GEOLOGY OF THE SILVER HILL AREA
SOCORRO COUNTY, NEW MEXICO

A Thesis

Presented to

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New Mexico Institute of Mining and Technology

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Donald Bruce Simon

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This thesis is accepted on behalf of the faculty of the Institute by the following committee:

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Richard E Beane

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ABSTRACT

The Silver Hill area is composed of generally eastward dipping Oligocene and Miocene rocks. Eroded fault blocks expose tuffs and flows of the Datil volcanics and flows of La Jara Peak Andesite; fanglomerates of the Popotosa Formation fill Miocene block-faulted basins. The unit of Arroyo Montosa (early Miocene), consisting of interbedded conglomerates and lava flows, is distinguished from similar-looking rocks of the Popotosa Formation on the basis of lithologic differences. This newly defined unit lies stratigraphically between La Jara Peak Andesite and the Datil volcanics. A late Oligocene monzonite pluton intrudes altered Datil volcanics in the southwestern portion of the area.

The predominant structural features of the Silver Hill area are steeply dipping faults with diverse trends. Faulting is divided into four age periods: 1) middle Oligocene, 2) late Oligocene, 3) early Miocene, and 4) middle to late Miocene. A shallow graben formed by middle Oligocene faults controlled deposition of the tuff of La Jencia Creek. The Mulligan Gulch graben, bordering the western margin of the area, began to form in late Oligocene and was modified by Miocene faulting. Onset of Basin and Range deformation may be extended to very early Miocene in the Magdalena area.

Late Oligocene argillic alteration and pyritization occur along the western margin of the Silver Hill area.

Some argillization may be related to supergene oxidation of pyrite. Sulfur and most of the iron in pyrite were probably introduced by hypogene solutions which apparently were not related to the nearby monzonite intrusive. Paragenetic relationships on Miocene vein mineralization suggest that some of the assemblage chrysocolla-malachite-hematite is hypogene. Excessive depths to the Kelly Limestone, insufficient tonnage of vein mineralization, and limited extent of altered rocks collectively indicate that the Silver Hill area is not a favorable target for mineral exploration.

INTRODUCTION

Statement of the Problem

The purpose of this study is to map and describe the stratigraphic and structural relationships and to investigate the alteration and mineralization of the Silver Hill area, Socorro County, New Mexico.

Location and Accessibility

The Silver Hill area is located 1.5 miles west of Magdalena, New Mexico in relatively low terrain northwest of the Magdalena Mountains. The area of investigation covers approximately 22 square miles and lies within the Silver Hill and Arroyo Landavaso 7.5-minute topographic quadrangles. The boundaries are La Jencia Creek and Dry Lake Canyon on the north, a north-south line between La Jencia Creek and State Road 107 on the east, Boxcar Well Road on the south, and a north-south line between Dry Lake Canyon and Arroyo Landavaso on the west (fig. 1).

Access to the northern and eastern parts of the thesis area is provided by State Road 52. U.S. Highway 60 bisects the southern part, and the southern boundary of the area can be reached by State Road 107. In addition, there are numerous ranch roads and woodcutter's trails which connect the western and eastern portions of the area. The larger arroyos are also driveable.

Previous Investigations

A general reconnaissance of the Datil and Gallinas

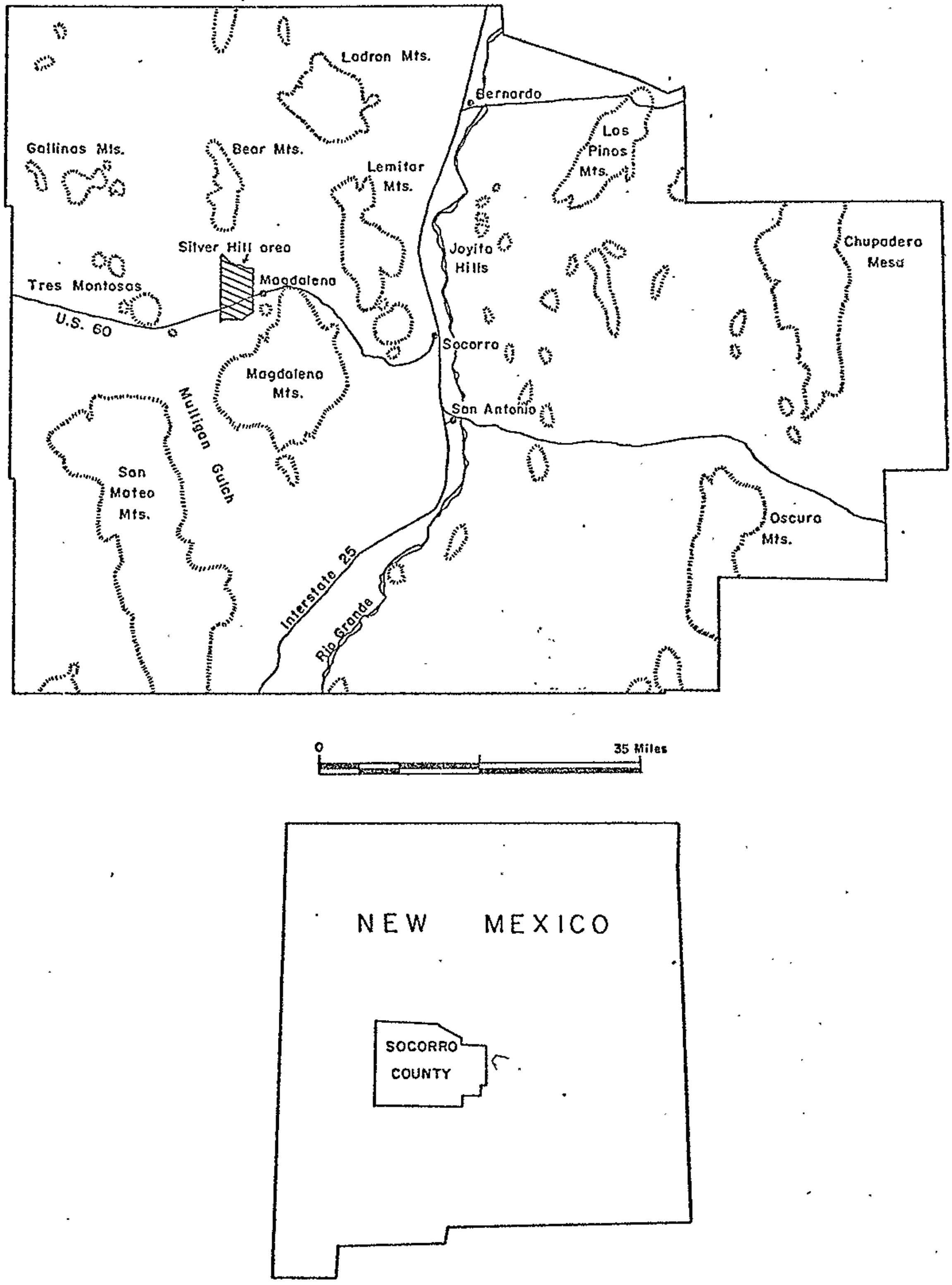

Figure 1 - Location map of the Silver Hill area

Mountains, northwest of the Silver Hill area, was completed by Herrick in 1899. In his report of 1900, he concluded that the rocks were mostly trachyte and rhyolite intrusives. In the San Mateo and Magdalena Mountains, Lindgren, Graton and Gordon (1910, p. 239) noted that the first volcanic rocks of the Tertiary period were predominantly andesite; later flows were mainly of rhyolitic composition. Winchester (1920) measured a partial stratigraphic section of the Tertiary rocks in the northern Bear Mountains and called the entire sequence of andesite, trachyte and rhyolite flows and intrusives, and some associated conglomerates and sandstones, the Datil Formation. The sedimentary rocks of the basal 684 feet of Winchester's section were later separated by Wilpolt and others (1946) and named the Baca Formation.

Mining activity was reported as early as 1919 in the North Magdalena district (Pueblo Springs) (Weed, 1920). Weed (1922) noted that the Copper Belt Silver and Copper Mining Company, which owned 13 claims on the east slope of Silver Hill, did a small amount of assessment work consisting primarily of open cuts and shafts. Two holes were drilled in 1925 to depths of 820 to 1042 feet (Neale, 1926). Both holes bottomed out in igneous rocks. Lasky (1932) also reviewed these claims and added that the prospects were aligned along a series of northwest-trending quartz veins which cut the predominantly andesitic and quartz latitic country rock. The mineralization, which included argentite, chalcocite, covellite, chrysocolla and malachite, occurred as small pockets and shoots in the veins and was structurally controlled by faults and fractures. Some gold was also reported (Neale, 1926). In some concluding remarks, Lasky (1932) postulated a hidden magmatic source for the copper and silver mineralization possibly related to the intrusives in the Kelly area. The last reported activity on the property was in 1927 (Howard, 1967, p. 201), although numerous small-scale exploratory operations have been carried out since then.

Loughlin and Koschmann (1942) studied the Kelly area in detail and published a comprehensive Professional Paper. They noted that several Tertiary volcanic units present in the Magdalena district extended to areas north and west outside the district. A geologic summary of the Magdalena mining district and discussion of the genesis of the Linchburg orebody, located in the southern portion of the district, were published by Titley (1959, 1961). Johnson (1955) attempted to correlate several Tertiary volcanic units in the Magdalena district with those that crop out in the Datil and Bear Mountains. On his geologic map, the rocks of the eastern half of the Silver Hill area were shown as Miocene upper latite.

Detailed stratigraphic work on the Datil Formation was conducted by Tonking (1957) in the Bear Mountains. He subdivided the formation into a basal Spears Ranch Member, a middle Hells Mesa Member, and an upper La Jara Peak

Member. The La Jara Peak Member was later reassigned to a series of post-Datil andesites and basalts by Willard (1959) and Weber (1963). In the Silver Hill area, these two investigators mistakenly correlated the La Jara Peak Member with a "lower volcanic group" of Late Cretaceous-early Tertiary age. Weber (1971) elevated the Datil Formation to group status and noted that further mapping would probably necessitate raising the subdivisions to formational rank.

Weber and Bassett (1963) published a preliminary report on several K-Ar dates of Tertiary volcanic and intrusive rocks in west-central New Mexico. One sample, near the base of the Hells Mesa Member, was dated at 30.6 ± 1.2 m.y. Kottlowski, Weber and Willard (1969) dated a number of Datil and post-Datil volcanic rocks including the Hells Mesa and Spears Ranch Members. Chapin (1971a) dated the La Jara Peak Andesite and discussed its significance to mineral exploration. Fission track dates for the Potato Canyon Rhyolite and a vitrophyre within the A-L Peak Formation were determined by Smith and others (1973).

Elston and others (1968, 1970) have attempted to fit the Datil volcanic rocks into an overall volcanic-tectonic framework related to the development of the Mogollon Plateau as a large-scale, ring-dike complex. They noted in one of their figures several source cauldrons for the volcanic rocks. In the San Mateo Mountains, Deal and Rhodes (1973) have established two additional ash-flow cauldrons. One of these, the Mt. Withington cauldron, is believed to be the source for the ash flows within the A-L Peak Formation.

In another article, Elston and others (1973) have interpreted the volcanic rocks of the Datil Formation or Group as consisting of 3 major volcanic episodes with the end of the last episode coincident with the beginning of Basin and Range faulting about 20 million years ago. The development of the Rio Grande rift and its influence on structural trends in the Magdalena and Bear Mountains was discussed by Chapin (1971b). A relationship between Basin and Range faulting, mid-Tertiary volcanism and plate tectonics was postulated by Elston (1972).

Most recently, a number of theses and dissertations have discussed in detail specific areas around the Magdalena district. Brown (1972) completed an investigation of the southern Bear Mountains. Part of the area he mapped lies directly north of the Silver Hill area and some of the structure and volcanic units present in the southern Bear Mountains extend into the Silver Hill area. Woodward (1973) mapped the Lemitar Mountains and described their stratigraphic and structural relationships to the Rio Grande rift. The origin of the Popotosa Formation was the subject of a dissertation by Bruning (1973). Investigations of the central Magdalena Mountains, the Cat Mountain-Tres Montosas area and the Council Rock district are being completed by Krewedl (in preparation), Wilkinson (in preparation) and

Chamberlin (in preparation). Blakestad (in preparation) is remapping the Kelly district and Siemers (in preparation) is investigating the Paleozoic stratigraphy of the Magdalena area.

Present Investigation

The study of the Silver Hill area began with detailed geologic mapping which was carried out during the summer and fall of 1972 and sporadically through the winter, spring and summer of 1973. The Arroyo Landavaso and Silver Hill 7.5-minute topographic quadrangles (scale 1:24000) served as base maps for field work. Aerial photographs of the GS-VARJ (1963) series were used to locate outcrops and to aid in structural interpretation.

Petrographic work consisted of examining 49 thin sections from different rock units mapped in the thesis area. The LL & E diamond-drill hole located on the south slope of Silver Hill (pl. 1) was logged by the author and Dr. C.E. Chapin; 21 thin sections were made and studied from representative samples. For comparison, several thin sections of core from the Crouch drill hole (sec. 7, T. 2 S., R. 4 W.) were also examined. In addition, alteration assemblages were checked in a suite of thin sections collected from samples in a roadcut on U.S. Highway 60, 3.75 miles west of Magdalena.

Modal analyses were performed by J.E. Bruning on 2 samples from the Hale Well pluton and 14 samples from the A-L Peak Formation obtained from the Crouch drill hole. In addition, the author performed modal analyses on 12 samples from many of the volcanic units as a check on estimated phenocryst and groundmass percentages. Approximately 2000 points per thin section were obtained from a square grid with 1/3-millimeter intervals. All point counting was done with a Swift automatic point counter attached to a Zeiss microscope using a magnification of 31.25.

In July 1973, a sample from the volcanic facies of the unit of Arroyo Montosa was submitted to Geochron Laboratories, Inc. for radiometric dating.

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core from their diamond-drill hole, and to Mr. Ben Donnegan for access to information gathered on the Silver Hill area.

STRATIGRAPHY AND PETROLOGY

Pre-Tertiary Rocks

No rocks older than Tertiary are exposed within the study area. However, about 4 miles to the east, on the east side of Granite Mountain and north of U.S. Highway 60, outcrops of Precambrian and Paleozoic sedimentary rocks are shown on the geologic map accompanying Professional Paper 200 by Loughlin and Koschmann (1942). They show a Paleozoic section beginning with the Kelly Limestone of Mississippian age and continuing through the Sandia and Madera Formations of Pennsylvanian age. However, recent work indicates that most of this stratigraphic section is not Pennsylvanian but Permian in age (W.T. Siemers, R.B. Blakestad and C.E. Chapin, oral commun., 1973). A partial sequence of the Abo, Yeso (?), Glorieta and San Andres Formations is present with the Spears Formation of early Oligocene age resting unconformably on San Andres Limestone. South of U.S. Highway 60, in the Kelly mining district, the Spears rest on the Abo Formation. West of the Silver Hill area and about 2 miles east of Tres Montosas, Wilkinson (in preparation) shows a small area of Paleozoic rocks unconformably overlain by the Spears Formation. The lithology of these rocks is similar to that of the Abo Formation in the area east of Granite Mountain and the two exposures have been tentatively correlated as Abo (W.T. Siemers, oral commun., 1973). Eight miles north of Silver Hill in the Puertecito quadrangle (Tonking, 1957), the

Spears rests on the Baca Formation of Eocene age which, in turn, overlies a thick Mesozoic section. Thus, the Silver Hill area is located on the north flank of a Laramide uplift which forms the southern edge of the Baca basin.

Tertiary Rocks

The Tertiary sequence in west-central New Mexico consists of both sedimentary and volcanic rocks intruded by numerous dikes and plutons of late Oligocene age. A thick sequence of fanglomerate and playa deposits with interbedded volcanic rocks (the Santa Fe Group) fills block-faulted basins of Miocene age. Pediment gravels of late Pliocene and Quaternary age mark the end of the Tertiary Period.

The sedimentary and volcanic rocks are divided into the Baca Formation (Eocene), the Datil volcanics (Oligocene), the La Jara Peak Andesite (early Miocene) and the Santa Fe Group (Miocene-Pliocene). The Baca and Spears Formations are not exposed within the thesis area. The Tertiary rock units mapped in the Silver Hill area, with the exception of intrusive bodies, are shown diagrammatically in fig. 2.

Hells Mesa Formation

The oldest rocks exposed in the Silver Hill area are rhyolitic and quartz latitic ash-flow tuffs belonging to the Hells Mesa Formation of mid-Oligocene age. Tonking (1957) named the Hells Mesa for a locality of that name on the east edge of the Bear Mountains; he measured a type

PLIOCENE		pediment gravels (late Pliocene-Quaternary)	
MIOCENE	Santa Fe Group	Popotosa Formation	fanglomerate of Dry Lake Canyon
		La Jara Peak Andesite	
		unit of Arroyo Montosa	volcanic facies
			conglomerate facies
			unconformity
OLIGOCENE	Datil volcanics	upper tuffs	
		andesite of Landavaso Reservoir	
		A-L Peak Formation	tuff of Allen Well
			andesite flows
			pumiceous member
			flow-banded member
			tuff of La Jencia Creek
			gray massive member
		Hells Mesa Formation	

Figure 2 - Generalized stratigraphic column of the Tertiary rock units exposed in the Silver Hill area; intrusive rocks excluded. Figure shows stratigraphic position only; relative thicknesses not indicated.

section and called the unit a member of the Datil Formation. Since then, the Datil Formation has been elevated to group status and the Hells Mesa given formational rank. Using the terminology adopted by Brown (1972), the Hells Mesa Formation consisted of the tuff of Goat Springs, the tuff of Bear Springs, some interbedded andesite flows and the tuff of Allen Well. Subsequent agreement among the various geologists mapping in the Magdalena area has restricted use of the term Hells Mesa to the basal crystal-rich, quartz-rich, ash-flow cooling unit of Tonking's type section; this unit correlates with the tuff of Goat Springs of Brown (1972). The overlying ash-flow units at Tonking's type section have been assigned to the A-L Peak Formation (Deal and Rhodes, 1973; Chapin and others, in preparation); the A-L Peak correlates with Brown's (1972) tuff of Bear Springs and tuff of Allen Well. K-Ar dates on the Hells Mesa Formation vary from 30.6 ± 1.2 m.y. in Tonking's type section to 32.4 ± 1.5 m.y. in the Joyita Hills (Weber, 1971).

