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

By

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New Mexico Bureau of Geology and Mineral Resources

Open-file Digital Geologic Map OF-GM 053

Scale 1:24,000

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GEOLOGY OF THE LUIS LOPEZ 7.5' QUADRANGLE, SOCORRO COUNTY, NEW MEXICO

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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 NMBGMR 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 this report and map should not be considered final and complete until it is published by the NMBGMR.*

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 Data depicted on this geologic map are based on field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation.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-

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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.

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

SUMMARY

The Luis Lopez quadrangle lies within the central Rio Grande rift, where WSW-directed lithospheric extension over the last 29 million years has broken an Oligocene ignimbrite caldera cluster into a north-trending array of "domino-style" tilted fault-block ranges and alluvial basins (Chapin and Cather, 1994; Chamberlin, 1983; Chamberlin et.al. in press). A regional ENE-trending tilt-block domain boundary, the Socorro accomodation zone (SAZ of Chapin, 1989) is here reinterpreted to cross the northern segment of the Chupadera Mountains, where it is expressed by a line of scissors faults and transverse folds (Fig.1). Major topographic elements of the quadrangle include the narrow north-trending Chupadera Mountains and the adjacent piedmont slopes of the Broken Tank and Socorro basins. The latter is represented by a dissected and faulted bajada-slope that descends to the floodplain of the Rio Grande at the east margin of the quadrangle.

The strongly east-tilted Chupadera Mountains block provides a cross-section like view of the southeastern sector of the 24-km diameter Socorro caldera, source of the 1200 km^3 31.9-Ma Hells Mesa Tuff. As much as 2 km of xenolith-rich, phenocryst-rich, rhyolite ignimbrite in the lower caldera-facies Hells Mesa Tuff defines the collapsed core of the caldera at Red Canyon. Moderate volume (~50km^3) upper caldera-facies Hells Mesa Tuff was formed by many small pulsed ash-flow deposits that contain comagmatic lag breccias with abundant clasts of phenocryst-rich spherulitic rhyolite (representing Hells Mesa magma, rapidly chilled along shallow vent walls and then explosively erupted). Many thin ash-fall beds in the upper Hells Mesa Tuff mark periods of repose as the Hells Mesa magma chamber became depleted in exsolved gases that drove the waning-stage eruptions (Chamberlin 2001a). Post-collapse volcanism was anomalously brief. Only one small (~0.3 km^3) 31.9-Ma ring-fracture lava dome, associated with incipient resurgent uplift, is present in the southeast sector of the caldera, near the Esperanza mine.

Sedimentary and volcanic units that back filled the Socorro caldera, prior to the next major ignimbrite eruption (28.7-Ma La Jencia Tuff), are collectively assigned to the Luis Lopez Formation. Basal Luis Lopez volcaniclastic sediments filled the shallow moat during an extended lull in

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volcanism (31.9 to ~ 30.5 Ma). Relatively primitive trachybasalt lavas (9.3% MgO, 170 ppm Ni) ponded in the southeastern moat shortly after renewed magmatic uplift of the caldera core at about 30.5 Ma. Basaltic eruptions signaled replenishment or initiation of a new crustal magmatic system under the now crystallized Hells Mesa magma body. Minor eruption of a more evolved basaltic andesite lava occurred in the northeast moat, just prior to eruption of a series of moderate volume (>10km^3) pumiceous, phenocryst-poor, rhyolite ignimbrites from a small collapse structure (Black Canyon vent area) nested in the northern moat, at 30.0 Ma. Mafic-rhyolite lava (69 % SiO$_2$, 70 ppm Cr), which formed by mixing the earlier basaltic andesite magma with the pumiceous rhyolite magma, was then erupted on the flanks of a central horst block during a brief lull in the pumiceous tuff eruptions. Following a second period of minor erosion and sedimentation, medium porphyritic and coarsely porphyritic intermediate lavas were erupted from NE-striking fissure vents in the northeast moat. Several high-silica rhyolite lava domes were then erupted from reopened ring-fractures of the Socorro caldera between 28.8-28.7 Ma, just prior to massive eruptions of the 28.7-Ma La Jencia Tuff (1250 km^3) from the adjacent Sawmill Canyon caldera, which obliterated most of the western half of the Socorro caldera.

The eastern topographic wall of the Sawmill Canyon caldera is partially exhumed near the Tower mine. Ancient colluvial breccias, conglomerates and sandstones of the Sawmill Canyon Formation, derived from Luis Lopez volcanics, are overlapped by 27.9-Ma Lemitar Tuff at the caldera wall. Distal lavas of the La Jara Peak Basaltic Andesite and the South Canyon Tuff outflow sheet were the last regional Oligocene volcanic units to flow across the mostly buried moat of the Socorro caldera at 27.3 Ma.

Moderately tilted volcanic-rich conglomerates and playa claystones of the Miocene Popotosa Formation are preserved in tilt-block depressions within and adjacent to the Chupadera range. An intercalated dacite flow and two trachybasalt flows of late Miocene age (~ 11, 9.7 & 8.4 Ma, respectively) help define several local unconformities associated with fault-block highlands in the early rift basins. The 8.4-Ma basalt of Broken Tank flowed westward across the mostly covered Chupadera block on inset piedmont gravels of the Popotosa Formation near Walnut Creek and then it flowed northward down the axis of the Broken Tank basin onto playa muds near Bear Canyon. The topographically highest point in the Chupadera Mountains (1984 m, 6510 ft above msl.) is formed by caldera-facies Hells Mesa Tuff immediately adjacent to an 8.4 Ma paleovalley wall locally preserved by the basalt of Broken Tank.

Episodes of hydrothermal alteration and mineralization were locally associated with shallow silicic magmatism and volcanism of Oligocene age (31.9, 30.0 and 28.7 Ma) and late Miocene age. Late Miocene potassium metasomatism at ~ 7.4 Ma (Dunbar and Miggins, 1996), and slightly younger manganese mineralization (6.6 Ma; Lueth et. al., in press) in the northern Chupadera Mountains appear to be temporally and spatially linked to five pulses of silcic to intermediate magmatism and volcanism (at 9.5, 8.7, 7.9, 7.4, 7.0, and 6.9 Ma) in the Socorro Peak area, about 6 km north of the quadrangle. Popotosa playa mudstones presumably formed a thick impermeable cap on the late Miocene hydrothermal system, allowing the upwelling hot waters to migrate laterally

from their source.

Pliocene and Pleistocene sedimentary deposits of the Sierra Ladrones Formation record the transition from early-rift closed basins to late-rift, valley-fill deposits of the ancestral Rio Grande and its tributary drainages. Important aquifers within the quadrangle include a newly recognized fluvial-fan deposit (Tsft) of early Pliocene age apparently emanating from the eastern Magdalena Mountains, and well- known sands and gravels of the ancestral Rio Grande (axial facies of Sierra Ladrones Formation, QTsf). Aquifer units, possibly as much as 300 m thick, are locally preserved on subsiding, high-angle fault blocks near the eastern margin of the quadrangle. Moderately deep wells that tap the ancestral Rio Grande aquifer west of I-25 provide over 27 million gallons of potable water to the San Antonio water system each year (Ramsey, 1994). The solid-waste landfill for the city of Socorro, a potential source of groundwater pollution, is located in the unsaturated zone of this primary aquifer (QTsf) about 1 km northwest of Luis Lopez and about 30m above the water table.

The north-trending Socorro Canyon fault, an active fault zone of the Rio Grande rift, displaces middle to late Pleistocene piedmont-slope deposits west of I-25, about 2 km west of Luis Lopez (Chamberlin and Harrison, 1996). Recent isotopic-dating studies of this active fault at Socorro Canyon (Ayarbe, 2000) indicate the most recent major displacement events (~2 m each) occurred at 92 ± 16 ka and 28 ± 20 ka, equivalent to a maximum slip-rate of about 0.3 mm/yr. Earthquake risk may be increased by on-going uplift (~ 2-3 mm/yr at San Acacia; Fialko and Simmons, 2001) and stretching of the Socorro region above the inflating modern-day Socorro magma body, which has been geophysically mapped at a depth of 19 km (Balch et.al., 1997).

Description of Map Units:

POST-SANTA FE-GROUP UNITS

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 buries

late Pleistocene scarp of the Socorro Canyon fault . Thickness 0–5 m.

Qca   Colluvium and alluvium, undifferentiated (Holocene to Pleistocene) — Talus and colluvium on steep to moderate slopes in the Chupadera 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 small upper Pleistocene debris flow on south wall of Blue Canyon. 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.

af   Artificial fill and mine waste (uppermost Holocene) — Mostly represents compacted fill, as roadway subgrades along Interstate 25 and adjacent flood control levees. Includes waste-rock piles east of abandoned MCA mines and a 10 m-high tailings pile east of the abandoned MCA mill site. Thickness 0–12 m.

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 the Rio Grande floodplain. Correlation of Qvo units into western third of quadrangle is tentative. 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. Distal alluvial-fan deposits contain siliceous sand and rare quartzite pebbles recycled from the underlying Sierra Ladrones fluvial facies (QTsf). 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, 1985). Thickness 0–24 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

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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 24 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 Chupadera Mountains. 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 remnants of high-level terraces and alluvial fans, as much as 9 m thick, within the Chupadera Mountains.

SANTA FE GROUP

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, 1983b). Remnants of the Las Cañas geomorphic surface of McGrath and Hawley (1987) locally cap the Sierra Ladrones Formation and forms top of Santa Fe Group.

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 (paleosol) as much as 2 m thick. Locally mantled with thin desert pavement or dark red argillic horizon. Mostly preserved where developed on the piedmont facies of the Sierra Ladrones Formation (QTsp). Projects 91 to 101 m above modern Rio Grande. Correlation with geomorphic surface in type area, east of the Rio Grande, is based on equivalent landscape position and soil development. Tentatively correlated with the lower La Mesa surface of Las Cruces area, which has been dated at 0.73–0.9 Ma (Mack et.al., 1993).

QTs_/Ts_   Sierra Ladrones Formation (lower Pleistocene to lower Pliocene) — Late-stage 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. Locally capped by Las Cañas geomorphic surface (Qlc) of McGrath and Hawley, 1987. As mapped here, younger piedmont facies (QTsp) and older piedmont facies (Tsp) lie in angular unconformity on tilted Popotosa beds at the basin margin. Also, the younger piedmont facies (QTsp) is locally inset against or disconformably overlies the older piedmont facies (Tsp). The base of the younger axial-river facies (QTsf) is not exposed here. A water well north of Walnut Creek (see sheet 2, E-E´) intersected 24.4 m of Qvo over 48.8 m of highly permeable QTsf, overlying a less permeable interval of greenish lacustrine(?) mudstones (6.1 m; E. Fry, oral commun. 1996) and fluvial sandstone (17.7 m). This lower, less permeable, interval probably represents moderately indurated, older, tributary-river deposits Tsft) Maximum thickness of Sierra Ladrones Formation probably 200–300 m.

QTsp   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 north to south, large, low-gradient alluvial fans (paleoslopes of 120–140 ft/mi) emanate from Socorro Canyon, Red Canyon, Nogal Canyon (Walnut Creek) and "South Chupadera Spring Canyon." Distinctive volcanic clasts demonstrate that all but the latter were fed by large canyons in the eastern Magdalena Mountains, namely Sixmile Canyon, Molino Canyon and Caronita Canyon. Abundant metamorphic clasts and large basalt boulders in the "South Chupadera Spring" alluvial fan indicate that it was derived from a large ampitheatre between Table Mountain and Chupadera Mountain. 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. A muddy transitional distal-fan facies (subscript "d") is locally delineated where well exposed in the area north of lower Red Canyon. The distal facies consists mostly of reddish orange silty mudstones and fine-grained sandstones, with a few pebbly conglomerates. Exposures of the distal facies average about 500 m in width and lie just west of the QTsp–QTsf facies boundary. A fine-grained, gypsum cemented sandstone within the distal facies (SE¼ Sec. 11, T4S, R1W) probably represents an overbank splay deposit of the ancestral Rio Grande. Buried calcic soil horizons (bc) are common within the piedmont facies. The gently east tilted base of the upper piedmont facies (QTsp), is locally exposed in the walls of "South Blue Canyon" where it appears to conformably overly poorly exposed fluvial fan deposits (well-sorted sands) of the lower Sierra Ladrones Formation (Tsft). Maximum thickness of upper piedmont facies, estimated from cross section (sheet 2, A A´) is 140 m. West of the MCA fault, on a structurally higher block, the uppermost piedmont facies is 9–18 m thick.

