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GEOLOGY AND MINERAL RESOURCES OF THE LAKE VALLEY AREA, SIERRA COUNTY, NEW MEXICO

By

C.J. Nutt, J.M. O'Neill, V.T. McLemore*, D.A. Lindsey, Ratté, J.C., and D. C. Hedlund
U.S. Geological Survey
*New Mexico Bureau of Mines and Mineral Resources

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GEOPHYSICAL EVALUATION OF LAKE VALLEY AREA

By

D.P. Klein and M.D. Kleinkopf
U.S. Geological Survey

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ABSTRACT

At the request of the Bureau of Land Management, the U.S. Geological Survey assessed the Lake Valley Area of Critical Environmental Concern (ACEC), which includes the historic Lake Valley townsite and silver-manganese mining district, for undiscovered mineral resources. The Lake Valley ACEC is along the southeastern margin of the Black Range of western Sierra County, New Mexico. The Black Range contains eleven mining districts from which silver, lead, zinc, manganese, copper, gold, and tin have been recovered. As part of the study, an area of over 75 square mi (195 square km) in the area of the Lake Valley ACEC was mapped to understand ore controls and to assess mineral-resource potential.

Lake Valley mining district is in Mississippian Lake Valley Formation carbonate rocks, but much of the surrounding terrane consists of volcanic rocks on the southeastern edge of the Emory cauldron which formed about 34.9 Ma. Volcanic rocks are part of the Mogollon-Datil volcanic province which include flows, breccias, ash-flow tuffs, and intrusive rhyolites. The Lake Valley mining district is located about 20 mi (32 km) south of the Late Cretaceous Laramide copper-gold porphyry intrusion at Hillsboro. It is also located at the western boundary of the Rio Grande rift basin.

The Lake Valey fault is the major structural feature of the study area. Geological and geophysical data suggest the fault is composed of two segments: a southern, northwest-striking segment that may have a pre-Tertiary history and a northerly-striking segment that is part of the Emory cauldron ring fracture. The mining district is bounded by the southern, northwest-striking segment of the fault which may have up to 800 ft (240 m) of normal offset.

Deposit types identified in the Black Range, and for which we assess mineral potential, are Laramide porphyry, Laramide skarns, Laramide veins, gold placer, carbonate-hosted, volcanic-epithermal, and rhyolite tin; no Rio Grande Rift barite-fluorite-galena deposits are known, but they are included in the assessment.

The most likely deposits to be discovered in the Lake Valley district are carbonate-hosted silver-manganese deposits. These deposits could be deposited by hydrothermal fluids or be related to intrusion of Oligocene rhyolite or Laramide porphyry. An aeromagnetic high south of the district probably reflects a small felsic intrusion of unknown age. We assess the Lake Valley ACEC as having low to moderate potential for undiscovered carbonate-hosted deposits associated with volcanic rocks or Laramide porphyry plutons, and low potential for gold placer and rhyolite tin deposits.

INTRODUCTION

The Caballo Resource Area is a Bureau of Land Management (BLM) designated region that includes all of Sierra and Otero Counties, south-central New Mexico (fig. 1). Within this resource area more than 21,000 square mi (33,789 square km), nearly one fourth of the land, is administered by the BLM. At the request of the BLM, the area of the historic Lake Valley mining district and townsite, at the southeastern margin of the Black Range of western Sierra County, New Mexico, was evaluated for its potential for undiscovered mineral resources (fig. 1). The BLM-designated study area, called the Lake Valley Area of Critical Environmental Concern (ACEC), is located in the northern part of the Lake Valley 7 ½' quadrangle, New Mexico. An area of over 75 square mi (195 square km) in the area of the Lake Valley ACEC were mapped to understand ore controls and to effectively assess mineral potential.

This report describes the geology of the northern Lake Valley quadrangle and most of the adjacent McClede Mountain 7 ½' quadrangle to the north and assesses the likelyhood that potentially economic, undiscovered mineral resources occur in the Lake Valley ACEC.

PREVIOUS INVESTIGATIONS

The discovery of gold deposits in the vicinity of Hillsboro, 20 mi (32 km) north of Lake Valley, and the mining of rich silver deposits in the Kingston district west of Hillsboro and at Lake Valley from 1882 to 1896 led to early geologic investigations in the area by Lindgren and others (1910). Their descriptions of the geology, mines, and structural and stratigraphic controls of ore deposition provided a framework for later studies. The decline of silver prices in 1893, which accompanied the demonitization of silver, greatly diminished mining activity in the southern Black Range.

Many of the silver workings were re-opened during World War II for production of low-grade manganese, which occurs in the oxidized parts of the silver and base-metal deposits in this region. Detailed district and mine maps of the Lake Valley manganese district were completed by the U.S. Geological Survey in 1953 (Creasey and Granger, 1953).

The regional geology was mapped and discussed by Jicha (1954).. Hedlund (1977a and b) mapped the geology and described the mineral resources of the Hillsboro 15' quadrangle directly north of Jicha's report area. A regional geologic map of the northwest part of the Las Cruces 1° by 2° sheet (Seager and others, 1982) includes both the Lake Valley and Hillsboro quadrangles. Seager (1986) also published a geologic map of the Hillsboro and adjacent San Lorenzo 15' quadrangles. These geologic maps have greatly aided in the resolution of the complex volcanic stratigraphy in this region.

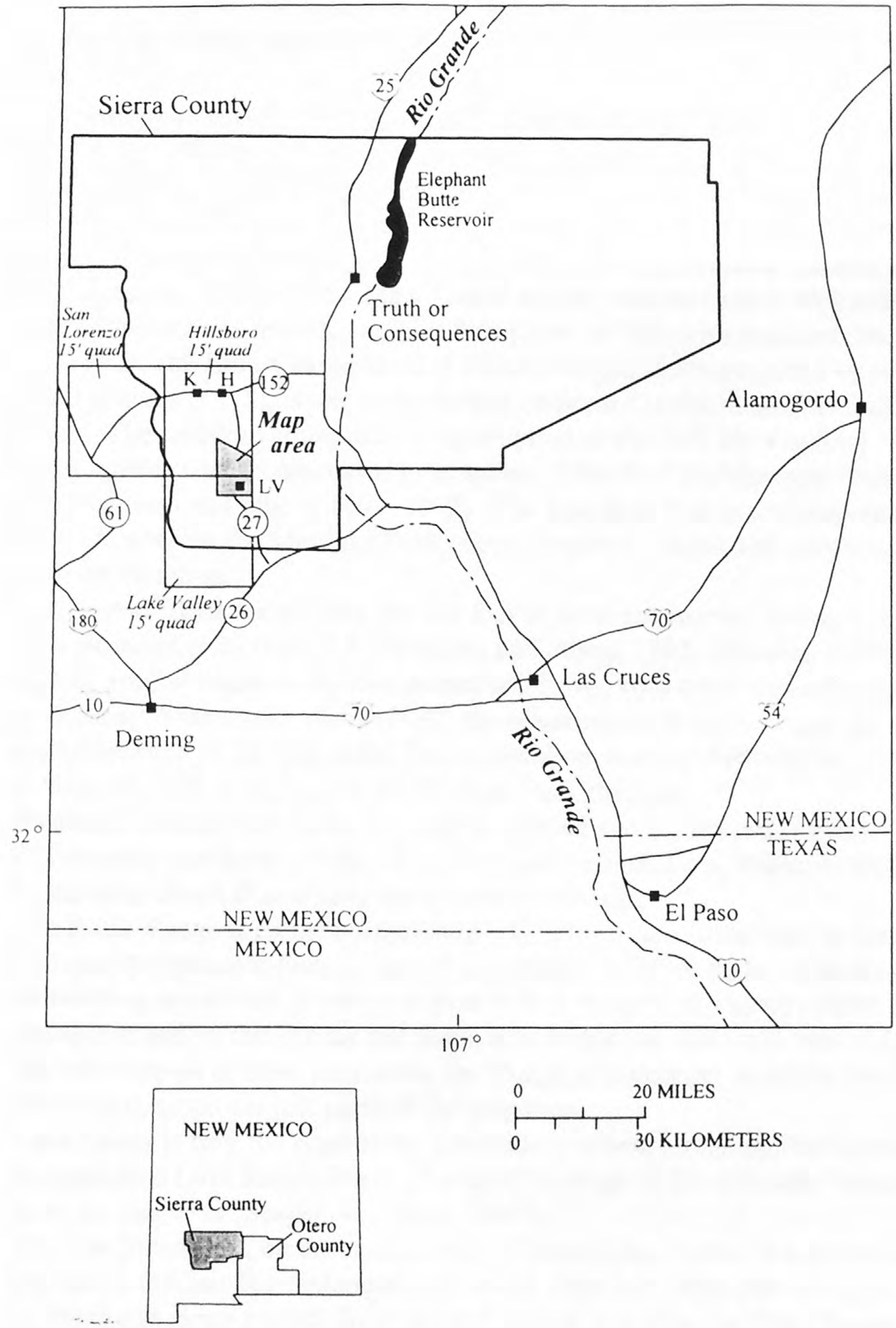

Figure 1. Index map showing location of Lake Valley map area.

GEOLOGY

REGIONAL GEOLOGY

The geology of the Black Range is dominated by Tertiary volcanic rocks, many associated with the Oligocene Emory cauldron that is located just northwest of the Lake Valley mining district. The Mogollon-Datil volcanic field of southwestern new Mexico consists of Eocene and Oligocene volcanic rocks. Eocene (40 to 36 Ma) intermediate volcanism was followed by Eocene to Oligocene (36 to 24 Ma) bimodal basaltic andesite and silicic volcanism. The 36 to 24 Ma volcanic activity was associated with multiple cauldron development and included at least four pulses of silicic magmatism (McIntosh and others, 1992) The Emory cauldron in the Black Range, first recognized by Elston, Seager, and Clemons (1975), is one of the largest cauldrons in the Mogollon-Datil volcanic field. The cauldron collapsed during eruption of the 34.9 Ma Kneeling Nun Tuff. Cauldron resurgence was accompanied by eruption of the 34.5 Ma Mimbres Peak Formation (McIntosh and others, 1991, 1992). The Kneeling Nun is a widespread ignimbrite unit, whereas the Mimbres Peak occurs largely in domes and intrusions along the edges of the cauldron.

The central Black Range was also the foci of local magmatism during a major episode of volcanism at 29.0 to 27.4 (McIntosh and others, 1992; Harrison, 1990), represented by emplacement of rhyolite domes and flows, with no related caldera. On their regional map, Seager and others (1982) show intrusions of this younger age along the southwestern edge of the Oligocene Emory cauldron, but had difficulty in distinguishing rhyolites of this age from Mimbres Peak rhyolites.

Paleozoic sedimentary rocks crop out in uplifted and eroded fault blocks. They consist of carbonate and lesser clastic rocks deposited on a shallow, stable, south-dipping platform present in much of southern and central New Mexico.

The Black Range is on the northeastern edge of the Late Cretaceous to early Tertiary (Laramide) volcanic-plutonic arc of southwestern United States. The west- to northwest-trending arc-related porphyry copper belt of Arizona and southwestern New Mexico is represented by the Tyrone and Santa Rita intrusions south and west of Lake Valley; the easternmost of these intrusions, the 75.1+2.5 Ma copper porphyry (Hedlund, 1974) at Hillsboro, crops out just north of the map area.

Lake Valley is near the edge of the Laramide northwest-trending Rio Grande uplift and associated Love Ranch Basin. Scattered outcrops of Love Ranch Formation are preserved in the map area (Seager and others, 1986).

The Rio Grande rift, on the eastern edge of the mining district, is a system of extensional faults that has been intermittently active since late Oligocene time, but most notably as basin and range normal faults in the Miocene and Pliocene time (Seager and others, 1984). The Miocene and Pliocene faults have appreciable displacement (5,000 to 10,000 ft [1525 to 3050 m]) and have served as conduits for the eruption of numerous basalt flows in the Hillsboro area north of Lake Valley (Hedlund, 1977a). A prominent,

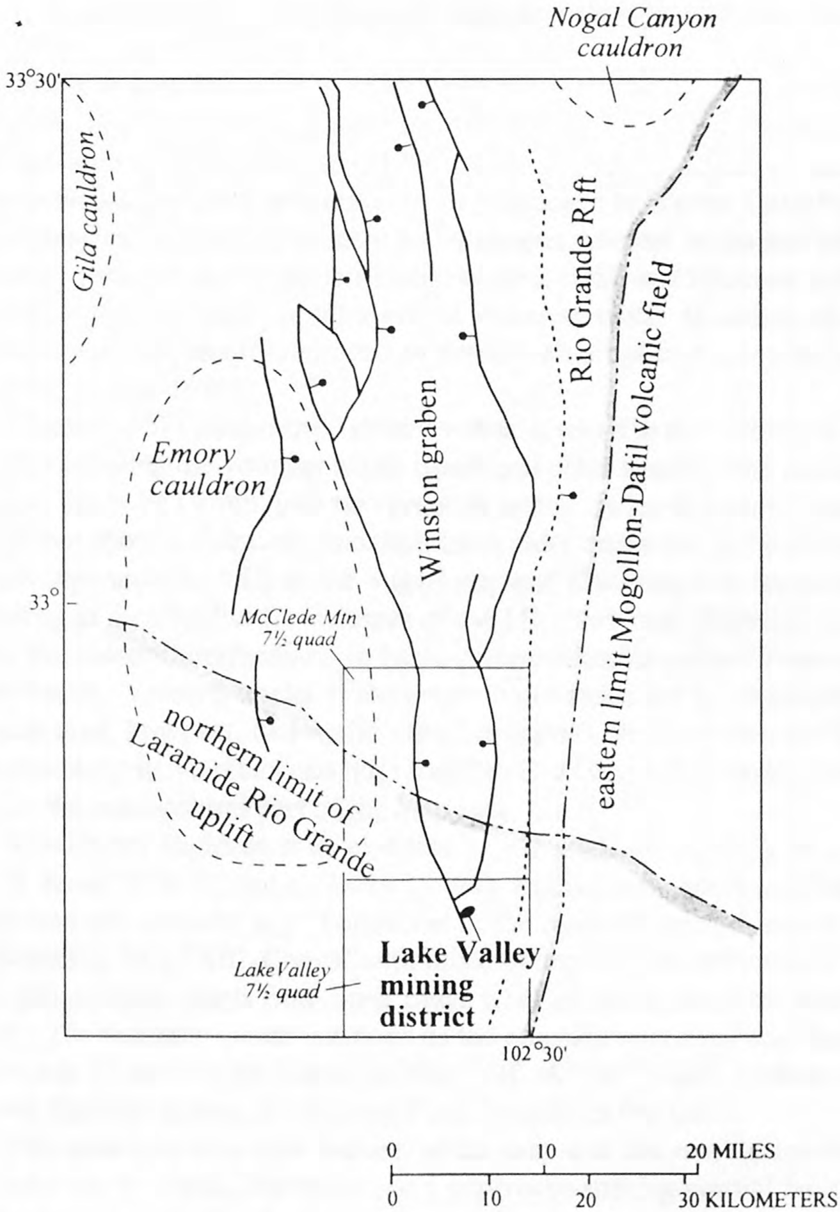

Figure 2. Map showing Lake Valley mining district in relation to the Mogollon-Datil volcanic field, Rio Grande rift, Winston graben, and Laramide Rio Grande uplift.

rift-related structure in the east-central part of the map area is the southern part of the Winston graben, a north-trending, 50-mi-long (80-km-long) structure that terminates near the Lake Valley mining district on the south (fig. 2); it is the most western of the extensional basins at this latitude.

GEOLOGIC SETTING OF MAP AREA

The map area is on the southeastern edge of the Emory cauldron and includes the Rio Grande rift-related Animas basin that is the southern part of the Winston graben (Seager and others, 1982; Harrison, 1990). Exposed rocks include Paleozoic carbonate and clastic rocks, scattered thin outcrops of Paleocene to Eocene Love Ranch sedimentary rocks, a complex sequence of Eocene to Oligocene volcanic rocks and interbedded sedimentary rocks of the Mogollon-Datil volcanic field, and Miocene and younger Santa Fe Formation sedimentary and interlayered volcanic rocks. Mesozoic strata are not present and were apparently removed by erosion after uplift of this area in Laramide time (Seager and others, 1986).

Elston (1957) placed the Tertiary volcanic rocks in the vicinity of the Emory cauldron, excluding the younger alkali basalt and other basalt flows in the Rio Grande rift-related Santa Fe Group, into two eruptive series. A lower series consist of lava flows and tuffs that show a chemical gradation from older andesites of the Rubio Peak Formation upward into tuffs of the Sugarlump and Kneeling Nun formations and culminating in the rhyolite flow-domes of the Mimbres Peak Rhyolite. An upper series includes the mostly intermediate- to basic-composition Razorback Formation and Bear Springs Basalt. Volcanic rocks of the lower, older series are the dominant igneous rock in the map area; however, two mafic intrusive centers, younger than the Emory cauldron extrusive and intrusive rocks and not related to Rio Grande rift basaltic volcanism, are present in the west-central part of the map area.

The Emory cauldron is an elongate, north-northeast-trending structure that measures about 30 by 12 miles (48 by 19 km), and is cut by north-trending normal faults of Oligocene and younger age. Formation of the cauldron commenced with the eruption of the Kneeling Nun Tuff. Coeval with this eruption was the intrusion of numerous rhyolite plugs; many clasts from these plugs were incorporated in the basal parts of the ash flow. The volcanic center subsided as the eruption continued and the newly-formed cauldron was filled with the Kneeling Nun Tuff. As the volatile content of the magma decreased, rhyolite domes of Mimbres Peak Formation formed.

The principal structural features of the map area are east- to southeast-dipping fault blocks cut by north-, northeast-, and northwest-striking normal faults. The Berrenda and Lake Valley faults divide the map area into separate tilted blocks. The Berrenda fault is the southeast and east boundary of the Winston graben; the northern part of the Lake Valley fault is a marginal fault of the Emory cauldron. The north-trending blocks or half-grabens in this area appear to have formed initially after deposition of the Oligocene Kneeling Nun Tuff in as much as mappable units of basin-fill coarse sand, arkose, and gravel are interlayered with overlying volcanic flows. The half-graben part of the southern Winston basin is now filled with thick deposits of Santa Fe Group rocks indicating major subsidence in Miocene and Pliocene time.

SEDIMENTARY ROCKS

Paleozoic

Ordovician to Pennsylvanian sedimentary rocks crop out in the map area (plate 1). Underlying Middle Cambrian strata that rest unconformably on Precambrian basement rocks are covered by volcanic rocks and faulted. Carbonate strata of dominantly shallow marine origin comprise most of the Paleozoic section; siliciclastic strata are the Devonian Percha Shale and, to a lesser amount, discontinuous exposures of the Ordovician Cable Canyon Sandstone and the arenaceous Mississippian Caballero Formation.

Ordovician

The oldest sedimentary rocks in the map area consist of the El Paso Group and is divided into the upper Bat Cave Formation and lower Sierrita Limestone (Kelly and Silver, 1952). Thickness of the group in the Lake Valley-Hillsboro region is about 500 ft (153 m) (Hedlund, 1977a); however, only the uppermost Bat Cave Formation is exposed in the study area. The Bat Cave consists of medium-light-gray, poorly fossiliferous limestone beds that are laminated to thin to medium bedded and finely crystalline. Some beds are pelletal and locally are brown weathering and silty. Intraformational breccias are common and nodular to ropy chert is especially common in the upper 70 ft (21 m).

The Montoya Group consists of three formations that were not mapped separately: the lowermost Second Value Dolomite, the Aleman Formation, and the uppermost Cutter Dolomite. All formations are of Middle and Late Ordovician age and in the Hillsboro area have a aggregate thickness of 458 ft (140 m) (Hedlund, 1977a). The lower Second Value Dolomite consists of two members: the Basal Cable Canyon Sandstone is a discontinuous, medium- to coarse-grained, well cemented thick bedded and cross bedded sandstone with a maximum thickness of about 25 ft (7.6 m). The upper part of the formation consists of medium gray, thick bedded, finely crystalline dolomite that grades upward into light-gray dolomite that contains abundant disseminated rounded and frosted quartz grains as much aas 4 mm across. The uppermost part of the formation is medium gray to black, massive, sugary textured dolomite. Total thickness is about 110 ft (34 m).

The overlying Aleman Formation consists of laminated chert layers 1-3 cm thick that alternated with medium-gray, very fine crystalline dolomite beds about 1 in. (2-3 cm) thick. The chert beds are more continuous in the l ower part of the section. Average thickness of the unit is about 70 ft (21 m).

The uppermost Cutter Dolomite is laminated to thinnly bedded in the lower 65 ft (20 m), becoming thickly bedded to massive in the uppermost 130 ft (40 m). The formation is poorly fossiliferous except for a few silicified colonial corals (Mesofavosites sp.).

Scattered jasperoid in the Montoya Group fills what we interpret as small karst-related collapse features.

Silurian

The Fusselman Dolomite is a distinctive cliff-forming, thick-bedded, medium-graya to dark-olive-gray dolomite in its lower part; it grades upward into ledge-forming, medium-gray dolomite that contains locally abundant brown-weathering chert and siliceous crusts, stringers, and lenses. This silicified rock, or jasperoid, is most prominent at the upper contact between the Fusselman and overlying Percha Shale. The jasperoid commonly shows breccia textures that predate silicification. In the map area, Quartzite Ridge is a dip slope of Fusselman jasperoid. We suggest that the jasperoid is concentrated in the upper Fusselman because of slippage and brecciation along the contact between competent Fusselman and ductile Percha Shale and because the Percha Shale served as a cap to fluids that moved out along the brecciated contact.