The only outcrops of Hells Mesa exposed in the thesis area occur in a group of hills bordering Arroyo Montosa in the north-central portion of the map area (pl. 1). The outcrops form a thin band bounded on the west by a north-trending normal fault and on the east by overlying ash-flow tuffs. To the south, the unit disappears beneath talus cones of the A-L Peak Formation and to the north it is covered by recent alluvium along La Jencia Creek.

The Hells Mesa forms small ledges and weathers to massive blocky talus. The color varies from pale purple in fresh hand specimens to very pale orange in altered hand specimens. Weathered surfaces have grayish tints. Characteristically, the unit is moderately to densely welded and contains approximately 40 to 50 percent crystals and crystal fragments. Phenocrysts include sanidine, plagioclase, quartz and biotite. The average phenocryst size ranges from 2 to 3 millimeters but occasional quartz "eyes" measure as much as 6 millimeters in diameter. Lithic fragments are abundant near the base; pumice is present but not conspicuous.

In thin section, the texture is porphyritic with a devitrified groundmass crowded with small broken crystal fragments. Anhedral and subhedral sanidine crystals dominate the total phenocryst content and show slight to moderate degrees of alteration to clay. Quartz is usually rounded and embayed and comprises 10 to 15 volume percent of the total rock. Plagioclase grains are often euhedral and intensely altered to clays and calcite. Simple albite twinning is common but combined carlsbad-albite twinning also occurs. The anorthite content of plagioclase was determined using the Fouqué method on 5 crystals; the average composition is An_{38}, or sodic andesine. When present, yellow-brown biotite ranges from 1 to 2 percent and occurs as small laths, either partially or totally replaced by magnetite and hematite. Lithic fragments resembling dark gray andesites of the Spears Formation contain altered plagioclase phenocrysts and have an opaque, hematized groundmass. Pseudomorphs of limonite after pyrite were observed within several fragments in 1 thin section.

A-L Peak Formation

The A-L Peak Formation is a composite ash-flow sheet (R.L. Smith, 1960) with widespread occurrence in southwestern Socorro County. The formation was named after A-L Peak in the northern San Mateo Mountains by Deal and Rhodes (1973). They described the formation as a sequence of crystal-poor ash-flow tuffs unconformably overlying the Hells Mesa Formation with a total thickness of 1970 to 2300 feet, (600 to 700 meters). A 31.8 ± 1.7 m.y. fission track date (E.I. Smith and others, 1973) obtained from the basal vitrophyre of A-L Peak Formation is in good agreement with the 30.6 to 32.4 m.y. K-Ar dates on the underlying Hells Mesa Formation.

The Mt. Withington cauldron in the northern San Mateo Mountains is suggested as the source of the A-L Peak ash flows by Deal and Rhodes (1973). In the thesis area, two north-south flow trends determined from lineated pumice in A-L Peak tuffs indicate a direction consistent with the location of the cauldron (pl. 1).

Outward from the San Mateo Mountains, the A-L Peak Formation is thinner, and andesite flows and crystal-rich ash flows are interstratified. In the southern Bear Mountains, the A-L Peak Formation, formerly called the tuff of Bear Springs (Brown, 1972), attains a thickness of approximately 1000 feet and was subdivided by Brown into 6 members. Woodward (1973) recognizes 8 members in the Lemitar Mountains, 15 miles east of Magdalena, where the unit has a maximum thickness approaching 1400 feet.

In the Silver Hill area, the A-L Peak Formation is divided into 6 members which are, in ascending order, the: 1) gray massive member, 2) tuff of La Jencia Creek, 3) flow-banded member, 4) pumiceous member, 5) interbedded andesite flow, and 6) tuff of Allen Well. An undifferentiated unit is mapped when a clear distinction between the gray massive member and the flow-banded member cannot be made. This unit is shown only on the geologic map and is not described in the text. Thickness of the A-L Peak Formation in the thesis area is difficult to determine accurately because of faults and limited exposures; a reasonable estimate is 700 to 900 feet.

<u>Gray Massive Member</u>. The lowest member of the A-L Peak Formation in the Silver Hill area is a massive, crystal-poor, rhyolitic ash-flow tuff. Basal andesite flows observed in surrounding areas (Brown, 1972; Woodward, 1973; Krewedl, in preparation; Chapin and others, in preparation) are not present.

The gray massive member crops out sporadically on ridges and small hills in the eastern and western portions of the map area. Upper sections of the member were also encountered in the Crouch and LL & E diamond-drill holes (see pl. 1). The member is a multiple-flow compound cooling unit and the individual flows form small ledges or, more typically, weathered, platy outcrops which comprise the dip slopes of ridges. Usually, the tuff is light gray but densely welded portions are darker and slightly reddish-brown. Altered outcrops have orange-pink to very pale yellow hues.

The unit is characterized in both hand specimen and thin section by a distinct paucity of crystals. Phenocrysts rarely exceed 10 percent of the total volume of the rock and commonly are less than 8 percent. Sharply euhedral sanidine is the most abundant constituent, but quartz, biotite and occasionally plagioclase also occur. Andesitic and rhyolitic lithic fragments are observed in portions of the unit.

Microscopically, sanidine occurs as subhedral to euhedral crystals, commonly twinned and ranging in size from 1 to 2 millimeters. Sanidine content varies between 3 and 9 percent of the total rock volume. The crystals are often a dusty brown color in plane light due to submicroscopic clay particles. Microperthitic texture is frequently observed. In thin sections of altered tuff, sanidine has been largely destroyed leaving only an occasional patch of the original mineral along the edges of the cavity.

Anhedral quartz crystals less than 1 millimeter in diameter are present in most samples. A few grains show slight embayment and holes filled with groundmass crystallites. Quartz generally makes up less than 2 percent of the total volume of the rock. The small size of the quartz crystals helps to distinguish the A-L Peak tuffs from the overlying upper tuffs.

Biotite occurs in many of the thin sections as reddish euhedral laths rimmed by opaques. In samples from the Crouch drill hole, the biotite is brownish and essentially unaltered, but a few laths are slightly hematized along cleavage traces and fractures.

Plagioclase is rare, but when present, it is frequently altered to calcite or partially etched. The composition of the plagioclase could not be determined.

Flattened pumice and crystal-rich clots are quite abundant in some thin sections, ranging to as much as 20 percent of the rock volume. Dark gray andesitic lithic fragments with microlites of plagioclase in an opaque groundmass are common, but these fragments are generally subordinate in amount to pumice and clots.

Devitrified glass shards and cryptocrystalline to microcrystalline aggregates of potash feldspar and quartz usually comprise a large majority of the groundmass. The glass shards are more conspicuous in some thin sections than in others and are frequently compressed and deformed. Locally, gas pockets filled with euhedral crystals of potash feldspar, quartz and occasionally biotite can be seen. Interstitial calcite and brownish dust constitute the remainder of the groundmass.

Tuff of La Jencia Creek. Welded to the gray massive member is a crystal-rich ash-flow tuff designated the tuff of La Jencia Creek (Brown, 1972). The exact position of this tuff within the lower part of the A-L Peak Formation is not known. In the southern Bear Mountains, the tuff of La Jencia Creek is missing and the gray massive member is overlain by the flow-banded member (Brown, 1972). A similar sequence was observed by Woodward (1973) in the Lemitar Mountains. Where the tuff of La Jencia Creek crops out in the thesis area, no overlying units can be seen. The two most likely alternatives are: 1) that the tuff occurs interbedded within the gray massive member, or 2) that the tuff lies between the gray massive member and the flow-banded member. With the information available, it is doubtful this problem can be resolved. Therefore, the tuff of La Jencia Creek has been arbitrarily assigned a position between the gray massive member and flow-banded members.

The tuff of La Jencia Creek usually crops out as discontinuous ledges which weather to platy slabs and occasionally form dip slopes of small hills. In some outcrops, such as ones in sec. 8, T. 2 S., R. 4 W. and sec. 24, T. 2 S., R. 5 W., the welded contact with the gray massive member can be seen. At the contact, a pumiceous and relatively crystal-poor zone at the top of the gray massive member grades into less pumiceous crystal-rich rock of the tuff of La Jencia Creek. Total thickness of this transition ranges from 2 to 4 feet. Fresh hand specimens from both zones are typically densely welded and have a reddish-purple color. Weathered samples are pale yellow-brown to light brownish-gray. Data from modal analyses on the upper portion of the gray massive member, the welded contact, the transition zone, and typical tuff of La Jencia Creek are listed in table 1 and shown in fig. 3. A photograph of the welded contact is shown in fig. 4.

In thin section, the tuff of La Jencia Creek is a porphyritic quartz latite with phenocrysts of sanidine, plagioclase, quartz and biotite in a devitrified, aphanitic groundmass. Crystal content generally ranges from 35 to 40 percent in the crystal-rich zone to 25 percent in the transition zone. Otherwise, the two zones are mineralogically identical. Typically, sanidine is more abundant than plagioclase, and accessory magnetite and orthopyroxene are present in many of the thin sections.

Sanidine crystals are generally anhedral and subhedral, and average from 1 to 2 millimeters in length. Most grains appear to be quite fresh with only minor incipient calcite along fractures. Twinning in sanidine is uncommon. Plagioclase is usually larger than sanidine and occurs primarily as subhedral crystals. The degree of alteration varies from moderate to intense and frequently the entire crystal is replaced by calcite and fine-grained aggregates of quartz. Phenocrysts of angular quartz, occasionally subrounded, range up to 3 millimeters in diameter, with the average being 1.5 to 2 millimeters. Scattered laths of fresh and slightly altered, yellow-brown biotite also occur. Very fine-grained magnetite is often present as borders

Table 1 - Modal data in volume percent for the tuff of La Jencia Creek and the upper part of the gray massive member from the Crouch drill hole.

	Sample number	Total phenocrysts*	Phenocryst Proportions				Pumice	Total points counted
			Sanidine	Plagioclase	Quartz	Mafics and Opaques		
Top of tuff of La Jencia Creek								
1	M-74-4	30.34	16.64	6.57	3.95	3.18	6.80	2176
2	M-74-5	40.73	18.86	11.83	5.58	4.46	4.83	2131
3	M-74-6	44.60	19.82	11.78	9.04	3.96	1.43	2301
4	M-74-7	36.93	18.26	13.74	1.21	3.72	0.90	2234
5	M-74-8	39.21	20.47	10.59	5.06	3.09	0.42	2135
6	M-74-9	37.44	23.08	8.90	2.48	2.98	2.52	2179
7	M-74-10-1	37.20	17.70	10.90	6.10	2.50	6.20	1000
8	M-74-11	37.46	18.32	10.11	5.57	3.46	1.03	1938
9	M-74-12	36.91	17.30	11.13	3.08	5.40	10.12	2075
10	M-74-13	35.60	14.90	13.76	2.90	4.04	9.21	2107
11	M-74-14	27.02	11.09	11.82	0.32	3.79	2.25	2191
Welded contact with gray massive member								
12	M-74-15	12.44	9.87	0.46	1.45	0.66	15.76	2411
13	M-74-16	9.47	7.38	0.35	1.26	0.48	6.91	2302
14	M-74-17	8.09	5.65	0.33	1.66	0.45	0.12	2409
Base of sequence								

* remainder of rock is groundmass, lithic fragments and crystal clots.

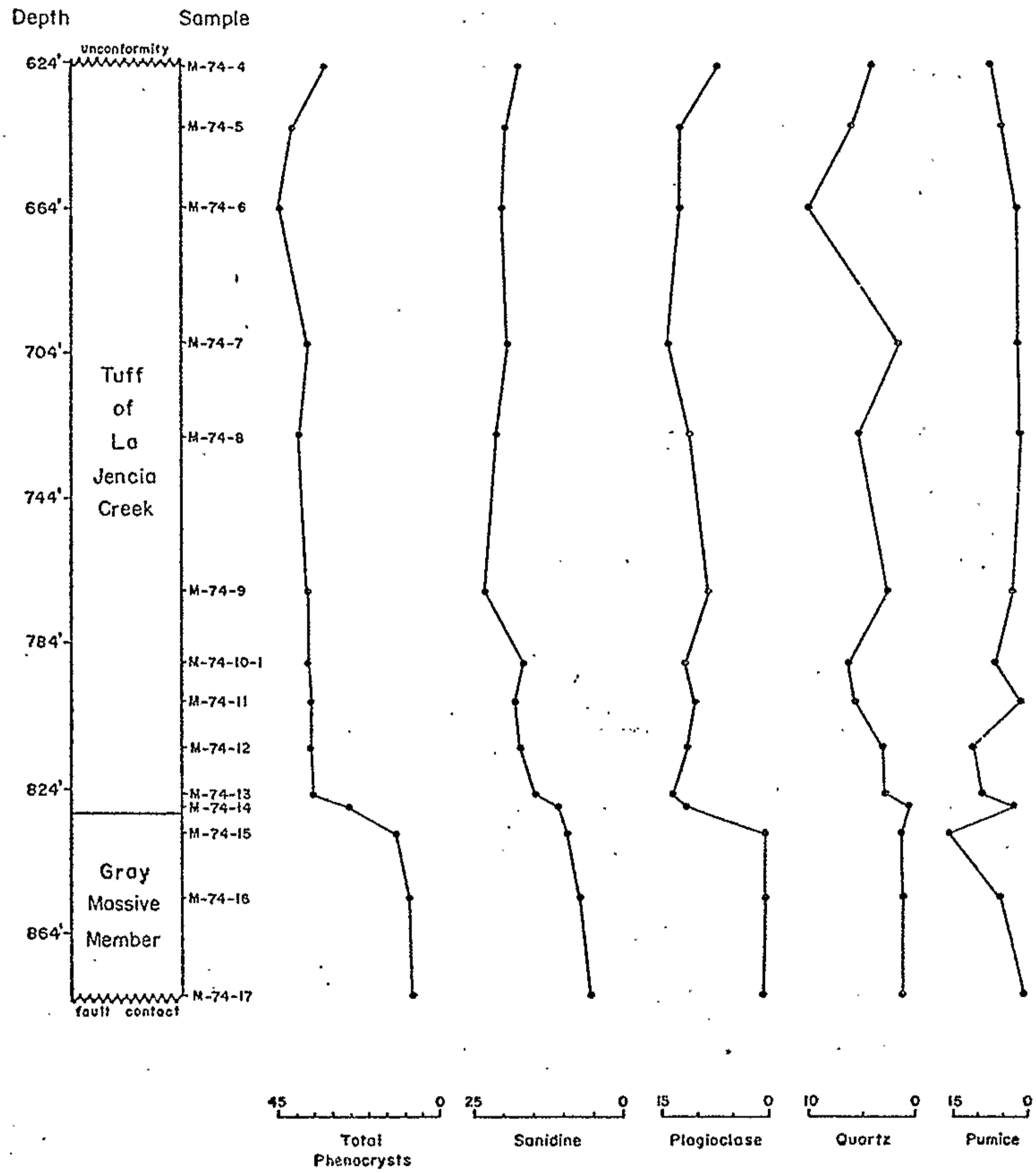


Figure 3 - Modal data on the tuff of La Jencia Creek and the upper part of the gray massive member from the Crouch drill hole showing mineralogical variations. Point-count grid measured 0.5 X 0.5 millimeter. Modal data are in volume percent taken from table 1.

Figure 4 - Section of core from the Crouch drill hole (Sec. 7, T. 2 S., R. 4 W.) showing welded contact (dashed line) between gray massive member of the A-L Peak Formation (right core and lower two-thirds of middle core) and the overlying tuff of La Jencia Creek (left core and top one-third of middle core). Note pumiceous zone (p) near top of gray massive member; this zone grades downward into crystal-poor, pumice-poor tuff which is typical of the gray massive member.

around biotite.

Pumice is abundant and highly compressed towards the basal contact of the tuff. Andesitic lithic fragments as much as 1 centimeter in diameter and moderately altered occur in a large majority of the thin sections. The groundmass is usually devitrified. Compaction structures can be seen, although they are generally less well-developed than in other members of the A-L Peak Formation.

A true thickness of the tuff of La Jencia Creek cannot be determined from surface exposures. Partial thicknesses range from 5 feet to approximately 80 feet (cross-section C-C', pl. 1). However, in the Crouch drill hole (see pl. 1), a 206-foot section of the nearly flat-lying tuff was observed. The upper contact is a major erosional unconformity at the base of the La Jara Peak Andesite; a thin layer of sandstone is present at the contact and the underlying tuff is weathered to a depth of about 6 feet.

Exposures of the tuff of La Jencia Creek occur along a crudely developed, northeast-trending belt which transects the central portion of the thesis area (see pl. 1). The belt is approximately 2 miles wide and discontinuous, being partially obscured by La Jara Peak Andesite. To the southwest, the belt is truncated by the north-trending Hale Well fault (pl. 1 and fig. 11, p. 68). However, outcrops of the tuff of La Jencia Creek continue outside the map area to the northeast (C.E. Chapin, oral commun., 1973). The limited geographic distribution of the tuff of La Jencia Creek suggests that the tuff was deposited in a paleovalley which is interpreted to be fault-controlled but may be entirely a result of differential erosion. Other examples of a paleovalley during A-L Peak time are located in the Lemitar Mountains (Woodward, 1973), and in a northwest extension of Stendel Ridge in the Kelly district (R.B. Blakestad, oral commun., 1973). The Stendel Ridge paleovalley was fault-controlled whereas the paleovalley in the Lemitar Mountains formed by erosion.

Flow-banded Member. The flow-banded member of the A-L Peak Formation is a densely welded, crystal-poor, ash-flow tuff with a conspicuous streaky and banded appearance (fig. 5). A similar unit is recognized in several localities in the Magdalena area and in the Lemitar Mountains. Mappable outcrops of the flow-banded member in the thesis area are limited to a narrow ridge bordering Arroyo Landavaso north of Landavaso Reservoir. Outcrops of a platy, densely welded tuff along La Jencia Creek (sec. 6, T. 2 S., R. 4 W.) may also belong to the flow-banded member but are shown as A-L Peak undifferentiated on pl. 1. A flow-banded tuff also occurs near the bottom of the LL & E drill hole located on the southwest slope of Silver Hill (pl. 1).

