Geologic Map of the San Lorenzo Spring Quadrangle, Socorro County, New Mexico

By

Richard Chamberlin

May, 2004

New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 86

Scale 1:24,000

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Comments to Map Users

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

A geologic map graphically displays information on the distribution, nature, orientation, and age relationships of rock and surficial units and the occurrence of structural features such as faults and folds. Geologic contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic map are based on field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist. Significant portions of the study area may have been mapped at scales smaller than the final map; therefore, the user should be aware of potentially significant variations in map detail. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown everywhere.

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

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

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 San Lorenzo Spring quadrangle includes the west flank of the Lemitar Mountains and the eastern margin of the La Jencia Basin about 19 km northwest of Socorro, New Mexico. San Lorenzo Arroyo (Canyon) flows around the north flank of the Lemitar Mountains and eastward to the Rio Grande near the north margin of the quadrangle. San Lorenzo Spring occurs where sandy arroyo-fill deposits wedge out across a bedrock sill of Oligocene dacitic lava. The dense lava forces easterly groundwater flow in the shallow alluvium to the surface; several other springs along San Lorenzo Arroyo occur at similar bedrock exposures. In contrast, "Query" spring, about 1.4 km east of San Lorenzo Spring, issues from sandstones of the Popotosa Formation adjacent to the upthrown corner of a major fault block. San Lorenzo Canyon is a popular area for picnics and day hiking.

The San Lorenzo Spring quadrangle lies within the central Rio Grande rift, where WSW-directed lithospheric extension over the last 29-32 million years has broken an Oligocene volcanic plateau into a north-trending array of tilted fault-block ranges and alluvial basins. Contemporaneous dip slip and westward rotation of early rift domino blocks is recorded in the Lemitar Mountains and NE of San Lorenzo Spring by wedge-shaped prisms of basaltic-andesite lavas (Tl_{1-3}) found between progressively less tilted ignimbrite sheets of late Oligocene age (see cross section A-A'). Two or three episodes of domino-style extension have rotated originally high-angle, east-dipping normal faults to near horizontal attitudes (e.g. large elliptical block centered 3 km south of Red Mountain). Minor displacement high-angle normal faults offset large displacement low-angle fault traces at several localities. Previously unmapped andesite porphyry lavas (Tar) and dacitic lavas (Tds) cap the La Jara Peak Basaltic Andesite near Red Mountain and San Lorenzo Spring. Mafic agglomerates, dacitic debris flows and felsic tuffs mark a small vent complex (Tvs) southeast of San Lorenzo Spring. Andesite lavas are preferentially preserved on downthrown early rift fault blocks. Boulder-rich andesitic breccias of the Popotosa Formation (Tpx_3), which are interpreted as scarp-derived colluvial deposits, locally cap the downthrown andesitic lavas. Notably the same porphyritic lavas are absent on the adjacent uplifted footwall blocks (e.g. Red Mountain) that were eroded and then buried by stratigraphically higher units in the Popotosa Formation. The earliest rift faulting is locally demonstrated by two down-to-the east normal fault scarps that were buried by the 28.7 Ma La Jencia Tuff in the area NE of Red Mountain.

A complex structural/tectonic evolution is apparent in the San Lorenzo Spring quadrangle. Strongly tilted domino blocks of the early Rio Grande rift are superimposed on a Laramide highland. Absence of Mesozoic strata and limestone-cobble conglomerates of the Baca Formation (Tb) record uplift and erosion of the Lemitar Mountains in early Tertiary time. Granite-derived boulder conglomerates within the Baca Formation in the footwall of the Puerto fault suggest that this normal fault was a Laramide reverse fault, upthrown on the north, prior to regional extension. The Polvadera thrust fault, near Canoncito del Lemitar, represents N-S crustal shortening associated with the Ancestral Rocky Mountains orogeny in middle Pennsylvanian (Atokan) time. The large ignimbrite hogback about 1.5 km NE of San Lorenzo Spring is underlain by 30m of thin bedded limestones and arkosic sandstones of the lower Permian Bursum Formation, which unconformably overlies a two-mica granite of Proterozoic age. The absence of Pennsylvanian strata at this locality implies that it was an ancestral Rocky Mountain highland similar to the Joyita Hills, located 17 km to the east. Proterozoic granite forms the structurally high crystalline core of the west-central Lemitar Mountains.

Moderate to strongly tilted volcanic-rich conglomerates, sandstones and mudstones of the Miocene Popotosa Formation accumulated in evolving tilt-block depressions of variable orientation (dominantly north-south), lateral extent and age of activity. Map patterns and intraformational unconformities indicate that the floor of the Popotosa basin (top of Oligocene volcanic pile) was complexly faulted prior to and during Popotosa deposition. The Popotosa Formation west of San Lorenzo Spring is as much as 2.1 km thick

and locally fills a transverse sag or graben between structurally high blocks just south of Red Mountain and northeast of San Lorenzo Spring (ignimbrite hogback). Popotosa beds in the transverse graben contain a distal flow unit of the 15.4 Ma basaltic andesite of Silver Creek and several water-laid pumiceous sandstones that project northward along strike into the Silver Creek quadrangle, where they have been dated at 15.6 to 14.5 Ma (Cather and Read, 2003). Older, presently undated ash beds, locally occur between basal debris flow units (Tpd_2/Tpd_1) exposed in the walls of San Lorenzo Canyon. Traverses across uniformly dipping stratigraphic sequences show that the conglomerates locally exhibit abrupt up section changes in the dominant lithology of entrained volcanic pebbles and cobbles. Thus conglomeratic subunits have locally been mapped and defined on the basis of distinctive clast suites. These compositional subunits, in conjunction with textural units defined by dominant grain-size and bedding character, provide some sense of stratigraphic sequence and position, which is not apparent by mapping only textural units (cf. Cather and Read, 2003). Map patterns imply that the Popotosa Formation generally thickens and becomes older northward along the west flank of the Lemitar Mountains. A 15-20° angular unconformity, observed at the base of the Popotosa Formation in the southwestern Lemitar Mountains, is not apparent at San Lorenzo Spring, where the basal debris flows essentially parallel the underlying lavas at the erosional unconformity. Anomalous southeasterly to northeasterly dips of Popotosa beds at San Lorenzo Canyon and Canoncito de las Cabras represent a complex ramp structure associated with westward and eastward splaying of the large displacement Silver Creek fault (> 2km), which bounds the east flank of the ignimbrite hogback north of San Lorenzo Canyon. Ongoing dating of ash beds from the Popotosa Formation should help test the preliminary correlation of Popotosa units as presented here.

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 (e.g La Jencia Creek). Moderately west tilted basal conglomerates of the Sierra Ladrones piedmont facies (QTse), which were derived from the Silver Creek uplift to the east (“Rock” ridge), lie in sharp angular unconformity on steeply tilted upper Popotosa conglomerates (Tpcu) near the SW corner of the Sevilleta National Wildlife Refuge. The Sierra Ladrones Formation may be as much as 1100 m thick under La Jencia Creek. Northeast transported piedmont gravels (QTsp) cap the rim of La Jencia Creek and locally define the original paleovalley walls of La Jencia Creek where the gravels are inset against nearly horizontal mudstones and sandstones beds of the underlying basin floor facies (QTsb).