QTsf   Sierra Ladrones Formation, axial-fluvial facies (lower Pleistocene to upper Pliocene) —

Axial river deposits of the ancestral Rio Grande, and minor intertonguing distal piedmont-slope deposits (see reference outcrops on sheet 1 for examples of intertonguing localities). 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 (crosses on map). Piedmont facies gravels that locally *cap* the fluvial facies (east of the facies boundary) are delineated as QTsp on the map. Axial river sands are mostly non indurated, however, a few lenses of friable calcite-cemented sandstone are locally present (NE¼ sec. 30, T4S, R1E). 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 et.al., 1996), commonly overlie floodplain mudstones near the western limit of the axial-river facies. Ash beds are 0.1–0.6 m thick and occur at three stratigraphic levels approximately 18, 27 and 33 m below the projected top of QTsf. The stratigraphically highest ash found near Walnut Creek, was deposited at 1.22 Ma or slightly later (Table 1, no. 1); and the middle ash (Table 1, no. 3A) is geochemically equivalent to pumice dated at 1.6 Ma (Table 1, no. 2 and 3). The oldest ash is widely exposed in the area southwest of Luis Lopez. This undated ash may be equivalent to the 1.78 Ma San Diego Canyon ignimbrite of Spell et.al., 1990, (N. Dunbar, pers. commun. 1996). Base of axial-river facies is not exposed in the Luis Lopez quadrangle. Minimum thickness, based on water well north of Walnut Creek, is 72.5 m. Possibly 300 m thick near down faulted axis of Socorro Basin.

Tsp   Sierra Ladrones Formation, lower member, piedmont facies (lower to upper Pliocene) — Easterly transported piedmont-slope deposits (SE¼, NE¼, Sec. 8, T4S, R1W). 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 in angular unconformity on upper Popotosa Formation (Tpf) and is disconformably overlain by upper Sierra Ladrones piedmont facies (QTsp). Locally contains an unusually well indurated conglomerate bed, which is cemented by manganese oxides and silica (SW¼ sec. 9, T4S, R1W). Lithologically similar to easterly transported piedmont-slope conglomerates that underlie 3.7 Ma basalt flow at Socorro Canyon (sec. 27, T3S, R1W; Chamberlin, 1980; 1999). An intertonguing relationship with lower Sierra Ladrones fluvial-tributary facies (Tsft) is indicated by exposures on the northeast flank of Socorro Peak (Chamberlin, 1999). Minimum exposed thickness is 90 m.

Tsft   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 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. Transition unit is poorly exposed in walls of "South Blue Canyon." Similar well-sorted quartz-rich sands and volcanic-rich conglomeratic sandstones locally underlie ancestral Socorro Canyon alluvial conglomerates (Tsp) and the 3.7 Ma basalt of Socorro Canyon (Chamberlin, 1999) at Socorro Canyon. The same unit is also found on the upper northeast flank of Socorro Peak, where it contains numerous well sorted crossbedded conglomerates and sandstones of *fluvial* character (Chamberlin, 1999). Easterly paleocurrents and rare cobbles of well indurated (K-metasomatized) lower Popotosa Formation (Tpfm) in the Socorro Peak exposures indicate this fluvial unit is partly recycled from uplifted lower Popotosa beds in the Magdalena Mountains. Unit probably represents a fluvial-fan tributary facies to the ancestral Rio Grande and marks a 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. Thickness estimated from cross section A-A' is 90–120 m; it maybe as much as 300 m thick north of Socorro Peak and it is probably absent due east of Socorro Peak.

Tp_   Popotosa Formation, undivided (lower to upper Miocene) — Intermontane bolson fill deposits of early Rio Grande rift half grabens; as presently used and mapped by most workers, the Popotosa Formation was probably not deposited in a single broad structural basin (e.g. "Popotosa basin" of Bruning, 1973). Originally defined by Denny, 1940; and redefined by Bruning, 1973; followed by Machette, 1978. Locally divided into a conglomeratic piedmont facies, aka. fanglomerate facies (Tpf, Tpfm), a claystone dominated playa (lacustrine) facies (Tpp), a transitional mudstone-sandstone facies (Tpt), an upper fanglomerate facies (Tpfu), and a basaltic boulder bed (Tpfb). Contains interbedded ashes and lava flows of Miocene age (Osburn and Chapin, 1983b; Cather et.al., 1994a). Undivided Popotosa is shown in cross section only.

Tpfu   Popotosa Formation, upper "fanglomerate" (piedmont) facies (uppermost Miocene) —

Light brown sandstone and volcanic-rich conglomeratic sandstone locally overlying thick playa facies near "South" Blue Canyon. One exposure of conglomerate that contains abundant mud clasts (NE¼, SW¼ sec. 4 T42 R1W) suggests reworking of underlying playa facies at erosional unconformity(?). If unconformity can be demonstrated, then this unit could be reassigned to the basal Sierra Ladrones Formation (as part of Tsft). Maximum exposed thickness is 75 m.

Tpp   Popotosa Formation, playa facies (lower to upper Miocene) — Mostly red or maroon claystone with minor greenish claystones and thin bedded, yellowish brown sandstones. Gypsum, as selenitic veinlets, occurs near north boundary of quadrangle. Claystones are poorly indurated and commonly masked by colluvium (Qca). Appears to conformably or paraconformably overlie metsomatized piedmont-facies conglomerates (Tpfm) in northern Chupadera Mountains; grades laterally to buff-colored distal- piedmont congolmeratic sandstones northeast of Socorro Peak. Thickness at "South Blue Canyon" is 460 m; northeast of Strawberry Peak (Socorro 7.5´ quadrangle) the playa facies is 850 m thick (Chamberlin, 1999).

Tpf   Popotosa Formation, "fanglomerate" (piedmont) facies (lower to upper Miocene) — Heterolithic volcanic-rich conglomerates and sandstones derived from stream-erosion of early rift, tilted fault blocks. Generally described as "fanglomerates" (Bruning, 1973) although alluvial fan geometries have not been delineated. Consists of poorly to moderately well indurated, tan, buff and pale red, conglomerates, conglomeratic sandstones, sandstones and minor mudstones. Conglomeratic sandstones are dominant, and range from moderately well sorted stream deposits with well developed pebble imbrications, to poorly sorted, matrix supported debris flow deposits. Pebble imbrications indicate that westerly paleo- transport directions are dominant in the lower half of the piedmont facies at Walnut Creek,"South Chupadera Spring Canyon," and Table Mountain. Sequence adjacent to Walnut Creek fines upwards from boulder conglomerate at base to pebble conglomerate below the intercalated basalt of Broken Tank (Tbt). Above the basalt flows, the sequence generally coarsens upwards. Basal contact is a slight angular unconformity or disconformity associated with as much as 100 m of erosional relief. Colluvial breccias derived from the immediately underlying volcanic unit are common at the basal contact. Maximum exposed thickness adjacent to Walnut Creek is 730 m.

Tpfb   Popotosa Formation, basaltic boulder bed (upper Miocene)—Poorly exposed bouldery bed in hanging wall of Extraño fault, primarily expressed as a narrow (30-60 m wide) north-trending belt of loose basaltic blocks and subangular to subrounded boulders. In situ basaltic boulder bed is locally exposed within light gray rhyolite-dominated

conglomerates near the north end of the belt (unit dips 15° east here). Basaltic boulders consist of two types: dense dark gray to black diabase and vesicular, medium gray, moderately porphyritic basalt; they are texturally similar to zones in the basalt of Olney Ranch (Tbo). Basalt boulders are as much as 1–2 m across near the south end of the belt and generally become smaller toward the north end (30–50 cm). This unique boulder bed, within the Popotosa piedmont facies (Tpf), was probably derived from erosion and mass wasting of a faulted cuesta of the basalt of Olney Ranch located on the uplifted footwall of the Extraño fault in late Miocene time. Estimated maximum thickness of boulder bed is 6–12 m; unit grades northward into typical heterolithic conglomerates (Tpf).

Tpfm   Popotosa Formation, silicified and potassium metasomatized "fanglomerate" facies (upper Miocene) — Silicified and potassium metasomatized lateral equivalent of Tpf in northern Chupadera Mountains; characterized by dark red to brick red color and extreme induration in association with jasperoidal silica cement. Silicification boundary (hachure line) locally cuts across fanglomerate beds southwest of the Torres Mine (SE¼, sec. 13, T4S, R2W). Fanglomerates here were derived from the footwall of the low-angle Chupadera fault and contain a mixture of Hells Mesa Tuff clasts and crystal poor rhyolite clasts similar to Tzc or Tirz. Chemical analyses of Hells Mesa clasts collected across this color and induration boundary demonstrates the red, well indurated exposures to the north are potassium metosomatized and poorly indurated exposures to the south are not metasomatized (Ennis, 1996). Overall, the silicification and potassium metasomatism boundary, as defined by well indurated (jasperized) Popotosa outcrops, trends ENE across the northern Chupadera Mountains, subparallel to the Black Canyon fault zone (Chamberlin and Eggleston, 1996). Jasperoidal silica also cements fault breccias and zones of presumed high initial permeability in the underlying volcanic units (heavy stipple pattern) in the northern Chupadera Mountains. $^{40}Ar/^{39}Ar$ ages of metasomatic adulalaria from the Socorro Canyon (Box Canyon) area indicate the K-metasomatism system was active from about 10.4 to 7.4 Ma (Dunbar et.al., 1994; Dunbar and Miggins, 1996). Silicified and metasomatized fanglomerates west of the Torres Mine are at least 300 m thick.

Tpt   Popotosa Formation, transitional facies (upper Miocene) — Consists of red non-gypsiferous mudstones and volcanic-rich lithnic arenites, may be transitional to a playa facies or an axial-fluvial facies. Occurs near middle of piedmont facies at Walnut Creek; 0–60 m thick.

LAVAS INTERBEDDED IN LOWER SANTA FE GROUP

Tbt   Basalt of Broken Tank (upper Miocene)—Moderately widespread trachybasalt flows interbedded within Popotosa Formation on southeastern; western and northern flanks of the Chupadera Mountains. Singular to multiple stacked flows range from dark gray to grayish black, slightly pophyritic to fine-grained diabasic, dense to microvesciular and amygdaloidal, trachybasalt (47–50% SiO_2). Slightly porphyritic basal zones locally contain sparse fine-grained (<1.5 mm) phenocrysts of plagioclase, clinopyroxene and olivene, the latter commonly altered to red-brown iddingsite. Amygdaloidal calcite and calcite veinlets are fairly common. Dense cores of flows typically exhibit fine grained diabasic textures, which range from ophitic to subophitic. Flows north of Walnut Creek are greenish gray, propylitically altered and locally contain minor manganese mineralization. New $^{40}Ar/^{39}Ar$ ages (Table 1, no. 4-8) and petrographic studies (Chamberlin, unpub. data) indicate that the basalt of Bear Canyon (Osburn and Chapin, 1983b, Chamberlin, 1980), is temporally and compositionally equivalent to the basalt of Broken Tank. The "basalt of Bear Canyon" (Osburn and Chapin, 1983b) is here subsumed into the basalt of Broken Tank. Outcrop distribution, thickness variations, and paleocurrent observations in underlying Popotosa conglomerates (Tpf) are consistent with a concealed source area near San Antonio. Flows at Walnut Creek apparently flowed westward down a piedmont slope and paleovalleys toward Table Mountain and Broken Tank. From Broken Tank these lavas flowed northward down a basin axis and then spread out as a thin flow on playa deposits near Bear Canyon. Correlation of basaltic lavas 1 km SW of MCA mine is tentative. Average of 9 $^{40}Ar/^{39}Ar$ age dates on this unit is 8.42 ±0.3 Ma (McIntosh and Chamberlin, unpublished data). Stacked flows at Walnut Creek and near Broken Tank are as much as 30 m thick; singular flow near Bear Canyon is 3–6 m thick. Unit locally wedges out against Miocene paleovalley wall about 2 km SE of Broken Tank (NW1/4 Sec. 31, T4S, R1W).