A measured section in the southern Bear Mountains (Brown, 1972) shows the flow-banded member overlying and welded to the gray massive member. Poor exposures obscure this relationship in the Silver Hill area.

The best surface exposure of the flow-banded tuff in the map area is seen in a large roadcut on U.S. Highway 60, 3.75 miles west of Magdalena. At the western end of the roadcut, the tuff is massive and relatively fresh (fig. 5), whereas to the east, it is altered and severely fractured (see fig. 15, p. 82). Limonite and occasionally epidote are found on fracture surfaces in the eastern section of the roadcut. The tuff, where fresh, is light purplish-gray and contains a few feldspar crystals, lithic fragments and elongate, dark, lenticular streaks. These streaks may represent low pressure areas formed during flowage along which volatiles accumulated.

Petrographically, the flow-banded member varies from rhyolite to latite with phenocrysts of sanidine, plagioclase and quartz in a cryptocrystalline groundmass. The phenocryst content is variable and ranges from 1 to 6 volume percent. Compressed pumice and crystal clots constitute 20 to 30 volume percent. Andesitic lithic fragments are present in minor amounts and typically contain altered, euhedral, plagioclase laths in an opaque matrix; lithic fragments of light-colored intrusive rock ? are also present.

Sanidine, commonly microperthitic, occurs as subhedral to euhedral crystals which average less than 1 millimeter in diameter. Plagioclase is occasionally present in minor amounts and shows a variety of twinning and alteration. Scarce quartz crystals are anhedral and occasionally slightly embayed. The groundmass is composed primarily of microcrystalline quartz and potash feldspar with locally

Figure 5 - Flow-banding developed in the flow-banded member of the A-L Peak Formation exposed in large roadcut on U.S. Highway 60. Note that the streaks bend around two lithic fragments in upper left corner of the photograph.

conspicuous devitrified glass shards. Small amounts of calcite and submicroscopic material which may be finely divided dust occur interstitially.

Pumiceous Member. The pumiceous member of the A-L Peak Formation is a densely welded, crystal-poor, ash-flow tuff equivalent to the upper tuff of Bear Springs in the southern Bear Mountains (Brown, 1972). Outcrops of the pumiceous member occur primarily near Allen Well which is located in the northwest corner of the thesis area. Additional outcrops are present 2 miles south of Allen Well in sec. 12, T. 2 S., R. 5 W. In the Bear Mountains, the pumiceous member is separated from the flow-banded member by andesite flows but these flows are not observed in the study area. The upper contact of the pumiceous member is irregular, and apparently represents a paleoerosion surface with a gently rolling topography. Andesite flows and the tuff of Allen Well can be seen in depositional contact with the pumiceous member in outcrops along the lower reaches of Council Rock Arroyo (sec. 1, T. 2 S., R. 5 W.). A thickness of 280 feet has been measured for the member in the southern Bear Mountains (Brown, 1972). Poor exposures prevent an accurate measurement in the Silver Hill area; thickness determined by Brown (1972) was used in cross-sections A-A' and B-B' (pl. 1).

The unit crops out as ledges and small cliffs which weather to a grus of small platy fragments. Fresh samples are purplish-gray and contain abundant lineated pumice and a few phenocrysts of feldspar. On weathered surfaces, the pumice is frequently etched. Altered samples are usually yellowish-brown; intensely bleached samples are white. When pumice and phenocrysts are obliterated by bleaching, the tuff can be confused with caliche capping nearby pediment gravels. Bleached samples characteristically show hematite staining fractures and cubic outlines of pyrite pseudomorphs with a halo of limonite.

Microscopically, the pumiceous member is rhyolitic in composition. Thin sections of fresh samples have a porphyritic texture with a cryptocrystalline to microcrystalline groundmass. Phenocrysts of sanidine, varying in size from 0.5 to 2 millimeters, constitute less than 3 percent of the total rock volume. Flattened pumice and crystal clots are abundant and constitute as much as 25 volume percent in some thin sections. The groundmass is composed primarily of potash feldspar, quartz and devitrified glass shards. In thin sections of altered tuff, remnants of sanidine are intensely altered to clay and average 1 millimeter in length; pumice and crystal clots are obscured, and coarse-grained intergrowths of potash feldspar and quartz compose the groundmass. Limonite pseudomorphs after pyrite are moderately abundant. Near silicified portions of the tuff, potash feldspar in the groundmass frequently occurs as radiating, fibrous crystals which may represent recrystallization. In addition, sanidine contains specks which have high birefringence, high relief and parallel extinction. These specks are thought to be sericite.

Andesite Flows. Thin andesite flows and volcaniclastic sandstones of andesitic composition occur near Allen Well. These andesites occupy a cooling break between ash flows of the pumiceous member and the tuff of Allen Well. The andesites are absent elsewhere in the thesis area. The andesite flows occur as discontinuous outcrops indicating that the flows filled topographic lows developed in the underlying pumiceous member.

The andesites are typically poorly exposed although good exposures occur along Dry Lake Canyon (sec. 36, T. 1 S., R. 5 W., unsurveyed). Outcrops show varying degrees of alteration and consequently form either depressions between more resistant tuffs or small rounded ledges. Thin basal flow breccias are present locally. Hand specimens are medium gray on fresh surfaces and reddish- to yellowish-brown when altered.

Microscopically, the andesites contain scattered phenocrysts of oxidized pyroxene about 0.5 millimeter long in a felty groundmass of plagioclase microlites. The centers of the pyroxene are totally altered to calcite and a fibrous variety of chlorite, possibly pennine. Opaque iron oxides form the perimeter. Plagioclase microlites about 0.2 millimeter long are frequently twinned and show a range in composition from An_{55} to An_{61}. Most of the plagioclase is moderately altered to calcite.

Thin layers of volcaniclastic sandstone occur randomly near the top of the andesite flows. In hand specimen, the sandstones are fine- to medium-grained with colors similar to those of the andesites. Microscopically, the sandstones consist primarily of quartz and feldspar with a fine-grained cement of granular chert and calcite. Epidote and a zeolite occur in small amounts.

The andesite flows exhibit effects of weak argillization which can be seen in outcrops along Dry Lake Canyon as irregular discolored patches thought to have formed from channelized solutions (C.E. Chapin, oral commun., 1973) (fig. 6). In places, these solutions appear to have favored the more permeable sandstone layers, but probably are controlled by fractures which transect both the andesites and the sandstones.

Tuff of Allen Well. The uppermost member of the A-L Peak Formation is a crystal-rich ash-flow tuff named the tuff of Allen Well by Brown (1972). The member is exposed in the northwest corner of the thesis area and in 3 small outcrops 2 miles south of Allen Well (sec. 12, T. 2 S., R. 5 W.).

The tuff of Allen Well crops out as cliffs and ledges and weathers to blocky talus similar to the Hells Mesa Formation which it strongly resembles. Excellent exposures occur within Council Rock Arroyo and along the north bank of Dry Lake Canyon at the northern boundary of the thesis area. An accurate thickness of the tuff cannot be obtained because the top of the unit is not exposed. A partial

Figure 6 - Outcrop of partially altered andesite near Allen Well. Tan areas are bleached and exhibit weak argillic alteration; gray areas are relatively fresh andesite. Channeling of solutions along fractures probably produced the contrasting alteration effects.

thickness of about 100 feet is indicated on cross-section A-A' (pl. 1), although the tuff is usually about 60 to 70 feet thick.

In hand specimen, the tuff of Allen Well closely resembles tuffs of the Hells Mesa Formation but the groundmass of Hells Mesa tuffs are more crowded with small crystal fragments. The tuff of La Jencia Creek is also similar to the tuff of Allen Well. Both of these tuffs contain more biotite and are slightly less crystal-rich than Hells Mesa tuffs. Distinction between these three units is not easily made except where stratigraphic relationships can be seen. Fresh hand specimens are pale purple to purplish-gray and weather pale brown. Samples of altered tuff are typically mottled brownish-yellow. Phenocrysts are more conspicuous in fresh samples than in altered samples and consist of sanidine, plagioclase, quartz and biotite. The latter two minerals increase slightly in abundance from the base to the top of the unit.

Microscopically, the tuff of Allen Well is a cryptocrystalline quartz latite with a porphyritic texture. Sanidine is the most abundant phenocryst and comprises from 15 to 20 volume percent of the rock; it occurs as anhedral and subhedral crystal fragments with an average size of 1 millimeter. Minor amounts of clay and sericitic alteration can be seen in most grains with clay alteration the more abundant. Intensely altered crystals appear as cavities partially rimmed with remnants of original sanidine.

Plagioclase, less abundant and smaller than sanidine, usually occurs as subhedral crystals. Size of the plagioclase crystals is quite variable, averaging less than 1 millimeter in some thin sections to about 2 millimeters in others. Calcite and clay alteration are common and, in one thin section of altered tuff, the plagioclase has been partially corroded in the center. Quartz occurs as anhedral and subhedral crystals which are often rounded and partially resorbed. The crystals range in size from less than 1 millimeter to 5 millimeters in diameter with an average of about 2 millimeters. Total volume varies between 3 and 10 percent. Yellow-brown biotite is common and occurs as euhedral laths which average about 1 millimeter in length, but may be as large as 3 millimeters. In thin sections of altered tuff, biotite has a ragged appearance with occasional inclusions of rutile. A fine-grained mixture of sericite and limonite often surrounds these grains. A devitrified groundmass constitutes 60 to 65 percent of the total volume of the rock. Limonite pseudomorphs after pyrite, and patches and bands of iron oxide are locally abundant.

Andesite of Landavaso Reservoir

The andesite of Landavaso Reservoir, named for Landavaso Reservoir (C.E. Chapin, oral commun., 1972) in the southwestern part of the Silver Hill area, is a highly variable series of porphyritic andesite flows. The andesite is correlative with several units mapped and described by Loughlin and Koschmann (1942) in the southwestern portion of the Magdalena mining district. In the Lemitar Mountains, Woodward (1973) recognizes a similar andesite which he maps as the basal unit of the Potato Canyon Formation. The andesite of Landavaso Reservoir is also observed in the Cat Mountain-Tres Montosas area (Wilkinson, in preparation).

In the thesis area, outcrops of the andesite of Landavaso Reservoir occur predominantly south of U.S. Highway 60 (pl. 1). To the north, scattered outcrops border the western margin of the thesis area from the southern boundary of sec. 25, T. 2 S., R. 5 W. to Hill "7048" approximately 2 miles to the north (pl. 1). Near Landavaso Reservoir, the andesite overlies the flow-banded member of the A-L Peak Formation and is overlain by the upper tuffs. Maximum thickness indicated on cross-section D-D' (pl. 1) is 800 feet. Woodward (1973) records a similar thickness in the Lemitar Mountains where a correlative andesite occupies a paleovalley; outside the paleovalley, the andesite is only about 20 feet thick. The andesite of Landavaso Reservoir has not been dated radiometrically but lies between units dated at 31.8 ± 1.7 m.y (A-L Peak) and 30.3 ± 1.6 m.y. (Potato Canyon) by the fission track method (Smith and others, 1973).

Where well exposed, the andesite of Landavaso Reservoir forms hills with ledges and small cliffs which weather to slopes of blocky talus. Poor exposures are partially covered by pediment gravels and usually can be found only with the use of aerial photographs.

The andesite of Landavaso Reservoir is composed of a number of individual flows which are highly variable in composition and appearance. Thickness and aerial extent of the flows cannot be determined because of limited and discontinuous outcrops. Basal flow breccias are quite common. A dense, black vitrophyre with a zone of alternating dark and light bands, ranging from 1 millimeter to 2 centimeters in width, occurs on Hill "6924" in the extreme southeastern corner of the thesis area. Samples from massive portions of flows vary considerably in color. Fresh surfaces are commonly shades of reddish-gray or gray and weather light brownish-gray. Near faults, colors frequently become black or dark brown. Irregular bands of hematite staining are a common feature of most outcrops.

Microscopically, the texture of the andesite is porphyritic with phenocrysts arranged in a felty to pilotaxitic groundmass. Phenocrysts usually comprise from 15 to 40 percent of the total rock volume and consist of plagioclase, pyroxene, biotite and hornblende. Plagioclase phenocrysts occur in all thin sections of the andesite and comprise from 10 to 30 volume percent of the rock. Plagioclase is commonly euhedral and ranges in length from less than 1 millimeter to 6 millimeters. Zoning with more calcic cores is frequently observed and is quite pronounced in untwinned crystals. Alteration is present in varying degrees but a large number of the phenocrysts are fresh. Calcite and clay are typical alteration products and occupy cracks and transverse fractures through the phenocrysts. Chloritic alteration is rare. The composition of the plagioclase was measured by the Fouqué method on several unaltered crystals in each thin section. The anorthite content ranged from An_{41} to An_{54} with most occurring in the An_{47} to An_{50} range.

Pale green clinopyroxene occurs in a majority of the thin sections and is usually subordinate in amount to plagioclase. The crystals, occasionally glomeroporphyritic, vary from subhedral to euhedral and average from 1 to 1.5 millimeters in greatest dimension. Measurements of extinction angles ($z \wedge c$) range from 36 to 44 degrees with optic angles (2V) of 40 to 50 degrees. These figures are compatible with those of augite, subcalcic augite or ferroan augite (Heinrich, 1965, p. 218). Alteration products consist primarily of calcite and hematite with minor amounts of chlorite and magnetite. Light brown hornblende and vermicular celadonite (Loughlin and Koschmann, 1942) are seen in 2 thin sections (fig. 7).

Biotite occurs in fewer thin sections than pyroxene and constitutes from 2 to 5 volume percent of the rock. The laths average from 1 to 2 millimeters in length. Most crystals are intensely altered to chlorite and magnetite but fresh yellow-brown biotite, frequently with inclusions of rutile (sagenitic), is occasionally seen.

Hornblende phenocrysts are rare, occurring in only 1 thin section. The phenocrysts are euhedral and range from

Figure 7 - Photomicrograph of clinopyroxene phenocryst in the andesite of Landavaso Reservoir showing alteration to vermicular celadonite (center of crystal) (X-nicols, x80 magnification).

2 to 8 millimeters in length. All crystals are completely altered to chlorite and calcite in the core and rimmed by fine-grained magnetite. A few specks of biotite occur inside some grains.

The groundmass is composed primarily of plagioclase microlites with interstitial pyroxene and magnetite. Cryptocrystalline and glassy groundmasses occur less frequently. A fine dust of hematite is present in most thin sections.

From the petrographic data, it is possible to divide the andesite of Landavaso Reservoir into 4 different types of flows based upon the major phenocrysts: 1) plagioclase-pyroxene, 2) plagioclase-biotite, 3) plagioclase-pyroxene-biotite, and 4) plagioclase-hornblende. The series is listed in order of decreasing abundance. Because exposures are limited, it could not be determined where these flows lie in relation to one another in the thesis area.

Upper Tuffs

The upper tuffs (C.E. Chapin, oral commun., 1972) is an informal name proposed for a series of variable crystal-rich and crystal-poor ash-flow tuffs overlying the andesite of Landavaso Reservoir. These tuffs may be correlative to the Potato Canyon Rhyolite described by Deal and Rhodes (1973) which overlies the A-L Peak Formation in the northern San Mateo Mountains. However, some outcrops of upper tuffs in the Silver Hill area have noticeably less crystals than most crystal-poor tuffs of the Potato Canyon

Rhyolite. These outcrops may be equivalent to the Beartrap Canyon Formation (Deal and Rhodes, 1973) which overlies the Potato Canyon Rhyolite and fills the moat of the Mt. Withington cauldron. An exact stratigraphic correlation of the upper tuffs to either the Potato Canyon Rhyolite or the Beartrap Canyon Formation is not possible at this time owing to discontinuous exposures and ambiguous stratigraphic relationships. Andesites, similar in stratigraphic position to the andesite of Landavaso Reservoir, are overlain by lithologically variable tuffs in the Lemitar Mountains (Woodward, 1973). Woodward correlates these units with the andesite of Landavaso Reservoir and the Potato Canyon Rhyolite, respectively. Woodward also recognizes a distinctive crystal-poor tuff within the Potato Canyon Rhyolite which may be similar to the distinctive crystal-poor tuff within the upper tuffs in the Silver Hill area. Rocks similar to upper tuffs are also observed in several other localities in the Magdalena area including the Cat Mountain-Grey Hill area (Wilkinson, in preparation) and the Magdalena Mountains (Krewedl, in preparation; R.B. Blakestad, oral commun., 1973).

The upper tuffs have a minimum thickness of approximately 600 feet, as estimated from cross-section D-D' (pl. 1). However, maximum thickness may be much greater. Thickness of the Potato Canyon Rhyolite in the northern San Mateo Mountains is approximately 3280 to 5575 feet (1000 to 1700 meters) (Deal and Rhodes, 1973). The Beartrap Canyon Formation attains a thickness of 820 feet (250 meters) near the same locality (Deal and Rhodes, 1973).

The upper tuffs in the Silver Hill area have not been dated radiometrically. However, a sample from 200 feet above the base of the Potato Canyon Rhyolite in the type locality yielded a fission track date of 30.3 ± 1.6 m.y. (Smith and others, 1973).

The upper tuffs are best exposed in the southwestern part of the thesis area. They form resistant ledges and cliffs and weather to blocks bounded by joint surfaces. Dip slopes are usually comprised of small angular fragments. The tuffs vary from crystal-rich west of Arroyo Landavaso to crystal-poor east of Arroyo Landavaso where they overlie the andesite of Landavaso Reservoir. The crystal-rich varieties are light gray to light brownish-gray on fresh surfaces and weather pinkish-tan or light grayish-purple. Samples are typically densely welded and contain phenocrysts of colorless and smoky quartz, chatoyant sanidine (moonstone), plagioclase and copper-colored biotite. Sanidine is usually the most abundant phenocryst but some varieties contain as much as 15 percent quartz. The crystal-poor tuffs can be divided into a basal unit and an upper unit. The basal unit directly overlies the andesite of Landavaso Reservoir and attains a thickness of about 250 feet. Tuffs in this unit are poorly welded, grayish-white to light purple, and are characterized by abundant, botryoidal pumice. On weathered surfaces, the pumice is partially etched giving the rock a sponge-like appearance. The basal tuffs grade into moderately to densely welded, light to medium gray tuffs. Abundant andesitic lithic fragments are typical of this unit but small, compressed, botryoidal pumice also occur. The crystal-poor tuffs usually have phenocrysts of chatoyant blue sanidine, quartz, plagioclase and rare biotite.