Groundwater in La Jencia Basin is largely untapped, except for a few stock wells and one irrigation well SE of the La Jencia playa. Poorly cemented and moderately sorted piedmont gravels of the Sierra Ladrones Formation are the most likely aquifer below the La Jencia playa. Much of the spring flow along San Lorenzo Canyon probably represents overflow from the totally saturated La Jencia Basin and perennial recharge of Holocene arroyo sands (Qa/Qvy) from sandstone aquifers in the Popotosa Formation. Coarse conglomeratic units in the Popotosa Formation are typically well cemented with carbonate or silica and probably represent poor aquifers, except for local fracture permeability. Sandstones in the upper Popotosa Formation (Tps) are commonly friable or poorly cemented and probably represent the best aquifer zones in the Popotosa Formation.

Quaternary faulting is not evident in the San Lorenzo Spring quadrangle. However, graded piedmont slopes underlain by the upper Sierra Ladrones Formation (Qsp) appear to reflect slight westerly tilting (~1°) of the La Jencia Basin in middle to late Pleistocene time. Graded surfaces on the east flank of the basin are anomalously steep (~2°) and those on the west flank are anomalously shallow (~1/2°). Westward tilting in Pleistocene time is presumably associated with inflation of the mid-crustal Socorro magma body and/or tectonic tilting associated with active faults that bound the Lemitar uplift and the western margin of the La Jencia Basin.

DESCRIPTION OF MAP UNITS:

POST-SANTA FE GROUP UNITS

Qa **Active channel deposits** (upper Holocene) Active channel deposits of larger tributaries to the Rio Grande; includes San Lorenzo Arroyo, La Jencia Creek, Canoncito de las Cabras, and Canoncito del Lemitar. Sand, gravel and minor mud; includes small bedrock lentils in drainage bottoms. Springs are commonly associated with bedrock exposures in floor of San Lorenzo Arroyo. Thickness 0-10m.

Qpl **Playa lake deposits** (Holocene to Pleistocene)—Unconsolidated mud, silt and sand in the playa lake depression of the central La Jencia Basin. Depression probably formed by ongoing southwest tilt of the La Jencia Basin (tilted fault block) combined with northeast progradation of the Water Canyon alluvial fan in middle to late Pleistocene time. Probably 10-20 m thick.

Qe **Eolian deposits** (Holocene to middle Pleistocene) — Light gray to pale red, fine-grained, well-sorted, wind-blown sand and loess. Small dune fields locally cap older surfaces at slope breaks east of the La Jencia playa and east of La Jencia Creek. Thin eolian sand veneers (<0.3m), on graded piedmont slopes, are mapped as piedmont deposits (i.e. Qpy, Qpo) . Thickness range: 0–3 m.

Qc **Colluvium and minor alluvium** (Holocene to lower Pleistocene) — Blocky angular talus, colluvium and minor alluvium on steep to moderate slopes in the Lemitar Mountains. Hogbacks of welded tuff are the primary source of loose angular debris on steep slopes. Includes large slide blocks in floor of upper San Lorenzo Canyon that lie on alluvium. Also includes minor gravelly slope wash on erosion surfaces cut in poorly consolidated deposits of the Popotosa Formation. Colluvial soils (fine platy slope wash on La Jara Peak lavas and cobbly lag gravels on Popotosa conglomerates) are more widespread than shown on map. Qc is shown primarily

	where it masks important structural or stratigraphic relationships. Usually 0.3-3 m. thick, locally as much as 10 m. thick.
Qvy	**Younger valley alluvium** (Holocene to uppermost Pleistocene) — Low terrace and alluvial-fan deposits of arroyos tributary to San Lorenzo Arroyo, Canoncito de las Cabras, Canoncito de Lemitar and La Jencia Creek. Includes active alluvial deposits in narrow drainages. Consists of poorly sorted, nonindurated, volcanic-rich sandy gravel, sand, silt, and clay. Associated with low graded surfaces formed during last major episode of valley entrenchment and backfilling. Thickness 0–20 m.
Qpy	**Younger piedmont-slope alluvium** (Holocene to upper Pleistocene)— Pebbly to sandy alluvial fan and arroyo-fill deposits on piedmont slopes. Graded to the closed basin floor at La Jencia basin playa. Probably less than 10 m thick
Qvo	**Older valley-fill alluvium** (middle to upper Pleistocene) — High level terrace and terrace-fan deposits of tributary arroyos associated with valley entrenchment and backfilling in the Socorro Basin controlled by changing base levels of the Rio Grande. Most units occur 10-30 m above modern drainages; oldest deposits occur about 50 m above grade at valley margins of western San Lorenzo Arroyo. Consists of poorly to moderately sorted volcanic-rich gravel, gravelly sand and muddy silts. Mostly nonindurated, however, uppermost beds beneath graded surfaces are poorly to moderately cemented by pedogenic carbonate horizons and basal beds are locally cemented by groundwater carbonate. 0–30 m thick, average thickness 6–9 m.
Qtg	**Terrace gravels** (middle to upper Pleistocene)—Cobbly volcanic-rich gravels capping small hills and ridges about 30-40 m above La Jencia Creek. Recycled from QTsp gravels. Some gravels represent initially inset terraces along La Jencia Creek, others represent fills of small arroyos tributary to La Jencia Creek. 0-3m thick.

Qpo **Older piedmont-slope alluvium and eolian deposits (**middle to upper Pleistocene)— Pebbly to sandy alluvial-fan and arroyo-fill deposits. Graded to central La Jencia Basin. 0-5m thick.

SANTA FE GROUP

Intermontane basin fill of the Rio Grande rift. As redefined by Machette, 1978, includes the Pliocene and Pleistocene valley and bolson fill of the Sierra Ladrones Formation (Machette, 1978; upper Santa Fe Group of this report), and Miocene bolson fill of the Popotosa Formation, named by Denny, 1940 (lower Santa Fe Group of this report).

UPPER SANTA FE GROUP:

Qs/QTs_ **Sierra Ladrones Formation** (lower Pleistocene to Pliocene) —Late-stage sedimentary fill of the La Jencia Basin; characterized by conglomeratic piedmont facies (QTse, QTsp) derived from adjacent mountains ranges, a fine-grained basin-floor facies (QTsb), locally exposed along La Jencia Creek valley, and several buried calcic soil horizons (QTc) and a minor axial-stream facies (QTsa). East-derived piedmont facies (QTse), at the east margin of the La Jencia Basin lies in angular unconformity on strongly west-tilted Popotosa beds. Younger west-derived piedmont gravels exposed along the rim of La Jencia Creek (QTsp) conformably overlie nearly horizontal basin-floor mudstones and sands (QTsb). Maximum thickness of Sierra Ladrones Formation in the western La Jencia Basin is probably about 1000 m.

