GEOLOGY OF THE KELLY MINING DISTRICT,

SOCORRO COUNTY, NEW MEXICO

by

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Thesis directed by Professor William A. Braddock.

The Kelly mining district was one of the largest producers of zinc, lead and copper in New Mexico. Recent work on a regional basis by the New Mexico Bureau of Mines and Mineral Resources has resulted in significant additions to the knowledge of the stratigraphic and structural history of the Magdalena area. A limited mapping program was undertaken in the Kelly district to apply this new knowledge in a revision of interpretations made by earlier workers in the district.

The oldest rocks exposed in the Kelly district are Precambrian argillites, felsite, gabbro and granite. The Caloso and Kelly Formations, of Mississippian age, were deposited on the deformed older rocks. Disconformably overlying the Kelly are 600 feet of dark shale interbedded with lenticular, coarse-grained quartzites and fossiliferous limestones of the Sandia Formation. The Sandia grades upward into the thick micritic limestones of the Madera Limestone. New information indicates that the Madera in the district may have a maximum thickness of about 1800 feet. The Madera grades upward into the red siltstones and sandstones of the Abo Formation. Mesozoic strata were deposited but were subsequently eroded.

Uplift during the Laramide orogen was accompanied and followed by extensive erosion during the Eocene Epoch which resulted in a broad, gently sloping surface underlain largely by Abo Sandstone. Downfaulting along a NE-trending zone during Laramide

to Eocene time preserved a thick sequence of Permian sediments just north of the Kelly district.

Volcanism began 37-38 m.y. ago with the deposition of a thick sequence of volcaniclastic sediments, lavas and ash-flow tuffs of the Spears Formation, followed by the deposition of the Hell's Mesa Formation about 30 m.y. B.P. Cauldron collapse accompanying the eruption of the Hell's Mesa tuff was centered south of the Kelly district. Faulting along the northern side of that cauldron preserved the entire thickness of the Madera Limestone. The main part of the Kelly district is located along the margin of another large cauldron centered to the west. Collapse of this cauldron during the eruption of one or more units of the 29 m.y.-old A-L Peak Formation formed the major structural features of the Kelly district. A spectacular megabreccia, formed when subsidence caused oversteepening of the caldera walls, is exposed in the workings of the Waldo mine. A large ring dike and at least four stocks, two of which are here documented for the first time, intruded the marginal faults of the cauldron and were closely followed by a series of north-trending mafic to rhyolitic dikes. Large zinc-lead-copper orebodies were formed in limestones adjacent to faults near all of the known stocks. A thick sequence of intracaldera andesites (andesite of Landavaso Reservoir) was deposited shortly after cauldron collapse and was locally capped by the tuff of Allen Well and the Upper Tuff (26 m.y.).

Block faulting related to basin and range deformation began at least 26 m.y. ago and resulted in rapid uplift and tilting of the range.

The discovery of at least two buried stocks near known centers of mineralization and the presence of a large band of diopsidic skarn in Madera limestone bode well for the discovery of new ore deposits in the Kelly district.

This abstract is approved as to form and content.

Signed William A. Bradbook
Faculty member in charge of thesis

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TABLE OF CONTENTS

PAGE

LIST OF FIGURES

INTRODUCTION

Location and Accessibility

The Kelly mining district is located in the northern part of the Magdalena Mountains in central Socorro County, New Mexico (see plate 1). The area is about 27 road miles from Socorro via U.S. Highway 60 to Magdalena, thence southeast approximately four miles along an all-weather dirt road to the abandoned town of Kelly, which is in the center of the district. Primitive dirt roads provide good access to most parts of the area.

Purpose

The purpose of this report is to present a reinterpretation of the geology of a part of the Kelly mining district utilizing detailed stratigraphic information developed during recent geologic studies of areas outside the district and to suggest areas favorable for the discovery of new ore deposits.

Field Methods

The geology of the area of study was plotted on a topographic map of 1:12,000 scale using the Magdalena District, New Mexico special topographic map as a base. Contacts and structural features were plotted as closely as possible, given the limited accuracy of the base map. Attitudes of the various planar and linear features measured were taken with a Brunton compass. Numerous rock specimens were taken and thin sections studied to determine textural and alteration features. Petrographic work was done on a Zeiss research microscope. This study is based on approximately 120 days of field work by the author and about twenty days of co-investigation with Dr. Charles E. Chapin of the New Mexico Bureau of Mines. This project is part of a geologic survey of Socorro County undertaken by the New Mexico Bureau of Mines and directed by Dr. Chapin.

Previous Work

The geology of the Kelly mining district was first described in some detail by Gordon (1910, p. 247-248) and Lasky (1932). The most comprehensive study of the geology and ore deposits of the Kelly district was made by Loughlin and Koschmann (1942). Their descriptions of the various mines of the district cannot be equalled and the reader is referred to their work for details concerning the history and subsurface geology of the mine workings.

STRATIGRAPHY

Precambrian Rocks

Precambrian rocks are widespread in and near the Kelly mining district and comprise the bulk of the northern part of the Magdalena Range. Horsts and uplifted fault blocks form a N 10°W- to N 15°W-trending alignment of outcrops through the central part of the district (plate 1). The Precambrian rocks consist of five mappable units which are, in order of relative age: argillite and schist, early gabbro, felsite, granite, and late gabbro or diabase. These units are described briefly below, but have not been differentiated on plate 1.

Argillite and Schist

The argillite is typically light greenish-gray, fine-grained, and thin-bedded. Distinctive banding, formed by the alternation of light and dark colored layers, is visible on weathered surfaces. Small-scale cross-bedding is common. In outcrop, the bedding strikes northerly and dips steeply, in many places being nearly vertical. Small and large-scale folding is conspicuous locally. The rock is resistant and weathers to angular, blocky talus. Loughlin and Koschmann (1942, p. 8) report that the principal mineral constituents are quartz and sericite, with subordinate amounts of biotite and chlorite. Argillite is found as the major rock type in the N 10°W to N 15°W- trending band of horsts and uplifted fault blocks in the central part of the Kelly district and in a small outcrop east of Granite Mountain. Krewedl (1974) indicated that argillite is the major rock type in the north-central part of the Magdalena Range.

The schist, which was not encountered by the author in the main Kelly district, is described by Loughlin and Koschmann (1942) as micaceous, and ranging from banded siliceous rock in the northern end of the Magdalena Range to very schistose sericitic rock east of Granite Mountain. The siliceous variety is composed of quartz, chlorite and muscovite; the very schistose rock is composed of quartz and planar-oriented muscovite.

Gabbro and Diabase

Masses of gabbro are intrusive into the argillite in the Kelly district and are intruded by granite and diabase. The largest gabbroic mass is located in the horst block northeast of Kelly (plate 1); other smaller masses are scattered throughout the district. Plagioclase forms about 70 percent of the rock, and uralitic hornblende is also abundant (Loughlin and Koschmann, 1942, p. 8). Biotite, magnetite, and apatite are among the accessory minerals. The gabbro is usually more altered than the diabase, with calcic plagioclase replaced by oligoclase, magnetite and hornblende, and pyroxene replaced by hornblende, and pyroxene replaced by hornblende.

The diabase forms short dikes having a predominant westerly trend on the east slope of the range and in the horst block of Precambrian rocks east of Kelly. Other dikes of similar trend occur east of Granite Mountain, to the north of the Kelly district, and in the Hardscrabble Mine area east of Stendel Ridge.

The diabase is comprised of both fine-grained and coarse-grained varieties in dikes of varying sizes. The coarser-grained dikes are generally dark-green or greenish-gray with the finer-grained rocks usually somewhat darker. Loughlin and Koschmann (1942, p. 12) report that the dikes are almost completely altered, with chlorite and epidote being the most common alteration minerals.

Felsite

A large mass of felsite intrudes argillite east of Hardscrabble Camp (plate 1). Of this mass, only the western tip of a large wedge-shaped body has been mapped. The body extends easterly to the top of the range, where it has been truncated by Precambrian granite. To the south, it is partly intruded by the Nitt Monzonite stock of middle Tertiary age and partly overlain by Paleozoic sediments. On the north, felsite is separated from the Anchor Canyon Granite by a narrow band of argillite.

Loughlin and Koschmann interpret the felsite as intrusive into the argillite. Fresh felsite is dark, purplish-to-black, fine-grained, and porphyritic. It is light-gray to pink on the weathered surface and is distinguished from the argillite by its lack of banding and by the presence of conspicuous, rounded (often oval), phenocrysts of opalescent quartz. As plagioclase appears to be somewhat more abundant than potash feldspar, the original composition may have been latitic, but the amount of material that has been introduced or simply rearranged cannot be easily determined.

Granite

Granite is the most widespread of the Precambrian rocks in the district and forms the bulk of the basement rocks along the crest of the range. Further south and east, Krewedl (1974) has mapped argillite as the predominant rock type, intruded by a stock of Precambrian granite. The full extent of the granite east of the range crest is not known. Dikes, plugs and stock-sized masses of granite intruded argillite, gabbro and felsite, but are intruded by east-trending diabase dikes. Dikes of granite cutting argillite in the southern part of the district strike N 10°-20°W, parallel to the middle Tertiary trend of structures and dikes, perhaps reflecting an ancient structural zone which has been activated repeatedly. Fractures of northerly and northeasterly trend in the granite were filled by diabase dikes.

The granite is generally a pink-to-tan, fine- to medium-grained rock that weathers into angular blocks. It is composed of pink feldspar and colorless quartz, with variable amounts of biotite. The Precambrian granite may be distinguished from the middle Tertiary Anchor Canyon Granite in that the younger rock is fresher looking, often coarser grained, and generally contains more phenocrystic biotite.

Paleozoic Rocks

Paleozoic rocks ranging in age from Mississippian to Permian crop out boldly in the Kelly district, forming extensive dip slopes in the central part of the area and massive, ledgy outcrops in the southern half. These rocks, which have been extensively faulted, are composed of five formations: The Caloso and Kelly Formations of Mississippian age, the Sandia and Madera Formations of Pennsylvanian age, and the Abo Sandstone of Permian age.

Mississippian System

The Mississippian system in the Magdalena district ranges in thickness from 60 to 125 feet. The system may generally be divided into a lower clastic unit ranging in thickness from zero to 35 feet and a 54- to 95-foot-thick upper crystalline unit (Siemers, 1973). Although the units are described separately below, they have been mapped as one unit on Plate 1. The reader is referred to those works by Armstrong (1955, 1958) for details of the regional distribution of Mississippian rocks.

Caloso Formation

The basal unit of the Caloso Formation generally consists of about five feet of poorly sorted, angular to rounded fragments of Precambrian rocks, which range in size from coarse sand to pebbles and are cemented by calcite. Thin beds of greenish clastic material are locally conspicuous, and were probably derived in part from the underlying mafic intrusive rocks and greenstones. Overlying this basal unit is as much as 25 feet of thick-bedded, light-gray limestone with abundant quartz sand and occasional Precambrian lithic fragments. Brachiopods, corals and bryozoans are found irregularly throughout the unit (Siemers, 1973). The Caloso occupies channels or troughs on the Precambrian surface, which causes the thickness to vary considerably along strike. The channels vary in width along the crest of the range from a few feet to more than one hundred feet. Their strike has not been ascertained, but it appears to be into the northeast quadrant.

Kelly Limestone

Overlying the Caloso Formation is a thick- to thin-bedded, medium- to coarse-grained, bluish-gray, fossiliferous limestone ranging from about 55 to 95 feet in thickness. Loughlin and Koschmann (1942, p. 15) and Titley (1961, p. 700) report the presence of a persistent dark-gray to black bed of dense argillaceous limestone, called the "silver pipe," in the middle part of this unit. The "silver pipe" was used as an important marker bed because of its relation to ore deposits but it is apparently not as persistent as previously reported. Siemers (1973) could not identify such a distinctive unit in the sections of Paleozoic rocks he measured in and around the Kelly district.