Small outcrops of upper tuffs also occur along a north-trending fault zone from Hale Driveway Well to Hill "7048" (pl. 1). The outcrops are poorly exposed and in most instances rest on the andesite of Landavaso Reservoir. One isolated outcrop is highly silicified and is interpreted to be a fault sliver (fig. 8). Along the fault zone, both crystal-rich and crystal-poor varieties are present. Fresh hand specimens are typically light gray and weather brownish-gray. Phenocrysts are chatoyant blue sanidine, plagioclase and colorless quartz. Pumice and andesitic lithic fragments are locally abundant but are small.

Two additional outcrops of ash-flow tuffs are located at Rabbe Well near U.S. Highway 60 and 1 mile south of Rabbe Well (sec. 31, T. 2 S., R. 4 W.). These tuffs are similar in appearance and lithology to the upper tuffs exposed on the west side of Arroyo Landavaso.

An outcrop of light gray to orangish-pink air-fall tuff is present 1 mile east of Boxcar Well in the southern part of the thesis area (sec. 1, T. 3 S., R. 5 W.). The tuff is well-indurated and stratified and contains abundant andesitic fragments, and tuffaceous ash and lapilli. Phenocrysts of

Figure 8 - Silicified fault sliver of upper tuffs (Tut) (foreground) along an early Miocene fault (dashed line) which crosses hill "7048". Sliver occurs between conglomerate facies of the unit of Arroyo Montosa (Tamc; left) and La Jara Peak Andesite (Tlp; right). Uplift of a major intra-graben horst to the left (west) reversed movement on the fault and resulted in the entrapment of blocks of older rocks between younger rocks within the fault zone. Knob of andesite of Landavaso Reservoir (Tlr) on skyline is a paleohigh projecting above La Jara Peak Andesite (Tlp) to right. View is to the north.

sanidine and quartz are scarce.

In thin section, the upper tuffs are rhyolitic with a porphyritic texture and a devitrified microcrystalline groundmass. Phenocryst content varies from 6 to 35 volume percent. Sanidine is frequently the most abundant phenocryst and occurs as anhedral to euhedral crystals. Although commonly fresh, a few crystals show minor clay alteration along cleavage cracks. Quartz in some samples is more abundant than sanidine. The quartz grains are often rounded and range in size from 0.2 millimeter to 3 millimeters. Both sanidine and quartz show effects of resorbtion. Plagioclase is minor in amount but frequently fresh. Two measurements of extinction angles gave compositions of An_{35} and An_{39}. Biotite varies from absent to 3 percent of the total rock volume. Typically, it is partially or totally altered to opaques or chlorite. The groundmass is composed primarily of microcrystalline aggregates of potash feldspar and quartz. In some thin sections, spherulitic chalcedony makes up 60 to 70 percent of the groundmass. Chlorite, calcite and iron oxides are minor constituents.

Unit of Arroyo Montosa

Outcrops of interbedded volcanic rocks and conglomerates occur along the western margin of the thesis area (pl. 1). These outcrops have been tentatively designated as the unit of Arroyo Montosa. Originally, this unit was thought to be a facies of the Popotosa Formation. The two rock units are very similar at first glance but the conglomerates of the Popotosa Formation contain abundant fragments of La Jara Peak Andesite. Field work by the author and C.E. Chapin has shown that: 1) the Arroyo Montosa conglomerates lack clasts definitely recognizable as La Jara Peak Andesite, and 2) volcanic rocks interbedded in the unit of Arroyo Montosa lie with depositional contact on the eroded Hale Well pluton. These observations indicate that the unit of Arroyo Montosa is definitely younger than the monzonite pluton (approximately 28 m.y.) and predates La Jara Peak Andesite (23.8 m.y.; Chapin, 1971a). A K-Ar date of 25.2 ± 1.2 m.y. recently obtained from a sample of a latite flow in the unit of Arroyo Montosa (sec. 14, T. 2 S., R. 5 W., unsurveyed) substantiates the above observations.

In this investigation, the unit of Arroyo Montosa is divided into 2 mappable, interbedded facies: a volcanic facies and a conglomerate facies. In cross-section C-C' (pl. 1), the volcanic facies was arbitrarily chosen as the lowermost member. At the Hale Well pluton, the volcanic facies is the lowest, but to the north, the conglomerate facies rests on upper tuffs.

Volcanic Facies. The volcanic facies consists of lava flows varying from quartz latite to latite and dacite, with dacite being dominant. The total number of flows present within the unit of Arroyo Montosa cannot be determined because of limited exposures. Available outcrops indicate that at least 2 individual flows occur. Likewise, maximum thickness of individual flows is not known; a minimum thickness obtained from cross-section C-C' (pl. 1) is 100 feet, but the top of the flow is eroded.

The volcanic rocks are generally poorly exposed and form slopes and caps on small hills along the western boundary of the thesis area. Basal flow breccias are seen in some places and contain fragments derived from the underlying conglomerates. Hematite is pervasive in the southern outcrops and diminishes to the north. Color of samples varies from dark reddish-gray to light gray corresponding to the amount of hematite present. Calcite veinlets are widespread and local outcrops are slightly to moderately silicified.

On Hill "7048", numerous subangular boulders of the volcanic facies are found resting on the conglomerate facies. Some of these boulders are as large as 6 feet in length and are believed to represent the bouldery remains of former outcrop.

In hand specimen, the flows contain phenocrysts of plagioclase, smoky and colorless quartz, and sanidine. Some plagioclase crystals attain dimensions of 3.75 centimeters in length and 2 centimeters in width. The large plagioclase is a distinctive feature which makes the flows easily recognizable in the field.

In thin section, the volcanic rocks have a porphyritic texture with a microcrystalline groundmass. Phenocrysts account for 20 to 30 percent of the total volume of the rock.

Plagioclase occurs as unaltered, euhedral crystals which are frequently twinned according to albite, albite-carlsbad and pericline twin laws. Most phenocrysts have lacy edges owing to minute inclusions of glass. The anorthite composition measured by the Fouqué method ranges from An_{29} to An_{37}. Sanidine is present in amounts varying from 2 to 15 volume percent of the rock. The crystals vary from anhedral to euhedral and average from 1 to 1.5 millimeters in greatest dimension. Sanidine is commonly altered to calcite and brownish clays. Anhedral and subhedral quartz phenocrysts comprise from 1 to 3 percent of the total volume of the rock. The quartz phenocrysts are typically deeply embayed and rimmed by fine-grained aggregates of calcite and chalcedony. Highly altered biotite and amphibole occur in trace amounts in some of the flows. The groundmass consists predominantly of plagioclase laths, interstitial quartz and potash feldspar, and opaques. In some thin sections, the opaques, which are primarily magnetite, constitute 10 percent of the rock by volume. Pyroxene, calcite and secondary quartz are also present in the groundmass.

<u>Conglomerate Facies</u>. The conglomerate facies consists of pebble conglomerates of fluvial origin with thin, interbedded sandstone lenses. A total thickness of the facies and the number of individual conglomerate units is not known. On cross-section C-C' (pl. 1), the estimated thickness varies from 500 to 700 feet.

The conglomerate facies crops out as small ledges which are persistent along the base of ridges and hills. The outcrops are characterized by predominantly westward dips of 6 to 14 degrees, but a 10 degree southeastward dip is recorded near the Hale Ranch driveway (sec. 25, T. 2 S., R. 5 W.). The discrepancy is probably a result of drag from uplift of a major intra-graben fault block to the northwest (pl. 1). The conglomerates are poorly sorted, crudely stratified, and well-indurated (fig. 9). Clasts consist of felsic and andesitic volcanic rocks. Imbrication of clasts indicates a source to the southwest (J.E. Bruning, oral commun., 1973).

In hand specimen, the color of the matrix is reddish-brown on both fresh and weathered surfaces. A large majority of the clasts are subangular but vary from angular to subrounded. The clasts can be as large as 7 to 8 inches in diameter but commonly are 1 to 2 inches. Welded tuffs from the Potato Canyon Rhyolite and to a lesser extent from the A-L Peak Formation comprise most of the clasts. The remainder of the fragments are andesites from various units in the Datil volcanics. Clasts of Arroyo Montosa volcanic rocks occur throughout the conglomerate facies and are easily recognized by their large plagioclase phenocrysts. Some andesitic clasts resemble La Jara Peak Andesite but they are present in such small volume that they are believed to have originated from flows in the A-L Peak Formation which are very similar to those in the La Jara Peak. If the Arroyo Montosa conglomerates were younger than La Jara

Figure 9 - Crude stratification developed in the conglomerate facies of the unit of Arroyo Montosa. Note the abundance of felsic volcanic detritus and relative scarcity of dark-colored andesitic detritus. This is typical of the facies and distinguishes it from the fanglomerate of Dry Lake Canyon. Note pebble imbrication which indicates transport was from left (SW) to right.

Peak Andesite, the conglomerates should be crowded with La Jara Peak detritus, but this is not observed.

La Jara Peak Andesite

The last volcanic event in the Silver Hill area is represented by a thick sequence of basaltic andesite flows with thin beds of intercalated, volcaniclastic sandstone. Tonking (1957) named this unit the La Jara Peak Member of the Datil Formation after La Jara Peak, 20 miles north of Magdalena in the Puertecito quadrangle. The La Jara Peak Member was later separated from the Datil rocks by Willard (1959) and is herein considered to have formational status.

Outcrops of La Jara Peak Andesite occupy much of the central portion of the thesis area and cover approximately 6 square miles. Local outcrops occur along Council Rock Arroyo and near Arroyo Landavaso. La Jara Peak Andesite rests unconformably upon tuffs of the A-L Peak Formation, the andesite of Landavaso Reservoir, and upper tuffs. Along Council Rock Arroyo, the fanglomerate of Dry Lake Canyon, an andesitic facies of the Popotosa Formation, apparently conformably overlies La Jara Peak Andesite and was derived largely from it. In the northwestern Bear Mountains, the Popotosa Formation is interbedded in the uppermost part of the La Jara Peak Andesite (Tonking, 1957; Bruning, 1973).

Thickness of the La Jara Peak Andesite in the Silver Hill area is difficult to determine accurately. Two diamond-drill holes (Crouch and LL & E) collared in the andesite penetrate approximately 600 feet of La Jara Peak but cross numerous small faults which may have repeated the section. A minimum thickness of about 800 feet is estimated from cross-section C-C' (pl. 1). Tonking (1957) and Brown (1972) both indicate much greater maximum thicknesses in the Bear Mountains; 2500 feet and 2900 feet, respectively. It is doubtful that the La Jara Peak Andesite has a total thickness of that magnitude in the Silver Hill area.

An accurate radiometric age for the andesite is difficult to obtain because of the altered and weathered condition of most samples. However, an unusually fresh sample from the Bear Mountains yielded a date of 23.8 ± 1.2 m.y. (Chapin, 1971a) which places the unit in the lower Miocene.

Outcrops of La Jara Peak Andesite typically form rounded hills. Occasionally, as on the slopes of Silver Hill and a few of the other hills, small ledges can be seen but usually they are not continuous. In some places, individual flows can be distinguished by the presence of autobrecciated tops and bottoms. These flow breccias are usually oxidized to a reddish-brown color. Individual flows cannot be traced very far owing to talus, soil cover, and lack of ledgey outcrops. However, in 2 areas, the basal zone imparts a reddish tint to the soil which can be followed for about 150 feet. Hand specimens are medium gray to dark gray on fresh surfaces and weather to light gray or light grayish-brown. Phenocrysts of hematized pyroxene, which are particularly obvious on weathered surfaces, are characteristic of the unit. Plagioclase phenocrysts are found in some samples. Vesicules and amygdules filled with calcite and silica occur locally.

Flow direction can be determined in many outcrops that possess elongate, lineated vesicules. Flow direction is shown on the geologic map (pl. 1) as a two-directional arrow. The lineations have a wide range in trends but most indicate a direction of flow from the northwest or southeast. A few possible feeder fissures for the La Jara Peak flows are found in scattered areas. The rocks which occupy the fissures resemble dikes but are mineralogically identical to the flows and lack observable chilled margins.

In thin section, the andesites have a porphyritic texture with an aphanitic and felty to pilotaxitic groundmass; ophitic texture is rare. Phenocrysts are usually pyroxene but occasionally may be plagioclase and olivine; the groundmass consists of microlites of plagioclase and pyroxene.

The most common phenocryst is clinopyroxene which comprises from 5 to 20 percent of the total rock volume. Individual crystals vary from anhedral to euhedral and average from 1 to 2 millimeters in length. Glomeroporphyritic crystals are seen in some thin sections. Most pyroxenes are altered to calcite in the center with a rim of hematite. Fresh pyroxenes occasionally show hourglass structure, concentric zoning and have extinction angles ($z \wedge c$) of 43° to 45°. This appears consistent with a composition between diopside and hedenbergite as determined by Tonking (1957, p. 46).

In some thin sections, plagioclase phenocrysts represent from 5 to 10 volume percent of the rock. They usually occur as euhedral and subhedral crystals ranging from 0.5 to 2 millimeters in length. Some are anhedral, partly resorbed and may be xenocrysts. Varying degrees of alteration to calcite are present. Using the Fouqué method, the anorthite composition was measured on 8 phenocrysts that showed the least amount of alteration. The range is An_{45} to An_{51}.

Subhedral and euhedral olivine phenocrysts are present in 1 thin section of unusually fresh andesite and comprise 20 volume percent of the rock. Optic angles (2V) varying from 70 to 90 degrees indicate that the olivine is forsterite or ferroan forsterite (Heinrich, 1965, p. 145). The crystals average from 1 to 1.5 millimeters in diameter but some are as large as 3 millimeters. A pale green, fibrous alteration product, probably serpentine, forms borders around the phenocrysts and fills cracks through the core.

Ragged biotite crystals, 1 to 2.5 millimeters in length, occur infrequently in some thin sections. The crystals are usually unaltered and always associated with calcite. One crystal displays undulatory extinction.

The groundmass is comprised mainly of plagioclase and pyroxene microlites with abundant specks of magnetite. The microlites range in size from 0.05 to 0.1 millimeter. Calcite alteration is common with plagioclase appearing more altered than pyroxene. Cavities filled with a zeolite may comprise 15 volume percent in some thin sections. The zeolite, possibly natrolite, occurs as radiating, needle-like crystals with positive elongation and parallel extinction.

Thin layers of volcaniclastic sandstone are present locally in La Jara Peak Andesite. Outcrops are discontinuous and weather to shallow depressions. Hand samples are light gray to light reddish-gray on fresh surfaces and brownish-gray on weathered surfaces. The sandstones are composed primarily of quartz and feldspar with varying amounts of andesitic and welded tuff fragments. In thin section, quartz ranges from 15 to 40 volume percent of the rock. The grains are typically subrounded to rounded and average 1 millimeter in diameter. Plagioclase feldspar and occasionally potash feldspar comprise from 10 to 45 volume percent. Plagioclase commonly shows very little alteration whereas potash feldspar is frequently severely altered to calcite. Biotite is scarce and usually slightly altered to hematite. Opaques, primarily magnetite, are scattered throughout most thin sections. Andesite and welded tuff detritus constitute 40 volume percent of the rock in some instances. The andesite fragments closely resemble La Jara Peak flows and are typically angular to subrounded. Most welded tuff clasts are crystal-poor and some show definite flow-banding with imbricated feldspars. The sandstones generally have a cement of sparry calcite, but in some thin sections silica cement is dominant.

Popotosa Formation

The Popotosa Formation (Denny, 1940), Miocene in age, is the basal unit of the Santa Fe Group. The formation consists of fanglomerates and playa deposits with local interbedded volcanic rocks (Bruning, 1973). The sedimentary rocks of the Popotosa Formation formed in a large basin extending from the Gallinas Range on the west to beyond the Rio Grande on the east. The major source areas for detritus were the Colorado Plateau and local uplifts produced by Basin and Range deformation (Bruning, 1973). Bruning has divided the Popotosa Formation into a playa facies and a fanglomerate facies. Two lithologically unique fanglomerates are present; one of these, the andesitic fanglomerate of Dry Lake Canyon, is exposed in the Silver Hill area.

Fanglomerate of Dry Lake Canyon. The fanglomerate of Dry Lake Canyon (Brown, 1972) is the youngest well-indurated sedimentary rock present in the thesis area. The fanglomerate crops out discontinuously from Boxcar Well in the south to Allen Well in the north and is confined to the down-dropped block west of the Hells Mesa fault. Exposures of the fanglomerate occur as rounded hills typically denuded of living vegetation (fig. 10). The surface of these hills is partially covered with clasts which generally range in diameter from a few inches to 1 foot. Detritus from La Jara

Figure 10 - Vegetation contrast across fault contact (dashed line) of fanglomerate of Dry Lake Canyon (left) and the pumiceous member of the A-L Peak Formation (right). Drought-killed (?) juniper bushes mark outcrops of the fanglomerate of Dry Lake Canyon in this area. View looking north with the Bear Mountains in the background.

Peak Andesite predominate but locally, south of U.S. Highway 60, fragments which resemble the upper tuffs are more abundant. In one locality near Allen Well (sec. 36, T. 1 S., R. 5 W., unsurveyed), the fanglomerate consists primarily of clasts derived from the unit of Arroyo Montosa and the andesite of Landavaso Reservoir.

Good exposures of massive fanglomerate are seen along Council Rock Arroyo and Dry Lake Canyon. Outcrops are generally composed of poorly sorted sandstone and gravel lenses. Hand specimens contain predominantly subrounded andesite fragments as much as 10 centimeters in diameter in a light brown sandy to silty matrix. In thin section, the matrix appears to be a mixture of chalcedony, calcite and clay.

Bruning (1973) has completed a detailed report on the origin of the Popotosa Formation and discusses a source for the detritus which makes up the fanglomerate of Dry Lake Canyon. His data indicate that flow directions were mainly "to northwest, west and southwest from the now down-faulted north end of the Magdalena Range" (p. 90).