Qsa **Sierra Ladrones Formation, axial alluvium, upper** (lower Pleistocene)—Poorly sorted muddy sands, mud, and well-sorted fine eolian sands. Similar to QTsb but younger than Qc. Underlies gentle NNE slope to east of La Jencia Creek. 0-3 m thick.

Qsc **Sierra Ladrones Formation, calcic soil horizon, upper** (lower Pleistocene) — Calcic soil horizon about 30-60cm thick, commonly caps or is interbedded in Qsp deposits on lower piedmont slopes. Tentatively correlated with the Las Canas surface of McGrath and Hawley, 1987. Shown as a solid line on the rim of La Jencia Creek valley (see explanation of map symbols).

Qsp **Sierra Ladrones Formation, piedmont facies, upper (**lower Pleistocene)— Pebbly to sandy alluvial-fan deposits, arroyo-fill deposits and interbedded fine-grained eolian sands. Deposits were graded from Red Mountain to floor of La Jencia Basin prior to incision along San Lorenzo Arroyo and La Jencia Creek (early Pleistocene time). Basal beds probably conformable on QTsp. Graded slopes indicate paleocurrent directions. Steeper slopes (~2°) on east flank of La Jencia Basin probably reflect about 1° westerly tilt in middle to late Pleistocene time. Thin veneers of upper Pleistocene eolian sands are generally not mapped separately. Exposed thickness less than 30 m.

QTsp **Sierra Ladrones Formation, older piedmont facies, west derived** (lower Pleistocene) — Medium to dark gray, mostly unconsolidated to poorly consolidated (locally consolidated in soil profile), volcanic-rich gravels mixed with sparse granite, quartz arenite, and limestone cobbles. Black vesicular basalt clasts are also common. Coarse clast-supported cobble beds are dominant, pebbly lenses less common, and some gravels are cross bedded. Locally intercalated with fine-grained sands and muds typical of the basin-floor facies (QTsb) along the east rim of La Jencia Creek valley. One coarse gravel bed is also inset against QTsb mudstones at the SE rim of La Jencia Creek valley (southeast bank of paleochannel is mapped). Northeasterly paleocurrents and clast lithologies are consistent with a source area in the northern Magdalena Mountains and the southern Bear Mountains (i.e. an ancestral La Jencia Creek). Thickness about 3-12 m.

QTse **Sierra Ladrones Formation, older piedmont facies, east derived** (Pliocene to lower Pleistocene)—Pale red to light brown, poorly to moderately consolidated, volcanic-rich, pebbly gravels, angular gravels (grits), and conglomeratic sandstones. Heterolithic conglomerates and gravels are lithologically very similar to the underlying upper Popotosa conglomeratic sandstones (Tpcu). Moderately west dipping Sierra Ladrones beds (7-13°) lie in sharp angular unconformity on the steeply west dipping upper Popotosa beds (40-45°). Westerly paleocurrents indicate a source area in the Silver Creek uplift (i.e. north-trending volcanic ridge at Rock VABM and east of Silver Creek). Maximum exposed thickness about 90 m.

QTc **Sierra Ladrones Formation, older carbonate beds** (Pliocene to lower Pleistocene)— Light gray to white, massive, vuggy and locally banded, carbonate beds. Commonly contain dispersed sand grains. 0.3-2 m thick. Interpreted as calcic and petrocalcic horizons of buried soils (paleosols). Mapped as lines (marker beds); interbedded in the basin-floor facies (QTsb).

QTsb **Sierra Ladrones Formation, basin-floor facies** (Pliocene to lower Pleistocene) — Light gray sand to poorly cemented sandstones and interbedded pale red to red mudstones. Bedding is tabular to indistinct; poorly cemented nodular sandstones probably associated with weakly developed soils. Sands are mostly fine grained and may be partly eolian. Maximum exposed thickness in La Jencia Creek valley is 60-70m.

QTsa **Sierra Ladrones Formation, axial stream facies** (Pliocene to lower Pleistocene) —Light gray pebbly conglomeratic sandstone and sandstone, minor beds in lower QTsb. Northeast paleocurrents, location, and heterolithic clast suite suggest this is an early ancestral La Jencia Creek deposit. 0-1 m thick.

LOWER SANTA FE GROUP:

Tp_ **Popotosa Formation** (lower to upper Miocene; basal graben fills may be latest Oligocene?)— Intermontane bolson fill deposits of early Rio Grande rift grabens and "half" grabens (tilted fault blocks). Defined by Denny, 1940, and redefined by Machette, 1978. Can locally be divided into lower conglomeratic piedmont facies (Tpx, Tpd, Tpc) and upper conglomeratic piedmont facies (Tpcu) on the basis of clast suites (cf. Bruning, 1973) and relative stratigraphic position to dated lavas and ash beds. The 15.4-Ma "Silver Creek Andesite" (Chamberlin and McIntosh, unpublished data) and several water-laid ash beds (0-3 m thick) that include pumiceous sandstones (15.6- 14.5 Ma; Cather et.al., 1994; Cather and Read, 2003) are interbedded in the medial to upper Popotosa Formation. Thin fall deposits are also present, but less visible than water-laid beds. The dated strata indicate a middle Miocene age for the medial and upper Popotosa Formation in the area northwest of Red Mountain (upper San Lorenzo Arroyo); correlative water-laid ash beds occur in the Canoncito de las Cabras area of the Lemitar quadrangle (Chamberlin et.al, 2001). An angular unconformity of 10–25 degrees is evident at the base of the lower Popotosa Formation in the southern Lemitar Mountains; this angularity generally decreases northward. Basal Popotosa debris flows and conglomerates are widely potassium metasomatized and often very well indurated with jasperoidal silica (Chapin and Lindley, 1986; Dunbar et al, 1994; Dunbar and Miggins, 1996; Chamberlin and Eggleston, 1996, Lueth et.al, 2004). Metasomatic adularia in the lower Popotosa near Socorro Canyon, 20 km to south, yields a ^{40}Ar/ ^{39}Ar age of 7.4 ±0.1 Ma (Dunbar and Miggins 1996). Field relationships in the San Lorenzo Canyon area suggest that metasomatism and hydrothermal alteration may be significantly older in this area (e.g. late Oligocene to early Miocene). Presently undated rhyolitic ash beds also occur in the lower Popotosa conglomerates. Assuming an unbroken floor to the La Jencia Basin, the projected thickness of the Popotosa Formation is about 4 to 5 km (cf. Cather and Read, 2003; section A-A'). However, map data in the San Lorenzo Spring quadrangle implies the floor of the La Jencia Basin (top of Oligocene volcanic pile) is probably broken by several down-to the-east normal faults that are concealed by upper

Popotosa strata. Assuming concealed faults, the Popotosa Formation is more likely to be about 2 km thick under the central La Jencia Basin. Lower Popotosa conglomerates and debris flows at Red Mountain have an aggregate exposed thickness of about 600-700 m.