The amount and diversity of the fossils in the Kelly increase upward in the section. While crinoids are by far the most abundant fossils, brachiopods, byrozoans, corals and ostracods are also present, especially in the upper parts of the section (Siemers, 1973). Some zones in the upper half of the unit are composed almost entirely of broken, well-sorted fossil debris.

The Kelly Limestone is distinguished from the limestones in the overlying Sandia and Madera Formations by its lighter color, coarser grain size, relative purity, lack of fusilinids, and the presence of light-gray to white chert that forms bands and lenses as much as one foot in thickness and fifteen feet in length.

The fossiliferous, thin-bedded nature of the upper part of the Kelly apparently rendered the unit especially favorable to alteration by hydrothermal fluids. Large areas of the Kelly have been completely silicified along the crest of the range where extensive outcrops of banded, vuggy jasperoid occur. Where the hydrothermal activity was most intense, the entire Kelly has been replaced by silicate, oxide, and sulfide minerals. Large zinc-lead orebodies with subordinate copper and silver occur almost exclusively along fault zones cutting the Kelly Limestone. The damming effect of the overlying Sandia shales may have played an important part in the formation of the ore bodies, as it appears to have done at North Baldy where the mineralized skarn occurs only at the Kelly-Sandia contact. This observation is at variance with Titley (1958), who indicated that the Sandia nowhere forms a cap over the ore bodies in the Linchburg mine and may not have had a significant effect. The argillaceous and siliceous character of the Caloso Formation was apparently more favorable for copper mineralization as copper-rich ores are found almost exclusively in this basal unit in the Linchburg mine (G. Lotspeich, pers. comm., 1973).

Pennsylvanian System

The type section for the Magdalena Group is in the Magdalena Mountains, where Gordon (1907) called the lower part of the Pennsylvanian section the Sandia Formation and the upper part the Madera Limestone. Kottlowski (1960) presented a comprehensive review of the Pennsylvanian in southwestern New Mexico and southern

Arizona. Siemers (1973) has recently studied the Paleozoic section in the Magdalena area in some detail. The reader is referred to these works for a more comprehensive treatment of the Pennsylvanian rocks.

Sandia Formation

Loughlin and Koschmann (1942) subdivided the Sandia Formation into six members, having an aggregate thickness of about 600 feet. A brief summary of their descriptions follows.

Lower quartzite member: The lower quartzite member, totalling about ninety feet in thickness, generally consists of gray, greenish-gray and brown quartzite with subordinate interbedded shale and limestone. The quartzite beds are fine- to coarse-grained and are sometimes conglomeratic, containing quartz pebbles as much as one inch in diameter. Calcareous and siliceous material cements the grains.

Lower limestone member: This unit is predominantely a fossiliferous, medium-grained, bluish-gray, argillaceous limestone with subordinate shale and quartzite. The limestones are typically nodular or lenticularly banded, forming mottled weathered surfaces. The unit is about 65 feet thick throughout most of the district. Thin, fossiliferous, shaly beds make up the majority of the lower part of the unit.

Middle quartzite member: This is a lenticular unit, having a maximum thickness of eighteen feet, that locally separates the lower limestone from the overlying shale. It generally consists of brown to gray, medium- to coarse-grained quartzite.

Shale member: The shale member is about 300 feet thick, constituting more than half of the Sandia Formation in the Magdalena area. It consists of black, locally carbonaceous, fossiliferous shale with interbedded quartzite and limestone. Limestones are generally more common toward the top of the unit.

Upper limestone member: This unit is a lenticular, bluish-gray to medium-gray limestone which is characterized by spherical, concentric algal growths as much as two inches in diameter. In the central part of the district, the upper limestone rests on shale; elsewhere it locally forms lenses in the upper quartzite. It may be as much as thirty feet thick.

Upper quartzite member: This member is a lenticular, gray quartzite containing subordinate interbedded limestone and shale. It has a maximum thickness of 65 feet in the Kelly district.

Fossil collections, taken from the Sandia by Loughlin and Koschmann and studied by Girty and White, indicate a lower Pennsylvanian age for the Sandia Formation (Loughlin and Koschmann, 1942, p. 16).

Siemers (1973), in his comprehensive study of the Paleozoic rocks in and around the Kelly district, found that the Sandia Formation varied between 550 and 600 feet thick and consisted of more than 75 percent shale and wacke with subordinate amounts of interbedded medium- to coarse-grained quartzite and dark-gray to black, fossiliferous micritic limestones. He noted that the fossil content of the limestones averaged about 32 percent, but ranged as high as 75 percent. He found that bedding varied from thin- to thick-bedded and that the limestones exhibited small-scale planar and cross-laminations while the quartzites were locally cross-bedded on a small to medium scale. Contacts between lithologies were found to be generally sharp. He identified brachiopods, echinoderms, mollusks, bryozoans, and horn corals among the faunal assemblage. He also concluded that the six-fold subdivision of the Sandia Formation by Loughlin and Koschmann (1942) was obscure almost everywhere in his study area, and was impractical for field use. He suggested that the use of the subdivisions be discontinued, and that the Sandia Formation in the Magdalena Mountains be described as a shale unit with interbedded quartzite and limestone. This writer is in accord with Siemers' conclusions and suggestions; the Sandia Formation was mapped as an undifferentiated unit in this report (plate 1). Exception to the above might be made, however, on a strictly local basis where good stratigraphic control over a small area has been established, such as in a mine or prospect.

Madera Limestone

Loughlin and Koschmann distinguished an upper and lower member in the Madera Limestone, totalling 600 feet in thickness. The lower 300 feet consists of thin-bedded bluish-black limestone with interbedded bluish-gray fossiliferous shale and gray, medium-grained quartzite. The beds are generally similar to those in the Sandia Formation, but Loughlin and Koschmann reasoned that since limestone beds are dominant and are continuous upward with greater thicknesses of limestone, the unit should be assigned to the Madera Limestone. They further believed that the upper quartzite of the Sandia Formation was a convenient horizon for placing a boundary between the Sandia Formation and the Madera Limestone, which together form a gradational sequence. Siemers (1973) generally agreed with the definition of the formational boundary; he suggested that the boundary be placed at the top of the quartzite below which shale predominates and above which limestone is the dominant lithology. This definition was used in the present study.

The "upper member" of the Madera Limestone, as defined by Loughlin and Koschmann (1942), was described to be about 300 feet of fine- to coarse-grained, homogeneous bluish-gray limestone with abundant black, nodular chert. Shaly limestones, limestone conglomerates, gray shales and gray to brown quartzites are interbedded with the thicker-bedded limestones. Prominent lenses of conglomerate composed of quartzite and limestone clasts occur at several places at the base of the upper member. These conglomerates contain pebbles of quartzite and Madera Limestone and grade into thin, fine- to medium-grained quartzite beds at their tops. Loughlin and Koschmann mapped three occurrences of conglomerate south and east of the Waldo Mine (op. cit., plate 2). Work by the writer has shown that two of these lenses are as mapped, but one of the lenses, about 2000 feet southeast of the Waldo tunnel, is an elongate mass of landslide material consisting of fragments of limestone and quartzite.

Because of faulting and erosion, Loughlin and Koschmann were unable to determine a true maximum thickness for the Madera Limestone within the district. They estimated it to be about 600 feet thick, but noted that the thickness may approach 1000 feet.

Siemers found, as did Loughlin and Koschmann, that the Sandia Formation grades into the overlying Madera Limestone. He found fossil assemblages to include brachiopods, horn corals, echinoderms, mollusks, bryozoans, and foraminifera, with large horn corals and large, dark gray to black chert nodules and lenses being most distinctive of the formation. This writer found that some of the limestones in the Madera are slightly petroliferous and give a distinctive odor when freshly broken.

Siemers (1973) reported that the maximum thickness of the Madera Limestone in his measured sections was about 800 feet, but all of these sections were bounded by faults. This writer has mapped an area of gently west-dipping Madera Limestone south of the Grand Ledge tunnel (plate 1) that is more than 600 feet thick in outcrop. More than 650 feet of gently-dipping Madera was cut in an Empire Zinc Company (now New Jersey Zinc) drill hole located west of the Connelly tunnel, in the southeast corner of the district. The top of the Madera Limestone is exposed south of this area, covered partially by landslide and talus material. The Abo Formation, of Permian age, overlies the Madera east of the latite porphyry dike in the northern part of Section 17, T3S, R4W. East of the large latite porphyry dike, the upper Madera is a sequence of interbedded green argillaceous micrites and mudstones and sandy red mudstones that are occasionally arkosic. Abundant limestone intraclasts are characteristic of these beds. Several one- to five-foot-thick, red, arkosic quartzites are present very near the top of the Madera further east of the dike, interbedded with green mudstones and micrites. The red and green mudstones and micrites form a distinctive lithologic unit, of which about 100 feet is exposed in the southern part of the Kelly district. It is probably equivalent to Kelley and Wood's (1946) Red Tanks Member of the Madera Limestone. Their Red Tanks Member grades downward into nearly 1400 feet of micritic limestones and upward into the Abo Formation. Krewedl (1974, p. 22) reports that recent drilling one mile west of North Baldy Peak, just east of the latite porphyry dike (plate 1), penetrated an apparently unfaulted section of Madera Limestone nearly 1800 feet thick. No Abo Formation was penetrated in the hole.

A maximum thickness of 1800 feet for the Madera is in accord with known thicknesses of Madera Limestone in nearby areas (Kottlowski, 1960) and should be considered as a probable maximum thickness for the Madera in the southernmost part of the Kelly district.

Should this new value for the maximum thickness be correct, there may be a deleterious effect on exploration for additional ore bodies in the Kelly Limestone outside of the main ore zone of the district, as there would be as much as 1000 feet added to the minimum drilling depths to the Kelly in areas where faulting and erosion have not reduced the thickness of the Madera.

On plate 1, the Madera is divided into upper (Pmu) and lower (Pml) units where the stratigraphic level of the limestones are known from mine workings, drilling or stratigraphic correlation. In this division, the lower Madera is considered to be the first 600 feet of massive limestones above the Sandia Formation.

Permian System

Abo Formation

Overlying the Madera Limestone in the Kelly district is the Abo Formation of Permian age. Due to faulting and erosion, the contact between the two units can be seen only in the extreme southern part of the district, east of the latite porphyry dike (plate 1). The Pennsylvanian rocks in this area are probably correlative to Kelley and Wood's (1946) Red Tanks Member of the Madera and have been described above. Although the exposures are not continuous or extensive, they have the appearance of a gradational contact between the Abo and Madera Formations and are interpreted as such by the writer. Similar gradational contacts have been described in nearby areas outside of the Kelly district (Kelley and Wood, 1946).

The Abo Formation is widespread in the Kelly district and typically consists of dark red to reddish-gray, fine- to coarse-grained, sometimes shaly, sandstone beds, generally less than one foot thick. Locally interbedded with the sandstones are lenses and thin layers of green to gray, argillaceous sandstone that apparently mark locally reducing conditions in the unit. Sandstone occasionally grades laterally into sandy shale. Small- to medium-scale, low-angle, ripple cross-stratification and thin laminations are common; ripple marks, mudcracks and rain drop impressions are locally abundant. By contrast, in the conglomeratic quartzites of the Sandia Formation, primary sedimentary structures are sparse and inconspicuous.

Where the Abo has been affected by hydrothermal fluids, such as along some dike contacts and near quartz veins, the normal reddish coloration has been changed to green, similar to the greenish lenses described above. These greenish zones often contain scattered pyrite, indicating that the original ferric iron has been reduced and mobilized to form sulfide.