Tertiary Intrusive Rocks

Mafic Dikes

Two small andesite dikes intrude ash-flow tuffs of the A-L Peak Formation. One dike cuts the flow-banded member in the large roadcut on U.S. Highway 60 and the other dike cuts the tuff of Allen Well in Council Rock Arroyo. The roadcut dike measures 20 feet in width and is poorly exposed in length for 25 to 30 feet along the top of the ridge. The other dike is much narrower and is exposed for only a few feet along strike. A trend of N 35° W to N 40° W was measured for both dikes with a westward dip of about 75 degrees recorded for the dike in the roadcut.

A typical sample of the dike exposed in the roadcut is aphanitic and dark gray on the fresh surface. Weathered fracture faces are pale brown to pale yellowish-brown. Hand specimens of the other dike have a speckled greenish-brown appearance and were difficult to obtain due to the weathered and fractured condition of the outcrop.

Microscopically, the dikes are similar. Thin sections show phenocrysts of pyroxene and infrequent plagioclase in a pilotaxitic groundmass of plagioclase microlites. Pyroxene occurs as subhedral and euhedral crystals ranging in size from 0.25 to 1 millimeter with an average of 0.5 millimeter. Most grains are totally altered to calcite, chlorite and hematite with rims of fine-grained magnetite. Less altered crystals occasionally have relict cleavage. Phenocrysts of plagioclase represent less than 2 percent of the volume of the rock. The euhedral crystals are remarkably fresh and average 0.5 to 0.75 millimeter in length. Groundmass, which makes up 90 to 95 percent of the rock, consists of euhedral plagioclase microlites with minor amounts of biotite and fresh pyroxene. The composition of groundmass plagioclase was determined as An_{60} by the Michel-Levy method. Opaques and interstitial calcite are abundant in 1 thin section.

Monzonite

A small exposure of monzonite occurs in the vicinity of Hale Driveway Well in the southwestern portion of the thesis area; the intrusive is informally named the Hale Well pluton. The monzonite crops out over an area slightly smaller than one-sixteenth of a square mile with an outcrop configuration in the shape of a slightly elongate ellipse oriented approximately N 35° W. The monzonite usually crops out as rounded mounds composed of highly weathered angular fragments. Where intermittent streams have cut below alluvium, the intrusive forms smoothly rounded outcrops and appears less weathered. Relatively fresh hand specimens are light brownish-red and weather to light reddish-gray.

The exposed portion of the Hale Well pluton is probably a border facies of a much larger buried intrusive. This intrusive apparently has been down-faulted into the Mulligan Gulch graben, a north-south structure extending from Mulligan Gulch on the south to Abbey Springs on the north and bordering the western margin of the thesis area (see fig. 1, p. 2).

The Hale Well pluton has a conspicuous porphyritic texture. Plagioclase phenocrysts, some as large as 3 centimeters in length, occur in a matrix of much smaller crystals. The phenocrysts are euhedral and essentially fresh but incipient calcite, chlorite and clay alteration can be seen along cracks and cleavage traces. In some instances, the plagioclase is speckled with opaques and appears to be poikilitically enclosing small flakes of hornblende and biotite. Zoned crystals show a range in composition from An_{33} to An_{42}. Groundmass constituents are primarily potash feldspar, plagioclase and clinopyroxene but very minor amounts of quartz and brown biotite are also present (table 2). Opaques are small and numerous. Slender laths of apatite occur throughout the groundmass and are partially enclosed within plagioclase phenocrysts.

Two thin sections of the monzonite were previously point counted by J.E. Bruning. The results were checked by the author and are presented in table 2.

The weathered condition of the intrusive prevented collection of a sample for radiometric dating. However, exposures show the pluton intruding the gray massive member and the tuff of La Jencia Creek of the A-L Peak Formation, and the upper tuffs. A latite flow in the unit of Arroyo Montosa and nearby outcrops of La Jara Peak Andesite are unaltered. From these observations, it is concluded that the Hale Well pluton is similar in age to other intrusives in the Magdalena area which have been dated at about 28 m.y. (C.E. Chapin, oral commun., 1973).

Rocks near the Hale Well pluton are argillically altered and pyritized. The pluton is unfractured, unaltered and contains only minor amounts of hydrous minerals. These observations suggest that the pluton may not have been the

Table 2 - Modal data from the Hale Well monzonite pluton (in volume percent)

Sample number*	M-83-1	M-83-2
Phenocrysts		
Plagioclase	48.5	50.0
Matrix		
Potash feldspar	34.1	26.2
Plagioclase	2.3	6.9
Clinopyroxene	2.9	5.3
Biotite	0.1	0.5
Quartz	0.0	0.1
Opaques	12.0	10.9
Total percent	99.9	99.9

*Sample M-83-1 was counted on a 1/2 X 1-2/3 millimeter grid which yielded 1227 counts. Sample M-83-2 was counted on a 1/3 X 2 millimeter grid which yielded 868 counts.

source for solutions which created the alteration in the surrounding rocks. Hence, the wall-rock alteration may pre-date intrusion of the pluton. Effects of contact metamorphism related to the pluton may be undistinguishable from effects of this older period of alteration, although contact effects are likely to be minimal because of the similarity in composition between the pluton and the wall-rocks.

Tertiary-Quaternary Deposits

Pediment Gravels

Pediment gravels are the oldest surficial deposits mapped in the thesis area. The deposits are unconsolidated and poorly-sorted and contain volcanic detritus ranging from pebbles to cobbles in size. A caliche zone, usually somewhat indurated, caps the pediment gravels. The thickness of the zone varies from a few inches to several feet. Frequently, a layer of brownish soil covers the caliche zone. In areas where this soil layer is extensively developed, the presence of the pediment surface can be detected by caliche-covered pebbles surrounding animal burrows. Cholla and prickly pear cactus, and assorted desert grasses are the dominant forms of vegetation but juniper occasionally grows where pediment cover over bedrock is thin.

Quaternary Deposits

Talus

Owing to limited topographic relief, extensive areas of talus do not occur in the field area. Primarily, the word talus represents: 1) talus cones derived from mass-wasting of upthrown fault blocks, and 2) colluvium where stratigraphic contacts are obscured and underlying bedrock could not be identified.

Eolian Sand

Areas of windblown sand occur in the northern half of the thesis area and are related to prevailing southwesterly winds. The sand accumulations are thickest on the leeward flanks of large ridges and thin to the northeast. Windblown sand generally supports better vegetation than pediment deposits; juniper bushes and piñon pine at higher elevations occur most often. No soil layer is present and ant hills and animal burrows are less abundant than on pediment surfaces.

Alluvium

In this study, alluvium is confined to: 1) deposits of sand and gravel filling arroyos and smaller intermittent stream channels, and 2) finely divided material filling small depressions and valleys.

STRUCTURE

Regional Structure

West-central New Mexico is part of a northern extension of the Sonoran-Chihuahua fault system (Eardley, 1962) which most physiographers include in the Basin and Range province. The extension continues along the Rio Grande depression into central Colorado and separates the Colorado Plateau on the west from the Southern Rocky Mountains and Great Plains on the east. The present tectonic pattern of the area largely reflects 2 major periods of deformation: 1) Laramide (late Cretaceous to early Tertiary), and 2) middle ? and late Cenozoic.

Laramide forces produced a series of north- and northwest-trending domal uplifts separated by downwarped basins. The Magdalena area is situated on the southern flank of one of these basins, the Baca basin. Erosion of Mesozoic rocks exposed along the flanks of the basin produced clastic debris which was deposited in the center of the basin to form the Baca Formation of Eocene age. Large open folds and thrust belts are typical of the Laramide orogeny (Kelley and Wood, 1946; Tonking, 1957; Eardley, 1962; King, 1967). Eardley (1962) proposed that vertical rather than compressional forces were mainly responsible for these features. The theory involves the formation of basaltic "megasills" which elevated the overlying crust into large blisters; hence, the name "blister concept". King (1967) noted that occasionally Laramide stocks were emplaced transverse to fold axes which indicated to him that vertical forces were especially active during this time. Recently developed concepts of plate tectonics, however, suggest that Laramide deformation was compressional and resulted from southwestward driving of the North American plate away from the opening gap between North America and Europe (Coney, 1971).

Following the Laramide orogeny, much of west-central New Mexico was beveled by an erosion surface which exposed Precambrian and Paleozoic cores of Laramide uplifts (Epis and Chapin, 1973). In the Magdalena area, an early Oligocene transverse fault trending N 78° W from the latitude of North Baldy in the Magdalena Mountains to Tres Montosas downdropped the Spears Formation and older rocks 1500 to 3000 feet on the south (Krewedl, in preparation; Chapin and others, in preparation). Copious ash flow eruptions, culminating at 32 to 30 m.y., buried the trace of this fault and formed the ignimbrite plateau which caps the Datil volcanic pile in the Magdalena area. Northeast-trending faults of relatively small displacement influenced drainage during formation of the plateau and may have helped localize cauldron development. Immediately following construction of the ignimbrite plateau, the Magdalena area was broken by numerous normal faults of N 10° W trend; these faults greatly influenced post-volcanic stock intrusion dated at about 28 m.y. (Loughlin and Koschmann, 1942; Chapin and others, in preparation). The onset of basin-and-range-type faulting and related sedimentation began in early Miocene and was related to the formation of the Rio Grande rift (Chapin, 1971b). Southwestward bifurcation of the rift through the San Augustin Plains developed in late Miocene (Chapin, 1971b). The cause of rifting has been attributed to a northwestward movement of the Colorado Plateau (Eardley, 1962; Chapin, 1971b). Formation of the rift and related structures has greatly affected the structural framework of the Silver Hill area and will be discussed in greater detail in the following sections.

Seismic activity and recent fault scarps, such as the one along the eastern flank of the Magdalena range about 4 miles east of Magdalena, suggest that deformation is still continuing.

Local Structure

The Silver Hill area is a structurally complex network of intersecting, superimposed faults. Faulting occurred intermittently from middle (?) Oligocene to Recent with major periods of deformation in late Oligocene, early Miocene, and late Miocene. The late Oligocene and early Miocene periods of faulting are separated by a regional erosion surface which was subsequently covered by a thick sequence of andesite flows; thus many of the Oligocene faults are buried, and their position and trend must be inferred from cross-secions (pl. 1).

In order to present the structure in an organized fashion, faults have been grouped into 2 age periods:

Oligocene and Miocene. An overlay for each period, showing fault trends, was constructed from the geologic map and reduced to page size (figs. 11 and 12). In addition, a regional structural map showing the relationship of faults in the thesis area to those elsewhere in the Magdalena area is presented in fig. 13 (p. 76).

Oligocene Faults

Two stages of faulting are recognized in the thesis area during the Oligocene Epoch. The first stage is represented by 2 parallel northeast-trending faults which formed a graben transecting the central portion of the thesis area (fig. 11). A paleovalley was present along the graben at the time of emplacement of the tuff of La Jencia Creek and controlled the distribution of the tuff. A northeast-trending paleovalley early in deposition of the A-L Peak Formation is compatible with the location of the Mt. Withington cauldron, the probable source of the A-L Peak ash flows, and with similar-trending paleovalleys in the Lemitar Mountains (Woodward, 1973) and near Stendel Ridge (R.B. Blakestad, oral commun., 1973). Recognition that deposition of the tuff of La Jencia Creek was structurally controlled helps to explain why the gray massive and flow-banded members of the A-L Peak Formation (which lie stratigraphically below and above the tuff, respectively) usually are not differentiable outside the graben. Displacement across the bounding faults of the graben may not have been large; cross-section B-B' (pl. 1) shows an

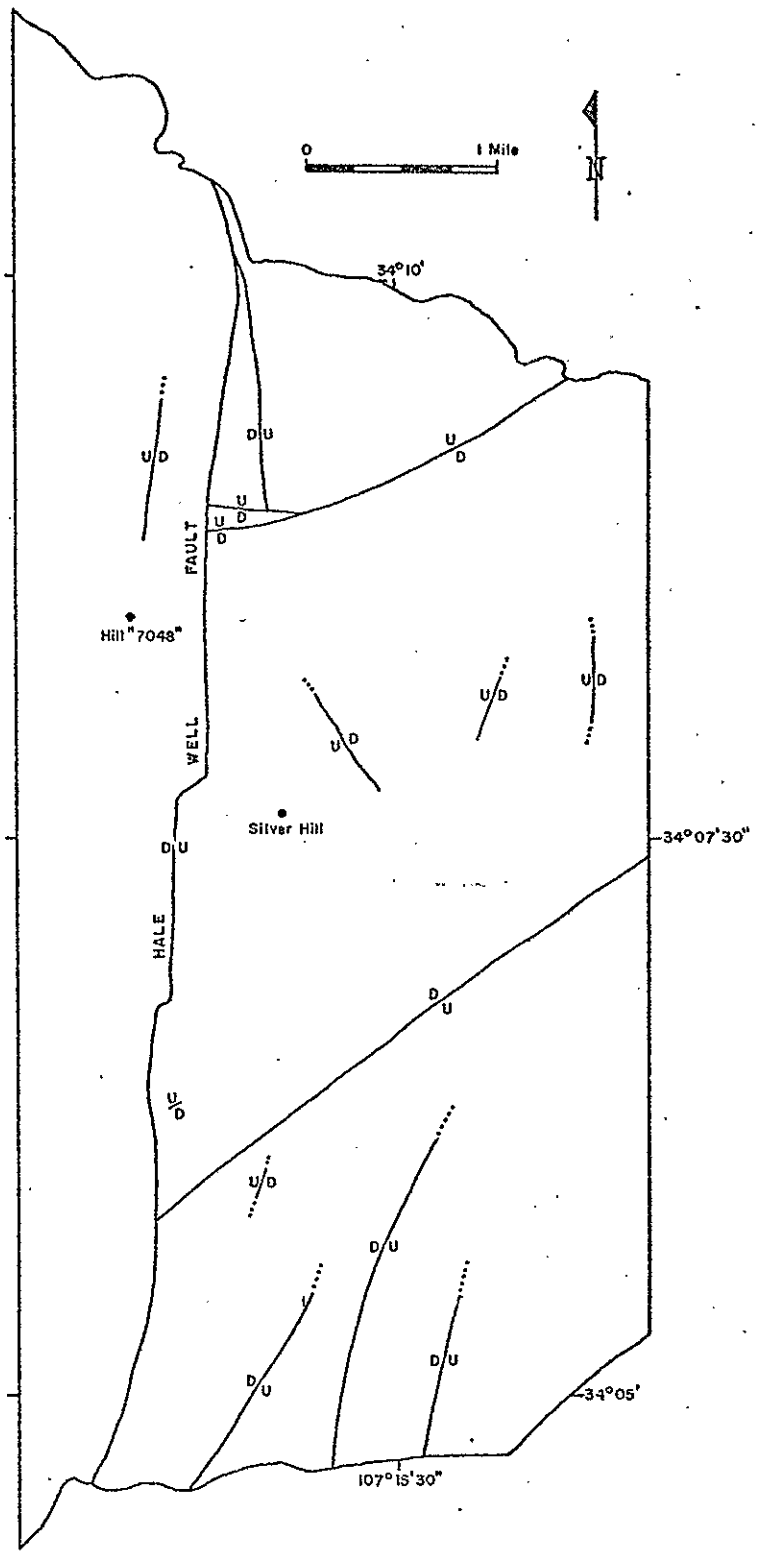


Figure 11 - Oligocene faults in the Silver Hill area. Faults are dotted when continuation is uncertain. Longitude and latitude are marked along the borders of the thesis area.

estimated vertical offset of about 100 feet on the northern fault.

A second stage of faulting occurred in late Oligocene (fig. 11). These faults trend from N 35° W to N 30° E and with 1 exception are traceable only for short distances. Half of the faults are downthrown to the west while the other half show the opposite sense of movement. The largest and most important of the down-to-the-west-type faults is the Hale Well fault (fig. 11 and pl. 1). This fault crossed the thesis area, cut the earlier northeast-trending paleovalley and formed the eastern boundary of an embryonic Mulligan Gulch graben. Movement along the Hale Well fault may have been initiated prior to deposition of the andesite of Landavaso Reservoir. Distribution of the andesite in the west-central portion of the thesis area (see pl. 1) suggests that the andesite was confined within a north-trending down-faulted area. Movement along the Hale Well fault was renewed after emplacement of the upper tuffs (cross-section D-D', pl. 1). Maximum total displacement is approximately 1000 feet (cross-sections B-B' and D-D', pl. 1). The Hale Well fault may have been instrumental in controlling emplacement of the Hale Well pluton, a monzonite body of unknown shape and size, which is partially exposed along the east side of the fault near Hale Driveway Well. North-trending, late Oligocene faults controlled emplacement of stocks in the Kelly mining district (Chapin, 1971a; Brown, 1972).

Miocene Faults

After Oligocene faulting, the Silver Hill area went through a period of relative quiescence during which erosion of uplifted fault blocks supplied detritus to form the conglomerate facies of the unit of Arroyo Montosa. Lava flows in the unit, probably of fissure origin, were erupted during deposition of the conglomerates. The unit of Arroyo Montosa probably formed in a basin-and-range-type environment similar to that present during deposition of the Popotosa Formation. This suggests that Basin and Range deformation in the Magdalena area may have begun in very early Miocene.

? source SW

The earliest Miocene fault cuts the unit of Arroyo Montosa (25.2 m.y.), but not La Jara Peak Andesite (23.8 m.y.) (fig. 12). The trace of the fault is best exposed on the south slope of Hill "7048" where the conglomerate facies of the unit of Arroyo Montosa has been downthrown and juxtaposed against the andesite of Landavaso Reservoir and the upper tuffs (pl. 1). A gray, crystalline calcite vein, approximately 8 to 10 feet wide and 30 feet long, occupies the fault zone. Calcite veins are also found within other fault zones along the Mulligan Gulch graben. Displacement along this fault may have been as much as 800 feet.

Following an initial stage of faulting, the Silver Hill area was inundated by La Jara Peak Andesite which filled the middle Oligocene, northeast-trending paleovalley after it had been exhumed during carving of the pre-La Jara

Peak erosion surface. Erosion of the flanks of the paleovalley continued during emplacement of La Jara Peak Andesite as evidenced by the presence of interbedded volcaniclastic sandstones. The sandstones are immature, containing primarily quartz, feldspar and rock fragments with occasional biotite. Hence, it appears that La Jara Peak Andesite occupied a graben with quartz- and feldspar-bearing rocks accessible to erosion along the sides.