Tpcu **Popotosa Formation, upper, conglomeratic sandstone facies** (middle to upper Miocene) — Light brownish gray to light gray, heterolithic conglomeratic sandstones, sandstones and minor mudstones. Characterized by wide variety of volcanic pebbles and minor cobbles representing the entire middle Tertiary volcanic pile; locally contain minor non-volcanic clasts. Conglomeratic beds are usually well cemented by carbonate. Conglomerate beds are commonly clast supported; low-angle trough crossbeds (cut and fill) and planar beds are common. Two alluvial systems of different provenance are evident. One occurs northwest of Red Mountain and the other northeast of San Lorenzo Spring. Northwest of Red Mountain, crystal-rich and crystal-poor ignimbrite pebbles (Hells Mesa-type and La Jencia type) are relatively common (5-10%) as are vesicular mafic lavas. Northeasterly paleocurrents and clast lithologies are consistent with a deeply dissected source highland near Magdalena. Northeast of San Lorenzo Spring, medium brown, crudely bedded, heterolithic pebbly conglomerates and conglomeratic sandstones exhibit easterly paleocurrent directions. The steeply west dipping, volcanic-rich conglomerate beds also contain sparse pebbles of fine-grained yellow brown quartz arenite (Dakota Sandstone?), laminated siltstones, and limestones, which suggest a source area on the southeastern Colorado Plateau (perhaps an ancestral Rio Salado fan system). Both fan systems appear to occur stratigraphically above or interbedded with middle Miocene ash beds that have been dated in the Silver Creek quadrangle (Cather and Read, 2003).

Tps **Popotosa Formation, sandstone facies** (lower to upper Miocene)— Light-gray, light brownish gray, pale red and reddish orange, planar bedded to low-angle cross bedded, sandstones with less abundant conglomeratic sandstones and subordinate mudstones. Sandstone intervals, generally too thin to map (<10m), locally mark progradational surfaces between conglomeratic fan lobes in the lower Popotosa Formation. Reddish orange to brown sandstones that occur in a fault bounded wedge northeast of "Query spring" contain several thin light-gray ash falls. (*"Query spring" is located approximately 1.6 km ENE of San Lorenzo Spring; a* **"?"** *is painted on the adjacent cliff of Vicks Peak Tuff*). A thin conglomeratic sandstone bed, with rare clasts of "moonstone-bearing tuff "(Tsc?), and a thin basaltic andesite debris flow bed are also present in the reddish orange sandstones near "Query spring". The reddish orange sandstones appear to project under Oligocene basaltic-andesite lavas (Tl_1) on the west wall of this valley, but contacts are obscured by colluvium. Lithologies described above indicate these are probably Popotosa beds that were faulted down to the east against the basaltic andesites. Popotosa sandstones are generally interpreted as braided stream deposits on distal piedmont slopes. Sandstone intervals are probably the best aquifers in the Popotosa Formation, because they tend to be less cemented than the coarser conglomeratic units. As much as 150-200 m thick NW of San Lorenzo Spring.

Tpm **Popotosa Formation, mudstone facies** (lower to upper Miocene)—Mostly pale red mudstones with thin bedded light-gray siltstones and minor fine- to coarse-grained sandstones, rarely conglomeratic. Eruption of the small Silver Creek shield volcano (Tbs) presumably interrupted northeasterly stream flows and caused mudstones to pond against its southwestern flank. This scenario explains the relatively thick interval of mudstones (~100 m) above the Silver Creek Andesite (Tas). Mudstones are poorly indurated and commonly masked by colluvium where they underlie Quaternary gravels. Generally less than 100m thick.

Tbs **Basaltic Andesite of Silver Creek** (middle Miocene) —Medium to dark gray, massive to vesicular, basaltic andesite lava with sparse fine phenocrysts (0.5-2mm) of olivine and plagioclase, also traces of quartz (xenocrysts?). Represents southern distal margin of a small basaltic andesite shield volcano centered in the Silver Creek quadrangle ("Silver Creek Andesite" of Cather and Read, 2003). Thin discontinuous flow lobes rest conformably on lower Popotosa conglomerates (Tpc_3) and are conformably overlain by medial Popotosa mudstones (Tpm). Weber, 1971, informally named the "Silver Creek basaltic andesite" and published a K/Ar age of 16.2 ± 1.5 Ma for this small shield volcano, which is now interbedded within the Popotosa Formation. A basaltic feeder dike and distal flow unit of the Silver Creek volcano yield $^{40}Ar/^{39}Ar$ ages of 15.49 ± 0.20 Ma and 15.33 ± 0.07 respectively (Chamberlin and McIntosh, unpublished data). Chemical analyses indicate a basaltic trachyandesite composition (53.6 % SiO_2, 4.5% Na_2O and 2.4 % K_2O; Chamberlin unpublished data). Thin southerly flowing lobes terminate NW of San Lorenzo Spring. 0-6m thick.

Tpc_ **Popotosa Formation, lower, conglomerates and conglomeratic sandstone facies** (lower to middle Miocene)— Pale reddish gray, purplish gray, light gray and light brownish gray conglomerates and conglomeratic sandstones. Conglomerates are mostly clast supported and crudely bedded to planar bedded. Three distinct sub-units (overlapping fan lobes?) are present northwest of San Lorenzo Spring. The lowest unit consists of pale red to purplish gray, basaltic-andesite dominated conglomerates with sparse vein quartz and white felsite clasts (Tpc_1). A medial sub-unit consists of pale red conglomerates that contain subequal South Canyon Tuff and basaltic andesite clasts (Tpc_2). The highest unit is a light to medium brown boulder to pebble conglomerate containing dominantly South Canyon Tuff clasts with less abundant basaltic andesites and sparse flow-banded rhyolites (Tpc_3). Tpc_3 also contains red mudstone and sandstone beds about 2-3m thick. All these conglomerate sub-units underlie the 15.4-Ma Silver Creek Andesite. Another light brown conglomeratic sandstone unit (Tpc4) is similar to a mixture of Tpc_3 and Tpc_1. Tpc_4 occurs stratigraphically above the Silver Creek Andesite and appears to grade southwards into another Tpc_1 type conglomerate. Sub-units 0- 200 m thick.

Tpd_ **Popotosa Formation, lower, debris-flow and conglomerate facies** (lower to middle Miocene)—Mostly well indurated, medium reddish brown to dark red, volcanic-rich, matrix supported, debris flows, conglomerates and minor fluvial conglomeratic sandstones. Commonly well cemented by red jasperoidal silica; but some red clayey cemented debris flows also form poorly exposed zones. Light gray poorly cemented zones also occur rarely. Cobble sized clasts are common; boulder beds occur locally near the base. Locally divided into three overlapping sub-units based on the dominant type of volcanic clasts. Deposits dominated by gray, iddingsite-bearing La Jara Peak Basaltic Andesite clasts are designated Tpd_1; deposits dominated by light-gray South Canyon Tuff clasts are designated Tpd_2; and deposits dominated by andesite porphyry clasts (Tar-type) are designated Tpd_3. Sub-units grade laterally from one composition to another where facies boundaries are shown; debris-flow units also grade laterally into compositionally equivalent conglomerates. Units fill narrow north-trending fault-block depressions in the western and central Lemitar Mountains; northerly paleocurrents are dominant here. In the transverse graben south of San Lorenzo Canyon, paleocurrent directions are locally to the west. Thickness of wedge-shaped fills is highly variable, from 0–300 m.