Devonian

The Percha Shale is typically poorly exposed, forming gentle slopes beneath the overlying Mississippian carbonate rocks. The formation has been divided into the lower ready pay Member and the overlying Box Canyon Member. The Ready Pay Member consists of black to olive-black, highly fissile shale that is 100 to 130 ft (30-39.6 m) thick. The upper Box Canyon consists of about 30 ft (9 m) of dark-gray to medium-gray to pale yellowish green silty shale with limestone nodules especially common in the lowest 20 ft (6 m).

Mississippian

Most of the Mississippian strata in the southern Black Range is Osagean in age, but in the map area, the lowermost Caballero Formation is of Kinderhookian age. In the map area the Mississippian strata consists of the lowermost Caballero Formation and the overlying Lake Valley Formation, named for exposures near the Lake Valley mining district. The Lake Valley Formation, divided into four members by Laudon and Bowsker (1949), is 200-225 ft (62-69 m) thick in the map area (Jicha, 1954). Because most of the mineralized rock in the Lake Valley mining district is largely restricted to certain members of the Lake Valley Formation, all members were mapped separately.

The lowermost Caballero Formation consists of a basal arenaceous, cross-bedded limestone overlain by thin-bedded, marly limestone beds that contain abundant crinoidal columnals and minor black, ropy chert. Thin interbeds of black and gray chert-pebble conglomerate are locally present in the upper part. Thickness is variable, ranging from several feet (1-2 m) in the north to as much as 65 ft (19.5 m) near Lake Valley.

The overlying Lake Valley Formation consists of four members. The lowermost Andrecito Member consists of medium-light-gray, thin-bedded argillaceous limestone with undulose bedding surfaces. The slope-forming limestone contains abundant fenestelloid bryozoa and minor crinoid columnals.

The overlying Alamogordo Member is a distinctive ledge-forming limestone unit. It consists of evenly spaced beds of 1.5 to 3 ft (0.5 to 1 m) thick and contains minor, distinctive dark-gray chert nodules in the lowest 5 ft (1.5 m). The limestone is medium gray to light gray, very finely crystalline, and non-fossiliferous.

The Nunn Member consists of medium-gray, thin bedded, slope-forming, marly, coarse-crystalline limestone that commonly contains abundant crinoid fragments. Minor amounts of ropy black chert occur in the upper 50 ft (15 m) of the member.

The uppermost Tierra Blanca Member consists of medium-light-gray limestone that contains distinctive and abundant white to very light-gray chert nodules and lenses. The member is medium bedded and medium to coarsely crystalline and commonly forms ledges that weather to abundant white chert rubble.

Pennsylvanian

The Magdalena Group carbonate rocks are incompletely exposed in the map area due to faulting and concealment by younger Tertiary volcanic rocks. The Magdalena consists of two formations—the lower Oswaldo and the overlying Syrena Formations—that were not mapped separately during this study. The Group consists mostly of medium-gray, medium- to thick-bedded, fine- to very fine-grained crystalline limestone. The unit commonly contains silty limestone laminae that weather to a yellowish gray and a rubble of light-brown plates up to 1 in. (2.5 cm) thick. The Group contains locally abundant brachiopods, gastropods, fusulinids, and horn corals.

Cenozoic

Discontinuous exposures of the Eocene to Paleocene Love Ranch Formation overlie the Paleozoic carbonate rocks in the map area (plate 1). The Love Ranch is a basin-fill deposit shed from the adjacent Laramide highlands (Seager and others, 1986). In the map area, the Love Ranch consists mostly of locally-derived pebble to cobble conglomerate and minor red siltstone and shale.

Oligocene fluvial and alluvial deposits locally are interlayered with volcanic rocks in the area south of McClede Mountain. These deposits are the oldest sedimentary fill of the southern part of the Winston graben. The alluvial-fluvial deposits separate Kneeling Nun Tuff from the overlying trachyandesite (Tta on plate 1) and the trachyandesite from andesitic and rhyolitic deposits (Tsa and Tsr on plate 1). All of the volcanic rocks interlayered with the sedimentary deposits are interpreted to be younger than the 34.5 Ma Mimbres Peak Formation; thus the clastic sedimentary lenses that separate them are no older than 34.5 Ma.

Sedimentary basin-fill deposits have been described from the Caballo Mountains 20 mi (32 km) east of the Lake Valley area. These rocks include the Eocene Palm Park Formation and the Oligocene Thurman Formation (Seager and Hawley, 1973). The Thurman Formation at its type locality is interlayered with middle Oligocene basaltic volcanic rocks and also includes basal ash-flow tuff that has yielded a K-Ar age of 34 Ma (Seager and Hawley, 1973, p. 9). Seager and Hawley interpret the Thurman Formation as a broad alluvial apron that was periodically inundated by basaltic andesites from vents of the Sierra de Las Uvas volcanic center. The thin alluvial and fluvial deposits south of McClede Mountain are similar in age to basal Thurman strata and interlayered with Oligocene volcanic rocks. Based on these similarities, the deposits in the map area are tentatively correlated with the Thurman Formation.

The Oligocene air-fall tuff that overlies Thurman-like strata pinches out on the south into strata that we suspect is also lower Thurman. Seager (1986) correlates these deposits with the upper Miocene Rincon Valley Formation of the Santa Fe Group. We do not dispute the presence of Santa Fe Group rocks in this area, but suggest that lowermost rocks included in the Santa Fe by Seager likely include Thurman Formation. Poor exposures and concealment of strata by younger pediment gravels does not permit the accurate mapping of the contact between the two rock units; the contact between the two units shown on plate 1 separates moderately east-dipping and indurated alluvium and fanglomerate resting directly on moderately east-dipping late Oligocene volcanic rocks from very poorly exposed, finer grained and less-well cemented basin-fill deposits of the Rincon Valley Formation.

Within the map area the Santa Fe Group is largely restricted to an east-tilted half graben directly west of Sibley Mountain and as poorly exposed consolidated deposits on the east side of Sibley Mountain. Deposits west of Sibley Mountain were mapped as middle Miocene Rincon Valley Formation of the Santa Fe by Seager and others (1986). As discussed above, we would include the basal Thurman Formation in this basin-fill deposit.

Quaternary surficial deposits are common in the map area and include older pediment deposits shed eastward from block-faulted mountain fronts along the eastern margin of the Black Range. Pediment gravels are commonly incised by contemporary stream systems and locally overlain by alluvial fan deposits directly adjacent to mountain fronts.

TERTIARY IGNEOUS ROCKS

Ignimbrites, lava flows, and rhyolite intrusive domes of late Eocene to Miocene (?) age constitute about 50 percent of bedrock exposures in the map area (plate 1). The stratigraphic nomenclature for the various volcanic units is largely based on the previous work of Elston (1957) in the Dwyer 15' quadrangle directly west of the Lake Valley 15' quadrangle and that of Jicha (1954) for the Lake Valley 15' quadrangle.

Rubio Peak Formation

The oldest Tertiary volcanic rock is the intermediate-composition Rubio Peak Formation. The source of the oldest Rubio Peak andesites is not known, but was probably numerous local vents.

The Rubio Peak Formation includes andesite and hornblende dacite flows, with minor interbeds of volcaniclastic sandstone and air-fall tuff and occurs over a wide area of the southern Black Range. Two K-Ar ages of 36.4$\pm$2.3 Ma and 32.6$\pm$2.1 Ma were acquired by R.F. Marvin, H.H. Mehnert, and Violet Merritt (written communication to Hedlund, 1975) from hornblende and plagioclase concentrates, respectively. The andesite and hornblende dacite flows underlie the 35.17$\pm$0.12 Ma Sugarlump Tuff (McIntosh and others, 1991); this relationship indicates that the Rubio Peak is probably closer to the 36.4 Ma age reported by Marvin, Mehnert, and Merritt.

The andesite and dacite flows are medium-gray, dark-greenish-gray to olive-gray and are locally autobrecciated. The andesite is typically porphyritic with as much as 30 percent phenocrysts of zoned andesine (An_{32-43}), oxyhornblende, clinopyroxene, and accessory dusky brown oxybiotite. In most andesites the pyroxene is a zoned augite that comprises as much as 4 percent of the rock. Accessory minerals include primary apatite and secondary iron oxides, epidote, celadonite, calcite, and chlorite. Hornblende dacite porphyry flows are generally olive-gray to dark-purplish-gray and contain conspicuous aligned black hornblende prisms up to 5 mm long that locally comprise about 15 percent of the rock. The oligoclase-andesine (An_{23-33}) phenocrysts are strongly zoned and comprise as much as 5 percent of the dacite. Resorbed and irregular quartz phenocrysts are locally present; accessory minerals include oxybiotite, iron oxides, and apatite. Two

Table 1. Major element geochemistry of extrusive and intrusive rocks of the Lake Valley map area.. Oxide analysis by X-Ray Fluorescence; analysist, Joseph Taggart. (LOI = Loss on ignition)

Sample #	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	Rubio Peak Fm.	**Rubio Peak Fm.**	**Kneeling Nunn Fm.**	**Trachy-andesite of Sibley**	**Dacite porphyry**	**Dacite of McLede Spring**	**Andesite of McClede Spring**
Field #	112MM	9LV	HL-5-71	100MM	144MM	24MM-3	104MM
Map unit	**Trp**	**Trp**	**Tkn**	**Tta**	**Tdp**	**Tsd**	**Tsa**
SiO2	59.0	63.0	72.0	60.8	66.8	64.0	52.7
TiO2	0.79	0.72	0.28	0.91	0.35	0.60	1.27
A2O3	16.4	16.4	14.6	16.4	16.0	16.1	16.0
Total Fe	5.39	4.09	1.76	5.42	3.46	3.61	8.08
MnO	0.04	0.05	0.04	0.06	0.14	0.05	0.11
MgO	1.95	1.48	0.38	2.40	0.62	1.60	5.72
CaO	3.24	3.50	1.20	4.77	2.13	3.76	8.73
Na2O	2.90	4.20	3.40	3.85	4.63	3.69	3.39
K20	4.51	3.33	4.80	2.54	3.38	3.22	1.31
P2O5	0.34	0.33	0.10	0.40	0.24	0.28	0.59
LOI	4.68	1.86	1.45	1.74	1.49	2.24	1.29
Totals	99.24	98.86	100.01	99.29	99.24	99.13	99.19

Column #	**8**	**9**	**10**	**11**
	Rhyolite of McClede Spring	**Rhyolite of McClede Spring**	**Intrusive andesite**	**Intrusive andesite**
Field #	24MM-1	109MM	48MM	14MM
Map unit	**Tsr**	**Tsr**	**Ta2**	**Ta1**
SiO2	76.8	81.6	55.3	60.3
TiO2	0.17	0.14	1.12	0.89
A2O3	11.50	8.04	18.1	16.1
Total Fe	1.36	1.00	6.42	5.72
MnO	0.11	0.07	0.08	0.08
MgO	<0.10	<0.10	2.84	2.81
CaO	0.11	0.28	5.83	4.99
Na2O	3.91	2.56	4.55	3.77
K20	4.54	3.19	1.80	3.02
P2O5	0.09	0.07	0.47	0.42
LOI	0.06	1.83	2.80	1.11
Total	99.19	98.78	99.31	99.21

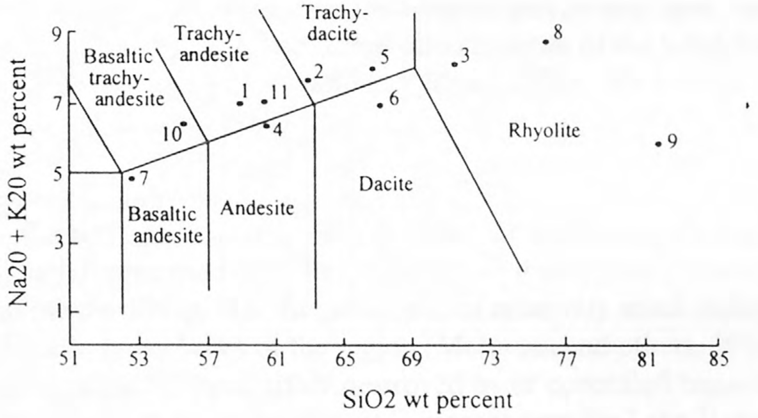

Figure 3 K_2O - Na_2O verses SiO_2 for igneous rocks of the Lake Valley area showing classification according to I.U.G.S. (Le Bas and others, 1986). Numbers refer to samples listed in Table 1.

chemical analysis of rocks of the Rubio Peak Formation are slightly alkali-rich and intermediate in silica composition.(table 1, figure 3). Sample1 represents typical Rubio Peak trachyandesitic flow rocks from the western part of map area. Sample 2 is a slightly more silicic rock (trachydacite) collected directly south of the Lake Valley townsite and originally mapped as Macho Formation by Jicha (1954). We include the Macho with the Rubio Peak as did Seager (1982).

Sugarlump Tuff

Air-fall tuffs, sandstones, and ash-flow tuffs of the Sugarlump Tuff unconformably overlie the Rubio Peak Formation throughout the southern Black Range (Seager and others, 1982). The Sugarlump is of relatively small volume as compared to other late Eocene ignimbrites of the region (McIntosh and others, 1991, 1992) and its main eruptive center has been either destroyed by or concealed beneath the voluminous Kneeling Nun Tuff. A small, local vent is present near the Lake Valley fault sosuthwest of Berrenda Mountain. An $^{40}/Ar^{39}Ar$ age for an upper tuff unit of the Sugarlump has been reported by McIntosh and others (1991) as 35.17±0.12 Ma.

Air-fall tuff of Sugarlump is generally thick massive beds in which abundant, weakly collapsed pumice lapilli are altered to clay minerals. Latitic lithic fragments comprise as much as 15 percent of the air-fall tuff, whereas phenocryst fragments make up only 5-10 percent of the tuff. Ash-flow tuff of the Sugarlump consists of weakly to moderately compressed ash shards and pumice and 3 to 10 percent fragmented phenocrysts of oligoclase (An_{23-25}), sanidine, quartz, and accessory biotite. The tuffaceous sandstones are generally thin-bedded, flaggy to platy, locally cross-bedded, and contain abundant medium- to coarse-grained reworked pumice, crystals, and latitic lava fragments.

Kneeling Nun Tuff

The welded, crystal-rich, rhyolitic ash-flow tuff of the Kneeling Nun Formation is the most conspicuous and thickest ash-flow tuff in the region. The tuff has been dated as Oligocene, 34.89±0.05 Ma using $^{40}Ar/^{39}Ar$ methods by McIntosh and others (1991). The tuff is phenocryst-rich, displays strong eutaxitic texture, and locally has well-developed cooling joints. The tuff typically contains 35-40 percent fragmented phenocrysts up to 4 mm across that are dispersed throughout a devitrified, felted to spherulitic groundmass of ash shards. The phenocryst content in percent is commonly as follows: oligoclase (An_{20-28}), 18 percent; sanidine, 13 percent; quartz, 5-6 percent, and biotite, 2-3 percent. Accessory minerals are sphene, magnetite, oxyhornblende, clinopyroxene, apatite, zircon, and secondary calcite. Chemical analysis of the rhyolitic tuff collected at Berrenda Mountain is shown in table 1, column 3.

Mimbres Peak Formation

Extensive, thick rhyolite domes are included within the Mimbres Peak Tuff. The rocks, outside the map area, have been dated using $^{40}Ar/^{39}Ar$ methods as 34.57±0.12 Ma (McIntosh and others, 1991). The rhyolite dome of Town Mountain is west of the Lake Valley townsite and was intruded along the northwest-trending Lake Valley fault system. A second dome of Mimbres Peak Formation rhyolite is west of McClede Mountain, where the Lake Valley fault juxtaposes Rubio Peak Formation against the rhyolite dome. The Lake Valley fault may have served as a conduit for intrusion of this dome.

Most rhyolite consists of less than 15 percent phenocrysts of sanidine and bipyramidal quartz; accessories include biotite and sphene and secondary iron oxides and calcite. Air-fall tuff and dark-grayish-black vitrophyre underlies the rhyolite flow rocks.. Highly fragmented phenocrysts comprise about 5 to 10 percent of the rock and include 1-4 percent sanidine, 1-2 percent oligoclase (An_{28-30}), and about 1 percent quartz; accessories include clinopyroxene, oxyhornblende, biotite, and iron oxides.

Dacite Porphyry

Phenocryst-rich dacite occurs as a shallow intrusive stock locally overlain by a brecciated carapace (Tapb) composed of fragments and blocks of Kneeling Nun Tuff and Rubio Peak Formation. The intrusion was partly exhumed prior to eruption of trachyandesite flows (Tta) that rest unconformably on the intrusive and carapace rocks. In thin section the dacite is seen to contain phenocrysts of sodic andesine (An_{30-32}) as much as 3 mm across set in a patchy felsitic groundmass that shows various stages of alteration to calcite, sericite, and secondary quartz. Andesine phenocrysts comprise 30-40 percent of the dacite and oxyhornblende, biotite, and iron oxides comprise less than 3 percent. Chemical analysis of the porphyry shows the rock to be a dacite (table 1, sample5).

$^{40}Ar/^{39}Ar$ age determinations of the porphyry attempted during this study have yielded spurious results suggesting contamination of the stock during emplacement. The stock has been interpreted to be older than Kneeling Nun Tuff (Seager and others, 1982, Hedlund, 1977a) and as Cretaceous in age by Kelley and Chapin (1997). The stock is likely middle Oligocene in age; it intrudes the 34.9 Ma Kneeling Nun Tuff and is overlain unconformably by the 28 Ma trachyandesite of Sibley Mountain.

Trachyandesite of Sibley Mountain

Trachyandesite to basaltic andesite flows are a major, unnamed volcanic unit in the map area that underlie Sibley Mountain on the east and a ridge of hills that extend south from McClede Mountain on the west. The predominantly medium-gray, aphanitic to slightly porphyritic flows characteristically have a platy weathering habit. In thin section the rocks show phenocryst content that varies from 0-15 percent and includes about 10 percent zoned calcic oligoclase (An_{28}), 3-4 percent oxyhornblende, 0-4 percent bipyramidal quartz, and 0-2 percent oxybiotite. The pilotaxitic to felted groundmass consists of sanidine and oligoclase microlites with interstitial iron oxides and clinopyroxene granules. Chemical analysis of the rock shows composition borderline between andesite and trachyandesite (table 1, sample 4).

The trachyandesite of Sibley Mountain was originally mapped as Pollack Quartz Latite by Hedlund (1977a) and later correlated with the Bear Springs Basalt by Elston (1989). The flows bear little resemblance to the Pollack Quartz Latite of Jicha (1954) at the type locality in the Lake Valley quadrangle and are probably too old to be correlative with the late Oligocene Bear Springs Basalt. Whole rock K-Ar age determination of 28.1 ± 0.6 Ma has been reported by Seager and others (1982) and Seager (1986) from a series of similar flows in the Hillsboro 7 ½' quadrangle.

Basalt, dacite, and rhyolite of McClede Spring

A series of discontinuous, unnamed basaltic to rhyoliticflows are exposed at McClede Spring southeast of McClede Mountain. The deposits rest directly on the trachyandesite of Sibley Mountain. North of Tierra Blanca Creek basaltic andesite is separated from the underlying tachyandesite of Sibley Mountain by a lens-shaped ash flow of dacitic tuff. South of Tierra Blanca Creek the mafic flow is underlain by a thin interval of tuffaceous sandstone and conglomerate correlated with the basal Thurman Formation of Oligocene age.

Overlying the mafic flow is a light-brown, crystal-poor ash-flow that contains abundant, weakly welded, devitrified ash shards and minor amounts of pumice. The crystal fragments are generally less than 2 percent of the rocks and include sanidine and bypyramidal quartz. The rhyolite is lithologically and chemically similar to the crystal-poor, high-silica Vicks Peak Tuff erupted from the Nogal Canyon cauldron in the southern San Mateo Mountains to the north (fig. 2). Chemical analyses of these volcanic units are shown in table 1, samples 6-9; alkali-silica variation plots of these rocks are shown on figure 3.

Younger intrusive rocks

Trachyandesite also occurs as two small intrusive bodies in the west-central part of the map area. A basaltic tachyandesite plug intrudes the Rubio Peak Formation about 0.5 mi (0.8 km) east of Highway 27 where it crosses Jaralosa Creek. A second trachyandesite body intrudes Sugarlump and younger volcanic flows as well as the overlying Santa Fe Group rocks along Jaralosa Creek at the eastern margin of the map area. The composition of these intrusive bodies (table 1 (columns 10 and 11) and figure 3) is similar to Mogollon-Datil volcanic rocks and as such they are not interpreted to be related to alkali basaltic flows and sills produced during younger Rio Grande rift igneous activity.

STRUCTURAL GEOLOGY

The principal structural feature of the southeastern Black Range is the uniform east-dipping attitude of volcanic and underlying sedimentary rocks that are cut by predominantly north-trending high-angle normal faults (Seager and others, 1982). The easterly dip of the rocks in the region is interpreted as a response to the listric shape of normal faults that, although steeply dipping at the surface, must flatten at depth. Normal faults displace outflow from the Emory cauldron of early Oligocene age and sedimentary basin-fill rocks of Pliocene to late Oligocene age; locally, they are concealed beneath pediment gravels of Pliocene and Pleistocene age and by younger alluvial deposits and landslides. The faults were formed during regional extension in Oligocene time, which in part overlapped with explosive volcanism and caldera formation, and were reactivated during Rio Grande rifting. Possibly, some segments of the normal faults in the southeastern Black Range follow pre-existing older faults or weaknesses in the Precambrian basement.