Hydrothermal fluids have had significant effects on rocks of the Abo Formation in parts of the Kelly district, resulting in the misidentification of altered Abo outcrops as rocks of the Sandia Formation by Loughlin and Koschmann (1942, pl. 2). They mapped a bold outcrop of fine-grained, cross-bedded, light-reddish-gray to grayish-green, locally shaly, quartzites with an interbedded limestone at the east base of Stendel Ridge as shales of the Sandia Formation. During the remapping of this area, several comparisons of the sandstones with outcrops of Sandia shale and quartzite elsewhere in the district were made. They were found to be quite different. The Sandia shales are very fine-grained, gray to black, locally carbonaceous, fissle rocks that weather to shades of brown. Sandia quartzites are gray to brown, generally coarse-grained and exhibit few prominent sedimentary structures.

In contrast, the rocks at the base of Stendel Ridge consist of coarse silt to fine sand-sized, well-sorted, quartz sand with subordinant feldspar. Sandy shales are interbedded with and grade laterally into the sandstones. Thin micaceous selvages are locally present and bedding thickness is generally between six inches and one foot. Planar laminations and ripple cross-laminations are common. Mudcracks, ripple marks and raindrop impressions are present. The interbedded, lenticular limestone is almost fossil-free, in contrast with the fossiliferous limestones of the Sandia.

The altered rocks exposed at the base of Stendel Ridge weather to a reddish-gray to grayish-green color, contrasting with the browns and grays of the Sandia. Drill holes put down by American Smelting and Refining Company (ASARCO) along the east base of the ridge cut more than 350 feet of apparently unfaulted, altered, interbedded sandy shales, quartzites, limy shales and thin limestones that are interpreted by this writer as being equivalent to the lower portion of the Abo Formation. It is concluded that the outcrops in the Stendel Ridge area, originally mapped as Sandia shales by Loughlin and Koschmann, are the Abo Sandstone of Permian age. Additional work has revealed several inconspicuous outcrops of Abo sandstone, dipping steeply to the west and surrounded by alluvium, in Hardscrabble Valley, east and south of Hardscrabble Camp (plate 1). A small block of rocks similar to those transitional between the Madera and Abo is found in the gulch just south of the Vindicator shaft.

Loughlin and Koschmann (1942) mapped a steeply-dipping sequence of altered limestones, shales, and quartzites north of Highway 60 and east of Granite Mountain as being a relatively normal section of Paleozoic rocks ranging from Kelly Limestone on the east to Madera Limestone on the west. The thickness of the Sandia as mapped by them is about 2400 feet, which they acknowledged as being anomalously thick, but apparently considered possible under their interpretation of a near-shore environment for the Sandia.

Work by Siemers (1973), aided in the field by this writer, has established that this sequence is not a Kelly-Sandia-Madera complex, as interpreted by Loughlin and Koschmann, but is instead approximately 1300 feet of Madera Limestone, 690 feet of Abo Sandstone, 525 feet of Yeso Formation, 135 feet of Glorieta Sandstone, and 660 feet of dolomitic limestone of the San Andres Formation. All units above the Madera Limestone are Permian in age.

The correct identification of these units in the Granite Mountain-Stendel Ridge area has significant implications with regards to the structural history of the Magdalena area which will be discussed under the structural section of this paper.

The maximum thickness of the Abo was believed by Loughlin and Koschmann (1942, p. 21) to be about 175 feet, but more recent studies indicate that the thickness may approach 700 feet as a maximum, especially in areas outside of the main mining district. As a result, the drilling depths to the Kelly Limestone may be further increased in some areas.

Tertiary Rocks

Volcanic rocks ranging in age from 37 m.y. to about 26 m.y. form a large part of the outcrops in the Kelly district. Most rocks so far distinguished can be related to one or more of several of the volcanic features identified in the region surrounding the area of this study. Definite sources have not yet been identified for the rocks of the Spears Formation, but calderas formed during the eruptions of all of the ash-flow tuffs older than the Spears have been recently recognized. Studies are currently underway to further the understanding about these large calderas under the direction of the New Mexico Bureau of Mines and Mineral Resources.

Because of their lack of knowledge of the regional geology and the detailed stratigraphy of the Datil volcanic rocks. Loughlin and Koschmann (1942) had some errors in their interpretations of the rocks and, therefore, structure in the Kelly district. Additional complications were made by the effects of hydrothermal fluids on some of the rocks. Figure 1 is a chart correlating the stratigraphy as it is presently understood with the rock units identified by Loughlin and Koschmann (1942) and Tonking (1957). This correlation is only partially complete; new studies now underway will doubtless make changes in the chart of figure 1 necessary.

Spears Formation

The Spears Formation may be divided into two members: a lower sedimentary unit of conglomerates and sandstones composed of latitic and andesitic volcanic debris, and an upper unit of interbedded volcanic and sedimentary rocks. The volcanic rocks consist of latite and andesite flows, tuffs and breccias, separated locally from the lower member by a pink to white, crystal-poor, poorly to densely-welded latite ash-flow tuff known as the tuff of Nipple Mountain (Brown, 1972). A latitic boulder near the base of the Spears has been dated at 37.1 m.y. (Weber, 1971). (in Jayita Hills)

Rocks of the Spears Formation crop out in two main areas of the Kelly district: the Stendel Ridge area and south of Chihuahua Gulch (plate 1). In the Stendel Ridge area, a nearly complete section of Spears forms a large, steeply-dipping rood pendant in

Figure 1. Correlation chart of the Cenozoic Formations of the Magdalena area.

	PUERTOCITO QUADRANGLE (Tonking, 1957)	COMPOSITE OF THE MAGDALENA AREA (Chapin and others, 1977)		KELLY DISTRICT (Loughlin and Koschmann, 1942) North / South
	Quaternary Alluvium Pediment Gravels	Talus, Alluvium, Blow sand, Basalt of Council Rock Pediment Gravels		Quaternary Alluvium
		Santa Fe Group	Upper Bolson Fill — Rhyolite of Magdalena Peak	
		Santa Fe Group	Popotosa Formation — Fanglomerate and playa deposits / Fanglomerate of Dry Lake Canyon	
Datil Formation*	La Jara Peak Member	La Jara Peak Andesite		Red andesite
		REGIONAL UNCONFORMITY		
Datil Formation*		"Upper tuffs" and volcaniclastic sediments Tuffs of Gray Hill and South Canyon (in part the Potato Canyon Formation of Deal and Rhodes, 1976)		Rhyolite porphyry Pink rhyolite
Datil Formation*		Andesite of Landavaso Reservoir		Upper andesite Red rhyolite
Datil Formation*	Hell's Mesa Member	Lomitar Tuff (also Tuff of Allen Well)		Pink rhyolite Rhyolite Porphyry
Datil Formation*	Hell's Mesa Member	A-L Peak Tuff	Andesite flows Pinnacles Member Andesite flows Flow-banded Member Gray Massive Member Andesite flows	Red andesite Banded rhyolite Red andesite Banded rhyolite Pink rhyolite Red andesite
Datil Formation*	Hell's Mesa Member	Hell's Mesa Formation		Rhyolite Porphyry Sill
Datil Formation*	Spears Member	Spears Formation	Upper member Tuff of Nipple Mountain Lower member	Upper latite White felsite Lower andesite Lower latite — Purple andesite
		REGIONAL UNCONFORMITY		
	Baca Formation (Eocene)	Permian rocks, Madera Formation (Penn.) or Sandia Formation (Penn.)		Abo Formation (Perm.), Madera or Sandia Formations (Penn.)

* Recommend abandonment of term "Datil Formation"

the Nitt Monzonite. South of Chihuahua Gulch, relatively fresh Spears forms a large, gently-dipping, wedge-shaped block between the major range-bounding fault of the Magdalena Range on the west and the main ore zone of the Kelly mining district on the east. Spears rocks also occur as narrow fault slivers adjacent to the main range-bounding fault west and south of the Waldo tunnel (plate 1).

The total thickness of the Spears varies locally. Tonking (1957, p. 27) gives a thickness of almost 1350 feet at the type section at Hell's Mesa, approximately ten miles north of the Magdalena district. Brown (1972) estimates a thickness of approximately 1950 feet in his study area, about five miles north of the area of this report. The Spears in the northern part of the Magdalena district is estimated from cross sections to be approximately 1700 feet thick, and the incomplete section at the south end of the district, composed predominately of volcaniclastic sedimentary rocks and mudflow deposits, is estimated to have a thickness of about 1800 feet.

The lower Spears is composed almost entirely of purplish pebble to cobble conglomerates and thin, fine-grained, often cross-bedded, sandstones. The clasts are of latites and andesites, distinguished by their abundant small, white feldspar crystals and lack of quartz. Individual sandstone beds are rarely more than one foot thick; conglomerate beds and mud-flow deposits vary greatly in thickness. Some of the finer grained beds have a shaly character. Small fluvial channels are distinguished by thin magnetite-rich layers at their base.

These conglomerates and sandstones grade upward into coarser conglomeratic rocks which contain sub-rounded to rounded clasts ranging in size from less than one inch to greater than one foot in diameter. The size of the clasts has a tendency to increase with distance from the base, with coarse-grained conglomerates and laharic breccias predominating in the middle portions of the formation. Tonking (1957) interpreted these deposits as representing deposition on alluvial fans, which may serve to explain the lateral and vertical variability of the Spears in the Magdalena area.

Approximately 800 to 900 feet above the base of the Spears in the Kelly district is a pink to white, moderately welded, crystal-poor ash-flow tuff designated the tuff of Nipple Mountain by Brown (1972). This conspicuous unit fills paleochannels cut in the Spears and, while widespread, is often discontinuous in outcrop. Propylitic alteration has bleached the pink tuff to white or dull green in some areas. A conspicuous "turkey track" andesite beneath the tuff of Nipple Mountain, reported by Brown (1972) in his study of the southern Bear Mountains, was observed stratigraphically below the southernmost exposure of the tuff in the Kelly district, southeast of South Camp (plate 1).

The tuff of Nipple Mountain provides a convenient marker that may be used to separate the predominately epiclastic lower Spears from the mixed volcanic and sedimentary upper Spears. In the Stendel Ridge area (plate 1), the upper Spears consists of laharic breccias and volcaniclastic conglomerates and sandstones that are interbedded with andesitic flow rocks and latitic ash-flow tuffs. The uppermost Spears in the Stendel Ridge area is a latite ash-flow tuff which grades imperceptibly into the overlying quartz latite of the Hell's Mesa Formation. A distinctive hematite-stained conglomerate that occupies channels cut into the top of the Spears section in the southern Bear Mountains (Brown, 1972) and in the Granite Mountain area (Chapin, oral commun., 1974) is missing in the Kelly district; here the Spears-Hell's Mesa boundary is considered to be the first appearance of abundant quartz phenocrysts in the latitic ash-flow tuffs.

Although incomplete due to faulting, the Spears in the southern part of the district is similar to that at Stendel Ridge. Because of the gradational nature of the Spears and the channel-type occurrence of the tuff of Nipple Mountain, the contact between the upper and lower Spears is nebulous in some areas and is only approximately located on the geologic map (plate 1).

The petrography of the Spears has been discussed in some detail by Brown (1972) and Tonking (1957) and is described briefly below.

The lower Spears is a well-indurated unit containing rounded latitic to andesitic clasts ranging in color from purple to gray-green. The hand specimens have a porphyritic appearance due to varying percentages of feldspar, hornblende, and biotite. The clasts are similar to the upper Spears latite flow rocks, as most of the clasts are porphyritic with abundant trachytically-aligned feldspar and hornblende in a cryptocrystalline groundmass. Mineralogically the clasts are fairly uniform, consisting of plagioclase, sanidine, hornblende, and biotite, with the percentages of these major consituents varying with individual clasts.

The latitic ash-flow tuffs near the top of the Spears are generally light purplish-gray to reddish brown. Welding is poor to moderate and the hand specimens are characterized by chalky feldspar, bronze-hued biotite and dark andesitic lithic fragments. Alteration may cause a color change to greenish hues and make the boundary between the matrix and the lithics less distinct. These tuffs have been informally termed the tuff of Granite Mountain (Chapin, pers. commun., 1976).