After emplacement of La Jara Peak flows, the Silver Hill area was cut by a number of steeply dipping normal faults with irregular trends (fig. 12). In the eastern and central portions of the map area and where these faults transect La Jara Peak Andesite, quartz veins containing calcite, barite and a few metalliferous minerals occupy some of the fault zones (Lasky, 1932). Secondary movement along some of these faults is indicated by slickensides within the veins.

In the western portion of the thesis area, along the Mulligan Gulch graben, formation of a major intra-graben horst caused a reversal of movement along part of the earliest Miocene fault (fig. 12 and pl. 1). On Hill "7048", the conglomerate facies of the unit of Arroyo Montosa rests in fault contact with La Jara Peak Andesite. Fault slivers of upper tuff and andesite of Landavaso Reservoir, which were dragged up along the fault, also rest against La Jara Peak Andesite (see fig. 8, p. 43). Near Hale Driveway Well, small outcrops of the conglomerate and

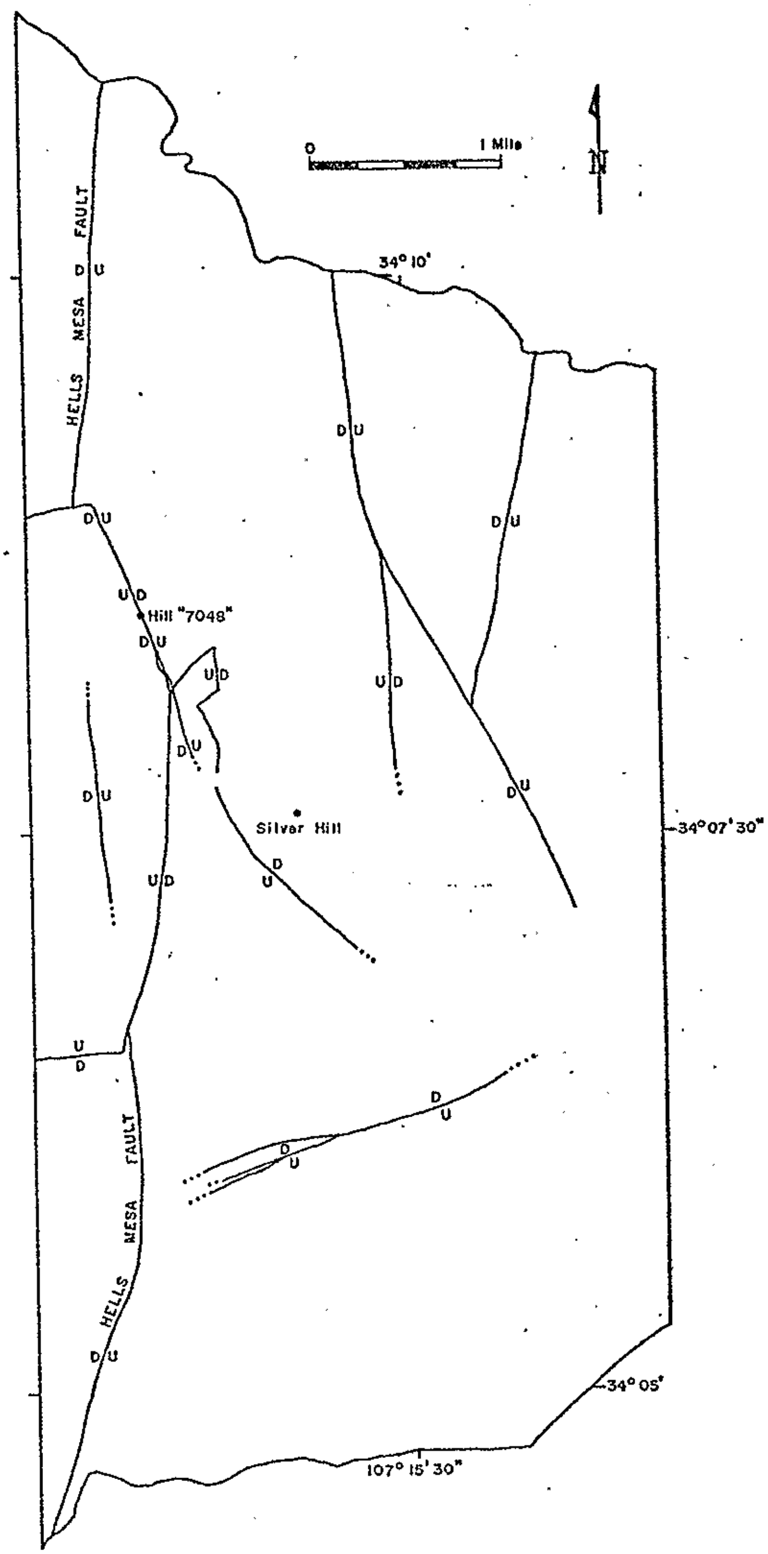


Figure 12 - Miocene faults in the Silver Hill area. Faults are dotted when continuation is uncertain. Longitude and latitude are marked along the borders of the thesis area.

volcanic facies of the unit of Arroyo Montosa disconformably overlie upper tuffs, the gray massive member of the A-L Peak Formation, and the Hale Well pluton. Apparently, the fault forming the eastern boundary of the intra-graben horst is located west of these outcrops (pl. 1). Movement along this fault may have caused a reversal of dips on the conglomerate facies of the unit of Arroyo Montosa from predominantly southwest to southeast near the Hale Ranch driveway (sec. 25, T. 2 S., R. 5 W.).

Immediately east of the central part of the intra-graben horst, a fault-bounded block, consisting of the andesite of Landavaso Reservoir and small outcrops of the upper tuffs, was uplifted and placed against La Jara Peak Andesite. This uplift probably occurred as a result of contemporaneous formation of the intra-graben horst to the west (fig. 12). This relationship cannot be seen in cross-section owing to recurrent movement along older faults.

The Hells Mesa fault (Tonking, 1957, p. 38) is a major north-south lineament along the western portion of the Silver Hill area (fig. 12). The trace of this fault continues as far north as Sierra Lucero near the northern boundary of the Puertecito quadrangle. Displacement along the Hells Mesa fault increases from 500 to 600 feet in southern portion of Puertecito quadrangle (Tonking, 1957) to about 1000 feet in the Bear Mountains (Brown, 1972). Near Arroyo Montosa in the Silver Hill area, the fanglomerate of Dry Lake Canyon is downthrown and juxtaposed against undifferentiated A-L Peak Formation; hence, vertical displacement may be as much as 1500 feet (cross-section B-B', pl. 1). The Hells Mesa fault does not transect the intra-graben horst (fig. 12). A minor fault with identical trend and movement but with a throw of only 50 feet is present instead (cross-section C-C', pl. 1). Movement along the Hells Mesa fault was apparently diverted along the bounding faults of the horst which may have been partially reactivated. South of the intra-graben horst, the Hells Mesa fault continues but the vertical offset is greatly reduced. Near Landavaso Reservoir, displacement of approximately 800 feet is indicated from cross-section D-D' (pl. 1).

Bifurcation of the Rio Grande rift along the San Augustin graben occurred in late Miocene and the north-trending structural grain of the Magdalena area was overprinted by northeast-trending normal faults which had some left-lateral movement (Chapin, 1971b; Brown, 1972). The southern bounding fault of the San Augustin rift parallels part of State Road 107 which forms the southeastern boundary of the thesis area. A subsidiary fault trending N 70° E occurs about 2 miles to the northeast along Arroyo Gato (sec. 25, T. 2 S., R. 5 W. and sec. 30, T. 2 S., R. 4 W.). This fault bifurcates into 2 smaller faults which cut the flow-banded member of the A-L Peak Formation exposed in the large roadcut on U.S. Highway 60. The intense fracturing prevalent along the roadcut may be due largely to the influence of these faults (see fig. 14, p. 81). It is not certain if left-lateral movement is associated with the roadcut faults, although an andesite dike in the south wall of the roadcut has no visible northward continuation. However, this observation can be explained with down-faulting on the north side of the roadcut if the dike pinches out upward.

Folding

A short segment of a flat-bottomed syncline (Brown, 1972) extends into the extreme northeastern corner of the thesis area from the southern Bear Mountains (cross-section B-B', pl. 1). The axis of the fold trends north-northeast and dips on the limbs vary from 10 to 15 degrees. The limbs of the syncline are poorly exposed and are truncated by La Jara Peak Andesite about 0.5 mile south of Joe Well (sec. 17, T. 2 S., R. 4 W.). No further continuation of the syncline could be located in the study area.

Information concerning the origin of the fold is limited by the poor exposures present in that part of the thesis area. Better exposures exist in the southern Bear Mountains, and therefore, the reader is referred to previous work by Brown (1972, p. 90-93).

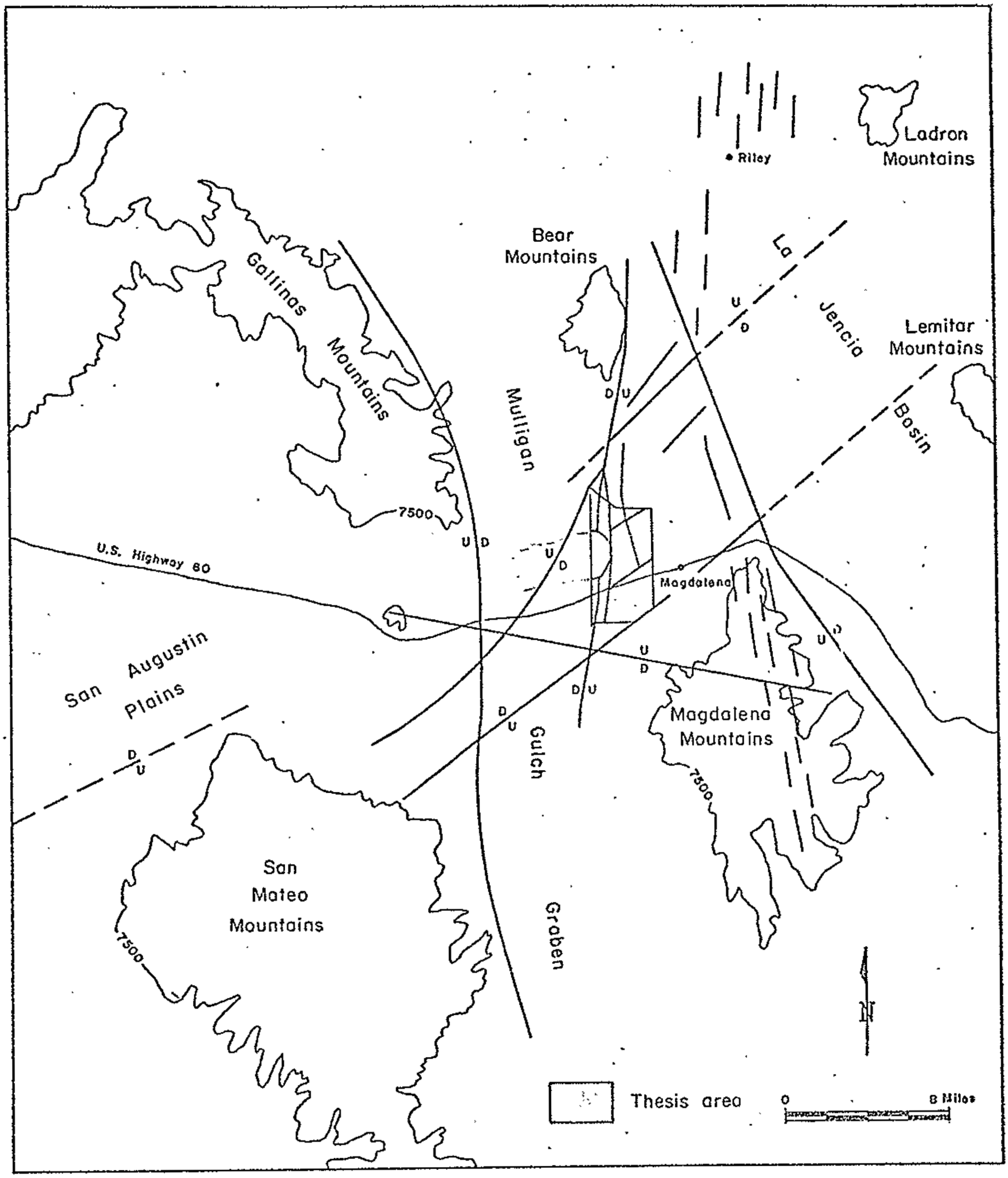


Figure 13 - Structural map of the Magdalena area showing relationship of the thesis area to major structural components (after Brown, 1972).

ECONOMIC GEOLOGY

The Magdalena-Tres Montosas area has seen some form of mining activity since about 1878. With the area's variable lithology and complex structural history, the occurrence of ore deposits is not surprising. The Kelly mining district contains the largest and most developed mines in the area and has been a major producer of zinc and lead with appreciable quantities of copper and silver. A number of other mining districts, such as the Cat Mountain district to the southwest of Magdalena and the Council Rock district to the northwest of Magdalena, occur within a 12-mile radius of the Kelly district. The Silver Hill area is approximately equidistant from these 3 districts.

Two features of the Silver Hill area warrant consideration from an economic standpoint. Areas of argillic alteration occur along portions of the western margin of the thesis area. The alteration affects all volcanic units of Oligocene age. The unit of Arroyo Montosa (25.2 m.y.) and La Jara Peak Andesite (23.8 m.y.; Chapin, 1971a) are unaltered. Hence, the age of the alteration is assigned as late Oligocene. Unrelated to the Oligocene alteration, are quartz-calcite-barite veins which cut La Jara Peak Andesite. The veins are Miocene or younger but no upper age limit can be determined from exposures in the thesis area.

Late Oligocene Alteration

Outcrops which exhibit effects of argillic alteration are stippled on the geologic map (pl. 1) and occur in 2 distinct places along the western half of the thesis area. The 2 areas are approximately 2.5 miles apart and are separated by outcrops which lack, or show very minor, hydrothermal alteration. The northern altered area extends from Allen Well south to one-quarter mile beyond Arroyo Montosa and east to La Jencia Creek. The southern altered area extends from the northern boundary of sec. 25, T. 2 S., R. 5 W., across U.S. Highway 60 and south to Boxcar Well.

The Allen Well-Arroyo Montosa area contains the most intensely altered rocks in the thesis area. The pumiceous member of the A-L Peak Formation, andesite flows, and the tuff of Allen Well show varying degrees of argillic alteration. In the pumiceous member, the typical purplish-gray color becomes bleached to almost white, feldspars become severely altered to clay and are frequently visible only as rectangular holes in thin section, and oxidized pyrite haloed by limonite is moderately abundant. Hematite staining is occasionally visible near fractures. Adjacent to quartz veinlets, the pumiceous member appears to be recrystallized and minor amounts of sericite is present locally. In the tuff of Allen Well, bleaching is not as intense as in the pumiceous member, but argillic alteration and oxidized pyrite are still prevalent. Argillic alteration and bleaching in the andesite flows is most visible near fractures which probably served as conduits for solutions.

Undifferentiated A-L Peak Formation has also been attacked by argillic alteration near Arroyo Montosa and in a group of hills bordering the arroyo to the east (secs. 1 and 12, T. 2 S., R. 5 W.). The most intensely argillized rocks exhibit the same features present in the pumiceous member near Allen Well. In general, moving northeast from Arroyo Montosa towards La Jencia Creek, the rocks of the undifferentiated unit become less bleached and their feldspars show lesser degrees of argillic alteration; limonite pseudomorphs after pyrite diminish and finally disappear.

In the Hale Driveway Well-Boxcar Well area, argillic alteration affects the gray massive member, the tuff of La Jencia Creek and the flow-banded member of the A-L Peak Formation and, to some extent, the upper tuffs. The andesite of Landavaso Reservoir seems to have largely escaped this type of alteration as the feldspars are exceedingly fresh. Instead, propylitic alteration is dominant, which, in the context of this study, is characterized by replacement of biotite and pyroxene by chlorite and calcite. In the gray massive member and tuff of La Jencia Creek, the typical gray and purplish-gray colors have been changed to yellow-brown, probably as a result of weathering of disseminated pyrite under oxidizing conditions. Minor amounts of hematite occur near fractures. In the large roadcut on U.S. Highway 60, 3.75 miles west of

Magdalena, the flow-banded member of the A-L Peak Formation and a mafic dike which cuts the member show weak to moderate degrees of argillic alteration (fig. 14). However, chloritic alteration of pumice and lithic fragments is frequently observed in the flow-banded member; hence, these rocks may be in transition from propylitic to argillic alteration. Alternatively, the argillic alteration may be superimposed on propylitized rocks by supergene processes. Oxidized pyrite is disseminated throughout both the flow-banded tuff and the dike, and hematite bands which have migrated inward from fractures in the tuff are superimposed on bleached rock (fig. 15). Near Hale Driveway Well and Boxcar Well, the upper tuffs have suffered only very weak argillic alteration. Pervasive hematization occurs locally in both of these areas and pyrite is absent.

Argillic alteration in the Silver Hill area is difficult to attribute to a single process. Undoubtedly, what is seen is an overprinting of both hypogene and supergene effects. To decipher what formed from hypogene processes and what formed from supergene processes, requires more information than is available at present. Almost certainly, the sulfur and some of the iron to make pyrite are of hypogene origin, while the bands of hematite adjacent to fractures are probably related to supergene oxidation of pyrite.

In the Hale Driveway Well area, argillic alteration is spatially related to outcrops of the Hale Well pluton. However, the absence of shattering, alteration and hydrous minerals in the exposed portion of the stock makes a genetic

Figure 14 - Roadcut on U.S. Highway 60 (3.75 miles west of Magdalena) in altered and intensely fractured flow-banded member of the A-L Peak Formation. Roadcut is near intersection of several faults and is about 1/3-mile southeast of outcrop of Hale Well pluton. Dark gray rock near vehicle is relatively fresh (see fig. 5, p. 27) compared to the bleached and hematite-stained rock to right. View is to the west.

correlation doubtful. Most of the Hale Well pluton has been down-faulted into the Mulligan Gulch graben; because the dimensions of the stock are unknown, it is possible, but not likely, that the exposed part of the stock is a "dry" border facies that escaped shattering and alteration. Near Tres Montosas, an exposed stock, some of which closely resembles the Hale Well pluton, is not spatially related to argillic alteration along the western edge of the Mulligan Gulch graben (Chapin and others, in preparation). Neither the Hale Well pluton nor the Tres Montosas stock appear to have been the source of the hydrothermal fluids which altered large volumes of rock along the edges of the Mulligan Gulch graben. The Hale Well pluton appears to post-date argillic alteration.