Tpx_ **Popotosa Formation, scarp-derived colluvial breccias and debris-flow deposits** (upper Oligocene to lower Miocene?)—Coarse, blocky, volcanic-derived, monolithic breccias and matrix-supported conglomerates preserved in narrow fault-block basins of the early Rio Grande rift. Often well cemented by red silica. Volcanic clasts typically match the lithology of immediately underlying volcanic unit. However, the volcanic source unit is often missing on the adjacent footwall block, which implies significant erosion of the uplifted footwall prior to deposition of stratigraphically higher Popotosa beds. Sub-units are distinguished by clast lithology: basaltic-andesite (Tpx_1), South Canyon Tuff (Tpx_2) and Tar-type andesite porphyry (Tpx_3). Basal breccias are 10-20m thick; breccias and debris flows as much as 100 m thick.

Tpu **Popotosa Formation, undivided** (lower to middle Miocene)— Poorly exposed Popotosa conglomerates and conglomeratic sandstones on west flank of Lemitar Mountains. Rounded hills are generally mantled with colluvial soils that contain abundant volcanic cobbles and pebbles.

EOCENE-OLIGOCENE VOLCANIC ROCKS OF MOGOLLON-DATIL FIELD:

Note: Oligocene tuffs in the Lemitar Mountains are commonly potassium metasomatized; phenocrystic plagioclase is typically replaced by metasomatic adularia and clay minerals; sanidine and biotite are usually not altered. Stratigraphic nomenclature of Eocene-Oligocene volcanic rocks is from Osburn and Chapin, 1983.

Tsc **South Canyon Tuff** (upper Oligocene)—Partially to densely welded, light gray to pale grayish red, phenocryst-poor to moderately phenocryst-rich, pumiceous, high silica rhyolite ignimbrite. Medium grained (1–3 mm) phenocrysts of subequal quartz and sanidine, with traces of biotite and plagioclase; crystals progressively increase upwards from about 5% near partly welded base to as much as 25% near densely welded top (where preserved). Sanidine commonly shows blue chatoyancy (i.e. moonstones). Partially welded, phenocryst-poor, pumiceous basal zone is commonly about 30m thick and grades upwards into densely welded moderately crystal-rich zone. Generally lithic poor except near base; light gray pumice (1–5 cm) is moderately abundant (5-15%). Represents remnants of 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 ranges from 0-90 m. Absent in northern Lemitar Mountains and San Lorenzo Canyon area.

Tar **Andesitic lavas at Red Mountain and "Rock VABM"** (upper Oligocene) —Ridge-forming, medium gray to light gray and purplish gray, andesite porphyry lavas characterized by sparse to moderately abundant (~3-10%) phenocrystic plagioclase (1-4mm), usually accompanied by sparse medium-grained (2-4mm) pyroxene and olivine (or iddingsite) phenocrysts. Flows east of Red Mountain also contain phenocrystic quartz. Flow unit 0.5 km north of San Lorenzo spring is distinctly less porphyritic than the flow unit 1.1 km north of the spring. Andesitic flows conformably overly the upper La Jara Peak tongue (Tl_3) in the northwestern Lemitar Mountains and along the ridge at Rock VABM (Silver Creek Quadrangle). Locally preserved in narrow half-graben basins that are capped by basal Popotosa scarp-derived breccias and debris flows (Tpx). Also notably absent on adjacent footwall blocks where removed by Miocene erosion at the base of the Popotosa Formation. Massive ridge-forming flows are about 20-30m thick, locally as much as 60m thick. Absent in eastern and southern Lemitar Mountains.

Tds/Tvs **Dacitic lava and vent complex at San Lorenzo Spring** (upper Oligocene)— Ridge-forming, purplish gray, bluish gray and gray, massive to weakly flow banded, phenocryst-poor lava flow (Tds). Maximum thickness of flow is about 30 m; it extends about 500m along strike to the north and south of San Lorenzo Spring. Phenocryst assemblage is quite variable and suggests a hybrid or zoned magma. Locally contains sparse fine- to medium-grained (1-4 mm) phenocrysts of green olivine, red iddingsite, pyroxene, amphibole, plagioclase, blue (chatoyant) sanidine, biotite, and quartz. Weak flow banding suggests a dacitic bulk composition. Bluish-green celadonite locally occurs in finely vesicular (vuggy) zones. ENE-striking sinistral shear veins (jasper and late-stage calcite) cut the dacitic flow and are well exposed just north of the spring waterfall. Dacitic lava overlies typical La Jara Peak lavas (Tl_3) and red andesitic sandstones well exposed below the waterfall. The southern margin of the dacitic flow butts against 30-40m of brick red, bedded scoria, which is overlapped by light gray argillized ash beds and a silicified breccia bed, 1-3m thick, that contains distinctive angular clasts of flow-banded dacitic lava. Ash beds and breccia extend northwards over the dacitic lava. A short west-trending dike (280) appears to feed basaltic-andesite lava at the west flank of the scoria beds. These mafic tephras, dacitic breccias, and associated ash beds are collectively mapped as the vent complex at San Lorenzo Spring (Tvs). The vent complex is a source for mafic units, but is not clearly a source for the dacitic lava, although a nearby dacitic vent is likely. The southern margin of the vent complex is overlapped by iddingsite and olivine-bearing lavas of the upper La Jara Peak Basaltic Andesite (Tl_3).

Tlp **La Jara Peak Basaltic Andesite, middle and upper tongues undifferentiated** (upper Oligocene)—Basaltic andesite lavas equivalent to Tl_2 and Tl_3 in the area north of San Lorenzo Canyon, where the Lemitar Tuff is missing. A black basalt about 1 km NNE of San Lorenzo Spring is tentatively correlated with the base of $Tl_{3.}$ The La Jara Peak Basaltic Andesite represents a widespread thick pile of alkaline basaltic lavas that accumulated on the SE margin of the Colorado Plateau in upper Oligocene time (Osburn and Chapin, 1983). The pile is locally divided into tongues where thin ash-flow sheets are intercalated with the basaltic pile. Wedge-shaped prisms of basaltic lavas in Lemitar Mountains indicate they were erupted contemporaneously with early extension and domino-style block rotation in the Lemitar Mountains (Chamberlin 1983; Cather, et. al., 1994).