In the Kelly district, the Spears rests disconformably or with slight angularity on the Abo Formation of Permian age. The basal five to ten feet of the Spears is commonly rich in angular to subrounded clasts derived from the underlying rocks. In the Stendel Ridge area, the contact between the Spears and the Abo is a conglomerate made up of angular, somewhat platy fragments of Abo sandstone generally less than three inches in length in a matrix of volcaniclastic material. Measurement of imbrication directions indicate a source to the west or southwest. The lowermost Spears elsewhere in the district generally contains less reworked Abo, but nonetheless contains between five and ten percent of fragments of older rocks, including some pieces of Madera-type limestone. The relative abundance of fragments of the Paleozoic rocks decreases rapidly upwards in the Spears; they are rarely seen more than twenty or twenty-five feet above the base. Tonking (1957, p. 29) describes a section of Spears in T1N, R6W, where the basal contact has many fragments of older rocks, some as much as twenty feet in length.

Hydrothermal alteration has significantly affected the rocks in the northern part of the district. Propylitization has changed the normally red and purple andesites and latites of the Spears to various shades of green and gray. In the Stendel Ridge area, alteration reactions have replaced hornblende with chlorite, calcite, quartz and iron oxides. Secondary quartz occurs as small aggregates, thin veinlets, and individual grains. Calcite occurs as irregular masses replacing the matrix material, as replacements of crystal fragments, and in veinlets. Sericite commonly replaces feldspar and matrix, and epidote occurs as replacements of crystal fragments, matrix and as numerous blebs. Hematite and magnetite are commonly found in the matrix and as replacements of ferro-magnesian minerals. Pyrite is locally abundant, particularly in the more intensely altered areas near faults and fracture zones. The contact between the Spears and the Abo along the east side of Stendel Ridge (plate 1) was apparently very permeable, as the volcanic matrix has been almost completely replaced by epidote and silica. The result is a distinctive outcrop of reddish quartzite fragments in a mottled, bright-green matrix.

The hydrothermal alteration has had two significant effects: (1) it has changed the normal reds and purples of the Spears to greens and grays, and (2) it has caused the rocks to appear somewhat different in hand specimen and thin section, mostly due to the addition of minor amounts of quartz and the alteration of hornblende and biotite to chlorite and epidote. It was these changes, along with the lateral and vertical variability, that apparently caused Loughlin and Koschmann (1942) to treat the Spears in an inconsistent and confusing manner. They distinguished five different units, based on outcrop color and petrography, that were "derived from at least two centers of eruption", (op. cit., p. 23). North of Highway 60, they subdivided the Spears into four different units: the "lower latite tuff", "lower andesite", "upper latite tuff", and "upper latite breccia". In the Stendel Ridge area, they lumped all the Spears into an "upper latite" and "upper latite flow", while in the southern part of the district they mapped only a "purple andesite".

Careful studies by Tonking (1957), Brown (1972), and Chapin (1974) have established the volcanic stratigraphy in the Magdalena area. It is from their work and this study that correlation of Loughlin and Koschmann's units can be made with the Spears Formation. Loughlin and Koschmann's "lower latite tuff," "lower andesite" and "purple andesite" correspond to the lower epiclastic and middle epiclastic-volcanic parts of the Spears, respectively. Their "upper latite", and "upper latite flow" and "upper latite breccia" in the Granite Mountain area are correlated with the upper volcanic member of the Spears (see fig. 1).

Loughlin and Koschmann's (1942) "white felsite tuff", which they interpreted as being the youngest extrusive rock in the district, corresponds to Brown's (1972) tuff of Nipple Mountain, which is near the middle of the Spears and thus one of the oldest volcanic rocks in the district.

Hell's Mesa Formation

Conformably overlying the Spears Formation in the Magdalena district are the quartz latite to rhyolite ash-flow tuffs of the Hell's Mesa Formation. Tonking (1957, p. 30) named the formation for a prominent hill of that name on the east edge of the Bear Mountains, where he measured a type section and assigned the unit to the Datil Formation. The Datil Formation was subsequently raised to Group status by Weber (1971, p. 35) and the Hell's Mesa to formational rank by Chapin (1971, p. 43) Brown (1972) subdivided the Hell's Mesa Formation into several units, including the tuff of Goat Springs, the tuff of Bear Springs, several andesite flows and the tuff of Allen Well. In later studies (e.g. Deal, 1973; Simon, 1973; Chamberlin, 1974; Spradlin, 1974, and Lopez, 1975) including this one, the name Hell's Mesa is restricted to the basal crystal-rich, quartz-rich, multiple-flow, simple cooling unit of Tonking's (1957) type section which correlates to Brown's (1972) tuff of Goat Springs and, in part, to Loughlin and Koschmann's (1942) "rhyolite porphyry sill." The overlying ash-flow tuffs and interbedded andesites and sedimentary rocks have been designated the A-L Peak Rhyolite by Deal (1973). This usage has been followed by subsequent workers except that they may prefer the term A-L Peak Formation or Tuff because of the heterogeneous composition of the unit.

Three K-Ar dates on samples of the Hell's Mesa vary from 30.6 $\pm$ 1.2 m.y. (Weber, 1971) to 32.4 $\pm$ 1.5 m.y. (Burke and others, 1963) and average about 31.5 m.y.

The Hell's Mesa Formation is one of the most widespread units of the Datil volcanics. It is known to occur extensively north of Magdalena in the Bear Mountains, to the east in the Lemitar Mountains and east of the Rio Grande, and in the central Magdalena Mountains.

Gordon (1910) identified outcrops of the Hell's Mesa as granite porphyry. Loughlin and Koschmann (1942, p. 33) called it a rhyolite porphyry sill and stated that it has the widest distribution of the Tertiary (?) formations in the district. They noted that it occurred over wide areas north and east of the Kelly district and interpreted the formation as a sill based on mineralogy, texture, and the belief that it was slightly discordant to the dips of the enclosing rocks. Titley (1959) accepted their interpretation in his summary of the geologic features of the district.

Extensive field and petrographic work by Brown (1972) has established with certainty the effusive character of the Hell's Mesa, and the reader is referred to his work and that of Tonking (1957) for details.

The Hell's Mesa Formation, which has been altered by hydrothermal fluids everywhere in the Magdalena district, weathers light tan to reddish-buff and forms rugged outcrops with blocky talus. The unit is moderately to densely welded and contains approximately 45 to 55 percent crystals and crystal fragments. Sanidine, plagioclase, quartz and biotite are the major phenocrysts. Quartz is often in distinctive "eyes" measuring as much as six millimeters in diameter. The base of the unit is often lithic-rich; pumice is not generally conspicuous, although it is plainly visible in some outcrops. Propylitic alteration has affected the Hell's Mesa in all exposures. Epidote, calcite, chlorite and sericite are present as alteration products in varying amounts. Many outcrops are speckled with limonite psuedomorphs after pyrite. Hell's Mesa rocks in the fault sliver between the main part of Stendel Ridge and the low hills to the northwest are intensely altered to a clay-quartz-sericite assemblage which may be the result of supergene alteration of originally pyritized sericitic rocks. Iron oxide after pyrite is much more common in this area.

Within the Kelly district, rocks of the Hell's Mesa Formation have been positively identified only north of Chihuahua Gulch and south of North Baldy Peak. Hell's Mesa caps "7610" hill at the head of Hardscrabble Valley (plate 1) and covers the upper parts of the southwest side of Stendel Ridge, where the gradational contact with the underlying ash-flow tuffs of the upper Spears Formation may be observed. Many xenoliths of Spears and Hell's Mesa rocks have caused considerable hybridization of the Nitt Monzonite where it has intruded those rocks in the "7610" hill area.

A narrow fault sliver of Hell's Mesa crops out in the pass between the main portion of Stendel Ridge and the low hills to the northwest. West-dipping Hell's Mesa also forms a small hill rising above the alluvium in the extreme northern part of the mapped area (plate 1).

Crystal-rich ash-flow tuffs identical to the Hell's Mesa occur in the much-faulted area west of the Waldo Mine (plate 1). In several places, the flow-banded member of the overlying A-L Peak Formation is fused to Hell's Mesa tuffs.

Cauldron Fill Facies: Extensive exposures of rocks equivalent to the Hell's Mesa also occur south of North Baldy Peak. In this area, an impressive 100-foot thick outcrop of moderately-welded Hell's Mesa tuff is exposed, forming a white bluff visible many miles away (fig. 2). Near the trace of the North Fork Canyon fault (plate 1 and fig. 8), the tuffs of the Hell's Mesa Formation contain approximately 10 to 15 percent of lithic fragments of Spears volcanic rocks with an occasional piece of Madera Limestone. These tuffs are interbedded with layers of breccia composed of approximately 85 to 90 percent Spears and 10 to 15 percent Madera Limestone with minor amounts of Abo sandstone. These lens-like deposits are landslides and mud-flow deposits marking the bases of individual ash flows in the Hell's Mesa (figs. 2 and 3). The size of individual fragments in the breccias ranges from sand to rare boulders approximately six feet (2 m.) in diameter, with an estimated average size of approximately 6 to 8 inches (15 to 20 cm.). The matrix is composed of finely abraded Spears material intermixed locally with small amounts of tuffaceous material resembling the crystal-rich Hell's Mesa. These rocks are capped by a 100-foot thick layer of volcaniclastic sandstones and conglomerates composed almost entirely of Spears material. The Hell's Mesa exposed in the bluff is continuous with, and grades into, thick, moderately to densely-welded Hell's Mesa tuffs about 2000 feet to the south.

The characteristics of the Hell's Mesa in the area just south and west of North Baldy is essentially identical to the caldera fill materials that Lipman (1976) describes in the western San Juan Mountains of Colorado. The interbedded breccias seen in the area

Figure 2. Outcrop of the cauldron-fill facies of the Hell's Mesa ash-flow tuff south of North Baldy Peak. Individual eruptions are commonly marked by thin anesitic mudflows at their base (dark gray zones).

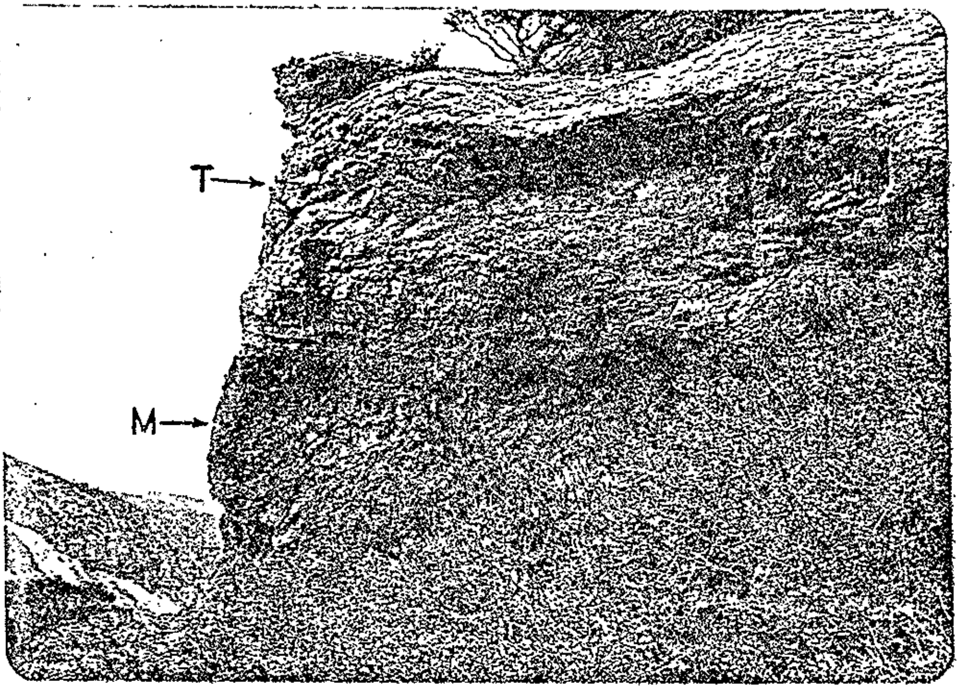


Figure 3a. Lens of mesobreccia in the caldera-fill facies of the Hell's Mesa Formation. M = mesobreccia
T = Hell's Mesa tuff

Figure 3b. Contact of mesobreccia shown in 3a with the enclosing Hell's Mesa tuff. The contact is welded to the mesobreccia material, which is composed of fragments of Spears, Abo, and Madera rocks. Thin films of ash-flow material are found around many of the fragments.

south of North Baldy corresponds to Lipman's (op. cit., p. 1398) mesobreccia and are here interpreted as such. The Hell's Mesa in this area is interpreted to have been deposited adjacent to a topographically high area formed during the collapse of the North Baldy cauldron, the source of the Hell's Mesa ash-flow tuff, which is centered south of North Baldy Peak.