Two major normal fault systems, here designated the Lake Valley and Berrenda fault systems, cut through the map area from Lake Valley to Tierra Blanca Creek (plate 1). Both fault systems downdrop volcanic and sedimentary rocks on the west side and rotate strata about 10-20° easterly. Rocks on the east side of these faults are also rotated down-to-the-east, indicating a third, concealed fault beneath pediment gravels and Miocene (?) and Pliocene (?) basalt east of the mapped area. North of Lake Valley townsite, the Lake Valley and Berrenda fault systems turn from their regional north-south trend to cross one another; one splay of the Berrenda fault system trends westerly and offsets the Lake Valley fault system; another splay trends southwest and abuts the Lake Valley fault system. North along the west side of Sibley Mountain, the Berrenda fault system downdrops the east side of the Winston graben, a structural basin filled with volcanic and sedimentary rocks of the Thurman Formation and the Santa Fe Group. The Winston graben can be traced almost 50 miles (80 km) north (Lovering and Heyl, 1989).

Lake Valley fault system

The Lake Valley fault system is divisible into two major segments: 1) a north-striking segment that extends from west of Berrenda Mountain past the west side of McClede Mountain, and 2) a northwest-striking segment that extends from south of Lake Valley townsite to Berrenda Mountain. Southwest of Berrenda Mountain, the two segments of the Lake Valley fault system are offset by small splays of the Berrenda fault system. The northern segment of the Lake Valley fault system has approximately 200 ft (61 m) of stratigraphic separation, whereas the southern segment, based on geophysical data (this report), has about 825 ft (252 m) of stratigraphic separation. Movement on the northern segment was dominantly dip-slip; on the southern segment, movement was oblique-slip, with slickenlines on most fractures indicating a component of right-slip. The southern segment passes northeast of Town Mountain and is accompanied by a parallel antithetic fault located south of Town Mountain. This graben was also detected in geophysical resistivity studies across the Lake Valley fault (this report).

Analysis of gravity and magnetic surveys of the Lake Valley and surrounding area conducted during this study suggest that although the Lake Valley fault system is mapped as a continuous fault zone (plate 1), two fundamentally different faults apparently have been tectonically linked in Tertiary time. The northern segment of the Lake Valley fault coincides with the aeromagnetically-defined structural margin of the Emory cauldron and appears to be directly related to formation and collapse of the volcanic vent system. On the other hand, the southern segment is oriented at a large angle to the cauldron margin, is subparallel to postulated northwest-trending Laramide structures (Seager and others, 1884), bounds a major northwest-trending graben filled mainly with pre-Emory caldera volcanic rocks of the Rubio Peak Formation (magnetic and gravity section, this report), and shows much larger displacement than the northern segment; the southern segment is interpreted to represent Tertiary reactivation of a Cretaceous or older fault or fault system.

A stereographic analysis of synthetic fractures and slickenlines in the Lake Valley fault zone near Town Mountain and the accompanying parallel antithetic fault south of Town Mountain indicates that both sets of fractures formed by near-horizontal northeast extensional stress that was accompanied by brittle fracture (fig. 4a).

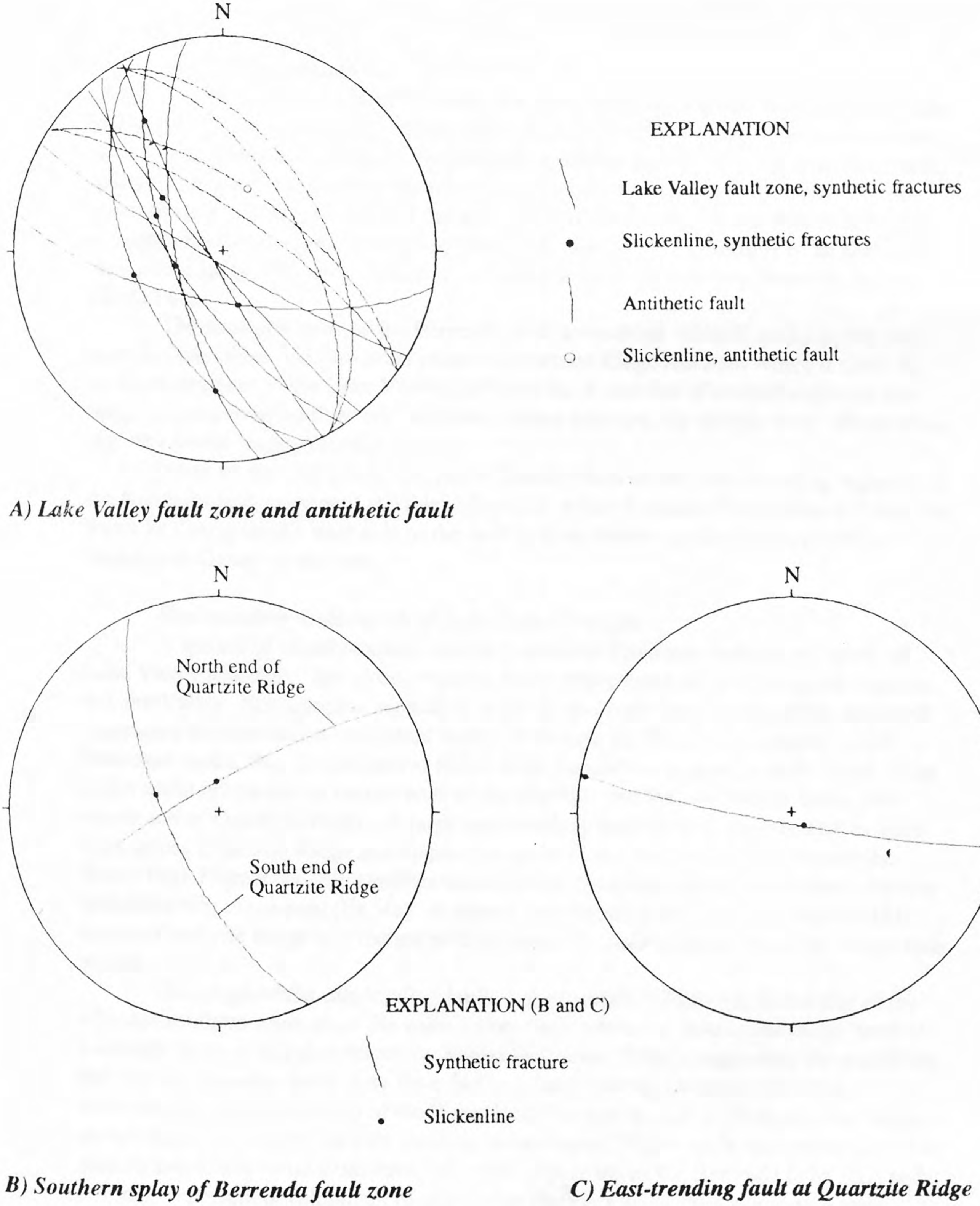

Figure 4. Lower hemisphere stereograms showing orientation of fractures and slickenlines in A) the Lake Valley fault system (from Berrenda Mountain southeast) and parallel antithetic fault, B) the southern splay of the Berrenda fault, and C) an east-trending fault at Quartzite Ridge.

Berrenda fault zone

The Berrenda fault zone consists of a north-trending segment along the west side of Sibley Mountain and two southern splays that turn southwesterly. The northernmost splay is a complex zone of down-to-the-north synthetic and down-to-the-south antithetic faults that extends from Sibley Mountain southwest past Berrenda Mountain. Overall displacement on the main fault of the splay is down-to-the-northwest, with rocks of the Thurman Formation against Kneeling Nun Tuff. An excellent example of an antithetic fault in the splay downdrops volcanic rocks to the south at Berrenda Mountain and O-Bar-O Peak.

The southern splay of the Berrenda fault downdrops volcanic rocks on the west against Ordovician and Devonian rocks of Quartzite Ridge and ends where it abuts the southern segment of the Lake Valley fault system. It consists of several segments that range in trend from north to northeast and, where exposed, dip steeply west. Slickenlines (fig. 4b) reveal largely dip-slip motion.

North of the two splays, the major displacement of the north-trending segment of the Berrenda fault is evident at Sibley Mountain where it crosses Tierra Blanca Creek; the Santa Fe Group on the west side of the fault is downthrown against Pennsylvanian Magdalena Group on the east.

East-trending faults north of Lake Valley townsite

A system of closely-spaced normal faults cuts Paleozoic rocks at and north of Lake Valley townsite. The closely-spaced faults may control silver-manganese deposits at Lake Valley. Stratigraphic separation is small, and both down-to-the-north and south separation is observed on individual faults. Although the faults were mapped mainly in Paleozoic rocks, they cut outliers of Rubio Peak Formation on Apache Hill. Most of the faults could not be traced east or west of Apache Hill, but the two longest faults were traced across Quartzite Ridge. A large east-trending fault north of Apache Hill extends west across Quartzite Ridge and displaces a splay of the Berrenda fault zone and the Rubio Peak Formation. Slickenlines measured on Quartzite Ridge indicate both dip-slip and strike-slip movement (fig. 4c). A second east-trending fault south of Apache Hill crosses Quartzite Ridge and merges with or abuts the main strand of the Lake Valley fault system.

The origin of the east-tending faults is problematic. Their trend, and that of the adjacent southern segment of the Lake Valley fault system, is subparallel to the trend of Laramide faults postulated nearby by Seager and others (1986), suggesting the possibility that the east-trending faults may have first originated during Laramide thrusting. However, the observed offset of the Rubio Peak Formation and the Berrenda fault zone reveals major movement on east-trending faults during Oligocene or later extension. The easterly trend may result from stress accommodation where the Berrenda fault zone ends, or it may represent development of en echelon fractures along the Lake Valley fault system, or it may have yet another explanation, unidentified by us. Other east-trending faults cut the northern segment of the Lake Valley fault system; their origin is also not understood by us.

EOCENE AND OLIGOCENE UNCONFORMITIES AND PALEOTOPOGRAPHIC FEATURES

Unconformities underlie and separate volcanic and sedimentary rocks of Eocene and Oligocene age. In ascending order, unconformities occur at the base of the Rubio Peak (and, where present, the Love Ranch Formation), the base of the Sugarlump Formation, and the base of the Mimbres Peak Formation and the base of the interlayered volcanic rocks of McClede Spring. Other, local unconformities may also occur in the complexly intertongued volcanic rocks of McClede Spring and Thurman Formation.

Unconformities at the base of the Love Ranch and Rubio Peak Formations may be of various ages, but are discussed together because they cannot be distinguished in the map area. As reported by Seager and others (1986), the Love Ranch Formation overlies the Lake Valley Formation north of Lake Valley townsite and west of the north end of Quartzite Ridge; it is in turn overlain by Rubio Peak Formation at these localities. At most localities, however, the Rubio Peak directly overlies rocks of Paleozoic age.

North of O Bar O Spring, in the western part of the map area, laharic breccia and flow rocks of the Rubio Peak Formation rest directly on limestone of the Pennsylvanian Magdalena Group. However, evidence of residual weathering prior to deposition of the Rubio Peak was observed locally. As seen in a gully cut by an ephermal stream, surfaces on the Magdalena limestone beneath the Rubio Peak are coated with thick argillaceous deposits; cracks in limestone are likewise filled with the deposits, and unstratified breccia immediately overlying the limestone contains red matrix and abundant fragments of limestone as well as andesitic rock. Love Ranch Formation mapped there by Seager and others (1982) was found to consist of poorly exposed remnants of loosely consolidated gravel resting on Rubio Peak Formation.

Northeast of the junction of Jaralosa Creek and State Route 27, paleohills of jasperoid in the Silurian Fusselman Formation, locally overlain by Rubio Peak and Sugarlump Formations, have been exhumed by present-day erosion. Jasperoid hills stand as much as 100 ft (30 m) above the base of the Rubio Peak. In some places, tuff of the Sugarlump Formation lies directly on jasperoid. At no place is the volcanic rock altered, indicating that the contacts with jasperoid are of neither intrusive nor hydrothermal replacement origin. These relationships date the jasperoid as pre-Rubio Peak.

The Sugarlump Tuff unconformably overlies Rubio Peak Formation on a surface of low relief throughout the map area. In the upper reaches of Jaralosa Creek, the outcrop of Sugarlump crosses the contact between flows and tuffaceous rocks of the Rubio Peak. Evidently, the Rubio Peak Formation was tilted slightly and eroded before deposition of the Sugarlump. Epiclastic rocks are not abundant at the base of the Sugarlump. On the west side of Berrenda Mountain, the Sugarlump Tuff rests directly on about 30 ft (9 m) of interbedded tuff and breccia. These deposits appear to be largely or entirely volcaniclastic in origin and do not indicate extensive erosion of the underlying volcanic rocks.

A landslide megabreccia composed largely of fragments of Kneeling Nun Tuff and Sugarlump Tuff unconformably overlies these formations and the Rubio Peak Formation at McClede Mountain. Fragments ranging up to tens of yards (meters) in size evidently slid off a west-facing escarpment in the Sugarlump and Kneeling Nun Tuffs. Scarps are exposed north and south of McClede Mountain, where megabreccia and the overlying basal tuff of the Mimbres Peak Formation abut Kneeling Nun and Sugarlump Tuffs along a steep, discordant surface. Foliation in some of the largest blocks of tuff is nearly horizontal, indicating little rotation during sliding. The megabreccia has been described in detail by Elston (1989), who interpreted it as a landslide deposit formed outside the Emory cauldron during collapse and erosion of the caldera wall. The landslide and associated scarp are part of the erosional surface on which the overlying Mimbres Peak Formation was deposited.

STRUCTURE OF LAKE VALLEY FAULT FROM GEOELECTRIC MEASUREMENTS

Methods

Measurements of electromagnetic fields using the tensor audiomagnetotelluric (AMT) method were made along traverses in the Lake Valley area in October 1997. The traverses were along northeast-southwest lines across the Lake Valley fault (fig. 5). Goals of the AMT survey were to investigate the distribution of geologic units and structure associated with the Lake Valley Fault, which forms the western boundary for silver-manganese mineralization in the Lake Valley mining area. The AMT method (Vozoff, 1972, 1991; Strangway and others, 1973) uses electromagnetic fields across a range of frequencies to map the distribution of electrical resistivity versus depth in the Earth. Geological inferences from this information are based on the relationships between electrical resistivity to lithology (table 2). Details of the acquisition and analysis of data are described in Klein and Wise (1998).

Observation sites and their projection onto lines are shown on figure 5. A cross-section south of Lake Valley (southeast of Monument Peak) is based on sites 111 to 124 that are projected onto line 100. Line 300 (sites 124, 325, and 326), northeast of Monument Peak, is discussed in the context of the resistivity structure associated with line 100. A cross-section northwest of Town Mountain uses sites 203-204 projected onto line 200. The succession of generalized lithological units of the study area are listed in table 3, showing their typical thicknesses and relative resistivity. Depths and distances in the following discussion are in meters and kilometers, with feet and mile conversions (rounded to the nearest 10 and 0.1 respectively) provided for convenience.

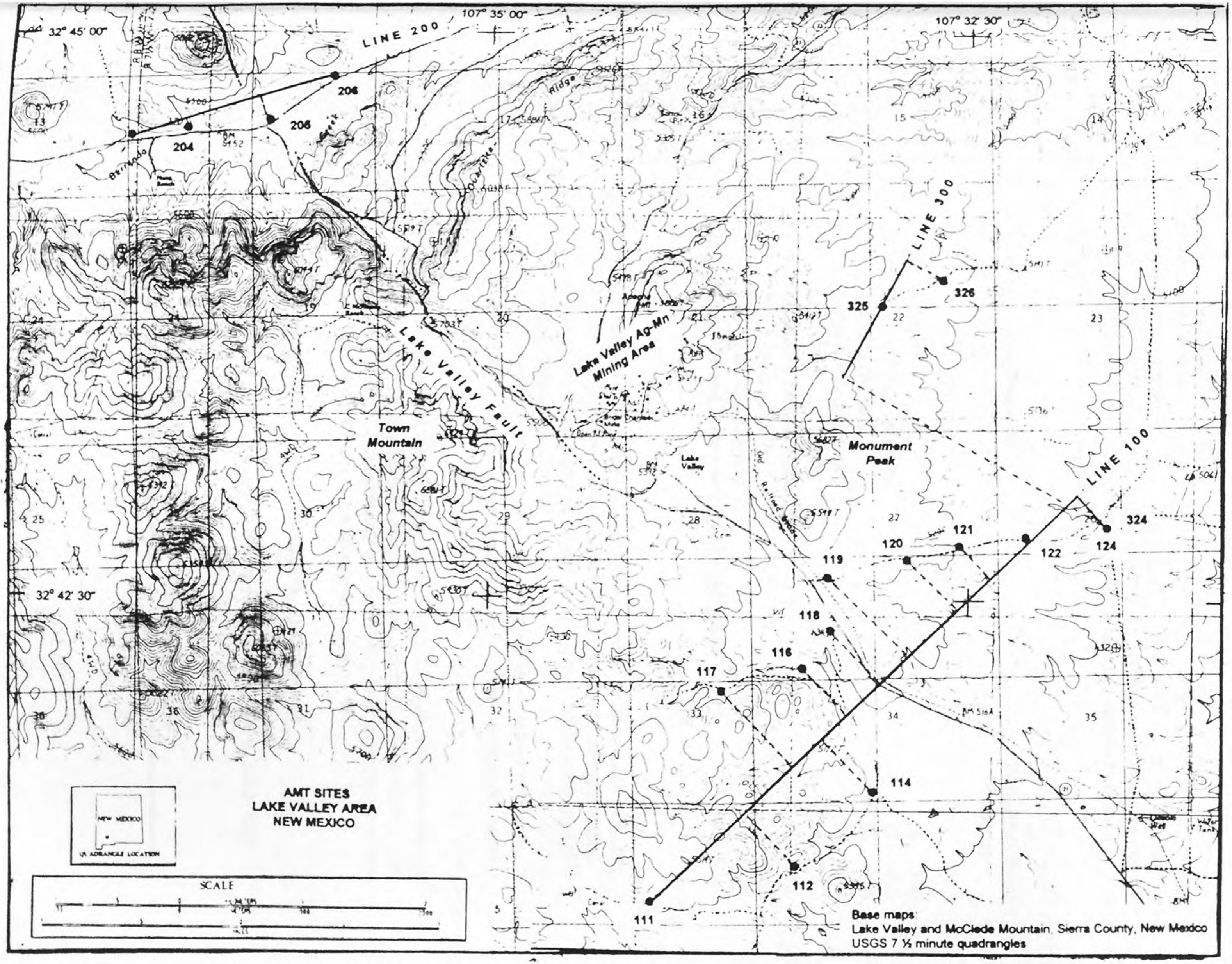

Figure 5. Map of AMT observation sites. Location of observation sites shown as filled circles with site designation. Dashed lines project to lines along which resistivity models were developed. Measurement at site 124 was used for both line 100 and 300.

Table 2.--Resistivity ranges of geologic materials in the southwest U.S. (Keller and Frischknecht, 1966, p.1-55; Brant, 1966; Klein, 1996). The lower 1/3 (approximate) of these ranges takes into account saturation by ground water (10-50 Ohm-m). The upper 2/3 of these ranges represent low-porosity, dry and unaltered, rock. Ranges shown may not account for the presence of conductive metallic sulfide minerals and hot saline water (0.1 - 10 Ohm-m) or resistive alteration such as silicification. Single geologic units may exhibit a range in resistivity caused by a variations in weathering, alteration, and pore-fluid content.

Geologic Material	**Resistivity Range (Ohm-m)**
Alluvium	10 - 100
Gravel and conglomerate	20 - 400
Argillite and shale	20 - 500
Tertiary volcanic rock	20 - 1000
Sandstone	40 - 1000
Mesozoic-Tertiary intrusions	50 - 2000
Proterozoic schist	50 - 5000
Limestone and dolomite	200 - 5000
Quartzite and Proterozoic granite and gneiss	200 - 5000

Table 3.--Generalized sequence of chief lithologic units in the vicinity of Lake Valley Mining shown with typical thickness' and relative resistivities. Refer to table 2 and text for actual ranges of resistivities encountered in various lithologies.

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Gravel, float and alluvium (Quaternary-Tertiary): variable thickness, probably less than 30 m; low resistivity

Tertiary volcanic rock (Tertiary, mainly Rubio Peak formation, lumped with about 20 m of various Mississippian calcareous rocks east of Lake Valley fault): 100 m thick east of Lake Valley fault; unknown thickness west of Lake Valley fault; moderate resistivity

Percha shale (Devonian): 40 m thick; low resistivity

Dolomites and Limestone (Ordovician-Silurian): 300 m thick; high resistivity

Granite and gneiss (Proterozoic): high resistivity

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Results

Cross-section south of Lake Valley

Geologic units in the vicinity of the Lake Valley mining area (table 3) have been estimated from geological mapping to dip about 20° to the southeast. Such a dip may result in a differential depth to units of about 350 m (1,150 ft) for each km of separation between the mining area and the AMT sites. Actual locations of the sites, rather than their projection to a cross-section line are considered when accounting for the dip.