Tbo   Basalt of Olney Ranch, new name (upper Miocene)—The new name "basalt of Olney Ranch" is here proposed for exposures of a porphyritic tabular basalt flow on the north flank of Table Mountain (SW1/4 Sec. 7, T5S, R1W), which lies on the southwest portion of Olney Ranch (formerly Nogal Ranch, sec. 6, T5S R1W) located in the west-central Chupadera Mountains. Correlative outcrops of this unit are found in the east-central Chupadera Mountains about 4.5 km ESE of Table Mountain. The basalt of Olney Ranch consists of medium to dark gray, slightly to moderately porphyritic trachybasalt (49% SiO_2) with about 1–4 percent fine to medium grained (1–4.5 mm) phenocrysts of tabular plagioclase and subhedral greenish olivine. Distinctly porphyritic basal zones are 3–6 m thick and typically grade upwards into a dense core zone of fine-grained diabase with rare medium-grained phenocrysts of plagioclase. Samples from northeast Table Mountain and eastern Chupadera Mountains yield $^{40}Ar/^{39}Ar$ ages of 9.64 ±0.12 and 9.71 ± 0.14 Ma, respectively (Table 1, no. 9 &10).

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Outcrops in the east central Chupadera Mountains dip about 20° east, in sharp contrast with the nearly flat lying outcrop on Table Mountain. Similar attitude differences are observed in the younger basalt of Broken Tank (Tbt, sheet 1). Basalt of Olney Ranch is interbedded with poor to moderately indurated conglomerates and sandstones of the Popotosa Formation that locally show westerly paleocurrent directions and inset paleovalley geometries with respect to underlying Oligocene volcanic rocks. The basalt of Olney Ranch apparently flowed westward down a Miocene paleovalley from a now concealed source area between San Antonio and the Bosque del Apache. Thickness 0–10 m; locally wedges out against older rhyolite (Tzbr1) at paleovalley wall on south side of Table Mountain.

Tsd   Socorro Peak Rhyolite, lower rhyodacite member (upper Miocene) — Light gray to pale red, flow banded, porphyritic rhyodacite lava flow containing 20–30 percent phenocrysts (1–3 mm) of plagioclase (locally replaced by adularia), hornblende and biotite. Outcrops north and west of Tower Mine contain secondary adularia in close proximity to numerous chalcedony and minor jasperoid veinlets of hydrothermal origin; this suggests adularia is also hydrothermal (Chamberlin and Eggleston, 1996). Unaltered dark gray vitrophyre is locally associated with the chilled base of flow approximately 700 m northwest of Tower Mine. Biotite from unaltered basal vitrophyre yields an ^{40}Ar/^{39}Ar age of 12.23 ± 0.04 Ma (Table 1, no.11); however biotite ages are commonly 10-20% older than comagmatic sanidine ages from the same rock sample (Newell, 1997). A similar rhyodacite in the Pound Ranch area *overlies* rhyolite lavas that yield a mean sanidine age of 11.31 ± 0.07 Ma (Newell, 1997). Source area uncertain, possibly erupted from Pound Ranch volcanic center; alternatively the silicified round knob immediately NW of Tower mine might represent an eroded neck. Maximum exposed thickness on downthrown western side of Chupadera fault is 110 m.

MOGOLLON GROUP

Tm   Mogollon Group undivided, shown in cross section only. The Mogollon Group includes all *volcanic* formations in the upper part of the Mogollon-Datil volcanic pile, which range in age from approximately 29 to 24 Ma (Cather et.al., 1994b). The Spears Group (not present in Luis Lopez quadrangle) includes all *volcaniclastic sedimentary* formations throughout the Mogollon-Datil volcanic pile, *except* volcaniclastic sedimentary units associated with calderas (Cather et.al., 1994b). As delineated here, the Mogollon Group includes 5 regional ignimbrites, plus locally erupted volcanic units and volcaniclastic-sedimentary fill within the Socorro caldera (Luis Lopez Formation), volcaniclastic sedimentary fill of the Sawmill Canyon caldera, and thin tongues of regional basaltic andesite lavas (La Jara Peak Basaltic Andesite). Minor unnamed

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rhyolitic sandstones and conglomerates (Tvs1 and Tvs2) that occur locally between ignimbrite outflow sheets are not assigned to the Spears Group because they are more likely related to caldera paleotopography or possibly early-rift block faulting, rather than constructional volcanic highlands. Formation nomenclature is from Osburn and Chapin, 1983b.

Tlp_4 La Jara Peak Basaltic Andesite, uppermost tongue of four regional tongues (Oligocene)— Medium to dark gray basaltic andesite lava flows, with sparse fine-grained phenocrysts of olivine altered to reddish brown iddingsite. Locally fills paleovalley cut in South Canyon Tuff on south side of Nogal Canyon (SW1/4, Sec. 6, T5S, R1W). Undated flow is tentatively correlated with the "basalt of Madera Canyon" as mapped by Osburn et.al. (1981), on the basis of similar lithology and stratigraphic position. The "basalt of Madera Canyon" has recently been dated at 26.95±0.2 Ma (McIntosh and Chamberlin, unpublished data). Thickness 0–20 m.

Tsc   South Canyon Tuff (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, 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%). Moderately crystal rich upper zone only locally preserved below Miocene erosion surface. 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 et.al., 1991). Correlation here is based on lithology and relative stratigraphic position. Thickness 30–60 m.

Tlp_3 La Jara Peak Basaltic Andesite, upper medial tongue of four regional tongues (Oligocene) — Reddish brown to dark gray, massive to vesicular, fine-grained, basaltic andesite lava flows characterized by small (1–2 mm) moderately abundant (10–15%) Fe-Mg phenocrysts altered to hematite or iddingsite. The latter presumably represent altered olivine. Repesents thin distal margin of formation in area of Tower Mine; 0–30 m thick.

Tvs_2 Unnamed volcaniclastic sedimentary unit, upper of 2 units (Oligocene) — Light gray to white, tuffaceous sandstone, siltstone, ash beds and minor pebble conglomerate in area south of Nogal Canyon. Occupies same stratigraphic interval as the upper-medial La Jara Peak Basaltic Andesite at Tower mine. Thickness 0–30 m.

Tlu/Tll   Lemitar Tuff; upper and lower members (Oligocene) — Compositionally zoned (77–65 wt% SiO_2), silicic ignimbrite subdivided into a lower member (Tll) of partially to densely welded, light gray, phenocryst-poor (5–15%), high-silica rhyolite, and an upper member (Tlu) of densely welded, dark red, phenocryst-rich (30–45%), rhyodacite to rhyolite. 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 andesitic porphyry are typical in outflow of the upper member. Distribution and thickness trends suggest that the Lemitar Tuff was erupted from the Hardy Ridge caldera on the west flank of the Magdalena Mountains (Fig. 2; G. R. Osburn oral commun. 1999; see McIntosh et.al., 1991, fig. 29). Lemitar ignimbrite locally appears to pinchout against eastern wall of the older Sawmill Canyon caldera in the Tower Mine area. Exposures in southern Chupadera Mountains fill broad troughs and paleovalleys. Mean $^{40}Ar/^{39}Ar$ age is 28.00 ± 0.08 Ma; paleomagnetic polarity is normal (McIntosh et.al., 1991). Correlation based on distinctive zonation of intercept in drillhole at Tower Mine (MC-1), a slightly younger $^{40}Ar/^{39}Ar$ sanidine age of 27.75 ± 0.16 Ma (Table 1, no. 14), and determination of normal polarity for the lower Lemitar Tuff exposure northeast of the Tower Mine (W. C. McIntosh, unpublished data). Thickness 0–230 m.

POST-COLLAPSE FILL OF SAWMILL CANYON CALDERA

Tx   Sawmill Canyon Formation, undivided (Oligocene) — Shown in cross section only. Volcaniclastic sedimentary deposits derived from the eastern wall of the Sawmill Canyon caldera (Osburn and Chapin, 1983a; Chamberlin et.al., in press). Fining upward sequence of breccia, conglomerate and sandstone, locally exposed northeast of the Tower mine.

Txs   Sawmill Canyon Formation, lower sedimentary member, upper sandstone beds (Oligocene)— pale red to grayish red, well sorted, fine-grained rhyolitic sandstone with minor conglomerates near the base; sandstones may be partly eolian. Grades downward into conglomerate/breccia unit (Txx). About 20-25m thick in surface outcrops; Tower Mine drill hole (MC-1) intercepted 25.6m of sandstones below Lemitar Tuff (Chamberlin, 1980).

Txx   Sawmill Canyon Formation, lower sedimentary member, basal breccia and

conglomerate beds (Oligocene)— basal rhyolitic breccias (ancient colluvial deposits derived from flow-banded Tzc) grade upward into crudely bedded debris flows with abundant locally derived clasts of Tzc, Tza$_3$ and Thu. Surface exposures of the basal breccias and conglomerates are well indurated by red jasperoidal silica, which is commonly associated with potassium metasomatism (Dunbar et.al, 1994: Chamberlin and Eggleston, 1996). Txx in Tower mine drill hole (MC-1) appears to be argillized (clay rich), but it is *not* cemented by jasperoidal silica. Outcrop is 40-50m thick, intercept in drill hole is 48.2 m.

LOCAL VOLCANICLASTIC SEDIMENTS AND REGIONAL TUFFS

Tvs$_1$ Unnamed volcaniclastic sedimentary unit, lower of 2 units (Oligocene) — Light gray tuffaceous sandstone and minor pebble conglomerates probably derived from the underlying La Jencia Tuff. These alluvial sandstones may locally represent late-stage erosional enlargement of the southeastern wall of the Sawmill Canyon caldera, since they occupy the same stratigraphic position as the Sawmill Canyon Formation (Txs/Txx). Alternatively Tvs$_1$ may be related to erosion of slightly uplifted fault blocks of the early Rio Grande rift, since Tvs$_1$ also occupies the stratigraphic position of the Vicks Peak Tuff (Tvp). Thickness 0–24 m.

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; Osburn and Chapin, 1983a). Appears to be preferentially preserved on the downthrown (southwestern) side of northwest to north- striking normal faults near southern margin of quadrangle. Mean ^{40}Ar/^{39}Ar age is 28.56 ± 0.06 Ma; paleomagnetic polarity is reverse (McIntosh et.al., 1991). Correlation here based on lithology and relative stratigraphic position. Thickness 0–125 m.

ROCKS ASSOCIATED WITH COLLAPSE OF SAWMILL CANYON CALDERA

Tjus   Upper zone of La Jencia Tuff and minor volcaniclastic sedimentary rocks (Oligocene) — Brick red, densely welded, phenocryst poor, rhyolite ignimbrite with abundant dark gray to black pumice fiamme. Contains sparse (1–3%) small phenocrysts of sanidine and quartz with traces of plagioclase and biotite. Grades downward into main body of the La Jencia Tuff (Tj). Brick red upper La Jencia Tuff is preserved only where locally overlain by the Vicks Peak Tuff (Tvp). As mapped here, includes a few meters of

tuffaceous sandstone and pebble conglomerate that discontinuously overly the brick red zone. Thickness 0–30 m.

