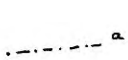


trace of *pseudo* reverse fault showing direction and angle of dip. Barbs on upthrown block. Interpreted as early antithetic *normal* fault (downthrown to east) rotated to present orientation of reverse fault by dominant down-to-west rotational normal faults.

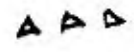


trace of Quaternary normal fault. Ball and bar on downthrown side; number indicates estimated surface displacement, at this location, in meters. Arrows indicate local downwarping along fault trend. Dip symbol in parenthesis indicates estimated local inclination of deformed land surface (sum of tilt and primary dip).

slump fault bounding rotated landslide block, generally delineates margin of landslide terrane.



local marker bed (or horizon) in Santa Fe Group. Includes rhyolitic water-laid ash beds (a), and buried calcic soil horizons (bc). Lenticular beds of rhyolitic pumice and scattered pumice fragments (r) are also indicated in some localities.



ancient colluvial breccia at base of lower Popotosa Formation.

c — good exposure of pedogenic carbonate horizon or calcrete.

x — representative exposure of late Cenozoic basin fill unit; indicates location of well sorted axial river sand or gravel where shown in QTsf.

55 — strike and dip of bedding or compaction foliation in welded tuffs.

⊕ — horizontal bedding.

75 — strike and dip of flow foliation in lava flow.

vertical flow foliation.

j — jasperoid vein or veinlets showing strike and dip.

syncline, showing approximate trend of trough line.

anticline, showing approximate trend of crest line.

orientation of flow lineation (elongated pumice) in rheomorphic La Jencia Tuff (Tj), or upper Luis Lopez Formation tuffs (Tzct).

general direction of paleocurrents (± 30°) based on pebble imbrication, or axis of trough cross bed (a), or cross bedding (b)

excavation in late Cenozoic basin fill deposits.

Municipal water supply well.

* — inferred approximate location of volcanic vent, queried where more speculative

||||| Qlc — Las Cañas geomorphic surface of McGrath and Hawley, 1987.

■ 2 — sample location for isotopic age analysis (numbers referred to in Table 1).

TABLE 1. $^{40}Ar/^{39}Ar$ ages of Miocene to Pliocene volcanic units in the Socorro 7.5' qudrangle. New Ar-Ar ages supercede most K-Ar ages reported by Osburn and Chapin, 1983. Includes one K-Ar date for the upper rhyolite member of the Oligocene Luis Lopez Formation; gm=ground mass.

Map No.	Map Symbol	Material dated	K/Ca	Age	± 2σ	Ref.	Comments
1	Tbsc	gm	0.1	3.61	0.18	1	
2	Tbsc	gm	0.1	3.71	0.09	1	near vent
3	Tbsc	gm	0.2	3.77	0.37	1	above # 1
4	Tbsc	gm	0.1	3.83	0.11	1	distal flow
5	Tbsc	gm	0.1	4.02	0.63	1	glassy vesicle walls
6	Tsr4	sanidine	53.70	7.02	0.05	2	
7	Tsr4	sanidine	39.70	7.06	0.03	2	
8	Tsr3	sanidine	86.2	7.52	0.09	2	
9	Tsr2	sanidine	—	7.85	0.04	3	
10	Tsr1	sanidine	29.0	8.66	0.05	2	
11	Tbb	gm	0.2	8.68	0.11	1	
12	Tsrd	biotite	—	9.51	0.06	2	
13	Tsrd (slump)	biotite*	—	10.76	0.14	2	
14	Tsd	biotite*	—	11.56	0.09	2	
15	Tbk	gm	0.6	8.77	0.23	1	hydrothermally altered
16	Tbk	gm	0.5	9.66	0.13	1	
17	Tbk	gm	0.6	9.79	0.05	1	
18	Tbk	gm	0.5	9.87	0.16	1	duplicate of #15
19	Tzc	biotite	—	29.4	1.1	4	