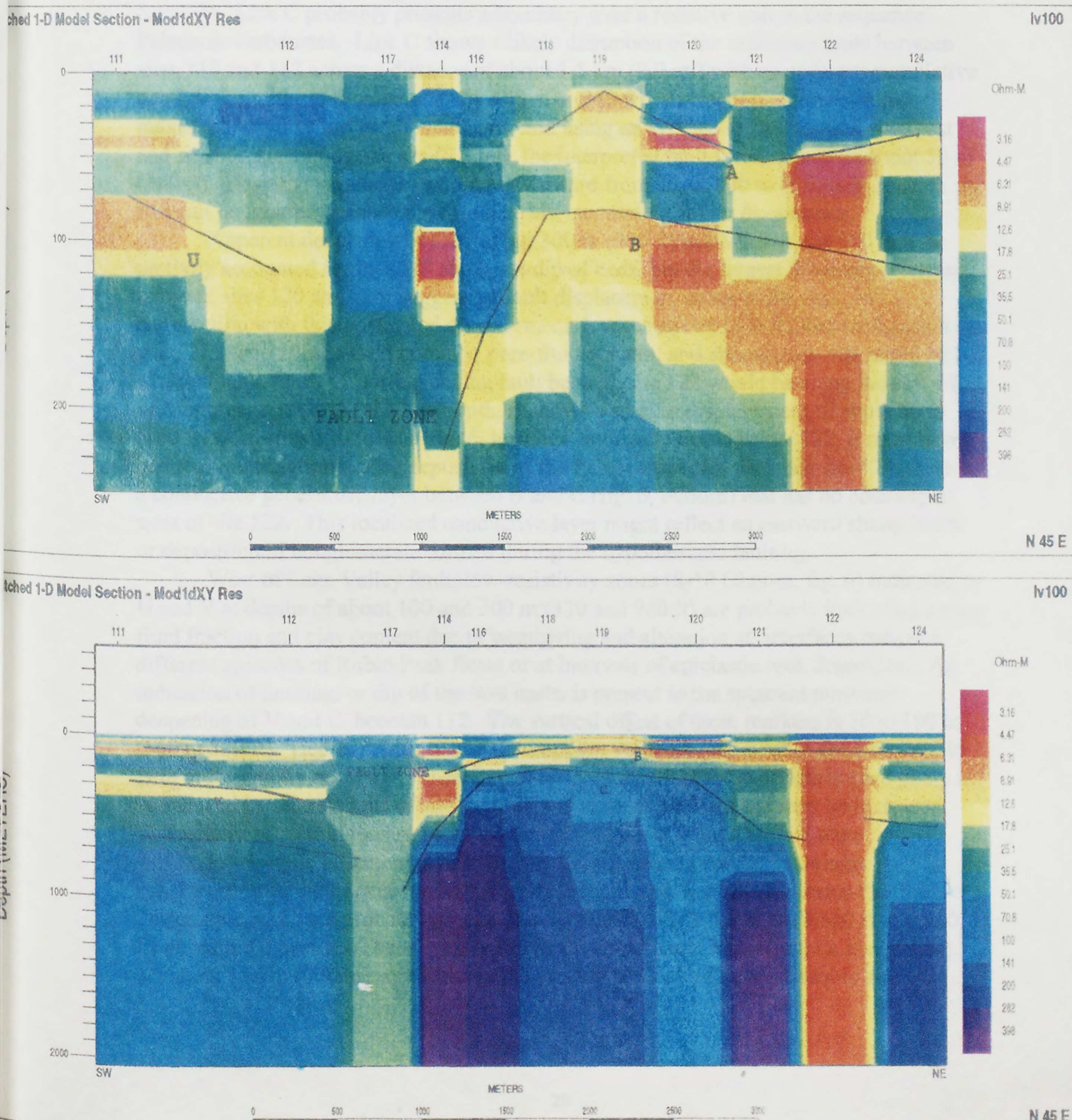
Figure 6 shows a resistivity section for line 100. Resistivity is color-coded as shown on the color bar with lower to higher resistivity corresponding to the color progression of various hues of red-yellow-green-blue-purple. The section was formed as a composite of layered-Earth (one-dimensional or 1-D) inversions (Constable and others, 1979). Therefore, the section is portrayed with a block of layers beneath each site. The plot shows a transition zone between the layers of adjacent sites that is arbitrarily plotted midway between sites and spans a distance of 30-percent of the separation between sites. Figure 6 (top) shows the upper 250 m (820 ft) of the model with a vertical exaggeration of about 10; the bottom shows the section to 2,000 m (6,560 ft) with no vertical exaggeration. The depth of resolution for the data is about 1,200 m (3,940 ft). Vertical bands for the deepest layer beneath each site are an artifact. Only depth and resistivity are resolved for the deepest layer detected; thickness is unknown and physically indistinguishable from being infinite in thickness.

In figure 6, interpretative lines labeled as A, B, C, U, V mark interfaces between electrical resistivity units. These units may differ from geologic units. Site 118 is near the inferred southward extension of the Lake Valley fault. The discontinuity in various lines on the section (fig. 6) is an expression of this fault. To the west of the fault, where geologic mapping indicates an sequence of andesitic volcanic rock (Trp) of unknown thickness, there are electrical units that are as well defined as those to the east of the fault where a thin cover of volcanic rock (Trp) overlays a succession of Paleozoic formations.

Northeast of site 118, A (fig.6, top) is at 10 to 50 m (30 to 150 ft) depth to mark the top of a low-resistivity unit (3-10 ohm-m). This low resistivity is interpreted to represent the bottom of unconsolidated gravel, float, and alluvium, a zone that is or has been conducive to weathering, and the collection of wet silts or clays.

Line B, shown on both the top and bottom of fig. 6 at a depth of 80 to 110 m (260 to 360 ft) northeast of site 118, and appears to be west-dipping west between sites 118 and 114, marks a conductive unit (10-15 Ohm-m) that is interpreted to represent the top of the Percha shale. The westward dip indicates possible vertical offset of this unit amounting to about 140 m (460 ft) between sites 118 and 114. Site 114 is about 1 km (0.6 mi) southeast of station 118 (fig. 5), and the offset of the unit could be accounted for by a southeast dip of the unit of 7°. Likewise, apparent dip on B northeast of 118 (fig. 6) may in part be related to the differential southeast offsets of sites over dipping stratigraphy.

Figure 6. Resistivity model for line 100. Model is composite of layered strata inversions for each site based on error-weighted apparent resistivity (Rxy) and phase (Pxy). X rotated approximately perpendicular to Lake Valley fault. Resistivity values are color coded as shown on bars. Top model to 250 m (820 ft) depth with vertical exaggeration of 10; bottom-model to 2,000 m (6560 ft) depth with no vertical exaggeration. Labeled ticks along top of sections show projected location of AMT sites. Lines labeled A, B, C, U, and V show interpreted top of geoelectric units.



Line C (fig. 6, bottom) marks the top of resistive units (50 to 300 Ohm-m). The true resistivity within this unit is probably 300 Ohm-m or greater, inasmuch as the inversion creates a smoothly varying resistivity model. The average depth of C is about 600 m (1,970 ft) southwest of site 117 compared to about 200 m (655 ft) to the northeast from sites 116 to 120. Northeast of site 120, C deepens to an average depth of about 500 m (1,640 ft). On the average, C is about 150 m (490 ft) deeper than B which was inferred to mark the top of the Percha shale. Using a geologic estimate of thickness of the Percha as 40 m (130 ft), C is about 100 m (330 ft) into the Ordovician-Silurian dolomites and limestone which has an geologically estimated combined thickness of 300 m (980 ft) (table 3). Line C probably presents a boundary over a resistive unit in the sequence Paleozoic carbonates. Line C shows a likely disruption of the carbonate units between sites 118 and 112 across a distance of about 1.5 km (0.9 mi) with an apparent cumulative downthrow of the carbonate units by 400 m (1,310 ft). Correcting for an assumed maximum regional dip of 20° southeast, and using an average offset between sites east and west of site 117 as one km (0.6 mi), the interpreted fault throw would be about 50 m (160 ft). Resistivity values extending downward from about 600 m (1,970 ft) beneath site 117 can be ignored because the data here are incomplete at low frequencies.

Apparent deepening of C by about 300 m (980 ft) northeast of site 120 may be partially accounted for by a 20° southeast dip of beds, but the largest downthrow occurs between sites 120 and 121, suggesting fault displacement down to the east. In conjunction with this postulated displacement, low resistivity (3 to 8 Ohm-m) beneath site 122 suggests increased porosity, pore-fluid content, and altered rock that might be found along a fault. A north-trending fault beneath site 122 would be along the east edge of Monument peak. At shallow depth, B shows a smaller displacement of about 50 m (160 ft) from sites 120 to 124 (fig. 6, top); if a fault zone exists below 122, it must have had recurrent motion during deposition of the Paleozoic rocks. Beneath site 124, there is a conductive geoelectric layer between B and C (fig. 6, bottom) that has no counterpart west of site 122. This localized conductive layer might reflect an eastward slump block or deposition of conglomerate formed during the hypothesized faulting.

West of Lake Valley fault, low-resistivity zones (8-10 Ohm-m, fig. 6) indicated by U and V at depths of about 100 and 300 m (330 and 980 ft) are probably indicating higher fluid fraction and clay content due to weathering and alteration at interfaces between different episodes of Rubio Peak flows or at intervals of epiclastic rock deposition. An indication of faulting, or dip of the lava units, is present in the apparent northeast deepening of V and C beneath 112. The vertical offset of these markers is 50 to 100 m (160 to 330 ft). Geologic dips on the outcropping volcanic rock west of the Lake Valley fault are generally northerly. Therefore, it is concluded that these offsets are not likely to be reduced by the relations of site location and stratigraphic dip and may be increased. The resistivity section thus suggests graben development along the fault zone.

Proterozoic basement is not identified in the present results. Geologic consideration of the thickness of the Paleozoic rocks and their dip, indicates that the Proterozoic rocks are probably present at a depth of 1,100 to 1,700 m (3,610 ft to 5,580 ft) beneath the profile. The nearest outcrops the Proterozoic rocks (granite and gneiss) are about 15 km (0.9 mi) southwest in the vicinity of Cooks Range. Granitic and carbonate rocks may have overlapping resistivity (table 2) so if basement is within reach of the electromagnetic fields, it is indistinguishable from the overlying carbonates.

Apparent dip of resistivity units

Sites 325 and 326, northeast of Monument Peak (fig. 5), along with site 124, provide insight into the average apparent dip of geoelectric units in the survey area. Line 300 was established to show the projection of sites 124, 325, and 326 as approximately equally spaced (fig. 7). This does not represent a realistic horizontal perspective; the line was constructed to provide a visual correlation of electrical units.

The upper two layers of low resistivity at site 124 are at depths of about 30 m (100 ft) and 120 m (390 ft) respectively; these layers have been interpreted as the base of overburden and the Percha Shale (fig. 6 and accompanying discussion). A deeper conductive layer starting at about 300 m (980 ft) beneath site 124 was unique to this site on line 100. It is apparently missing at sites 325 and 326. At site 325, the shallower conductive layers converge at a depth of less than 100 m (330 ft) implying that the basin cover and volcanic rocks may be thinner here compared to line 100. Both conductive units and deeper resistive units (about 50 Ohm-m or greater) at sites 325 and 326 indicate an apparent eastward dip.

The geoelectric marker within carbonate section used for inferring throw across Lake Valley fault on line 100 was the top of resistivity greater than about 50 ohm-m, located at a depth of about 500 m (1,640 ft) beneath site 124 (C, fig. 6 and accompanying discussion). At station 325, the top of geoelectric units with resistivity greater than 50 ohm-m is at a depth of about 120 m (390 ft). This apparent vertical offset of 380 m (1,250 ft) between 325 and 124 is consistent with an average south apparent dip of 8° from site 325 to 124. The previously estimated minimum throw, using a dip of 20° for strata beneath the measurements of line 100 is about 50 m (160 m). Using an 8° dip, a maximum throw of about 250 m (820 ft) is possible.

Cross-section north of Town Mountain

Line 200, located northwest of Town Mountain (fig. 5), is composed of 4 AMT sites acquired along Berrenda Creek. The line should intersect the northwest extension of Lake Valley fault near site 205. The Lake Valley fault disappears beneath cover about 1 km (0.6 mi) southeast of line 200 and reappears in outcrop again about 1 km (0.6 mi) to the northwest. Measurements lay on the Berrenda Fault system that is bounded by two mapped northeast-trending splays roughly orthogonal to the Lake Valley fault (fig. 5).

A factor that weighs on the accuracy and interpretation of the AMT data on line 200 is a power line about 1 km (0.6 mi) NW of sounding 206 that is sub-parallel to the line of sites. In the vicinity of sites 203 and 204, this power line is tapped to provide electricity to a ranch southeast of line 200. The subsidiary power line is about 150 m (490 ft) from site 204, and about 50 m (160 ft) from site 203. Power line signals at 60 Hz and it's harmonics can produce deterioration of the signal-to-noise ratio for nearby measurement at frequencies less than a few thousand Hz. Power lines may also carry induced electric currents that distort the electromagnetic response of the Earth.

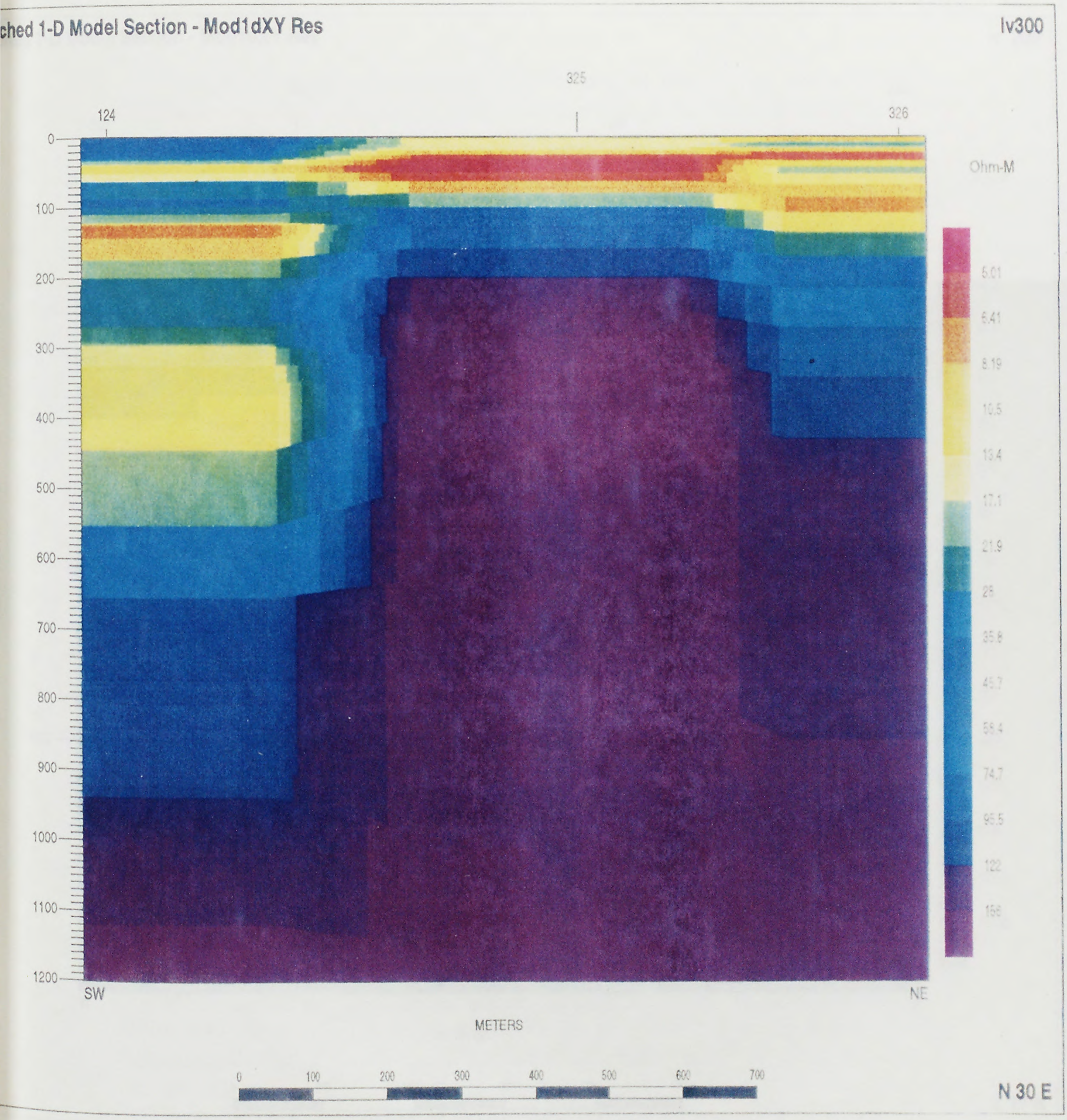


Figure 7. Resistivity model for line 300. This model is intended to show the vertical offset of correlative resistivity layers between sites 325 (and 326) with respect to 124. This offset is inferred to be related to the apparent dip of strata between the sites 325 and 124 (see text). Model is composite of layered strata inversions for each site based on error-weighted apparent resistivity (Rxy) and phase (Pxy). X rotated approximately perpendicular to Lake Valley fault. Model resistivity vs. depth and distance has no vertical exaggeration. Labeled ticks along top of section show projected locations of AMT sites. Resistivity values are colored coded as shown on bars.

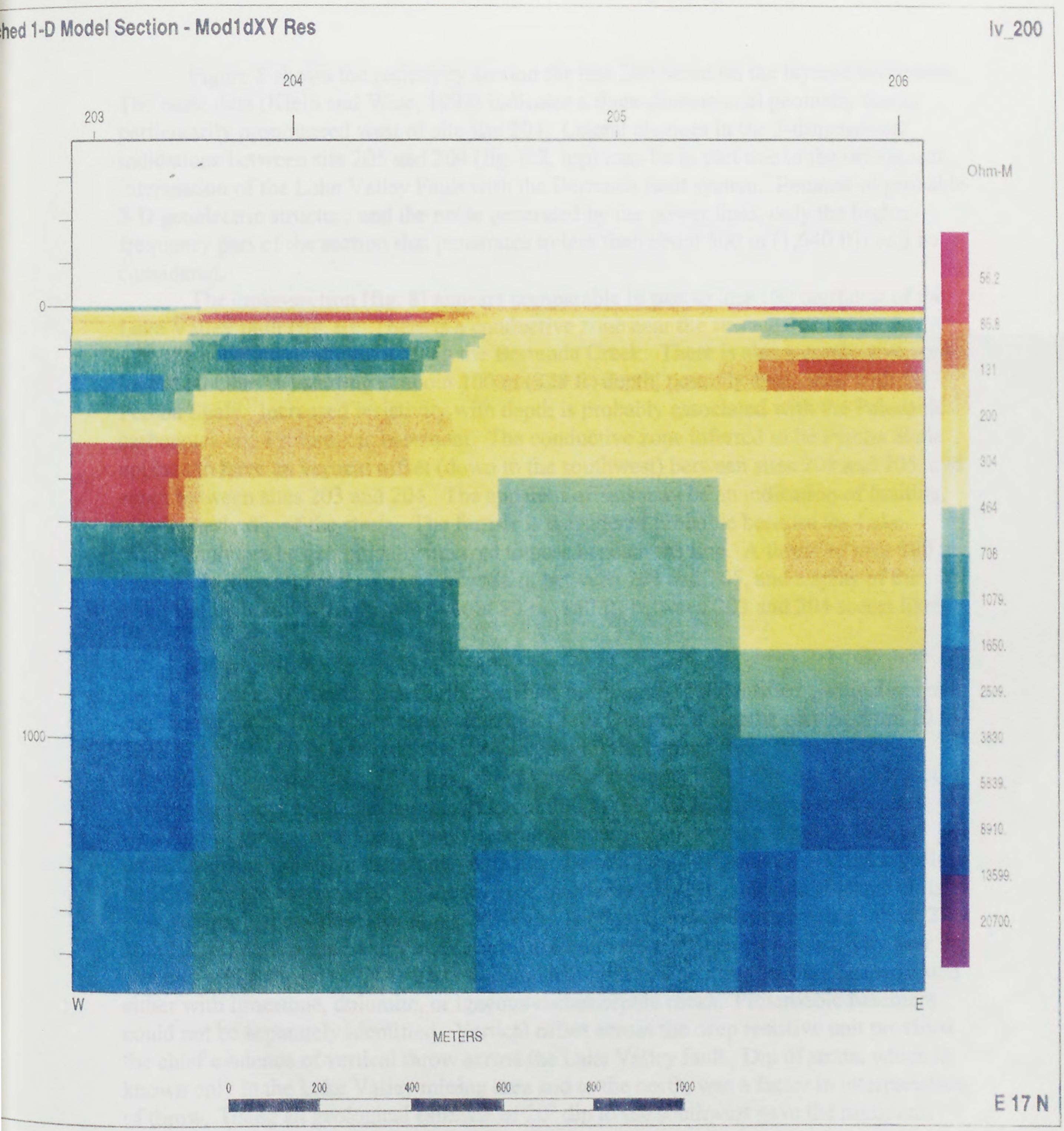


Figure 8. Resistivity model for line 200. Model is composite of layered strata inversions for each site based on error-weighted apparent resistivity (Rxy) and phase (Pxy). X rotated approximately perpendicular to Lake Valley fault. Model resistivity vs. distance and depth has no vertical exaggeration. Labeled ticks along top of sections show projected locations of AMT sites. Resistivity values are colored coded as shown on bars.

Figure 8 shows the resistivity section for line 200 based on the layered inversions. The basic data (Klein and Wise, 1998) indicates a three-dimensional geometry that is particularily pronounced west of site site 204. Lateral changes in the 3-dimensional indications between site 205 and 204 (fig. 6.2, top) may be in part due to the orthogonal intersection of the Lake Valley Fault with the Berrenda fault system. Because of probable 3-D geoelectric structure and the noise generated by the power lines, only the higher-frequency part of the section that penetrates to less than about 500 m (1,640 ft)) will be considered.

The cross-section (fig. 8) appears comparable in part to line 100 northeast of the Lake Valley fault (fig. 6). There is a conductive zone near the surface that is consistent with the conductive alluvium along the Berrenda Creek. There is also a conductive zone (about 50 Ohm-m) starting at about 100 m (328 ft) depth, possibly associated with the Percha Shale. Increased resistivity with depth is probably associated with the Paleozoic carbonates and Proterozoic basement. The conductive zone inferred to be Percha Shale appears to have an vertical offset (down to the southwest) between sites 204 and 205, and again between sites 203 and 204. The apparent offsets may be an indication of faulting, or a westerly dip of the strata. The former is considered probable because the Lake Valley fault can be geologically inferred to pass beneath the line. A throw of near 100 m (330 ft) down west for the Lake Valley fault between 204 and 205, and a splay of the Lake Valley fault with a throw of about 50 m (160 ft) between 203 and 204 seems likely.