The mixture of Spears, Madera and Abo rocks in the breccias may indicate that the lowermost Spears and lower Abo-upper Madera were exposed in the caldera wall. Alternatively, the Paleozoic fragments seen in the breccia may only reflect reworked material from the lower Spears. Inasmuch as the cauldron-fill facies of the Hell's Mesa overlies directly the Abo and Madera rocks north of the projected trace of the North Fork Canyon fault (plate 1 and fig. 8), the first hypothesis seems most likely. Details concerning the actual extent of the cauldron-fill facies and its relationship to the North Baldy cauldron are not known as of this writing, but Krewedl (1974, p. 39) reports that thin volcaniclastic sediments occur in the Hell's Mesa as much as 2.5 miles south of North Baldy Peak.

The true thickness of the Hell's Mesa Formation is nowhere exposed in the Kelly district. Thicknesses elsewhere range from zero to 640 feet (Chapin, 1974), and Krewedl (1974, p. 39) has estimated that the tuffs may be as much as 3850 feet thick in central Magdalena Range. The maximum estimated thickness in the Kelly district north of North Baldy is 450 feet, which was used in the construction of cross sections on plate 1. Actual thickness may later prove to be much different.

A-L Peak Formation

The A-L Peak Formation is a composite ash-flow sheet (Smith, 1960) of widespread occurrence in west-central Socorro County. The formation was named A-L Peak in the northern San Mateo Mountains by Deal and Rhodes (1976), who described a thick sequence of crystal-poor rhyolitic ash-flow tuffs unconformably overlying the Hell's Mesa Formation. No reliable dates have yet been obtained from the rocks of the A-L Peak Formation. Chapin (pers. commun., 1976) believes the flow-banded member to be slightly older than the Anchor Canyon and Nitt stocks (28 m.y.), which intrude the A-L Peak in the northern part of the Kelly district.

Deal (1973) delineated a large resurgent cauldron centered about Mt. Withington in the San Mateo Mountains, about eighteen miles west of the Kelly district, where the A-L Peak Rhyolite is more than 2000 feet thick. Simon (1973, p. 15) reported a north-south axis of transport for some ash flows in the A-L Peak as determined from elongate pumice fragments in his study area north-northeast of the San Mateo Mountains. Several azimuth directions derived from stretched pumice in the flow-banded member of the A-L Peak indicate a northeast-southwest transport direction in the central part of the Kelly district. Recent reconnaissance work by C. E. Chapin and others has revealed that the Sawmill Canyon area of the southern Magdalena Mountains may be another source area for at least some of the A-L Peak Formation.

Within the San Mateo Mountains, Deal (1973) described the A-L Peak Formation as a 2000-foot-thick sequence of crystal-poor rhyolitic ash-flow tuffs. Outward from the San Mateo Mountains, the A-L Peak is thinner and has andesite flows and volcaniclastic sediments. North of the Magdalena district, Brown (1972) named the unit the tuff of Bear Springs, which he subdivided into six members having an aggregate thickness of about 1000 feet. Woodward (1973) noted eight members in the formation and recorded a 1400-foot thickness in the Lemitar Mountains approximately fifteen miles east-northeast of Magdalena. Simon (1973) distinguished six members of the A-L Peak Formation with an estimated total thickness of 700 to 900 feet in the Silver Hill area. Within the Magdalena Mountains, Krewedl (1974) recorded a sequence of A-L Peak-like tuffs and andesites with a reported maximum thickness of about 4000 feet in the central part of the range.

Within the area of this study, the A-L Peak Formation may be comprised of three rhyolite ash-flow members which are locally separated by andesite flows. The members are, in ascending order: (1) the gray massive member, (2) the flow-banded tuff and associated sediments, and (3) the pinnacles member. The thickness of the A-L Peak Formation in the Kelly district cannot be accurately determined because of faulting and limited exposures, but a reasonable estimate is 500 to 800 feet. Because of the composite character and incomplete knowledge of the detailed stratigraphy of the A-L Peak Formation, total thicknesses and local stratigraphy may vary from those cited in this paper.

In view of the fact that Brown (1972) and Simon (1973) have rather detailed petrographic descriptions of the various members of the A-L Peak Formation, only pertinent features of the rocks readily distinguishable in the field will be described below.

Gray Massive Member - The gray massive member is described by Brown (1972) as the basal member of the A-L Peak Formation in the southern Bear Mountains. The unit is a massive, crystal-poor rhyolitic ash-flow tuff characterized by a distinct paucity of crystals. Phenocrysts rarely exceed 10 percent of the total rock volume, with euhedral sanidine as the most abundant phenocryst accompanied by quartz, biotite, and rarely, plagioclase. The unit has not been positively identified in the Kelly district, but one small outcrop of well-altered crystal-poor rhyolite tuff, measuring no more than a few feet square, possibly correlating to the gray-massive member, is exposed just west of the Contact shaft. It appears to be a sliver along the Waldo fault zone.

Flow-Banded Member - The flow-banded member of the A-L Peak Formation is densely-welded, crystal-poor ash-flow tuff characterized by a conspicuous flow-banding marked by flattened and elongated gas cavities (the "lenticulties" of Mackin, 1960) and pumice. Outcrops of the flow-banded tuff usually have a platy fracture parallel to the foliation, and banding is often contorted in asymmetric folds of varying wavelengths. Phenocryst content is generally less than 10 percent, consisting almost wholly of sanidine and quartz.

The flow-banded member is widespread within the Kelly district, occurring in a discontinuous band west of the major range-bounding fault from Stendel Ridge to the high ridge at the southern boundary of the mapped area. Within this area, the flow-banded tuff has been variably affected by alteration. In the low hills northwest of Stendel Ridge, the flow-banded unit exhibits shades of brown and purple and is hornfelsic, apparently having been baked by the underlying stock. In the area northwest of the Waldo tunnel, the steeply-dipping tuff has been bleached and is locally pocked with limonite pseudomorphs after pyrite. Still further south, in exposures along the high northwest-trending ridge at the southern boundary of the study area, the flow-banded unit has been extensively brecciated and silicified along a northwest-trending fault. Here the tuff is usually light to medium gray, with contrasting light-colored stretched pumice. In the fault zone, angular fragments of the flow-banded unit are readily visible in areas of vuggy breccia, but fragments are distinguishable only on close inspection in those areas where the breccia is cemented by gray silica that often has a finely-banded appearance. Away from the fault, the tuff is less-silicified and purplish hues, typical of the fresh flow-banded tuff elsewhere, are common. The flow-banded member is found in welded contact with the underlying Hell's Mesa Formation in the area south and west of the Waldo tunnel. In one fault block just west of the Waldo, the contact between the units appears to be marked by a small conglomerate-filled channel cut into the older rock. The contact with the overlying pinnacles member is variable, but appears to be unwelded, as it is marked by the abrupt appearance of poorly-welded pumice fragments and local volcaniclastic sedimentary rocks. The outcrop of flow-banded tuff in the low hills northwest of Stendel Ridge contains what appears to be a fault-controlled (?) channel filled with stratified, coarse-grained volcaniclastic sandstones.

The true thickness of the flow-banded member of the A-L Peak Formation in the Kelly district is impossible to determine because of limited exposures. Brown (1972) reports a thickness of 120 feet in the southern Bear Mountains, and the unit is probably no more than 200 feet thick in the area of this study.

Pinnacles Member - The pinnacles member in the Kelly district is a moderately to densely-welded rhyolite ash-flow tuff that corresponds to the "upper tuff" of Brown's (1972) tuff of Bear Springs and to Simon's (1973) "pumiceous member". The exact position and character of the tuff above the flow-banded member is poorly understood. In the southern Bear Mountains, the pinnacles member (as used in this paper) is separated from the flow-banded member by andesite. Simon (1973) reports no such andesite in the Silver Hill area. Within the Kelly district, both situations may be present. West of the Waldo tunnel, the flow-banded unit is in sharp contact with a moderately-welded rhyolite ash-flow tuff that differs from the underlying units in its lesser degree of welding and consequently more ovoid or lenticular pumice fragments and by the apparent lack of any contorted flow-banding. The unit is apparently more porous and permeable, as it is usually the more highly altered of the two rocks. Other small exposures of the tuff are exposed between North Camp and the Kelly townsite, where the tuff is also intensely altered and has been bleached to colors ranging from cream to orange. Locally-conspicuous pumice have been stained purple, possibly by solutions containing manganese.

The pinnacles member is missing above the flow-banded unit south of Chihushua Gulch. Instead, the flow-banded unit is succeeded by approximately 200 feet of non-porphyritic andesite (see plate 1).

Andesites Interbedded in the A-L Peak - Andesite is found interbedded with the A-L Peak rocks only at the extreme southern edge of the district, where it separates the pinnacles member from the flow-banded member. Andesite is found interbedded at different stratigraphic positions at various places outside of the Kelly district. Simon (1973) and Brown (1972) report andesite between the pinnacles member and the tuff of Allen Well; Brown also describes andesite between the flow-banded member and the pinnacles member. Woodward (1973) reported a thicker sequence of andesite flows at both of the above stratigraphic positions in the Lemitar Mountains.

The andesites are typically dark and outcrops weather to talus-covered slopes. Lineated amygdules are commonly filled with quartz, calcite, or celadonite. The fresh surfaces of the andesites range from gray to dark reddish-brown, and generally weather to lighter shades of brown. The interior zones of the flows are generally dense and aphanitic with a few phenocrysts of pyroxene and/or olivine. The pyroxenes are usually hematized, giving the rocks a close similarity to the younger La Jara Peak andesites. The flow tops and bottoms are vesicular and autobrecciated. Thin volcaniclastic sandstones are locally intercalated with the flows.

Andesites of similar character are found as faulted remnants rimming the western and northern sides of the hill on the north side of the mouth of Mistletoe Gulch. Outcrops of the andesite at the southern edge of the district indicate that the thickness of the unit is approximately 300 feet. The andesite is believed to fill erosion channels in the A-L Peak tuffs and may pinch out rapidly.

Tuff of Allen Well

The name tuff of Allen Well is applied to a rhyolitic, multiple-flow, compound cooling unit that disconformably overlies the pinnacles member of the A-L Peak Formation. Chamberlin (in prep.) and Osburn (in prep.) have recently identified the source of the tuff of Allen Well as the Socorro Cauldron(s), centered in the Chupadera Mountains, south of Socorro. The Socorro Cauldron(s) occurs at the northeastern end of a group of overlapping cauldrons which extend southwestward through the Magdalena and San Mateo Range (see fig. 7).

The tuff of Allen Well is composed of two members: a crystal-poor lower unit which strongly resembles the gray massive member of the A-L Peak Formation and a crystal-rich upper member which is very similar in appearance to the Hell's Mesa Tuff. Both the upper and lower members are present in the Kelly district; all outcrops of the tuff occur south of the Kelly townsite (plate 1).