Tj   La Jencia Tuff, main body (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 medial zone grades upwards and downwards to normal eutaxitic ignimbrite near top and base. Contains sparse (3–5%) phenocrysts of sanidine and quartz with traces of plagioclase and biotite. Orientations of lineated (stretched) pumice are consistent with a source area to the west or northwest (Eggleston,1982). Erupted from the composite Sawmill Canyon-Magdalena caldera in the north central and western Magdalena Mountains (Osburn and Chapin, 1983a). Mean bulk sanidine $^{40}Ar/^{39}Ar$ age is 28.85 ± 0.04 Ma; paleomagnetic polarity is reverse (McIntosh et.al., 1991). Correlation here based on lithology, relative stratigraphic position and a single-crystal sanidine age of 28.69 ± 0.16 Ma (Table 1, no. 15). Thickness in area south of Nogal Canyon ranges from 45–360 m; locally absent in northern Chupadera Mountains.

POST COLLAPSE FILL OF SOCORRO CALDERA

Tz_   Luis Lopez Formation (Oligocene) — Heterogeneous fill of the Socorro caldera consisting of volcaniclastic sedimentary rocks, pumiceous rhyolitic ignimbrites, basaltic to intermediate lavas, and rhyolitic lavas associated with minor cogenetic tuffs. Locally erupted volcanic units within the formation range from 30.0 Ma to 28.7 Ma (Table 1), compositional trends and age data suggest they are premonitory events related to a developing magma system which culminated in eruption of the La Jencia Tuff from the Sawmill Canyon caldera (Chamberlin et.al., in press). Overall distribution and thickness, of the Luis Lopez Formation indicate that it filled a preexisting depression created by eruption of the Hells Mesa Tuff. Local unconformities within the Luis Lopez Formation imply that the central horst block at Red Canyon was magmatically uplifted shortly before eruption of the 30.0-Ma pumiceous tuffs from a small collapse structure northwest of Black Canyon ("Black Canyon vent area", Chamberlin et.al. in press). The correlation of seven members, twelve volcanic flow units, and three sedimentary units (Table 2) within the Luis Lopez Formation is based on lithologic similarity of the discontinuous exposures, coupled with relative stratigraphic position and several new $^{40}Ar/^{39}Ar$ ages (Table 1, no. 16-23). Medial volcanic units of the Luis Lopez Formation typically lie in moderate angular unconformity (5–12°) on Hells Mesa-age units, immediately adjacent to the central horst block. South of the ring fracture zone near Chupadera Spring, the basal sedimentary unit rests conformably on xenolith-bearing

lower Hells Mesa Tuff (Thw). Luis Lopez Formation north of Black Canyon is at least 700 m thick; south of Nogal Canyon the maximum thickness is approximately 900 m.

Members of Luis Lopez Formation in southern Chupadera Mountains:

Tzs_3 Upper sedimentary member (Oligocene) — Light gray, light brown, or pale red rhyolitic sandstones, conglomerates and minor mudstones. Conglomerates locally fill paleovalley cut in underlying rhyolite lava ($Tzbr_1$) in area south of Nogal Canyon. Assignment to Luis Lopez Formation is arbitrary. Exposed thickness 0–30 m, possibly 90 m thick in subsurface.

$Tzbr\_$ Upper rhyolite member, two lava flow units and one intervening tuff unit (Oligocene) —*Formally designated as the rhyolite of Bianchi Ranch member of the Luis Lopez Formation* (Osburn and Chapin, 1983b).
Includes upper rhyolite flow unit ($Tzbr_2$), medial rhyolite tuff unit (Tzbrt) and lower rhyolite flow unit ($Tzbr_1$). All units of the Bianchi Ranch member have reverse paleomagnetic polarity (McIntosh et.al., 1991). Maximum thickness is 550 m.

$Tzbr_2$ Upper rhyolite flow unit— phenocryst-poor rhyolite lava flow consisting of a basal dark gray vitrophyric flow breccia that grades upwards into a dense flow-banded black vitrophyre and an upper zone of reddish brown spherulitic rhyolite. Contains sparse, small phenocrysts of plagioclase, sanidine and rare biotite. Upper flow unit wedges out to south against crest of underlying lava dome (Tzbr1). Yields $^{40}Ar/^{39}Ar$ sanidine age of 28.72 ± 0.11 (Table 1, no. 16). Exposed thickness of upper unit is 0–60 m.

Tzbrt   Medial tuff unit — light gray, phenocryst poor, pumiceous, crossbedded, base-surge deposits and thin, poorly welded, pumiceous ignimbrites; compositonally similar to the overlying rhyolite flow unit ($Tzbr_2$). Fragments of lithoidal rhyolite; vitrophyric rhyolite and andesite are locally abundant. Interpreted as a proximal pyroclastic deposit associated with a vent clearing event. Thickness is 0–20 m.

$Tzbr_1$ Lower rhyolite flow unit— high-silica rhyolite lava dome and flow complex (~75% SiO_2) that appears to be centered (thickest) near the latitude of Nogal Canyon. Dominant lithology is light brown, phenocryst-poor, flow-banded, lithoidal rhyolite with minor vitrophyric and spherulitic zones. Contains sparse phenocrysts of plagioclase, sanidine and biotite with traces of hornblende and sphene. Steep flow foliations and paleotopographic crest of lava dome south of Nogal Canyon (center, sec. 5, T5S, R1W), suggest a primary vent near here. Inferred vent area probably marks a point on the older ring fracture zone of the Socorro caldera. Maximum thickness near Nogal Canyon is 550 m; unit locally terminates near south margin of caldera (Sheet 2,

G-G´).

Tzas   Upper intermediate lava member, medium-grained trachyandesite flow unit and volcaniclastic sediments (Oligocene) — Consists of trachyandesite porphyry lava flow intercalated with well indurated, maroon, andesitic conglomerates and sandstones. Andesitic porphyry lava contains 15–20 % phenocrysts of fresh to variably altered medium-grained plagioclase, pyroxene and hornblende; it is correlative with Tza_3 in the northeast moat. Andesitic conglomerates also contain sparse rhyolite tuff and lava clasts. Thickness 0-40m.

Tzs_2 Medial sedimentary member (Oligocene)— Light gray tuffaceous sandstones and minor conglomerates near near Nogal Canyon. Locally fills paleovalleys cut in upper part of Tzt. Thickness 0–30 m.

Tzt   Medial pumiceous tuff member, locally divided into lower and upper cooling units (Oligocene) — Light gray to pale red, poorly to densely welded, pumiceous, phenocryst-poor, rhyolite ignimbrites (75-77 % SiO_2); locally lithic rich and generally mapped as a single unit in southern Chupadera Mountains (Eggleston, 1982). Lithic-rich lenses that contain abundant small andesitic fragments (< 20 cm) are common near the base; moderately lithic-rich zones with both Hells Mesa and andesite fragments occur in the uppermost 30m. Small (1–3 cm) aphyric to very crystal poor, white pumice lapilli form 15 to 30 percent of the rock. Pumice is commonly altered to white clay or zeolites; rare phenocrysts of plagioclase, sanidine and quartz indicate the pumice is rhyolitic. Sparse crystals (3–5%) of sanidine, plagioclase, quartz and biotite found in the matrix of the upper lithic-rich zones are most likely xenocrysts derived from fragmentation of the accompanying Hells Mesa clasts. A thin bed of water laid ash and mudstone that contains plant impressions occurs at the base of the medial tuff member about 2 km north of Nogal Canyon. About 1 km north of Nogal Canyon, the pumiceous tuffs are locally divisable into a lower light gray, poorly welded cooling unit about 50m thick (Tzt1) and and upper pale red moderately to densely welded cooling unit about 40m thick. A 2m-thick zone of argillized nonwelded ash at the top of the lower cooling unit is locally well exposed in a ravine wall. Maximum xenolith size in the lower cooling unit is 20cm; in the upper unit it is 5 cm. Sanidine from a densely welded lithic-poor interval of the upper cooling unit yields an $^{40}Ar/^{39}Ar$ age of 30.05 ±0.17 Ma (table 1, no. 20), which is analytically equivalent to the age of the lower cooling unit (Tzt_1) near Black Canyon (30.04 ± 0.15 Ma; table 1, no. 19). Pumiceous tuffs were erupted from the Black Canyon vent area in the northern Chupadera Mountains (see Luis Lopez units in northern Chupadera Mountains; Chamberlin et.al, in press). Thin outflow sheets of pumiceous tuff, stratigraphically between Hells Mesa Tuff and La Jencia Tuff, occur

widely in the Socorro-Datil region; they are commonly mapped with the base of the La Jencia Tuff or correlated with tuffs in the lower South Crosby Peak Formation (Osburn et.al., 1993; McIntosh and Chamberlin, 1994). Maximum thickness approximately 120 m, locally wedges out to south near caldera wall, but a lithostratigraphically similar tuff is present in a paleovalley on the south rim of the caldera near Chupadera Mountain ("tuff of Chupadera Peak", of Eggleston, 1982).

Tza_2 Medial mafic-rhyolite flow unit, within medial pumiceous tuff member (Oligocene) — Dark gray to reddish gray and bluish gray, massive to platy (weakly flow banded), phenocryst-poor (5–10%) low-silica rhyolite lava (69.5 % SiO_2) with anomalous mafic component (72 ppm Cr). Contains fine- to medium-grained phenocrysts of pyroxene and plagioclase with traces of fine-grained biotite and quartz. Some quartz crystals exhibit reactions rims of pyroxene, and a glassy basal zone exposed north of the Esperanza mine contains small inclusions of siliceous schist and fine-grained diorite. Compositional data, age relationships, and magmatic disequilibrium textures support the interpretation that the mafic-rhyolite flow unit represents a hybrid magma, a mixture of magmas equivalent to about one part Tza_1 and two parts Tzt_1 (Chamberlin et.al., in press). Lies in angular unconformity on Hells Mesa-age dome-derived tuffs (Trt) north of the Esperanza mine, and locally overlaps lower pumiceous tuff unit (Tzt_1) southeast of the Esperanza Mine. Undated mafic-rhyolite flow unit is bracketed by lower (Tzt_1) and upper (Tzt_2) cooling units of the medial pumiceous tuff member, thus it must have been erupted at about 30.0 Ma. As much as 180 m thick northeast of the Esperanza mine and absent at Nogal Canyon; probably erupted from vent area along south flank of central horst block near the Red Canyon fault.

Tzb   Lower basaltic member, trachybasalt flow unit (Oligocene) — Dark gray to black, massive to vesicular, trachybasalt lava flows (47 % SiO_2, 9.3 % MgO) characterized by sparse (2–7%) small phenocrysts of olivene, often partially altered to iddingsite. Vesicular zones containing amygadaloidal calcite are common in the upper half of the unit. Groundmass separate from sample near Nogal Canyon yields a moderately precise plateau age of 29.2 ± 0.47 Ma (Table 1, no. 20). However, this plateau age must be innaccurate since since the trachybasalt unit is immediately overlain by pumiceous tuffs (Tzt) dated at 30.05 ± 0.17 Ma (Table 1, no. 20). Stratigraphic relationships and bracketing age data suggest the trachybasalt was emplaced at about 30.5 Ma. Unit ponded to maximum thickness of 90m in southeast moat of Socorro caldera; pinches out to south near caldera wall at Chupadera Spring and is absent near central horst block, southeast of the Esperanza mine. Probably erupted from vent area near southeast rim of the Socorro caldera (Chamberlin et.al., in press).