Tl_3 **La Jara Peak Basaltic Andesite, upper tongue** (upper Oligocene)— Mostly medium gray to purplish gray, massive and platy to vesicular basaltic andesite lavas characterized by moderately abundant (5–10%) fine- to medium-grained phenocrysts of olivine, usually altered to reddish brown iddingsite. Phenocrystic plagioclase is typically absent. A black to medium gray olivine-bearing basalt is often present immediately above the Lemitar Tuff and locally helps define the base of the upper La Jara Peak tongue where the Lemitar Tuff is absent north of San Lorenzo Canyon. Thin flows (3-6m) commonly exhibit vesicular tops and reddish basal zones. In the northern Lemitar Mountains and San Lorenzo Canyon area, the upper flows are commonly interbedded with grayish to reddish brown, fine-grained sandstones that occasionally contain thin light-colored ash beds. Monolithic debris flows that contain only basaltic andesite clasts are also interbedded with mafic lavas in the northern Lemitar Mountains and San Lorenzo Canyon area. These basaltic-andesite debris flows are rare and of minor volume, in contrast with thick wedges of mafic (andesitic to basaltic) debris flows in the lower Popotosa Formation that are not intercalated with lavas. In the Lemitar Mountains, Tl_3 is older than South Canyon Tuff and younger than the Lemitar Tuff. Thickness of wedge-shaped prism usually ranges from 60-330 m; unit is locally truncated by paleovalley fills in the lower Popotosa Formation at the Red Mountain fenster.

Tlu/Tll **Lemitar Tuff; upper and lower members** (upper Oligocene)—Compositionally zoned (77 –65 wt% SiO_2), ignimbrite subdivided into a partially to densely welded, light gray, phenocryst-poor (5-15%), rhyolite lower member (Tll), and densely welded, red to grayish red, phenocryst-rich (30–45%), dacitic to rhyolitic upper member (Tlu). Contains sparse to abundant, medium-grained (1-4 mm) phenocrysts of quartz, sanidine, plagioclase (altered), 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 clots” of dacite/andesite porphyry are typical in outflow of the upper member. Basal vitrophyre often occurs where the lower member is absent. Represents outflow sheet erupted from the Hardy Ridge caldera in the west-central Magdalena Mountains (G. R. Osburn oral commun. 1997, Chamberlin et al, 2004). Lower member (< 40 m) and upper member (< 50 m) locally wedge out onto paleotopographic highs. “V” indicates vitrophyre at base of Tlu. Lemitar Tuff fills in tilted early rift fault blocks in the Lemitar Mountains (Chamberlin, 1983). Mean ^{40}Ar/^{39}Ar age (bulk sanidine) is 28.00 ± 0.08 Ma ; paleomagnetic polarity is normal (McIntosh and others, 1991). Correlation here based on distinctive lithology and stratigraphic position. Thickness in wedge-shaped paleovalleys ranges from 0-90 m; absent north of San Lorenzo Canyon.

Tl_2 **La Jara Peak Basaltic Andesite, medial tongue** (upper Oligocene)—Mostly medium to dark gray and purplish gray, platy to vesicular, fine-grained basaltic andesite lavas generally characterized by sparse small reddish brown phenocrysts of “iddingsite” (oxidized and hydrated olivine). Represents many thin flows (~ 40), stacked one on another, commonly with vesicular tops and reddish basal zones. Amygdaloidal calcite is common in vesicular zones. Occurs between Lemitar Tuff and Vicks Peak Tuff. Thickness of wedge-shaped prisms ranges from 75-210 m, over west-tilted fault blocks of the early Rio Grande rift (Chamberlin, 1983). Locally absent in southwestern Lemitar Mountains.

Tv **Vicks Peak Tuff** (upper Oligocene)— Cliff-forming, brown to light brownish gray and light gray, phenocryst poor, pumiceous, densely welded rhyolite ignimbrite. Distinctive aspects include craggy cliff-forming character, pervasive well developed compaction foliation, and large “sandy” (vapor phase) pumice lapilli as much as 30 cm long. Contains 1–5 percent phenocrysts of sanidine and sparse quartz. Represents outflow sheet erupted from the Nogal Canyon caldera in the southern San Mateo Mountains (Osburn and Chapin, 1983). Mean ^{40}Ar/^{39}Ar age is 28.56 ± 0.06 Ma; paleomagnetic polarity is reverse (McIntosh and others, 1991). Correlation here based on lithology and relative stratigraphic position. 60-75 m thick.

Tl$_1$ **La Jara Peak Basaltic Andesite, lower tongue** (upper Oligocene)—Medium gray to purplish gray, basaltic andesite lavas characterized by sparse small reddish brown phenocrysts of “iddingsite” (oxidized and hydrated olivine), locally represents stacked flows. Thickness variations define relative up and down relationships of early rift normal fault blocks (Chamberlin, 1983). Locally includes 0-6m of rhyolitic volcaniclastic sandstones at the base of this unit near Canoncito de Lemitar and east of Red Mountain. Upper part commonly masked by colluvium from overlying Vicks Peak Tuff. 0-60 m thick.

Tj **La Jencia Tuff** (upper Oligocene)—Light gray, pale red and grayish red, phenocryst poor, rhyolite ignimbrite, characterized by gray massive basal zone and a medial zone of very densely welded rheomorphic (flow banded) ignimbrite. Flow-banded core grades to normal eutaxitic ignimbrite near base and top. Locally displays auto-intrusive relationships near probable Oligocene fault (low-angle fault) in SE Lemitar Mountains. Contains sparse (3–5%) phenocrysts of sanidine and quartz with traces of plagioclase and biotite. Represents outflow sheet erupted from the composite Sawmill Canyon caldera in the west-central and eastern Magdalena Mountains (Osburn and Chapin, 1983). Mean ^{40}Ar/^{39}Ar age from bulk sanidine separate is 28.85 ± 0.04 Ma; paleomagnetic polarity is reverse (McIntosh and others, 1991). Correlation here based on distinctive lithology and relative stratigraphic position. Locally buries NNW-trending early rift fault in area northeast of Red Mountain, where flow banded zone dips anomalously to the east. As much as 120-150 m thick in Lemitar Mountains

Tz **Tuff of Luis Lopez Formation** (upper Oligocene) — Light brownish gray to light gray, nonwelded to poorly welded, pumiceous, lithic-rich, rhyolitic ignimbrites. Pale orange gray upper zone locally appears to be fused to light gray densely welded basal zone of the La Jencia Tuff. Contains moderately abundant pumice (mostly aphyric), and sparse to moderately abundant small lithic fragments in crystal-poor rhyolitic matrix. Lithic fragments consist primarily of andesite porphyries and rare crystal-rich, quartz-rich, Hells Mesa Tuff clasts. Medial tuffs of Luis Lopez Formation were erupted from a small collapse structure partly exposed in the Northern Chupadera Mountains approximately 15 km south of the Lemitar Mountains (Chamberlin et al., 2004). Samples from Chupadera Mountains yield mean single-crystal sanidine ^{40}Ar/ ^{39}Ar age of 30.04± 0.16 Ma. Correlation based on lithology and stratigraphic position. Commonly masked by colluvium from the overlying La Jencia Tuff. Thickness approximately 10-30 m.

Th **Hells Mesa Tuff** (lower Oligocene)—Mostly pale reddish to purplish gray, densely welded, phenocryst-rich (40–50%), quartz-rich, rhyolite ignimbrite. Typically contains abundant medium grained (1–3 mm) phenocrysts of sanidine, plagioclase, quartz and minor biotite. Quartz is minor component (1-2%) only in thin basal zone. Mean ^{40}Ar/ ^{39}Ar age (bulk sanidine) is 32.06 ± 0.1 Ma; paleomagnetic polarity is reverse (McIntosh et al. 1991). Large volume ignimbrite (1200 km^3) erupted from Socorro caldera (Chamberlin et. al, 2004: McIntosh et. al., 1991). Correlation is based on distinctive lithology and relative stratigraphic position. Thickness range is 90-150 m.