The upper part of the densely-welded, crystal-poor lower member of the tuff is exposed in the low hills approximately 2000 feet ESE of the old charcoal oven, in the central part of Section 1, T3S, R4W (plate 1). It is seen to be welded to, and grade upward into, the crystal-rich upper member. The upper member may be distinguished only with difficulty from the Hell's Mesa Tuff in hand specimen by the slightly greater ratio of matrix to crystals and the somewhat greater biotite content of the tuff of Allen Well. The similarity between the tuff of Allen Well and the Hell's Mesa has caused some confusion in earlier studies.

Faulted silicified remnants of the tuff of Allen Well occur, surrounded by andesites of the A-L Peak Formation, near the mouth of Mistletoe Gulch (plate 1); another brecciated and silicified sliver of the lower member occurs enclosed in andesites of the Andesite of Landavaso Reservoir at South Camp (plate 1). A flat-lying outcrop consisting of both members of the tuff caps ridges at the southern end of the mapped area, where it overlies andesites of the A-L Peak Formation (plate 1). The tuff is overlain by andesites similar to those found interbedded in the A-L Peak on the "9618" peak approximately one mile west of North Baldy.

The maximum exposed thickness of the tuff in the Kelly district is about 200 feet. Chamberlin (in prep.) reports as much as 500 feet of the lower member and 500 feet of the upper member within the Socorro cauldron. He has renamed the unit the Lemitar Tuff, after better exposures of these rocks in his study area. Simon (1973) reported a partial thickness of almost 100 feet at the type locality. Chapin (pers. commun., 1977) reports a K-Ar age of 26.3 ± 1.0 m.y. for the upper member of the tuff. This age would indicate that the tuff of Allen Well was erupted subsequent to the intrusion of the Nitt and Anchor Canyon stocks (28 m.y.) and, therefore, may have flowed into the depression formed by the collapse of the Magdalena cauldron, formed during the eruption of the flow-banded member of the A-L Peak Formation.

The Andesite of Landavaso Reservoir

The andesite of Landavaso Reservoir is a highly variable series of porphyritic andesite flows named for exposures near Landavaso Reservoir, west of the Kelly district (Simon, 1973). The andesite is correlative to several units mapped by Loughlin and Koschmann (1942) in the southwestern part of the Magdalena district, including their "red andesite", "red rhyolite", and "upper andesite" (fig. 1).

Exposures of the andesite in the Kelly district are restricted to the area south of Kelly and west of the South Camp fault. The andesite, capped by upper tuffs, forms the bulk of the high ridge in the west half of Section 13 in the southwest corner of the district, and is exposed on most of the low, rounded hills north of South Camp. Variable lithologies and hydrothermal alteration appear to have caused Loughlin and Koschmann (1942, p. 28-29) to distinguish three different facies in the unit and to confuse andesites in the A-L Peak Formation with those in this unit.

Exposures of the andesite of Landavaso Reservoir are generally confined to small ledges or outcrops on the larger hills and to abundant blocky fragments covering the ground in areas of lower relief. The andesite is composed of a number of flows that are highly variable in both composition and texture. They are distinguished from the andesites of other units by their highly variable character and the fact that they tend to be porphyritic, with phenocrysts of plagioclase, pyroxene, and biotite being relatively conspicuous. Fresh surfaces are commonly shades of gray or reddish-gray and tend to weather to shades of reddish-brown or brownish-gray. The flows are often vesicular, with vesicles being as much as one centimeter in diameter, occasionally filled with calcite, opal, or celadonite. Irregular bands of hematite staining are common on most outcrops.

The thickness and lateral extent of the individual flows cannot be determined because of limited exposures. Zones of auto-brecciated flow material are common in the basal portions of many of the flows. Some flows appear to be entirely brecciated.

Although a detailed stratigraphic study of the andesite of Landavaso Reservoir is not included in this report, this writer noted that what appeared to be altered latitic or rhyolitic ash-flow tuffs were interbedded with the andesites of this unit. One such tuff was noted in the low hill just southeast of the old charcoal oven in the west half of Section 1, T3S, R4W and another in the extreme southwestern part of the mapped area (plate 1). The actual extent and relative amounts of the ash-flow tuffs in the andesite of Landavaso Reservoir will require further detailed work.

Simon (1973, p. 36), in his petrographic study of the andesite of Landavaso Reservoir, observed that they were porphyritic with a felty to pilotaxitic groundmass. He noted that phenocrysts, consisting largely of plagioclase, pyroxene, biotite and hornblende, formed 15 to 40 percent of the total rock volume, with plagioclase being the dominant mineral. He was able to distinguish four types of andesite flows: (1) plagioclase-pyroxene, (2) plagioclase-biotite, (3) plagioclase-pyroxene biotite, and (4) plagioclase-hornblende.

Loughlin and Koschmann (1942, p. 29) identified the altered, variable volcanic rocks forming the low hills north of South Camp as "red rhyolites" and noted that it resembled their "red andesite" but was somewhat more pale in color and was distinctly silicified. These rocks have been identified as altered flows of the andesite of Landavaso Reservoir. The rocks here are locally intensely brecciated and silicified. Barite and drusy quartz are locally present, especially along larger fractures and in some vugs. Minor copper staining has enticed prospectors to dig small pits on some of the more promising shows.

The true thickness of the andesite of Landavaso Reservoir is nowhere exposed in the Kelly district. Recent regional work has indicated that the andesite of Landavaso Reservoir is restricted largely to the geographic area of the Magdalena cauldron, the eastern boundary of which is interpreted in this paper to extend northward through the Kelly district. It thus appears that the andesite is part of the cauldron fill of the Magdalena Cauldron. As such, the thickness in the south end of the Kelly district could be considerable, and could exceed the 800 feet reported by Simon (1973) in the Silver Hill area.

None of the andesites has been dated; however, they lie between the tuffs of the A-L Peak Formation (about 28-29 m.y.) and the 26 m.y.-old Upper Tuff.

Upper Tuff

Crystal-rich ash-flow tuffs cap the andesite of Landavaso Reservoir west of the South Camp fault in section 13 at the extreme southern edge of the district. The tuffs are light-gray to light brownish-gray on fresh surfaces and generally weather to a purplish-gray. The outcrops form somewhat resistant ledges and blocky talus. Hand specimens are typically densely welded and contain phenocrysts of quartz, chatoyant sanidine, plagioclase, and some coppery-hued biotite. These tuffs are similar to the Potato Canyon Rhyolite described by Deal (1973), and Deal and Rhodes (1976). Partial thicknesses of the Upper Tuff measured at the southern edge of the Kelly district approach 250 feet. Thicknesses of similar rocks elsewhere range from 3300 feet in the San Mateo Mountains (Deal, 1973) to at least 600 feet in the Silver Hill area (Simon, 1973, p. 40). A fission-track date of 30.3$\pm$1.6 m.y. was obtained on a sample 200 feet above the base at the type section of the Potato Canyon Rhyolite in the San Mateo Mountains by Smith and others (1973), but Chapin (pers. commun., 1976) has recently obtained a 26 m.y. age by the K-Ar method on a correlative unit in the Joyita Hills.

The Upper Tuff also appears to be a cauldron fill unit that flowed into the depression formed during collapse of the Magdalena cauldron. The Upper Tuff has an age roughly equivalent to the tuff of Allen Well, a post-A-L Peak unit, and may be equivalent to the intracaldera tuffs and sedimentary rocks described below. Osburn (in prep.) has recently identified a thick sequence of crystal-rich tuffs within the Socorro Cauldron (the tuff of South Canyon) that may be equivalent to the Upper Tuffs.

Intracaldera Tuffs and Sedimentary Rocks

A series of felsic tuffs and sedimentary rocks occurs on the isolated cresent-shaped hill west of the Kelly townsite. At the eastern base of the hill, about 40 feet of volcaniclastic sedimentary rocks and possible air-fall tuffs are in probable fault contact with A-L Peak-like andesites to the east (plate 1). The sedimentary rocks exhibit good laminar bedding with individual beds generally not exceeding two inches in thickness. Cross-bedding is not common. They contain a few percent of lithic fragments, most of which appear to be pieces of crystal-poor ash-flow tuff.

Overlying the sedimentary rocks is a series of unwelded to moderately-welded, crystal-poor to crystal-rich, ash-flow tuffs. Directly overlying the sedimentary rocks is a crystal-poor unit containing moderately to densely-welded pumice as much as four inches in length. This tuff contains approximately 10 percent of crystals, predominately quartz and orthoclase. Felsic lithic fragments comprise about 20 percent by volume of this tuff and appear to be concentrated mostly in the central part of the unit, which may mark a contact between two similar ash-flow tuffs. Other crystal-poor tuffs, with varying amounts of pumice and exhibiting varying degrees of welding, overlie this basal unit. Interbedded with these crystal-poor tuffs is a crystal-rich unit less than fifteen feet thick that forms discontinuous outcrops on the western side of the hill. The crystal-rich tuff is similar in many respects to the tuff of Allen Well, and some crystal-rich tuffs in the Potato Canyon Rhyolite (Deal, 1973). The unit contains conspicuous quartz phenocrysts and crystals of plagioclase (?) and biotite. Flattened pumice as much as one inch in length give the tuff an eutaxitic structure and are particularly abundant towards the base of the unit.

These tuffs are overlain by dense, red and brown, non-porphyritic andesites similar to andesites of the A-L Peak Formation. These andesites form an arcuate outcrop in the tuffs, which suggests that they may fill a channel eroded in the ash-flow tuffs. The andesite is apparently not equivalent to the similar La Jara Peak Andesite, as it has been hydrothermally altered. Widespread hydrothermal alteration preceeded deposition of the La Jara Peak Andesite, (Chapin, 1971b).

The tuffs and sedimentary rocks have been intensely altered and are a uniform cream to light orange, speckled profusely with tiny limonite psuedomorphs after pyrite. Alteration of the tuffs is as severe as any in the district and may be related to fluids circulating along the margin of the Nitt stock, which is probably under the alluvium at no great distance to the north.

The extensive alteration of the tuffs and sedimentary rocks in the hill west of Kelly cause the tuffs to resemble somewhat the rhyolite ash-flow tuffs of the A-L Peak Formation. This similarity led Loughlin and Koschmann (1942) to correlate these rocks with their "pink rhyolites" and to equate the crystal-rich tuffs with their "rhyolite porphyry sill". More detailed knowledge of the volcanic stratigraphy has shown that the upper tuffs are not equivalent to the rocks of the Hell's Mesa and A-L Peak Formations but are, in fact, younger.

The tuffs and volcaniclastic sedimentary rocks are interpreted to be intracaldera deposits within the Magdalena Cauldron. They are products of post-cauldron collapse ash-flow tuff eruptions and erosion of older rocks within the cauldron. The deposition of these rocks preceeded the eruption of the La Jara Peak Andesite and may have been contemporaneous with the deposition of the andesite of Landavaso Reservoir. The outcrop west of the Kelly townsite may represent only a small part of a larger mass of similar cauldron-fill deposits buried under the La Jara Peak Andesite.

Tertiary Intrusive Rocks

Several large dike- or stock-like intrusive bodies of Tertiary age are now known within the Kelly mining district. Two of these bodies, the Anchor Canyon and Nitt stocks, are part of a large, composite pluton intruded along the eastern margin of the Magdalena Cauldron and designated the Magdalena pluton by C. E. Chapin (pers. commun., 1973). The Nitt Monzonite and Anchor Canyon Granite are distinguishable bodies within the larger intrusive mass that has a north-south dimension of six and one-half miles and has a maximum east-west dimension of four miles. Within the pluton are a variety of facies ranging from andesite at the borders through alkali gabbro (D. Braun, pers. commun., 1974) and mafic monzonite to quartz monzonite and granophyre.