Discussion

South of Monument Peak, the east half of traverse 100 identified two widespread conductive units. The upper conductive unit (3-10 Ohm-m) at depths varying from 10 to 50 m (32 to 164 ft) is inferred to be associated with the base of the unconsolidated alluvium, gravel and float. The next lower conductive unit (10-15 Ohm-m) is interpreted to represent Percha Shale at a depth of about 200 m (660 ft). Conductive units on the west half of the traverse are probably reflecting interfaces between andesitic volcanic units. A discontinuity in these units indicates the southward continuation of Lake Valley fault. Apparent eastward dip of the inferred interfaces between andesitic volcanic units indicates graben development along the fault. An unmapped fault is suggested about 2 km (1.2 mi) east of the Lake Valley Fault based on various contrasts in resistivity near the east end of the traverse. Deep units detected had high resistivities that may be associated either with limestone, dolomite, or igneous-metamorphic rocks. Proterozoic basement could not be separately identified. Vertical offset across the deep resistive unit provided the chief evidence of vertical throw across the Lake Valley fault. Dip of strata, which is known only in the Lake Valley mining area and to the north, was a factor in interpretation of throw. Using an geological estimate of 20^{o} dip to the southwest gave the minimum displacement of 50 m (160 ft) to the west. The largest displacement that can be inferred is 250 m (820 ft) based on comparing resistivity structure east of Monument Peak with that on line 100 to establish an apparent dip of 8^{o}.

Measurements north of Lake Valley on a traverse along Berrenda Creek were influenced by power lines and intersecting faults. Shallower penetrating data affected least by these complications provide hints on the northward extension of Lake Valley fault. The upper 500 m (1,640 ft) of the model suggests an apparent westward dip of strata of about 20° that may be associated with multiple faults with a combined throw of 100-150 m (330-400 ft).

OBSERVATIONS ON AEROMAGNETIC AND GRAVITY ANOMALIES

Introduction

The aeromagnetic and gravity anomaly maps are analyzed to provide information about faults, igneous intrusions, cauldrons, and rift basins in the area of the Lake Valley ACEC. The purpose is to examine the regional geophysical setting of the study area in the context of regional features shown on the maps (figs. 9, 10, 11) and modeled structure section (fig. 12). Although the aeromagnetic expressions of the Emory caldera and the large igneous intrusions near Hillsboro are prominent, it is not within the scope of this report to make a detailed analysis of these features.

Aeromagnetic and gravity anomalies result from juxtaposition of rocks of contrasting physical properties. Aeromagnetic anomaly data distinguish highly magnetic mafic rocks, such as basalts, from weak-moderately magnetized rocks, such as granites, hydrothermally altered rocks, and most sedimentary rocks. Aeromagnetic data provide more detail about shallow structure and lithology than gravity data because of the greater range of values of magnetic properties compared with smaller ranges of densities of most rocks. The aeromagnetic data may exhibit signatures of intrusions and faults associated with ring structure and faulted volcanic rocks. Gravity data help identify large lithologic units and major fault zones in the crust. For example, gravity lows may reflect granite plutons intruded into higher density gneissic terrane.

Previous work

Results of earlier studies of magnetic and gravity anomaly data applied to geologic framework and mineral resource investigations that include the Lake Valley area have been reported by Adams and Keller (1994); Cordell (1978, 1983); Cordell and Grauch (1985), Kleinkopf (1997); and Schneider and Keller (1994).

Adams and Keller, (1994) made studies of crustal structure and basin geometry in south-central New Mexico and show a series of gravity models depicting regional cross sections a few hundreds of mi (several hundred km) in length. The western quarter of their profile C-C' passes across the Palomas basin about 30 mi (50 km) north of the Lake Valley area and is generally on geologic strike. Their gravity models were constrained by seismic profiles and scattered wells that penetrated Precambrian rocks.

Aeromagnetic data

The aeromagnetic anomaly maps (figs. 9, 10) were compiled from data purchased from the firm of Pearson, deRidder and Johnson, Inc. The survey was flown at line spacings of 0.33 miles (0.53 km) and at a mean terrane clearance of 500 ft (152 m). The aeromagnetic maps in this report are at scales of 1:500,000 or smaller. Under the purchase agreement, the data cannot be published at scales larger than 1:500,000, or released in digital format. These data provide considerably more detail about the geology than the published data that were collected from surveys at higher altitude and wider line spacings (Cordell, 1983).

The total-intensity aeromagnetic anomaly data (fig. 9) were reduced to the pole (R2P). The R2P map corrects anomaly locations for inclination of the earth's magnetic field and shifts anomaly centers over the causative sources. A residual anomaly map (31 mi [50 km] high-pass) and a magnitude of the horizontal gradient of pseudogravity map (fig.10) were prepared in order to enhance anomalies for geologic interpretation. The processing was done with software that uses fast fourier transforms to convert aeromagnetic anomaly data in the space domain to the frequency domain (Hildenbrand, 1983).

The residual aeromagnetic anomaly map (fig. 10) was prepared by wave-length filtering the total-intensity aeromagnetic anomaly data. The filtering (31 mi, 50 km high pass) enhances anomaly definition and emphasizes anomalies due to sources in the upper crust, on the assumption that anomaly wavelength is proportional to depth of source (Bankey and Kleinkopf, 1988).

The maxima plot of magnitude of horizontal gradient of pseudogravity (fig. 10) was prepared to help delineate magnetization boundaries (Cordell and Grauch, 1985) that may signify geologic contacts or linear geologic features. The pseudogravity is transformed from the total-intensity aeromagnetics (Hildenbrand, 1983; Baranov, 1957).

Gravity data

The complete Bouguer gravity anomaly map was compiled from non-proprietary data obtained from the National Imagery and Mapping Agency (NIMA). During field work in September 1996, 11 new gravity stations were read in the Lake Valley area to better constrain the gravity interpretations. The reference base used was DOD 3918-1 located at the Truth or Consequences Post Office. The gravity data were reduced using standard USGS procedures described by Bankey and Kleinkopf (1988). Gravity control for the map area consists of about 329 unevenly spaced stations mainly along roads and trails (fig. 11). The observed gravity values are referenced to the IGSN-71 gravity datum (Morelli and others, 1974) and are based on the 1967 ellipsoid (International Association of Geodesy, 1971). The digital gravity data may be obtained from the National Geophysical Data Center (NGDC), National Oceanic and Atmospheric Administration (NOAA), Boulder, CO 80303.

Gravity model

A gravity model (A-A') was prepared to provide information about the surbsurface across the Lake Valley area (figs. 11, 12). The model was produced using a 2.0-dimensional program (GM-SYS^{TM} , version 4.04) developed by Northwest Geophysical Associates, Inc. Since there is generally less than 100 ft (30 m) of topographic relief along the model, Bouguer gravity values were used to calculate the model with a flat upper surface that corresponds to the surface of the earth. Regional cross-sections from gravity modeling by Adams and Keller (1994) provided guidelines for preparing A-A'. The western quarter of their profile C-C' passes across the Palomas basin about 31 mi (50 km) north of the Lake Valley area and is generally on geologic strike. Their gravity models were constrained by seismic profiles and some well data that penetrated Precambrian basement. Density values were also determined from values given in the tables of Dobrin and Savit (1988) and Telford and others (1990).

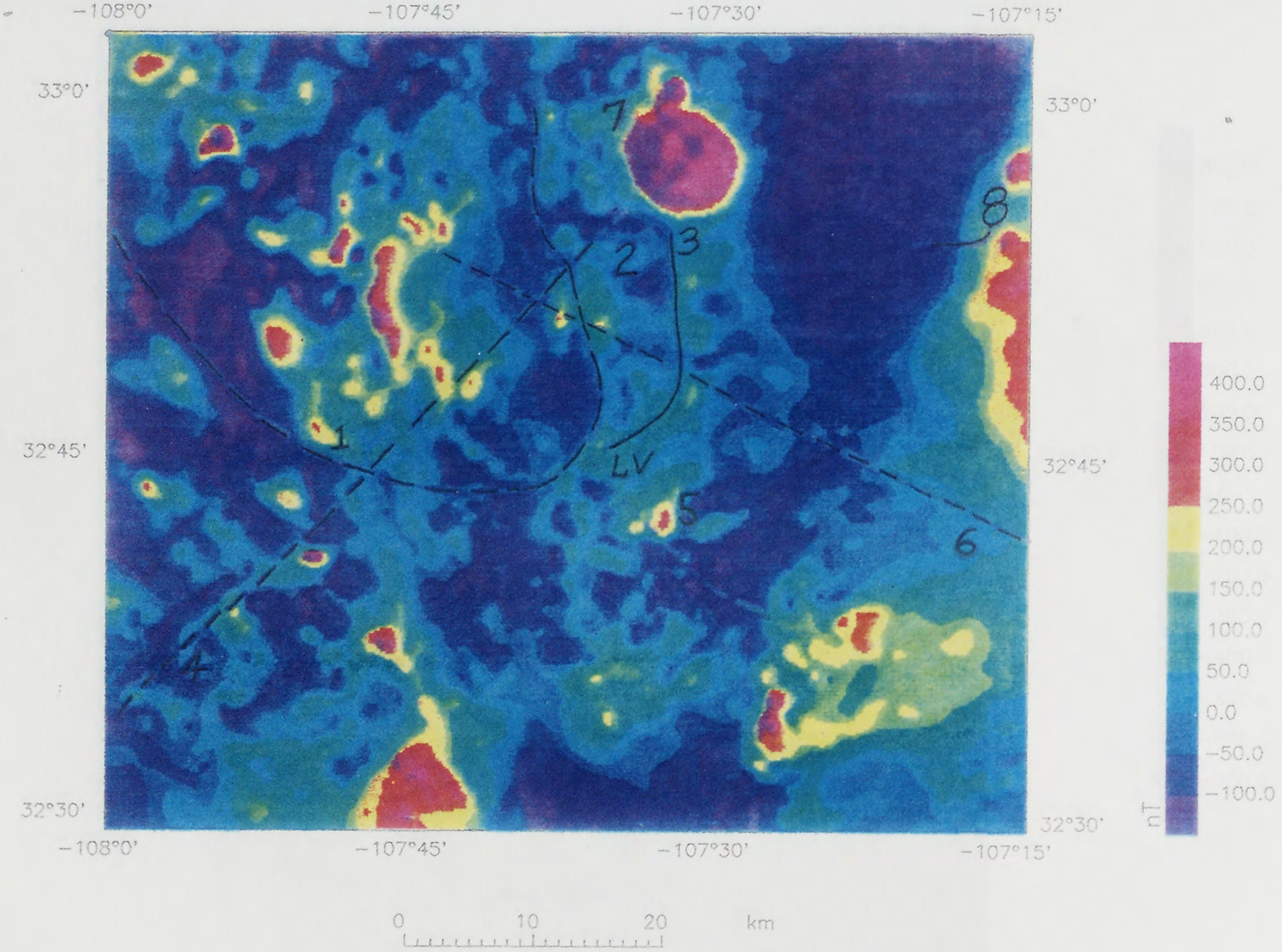


Figure 9. Total-intensity aeromagnetic anomalies reduced to pole. Key to Numbers: 1 - outline of Emory caldera; 2 - Animas basin; 3 - Berrenda fault; 4 - Santa Rita lineament; 5 - suspected near-surface granitic intrusion; 6 - trace of regional thrust fault; 7 - Copper Flat porphyry at Hillsboro; 8 - Palomas basin

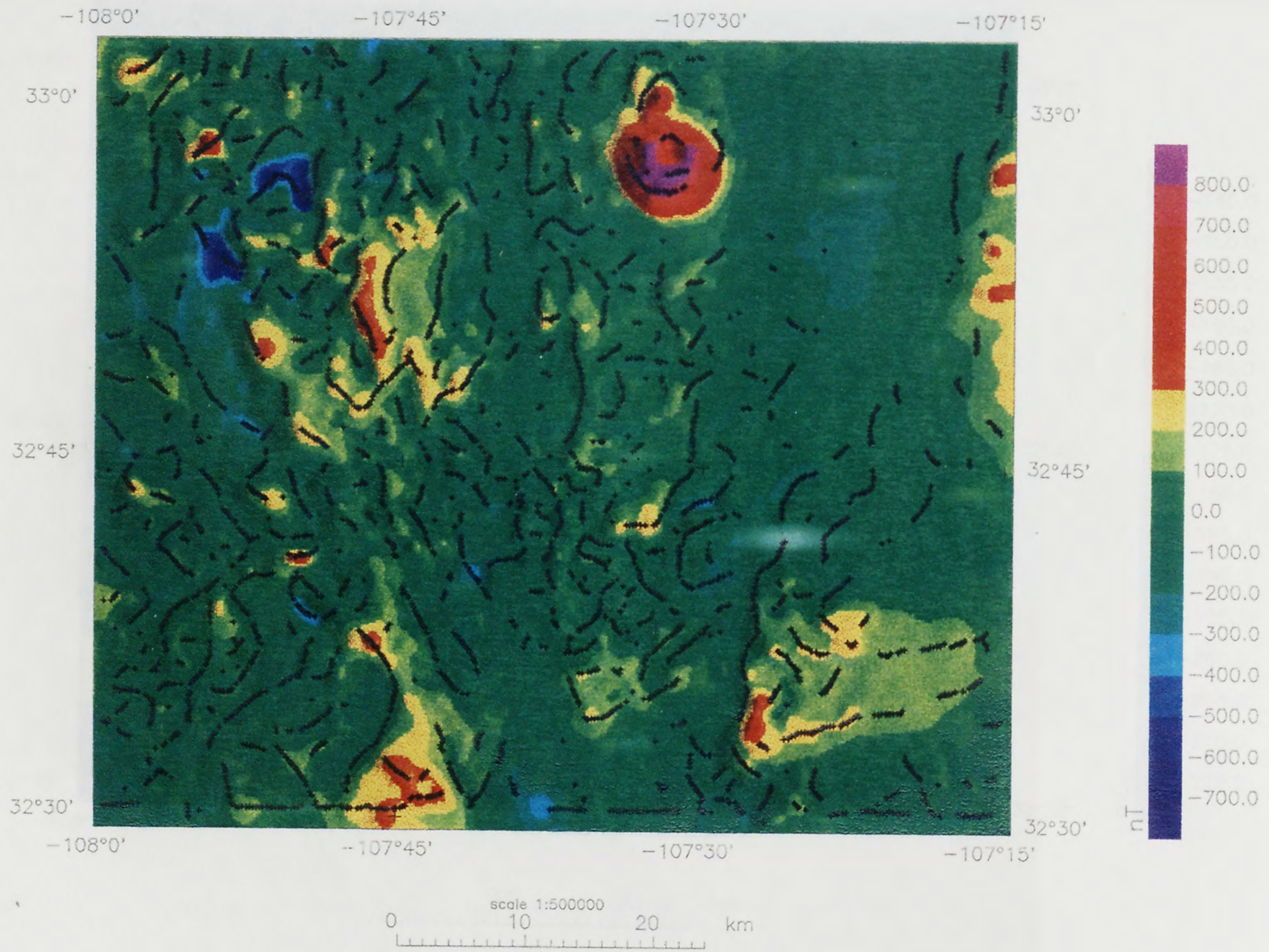


Figure 10. Residual total-intensity aeromagnetic anomalies. Plots of circles denote maxima of the horizontal gradient of the pseudo gravity.

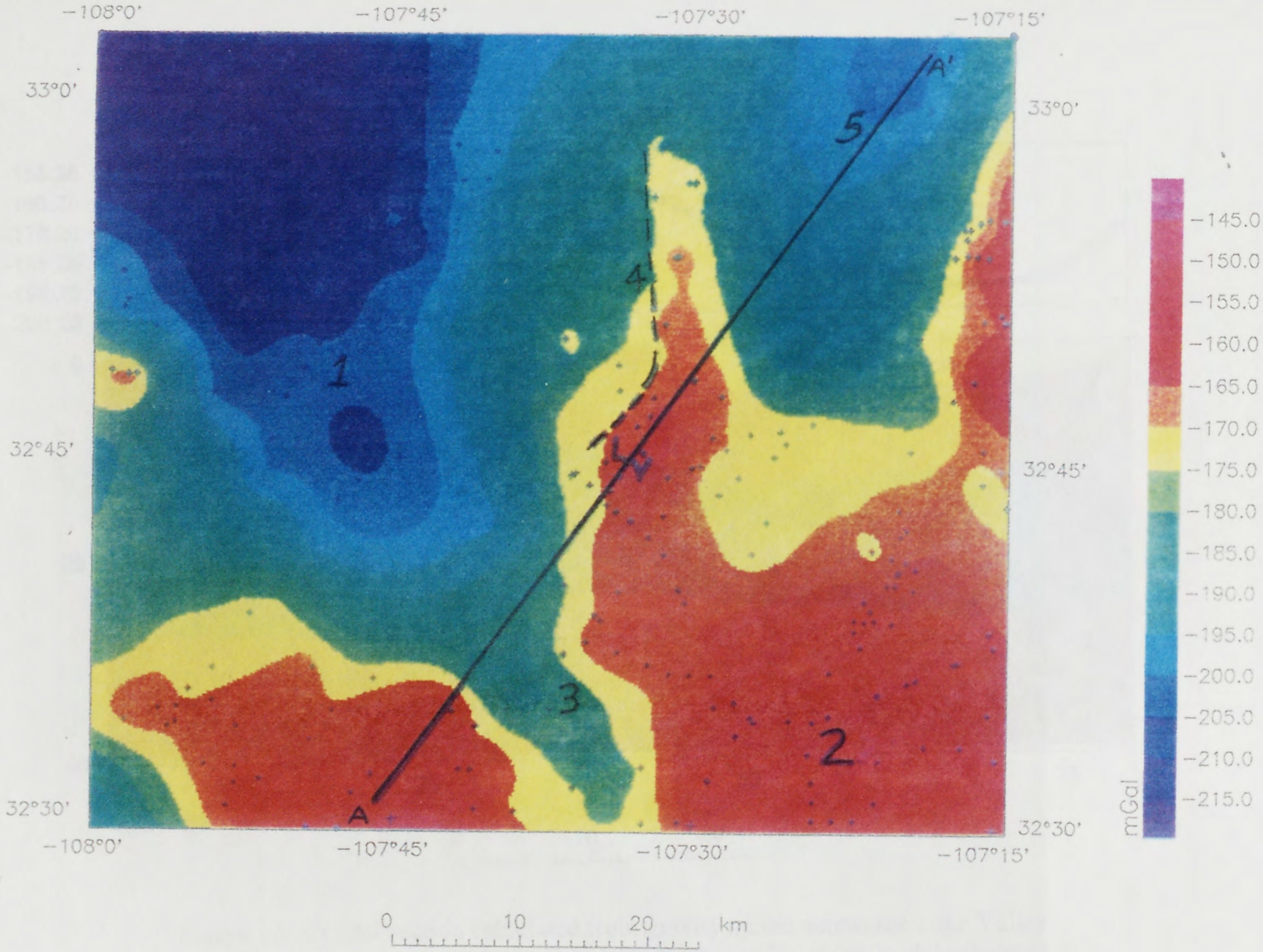


Figure 11. Complete Bouguer Gravity Anomalies. Gravity station + Line of section of gravity model A----A′. Key to numbers: 1 - Emory caldera; 2 - Rio Grande uplift 3 - graben, 4 - Berrenda fault, 5 - Palomas basin.

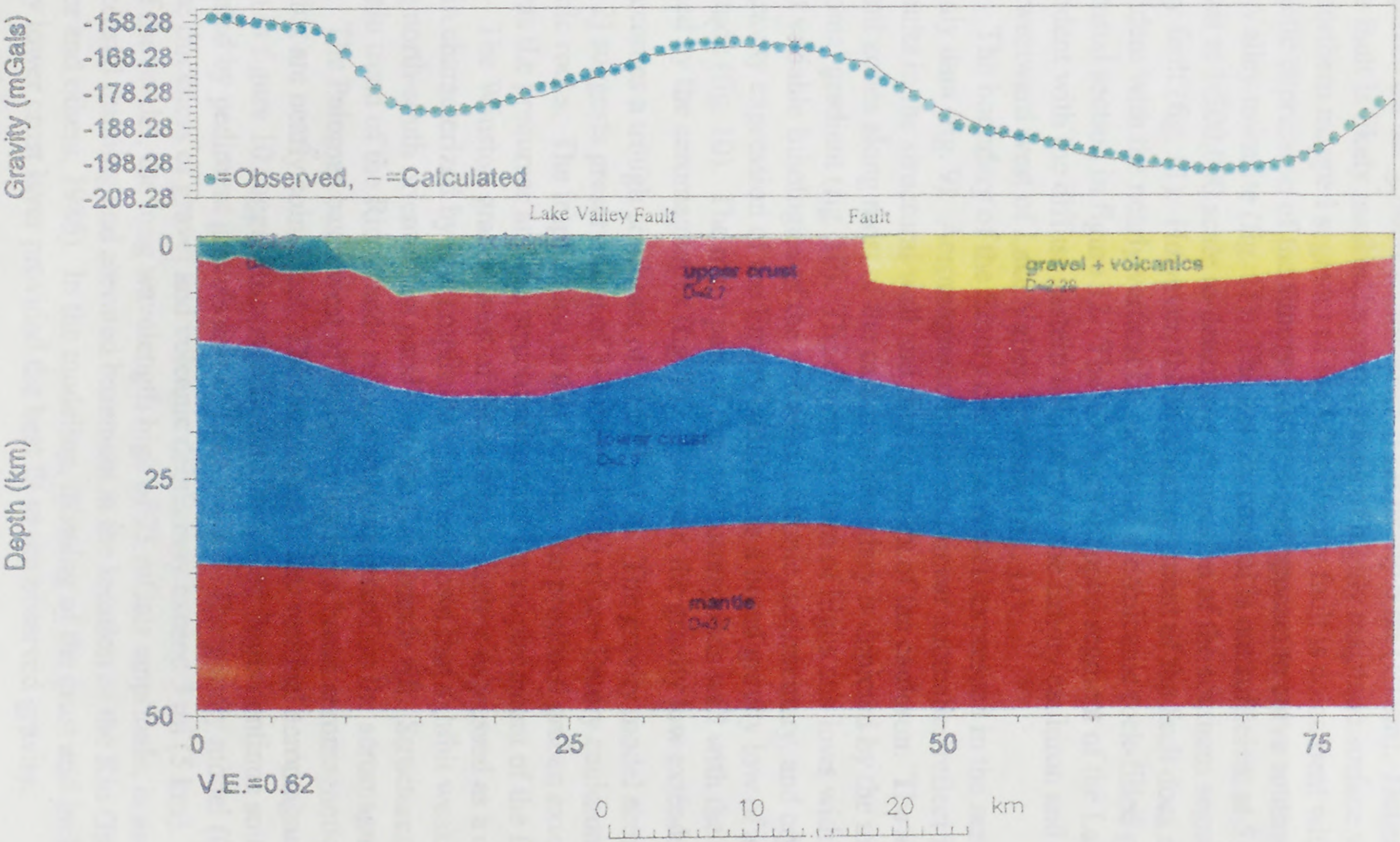


Figure 12. Crustal section calculated from gravity model across the Lake Valley area. Numbers show densities assumed (D=2.67 g/cm^3). Zero depth in the model represents sea level. Geologic units of the model are upper crust; lower crust, gravel and volcanic rock, volcanic rock, mantle rock.