Tzs$_1$ Basal sedimentary member (Oligocene) —Volcaniclastic conglomerates, sandstones and mudstones spatially divisable into a southern andesitic facies, a northern rhyolitic facies and a late-stage heterolithic axial facies containing distinctive cobbles of moderately phenocryst-rich spherulitic rhyolite and minor andesite clasts. Southern facies near Chupadera Spring is about 240m thick; it generally fines upward from coarse andesitic debris flows and breccias, to bed-load conglomeratic sandstones and mudstones, all of which are mostly purple to dark red in color. Clast compositions and grain-size trends imply the southern andesitic facies was derived from the southern caldera wall. Northern rhyolitic facies at Nogal Canyon is 200m thick; it consists of 170m of pale red tuffaceous mudstones and thin interbeds of light-gray rhyolite-derived sandstone unconformably overlain by 30m of upward coarsening conglomeratic sandstones dominated by cobbles and small boulders derived from crystal-rich Hells Mesa Tuff. An angular unconformity of about 5° separates the basal mudstone facies from the overlying conglomeratic unit; imbricated pebbles and cobbles indicate southerly paleocurrent directions. Compositional trends and paleocurrent observations imply that the northern rhyolitic facies was initially derived from a slightly positive core area, and then later derived from a rapidly emerging central uplift located a few kilometers north of Nogal Canyon. A late-stage axial conglomeratic facies is exposed in the uppermost 20m of section about 1 km south of Nogal Canyon. It consists of light gray conglomeratic sandstones containing abundant cobbles of moderately phenocryst-rich spherulitic rhyolite, which are often flow banded, and minor andesitic clasts. Clast imbrications indicate westerly paleocurrent directions. Sanidine from the spherulitic rhyolite clasts yield ^{40}Ar/^{39}Ar ages of 33.74 ± 0.10 and 33.68 ± 0.15 Ma (Table 1, no. 22 and 23), which supports the intepretation that they were derived from precaldera rhyolite lavas on the southeast margin of the caldera. Basal sedimentary member conformably overlies Hells Mesa Tuff near Chupadera Spring. Just south of map area, it wedges out against Precambrian rocks that locally define the southern wall of the Socorro caldera, (Eggleston, 1982); it is also absent at the central-horst block near the Esperanza mine. Age is bracketed by the underlying 31.9-Ma Hells Mesa Tuff and the superjacent 30.0-Ma pumiceous tuff member. Maximum thickness is 240m.

Members of Luis Lopez Formation in the northern Chupadera Mountains:

Note: Oligocene volcanic rocks in northern Chupadera Mountains are commonly hydrothermally altered and potassium metasomatized (Chapin and Lindley, 1986; Dunbar et.al. 1994; Chamberlin and Eggleston, 1996). In K-metasomatized rocks, plagioclase is replaced by white clay or adularia, pyroxenes and hornblendes are replaced by hematite and clays, and sphene is replaced by leucoxene. Biotite and sanidine commonly appear to be

unaltered in metasomatized rocks. Metasomatized Popotosa conglomerates (Tpfm) southwest of the Tower mine are very well indurated by red jasperoidal silica (Ennis, 1996; Chamberlin and Eggleston, 1996). Hydrothermal alteration in Oligocene rocks includes silicification, propylitic alteration, high-temperature potassic alteration of Oligocene rhyolite dikes and a red hematitic/sericitic zone superimposed on lower caldera-facies Hells Mesa Tuff (Eggleston, et.al., 1983; Chamberlin and Eggleston, 1996).

Tzc_   Upper rhyolite member, upper flow unit and lower tuff unit (Oligocene) — *Formally designated as the rhyolite of Cook Spring member of the Luis Lopez Formation* (Osburn and Chapin, 1983b).

Tzc   Upper rhyolite lava flow unit (Oligocene)— Light gray to pinkish gray, finely flow banded, phenocryst-poor rhyolite lava. Erosional remnants northeast of Tower Mine are 0–20 m thick. Contains small phenocrysts (2–5%) of plagioclase with traces of quartz, biotite and sanidine. Drill hole at the Tower mine, MC-1, intersected 60 m of intensely brecciated Tzc (previously interpreted as brecciated La Jencia Tuff; Chamberlin, 1980); probably representing an Oligocene slump block on the eastern wall of the Sawmill Canyon caldera.

Tzct   Lower tuff unit (Oligocene)— Consists of light gray, bedded ash-fall tuffs and thin zones of fused tuffs mineralogically equivalent to overlying flow unit. An unusually fresh fused zone near Highway 60 (Socorro quadrangle, Chamberlin, 1999) yields a precise $^{40}Ar/^{39}Ar$ age of 28.77 ± 0.10 Ma from a plagioclase separate (Chamberlin et.al., in press); thus confirming correlation of the rhyolite of Cook Spring with the rhyolite of Bianchi Ranch, as inferred by Obsurn and Chapin, 1983b. Thickness 0-30m.

Tza_   Upper intermediate lava member, upper coarsely porphyritic flow unit and lower medium porphyitic flow unit (Oligocene) — Trachyandesite to trachydacite porphyry lavas (~ 58-62 % SiO_2), characterized by moderately abundant and upward coarsening phenocrystic plagioclase (Chamberlin et.al, in press). Paucity of epiclastic facies suggests relatively low relief vent areas.

Tzap   Upper coarsely porphyritic flow unit— Consists of medium gray to reddish brown trachydacitic lava with moderately abundant phenocrysts (10–15%) 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 (Chamberlin, 1999) represent probable sources for the upper flow unit. 0–30 m thick.

Tza$_3$ Lower medium-grained flow unit (Oligocene)— Dark purplish gray, gray, and reddish brown, medium grained (1–3 mm) trachyandesite porphyry lavas, flow breccias and finely vesicular, near vent, cinder deposits. Massive to platy and locally vesicular lavas contain moderately abundant (5–10 %) phenocrysts of altered plagioclase and pyroxene. Northeast-striking porphyry dike about 2 km NE of Tower Mine appears to be a feeder dike for Tza$_3$ flows; another vent for Tza$_3$ is well exposed on the west wall of Box Canyon, near Socorro Canyon (Chamberlin et al., 1987, fig. 14; Chamberlin, 1999). Thickness 60–180 m.

Tzs$_2$ Medial sedimentary member (Oligocene)— Planar bedded tuffaceous sandstones and minor andesitic debris-flow conglomerates. Confomably overlies upper pumiceous tuff unit (Tzt$_2$) in area north of Black Canyon, where tuffaceous sandstones are commonly intensely silicified by red jasper. A purplish gray andesitic debris flow is present at the base of this unit near Socorro Canyon (Chamberlin, 1999). About 7-60m thick; thins to northwest; absent at Socorro Peak.

Tzt_   Medial pumiceous tuff member, upper and lower cooling units (Oligocene) — Moderate volume (>10 km^3) phenocryst-poor, rhyolite ignimbrites locally erupted from a small subsidence structure bound by the Black Canyon fault zone on its southeast margin ("Black Canyon vent area" of Chamberlin et.al., in press). Upper and lower cooling units of pumiceous tuff are locally separated by a minor volume mafic-rhyolite flow unit (Tza$_2$).

Tzt$_2$ Upper pumiceous tuff unit (Oligocene)— Light brownish gray, variably welded, pumiceous, phenocryst-poor, rhyolite ignimbrites (75-77% SiO$_2$); coarse xenolith-rich zones containing abundant fragments of upper caldera-facies Hells Mesa Tuff are common north of Black Canyon. Very phenocryst-poor rhyolitic pumice (<1% crystals) comprise about 15-30 % of the poorly to moderately welded ignimbrites where they are xenolith poor (1-10% lithics). Rare crystals of sanidine, plagioclase, and quartz occur in the pumice and matrix of lithic-poor zones. Tuff matrix of lithic-rich zones contains moderately abundant xenocrysts of feldspar and quartz derived from abrasion of crystal-rich lithics. Several lenses of clast-supported lithic-tuff breccias (1-3m thick), which look similar to debris-flow deposits, occur in the moderately lithic-rich pumiceous tuffs between Black Canyon and Socorro Canyon. Angular to rounded clasts of densely welded upper Hells Mesa Tuff are dominant in the very-lithic rich lenses (80-90% lithics, 10-20 % light gray rhyolitic tuff matrix). Larger xenoliths, as much as 90cm in diameter, are anomalously well rounded, which suggests that the clast-supported lenses repesent rock-avalanche deposits derived from preexisting Hells-Mesa derived

conglomerates (i.e. Tzs_1) on the west rim of the infered collapse structure (Black Canyon vent zone). Large subangular to subrounded blocks of densely welded upper Hells Mesa Tuff, commonly over 3m long, are widely distributed in zones of moderately lithic-rich pumiceous tuff north of Black Canyon. One large block near Socorro Canyon is bisected by a narrow fracture filled with pumiceous tuff, which suggests tumbling or impact during emplacement. Meter-sized blocks of Hells Mesa Tuff and rare blocks of coarsely porphyritic "turkey-track" andesite occur in clusters around the larger blocks. Largest lithic blocks (3.4m) are less than 5 km from their source vent (Freundt et.al., 2000, fig.4). Clast-size distributions support the interpretation of a primary vent located a few kilometers northwest of Black Canyon, an area that is now obliterated by the younger Sawmill Canyon caldera (Chamberlin, unpublished mapping; Chamberlin et.al., in press). As much as 270 m thick near Black Canyon, about 50m thick at Socorro Peak and 40m thick near Nogal Canyon.

Tzt_1 Lower pumiceous tuff unit (Oligocene)— Light gray, poorly welded, pumiceous, lithic-rich, rhyolitic ignimbrite compositionally and texturally similar to lower part of Tzt in southern Chupadera Mountains. Fine to medium-grained andesite porphyry clasts are locally abundant and crystal-rich Hells Mesa Tuff clasts are typically rare to absent. Rare crystals of sanidine and quartz in matrix are probably primary phenocrysts. Andesite blocks as much as 2m in diameter indicate the Black Canyon-Socorro Canyon area is a proximal zone for the lower puimceous tuff unit (Chamberlin, unpublished mapping). Sanidine from the lower cooling unit near eastern Black Canyon yields an $^{40}Ar/^{39}Ar$ age of 30.04 ± 0.15 Ma (table 1, no. 19), thereby demonstrating it is coeval with the upper pumiceous tuff unit at Nogal Canyon (Chamberlin et.al., in press).
About 60m thick at Black Canyon, base not exposed at Socorro Canyon.

Tza2   Mafic-rhyolite flow unit,(Oligocene)— Purplish gray to dark gray, phenocryst-poor, mafic-rhyolite lava flow (~ 68 % SiO_2) with anomalously high Cr content (62 ppm Cr). Contains sparse phenocrysts of plagioclase and pyroxene replaced by metasomatic adularia and Fe oxides, respectively; traces of fine-grained phenocrystic quartz and biotite are also present. Thick hogback former transected by Black Canyon appears to represent a singular massive flow, about 120 m thick; thickness and distribution patterns suggest a source vent near the Black Canyon fault zone. Conformably interbedded within lower and upper cooling units of the medial pumiceous tuff member (Tzt_1 and Tzt_2). Compositional data, age relationships, and magmatic disequilibrium textures support the interpretation that the mafic-rhyolite flow unit represents a hybrid magma, a mixture of magmas equivalent to about one part Tza_1 and two parts Tzt_1 (Chamberlin et.al., in press). Maximum thickness is 120 m; absent at Socorro Canyon and at Socorro Peak (Chamberlin, 1999).