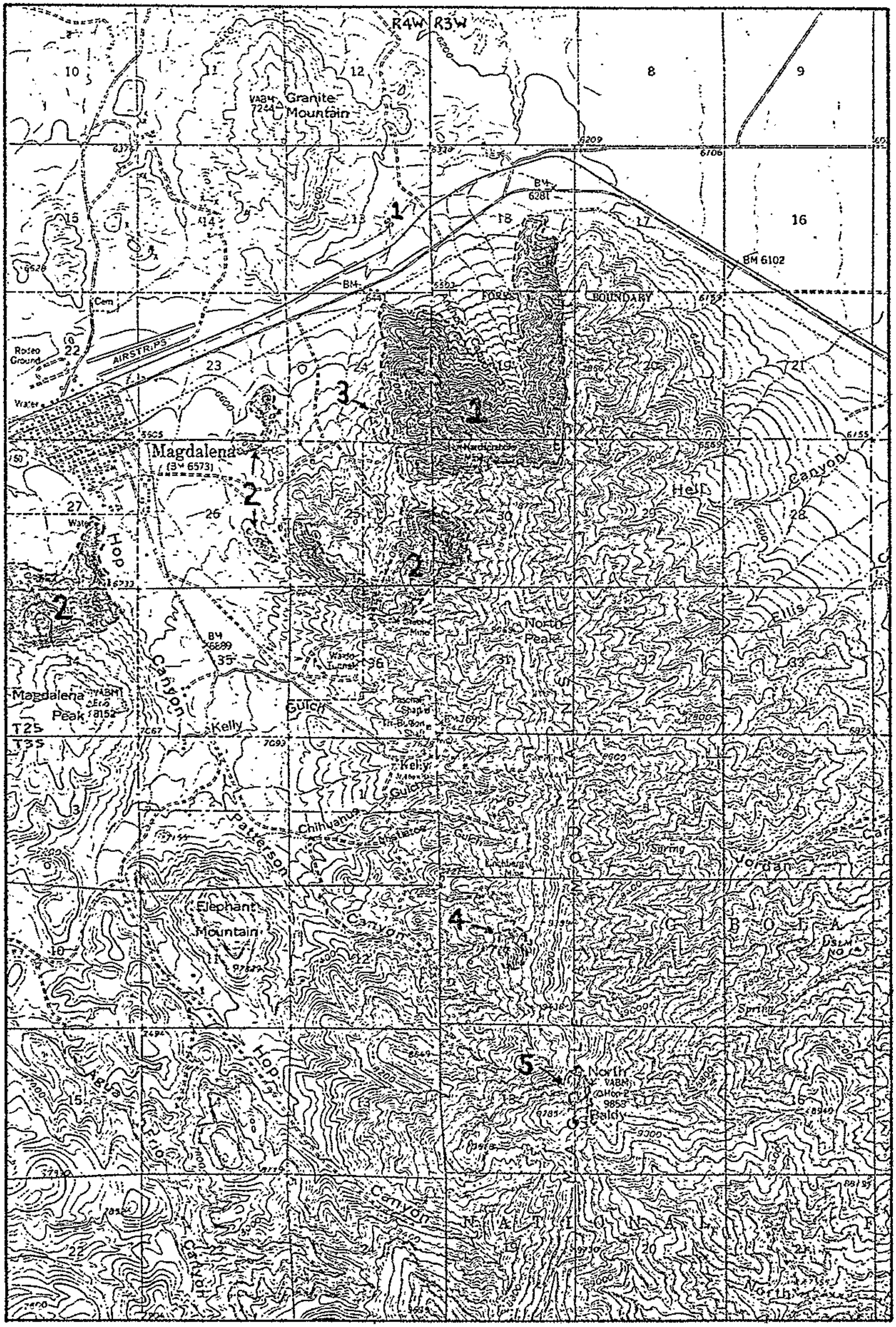
The latite porphyry of Mistletoe Gulch occurs as several large dike-like bodies in the southern part of the district, which may represent part of a ring dike along the east edge of the Magdalena cauldron. In the same area, the Linchburg Quartz Monzonite forms a body of unknown size and geometry which is exposed only in the workings of the Linchburg mine. Both of these intrusive rocks appear to have had significant effects on the patterns of hydrothermal alteration and ore deposition within the Kelly mining district. Other intrusive bodies are known from limited drilling at North Baldy Peak and near the Vindicator Mine.

Dikes are common within the Kelly district, especially in the area north of Chihuahua Gulch (plate 1). Many of the dikes can be correlated to one or another of the known stocks, but no dikes are known for several of the buried intrusives. Figure 4 shows the distribution of the known exposed and buried intrusive bodies in the Kelly district.

Anchor Canyon Granite

The Anchor Canyon stock is the largest exposed intrusive body in the Kelly mining district. It is exposed over about 2-1/2 square miles at the northern end of the district, east of Hardscrabble Valley. The rock of the stock, which has been dated at 28.3 m.y. (Weber and Bassett, 1963) was initially described as a granite by Loughlin and Koschmann (1942). Park (1971) found it to be a composite, horizontally and vertically zoned intrusive comprised of four distinguishable facies which include: (1) augite quartz monzonite, (2) hornblende biotite quartz monzonite, (3) augite granite, and (4) hornblende biotite granite. Park found that contacts between lithologies are gradational and that there is a systematic compositional variation in both the vertical and east-to-west directions.

Figure 4. Index map showing locations of exposed and known or suspected buried intrusive rocks: (1) Anchor Canyon stock, (2) Nitt Monzonite, (3) Vindicator intrusive, (4) Linchburg stock, (5) North Baldy stock.


R4W R3W
Granite Mountain
Magdalena
AIRSTRIPS
Rodeo Ground
Cem
Water
FOREST BOUNDARY
BM 6102
Hop Canyon
Magdalena Peak
North Peak
Hell Canyon
Ellis
Kelly
Gulch
Kelly Gulch
Chihuahua Gulch
Patterson
Elephant Mountain
Canyon
Jordan
Spring
North Baldy
T2S
T3S
Agua Frio
Hop Canyon
Canyon
N A T I O N A L
C I B O L A
1
2
3
4
5

In the field, rocks of the Anchor Canyon stock appear leucocratic, with the color of fresh rock varying from light- to dark-pinkish-gray with increasing grain size (Park, 1971, p. 23). The rock weathers to buff, is resistant to erosion, and forms especially rugged outcrops in the Hardscrabble Gulch and Anchor Canyon areas. Sphene is conspicuous in some areas, which according to Park, correspond to the augite-quartz monzonite facies of the stock.

Park's study of the Anchor Canyon stock includes a detailed description of the mineralogic and geochemical variations of the intrusive in which he notes that the major constituents include plagioclase, orthoclase, microperthite, quartz, biotite, hornblende, and augite. Major accessory minerals include magnetite, apatite, sphene, zircon and allanite. His study indicated that the stock was not significantly hydrothermally altered, as sericitization of plagioclase is scant and chloritization of biotite is minor.

Contacts with the wall rocks are generally sharp and xenoliths are common near the margins. Xenoliths include quartzite, Precambrian granite, monzonitic rock, and limestone, and range in size from a few inches to more than two feet in diameter (Park, _op. cit._, p. 42). Park notes that contact metamorphic effects are generally absent or are very minor; few such effects were seen in the field by this writer.

The western boundary of the stock is marked by the Vindicator fault, along which there is no apparent contact at the surface between the immediately adjacent limestones and the stock, due to the intervening white rhyolite dike. Along this zone, the Anchor

Canyon Granite shows little evidence of significant hydrothermal alteration at the surface, although the Paleozoic rocks have been considerably altered and metasomatized over large areas just a few feet away. Recent drilling along the contact zone has revealed that the Anchor Canyon Granite has been altered at depth in certain areas. The granite has been intensely sericitized locally, and disseminated pyrite and specularite are abundant in some areas adjacent to the Vindicator Fault. Minor chalcopyrite is found in veinlets and as sparse disseminated grains in the more intensely pyritized areas.

The Nitt Monzonite lies south and west of the Anchor Canyon Granite, occupying the southern half of Hardscrabble Valley and underlying Stendel Ridge. The Nitt Monzonite has been dated at 28 m.y. by Weber and Bassett (1963) and although only a few feet separate rocks of the Nitt and Anchor Canyon stocks along the eastern side of Hardscrabble Valley, no direct contact relationships are exposed that could define the relative ages of the two intrusive bodies.

Rocks of the Nitt Monzonite are known in the workings of the Waldo mine, at least 1000 feet south of the southernmost surface exposures. Numerous small patches of monzonite are exposed along the low ridges and valleys west of Stendel Ridge. The presence of rocks very similar to the Nitt Monzonite on a small hill just east of the Magdalena village limits and over a considerable area north of Magdalena Peak, about four miles west of Stendel Ridge, indicates that monzonite may be the dominant facies in the Magdalena composite pluton.

The monzonite is typically fine- to medium-grained and non-porphyritic, with an average grain size of about two millimeters. The fresh rock is gray or greenish-gray, and weathers to a reddish-brown. Darker shades prevail where the monzonite is finer-grained.

In thin section, the monzonite typically exhibits as uneven granular texture with irregular, interlocking, and often indistinct grain boundaries. Loughlin and Koschmann (1942, p. 37) noted that feldspars constitute 75 percent of the rock, with plagioclase slightly in excess of orthoclase. Pyroxenes were reported to make up fourteen percent of the rocks they examined, with biotite, quartz, and hornblende conspicuous. They noted that magnetite constitutes as much as three percent of the rock.

Loughlin and Koschmann's petrographic work indicates that the Nitt Monzonite is typically a pyroxene monzonite, but the rock on the east side of Hardscrabble Valley, near the Azurite prospect, contains biotite as the chief ferromagnesian mineral, with lesser amounts of pyroxene and hornblende. The extent of this rock type is unknown, but it extends for at least 1000 feet east of the Azurite shaft.

Alteration of the monzonite is not marked, with one notable exception. Chloritization of the ferromagnesian minerals is present in variable amounts; much of the biotite in the biotite monzonite described above appears fresh. The monzonite on Stendel Ridge and in the small exposures further west are more thoroughly propylitized, with chlorite, sericite, calcite, and epidote occurring as replacements of ferromagnesian minerals and in veinlets cutting the stock. The most intense hydrothermal alteration occurs in a shattered zone approximately 500 feet wide and 2000 feet long adjacent to the white rhyolite dike along the eastern side of the head of Hardscrabble Valley, near the Azurite prospect. Here, the monzonite has been altered to a propylite consisting of chlorite, sericite, carbonate, quartz, iron and copper sulfides, and minor hematite. Chlorite occurs as veinlets and replacement of ferromagnesian minerals accompanied by carbonate, quartz and sulfides giving the rock a distinct greenish color and causing it to be less resistant to erosion. Sericite is common, and occurs as replacement of plagioclase and in veinlets with quartz, carbonate and sulfides. The rock is so altered that the plagioclase has been completely destroyed. Orthoclase appears to be somewhat more abundant in this zone than in the typical monzonite. Relict textures and estimates of original composition by this writer indicate that some of the rock may have been a granite, possibly a dike cutting the monzonite, but the intense alteration of the rock precludes any positive identification.

The intensity of shattering and alteration decreases gradually east and south of the Azurite shaft. The monzonite 500 feet east of the Azurite shaft appears to be only slightly altered. The alteration decreases less rapidly to the south, and never completely disappears; outcrops of the stock just north of the Graphic tunnel are noticeably propylitized and slightly mineralized over a zone 300 feet or more in width. The degree and type of alteration found in this zone is very similar to that found in intensely propylitized rocks of intermediate composition near porphyry copper systems. Copper-rich ores in the Nitt mine are said to be closely associated with monzonite dikes and contacts near the southern end of the Nitt stock. Altered monzonite dikes exposed in the Waldo mine were correlated to the Nitt Monzonite by mine geologists.