Discussion

The Lake Valley ACEC is located in an area of diverse aeromagnetic signatures that reflect mainly the distribution of volcanic rocks of variable magnetizations. The southern segment of the Lake Valley fault (see discussion of Structural Geology above) is poorly expressed by discontinuous aeromagnetic trends. Total-intensity aeromagnetic anomalies (fig. 9) are not definitive; however, residual anomalies (fig. 10) do show discontinuous linear features that trend from where the Lake Valley fault has been recognized on the ground southeastward for nearly 6 mi (10 km). Definitive expression of the fault is likely masked by expressions of highly magnetic surface volcanic rocks. The northern mapped segment of the Lake Valley fault is coincident with the prominent magnetic expression of the Emory cauldron and appears to curve southwestward west of Lake Valley townsite (fig. 11). The gravity control is not sufficient at 5 mGal contour interval at 1:500,000 scale to detect any expression of the southern segment of the Lake Valley fault (fig. 11). However, the southern segment of the fault does appear to be coincident with the nearly vertical boundary of the volcanic rock-filled graben modeled in the crustal section in figure 12. The northern mapped segment of the Lake Valley fault is coincident with the diffuse eastern boundary of the Emory cauldron and appears to curve southwestward west of Lake Valley townsite (fig. 11).

The boundary of the Emory cauldron is well expressed in the aeromagnetic anomaly data (fig. 9). Aeromagnetic highs and linear anomalies reflect igneous intrusions and faults in the structural wall and ring complex of the cauldron. The alignment of high gradient zones along most of the cauldron boundary is depicted by the maxima of the horizontal gradient (fig. 10). The diverse pattern of highs and lows within the cauldron reflect variable lithologies of the volcanic, plutonic, sedimentary, and crystalline rocks. The gravity expression of the Emory cauldron is a broad gravity low of about 30 mGal amplitude (fig. 10). The main part of the low corresponds well with the cauldron as outlined by the aeromagnetics (fig. 9). However, the gravity low extends to the southeast and becomes a trough southeast of lat 32^{o} 40' N. The gravity model across the trough (fig. 12) suggests preservation of 3-4 mi (5-6 km) of pre-Emory cauldron Rubio Peak volcanic rocks. The implication is that perhaps the proposed graben extended northwest and was the precursor and the structural control for emplacement of the Emery caluldron.

The Winston graben west of the Berrenda fault is expressed as a discrete magnetic domain characterized by low amplitude highs and lows that exhibit weak east-west or strong north-south orientations parallel to the Rio Grande rift. Structures associated with the main trend of the Rio Grande rift are well expressed on the aeromagnetic maps (figs. 9, 10). The Palomas basin west of Hillsboro exhibits broad aeromagnetic and gravity lows that are nearly coincident. Discontinuous linear residual aeromagnetic anomalies shown in figure 10 suggest that significant rift-related faults continue south and are concealed by pediment gravels east of Lake Valley. The gravity model (fig. 12) suggests that the thickness of gravel and volcanic debris may exceed 3 mi (5 km). In the central part of the model, the long wavelength high of 25 mGals amplitude, is associated with local crustal thinning and elevated basement at the location of the Rio Grande uplift (Seager and others, 1986). In the modeling, thinning of the crust and inclusion of a high density lower crust layer provided the best fit to the observed gravity.

The northwest-trending buried thrust fault interpreted by Seager and others (1986) to extend into the Lake Valley area has aeromagnetic verification in the form of anomaly alignments along the postulated trend and in other places breaks in trends across the feature. South of the postulated thrust fault, the increase in gravity intensity and the presence of high magnetic gradient zones are permissive for the presence of a thrust fault that brought crystalline basement rocks of the Laramide Rio Grande uplift near the surface.

The Santa Rita lineament (fig. 9), part of a regional alignment of Laramide intrusions, extends into the area from the southwest. The structure exhibits a zone of linear aeromagnetic anomalies that trend northeast as far as the prominent magnetic high that underlies the Cretaceous Copper Flat intrusion at Hillsboro. A small magnetic high of about 200 nT amplitude is also present southeast of the lineament and about a mi (few km) southeast of Lake Valley. From gradient measurements, an inferred felsic intrusion is estimated to be at depth of burial of 1000-1300 ft (300-400 m). This inferred intrusion is smaller and less magnetic than the Copper Flat intrusion at Hillsboro that exhibits an anomaly of nearly 1000 nT.

DEPOSIT TYPES IN THE BLACK RANGE

The Black Range contains 11 mining districts : Chloride, Carpenter, Kingston, Taylor Creek, Tierra Blanca, Hermosa, Lake Valley, Macho, Cuchillo, Georgetown, and Hillsboro (fig. 13, table 4). Deposit types identified, and for which we assess potential, are Laramide porphyry, Laramide skarns, Laramide veins, gold placer, carbonate-hosted, volcanic-epithermal, and rhyolite tin (table 5); no Rio Grande rift deposits are known, but they are included in the assessment. The favorability for the presence of these deposit types is a function of the geologic setting of the range. The Black Range is on the northeastern edge of the major western North America Laramide copper porphyry belt in Arizona and New Mexico, is largely underlain by volcanic rocks of the mid-Tertiary Mogollon-Datil volcanic field, and is on the western edge of the Rio Grande rift (fig. 13). Placer tin and gold deposits are known in the Black Range, but only north of the study area.

Because multiple episodes of mineralization affected this area, we have classified silver and base metal deposits by their host rock: carbonate-hosted and volcanic-hosted (table 5). Volcanic-epithermal deposits are in the Eocene and younger rocks, and we suspect that much of the carbonate-hosted replacement deposits are of the same age. However, the carbonate-hosted deposits may, in part, be Laramide.

Table 4. Production from mining districts near Lake Valley.

District	Mn	Cu (lbs)	Au (oz)	Ag (oz)	Pb (lbs)	Zn (lbs)
Carpenter	—	310,000	300	60,000-180,000	6,000,000	12,500,000
Chloride	—	10,127,097	25,253	3,647,763	1,300,000	1,500
Cuchillo	—	withheld	—	27,525	withheld	withheld
Hermosa	—	1,850	3	1,250,000	47,600	8,000
Kingston	2,520 long tons of 34-39% Mn ore plus 1,651 long tons of 35-40% Mn concentrate	111,950	124	6,126,000	676,820	566,900
Macho	—	—	61.4	20,000	679,000	11,000
Tierra Blanca	—	92,784	97	165,000	318,687	464,055
Hillsboro	withheld	24,000,000	270,000	78,000	153,387	withheld
Lake Valley	57,800 tons of 25% Mn concentrate plus 45,224 long tons at 23 % Mn ore	100,000	10	6,126,000	>500,000	—

Table 5. Mining districts, other than Lake Valley, in the Black Range area. Pb, lead; Zn, zinc; Ag, silver; Mn, manganese.

Mining District	Type of Deposit
Chloride	Volcanic-epithermal, placer gold, carbonate-hosted Pb-Zn
Carpenter	Carbonate-hosted Pb-Zn-Ag
Kingston	Carbonate-hosted Ag-Mn
Taylor Creek	Placer tin and tin vein deposits
Tierra Blanca	Carbonate-hosted Ag-Mn, volcanic epithermal
Hermosa	Carbonate-hosted Pb-Zn
Macho	Volcanic-epithermal, carbonate-hosted Pb-Zn-Ag
Cuchillo	Carbonate-hosted Pb-Zn-Ag, Placer tin and tin vein deposits, sedimentary copper, replacement Fe
Georgetown	Carbonate-hosted Ag
Hillsboro	Laramide vein, porphyry copper, carbonate-hosted Pb-Zn and Ag-Mn, Laramide skarn, placer gold

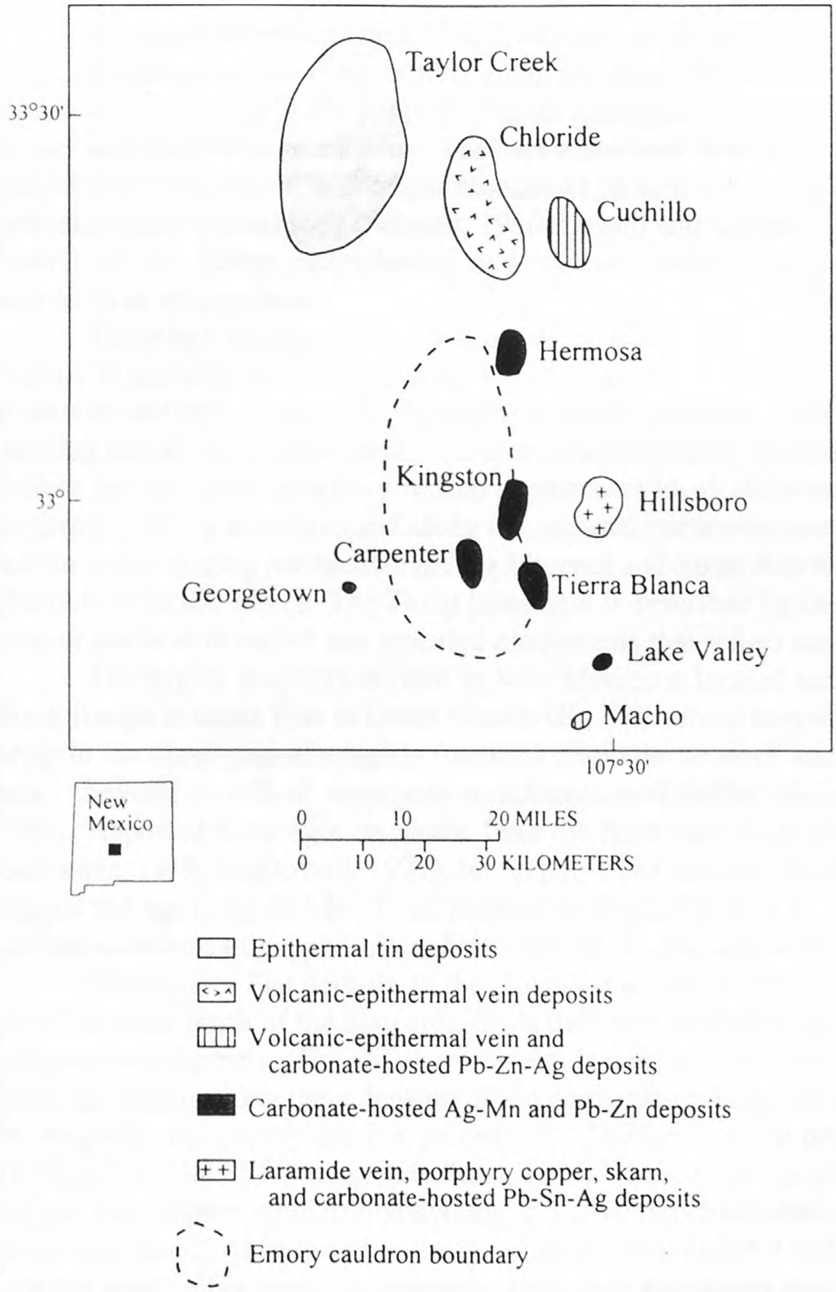


Figure 13. Map showing location of mining districts in the area of the Lake Valley mining district and their spatial relationship to the Emory cauldron.

Laramide porphyry copper (molybdenum, gold) deposits

Porphyry-copper (with molybdenum and gold) deposits are large (millions of tons) and low-grade (<0.8% copper), contain disseminated and stockwork veinlets of copper and molybdenum sulfides. They are associated with porphyritic diorite, granodiorite, monzonite, and quartz monzonite plutons surrounded by zones of hydrothermally altered rock (Schmitt, 1966; Lowell and Guilbert, 1970; Kesler, 1973; Lowell, 1974). Silver, molybdenum, and gold are present in most deposits and can be recovered as by-products.

The Black Range is on the northeastern edge of the Late Cretaceous to early Tertiary (Laramide) volcanic-plutonic arc of southwestern United States that host numerous and rich copper (molybdenum) porphyry deposits. This north to northwest-trending belt of arc-related porphyries is wide and includes southwestern New Mexico. In New Mexico, most porphyry-related deposits are localized along local northwest- and northeast-striking structures and along the regional northwest-trending Texas lineament and the cross-cutting northeast-trending Morenci and Santa Rita lineaments (fig.14) (Bartsch-Winkler, 1997). The Texas lineament is described by Drewes (1991) as a broad zone of faults with varied and repeated movements that reflect basement structure.

The largest porphyry deposit in New Mexico is located about 10 miles west of the Black Range at Santa Rita in Grant County (fig. 14), where copper sulfides and oxides occur in the upper part of a highly fractured granodiorite stock and adjacent sedimentary rocks. Several periods of supergene enrichment have further concentrated the ore (Cook, 1994). Reported K-Ar ages on biotite from the stock vary from 64.4 to 59.7 Ma (Schwartz, 1959; McDowell, 1971), but unpublished data by Phelps Dodge Corporation suggest the age is 55-56 Ma. Total production from 1911 to 1993 is estimated as 4.54 million short tons of copper, more than 500,000 oz gold, and 4.75 million oz silver.

The Copper Flat deposit, in the Hillsboro mining district of the Black Range and about 10 miles north of the map area, hosts the most northeastern of the known Laramide-age porphyry deposits. The Hillsboro district is north of the northwest-trending Texas lineament, but is along the extension of the northeast-trending Santa Rita lineament (fig. 14; magnetic and gravity section, this report). The Copper Flat porphyry was emplaced 73.37±2.7 to 75.1±2.5 Ma ago (Hedlund, 1974; NMBMMR age determination files). At Copper Flat, copper, gold, molybdenum, and silver are disseminated in a quartz monzonite stock and in quartz veins (Kuellmer, 1955; Dunn, 1982,1984). Unlike Santa Rita and many other porphyry deposits, there is no significant secondary enrichment zone at Copper Flat. Open pit production in 1982, prior to the closure of the mine, was 7,000 pounds of copper prior to the closure of the mine. Alta Gold Company is currently applying for mining permits to reopen the Copper Flat mine. Reserves are estimated at 487 million lbs copper, 243,000 oz gold, 3.2 million oz silver and 15.7 million oz molybdenum.

Laramide copper and lead/zinc skarn deposits

Laramide skarn deposits in New Mexico are contact-metasomatic deposits that formed in Paleozoic shallow-water, marine limestones and dolomitic limestones adjacent to calc-alkaline plutonic rocks emplaced during the Laramide event (McLemore and Lueth, in press). Three types of Laramide skarns occur in southern New Mexico: copper

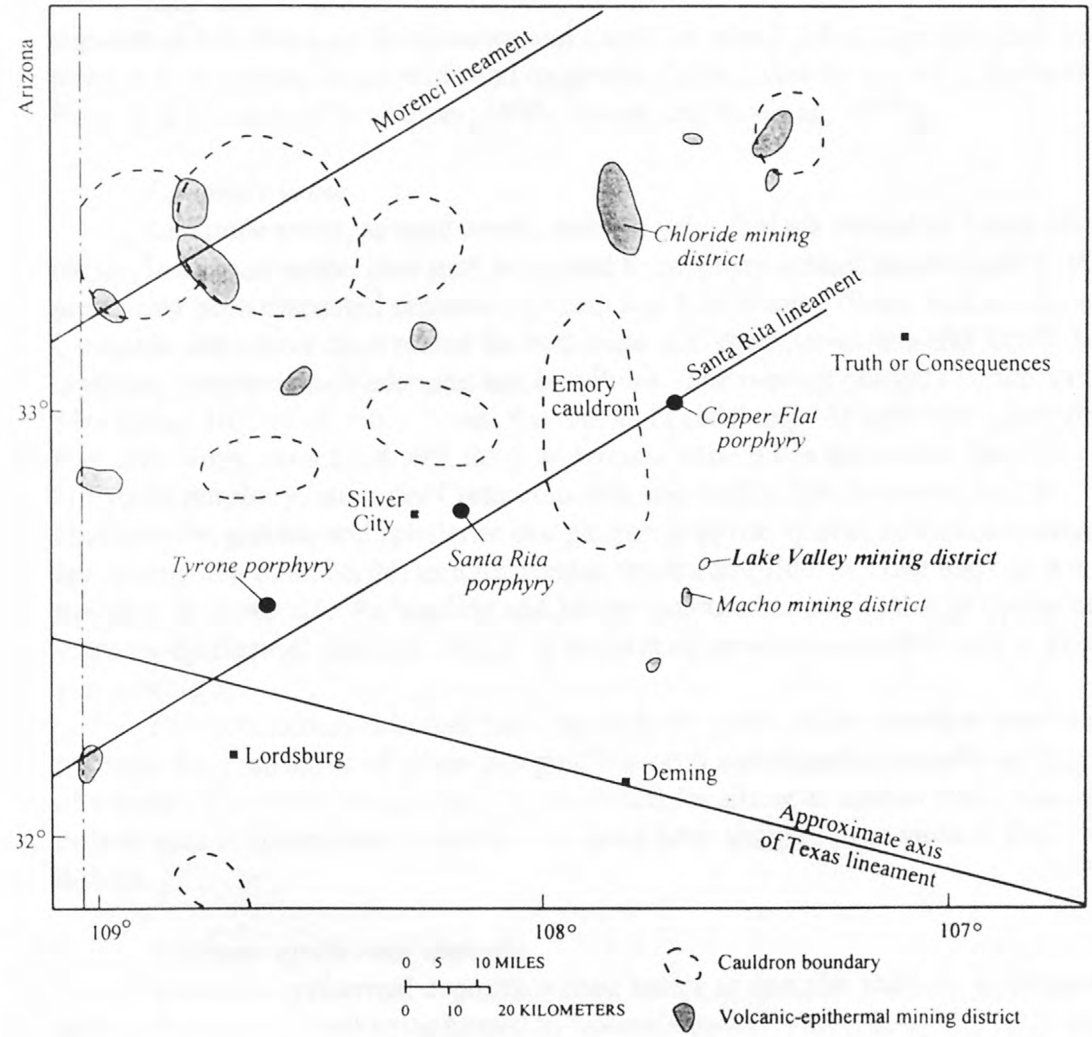


Figure 14. Map showing location of Lake Valley mining district in relationship to geologic features. Stippled areas are districts with documented Eocene and younger epithermal-volcanic deposits. Modified from McLemore, 1996.

(typically associated with copper porphyry deposits; Einaudi and others, 1981; Einaudi, 1982; Lueth, 1984), lead-zinc (proximal and vein-type deposits; Meinert, 1987; Turner, 1990; Turner and Bowman, 1993; Lueth, 1996), and iron skarns (Lueth, 1984; 1996).

Copper skarns are typically intimately associated with plutons (e.g., Santa Rita, Piños Altos) whereas the lead-zinc skarns are locally distal to igneous rocks. Some lead-zinc skarns occur along faults distal from intrusive rocks (e.g., Groundhog, southwestern deposits at Piños Alttos, Eureka). The largest zinc deposits in New Mexico are in the Fierro-Hanover district. District zoning is common in most areas with copper adjacent to the intrusive rocks grading outwards to zinc-lead, lead/zinc, lead-silver, and locally, lead-silver-manganese (Meinert, 1987; McLemore and Lueth, in press).

The Laramide skarns in New Mexico formed from variable, but higher temperature and more saline fluids compared to carbonate-hosted lead-zinc replacement deposits in New Mexico (McLemore and Lueth, in press). Most deposits probably formed from mixing of meteoric and magmatic fluids (Abramson, 1981; Ahmand and Rose, 1980; Lueth, 1984; Turner, 1990; Turner and Bowman, 1993).