Tza$_1$ Lower basaltic member, compositionally zoned basaltic andesite to andesite flow unit (Oligocene) — Purplish gray, phenocryst-poor to moderately phenocryst rich, basaltic andesite to andesite lava and minor andesitic conglomerates. Lavas at Black Canyon are intensely altered. Basal basaltic-andesite zone contains sparse olivene phenocrysts (six-sided euhedra) repalced by hydrothermal silica and hematite; basaltic andesite composition is indicated by high Cr content (160 ppm Cr) and a relatively high TiO$_2$ content (1.29 %) Upper andesitic zone contains moderately abundant (~10%) fine-grained plagioclase laths (1-2mm long) and octagonal pyroxene phenocrysts preferentially replaced by metasomatic adularia and hematite, respectively. Later-stage calcite and epidote also partially replace adularia and hematite. Altered plagioclase microlites form 70-80% of groundmass in both zones. Vesicular or amygdaloidal zones are common near top. As mapped, includes 2-3 m of andesitic conglomerates at the base of the unit. Limited extent suggests source vent near Black Canyon. Approximately 30 m thick at Black Canyon, absent in eastern Black Canyon and at Socorro Peak. Basaltic andesite to andesite flow unit at Black Canyon occupies the same stratigraphic position as the trachybasalt flow unit (Tzb) at Nogal Canyon. Lies in angular unconformity on bedded facies of the upper Hells Mesa Tuff (Thuf).

Tzs$_1$ Lower sedimentary member (Oligocene) — Light gray, pinkish gray, and purplish gray, medium- to coarse-grained rhyolitic sandstones, and minor andesitic debris flows in upper part. Rhyolitic sandstones most likely derived from underlying caldera-facies Hells Mesa Tuff. Well exposed in eastern Black Canyon; occupies same stratigraphic position as lower basaltic andesite to andesite flow unit (Tza$_1$) exposed at the Black Canyon box. Lies in angular unconformity on bedded facies of the upper Hells Mesa Tuff. Maximum thickness in eastern Black Canyon is 30 m; less than 3 m thick at Black Canyon box. Presumably derived from moderate uplift of the central horst block area near western Black Canyon; probably correlative to uppermost 30 m of the lower sedimentary member at Nogal Canyon.

DATIL GROUP

Includes all volcanic strata younger than the Baca Formation and older than (and including) the Hells Mesa Tuff (Osburn and Chapin, 1903; Cather et al, 1994).

ROCKS ASSOCIATED WITH INCIPIENT RESURGENCE OF SOCORRO CALDERA

Tr_   Hells Mesa-age lava dome and dome-derived tuffs (Oligocene)— Small volume (~ 0.3

km^3) ring-fracture lava dome and associated tuffs. Comagmatic with underlying caldera-facies Hells Meas Tuff; found only in southeast quadrant of Socorro caldera near the Esperanza mine. Represents slight resurgence of the Socorro caldera about 10-100 ka after collapse (Chamberlin, 2001a: Chamberlin et.al., in press).

Tre Hells Mesa-age lava dome (Oligocene)— Grayish red, flow banded to massive, very phenocryst-rich, spherulitic rhyolite lava dome (~ 68-74 % SiO$_2$) near Esperanza mine. Contains very abundant (~52% phenocrysts), fine- to coarse-grained crystals of sanidine, argillized plagioclase and quartz with minor biotite and traces of sphene in a spherulitic to cryptocrystalline matrix (Chamberlin, 2001b). Coarse sanidine phenocrysts are 6-9mm long, distinctly larger than in the underlying caldera-facies Hells Mesa Tuff (~3-5mm long). Narrow north-trending exposures east of Esperanza mine represent the faulted crest of a lava dome about 200-300 m high; over 300m of early Luis Lopez strata (Tzs$_1$, Tzb, Tzt$_1$ and Tza$_2$) are missing on the the apparent crest of the lava dome (Sheet 2, section G-G'). Probably erupted from an inner ring-fracture zone as expressed by a local NE-trending jog in the overall north-trending Esperanza fault (Chamberlin, 2001a). A single-crystal laser-fusion sanidine ^{40}Ar/^{39}Ar age of 31.89 ± 0.16 Ma (Table 1, no. 24) indicates the small lava dome is equivalent in age to the underlying caldera-facies Hell Mesa Tuff. Maximum thickness is about 200-300m.

Trt Dome-derived tuffs (Oligocene)— Light gray, poorly to densely welded, crudely bedded, phenocryst-rich, quartz rich, rhyolite ash-flow tuffs (~ 72% SiO$_2$). Densely welded basal tuff breccias about 0.7 km northwest of the lava dome contain large subangular blocks of reddish gray flow-banded crystal-rich lava texturally equivalent to the lava dome. Comagmatic lithics fragments progressively decrease in size northward along the narrow outcrop belts, from greater than 1m at 0.7 km from the source lava dome to less than 10 cm at about 2 km from the dome (Chamberlin, 2001b). Large compositionally zoned sanidine phenocrysts are also characteristic. Large blocks of sanidine granite (0.3-1 m) are are clustered near the base of the tuff unit about 1.2km north of the dome; they represent ballistic blocks of contact metamophosed Proterozoic granite presumably derived from the walls of the Hells Mesa pluton at depth (Chamberlin, 2001a). Conformably overlies about 30m of upper caldera-facies Hells Mesa Tuff (Thu). A 7m thick nonwelded zone, preserved at the top of the upper Hells Mesa, and significantly greater crystal size of the dome-derived tuffs indicates a moderate hiatus (~10^4 yrs) between upper Hells Mesa eruptions and eruption of the dome-derived tuffs (Chamberlin, 2001b). Tuff unit thins northward from maximum thickness of 120m to about 60m at the Red Canyon fault, where it is abruptly truncated; absent on south side of lava dome.

ROCKS ASSOCIATED WITH COLLAPSE OF SOCORRO CALDERA

Th__   Caldera-facies Hells Mesa Tuff (Oligocene) — Mostly densely welded, reddish colored, phenocryst-rich (30-55 % crystals), quartz-rich, lithic-rich to lithic-poor, rhyolite ignimbrite (69-75 % SiO_2). Divided into two members, upper and lower, and six mappable zones or facies, primarily on the basis of size, abundance and lithology of enclosed lithic fragments (Table 3; Chamberlin et.al, in press). Moderate volume (~50km^3) upper caldera-facies Hells Mesa Tuff is interpreted as a waning-stage facies, associated with volatile-depleted ignimbrite magma (Chamberlin, 2001a). Large volume (~1200km^3) lower caldera-facies Hells Mesa Tuff represents the primarry collapse-stage facies of ignimbite eruption. Typically contains abundant, fine- to medium-grained phenocrysts (1-5 mm) of sanidine, plagioclase, quartz and minor biotite plus magnetite, with traces of sphene, apatite and zircon (Chamberlin, 2001a). Plagioclase is commonly and widely altered to clay minerals or adularia in association with potassium metasomatism or older argillic alteration (Chamberlin and Eggleston, 1996). Biotite and other Fe-rich phases, including small mafic lithic fragments, are typically replaced by hematite in the red alteration zone, centered north of Red Canyon (Eggleston, et.al., 1983). Cleavage faces of normally clear sanidine commonly show milky to pearly pink lusters within the stratigraphically lower western part of the red hematitic zone (Chamberlin and Eggleston, 1996). Large volume (~1200 km^3) ignimbrite erupted from the 24-km diameter Socorro caldera, which extends from the central Chupadera Mountains westward across the Magdalena Mountains (Osburn and Chapin, 1983a; McIntosh et.al., 1991; Chamberlin et.al., in press). Mean bulk sanidine $^{40}Ar/^{39}Ar$ age of outflow facies is 32.06 ± 0.10 Ma; paleomagnetic polarity is reverse (McIntosh et.al., 1991). Correlation based on lithology, stratigraphic position and two single-crystal $^{40}Ar/^{39}Ar$ sanidine ages averaging 31.9 Ma (Table 1, no.25 & 26). Base not exposed, except at southern caldera wall; maximum exposed thickness in core of caldera is 2740 m (9000 feet, Sheet 2, C-C').

Thuf   Caldera-facies Hells Mesa Tuff, upper member, bedded zone (Oligocene)— Mostly densely welded, pale red, crystal-rich ignimbrites with many thin tongues (15-20) of comagmatic-lithic lag breccias that are commonly capped by thin, fine-grained ash-fall beds. Distinctly bedded appearance is mostly derived from resistant ledges of thin (2-30cm thick) densely welded (or fused), upward fining, ash-fall deposits. Comagmatic lag breccias contain angular to moderately flattened clasts of reddish brown, spherulitic, phenocryst-rich rhyolite (~72 % $SiO2$) compositionally similar to the surrounding pale red crystal-rich tuff matrix. Lag breccias are coarser and fine-grained fall beds are more common near the top of the bedded zone. Distribution patterns of maximum clast sizes (10-75cm) suggest the presence of a concealed vent area about 3-4 km ESE of the

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Bursum mine (Chamberlin 2001b). Explosive origin of comagmatic lag breccia is demonstrated by fragmented spherulites in the ignimbrite matrix and microfaults (mm scale offsets) in larger quartz or feldspar phenocrysts within the spherulitic clasts (Chamberlin, 2001a). Conformably overlies a 10m-thick poorly welded zone at the top of the massive zone of upper Hells Mesa Tuff (Thu). Sanidine from upper bedded zone at Black Canyon box yields a $^{40}Ar/^{39}Ar$ age of 31.94 ± 0.17 Ma (Table 1, no. 25). Maximum thickness is 200 m, absent outside the Socorro caldera and in southeast sector near the Esperanza mine.

Thu   Caldera-facies Hells Mesa Tuff, upper member, massive zone (Oligocene)— Pale red, mostly densely welded, crystal-rich rhyolite ignimbrite with sparse to rare comagmatic lag breccias that contain small pumice-like clots and angular clasts of dark red spherulitic rhyolite and 2 or 3 fine-grained ash-fall beds. Occurs near Bursum mine and near the Esperanza mine. Gradational basal contact is marked by upward dissapearance of rare small andesitic xenoliths at the top of the densely welded, lower xenolith-poor Hells Mesa Tuff (Thx) and appearance of rare small clasts of red spherulitic rhyolite in the densely welded massive zone (Thu). Both types of clasts can be present in the same rock sample near the gradational contact. Subtle contact zone is locally well exposed along the road to the Bursum mine. A 20 cm thick ash-fall bed, about 10m above the basal contact, is well exposed in a ravine about 100m south of the road. A 7-10m thick poorly welded to non-welded zone occurs at the top of the massive zone. Massive zone is about 200m thick in area east of the Bursum mine; it is over 100m thick south of the Esperanza mine and about 30m thick north of the Esperanza mine (Chamberlin 2001b). Thickness variations near the Esperanza mine suggest at least 70m of local uplift prior to emplacment of the Hells Mesa-age lava dome (Tre).

Thx   Caldera-facies Hells Mesa Tuff, lower member, xenolith-poor zone (Oligocene)— Densely welded, grayish red to dark red, pumice-poor, xenolith-poor (0–2%), blocky jointed, phenocryst-rich rhyolite ignimbrite. Typically contains sparse to rare small xenoliths of medium gray andesitic porphyry. Grades downward into lithic-rich mesobreccia zone (Thm), basal contact approximately located. Maximum thickness south of Black Canyon is 550 m, thins southward and grades into mesobreccia zone.

Thm   Caldera-facies Hells Mesa Tuff, lower member, xenolith-rich mesobreccia zone (Oligocene)— Mostly xenolith-rich (5–50%), reddish orange to reddish brown to grayish red, densely welded, phenocryst-rich, rhyolite ignimbrite *mesobreccia*. Angular to subrounded accidental lithic fragments, mostly 1–50 cm across, consist mostly of dark gray to purplish-gray DatilGroup-type andesite porphyry (containing medium-grained plagioclase phenocrysts) with and crystal-poor rhyolite blocks; also with minor

amounts of granite and schist of Precambrian affinity, plus rare limestones and sandstones of Paleozoic affinity. Mesobreccias in lower caldera-facies tuff are intimately interleaved with large coignimbrite landslide blocks of andesite and adjacent zones of very lithic-rich ignimbrite megabreccia (Thb). Thm is interpreted as a relitively finer grained mesobreccia facies laterally equivalent to more proximal caldera-collapse megabreccias (Thb) apparently derived from the southern wall of the Socorro caldera (Eggleston, 1982). As mapped, Thm includes a 100 m thick, xenolith-poor zone in its lower part, south of the Torres mine. Maximum estimated thickness of Thm plus Thb in area south of Red Canyon is 2400 m.