Ref: 1) W. C. McIntosh and R. M. Chamberlin unpub. data
2) H. N. Newell, 1997
3) Chamberlin and Barker, 1996
4) Osburn and Chapin, 1983

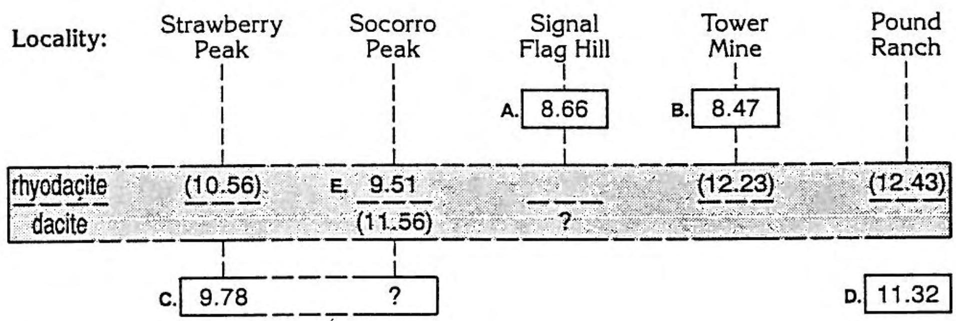
*Note: biotite ages tend to be 5–20% older than sanidine ages from the same rock (Newell, 1997; see Fig. 1)

TABLE 2. Apparent eruption ages (arithmetic means) of Oligocene to Pliocene volcanic units in the Socorro 7.5′ quadrangle. All dates are high precision $^{40}Ar/^{39}Ar$ analyses, except where indicated as K/Ar.

Age	± 2σ	No. Analyses	Map Symbol	Reference
3.73	0.1	4	Tbsc	1
7.04	0.04	2	Tsr4	2
7.48	0.08	2	Tsr3	2
7.85	0.04	1	Tsr2	3
8.47	0.2	3	Tbb	1
8.66	0.05	1	Tsr1	2
9.51	0.06	1	Tsrd	2
~9.6		—	Tsd	see fig. 1
9.77±	0.06	3	Tbk	1
27.37	0.07	3	Tsc	4
28.00	0.08	2	Tlu/Tll	4
28.56	0.06	4	Tvp	4
28.85	0.04	6	Tj	4
28.61	0.17	1	(Tzbr, Tzc equivalent)	5
29.4	1.17 (K/Ar)	1	Tzct	6
30.10	0.07	1	Tzt	5
32.06	0.10	9	Thm	4

Reference

1. W. C. McIntosh and R. M. Chamberlin, unpublished data
2. H. H. Newell, 1997
3. Chamberlin and Barker, 1996
4. McIntosh et al, 1991
5. Chamberlin and Eggleston, 1996
6. Osburn and Chapin, 1983



Constraining stratigraphic units:

A. rhyolite of Signal Flag Hill—8.66 ± 0.10 Ma (sanidine)
B. basalt flow at Bear Canyon—8.47 ± 0.20 Ma (groundmass)
C. basalt of Kelly Ranch—9.78 ± 0.10 Ma (groundmass)
D. rhyolite of Pound Ranch (lower flow)—11.32 ± 0.14 Ma (sanidine)

Age in agreement with stratigraphic constraints:

E. rhyodacite of Radar Peak—9.51 ± 0.12 Ma (biotite)

Fig. 1 Local stratigraphic and $^{40}Ar/^{39}Ar$ age constraints (in Ma) on rhyodacite/dacite lavas in the Socorro Peak–Pound Ranch area. Ages from biotite, which are commonly 5–20 percent too old (relative to sanidine and groundmass ages), shown in parenthesis. Query shown where unit locally not dated. Diagram assumes roughly contemporaneous eruption of dacite/rhyodacite lavas from multiple source vents.

Correlation of Map Units: Socorro 7.5' Quadrangle