Laramide veins

Laramide veins, as used herein, refer to veins that are related to Laramide igneous rocks. In a larger sense, they may be related to porphyry-related mineralization but have previously been discussed separately (North and McLemore (1986); McLemore, in press). Laramide veins have been mined for both base- and precious-metals and locally contain uranium, tungsten, molybdenum, and beryllium. The most important districts in New Mexico are Hillsboro, Piños Altos, Bayard, and Lordsburg. At Hillsboro, just north of the map area, veins associated with latite and quartz latite dikes radiate out from the Hillsboro porphyry into older Cretaceous volcanic rocks. Ore minerals include chalcopyrite, galena, and sphalerite in a gangue of pyrite, quartz, tourmaline, calcite, specularite hematite, barite, sericite, rhodochrosite, and fluorite. Ore textures are massive, in contrast to the banding and bladed quartz after calcite that is typical of volcanic-epithermal deposits. Much of the historic production at Hillsboro is from these veins (table 5).

Past production indicates that Laramide vein deposits are small to medium tonnage, but production of silver and gold has been significant, especially as a by-product of copper. Ores from these veins have potential for siliceous smelter flux. Nearly two million tons of mineralized siliceous flux have been shipped from veins in the Lordsburg district.

Volcanic-epithermal deposits

Volcanic-epithermal deposits is used herein to describe shallow, hydrothermal base and precious metal veins hosted by volcanic rocks. Volcanic-epithermal deposits occur along the margins of calderas (Rytuba, 1981; Elston, 1994), as well as in other structurally complex volcanic settings such as silicic domes and andesitic stratovolcanoes. Epithermal deposits are also hosted by sedimentary and other crystalline rocks; for example, some Carlin-type sedimentary-hosted deposits are considered epithermal (Bagby and Berger, 1985; Berger and Henley, 1989) and the McLaughlin deposit in California is hosted by mafic and ultramafic metamorphic and sedimentary rocks (Lehrman, 1986). However, in this report, sediment-hosted deposits are classified as carbonate replacements following North and McLemore (1986) and McLemore (in press). Known volcanic-epithermal deposits in the Black Range include Chloride and Macho (fig. 13, table 5); minor volcanic-epithermal deposits also occur in the Tierra Blanca deposit.

Volcanic-epithermal deposits in New Mexico occur most commonly as siliceous vein fillings, breccia pipes, disseminations, and replacement deposits along faults and fractures in intermediate to silicic volcanic and volcanoclastic rocks. Common ore textures include open-space and cavity fillings, drusy cavities, comb structures, crustification, colloform banding, brecciation, replacement, quartz pseudomorphs after bladed calcite, and irregular sheeting (Buchanan, 1981; Dowling and Morrison, 1989). Mineralogy and metal associations of these deposits are diverse. Common ore minerals include auriferous pyrite, native gold, acanthite, chalcopyrite, bornite, argentiferous galena, native silver, and sphalerite. Quartz, calcite and pyrite are common gangue minerals and alteration minerals include chlorite, epidote, illite/sericite, adularia, and kaolinite. Most deposits in New Mexico are classified as low sulfidation, also known as quartz/adularia (Berger and Henley, 1989; Cox and Singer, 1986). Both gold and silver are usually produced from these deposits with variable amounts of base metal production; fluorite, uranium, tellurium, and vanadium were produced in places. Most veins are less than 3 ft (0.9 m) wide, but economic veins are as wide as 30 ft (9 m). District zoning is variable, but in some districts precious metals occur in the upper levels of the epithermal system and grade into base metals at depth; an example is the Chloride district in the Black Range (Harrison, 1986, 1988). Typical deposits are a few hundred thousand short tons or less grading 0.2 oz/short ton gold and/or 6-20 oz/short ton silver or less (McLemore, 1996).

Most volcanic-epithermal deposits of New Mexico formed largely in faults and fissures in rhyolite and andesites of Oligocene-Miocene age, commonly within or adjacent to resurgent caldreas (Elston, 1978; 1994; Rytuba, 1981). Where isotopic ages are available, the ore deposits tend to be 10-12 Ma younger than the primary pulse of volcanism and are related to hydrothermal fluid or magmatic pulses; they not related to extrusion of the large volumes of ash-flow tuff. Commonly, ore is spatially associated with small rhyolite domes that are emplaced in caldera structures (Elston, 1978, 1994).

The Chloride and Macho districts in the Black Range are volcanic-epithermal deposits in the Mogollon-Datil volcanic field. At Chloride the host is Rubio Peak Formation, and to a lesser extent, Kneeling Nun Tuff. Rhyolite domes that are 29 to 28 Ma and interpreted as related to the Rhyolite of Moccasin John Canyon by Harrison (1986) are spatially associated with mineralized rock. K-Ar ages from adularia in veins indicate mineralization at 28.9+1.1 and at 25-26 Ma (Harrison, 1986). In the Macho district, near surface ore is in the Macho andesite, which we include as the lowest part of the Rubio Peak Formation, and mineralized zones at depths of 3000 ft (915 m) are in carbonate rock (NMBMMR petroleum file data). Chloride is north of the Emory cauldron and Macho is south of it, but both likely involve structures that were active or reactivated during cauldron collapse.

Precious and base metals were recovered from both Chloride and Macho, though Chloride is the larger district. Silver production was much greater than gold. From 1934 to 1988, Chloride produced 3,647,763 oz silver, 25,253 oz gold, 10,127,097 lbs copper, 1,300,000 lbs lead, and 1,500 lbs zinc (NMBMMBR file data). The estimated and reported production of Macho from 1879-1977 was 20,000 oz silver, 61 oz gold, 679,000 lbs lead and 11,000 lbs zinc (Harley, 1934; Jicha, 1954, NMBMMR file data).

Carbonate-hosted lead-zinc and silver (manganese) replacement deposits

Carbonate-hosted lead-zinc and silver (manganese) replacement deposits occur in southwestern New Mexico and formed about 75-20 Ma (North and McLemore, 1986, 1988; McLemore, in press; McLemore and Lueth, in press). The deposits vary in size and grade, ranging from a few thousands of short tons to a few hundreds of thousands of short tons and typically grading 5-30% combined lead and zinc; silver content varies and gold is rare. In the Black Range, carbonate-hosted deposits are in the Carpenter, Kingston, Tierra Blanca, Hermosa, Cuchillo, Georgetown, and Hillsboro districts (table 5). The deposits are in carbonate rocks with no associated calc-silicate minerals, in minor skarns with calc-silicate minerals, and in minor veins in carbonate rocks and nearby intrusive and sedimentary rocks. Two types of deposits occur. One type is typically lead-zinc dominant, with by-product copper, silver, and gold; the second type is manganese, locally with silver, and is distal to the lead-zinc. Galena and sphalerite are the predominant ore minerals with lesser amounts of chalcopyrite. A second type is predominantly silver and manganese oxides; over 20 million oz of silver have been recovered from these deposits (North and McLemore, 1986). Most ore was recovered from oxide zones; recognizable silver and gold minerals are rare.

The deposits are hosted by Paleozoic limestone and dolomitic limestone, most commonly the Silurian Fusselman Dolomite and the Mississippian Lake Valley Formation, and in many places are associated with jasperoid. Mineral deposits are in structures and are also stratabound. The Devonian Percha Shale, as well as jasperoid in the upper part of the Fusselman Dolomite, locally act as an impermeable cap that controls some of the stratabound ore.

The carbonate-hosted Carpenter, Kingston, Tierra Blanca, and Hermosa districts in the Black Range are within the Mogollon-Datil volcanic field and are near the Emory cauldron and partially controlled by cauldron structures (fig. 13). Perhaps the best example of ring-structure control is at Kingston, where Sanders and Giordano (1986) show that the major mining claims cluster along and between two north- to northwest-striking normal faults that drop rocks down-to-the-west in the direction of the center of the cauldron and are interpreted as structural margin faults. The Hermosa district is localized along the Emory cauldron margin (Seager and others, 1982), and Shepard (1984) reports that ore is localized along northwest-striking faults that downdrop rocks to the west and are interpreted as part of the ring fracture zone of the caldera. The mineralized rocks hosted by caldera structures in these districts postdate deposition of the widespread 34.89 Ma Kneeling Nun Tuff.

Igneous rocks are in the districts with carbonate-hosted deposits, although the direct relationship between exposed igneous rocks and mineralization is not always clear. The 73-75 Ma Laramide porphyry crops out at Hillsboro and 71.2±2 Ma intrusive rock is at Georgetown. Rhyolite domes and intrusives, ranging from 34.57±0.12 Ma (Mimbres Peak) to 28-29 Ma (Rhyolite of Moccasin John) are at Kingston, Terra Blanca, Hermosa, and Carpenter. Carbonate-hosted deposits could be associated with both Laramide and Tertiary magmatism, and overprinting is possible. Drilling in the Macho district encountered carbonate-hosted replacement deposits in Fusselman Dolomite at 3000 ft (915 m) below the volcanic-epithermal veins (NMBMMR petroleum file data); this association of volcanic-epithermal and carbonate-hosted deposits suggests that at least some of the carbonate-hosted mineralization is related to volcanic-epithermal processes.

Lead isotope data from Stacey and Hedlund (1983) show that lead in galena in replacement deposits at Carpenter, Kingston, Hermosa, and Chloride show similar sources; at Carpenter, they demonstrate that lead is from a near-by source similar in composition to 34.5 Ma rhyolite. The lead in the galenas at these districts along the edge of the Emory cauldron are isotopically different from lead data collected from Copper Flat porphyry at Hillsboro (Stacey and Hedlund, 1983). We suggest that many of the carbonate-hosted deposits are most likely related to episodes of Oligocene rhyolite domes emplaced along structures of the collapsed Emory cauldron.

Distal carbonate-replacement deposits may be associated with copper porphyry deposits, and it is likely that some of the carbonate-hosted ore in the Black Range, especially near Hillsboro, is Laramide in age.

Rhylolite-related tin deposits

Rhyolite-related tin deposits occur as discontinuous veins and veinlets in rhyolite domes and volcanic centers (Cox and Singer, 1986; Christiansen and others, 1986). The tin deposits are in the fractured and brecciated outer parts of flow-dome complexes and are hosted by high-silica (>75%), peraluminous rhyolites and/or pyroclastic deposits (Lufkin, 1972; Correa, 1981; Goerold, 1981; Woodard, 1982; Duffield and Dahymple, 1990; Duffield and Ruiz, 1992). The deposits are typically small (less than several hundred thousand tons of ore) and low grade (<2% Sn) (Cox and Singer, 1986).

In the Black Range, tin deposits in the Taylor Creek mining district (fig. 13) are related to the 28 Ma Taylor Creek Rhyolite (Duffield and others, 1987; Duffield and Dalrymple, 1990). Cassiterite is in miarolitic cavities, veins and veinlets, and disseminations in rhyolite, and in placer deposits in streams and alluvial deposits on the flanks or adjacent to rhyolite domes and flows (Maxwell and others, 1986; Eggleston and Norman, 1986). The rhyolite, consisting of flows, domes, and tuffs, erupted from local vents along a north-trending zone that is not related to a caldera (Ratté and others, 1984; Duffield and others, 1987). The Taylor Creek Rhyolite is restricted to the Taylor Creek mining district.

The Taylor Creek Rhyolite is a metaluminous to weakly peraluminous, high-silica, fluorine-rich rhyolite (Duffield and du Bray, 1990). Domes in the rhyolite field have similar major element compositions (Correa, 1981; Lawrence, 1985; Duffield and others, 1987), but have variable trace element concentrations, which indicate that the Taylor Creek Rhyolite is a highly evolved igneous rock (Duffield and Dalrymple, 1990).

Rio Grande Rift related lead-zinc deposits

Rio Grande rift (RGR) deposits, formerly called sedimentary-hydrothermal barite-fluorite-galena (±silver) (North and McLemore, 1986, 1988) and Mississippi Valley-type deposits (Putnam and others, 1983) are in or near basins along the Rio Grande Rift in central New Mexico (Van Alstine, 1976; McLemore and Barker, 1985; North and McLemore, 1985; Hill, 1994; McLemore and Lueth, in press; McLemore and others, 1998). The largest deposits of this type are in the Hansonburg district in Socorro County (McLemore and Lueth, 1995; McLemore and others, 1998). RGR deposits are small, low-temperature open-space fillings with little or no replacement of host rock and are not obviously associated with magmatic or volcanic activity. They consist of barite, fluorite, and galena (locally argentiferous) and, in places, minor chalcopyrite and sphalerite, and are locally associated with silicification or dolomitiziation. The deposits are primarily in veins, breccia cement, and cavities in or near basin and range faults in Paleozoic rocks, but do occur in structures cutting Precambrian and Tertiary rocks. Most RGR deposits in New Mexico are typically less than a few thousand tons of ore and are too small to be economic at 1998 prices.

All RGR deposits are in or along the flanks of the Tertiary rift basins on the edges of Laramide highs, and McLemore and others (1998) suggest that they are Miocene or younger. The geologic data along with trace element and isotopic data summarized in McLemore and others (1998) indicate mineralization began at about 12 Ma, and was most common between 8 and 5 Ma.

Placer gold deposits

Placer gold deposits are low-grade, disseminated deposits consisting of fine-grained gold, locally with silver as a byproduct. In New Mexico, placer deposits are mostly in late Tertiary to Recent alluvial fans, bench or terrace gravels, stream deposits, or as residual placers formed directly on top of lode deposits (McLemore, 1994). Most deposits in New Mexico, which are similar in occurrence, size, and grades to placer gold deposits world-wide (Cox and Singer, 1986) are less than 45 ft (14 m) below the surface (Lindgren and others, 1910; Johnson, 1972) and contain less than 0.05 oz/yd^3 (McLemore, 1994). In the Black Range, 120,000 oz of placer gold were recovered in alluvial fans on the eastern side of the Hillsboro district (fig. 13). Most gold was probably derived from porphyry-related veins.

LAKE VALLEY MINING DISTRICT

The Lake Valley mining district hosts small, high-grade carbonate-hosted silver manganese deposits in Mississippian Lake Valley Formation. Rubio Peak and Mimbres Peak Formation crop out in the area, but are not mineralized. We consider the Lake Valley deposits to be carbonate-hosted replacements, as defined above in the section on deposit types. Descriptions of the mine workings are from Harley (1934), Creasey and Granger (1953), and this study. Production from the district is shown in table 6.

Table 6. Metals production from the Lake Valley district (Harley, 1934; NMBMMR file data).

YEAR	ORE (short tons)	COPPER (lbs)	GOLD (oz)	SILVER (oz)	LEAD (lbs)	VALUE ($)
1878-1893	—	—	—	5,000,000	—	5,000,000
1893-1910	—	—	—	500,000	—	100,000
1910-1931	46,261	—	—	275,000	—	137,500
1934	352	100	1.8	4,616	1,000	3,092
1935	56	—	—	1,550	400	1,130
1936	60	120	6.6	488	1,200	675
1938	29	100	—	215	1,100	200
1939	119	100	—	1,572	300	1,091
1940	132	100	—	1,499	800	1,117
ESTIMATED TOTAL 1878-1957	—	100,000	10	6,126,000	>500,000	5,400,000

Mining history

Lake Valley is a small mining district in central Sierra County, New Mexico, that contains carbonate-hosted silver-manganese deposits. So much has been written about this district with little preserved documentation, it is hard to separate fact from fiction. The district is most famous for the discovery in 1881 of the Bridal Chamber, one of the richest silver ore bodies ever to be mined (Eveleth, 1986), although actual production from the Bridal Chamber is unknown. Clark (1895) estimated that 2.5 million ounces of silver were produced from the ore pocket, but production estimated from company reports of the time suggest that total production may have been less than 1 million ounces (NMBMMR file data, newspaper accounts). The Bridal Chamber and nearby workings were ore pockets of silver chlorides and bromides—mostly chlorargyrite (cerargyrite)--a couple of hundred feet long and 25 feet thick (about 100 m long and 7 m thick), with assays as high as 20,000 oz/short ton (MacDonald, 1908). Samples, the largest of which was 640 lbs of chlorargyrite, were sent to the National Mining Exposition at Denver, Colorado, in 1882.

The district was discovered in August 1876 by Mr. McEverts, a rancher (Keyes, 1908). However, many accounts credit the discovery to George W. Lufkin in 1878. Lufkin, probably with McEverts, staked the first mining claims and named them after the nearby small lake. Lufkin soon took on a partner, Chris Watson, and began working the claims. Later, Lufkin borrowed money from John A. Miller, the post trader at Fort Bayard, and made him a third partner. In April 1881, Miller obtained the claims and sold them to George Daly. George Daly found a group of investors that formed four companies in July 1881: Sierra Grande, Sierra Bella, Sierra Plata, and Sierra Apache. The Sierra Grande group includes the Twenty-Five cut, Thirty stope, Bridal Chamber, and Carolina. The Sierra Bella workings include the Emporia incline, Harrison, Bella Chute, Bunkhouse, Columbia, Last Chance and Strieby. The Sierra Apache workings include the Apache and Bacon claims. The Sierra Plata includes the Plata claim. Mining claims are listed in table 7. The Sierra Grande Co. operated the companies from 1881 to 1893. John Leavitt held a lease on one of the claims and is credited with discovering the Bridal Chamber (Jones, 1904). Mining in the district ceased in 1893 following the dramatic decline in silver prices as a result of the federal government's demonitization of silver.

Table 7. Mining claims in the Lake Valley district.

MINE NAME/ALAIS	SIZE	OWNERSHIP	MINERAL SURVEY NO.	PATENT NO.	YEAR PATENTED
Annie P	19.67 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	532A	14982	5/17/1889
Apache	—	Lake Valley Mines Co. (estate of Lucius G. Fisher)	894	22958	5/13/1893
Arizona	18.71 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	717C	—	11/20/1891
Bacon (Francis Bacon)	18.29 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	892	22385	2/19/1932
Carolina (originally Lincoln)	17.733 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	657	17027	1/10/1891
Columbia	13.65 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	893	22959	5/13/1893
Compromise	—	Lake Valley Mines Co. (estate of Lucius G. Fisher)	1810	832415	11/15/1921
Comstock (Looney shaft)	8.08 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	717E	—	11/20/1891
Emporia	17.04 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	717H	—	11/20/1891
Good Luck	—	Central Mining Co., Santa Fe (1960)	—	none	—
Jim Finch	—	D. S. Miller ptd, F. H. Perry (1947)	1746	654504	11/25/1918
Last Chance	20.14 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	717F	—	11/20/1891
Little Boy	18.46 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	717D	—	11/20/1891
Little One	no application	Lake Valley Mines Co. (estate of Lucius G. Fisher)	134	none	—
New Era	—	—	246	none	—
North Carolina (originally Stanton)	19.74 ac	W. C. Hadley-Lake Valley Mines Co	656	17028	1/10/1891
Plata	20.42 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	717A	18945	11/20/91
Sierra Grande millsite	4.9 ac patent	Lake Valley Mines Co. (estate of Lucius G. Fisher)	532B	21009	4/23/1892
Silver Reef (Silver Rut)	17.94 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	717B	—	11/20/1891
South Carolina	19.99 ac	W. C. Hadley-Lake Valley Mines Co	658	16976	12/26/1890
Stone Cabin	18.741 ac	J. H. Winslow (1967)	425, 1122	—	—
Strieby (Bella)	12.93 ac	Lake Valley Mines Co. (estate of Lucius G. Fisher)	717G	—	11/20/1891

From 1893 to 1900, various individuals and companies leased the mines periodically. In 1900, the entire property of the former Sierra Grande Company was sold to Lucius G. Fisher, who organized it under the Lake Valley Mines Company (Jones, 1904). From 1910 to 1931, shipments of silver-flux ore were made. During World War I and II, manganese was produced. The last production from the district was probably in 1958 or 1959. Total production from the district (tables 7, 8) is estimated as 5,000,000-6,126,000 oz silver, 500,000 pounds lead, 45,540 long tons 23% manganese ore, and 57,800 long tons 25% manganese concentrates (Farnham, 1961).

Table 8. Manganese production from mines from the Lake Valley district (Farnham, 1961).

	LONG TONS ORE	LONG TONS CONCENTRATE
Prior to 1942	8,000	—
1942-1943	37,224	—
Good Luck 1953	316	—
1953-1955	—	57,301
1958-1959	2,000	500
total	45,540	57,801

Local Geology

The Lake Valley mining district is only about a mi (0.6 km) in length, with the richest deposits near the Lake Valley fault. The rocks are tilted to the east-southeast, as are volcanic and Paleozoic rocks throughout the map area. The map pattern shows that in the mining area, the beds have a slightly more easterly strike than elsewhere in the map area. In the district itself, west-striking faults of small offset and associated fractures are the dominant structures and are generally not present elsewhere in the map area.

The richest ore in the Lake Valley mining district is in the drag zone of the Lake Valley fault (Jicha, 1954). The detailed map of the mining district and underground workings by Creasey and Granger (1953) show that while ore is concentrated near the Lake Valley fault, it is not along the fault. Abandoned pieces of brecciated rhyolite core drilled from along the fault by unknown persons just northwest of the known mines was barren. However, minor faults northeast of the Lake Valley fault contain mineralized rock (Creasey and Granger, 1953).

Mineralized rock is localized in fractures and replacements at and near the contact between the Alamogordo and Nunn Members of the Lake Valley Formation. The Alamogordo Member is thick- to medium-bedded, fine grained to aphanitic limestone that shows a concoidal fracture. In contrast, the overlying Nunn Member is thin-bedded, contains abundant clays, and breaks along bedding planes. The contact between the members is exposed in the old workings, where slickensides indicate bedding plane slippage of the ductile Nunn Member over the rigid and fractured Alamogordo Member. Jasperoid replaces fractured Alamogordo, and is itself brecciated. Harley (1934) reports 1-2 ft (0.3-0.6 m) of jasperoid at the top of the Alamogordo. Iin the western part of the district the jasperoid is brecciated and hosts ore, whereas in the eastern part it is less disrupted and forms the footwall of mineralized rock in the lower Nunn Member.