Thb   Caldera-facies Hells Mesa Tuff, lower member, xenolith-rich megabreccia zone (Oligocene)— Caldera-collapse megabreccia slabs and very xenolith-rich mesobreccias within densely welded to partially welded phenocryst-rich rhyolite ignimbrite. Dominated by large slabs of Datil Group-type andesite porphyry as much as 1 km long and 100 m thick. Rare "dikelets" of quartz-rich Hells Mesa ignimbrite injected into fractures in the andesite slabs locally help distinguish them from Datil Group andesites (Eocene) that could represent caldera floor rocks. A large coherent block of Spears-type conglomerate, as much as 120 m thick, is also present about 1 km north of Olney Ranch (aka. Nogal Ranch). Thb includes very lithic-rich and blocky mesobreccias (>50% clasts) that contain abundant large blocks of andesite, rhyolite, granite, schist and limestone typically 0.5 to 3 m across. These two major lithologies probably represent large landslide blocks and rock-avalanche deposits, respectively. Wedges of Thb thicken to the south, indicating that they were most likely derived by slumping of the south wall of the Socorro caldera, during early stages of eruption of the Hells Mesa Tuff (Eggleston, 1982). Combined maximum thickness of megabreccia (Thb) and mesobreccia (Thm) facies is 2400m.

Thw   Caldera-facies Hells Mesa Tuff, lower member, xenolith-bearing caldera-wall facies (Oligocene)— Densely to poorly welded, light-gray to pale red, locally xenolith-rich to xenolith-poor, phenocryst-rich, quartz-rich, rhyolite ignimbrite. Locally contains abundant andesite and granitic xenoliths; Spears-type conglomeratic megabreccia slabs locally occur at the base. Also contains xenocrysts of microcline derived from Precambrian rocks. Lower half is strongly bleached and "argillized" (milky sanidines) in area near Chupadera Spring. Slightly altered, xenolith-poor, phenocryst-rich ignimbrite from top of xenolith-bearing facies yields a single-crystal laser-fusion $^{40}Ar/^{39}Ar$ sanidine age of 31.85 ± 0.17 Ma (Table 1, no. 26), thereby confirming correlation with the Hells Mesa Tuff. Unconformably overlies Proterozoic schists and granites. Interpreted as medial Hells Mesa Tuff (laterally equivalent to Thm & Thx) filling a shallow embayment in the southern topographic wall of the Socorro caldera. Previously assigned

to lower Luis Lopez Formation ("Tzt$_1$" of Eggleston, 1982; and "Tzt$_1$" of Osburn and Chapin, 1983b). Maximum thickness near Chupadera Spring is 270 m. About 1 km south of the quadrangle, Thw wedges out against Precambrian rocks that locally define the inner topographic wall of the caldera (Eggleston, 1982).

PRE-CALDERA ROCKS

Xp   Porphyritic schists (lower Proterozoic) — Light to medium gray, quartz-feldspar porphyritic schist and porphyry. Includes minor mafic schists and amphibolite (Kent, 1982).

Xf   Feldspathic schists (lower Proterozoic) — Reddish orange quartzo-feldspathic schists, locally grades into minor pelitic schists (Kent, 1982). Foliated granite, also in this basement block, yields U-Pb age from zircon of 1659 ± 3 Ma (Bowring et.al., 1983).

Xu   Metamorphic basement rocks undivided (lower Proterozoic) — shown in cross section only.

INTRUSIVE ROCKS

Tim   Mafic dikes (Oligocene to Miocene?) — Medium gray to purplish gray, aphanitic to phenocryst-poor, mafic to intermediate dikes about 3–10 m wide. Locally cuts upper rhyolite member of Luis Lopez Formation (Tzbr1) in area southeast of Esperanza Mine. Also includes a small, grayish red, andesite porphyry dike in large rhyolite plug (Tirz) south of Black Canyon. Aphanitic dike near Esperanza Mine is texturally unlike diabasic flows in Popotosa Formation and is probably not related to the Miocene flows.

Tirs   Coarsely porphyritic rhyolite dikes and plug-like intrusion (Miocene) — Light pinkish gray, moderately phenocryst rich (15–20%) coarsely porphyritic rhyolite. Contains large phenocrysts (3–7 mm) of sanidine, with smaller plagioclase, quartz and biotite. Cuts lower caldera-facies Hells Mesa Tuff in area near Red Canyon. Larger exposures at west mouth of Red Canyon may represent top of cupola or small stock. Plagioclase is locally altered to metasomatic clays adjacent to the Chupadera fault. Main part of dike is unaltered where it cuts across the "red alteration zone" of Eggleston et.al, 1983. ^{40}Ar/^{39}Ar age of 10.99 ± 0.06 Ma (Table 1, no. 29) agrees well with published K-Ar age of 11.6 ± 0.6 Ma (Willard, 1971). This ^{40}Ar/^{39}Ar age is slightly younger than the lower rhyolite flow of the Pound Ranch member of the Socorro Peak Rhyolite of Osburn and Chapin (1983b) dated at 11.31 ± 0.08 Ma (Newell, 1997)

Tirx   Moderately phenocryst-rich rhyolite dike (Oligocene) — Pale red, moderately phenocryst rich (15–20%), massive rhyolite dike (~3 m wide) in northeast-striking tension fracture north of Black Canyon (part of composite dike adjacent to Tiaz). Contains medium to coarse-grained phenocrysts of sanidine, quartz, argillized plagioclase and biotite. $^{40}Ar/^{39}Ar$ age of 28.33 ± 0.15 Ma from sanidine (Table 1, no. 28) indicates intrusion was coeval with silicic volcanism that backfilled the Sawmill Canyon caldera (Sawmill Canyon Formation of Osburn and Chapin, 1983b), about 14 km west of Black Canyon. Moderately porphyritic dike is geochemically distinct (62 ppm Y, 35 ppm Nb) from the phenocryst-poor rhyolite dikes of the Black Canyon fault zone (Tirz; 16ppm Y, 17 ppm Nb; Chamberlin et.al, in press).

Tirz   Phenocryst-poor rhyolite dikes and plugs (Oligocene) — Light gray to light purplish gray, phenocryst poor, flow banded to massive, east-northeast striking high-silica rhyolite dikes (76 % SiO_2) and small to large plugs in area south of Black Canyon. Width of dikes ranges from 5 to 60 m. Rhyolite plugs near Torres Mine and Black Canyon are 300 to 600 m across and locally merge with northeast trending dikes. Plug at Torres mine includes a minor purplish gray mafic-rhyolite phase (69 % SiO_2 & 55 ppm Cr) along its eastern margin. Dikes and plugs typically contain sparse (3–8%) fine grained (1–3 mm) phenocrysts of plagioclase, sanidine, quartz and biotite. Plagioclase is commonly altered to white clay and generally weathers out leaving tabular holes in rock face. Mineralogy, phenocryst size, phenocryst abundance and trace element chemistry are similar to upper rhyolite member of Luis Lopez Formation (Tzc; Chamberlin et.al., in press) $^{40}Ar/^{39}Ar$ age of sanidine in dike at eastern range front (sec. 8, T1S, R4W) is 28.53 ± 0.14 Ma (Table 1, no. 27), which is analytically equivalent to the upper Luis Lopez rhyolites and La Jencia Tuff, but the latter is chemically unlike the phenocryst-poor likes (Chamberlin et.al, in press). Equivalent ages and lithologies suggest that these dikes may have fed Tzc flows. Correlation of similar phenocryst-poor rhyolite intrusions within Thm near Madera Canyon (SE¼ sec. 36, T4S, R2W) with Tirz is tenuous.

Tiaz   Andesite dikes (Oligocene) — Dark gray to purplish gray, moderately porphyritic, northeast striking, andesitic dikes (5–20 m wide) cutting Hells Mesa Tuff and lower Luis Lopez members in area north of Black Canyon. These potassium metsomatized dikes contain sparse phenocrysts of plagioclase altered to white clay and pyroxene altered to Fe oxide. Dike approximately 2 km northeast of Tower Mine appears to feed Tza_3 flow. Dike 3 km east-northeast of Tower Mine appears to feed a Tza_2 flow.

Explanation of Map Symbols:

Depositional contact, long dashed where approximately located, short dashed where gradational, queried where inferred. Direction and angle of dip shown where observed.

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

Approximate projected trend of Miocene paleovalley wall; generally defined by

truncation of valley floor strata or wedge out of valley fill. Hachures point toward local valley axis; acute angles point toward inferred downstream direction.

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

Alteration boundary that cuts across bedding. Separates well indurated (jasperoidal silica cemented) and potassium metasomatized Popotosa fanglomerate facies (Tpfm) from poorly indurated, non-metasomatized Popotosa fanglomerate facies (Tpf) in area southwest of Torres Mine.

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 northeast-striking scissors fault; locally defines south margin of Socorro accomodation zone (SAZ of Chapin, 1989; modified after Chamberlin and Eggleston, 1996).

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.

MAP SYMBOLS (continued)

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 small landslide block.

Local marker bed (or horizon) in upper Santa Fe Group. Includes rhyolitic water-laid

ash beds (a), buried calcic soil horizons (bc), gypsiferous sandstone beds (gyp. sandst), and a manganese cemented (Mn) conglomerate bed. Lenticular beds of rhyolitic pumice and scattered pumice fragments (r) are also indicated in some localities.

Good exposure of pedogenic carbonate horizon or calcrete.

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

Selected reference exposure of basin-fill map unit showing approximate total thickness in meters, and approximate thickness of intertonguing lithofacies. Example is read as 8 m of piedmont facies, over 2 m of axial river facies, over 4 m of piedmont facies, over 10 m of axial river facies. Gravel-sand ratios (g:s) are indicated for some piedmont facies exposures. Post Santa Fe reference exposures are divided into piedmont facies (vo) and axial river facies (vof).

Las Cañas geomorphic surface of McGrath and Hawley, 1987.

Strike and dip of bedding or compaction foliation in welded tuffs.

Horizontal bedding.

Strike and dip of flow foliation in lava flow.

Vertical flow foliation.

Manganese vein or veinlets showing strike and dip.

MAP SYMBOLS (continued)

Abandoned manganese mine (names from Willard, 1973).

Syncline, showing approximate trend of trough line.

Orientation of flow lineation (elongated pumice) in rheomorphic La Jencia Tuff (Tj).

General direction of paleocurrents, based on pebble imbrications.

Collar and surface projection of inclined diamond-drill hole at Tower Mine (Mountain Copper hole #1, MC-1; graphic log of core available in Chamberlin, 1980).

Excavation, or landfill, in late Cenozoic basin fill deposits.

Water supply well; "C" indicates community supply well of San Antonio Mutual Domestic Water Consumers Association, "D"= minor domestic well, "S"= livestock well, "BLM" = BLM well at MCA mill site.

Groundwater seep at man-made cut and cattle tank (South Blue Canyon and Shrine Valley).

Earthen safety berm at Socorro Gun Range.

Area of "red alteration" (Eggleston et.al., 1983) associated with hematite replacing biotite, Fe-rich phases and some small mafic lithic fragments in lower caldera-facies Hells Mesa Tuff.; also associated with sericitic plagioclase and high-temperature potassic alteration of rhyolite dikes (Tirz). Red zone is cut by an unaltered 11.0-Ma rhyolite dike (Tirs) near Red Canyon.