Supergene effects, related to either the pre-La Jara Peak erosion surface or the present erosion surface, or both, may have accounted for a large part of the argillic alteration. The abundance of oxidized pyrite in the altered rocks and association of argillic alteration with major fault zones lends credence to this hypothesis. Several features, though, point to a hypogene origin for the argillization, and more work is necessary in order to decide which process, hypogene or supergene, is dominant.

Miocene (?) Mineralization

The central portion of the thesis area is dotted with shallow prospect pits, shafts and adits. Some of the workings date back to the 1920's when the Silver Hill area was the site of small-scale mining activity. Although copper and silver ores were mined, production from the area was limited. No records concerning ore grade or tonnage could be located.

The mineralization occurs as veins which are confined primarily to outcrops of La Jara Peak Andesite; a few veins are found cutting the A-L Peak Formation. Vein mineralization was dependent upon open space created by a series of fault zones and related fracture systems probably during Basin and Range deformation in early Miocene time. In general, vein trends are northwesterly, but vary from N 70° W to N 35° E. The veins are plotted on the geologic map (pl. 1) and their orientation is shown in a rose diagram (fig. 16). Dips on the veins range from 60° to vertical. A few veins are as wide as 6 feet but usually the veins are 8 inches or less in width. Veinlets and stringers often parallel or diverge from larger veins. The veins pinch and swell both horizontally and vertically; hence, veins or vein systems are seldom traceable for long distances.

Vein material consists of a variety of gangue and ore minerals. Quartz, calcite, barite and hematite are the dominant gangue minerals, but minor amounts of goethite occur locally. The ore minerals, listed in order of approximate decreasing abundance, are chrysocolla, malachite, chalcocite, covellite, galena, sphalerite, argentite (Lasky, 1932) and vanadinite. Chrysocolla and malachite are widespread whereas the other ore minerals are observed in

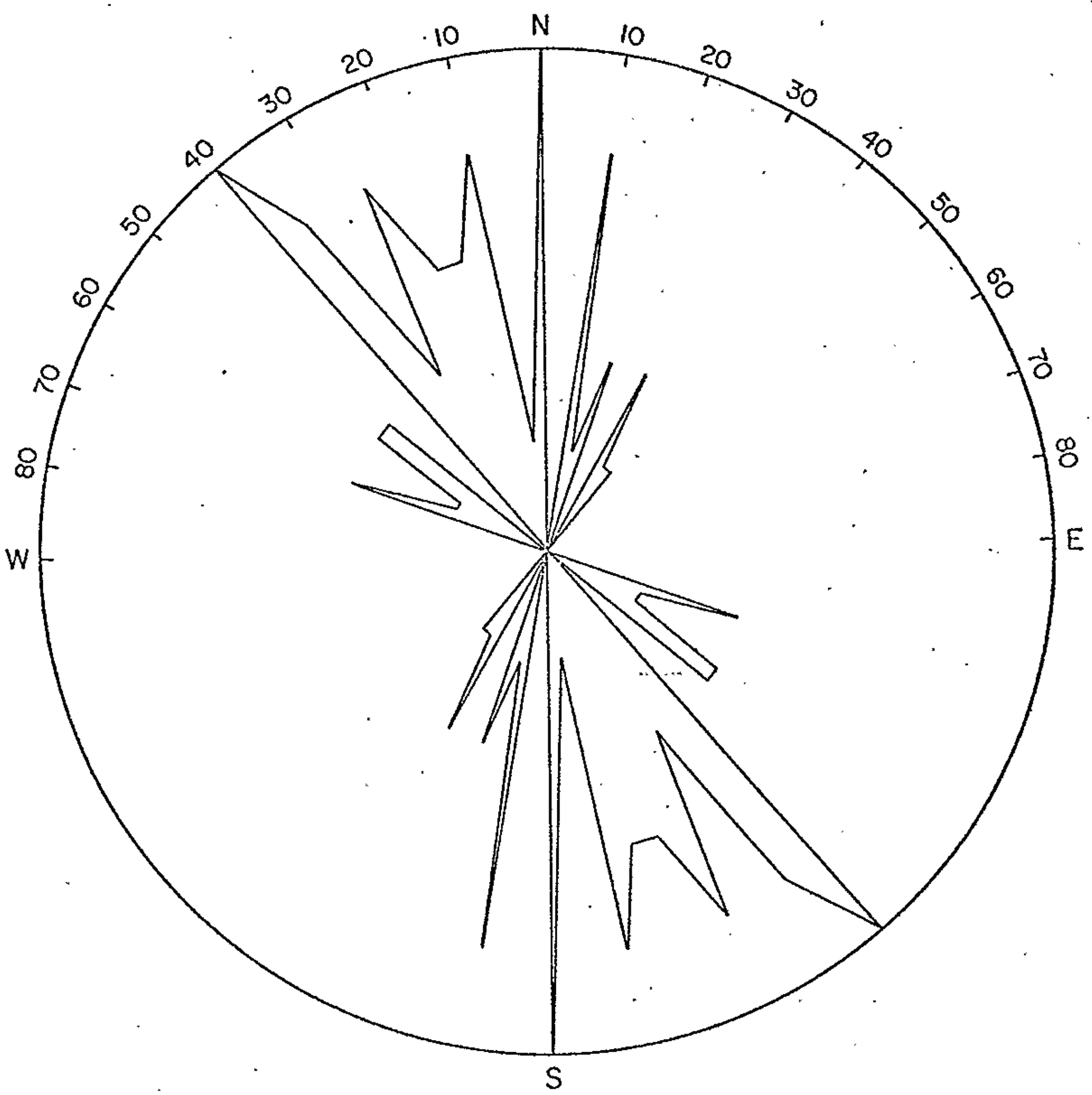


Figure 16 - Rose diagram to 50 vein trends in La Jara Peak Andesite. Trends were grouped and counted within 5 degree sectors.

only a few localities. A common vein assemblage is shown in fig. 17.

Paragenesis of Vein Minerals

In a majority of the veins, quartz is the earliest mineral formed. Calcite, both white and brown varieties, forms later, with white calcite slightly earlier than brown calcite. Initial silicification is absent in some veins; in such cases, brown calcite is usually the first mineral to form (fig. 17). Quartz, in these veins, occurs as a late-stage mineral. Barite generally forms later than either brown or white calcite, although barite does occur contemporaneously with brown calcite. Hematite appears to be later than most of the other gangue minerals and is principally associated with malachite and chrysocolla. Although massive hematite is most frequently encountered, specular hematite occurs along cavities in the andesitic country rocks in some localities. No relationship between goethite and other gangue or ore minerals could be found.

Malachite and chrysocolla are early ore minerals. Malachite may have slightly preceeded formation of chrysocolla, but usually the two minerals are intimately associated. Minor amounts of chalcocite with covellite are found rimmed by, intergrown with, and surrounding chrysocolla and malachite in a recent prospect (NE1/4 sec. 24, T. 2 S., R. 5 W.) and on a few dumps of older mines. Lasky (1932) reported the presence of "granular orthorhombic chalcocite" and associated covellite from claims owned by

Figure 17 - Boulder of vein material typical of prospects in La Jara Peak Andesite. An intimate association of chrysocolla and hematite occupies the center of the vein surrounded by coarsely crystalline, brown calcite. A small barite veinlet (left side of vein) cuts the calcite and parallels the boundary with chrysocolla and hematite. Quartz is a common gangue mineral in many veins but is not abundant here. The prospect is located in NE1/4 sec. 19, T. 2 S., R. 4 W.

the Copper Belt Silver and Copper Mining Company to the east of Silver Hill. Galena and yellow-green sphalerite may be later than the copper sulfides but are definitely later than chrysocolla. The only vein found to contain both galena and sphalerite (SW1/4 sec. 19, T. 2 S., R. 4 W.) also contains fragments of La Jara Peak Andesite cut by veinlets of chrysocolla. Occasionally, where galena and sphalerite coexist, galena is observed to form a partial perimeter around sphalerite; hence, at least some of the galena is definitely earlier than sphalerite. Color and X-ray diffraction analyses of the sphalerite show it to be an iron-poor variety. Vanadinite was noted in one locality (SE1/4NE1/4 sec. 18, T. 2 S., R. 4 W.) as euhedral crystals encrusting fracture surfaces. Argentite, which was reported by Lasky (1932), was not seen by the author.

The paragenetic sequences observed in the veins is shown in fig. 18. The diagram indicates relative position in time and is not intended to show mineral quantities.

Some interesting features arise from the paragenetic sequence. The copper minerals generally formed earlier than galena and sphalerite, with at least some malachite and chrysocolla preceeding formation of the copper sulfides, chalcocite and covellite. Hence, when copper was introduced into the system apparently no sulfur was available to combine with copper and precipitate as copper sulfides. Iron, represented in the diagram by hematite, occurs relatively early in the paragenetic sequence and may have

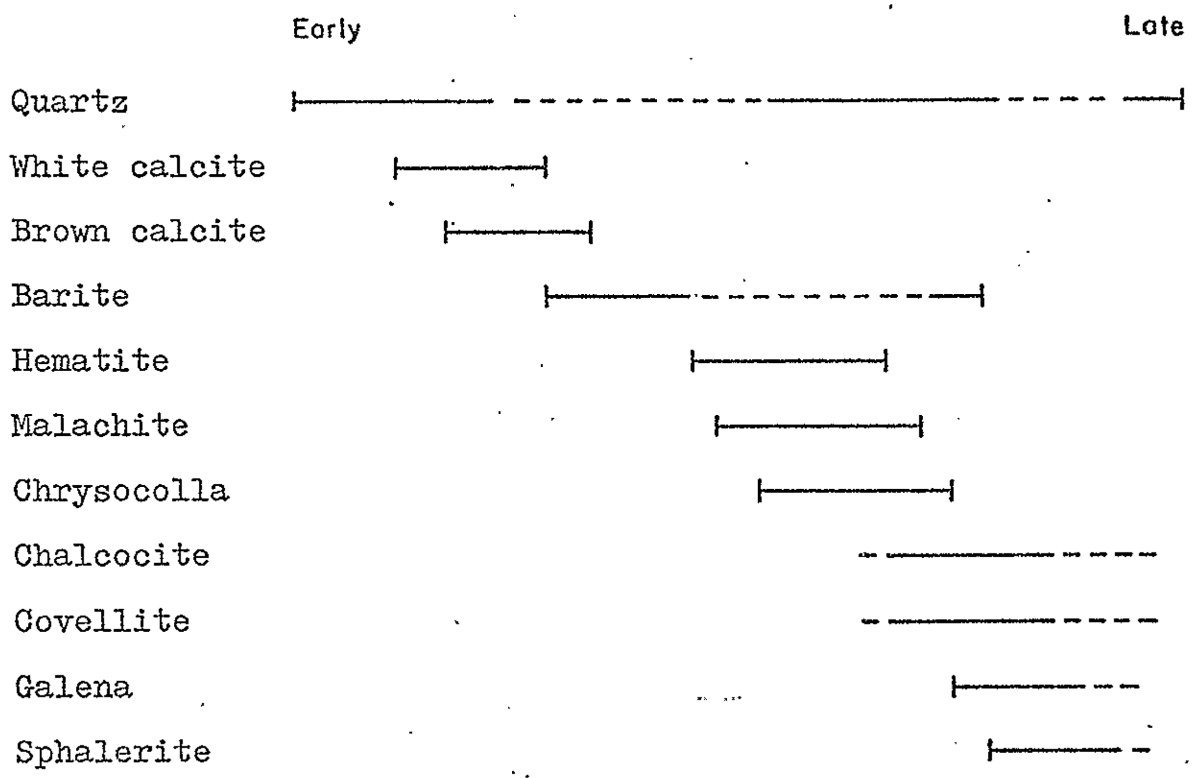


Figure 18 - Paragenetic sequence for vein minerals in the Silver Hill area. Solid lines indicate that the mineral definitely formed at that time in the sequence. Dashed lines indicate that the mineral possibly formed at that time but lack of relationships with other minerals prevents a definite determination.

been essentially depleted or absent in the later stages of mineral formation. Evidence which supports this hypothesis is based on the low iron content of sphalerite and the absence of pyrite and chalcopyrite from the sulfide assemblages.

Wall-Rock Alteration

Weak alteration commonly surrounds veins which cut La Jara Peak Andesite. In places, the alteration may be silicification, hematization, or weak argillization. Generally, in veins with quartz as the main gangue mineral, silicification is the attendant alteration. Weak argillization is also associated with these veins. In calcite-dominated veins, either very little alteration is seen or hematization is the principal altering process. Near some veins, hematite is so pervasive that phenocrysts in the andesite are not visible in hand specimen. Bleaching of wall-rock adjacent to veins is not common, although fragments of the andesite entrapped in the veins are often partially bleached. No pyrite is visible within the alteration zones or the veins; thus, the bleaching effect may be due to acidic solutions of hypogene origin.

Widths of alteration zones generally vary from 2 inches to 1 foot directly proportional to the widths of the veins. However, in areas of abundant veining, overlapping alteration zones affect large areas of rock. These large zones are generally located along major faults where the rock has been brecciated, thus permitting deep penetration of altering fluids into the wall-rock.

Discussion of Vein Mineralization

Veins in the Silver Hill area show many similarities to epithermal veins described by Lindgren (1933, p. 444-513). Lindgren relates the solutions which formed the vein material genetically to intrusive rocks, but this may not be true for veins in the Silver Hill area. Recently, Taylor (1973) has proposed that all epithermal vein deposits may have originated from heated meteoric waters, provided the deposits are: 1) located in continental-erupted volcanic rocks which have been intensely faulted, 2) near an exposed or inferred intrusive of approximately the same age as the volcanic rocks, 3) associated with intense hydrothermal alteration in the volcanic rocks, and 4) younger than or correlative in age to the volcanic rocks and the intrusive. With the exception of intense alteration of the volcanic rocks, these conditions are met by vein deposits in the thesis area. The deposits occur in highly faulted La Jara Peak Andesite, and the rhyolitic intrusive and flows at Magdalena Peak (14.3 m.y.; Weber, 1971) may have been the necessary heat source.

The Silver Hill vein deposits show similarities in mineral assemblage to a group of vein deposits associated with andesitic volcanic rocks in southern California studied by Beane (1968). Beane noted that the assemblage chrysocolla-hematite is typical of the supergene oxidation zone associated with copper-iron sulfide deposits. However, the presence of barite with the assemblage and the small quantity of early sulfide minerals suggested to him that the vein deposits may have been of hypogene origin. Some evidence suggests a hypogene origin for a chrysocolla-malachite-hematite assemblage in the Silver Hill area. Galena and sphalerite appear to be later than chrysocolla based on textural evidence. Some chalcocite and covellite appear to have formed later than chrysocolla and malachite, although in a few samples, the sulfides are earlier. Barite is common in veins which contain the assemblage chrysocolla-malachite-hematite and is usually earlier than the assemblage, but is occasionally found to be later. The fact that some sulfides are found earlier than chrysocolla and malachite may be construed as evidence for supergene origin, in addition to the observation that chrysocolla and malachite are commonly known as supergene minerals. Veins in the Silver Hill area contain such minor amounts of sulfide minerals that observable relationships to chrysocolla and malachite are scant. However, the possibility that the chrysocolla-malachite-hematite assemblage may be of hypogene origin should not be ruled out.

Economic Potential

Three aspects need to be considered in order to evaluate the economic potential of the Silver Hill area. They are: 1) base-metal replacement deposits in the Kelly Limestone, 2) vein mineralization in La Jara Peak Andesite, and 3) porphyry copper mineralization along the Mulligan

Gulch graben.

Much of the early exploration in the Silver Hill area was directed towards the possibility that the Kelly Limestone, a host for mineralization in the Kelly mining district, underlies volcanic rocks exposed in the thesis area. Present information regarding the Paleozoic and volcanic stratigraphy of the Magdalena area indicates that drilling depths to the Kelly Limestone, if it were present, would probably be at least 8200 feet but may be as much as 12000 (La Jara Peak Andesite 0-1000 ft., upper tuffs 0-600 ft., andesite of Landavaso Reservoir 0-800 ft., A-L Peak Formation 0-900 ft., Hells Mesa Formation 600 ft., Spears Formation 2000 ft., Baca? Permian rocks 3000 ft., Madera Limestone 2000 ft., Sandia Formation 600 ft.). Therefore, within the Silver Hill area, possible base-metal replacement deposits in the limestone would be uneconomic under present conditions.

Vein deposits in La Jara Peak Andesite were mined primarily for copper and silver; small amounts of gold occurred as a by-product. Geochemical analyses on vein material collected from a recent sampling showed several high values (>2%/ton) for copper, lead and zinc, with silver values about 2 ounces/ton. Analyses were not conducted for gold. These values occur erratically and large tonnages of vein material probably could not be mined economically from the deposits.

In recent years, exploration activity in the Magdalena-Tres Montosas area has been renewed in search of possible porphyry copper mineralization and related base-metal deposits. The possibility that such mineralization occurs within the Silver Hill area is extremely unlikely because, except along the western margin, the rock units are relatively unaltered and unmineralized. However, there is the possibility that a buried intrusive lies to the west of the thesis area within the Mulligan Gulch graben. Hydrothermal alteration, felsic dikes and epithermal veins containing small quantities of copper, silver, gold and lead occur along the western flank of the graben from the Cat Mountain district in the south to the Council Rock district in the north. Along the eastern flank of the graben, the alteration is more restricted and may be partially of supergene origin; pre-La Jara Peak mineralization and felsic dikes appear to be absent. Furthermore, a partially exposed monzonite pluton near Hale Driveway Well (Hale Well pluton) is unaltered and does not appear to be genetically related to hypogene alteration. Thus, exploration for possible large ore deposits should be directed towards the western flank of the Mulligan Gulch graben.

CONCLUSIONS

Investigation of the Silver Hill area has yielded several important contributions to knowledge of the geologic framework of the Magdalena-Tres Montosas area.