Tg **Tuff of Granite Mountain** (lower Oligocene)— Grayish red to light brownish gray, non-welded to densely welded, moderately pumiceous, phenocryst-rich, dacitic to rhyolitic ignimbrite. Contains abundant medium-grained phenocrysts (35-45%) of predominantly plagioclase (commonly replaced by adularia), with minor biotite, sanidine, altered hornblende and clinopyroxene (?), with traces of embayed quartz (<0.2%). Small lithics of andesitic composition are sparse to moderately abundant in thin zones; thin argillized fall deposits locally occur near base. The absence of, or only trace amounts of phenocrystic quartz, distinguish the Tuff of Granite Mountain from the overlying quartz-rich Hells Mesa Tuff. Represents undated, small to moderate volume early ignimbrite sheet of Socorro-Magdalena region (Osburn and Chapin, 1983). Source area unknown, possibly erupted from a small vent structure in Magdalena Mountains area that was later obliterated by the Socorro caldera. Correlation based on lithology and relative stratigraphic position. Usually 30-40m thick; appears to be absent north of San Lorenzo Canyon.

Ts **Spears Formation** (upper Eocene)— Purplish gray, light brownish gray and light gray conglomerates, sandstones, siltstones and reddish mudstones derived from intermediate composition volcanic highlands, primarily to southwest of Lemitar Mountains. Subrounded to subangular dacite and andestite porphyry clasts range from boulders to pebbles; they are common in lenticular to tabular conglomeratic beds, usually 1-3m thick. Dacitic clasts are characterized by sparse to abundant phenocrysts of plagioclase, hornblende and biotite; andesitic clasts are typically plagioclase, pyroxene porphyries. Gray micritic limestone and red siltstone cobbles and pebbles are common in basal conglomerates (lowest 30m). Medium-grained pyroxene monzonite and dark gray, aphanitic basaltic andesite (?) clasts occur sparsely in the upper half of the formation. Calcite and pinkish clays are dominant cements; chalcedonic quartz is relatively rare. Age range from K/Ar dates of volcanic clasts and interbedded tuffs is approximately 39-33 Ma (Osburn and Chapin, 1983). Correlation based on lithology and relative stratigraphic position. Thickness ranges from 120-330m in western Lemitar Mountains. Locally absent north of San Lorenzo Canyon.

CONGLOMERATES ASSOCIATED WITH LARAMIDE UPLIFT:

Tb Baca Formation (Eocene)— Grayish to reddish brown, limestone- and sandstone-clast conglomerates and conglomeratic sandstones are dominant lithology in the western Lemitar Mountains. Trough and tabular bedded conglomerates appear to fill shallow paleovalleys cut in underlying Paleozoic formations. Non-volcanic character and position, at base of Eocene Spears Formation, implies correlation with Baca Formation. In footwall of the Puerto fault (NE Lemitar Mountains), the Baca Formation consists of brick-red, cobble to boulder conglomerates, dominated by granitic clasts. Field relationships suggest that the Puerto fault was a Laramide reverse fault (upthrown on the north), that has been reactivated as a major transverse normal fault in Neogene time. 0-30m thick.

TERTIARY INTRUSIVE ROCKS:

Tia **Andesitic intrusion** (upper Miocene to Pliocene?)—Medium-dark gray to purplish gray, andesitic dike and sill-like mass southwest of Red Mountain. Fine-grained, aphanitic intrusive contains rare phenocrysts of plagioclase and pyroxene (2-3mm), consistent with an intermediate composition. Flaggy flow banding is common and suggests an intermediate to silicic composition. Narrow NNW-striking dike cuts Popotosa Formation and appears to feed thin sill-like body in a low-angle normal fault south of Red Mountain. Lithology and structural relationships suggest this undated intrusion is probably of middle to late Miocene age.

Tib **Biotite-rich mafic dike** (late Oligocene to Miocene?)— Medium gray, biotite-rich mafic dike, tentatively classified as an altered minette, about 1 m wide. Contains moderately abundant (10-15%) platy phenocrysts of biotite, some as large as 5mm. Also contains about 5% small euhedral Fe-Mg phenocrysts (1-2mm) altered to chlorite and hematite.. Cuts Vicks Peak Tuff and medial La Jara Peak Basaltic Andesite member in area north of San Lorenzo Canyon. Locally fills low-angle fault in basaltic andesite lavas. Similar biotite-bearing mafic dikes occur in east central Lemitar Mountains (Chamberlin et al. 2001)

PALEOZOIC STRATA:

Pba **Bursum and Abo Formations, undivided** (lower Permian, Wolfcampian)—Gray, thin bedded micrites and pale reddish mudstones. Grades upwards into reddish brown to light gray conglomeratic sandstones and mudstones. Quartz and granite pebbles are abundant in the conglomeratic sandstones. Locally truncated by Eocene erosion surface associated with Laramide uplift. 0-60m thick.

Pb **Bursum Formation** (lower Permian, Wolfcampian)— Pale red, arkosic sandstones and conglomeratic sandstones; interbedded with light gray thin-bedded limestones, often finely laminated. Unconformably overlies Proterozoic granite and gneiss in small exposure north of San Lorenzo Canyon. Approximately 10-20 m thick. The absence of Pennsylvanian and Mississippian strata here indicates the San Lorenzo structural block was an ancestral Rocky Mountain highland. In addition the absence of overlying Baca and Spears Formations here suggests it was also an early Tertiary highland of Laramide ancestry.

IPm **Madera Limestone** (middle to upper Pennsylvanian, Desmoinsean to Missourian)—Mostly light- to medium-gray ledge and cliff forming micritic limestones interbedded with dark greenish gray limy shales and minor sandy limestones. Nodular black chert is common in the micritic limestones. Cliff-forming limestones are medium to thick bedded and moderately fossiliferous (fusulinids, brachiopods, crinoids and corals). Several limestone beds in the west central Lemitar Mountains are locally silicified (stippled on map). Maximum thickness is 210 m. Madera Limestone is locally absent north of San Lorenzo Canyon.