Stratigraphically and structurally controlled zones of jasperoidal silicification (hematitic chalcedony) in Oligocene volcaniclastic and volcanic rocks. Includes a silicified breccia pipe in footwall of Chupadera fault near Torres Mine, a silicified tectonic breccia of South Canyon Tuff at portal of Nancy Mine, a zone of high primary permeability in the upper pumiceous tuff (Tzt2), a basal andesite flow breccia in Tza3, and all exposures of Txx. Presumably represents same jasperoidal silicification event as that associated with potassium metasomatism of Popotosa fanglomerates in the northern Chupadera Mountains. Most mappable faults adjacent to and north of Black Canyon are cemented by jasperoidal silica.
MAP SYMBOLS (continued)

Area of large (>10 m) jumbled blocks of South Canyon Tuff that are bound together by jasperoidal silica; exposed north of Tower Mine. May represent *very* coarse grained basal Popotosa Formation.

Inferred approximate location of volcanic vent, queried where more speculative

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Sample location for $^{40}Ar/^{39}Ar$ age analysis (numbers referred to in Table 1)

Sample location for paleomagnetic analysis (numbers referred to in Table 4)

Lithic-tuff breccia bed in upper upper pumiceous tuff unit (Tzt_2)

Maximum size (m) of large xenolith in upper pumiceous tuff unit (Tzt_2)

Maximum size (cm) of comagmatic-lithic fragments in upper Hell Mesa Tuff (Thu,Thuf) or in dome-derived tuffs (Trt)

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TABLES

Table 1. Summary of ^{40}Ar/^{39}Ar ages of volcanic rocks in the Luis Lopez 7.5 minute quadrangle. Data for Oligocene rocks from Chamberlin, McIntosh and Eggleston (in press). Data for Miocene and younger samples from W. C. McIntosh, New Mexico Geochronology Laboratory, New Mexico Tech. All sanidine ages represent single crystal laser fusion analyses that tend to be slightly younger (e.g. 0.1-0.2 Ma at ~30 Ma; McIntosh and Chamberlin, 1994) than bulk furnace analyses published by McIntosh et.al., 1991. "N" equals number of crystals analyzed; letters, eg. "C-H," indicate number of heating steps in furnace analysis used to determine plateau age (i.e. C-H = 6 steps). Preferred age based on relative age relationship to other dated units and average ages of correlative dated units in addition to analytical error at approximately ±2σ. Geochemical correlation of No. 3A from Dunbar and others, 1996.

Map No.	Unit	Field No.	Lat. (N)	Long. (W)	Mineral or material dated	N: number of analyses	Age (Ma)	Error ±2σ	Comment	Preferred age (Ma)
1	Qtsf(a)	LLZ-1 (NM 1072)	33°55′47.5"	106°54′08"	sanidine + microcline?	3	1.22	0.06	3 youngest analyses approx. depositional age	1.2
2	QTsf(r)	LLZ-5	33°58′02.5"	106°54′26"	sanidine	25	1.57	0.07	max. depositional age	1.6
3	QTsf(r)	LLZ-27	33°59′12"	106°54′26"	sanidine	23	1.67	0.06	max depositional age	1.6
3A	QTsf(a)	LLZ-26	33°59′09.5	106°54′21"	geochemical correlative of No. 3				depositional age	1.6
4	Tbt	NM-1531	33°53′55"	106°56′19"	groundmass	C-H	8.36	0.05	eruption age	8.4
5	Tbt	NM-1530	33°54′11'	106°55′40"	groundmass	A-I	8.39	0.16	eruption age	8.4
6	Tbt	LLZ-47	33°53′16"	106°59′25.5"	groundmass	A-F	8.41	0.12	eruption age	8.4
7	Tbt	LLZ-33	33°59′42"	106°58′21"	groundmass	B-I	8.68	0.22	eruption age	8.4
8	Tbt	LLZ-45	33°55′20"	106°59′28.5"	groundmass	A-E	8.70	0.20	eruption age	8.4
9	Tbo	LLZ-46	33°53′30.5"	106°59′27"	groundmass	B-H	9.64	0.12	eruption age	9.7
10	Tbo	LLZ-99-8	33°52′48.5"	106°56′42"	groundmass	D-K	9.71	0.14	eruption age	9.7
11	Tsd	HN-95-16B	33°59′07"	106°59′53"	biotite	G-J	12.23	0.04	biotite often 10-20% older than sanidine in same rock (Newell, 1997)	~9.5 (Chamberlin, 1999)
12	Tsc	LLZ-99-1	33°54′32"	106°57′11"	sanidine		in progress			
13	Tlu	LLZ-99-2	33°54′35.5"	106°57′13"	sanidine		in progress			
14	Tlu	KMET-93-56	33°58′49"	106°59′34.5"	sanidine	7	27.75	0.16	K metasomatized, ~ eruption age	27.9
15	Tj	LLZ-43	33°54′25.5	106°57′29"	sanidine	10	28.69	0.16	eruption age	28.7
16	Tzbr2	NM-449	33°54′56"	106°57′23.5"	sanidine	45	28.72	0.11	eruption age	28.7
17	Tzbr1	LLZ-99-5F	33°56′11"	106°57′39.5"	sanidine	2	28.75	0.15	eruption age	28.7
18	Tzbr1	LLZ-99-4	33°54′27"	106°57′46.5"	sanidine	20	28.64	0.09	eruption age	28.7
19	Tzt1	LLZ-34	33°59′02.5"	106°57′42"	sanidine	22	30.04	0.15	eruption age	30.0
20	Tzt2	LLZ-44	33°54′24.5"	106°58′18.5"	sanidine	7	30.05	0.17	eruption age	30.0
21	Tzb	NM-1532	33°54′03.5"	106°58′16.5"	groundmass	A-I	29.20	0.47	inaccurate age, underlies Tzt 2,	~30.5

Map No.	Unit	Field No.	Lat. (N)	Long. (W)	Mineral or material dated	N: number of analyses	Age (Ma)	Error ±2σ	Comment	Preferred age (Ma)
									>30.05 Ma	
22	Tzs1 (cobble)	NM-1534A	33°53′49"	106°58′17"	sanidine	15	33.74	0.10	maximum depositional age, precaldera rhyolite lava clast in moat sediment	33.7 (of lava flow)
23	Tzs1 (cobble)	NM-1534B	33°53′49"	106°58′17"	sanidine	13	33.68	0.15	maximum depositional age	33.7 (of lava flow)
24	Tre	LLZ-41	33°55′41"	106°57′49"	sanidine	15	31.89	0.16	eruption age, Hells Mesa -age lava dome	31.9
25	Thf	KMET-93-58	33°59′07"	106°58′52"	sanidine	12	31.94	0.17	eruption age, K metasomatized	31.9
26	Thw	LLZ-36	33°52′34.5"	106°56′54.5"	sanidine	14	31.85	0.17	eruption age	31.9
Silicic Intrusions										
27	Tirz	NM-1337	33°58′37.5	106°57′50"	sanidine	7	28.53	0.14	intrusion age	28.7
28	Tirx	LLZ-9	33°59′13"	106°59′00"	sanidine	14	28.33	0.15	intrusion age	28.3
29	Tirs	LLZ-35	33°56′50"	106°59′43"	sanidine	15	10.99	0.06	intrusion age	11.0
30	Tirs	RC-KM-28	33°56′52"	106°59′17"	in progress					
31	Tirz/Tzbr ?	LLZ-01-01	33°54′40"	106°59′59"	in progress					

Table 2. Map units and member designations of the Luis Lopez Formation in the eastern Socorro caldera. Dashed line indicates unit is locally absent. Tzt is undivided equivalent of Tzt_1 and Tzt_2. Table is modified after Chamberlin et. al (in press).

Northeast moat	Southeast moat		Member designation
---	Tzs_3		upper sedimentary member
---	$Tzbr_2$		upper rhyolite member
---	Tzbrt		(Rhyolite of Bianchi Ranch)
Tzc	Tzbr1		(Rhyolite of Cook Spring)
Tzct	---		
Tzap	---		upper intermediate lava member
Tza_3	Tzas		
Tzs_2	Tzas	Tzs_2	medial sedimentary member
Tzt_2	Tzt_2	Tzt	medial pumiceous tuffs member
Tza_2	Tza_2		and mafic-rhyolite flow unit
Tzt_1	Tzt_1		
Tza_1	---		lower basaltic member
---	Tzb		
Tzs_1	Tzs_1		basal sedimentary member

Table 3. Map units, facies, members and stages of the Hells Mesa Tuff and a comagmatic lava dome. Nonwelded zone in upper part of Thu (dashed line) locally underlies Thuf and Trt, thereby indicating a brief to moderate hiatus in deposition. Stage interpretations from Chamberlin (2001a, 2001b). Table modified after Chamberlin et.al. (in press).

Map unit	facies or zone	member	stage
Tre	rhyolite lava dome	comagmatic lava dome	weak resurgent stage
Trt	dome-derived tuffs	(post-Hells Mesa Tuff)	(second boiling point)
Thuf	bedded zone	upper caldera-facies Hells	waning stage
	abundant comagmatic lithics	Mesa Tuff	(volatile depleted)
	and bedded fall deposits		

Thu	massive zone		
	sparse comagmatic lithics		
Thx	xenolith-poor zone	lower caldera-facies	primary collapse stage
Thm	xenolith-rich mesobreccias	Hells Mesa Tuff	(volatile rich)
Thb	xenolith-rich megabreccias		
Thw	xenolith-bearing caldera-wall facies	lower caldera-facies Hells Mesa Tuff	primary collapse stage (volatile rich)

TABLE 4—Site-mean paleomagnetic data for volcanic rocks in the Luis Lopez 7.5 minute quadrangle (from McIntosh et.al., 1991). Explanation: Second through fourth columns show age constraints provided by stratigraphically adjacent $^{40}Ar/^{39}Ar$-dated ignimbrites (abbreviations explained below); demag is alternating field demagnetization level for site-mean data; n/t denotes number of samples used in site mean/total samples; inc, dec, and int are site-mean inclination, declination, and intensity; k is Fisher's (1953) precision parameter; α_{95} is radius of cone of 95% confidence, type denotes demagnetization behavior: 1=TRM, 2=TRM+IRM; Letter R following type number identifies sites with poor precision ($\alpha_{95}>15°$). Ignimbrite abbreviations: LJ=La Jencia, HM=Hells Mesa.

Unit Symbol	constrained type age (Ma)	bracketing ignimbrites		site	lat (°N)	long (°W)	dip	strike	demag (mT)	n/t	inc	dec	intensity (A/m)	k	α_{95}	type
Tzbr1	32.1–28.9	HM	LJ	446	33.907	106.965	8	0	40	4/4	-67	102	0.11	186	7	1
Tzbr1	32.1–28.9	HM	LJ	447	33.909	106.964	8	0	30	4/4	-74	127	0.19	62	12	1
Tzbr2	32.1–28.9	HM	LJ	449	33.916	106.956	0	0	40	4/4	-30	165	0.18	11	29	2 R
Tzbr1	32.1–28.9	HM	LJ	450	33.931	106.956	8	0	30	4/4	-57	108	0.04	188	7	1

Figure 1. Index map of the Luis Lopez quadrangle and adjacent quadrangles. Heavy dots show projected margins of Oligocene ignimbrite calderas: **I** 31.9-Ma Socorro caldera, **II** 30.0-Ma Black Canyon vent area, **III** 28.7-Ma Sawmill Canyon caldera. Dashed line shows Socorro accomodation zone (SAZ of Chapin, 1989), modified after Chamberlin and Eggleston (1996). Hachured line shows main trace of the Socorro Canyon fault (SCF). Smaller open dots show mountainward limits of ancestral Rio Grande deposits (QTsf).