1) A new stratigraphic unit, named the unit of Arroyo Montosa, has been mapped along the western boundary of the thesis area. The unit is comprised of 2 facies: a volcanic facies and a conglomerate facies. Originally, the conglomerate facies was confused with similar-looking conglomerates within the Popotosa Formation. However, based on lack of La Jara Peak Andesite detritus, which is a major constituent of the Popotosa Formation, the stratigraphic position of the unit of Arroyo Montosa was deduced to be below La Jara Peak Andesite. A K-Ar date of 25.2 ± 1.2 m.y. substantiates this conclusion. The unit of Arroyo Montosa probably formed in a basin-and-range-type environment similar to that present during deposition of the Popotosa Formation. Thus, the onset of Basin and Range deformation in the Magdalena area is at least very early Miocene.

2) The tuff of La Jencia Creek is limited to a narrow, northeast-trending zone through the central portion of the thesis area. The zone is interpreted to be a fault-controlled paleovalley present prior to deposition of the tuff. Recognition of this paleovalley reinforces the existence of a northeast-trending structural grain in the Magdalena area in mid-Oligocene time. Preservation of La Jara Peak Andesite in the central part of Silver Hill area

can also be explained by the presence of the paleovalley.

3) Initial stages of formation of the Mulligan Gulch graben apparently occurred in late Oligocene with movement along the Hale Well fault. The embryonic graben undoubtedly attained greater development during Basin and Range deformation which, as suggested by the 25 m.y. date on the unit of Arroyo Montosa, may have begun in very early Miocene. Uplift of a major intra-graben horst in Miocene time modified the Mulligan Gulch graben and accounts for its apparent shallow depth west of the thesis area. The graben was further modified by the Hells Mesa fault later in the Miocene Epoch.

4) Argillic alteration along the western margin of the thesis area does not seem to be related genetically to hydrothermal fluids derived from the Hale Well pluton. Some of the argillic alteration may have resulted from acidic solutions created by supergene oxidation of pyrite. However, hypogene solutions which introduced the sulfur and possibly the iron to make pyrite probably imparted some argillization to the rocks also. Hence, the rocks may have been originally altered by hypogene solutions, and subsequently overprinted by alteration related to supergene processes.

5) The paragenetic sequence of vein minerals indicates that at least some chrysocolla and malachite formed earlier than copper sulfides and thus may be of hypogene origin. However, opposite paragenesis in a few samples supports a

supergene origin. Galena and sphalerite, though present in small quantities, are late-stage minerals.

6) The Silver Hill area is one of the less favorable parts of the Magdalena district for base-metal exploration. The Kelly Limestone, if present, lies at depths of 8200 to 12000 feet beneath the surface; hence, exploration for possible base-metal replacement deposits is not economically feasible. Epithermal vein deposits in La Jara Peak Andesite lack sufficient quantities of mineralization to be economic under present conditions. Lack of alteration away from the eastern boundary of the Mulligan Gulch graben, indicated from drill hole data and detailed geologic mapping, suggests that the Silver Hill area is not prospective ground for disseminated copper deposits.

 D.R. Simon 1973

BIBLIOGRAPHY

Beane, R.E., 1968, An investigation of the manner and time of formation of malachite: unpublished M.S. thesis, Univ. of Arizona, 82 p.

Blakestad, R.B., in preparation, Revised geology of a portion of the Kelly mining district, Socorro County, New Mexico: unpublished M.S. thesis, Univ. of Colorado.

Brown, D.M., 1972, Geology of the southern Bear Mountains, Socorro County, New Mexico: unpublished M.S. thesis, N. Mex. Inst. Min. and Tech., 110 p.

Bruning, J.E., 1973, Origin of the Popotosa Formation, northcentral Socorro County, New Mexico: unpublished Ph.D. dissertation, N. Mex. Inst. Min. and Tech., 131 p.

Chamberlin, R.M., in preparation, Geology of the Council Rock district, Socorro County, New Mexico: unpublished M.S. thesis, N. Mex. Inst. Min. and Tech.

Chapin, C.E., 1971a, K-Ar age of the La Jara Peak Andesite and its possible significance to mineral exploration in the Magdalena mining district, New Mexico: Isochron/West, no. 2, p. 43-44.

Chapin, C.E., 1971b, The Rio Grande rift, Pt. I: Modifications and additions, _in_ Guidebook of the San Luis Basin: N. Mex. Geol. Soc., 22nd Field Conf., p. 191-201.

Chapin, C.E., Brown, D.M., Chamberlin, R.M., Krewedl, D.A., and Wilkinson, W.H., in preparation, Exploration framework of the Magdalena-Tres Montosas area, Socorro County, New Mexico: N. Mex. Bur. Mines and Mineral Resources Bull.

Coney, P.J., 1971, Cordilleran tectonic transitions and motion of the North American plate: Nature, v. 233, p. 462-465.

Deal, E.G. and Rhodes, R.C., 1973, Volcano-tectonic structures in the San Mateo Mountains, Socorro County, New Mexico: Univ. of New Mexico Publ. Geol., no. ~~28~~ (in press).

Denny, C.S., 1940, Tertiary geology of the San Acacia area, New Mexico: Jour. Geology, v. 48, no. 1, p. 73-106.

Eardley, A.J., 1962, Structural geology of North America: New York, Harper and Row, 743 p.

Elston, W.E., 1972, Mid-Tertiary volcanism and tectonism in Basin and Range Province, New Mexico: test for plate tectonic models: Geol. Soc. America, Abs. with Programs (Ann. Mtgs.), v. 4, no. 7, p. 499.

Elston, W.E., Coney, P.J., and Rhodes, R.C., 1968, A progress report on the Mogollon Plateau volcanic province, southwestern New Mexico: Quart. Colorado School Mines, v. 63, no. 3, p. 261-287.

Elston, W.E., Coney, P.J., and Rhodes, R.C., 1970, Progress report on the Mogollon Plateau volcanic province, southwestern New Mexico: No. 2, in Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: N. Mex. Geol. Soc., 21st Field Conf., p. 75-86.

Elston, W.E., Damon, P.E., Coney, P.J., Rhodes, R.C., Smith, E.I., and Bikerman, M., 1973, Tertiary volcanic rocks, Mogollon-Datil Province, New Mexico and surrounding region: K-Ar dates, patterns of eruption and periods of mineralization: Univ. of New Mexico Publ. Geol., no. 38 (in press).

Epis, R.C. and Chapin, C.E., 1973, Geomorphic and tectonic implications of the post-Laramide, late Eocene erosion surface in the Southern Rocky Mountains: Geol. Soc. America, Abs. with Programs (Rocky Mountain Sec.), v. 5, no. 6, p. 479.

Heinrich, E.W., 1965, Microscopic identification of minerals: New York, McGraw-Hill Book Co., 414 p.

Herrick, C.L., 1900, Report of a geological reconnaissance in western Socorro and Valencia counties, New Mexico: Am. Geol., v. 25, no. 6, p. 331-346.

Howard, E.V., 1967, Metalliferous occurrences in New Mexico: State Resources Development Plan, Phase 1, State Planning Office, 270 p.

Johnson, J.T., 1955, A northern extension of the Magdalena mining district: unpublished M.S. thesis, N. Mex. Inst. Min. and Tech., 46 p.

Kelley, V.C. and Wood, Jr., G.H., 1946, Lucero uplift, Valencia, Socorro and Bernalillo counties, New Mexico: U.S. Geol. Survey, Oil and Gas Inv. Prelim. Map 47.

King, L.C., 1967, Morphology of the Earth: Edinburgh, Oliver and Boyd, Ltd., 726 p.

Kottlowski, F.E., Weber, R.H., and Willard, M.E., 1969, Tertiary intrusive-volcanic-mineralization episodes in the New Mexico region: Geol. Soc. America, Abs. with Programs (Ann. Mtgs.), v. 1, no. 7, p. 278-280.

Krewedl, D.A., in preparation, Geology of the central Magdalena Mountains, Socorro County, New Mexico: unpublished Ph.D. dissertation, Univ. of Arizona.

Lasky, S.G., 1932, The ore deposits of Socorro County, New Mexico: N. Mex. Bur. Mines and Mineral Resources Bull. 8, 139 p.

Lindgren, W., 1933, Mineral deposits, 4th ed.: New York, McGraw-Hill, 930 p.

Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geol. Survey Prof. Paper 68, 361 p.

Loughlin, G.F., and Koschmann, A.H., 1942, Geology and ore deposits of the Magdalena mining district, New Mexico: U.S. Geol. Survey Prof. Paper 200, 168 p.

Neale, W.G., 1926, The mines handbook, volume XVII: New York, The Mines Handbook Co., Inc., p. 1359-1360.

Siemers, W.T., in preparation, Mississippian and Pennsylvanian stratigraphy of the Magdalena area, Socorro County, New Mexico: unpublished M.S. thesis, N. Mex. Inst. Min. and Tech.

Smith, E.I., Aldrich, Jr., J.M., Deal, E.G., and Rhodes, R.C., 1973, Fission track ages of Tertiary volcanic rocks, Mogollon Plateau, southwestern New Mexico: Univ. of New Mexico Publ. Geol., no. 8 (in press).

Smith, R.L., 1960, Zones and zonal variations in welded ash flows: U.S. Geol. Survey Prof. Paper 354-F, p. 149-159.

Taylor, Jr., H.P., 1973, O^{18}/O^{16} evidence for meteoric-hydrothermal alteration and ore deposition in the Tonopah, Comstock Lode, and Goldfield mining districts, Nevada: Econ. Geology, v. 68, no. 6, p. 747-764.

Titley, S.R., 1959, Geological summary of the Magdalena mining district, Socorro County, New Mexico, _in_ Guidebook of West-Central New Mexico: N. Mex. Geol. Soc., 10th Field Conf., p. 144-148.

Titley, S.R., 1961, Genesis and control of the Linchburg orebody, Socorro County, New Mexico: Econ. Geology, v. 56, no. 4, p. 695-722.

Tonking, W.H., 1957, Geology of Puertecito quadrangle, Socorro County, New Mexico: N. Mex. Bur. Mines and Mineral Resources Bull. 41, 67 p.

Weber, R.H., 1963, Cenozoic volcanic rocks of Socorro

County, in Guidebook of the Socorro Region: N. Mex. Geol. Soc., 14th Field Conf., p. 132-143.

Weber, R.H., 1971, K/Ar ages of Tertiary igneous rocks in central and western New Mexico: Isochron/West, no. 71-1, p. 33-45.

Weber, R.H. and Bassett, W.A., 1963, K-Ar ages of Tertiary volcanic and intrusive rocks in Socorro, Catron, and Grant counties, New Mexico, in Guidebook of the Socorro Region: N. Mex. Geol. Soc., 14th Field Conf., p. 220-223.

Weed, W.H., 1920, The mines handbook and copper handbook, volume XIV: New York, The Mines Handbook Co., Inc., p. 1241.

Weed, W.H., 1922, The mines handbook, volume XV: New York, The Mines Handbook Co., Inc., p. 1396.

Wilkinson, W.H., in preparation, Geology of the Cat Mountain-Tres Montosas area, Socorro County, New Mexico: unpublished M.S. thesis, N. Mex. Inst. Min. and Tech.

Willard, M.E., 1959, Tertiary stratigraphy of northern Catron County, New Mexico, in Guidebook of West-Central New Mexico: N. Mex. Geol. Soc., 10th Field Conf., p. 92-99.

Wilpolt, R.H., MacAlpin, A.J., Bates, R.L., and Vorbe, G., 1946, Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Piños Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro counties, New Mexico: U.S. Geol. Survey, Oil and Gas Inv. Prelim. Map 61.

Winchester, D.E., 1920, Geology of Alamosa Creek Valley, Socorro County, New Mexico, with special reference to the occurrence of oil and gas: U.S. Geol. Survey Bull. 716-A, p. 1-15.

Woodward, T.M., 1973, Geology of the Lemitar Mountains, Socorro County, New Mexico: unpublished M.S. thesis, N. Mex. Inst. Min. and Tech., 73 p.

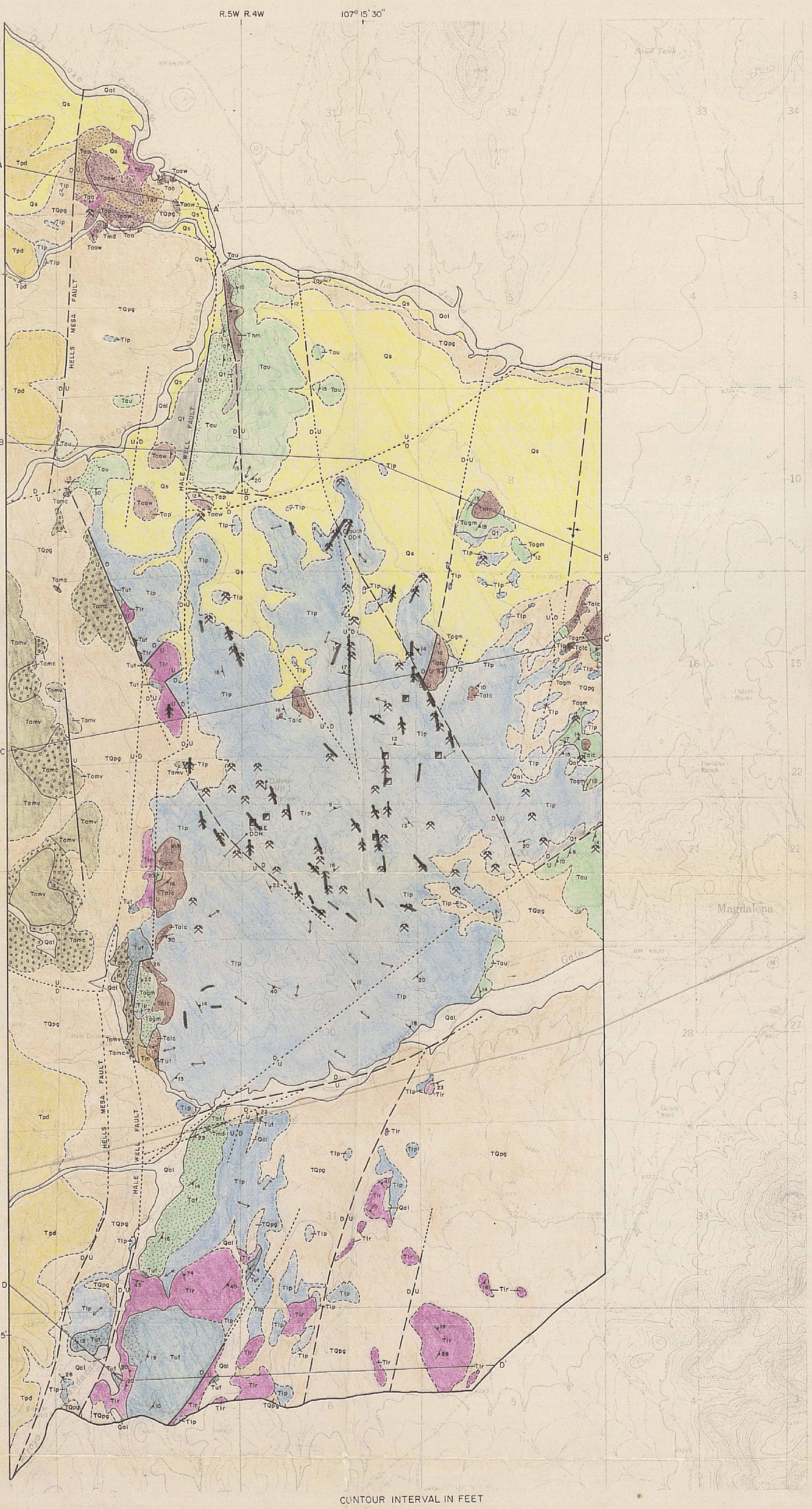
GEOLOGIC MAP AND SECTIONS OF THE SILVER HILL AREA, SOCORRO COUNTY, NEW MEXICO

by

Donald B. Simon, 1973

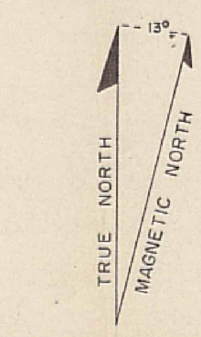
SCALE 1:24,000

1/2 0 1 Mile



CONTOUR INTERVAL IN FEET
Datum is mean sea level

LEGEND



Approximate Mean Declination, 1964

Quaternary

- Qal — Alluvium
- Qs — Eolian sand
- Qt — Talus

Tertiary-Quaternary

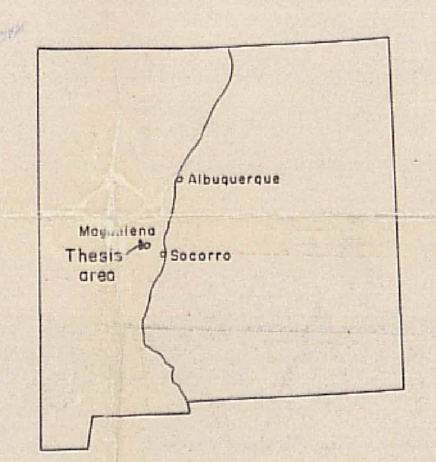
- TQpg — Pediment gravels

Tertiary

- Tpd — Popotosa Formation; fanglomerate of Dry Lake Canyon
- Tlp — La Jara Peak Andesite
- Tamv, Tamc — Unit of Arroyo Montosa; volcanic facies (Tamv), conglomerate facies (Tamc)
- Tm — Monzonite
- Tut — Upper tuffs
- Tlr — Andesite of Landavaso Reservoir
- A-L Peak Formation:
  - Taaw — Tuff of Allen Well
  - Taa — Andesite flows
  - Tap — Pumiceous member
  - Tau, Taf, Talc, Tagm — Flow-banded member (Taf), tuff of La Jencia Creek (Talc), gray massive member (Tagm), undifferentiated flow-banded member and gray massive member (Tau)
- Thm — Hells Mesa Formation
- Ts — Spears Formation (subsurface only)
- Tmd — Mafic dikes

SYMBOLS

- Contact, dashed where approximately located
- Fault, upthrown side (U), downthrown side (D), dashed where approximately located, dotted where inferred or covered
- Syncline showing trace of axial plane and plunge of axis, dotted where inferred
- Strike and dip of bedding
- Strike and dip of flow structure in volcanic rocks
- Horizontal flow structure
- Trend of lineation
- Argillic alteration of Oligocene age
- DDH — Diamond-drill hole
- Shaft
- Prospect
- Vein



Index map of New Mexico