Jasperoid occurs not only in the Lake Valley Formation, but is also in the upper part of the Fusselman Dolomite and Montoya Formation north and northeast of the mining district. The best-developed and most extensive jasperoid is in the Fusselman. In the map area, jasperoid in the Fusselman is overlain by unaltered Rubio Peak Formation and Sugarlump Tuff; therefore the jasperoid is Eocene or older and predates caldera magmatism. The jasperoid in the Fusselman Dolomite that holds up Quartzite Ridge is aphanitic and white to gray colored, and is in places brecciated and recemented by aphanitic silica. Jig-saw puzzle textures are found locally. However, large areas of red to brown to white jasperoid are unbrecciated and aphanitic. Locally, manganese oxide and crystalline quartz veinlets cut the jasperoid and drusy quartz and iron and manganese oxides fill vugs. Pyrite is rare to absent except where the jasperoid is cut by faults.

Lovering and Heyl (1989) report these jasperoids are barren except where cut by the Lake Valley fault.

Rhyolite at the southwestern edge of the Lake Valley district underlies a low hill that is localized between two strands of the Lake Valley fault (plate 1). The rhyolite is probably part of the Town Mountain rhyolite dome of Mimbres Peak Formation that crops out west of the district and on the downthrown side of the Lake Valley fault. The rhyolite of the hill is characterized by delicate banding and vertical foliation, abundant altered pumice fragments aligned along foliation, very fine grain size, a paucity of phenocrysts, and numerous lithic fragments. Lithic fragments include Kneeling Nun, Rubio Peak, and Proterozoic basement rocks. Locally, brecciated Rubio Peak and Kneeling Nun occur along the edges of the rhyolite. A very fine grained sill (vertical dike along foliation), and, locally, veinlets of similar composition, cut the rhyolite. The rhyolite is not mineralized except for minor manganese-oxide veinlets and pockets. The lithic fragments, altered pumice fragments, sills, and breccia suggest explosive activity related to intrusion.

A paleochannel filled with poorly consolidated gravel that cuts across the mining district and overlies the Bridal Chamber is shown on the detailed map of Creasey and Granger (1953). The gravels, as mapped by Creasey and Granger (1953), lie in the present-day topographic low that generally follows the contact between the Alamogordo and Nunn Members of the Lake Valley Formation. Clasts include pebbles and cobbles of jasperoid, rhyolite, and limestone. The lower part of the gravels is locally cemented by calcite and silica. This paleochannel was described as an igneous "porphyrite" by Clark (1895), who noted a spatial relationship between the "porphyrite" and underlying ore. Creasey and Granger (1953) mapped the unit as a Tertiary conglomerate that predated Eocene volcanic rocks, but Jicha (1954) mapped the unit as Quaternary gravels. We consider the rock as younger than Santa Fe Group and deposited about the same time as nearby Quaternary terrace (Qtg) and pediment (Qg) gravels. The gravels probably extended southward and were continuous with pediment gravels on the southeast, but have since been stripped by erosion.

The Lake Valley Limestone in the district was exposed or close to the surface in Paleocene to Eocene time and in Pleistocene(?) time; in addition, it may well have been near the surface in late Paleozoic and Mesozoic time. On top of Apache Hill and to the south and southeast of the district, thin deposits of Love Ranch Formation sit on the Tierra Blanca Member of the Lake Valley Formation, and the basal conglomerate includes numerous pieces of Tierra Blanca chert. In places where the Love Ranch is missing, Eocene Rubio Peak Formation volcanic rocks sit directly on the Lake Valley Formation. In Pleistocene time, gravels now exposed as pediment surfaces and including the gravel of the paleochannel at the Lake Valley district, were deposited on the Lake Valley Formation. We suggest that some karst features, including the cave that hosts the Bridal Chamber, may have formed during these periods of subaerial exposure.

Description of deposits

Primary silver minerals, since mined out, were stephanite, proustite, pyargyrite, and argentiferous galena (Harley, 1934); alteration minerals are primarily quartz and calcite-clay (talc?). The quartz is mostly jasperoid and in aphanitic veins; the calcite-clay assemblage is mostly in the lower part of the Nunn Member of the Lake Valley Formation and may reflect minor recrystallization of the clay-rich limestone. Oxidized minerals (cerargyrite, embolite, native silver, cerussite, vanadinite, wulfenite, endlichite, descloizite, iodyrite) were either deposited as primary minerals when the fluid evolved to a more oxidizing state or were formed by later supergene fluids. Other minerals found in the district include pyrolusite, manganite, psilomelane, limonite, hematite, calcite, anderite, and apatite (Silliman, 1882; Genth and von Rath, 1885; Clark, 1895; Lindgren and others, 1910). Production from the mines at Lake Valley is shown in table 9.

The mineral deposits occur in two forms: 1) fault and fracture controlled replacements and 2) stratabound replacement bodies. The fracture and fault controlled deposits are in irregular, steeply dipping zones locally at the intersection of northeast- and northwest-striking fractures and faults (Creasey and Granger, 1953) and along east-striking faults. Cross-cutting mineralized rock is most common in structures in the western part of the mining district. Deposits at the Daly shaft (see Creasey and Granger, 1953, for localities of workings) and at the A14 surface cut (near the Boiler shaft northwest of the Bridal Chamber) are at the intersection of fractures. In addition, smaller fissure deposits occur along the Bella, Columbia, Furnace, and Stone Cabin faults (Creasey and Granger, 1953). Most of these fissure deposits are in the Alamogordo Member. Locally, the lower 1-3 ft (0.3-0.9 m) of the Nunn Member is mineralized, as well as the Andrecito Member in the underground workings of the Daly shaft.

Table 9. Silver production from mines from the Lake Valley district, 1878-1893 (Clark, 1895).

MINE	PRODUCTION (oz of silver)
Bridal Chamber	2,500,000
Thirty stope	1,000,000
Emporia incline	200,000
Bunkhouse	300,000
Bella chute	500,000
Twenty-five cut	200,000
Apache and others	300,000
Total	5,000,000

Tabular, stratabound replacement deposits are adjacent to the fault and fracture-controlled deposits. The silver ore bodies were thin, irregular tabular zones 3-8 ft (0.9-2 m) thick that were underlain and laterally surrounded by larger manganese-silver replacement bodies 5-30 ft (1-9 m) thick. The high-grade silver zones were mined out in the 1880's, leaving only manganese replacements, some of which contain low-grade silver. Thin manganese-silver deposits, 5-10 ft (1-3 m) thick, are in several stratigraphic intervals in the Apache and Stone Cabin workings.

A high-grade silver pocket was mined from the Bridal Chamber, and smaller silver bonanza pockets from the Emporia and Bunkhouse (Clark, 1895). The Bridal Chamber consisted of nearly pure cerargyrite in a pocket a few hundred ft long and 25 ft thick (about a hundred meters long and 7 m thick) (MacDonald, 1908). A streak of pure cerargyrite or chlorargyrite (AgCl) was 4 ft (1 m) thick, and assays as high as 20,000 oz/short ton were common. Silver pockets in the Emporia decline contained 200-500 oz/short ton silver and 50-60% lead as galena (Clark, 1895). Ore from the Bunkhouse mine contained 200-500 oz/short ton silver. A 5-ton shipment from the Columbia mine contained 3600 oz/short ton silver (Silliman, 1882).

A crude zonation exists in the district, and is predominantly a reflection of the abundance of silver and jasperoid in the western part of the district. The western deposits, known as the Grande workings (Twenty-five cut, Thirty Stope, Office, Daly, Bridal Chamber, Carolina, and A14 cut [Clark, 1895; Apell and others, 1947; Creasey and Granger, 1953]), contain the largest and highest grade deposits (Clark, 1895; Creasey and Granger, 1953) and consisted of predominantly siliceous ore. Early ore mined from these workings averaged 65% silica, 6% iron, 12% manganese, and 20 oz/short ton silver (Clark, 1895). High-grade silver bodies were common. Manganese ore assayed in the 1940's averaged 42.7% silica, 8% iron, and 20.8% manganese (Creasey and Granger, 1953). The middle Bella workings (Bella, Emporia decline) were intermediate in silica composition. Early ores mined from these workings averaged 30% silica, 12% iron, 18% manganese, and 30-50 oz/short ton silver (Clark, 1895). Manganese ore assayed in the 1940's averaged 45.6% silica, 8% iron, and 20.2% manganese (Creasey and Granger, 1953). Ore from the eastern deposits (Buckhouse, Columbia, and Apache) consisted of more manganese and typically, less silica and silver. Early ore from these deposits averaged 8% silica, 12% iron, 24% manganese, and 20-30 oz/short ton silver (Clark, 1895). Manganese ore assayed in the 1940's averaged 38.2% silica, 6% iron, and 21.4 % manganese (Creasy and Granger, 1953).

All of the deposits are shallow. The Boiler shaft was sunk to a depth of 175 ft (53 m) and the deepest mineralized area was 162 ft (49 m) (Clark, 1895). Most of the other workings in the Grande area are less than 120 ft (37 m) deep. The John's shaft, south of the Grande workings, is 158 ft (49 m) deep; a drift connects it to the Emporia decline. Several replacement deposits are intersected by the drifts at the John's shaft, but silver concentrationswere low (samples Lake 32, 33, table 7). Harley (1934) reports that a drilling program in 1928-1929, exploring the potential for deeper deposits in the lower Lake Valley and Fusselman Dolomite, was unsuccessful. The exact locations of these holes are unknown.

Several episodes of brecciation and silicification affected the Lake Valley Formation in the district. Clark (1885) reports that in the western part of the district, the jasperoid at the top of the Alamogordo was cut by silver-bearing jasperoid. Observations from near the Bridal Chamber reveal banded green and gray jasperoid in replacement pods. The green and gray jasperoid is brecciated and cemented by red and light brown jasperoid, which is in turn brecciated and cemented by manganese-iron oxides, black jasperoid, and calcite that formed both fissure and bedded deposits. These deposits were brecciated and cemented locally by chocolate brown, gray, green, black, and red jasperoid, and then cut by manganese-quartz veins. The final event was deposition of box work quartz. White, clear, crystalline quartz and calcite veinlets and white to brown, crystalline calcite fill vugs. Vanadinite occurs as very fine grained hexagonal prisms and thin coatings (Silliman, 1882; Genth and von Rath, 1885) and probably formed during a late oxidation stage. Iodyrite is within calcite crystals (Genth and vom Rath, 1885). Deposits northeast of the Bridal Chamber are lower grade, contain less silica, and exhibit only one or two stages of brecciation. One area northeast of the deposits contained delicate banded manganese oxide typical of epithermal deposition.

It is difficult to place the silver mineralization in a paragenetic sequence because the silver minerals were mined out. Silliman (1882) suggested silver, as embolite, occurred with the green jasperoid (also called flint or vein stone), and Clark's (1885) observation of early barren jasperoid cut by veins of silver-bearing jasperoid supports this idea. Manganese and silver content correlate positively, suggesting that at least some silver was deposited during the manganese event. In addition, late supergene enrichment is possible.

Korzeb and others (1995, 61 samples) and V.T. McLemore (this report, 29 samples) collected samples of the carbonate-hosted replacement deposits within the district. Trace element analyses of the samples indicate that many of these deposits are enriched in silver (0.6 >300 ppm), lead (10-14,900 ppm), manganese (28-118,000 ppm) and zinc (4-92,500 ppm) and are relatively low in copper (1-79 ppm) and gold (<0.2-175 ppb). Silver has a high Pearson correlation coefficient with lead (0.50), bromine (0.51), arsenic (0.13), and vanadium (0.45). These data reflect the predominant mineralogy of manganese and iron oxides and silver halides and bromides in a gangue of quartz and calcite. Selected assays are in table 10.

Table 10. Assays of selected samples collected from underground workings (Collected by V. T. McLemore and analyzed by USGS by ICP methods).

SAMPLE	Ag ppm	Cu ppm	Pb ppm	Zn ppm	Mn ppm	Au ppb	LOCATION
Lake 25	245	41	9900	4100	71,500	175	lower workings at Savage decline
Lake 32	38	5	317	265	48,600	<5	East of John's shaft
Lake 33	9	8	136	410	91,700	<5	John's shaft
Lake 36	143	<2	3110	2740	81,200	<5	Below Daly shaft
Lake 37	222	6	2180	686	108,000	<5	Lowest level at Office shaft
Lake 40	219	59	14,900	16,400	103,000	12	Near Daly shaft

Model for mineralization

We propose that the mineral deposits in the Lake Valley district are epithermal and distally related to rhyolite intrusion and fluid flow, but recognize that Laramide mineralization is also possible. Barren jasperoid that hosts mineralized jasperoid is Eocene or older, and may be related to Laramide magmatism. At Lake Valley, ore textures, ore controls, and ore zonation are similar to other volcanic-epithermal deposits in southwestern New Mexico. Arguments for mid Tertiary volcanic-related mineralization are:

- The Lake Valley metal enrichments are similar to those in volcanic-epithermal deposits at Chloride, and Macho (table 11). In particular, Lake Valley and the volcanic-epithermal deposits are high in silver and low in gold and copper. In contrast, the Laramide veins at Hillsboro are copper- and gold-rich.

- The ore is controlled by the Lake Valley fault, which was active during and following caldera collapse. District zoning, with the higher-grade deposits near the Lake Valley fault, suggests that the Lake Valley fault may have acted as a pathway for mineralizing fluids that formed the Lake Valley deposits.
- Oligocene rhyolite domes have been linked to mineralization at Chloride and Carpenter mining districts.
- Harrison (1986) showed that, at Chloride, mineralization occurred at 25-27 Ma, which is an age that follows closely rhyolite emplacement at 28-29 Ma.
- At Macho, mineral deposits are in both carbonate rocks and Eocene Rubio Peak Formation. This association suggests that carbonate-hosted replacement deposits at Macho postdate the Eocene Rubio Peak Formation, although it is possible that separate mineralizing events occurred.

Arguments for Laramide age are:

- The silver-manganese-lead assemblage is consistent with distal porphyry-related replacement deposits. Similar carbonate-hosted silver-manganese deposits occur distal to the Copper Plat porphyry deposit at Hillsboro.
- The district is near Laramide structures. The Santa Rita lineament (fig. 14), which goes through the Hillsboro district, is west to northwest of the district and we propose that the Lake Valley fault in the mine area has a component of Laramide movement.
- The highest-grade ore is in beds dragged along the Lake Valley fault, but ore is not in the fault itself. Reactivation of the fault during caldera collapse would have offset any ore in the fault zone.
- Mineralized rock is restricted to the Lake Valley Formation. The lack of mineralized rocks in the volcanic rocks can be interpreted as showing ore predates volcanic rocks.

Table 11. Mining districts in the Black Range area. Pb, lead; Zn, zinc; Ag, silver; Mn, manganese.
Where known, host units and age of intrusive rocks are shown. Districts located on Figure 13.

Mining District	Type of Deposit	Host formation/rock	Max. Age Ma
Chloride	Volcanic-epithermal, placer gold, carbonate-hosted Pb-Zn	Rubio Peak, Kneeling Nun, Madera Limestone	25-27
Carpenter	Carbonate-hosted Pb-Zn-Ag	Montoya Dolomite, Lake Valley Formation	26.6±0.8, 41.6±1.6
Kingston	Carbonate-hosted Ag-Mn	Fusselman Dolomite	28.1
Taylor Creek	Placer tin and tin vein deposits	Taylor Creek rhyolite	28
Tierra Blanca	Carbonate-hosted Ag-Mn, volcanic-epithermal	Fusselman Dolomite, Bliss and El Paso Formations	
Hermosa	Carbonate-hosted Pb-Zn	Upper Ordovician-Silurian Upham, Aleman, Cutter, Fusselman dolomites, Lake Valley, Kelly, Madera limestone	
Lake Valley	Carbonate-hosted Ag	Lake Valley Formation	
Macho	Volcanic-epithermal, carbonate-hosted Pb-Zn-Ag	Macho andesite, Fusselman Dolomite	40.7
Cuchillo	Carbonate-hosted Pb-Zn-Ag, Placer tin and tin vein deposits, sedimentary Cu, replacement Fe	Magdalena Group, rhyolite	48.8±2.6
Georgetown	Carbonate-hosted Ag	Fusselman Dolomite	71±2?
Hillsboro	Laramide vein, porphyry copper, carbonate-hosted Pb-Zn and Ag-Mn, Laramide skarn, placer gold	Andesite, quartz monzonite, , quartz late dikes, Lake Valley Formation, Fusselman Dolomite	74.57±0.51

A magnetic high south of Monument Peak is interpreted as a felsic intrusion (aeromagnetic and gravity section, this report). This magnetic high is much less pronounced than the high associated with the porphyry at Hillsboro. Only drilling will resolve whether the intrusion is Laramide or associated with Eocene-Oligocene volcanic rocks. Laramide skarn deposits also could produce a magnetic high.

We propose that the primary factors in concentrating ore at Lake Valley were the Lake Valley fault and the competency differences between the Alamogordo and Nunn Members of the Lake Valley Formation. The paleochannel filled with Quaternary gavel may have played a role in secondary silver enrichment. The Lake Valley is a major fault extending to depth along which repeated movement and magma intrusion occurred. We propose that the fault was the conduit for hydrothermal fluids related to rhyolite intrusion and that post-ore displacement has displaced any ore in the fault zone. The structural location of the Lake Valley district at the southern terminus of the Winston gaben would have enhanced the concentration of fluids and ore in the Lake Valley district.

ASSESSMENT

The potential for volcanic-related epithermal precious metal deposits in the Lake Valley ACEC is low to moderate (see fig. 15 for definition of levels of resource potential). The primary target for more deposits is on and near the Lake Valley fault.

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

LEVELS OF RESOURCE POTENTIAL

- H HIGH mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data support mineral-deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.
- M MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate reasonable likelihood for resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.
- L LOW mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment in which the existence of resources is permissive. This broad category embraces areas with dispersed but insignificantly mineralized rock, as well as areas with little or no indication of having been mineralized.
- N NO mineral resource potential is a category reserved for a specific type of resource in a well-defined area.
- U UNKNOWN mineral resource potential is assigned to areas where information is inadequate to assign a low moderate, or high level of resource potential.

Figure 15. Definition of levels of mineral resource potential (from Goudarzi, 1984).

The richest ore in the Lake Valley district is near the fault, and we have proposed it as a conduit for primary mineralization. In addition, anomalous silver, lead, zinc, and molybdenum occur in jasperoid near the Lake Valley fault (northwest of the mine workings as reported by Young and Lovering (1966)). Mineralized rock in the workings is absent at depths greater depth than 150 ft (46 m), and no mineralized rock was encountered at depth during a 1928-1929 drilling program; however, what was probably silicified Fusselman Dolomite was found in a 400 ft hole. In the field, we observed abandoned drill core of brecciated unaltered Mimbres Peak Rhyolite on the Lake Valley fault just northwest of the Lake Valley workings. The lack of follow-up drilling suggests little mineralized rock was encountered at depth. Rich pockets of shallow, oxidized ore may exist, but the extensive workings of the near-surface suggest little of economic importance remains.

The potential for Laramide copper-gold porphyry deposits, skarns, and veins in the Lake Valley ACEC is low to moderate. The moderate potential is based on the presence of the nearby Copper Flat porphyry at Hillsboro about 10 mi (16 km) to the north of the map area and the larger deposits of the Arizona and New Mexico porphyry belt about 30 mi (48 km) to the west, and on the anomalous magnetic high southeast of Lake Valley. The low potential is based on: 1) geochemical anomalies in the Lake Valley do not show the gold enrichment characteristic of the Laramide porphyries and present at the Copper Flat porphyry at Hillsboro, 2) lack of Cretaceous volcanic rocks like those at Hillsboro, and 3) lack of the prominent magnetic signature that characterizes the Hillsboro district. The magnetic high south of the district that may indicate a Laramide or Tertiary subvolcanic rock or Laramide skarn deposits. Drilling is needed to resolve this question.

The potential for Rio Grande rift-related barite-fluorite-galena deposits in the Lake Valley ACEC is low. The ACEC is at the southern end of the Winston graben, which is the westernmost rift basin at this latitude. However, no barite-fluorite occurrences, which are ubiquitous in these deposits, are known in the area.

The potential for rhyolite tin deposits in the Lake Valley ACEC is low. The placer and lode tin deposits at Taylor Creek are related to domes of crystal rich, high-silica peraluminous, moderately-evolved rhyolite with rare-earth patterns similar to those of topaz rhyolites. Rhyolite of this composition is not present at Lake Valley, although we acknowledge we do not have the rare-earth chemistry to conclusively rule out tin-related rhyolite.

Conclusion

Drilling results and the extensive underground workings suggest that most of the low tonnage, high-grade silver deposits in the district were found, although it is always possible that some remain undiscovered (Harley, 1934; Apell and others 1947; Creasey and Granger, 1953; unpublished NMBMMR file data; underground examination by V. T. McLemore). The 1928-1929 drilling program looking for deeper deposits in the lower Lake Valley Formation and Fusselman Dolomite encountered only barren rock (Harley, 1934). Apell and others (1947) report that U.S. Bureau of Mines drilling in 1942-1943 successfully delineated manganese reserves, as did subsequent drilling by Haile Mines Inc., but these are reserves that were economic in the exceptional market of World War II and creation of national manganese stockpiles in the 1950's. Most of these identified resources were mined from 1942 to 1959.

The best potential for additional deposits in the ACEC area would be in the underlying Fusselman Dolomite and along the Lake Valley fault. However, any undiscovered deposits would have to be high-grade in order to be economic. A mill would be needed to concentrate the ore, because the presently operating mills in New Mexico and Texas probably could not mill silica-poor, manganese-rich silver ores. The silica content in the Lake Valley district is too low for use as silica flux for the copper smelters in New Mexico and Texas. The deposits are low in gold (<175 ppb), which is a major economic consideration in silica flux ore.

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