IPs **Sandia Formation** (middle Pennsylvanian, Atokan)—Dark gray to black, slope-forming carbonaceous shales with minor fossiliferous biomicrites and fine-grained quartz arenites are dominant in the upper third. Lower 2/3 (south of Polvadera thrust) consists of ledge-forming quartz arenites that are dark reddish brown to light gray, fine to coarse grained, massive to cross bedded, feldspathic to miaceous, and mostly medium to thick planar bedded. Arenites contain several 1–2 m thick interbeds of gray siltstone and limy mudstone. Upper contact with Madera Limestone is gradational and generally placed at break in slope to ledge and cliff-forming limestones. The Sandia Formation is approximately 180m thick on southern lower plate of the Polvadera thrust; it is about 60m thick on the northern upper plate. Also, the Polvadera thrust does not appear to offset the overlying Madera Limestone. These observations indicate a late Pennsylvanian (Atokan) age for the Polvadera thrust. Sandia Formation is locally absent north of San Lorenzo Canyon

Mk **Kelly and Caloso formations, undivided** (lower Mississippian)— Silicified limestones and shales of the Kelly Formation overlying silicified sandstones of the Caloso Formation. Correlation with relatively unaltered Mississippian strata in southeastern Lemitar Mountains is based on equivalent stratigraphic position and similar bedforms plus lithologic sequence (Chamberlin et. al., 2001). Mississippian strata are absent north of the Polvadera thrust. 0-30m thick.

PROTEROZOIC ROCK UNITS:

Zmd	**Mafic dike** (late Proterozoic?)—Dark gray to greenish gray, fine-grained mafic dike. Northeast-striking dike cuts Polvadera granite.
Xpg	**Polvadera granite** (middle Proterozoic?)— Medium-to coarse-grained granite consisting of quartz ,plagioclase feldspar, potassium feldspar and minor amounts of biotite, hornblende and magnetite. Generally nonfoliated and nonlineated. Forms crystalline core of western Lemitar Mountains.
Xmbg	**Muscovite-biotite granite** (middle to early Proterozoic?)— Fine- to medium-grained two-mica granite, contains potassium feldspar, plagioclase feldspar, quartz, muscovite and biotite; includes pegmatite lens along west margin. Occurs in small exposure north of San Lorenzo Canyon.
Xg	**Quartzo-feldspathic gneiss** (early Proterozoic)—Finely banded micaceous quartzo-feldspathic gneiss or mylonite(?). Exhibits well developed “pencil” cleavage and intrafolial mineral lineation. Gneiss foliation dips 75° to 285; mineral lineation plunges 47° to 015. Contains small pegmatite lenses near contact with younger two-mica granite. Occurs in small exposure north of San Lorenzo Canyon; possibly correlative with the Corkscrew Canyon metasediments exposed in the east-central Lemitar Mountains (Chamberlin et.al. 2001)
X	**Proterozoic rocks undivided**—Shown in cross section only.

Explanation of Map Symbols:

Depositional contact, long dashed where approximately located, short dashed where inferred. Dip and dip direction (azimuth) shown where observed. **Quaternary contacts are primarily based on air photo interpretation and most are approximately located. They are generally shown as continuous lines to aid map legibility.**

Paleochannel wall, dashed where concealed, dotted where projected. Locally defined by piedmont gravels (QTsp) inset against basin-floor mudstones (QTsb) at SE-rim of the La Jencia Creek valley.

Marker bed or horizon, includes pedogenic carbonate layers in the Sierra Ladrones Formation (Qsc, QTsc) and the base of a black basalt flow (b) in the La Jara Peak Basaltic Andesite (tentative base of Tl_3).

Rhyolitic ash beds; includes thin fall beds in the upper La Jara Peak Basaltic Andesite (Tl_3), ash beds in the vent complex at San Lorenzo Spring (Tvs), and mostly water-laid rhyolitic ash beds in the Popotosa Formation. Includes an ash bed along the depositional unit contact (Tpd_2/Tpd_1) on south wall of San Lorenzo Canyon.

Lateral facies boundary in the Popotosa Formation; queried where uncertain.

Ancient colluvial breccias and thin debris-flow beds. Includes scarp-derived deposits in the basal Popotosa Formation (Tpx), silicifed debris-flow breccias in vent complex at San Lorenzo Spring (Tvs), and minor debris flows within the upper La Jara Peak Basaltic andesite (Tl_3).

Bedded scoria deposits (near vent agglomerates).

Volcanic vent

Silicified limestones or lavas (j = jasper)

Fault trace, dashed where approximately located, dotted where projected under younger deposit. Ball and bar on downthrown side. Where concealed U= upthrown side, D= downthrown side. Short tick mark indicates direction and angle of dip. Tick mark for dip is not shown on dip-slip fault. Arrow indicates bearing and plunge of striations or mullions on fault surface. Half-arrows indicate sense of lateral slip.

Minor displacement fault showing dip direction, bearing and plunge of striations.

Minor dip-slip fault

Sinistral shear vein. Shows predominant dip and dip azimuth, plunge and bearing of striations.

Calcite vein showing dip and dip azimuth (t = travertine)

Thrust fault of Pennsylvanian age (Polvadera thrust, **PT**). Offsets Kelly and Sandia Formations, but not the overlying Madera Limestone. Dip and dip azimuth shown where observed.

Low-angle normal fault (dip = 0- 30º) showing dip and dip azimuth. Interpreted as initially high-angle, down-to-east, early rift, normal fault that has been rotated (domino style) to present position of low-angle normal fault (Chamberlin, 1983). Commonly expressed by cuspate traces and klippe-like traces.

Pseudo reverse fault showing direction and angle of dip. Open squares on upthrown block. Within the strongly west-tilted Lemitar Mountains block, north-striking high-angle-reverse faults are interpreted as early antithetic *normal* faults (downthrown to west) that have been rotated to present orientation of reverse faults by dominant down-to-east domino faults (Chamberlin,1983).

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

Horizontal bedding.

Overturned bedding

Strike, dip, and dip direction of foliation in rheomorphic tuff (Tj), lava (Tds, Tar), or metamorphic gneiss (Xg).

Syncline, showing approximate trend of trough line.

Overturned syncline, showing approximate plunge and trace of axial plane

Anticline, showing approximate trend of crest line.

General direction of paleocurrents (± 30°) based on pebble imbrication or cross bedding (b). Observation point at base of arrow or nearest bedding observation.

Sample location for ^{40}Ar/^{39}Ar age dating or geochemical analysis (Tables 1 and 2). All samples have prefix “SLS”.

Spring

` Vitrophyre at base of upper Lemitar Tuff (Tlu)

CORRELATION OF MAP UNITS:

Epoch / Period
Qa Qpl Qe Qc
Qvy Qpy **Holocene**

* upper

Pleistocene
Qvo Qtg Qpo middle

Qsa Sierra Ladrones Fm. Qsp Qsc lower
QTsb QTse QTsp QTsc upper
QTsa **Pliocene**
lower

Tps Tpm Tpu Popotosa Fm. Tpcu upper
Tpc Tia (intrusive) **Miocene**
Tbs (lava)
Tpd Tpx lower

Tsc Mogollon-Datil volcanics
Tar
Tds/Tvs upper
Tl_3
Tlu/Tll Tlp
Tl_2 Tib (dike)
Tv
Tl_1
Tj **Oligocene**
Tz

Th
Tg lower
Ts upper

Eocene
Tb Laramide conglomerates middle

Pb Pba lower **Permian**
IPm upper **Pennsylvanian**
IPs middle **Pennsylvanian**
Mk upper **Mississippian**
Zmd late **Proterozoic**
Xpg middle **Proterozoic**
Xmbg X
Xg early **Proterozoic**

*Bar indicates inferred age range.

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