Facies within the Nitt stock are almost as varied as those in the entire Magdalena pluton. The small outcrops of Hell's Mesa Formation capping the higher hills forming the western ridge of Stendel Ridge form a datum marking the highest stratigraphic level of intrusion in that area. The monzonite below these caps, especially along the slope of the southern part of Stendel Ridge, is a hybrid formed by reaction of the melt with the wall rocks. The rock resembles neither the monzonite, the overlying Hell's Mesa nor any of the units of the Spears Formation. The rock is generally a pale tan or grayish-orange in outcrop and is light gray on the fresh surface. The rock is fine-grained and characterized by clots of ferromagnesian minerals, which appear to be mostly amphibole. Other clots contain a mixture of amphibole and plagioclase probably formed as a result of the chemical reaction of the melt with the cooler and perhaps chemically different wall rocks, initiating rapid crystallization, which according to Bowen (1928, p. 197) should cause formation of the "heat equivalent of the member of the (reaction) series with which the member is saturated." The contact between the typical monzonite and the hybrid rock is gradational over about 200 feet of elevation. Dikelets of monzonite may be observed cutting the Hell's Mesa and locally forming matrix material for suspended fragments of wall rock.

Similarly hybridized monzonite is found about one-half mile west of the Waldo tunnel and in small exposures cutting the A-L Peak northwest of the Waldo mine.

Contacts along the southern border, where Precambrian argillite constitutes the bulk of the wall rock, are generally sharp, with little hybridization observed. Further east and north, Loughlin and Koschmann (1942) report other facies ranging in composition from granite to norite. The reason for these contrasts may be that the magma was hotter and possibly more fluid in the areas where hybridization was not intense; this caused the engulfed wall rocks to be more completely assimilated into the melt. The xenolith-rich hybridized material on Stendel Ridge may mark a cooler, more viscous portion of the magma that froze before the engulfed rocks could fully equilibrate with the melt.

Another interesting group of facies is found in the north and west portions of the small hills northwest of Stnedel Ridge, where central cores of granophyric rocks are bordered by more mafic facies. Medium- to coarse-grained granite exhibiting striking graphic intergrowths of orthoclase and quartz forms the northwest portion of the outcrops. The rock is bordered by a narrow belt of finer-grained pyroxene monzonite which is, in turn, bordered by a dark, purplish, fine-grained facies similar to the andesitic facies seen bordering the Magdalena pluton further north. The granophyric intrusive has reached a higher stratigraphic level (A-L Peak) in the volcanic pile than did the Nitt Monzonite to the south (Hell's Mesa), and may represent another distinguishable intrusive body in the larger Magdalena pluton. The spectrum of facies and the higher position of the intrusive in the volcanic pile support this interpretation. The lack of an andesitic border facies around the Nitt and Anchor Canyon stocks may also tend to distinguish the granophyric rock as a separate phase. Alternatively, the granophyric rock may represent eutectic crystallization of a late-stage residual magma differentiated from underlying monzonite and encased in earlier chilled margins of more mafic material.

Latite Porphyry of Mistletoe Gulch

The latite porphyry of Mistletoe Gulch occurs as a much-faulted, discontinuous series of dike-like masses that crops out through the center of the district from its southern edge to Chihuahua Gulch (plate 1).

In hand specimen, the latite porphyry is generally greenish-gray and weathers to greenish-yellow or yellow-brown. Hornblende and biotite (?) form thin, tabular phenocrysts as much as six millimeters in length. Small, chalky-white plagioclase crystals averaging three or four millimeters in length comprise approximately fifteen percent of the rock. Weathered surfaces often have a somewhat pitted appearance caused by selective weathering of the hornblende crystals.

The latite porphyry ranges in composition from a hornblende latite, which appears to be the dominant facies, to quartz latite, which locally occurs as later dikes cutting the hornblende-rich facies. Titley (1958, p. 38) states that the latite found south of the Linchburg workings grades from a biotite-hornblende latite at the outer portions to quartz latite in the central part of the mass. Outcrops of the latite are generally subdued, as the latite tends to weather to small grus.

In thin section, the latite porphyry reveals a uniform porphyritic texture with the larger crystals of plagioclase, hornblende and biotite (?) in a matrix of altered plagioclase microlites. Alteration of the latite porphyry ranges from moderate to intense, with plagioclase altering to sericite and calcite and the ferromagnesian minerals replaced by chlorite and pyrite or magnetite. The rock becomes noticeably bleached and more sericitic near faults and veins. Pyrite becomes more common with an increase in alteration intensity.

Loughlin and Koschman (1942, p. 32) interpreted the latite porphyry mass as a sill because of its apparent stratigraphic position between the Madera and Abo Formations or between the Madera and Spears Formations where the Abo was "missing". Titley (1958, 1961) adopted their interpretation in his studies of the orebody in the Linchburg mine. Work by this writer indicates that the latite porphyry mass is not a sill, but is, instead, the dike-like top of a larger intrusive body that occupies a north-trending fault zone along which substantial displacements appear to have occurred.

Several lines of evidence point to the hypothesis that the latite porphyry mass is not a sill:

(1) In the southern part of the district, the latite porphyry occupies a north-trending fault zone of Oligocene age which is extensional in character and which elsewhere in the district has steep easterly or westerly dips. The east side of the latite porphyry is generally bordered

by rocks of the middle or lower Madera Limestone, except at the extreme southern edge, where adjustments along a pre-latite transverse fault (the Unity fault) has caused the Abo Formation to be in juxtaposition. On the west side, the latite is in contact with rocks of the lower Spears Formation. If the true maximum thickness of the Madera Limestone is about 1800 feet, this means that the stratigraphic level present at the surface on the east side of the latite is about 1000 to 1200 feet below the surface on the west side.

(2) Contacts of the latite porphyry with the enclosing rocks are steep in the southern part of the district; this relationship is indicated by the fact that the traces of the contacts do not change strike appreciably when crossing major topographic features, such as deep drainages and hilltops.

(3) Exposures of the latite porphyry are found in the Patterson adit, in the southern part of the district, to be approximately 300 feet west of the alignment of the western contact of the intrusive and the small outcrops cutting the Abo to the north. Several large blocks of Spears and Abo rocks appear to be engulfed in the latite porphyry at the adit level. Although the exposures are limited, it appears that the latite porphyry is expanding rapidly with depth in this area and was beginning to stope out the overlying rocks before it consolidated.

(4) Examination of elongate hornblende and plagioclase phenocrysts within the mass in the Mistletoe Gulch area shows that they are randomly oriented over relatively small areas, and appear to be random even when observed close to the contacts. The lack of mineral alignment indicates that the magma probably had neither a strong horizontal nor strong vertical component of movement at the time the magma congealed. This fact, plus the highly irregular contact in the Mistletoe Gulch area, indicates that the magma may have been passively emplaced through a process of stoping out of the overlying rocks.

In the Mistletoe Gulch area, the eastern and northern contacts of the latite porphyry are pre-intrusion faults. Along the eastern boundary the lower part of the Madera Limestone is exposed. Drilling by the New Jersey Zinc Company in the Mistletoe tunnel area has established that the thickness of the Madera in this area is about 275 feet. On the west side of the fault, sandstones of the Abo Formation form a partial sheath on the latite porphyry. In accord with earlier arguments that the Madera may have a maximum thickness of about 1800 feet in the Magdalena district, the displacement across the fault now occupied by the latite porphyry in the Mistletoe tunnel area is on the order of 1500 feet. Thus, the latite porphyry cannot be a sill between the Madera and Abo Formations as postulated by Loughlin and Koschmann. Similar relationships apply throughout the exposed length of the intrusive.

The surface exposures of the latite porphyry end abruptly against the fault that follows the course of Chihuahua Gulch. The only known surface exposure of the latite north of Chihuahua Gulch is a small dike-like mass cutting a small outcrop of Abo Formation along a north-trending fault just east of the Kelly townsite (plate 1). The relationship of the latite porphyry to the north-trending fault indicates that they are both extensions of similar phenomena south of Chihuahua Gulch.

A latite porphyry dike is reported in the South Juanita mine, just north of Chihuahua Gulch, and other small dikes of latite porphyry are known in the Kelly mine further north. Mining activities in the Waldo mine has revealed the presence of a large mass of hornblende latite porphyry, virtually identical to that exposed south of Chihuahua Gulch. Indications are that this mass, which is known to extend downward from the 14th level (6800 elevation) at least 500 feet, is a large dike-like mass that expands to a larger body at depth. Figure 5, a modification of a cross-section prepared by ASARCO geologists, illustrates the position of the latite porphyry to the mine workings.

The latite porphyry intrudes Precambrian greenstones and the overlying Kelly and Sandia Formation in the Waldo mine. The latite porphyry may have exerted at least partial control over the development of one of the larger orebodies in this mine. Intrusion was apparently partly controlled by the complex Waldo-Madera fault zone. Dikes and stringers of latite porphyry can be seen cutting the jumbled blocks of Madera Limestone in the Waldo-Madera fault zone at the Waldo tunnel level, approximately 1000 feet above the main mass.

Data taken from ASARCO mine maps indicate that the latite porphyry becomes thinner and more dike-like in character as it extends northward along the eastern boundary of the Waldo-Madera fault zone, where it has been cut in drill holes approximately 900 feet north of the Waldo shaft. Mine maps indicate that the latite comes within 100 feet of a large dike of Nitt Monzonite, which also followed the Waldo-Madera fault zone for about 500 feet south beyond its southernmost surface exposure. No actual contacts between the two intrusives is known, so the relative ages of the rocks cannot be determined.

In summary, it is apparent from all available information that the latite porphyry is not a sill, as previously envisioned by Loughlin and Koschmann (1942), but is instead a large, elongate dike-like intrusive which rose along north-trending faults of Oligocene age. Incomplete information suggests that the latite porphyry may have one of the most extensive distributions of any intrusive rock in the Kelly district.

In view of the interpretation that the Kelly district is located on the eastern margin of a large cauldron (the Magdalena Cauldron, to be described more fully below), the latite porphyry of Mistletoe Gulch is interpreted to be part of ring dike that has intruded deeply-penetrating faults along the edge of the cauldron.

Latite Dikes

Numerous latite dikes are found in close association with the latite porphyry of Mistletoe Gulch and are especially numerous in the Mistletoe Gulch area. One 25 to 30-foot wide mass is found along the major range-bounding fault at the mouth of Mistletoe Gulch and others have intruded transverse structures east of the Mistletoe tunnel (plate 1).

A dike of quartz latite occupies the northernmost transverse fault of the North Fork Canyon fault zone, in the southermost part of the district. The rock has a distinctive porphyritic texture defined by quartz "eyes" and is characteristically flow-banded. The dike appears to be uniformly altered and is light greenish-gray. Pyrite is a common alteration mineral and is seen in addition to chlorite as replacement of former biotite (?) phenocyrsts. The quartz latite is only about three or four feet wide in outcrop at North Baldy, but widens to approximately 100 feet to the east along the fault zone.

Other even-textured, fine-grained latitic (?) dikes and a sill are found intruding the Sandia shales along the eastern flank of North Baldy (plate 1). These dikes are light greenish-gray and commonly contain fragments of the enclosing wall rocks. Several of these fragments have been replaced by calcite, quartz and pyrite. Pyrite also occurs as disseminated grains in the dikes.

Linchburg Quartz Monzonite

One of the most intriguing and least-known of the intrusive rocks in the Magdalena district is the quartz monzonite exposed in the workings of the Linchburg mine, here named the Linchburg Quartz Monzonite. There are no known outcrops. The intrusive has been exposed in the southern end of the Linchburg mine, where an irregular mass of porphyritic quartz monzonite was encountered in the workings of the main adit level. Another thin dike of this material is found in a short adit just north of the Grand Ledge tunnel, but no outcrop of the intrusive could be found at the surface, just fifteen feet above the adit level. Additional dikes of quartz monzonite porphyry were cut in drill holes collared in the ravine just east of the Patterson adit (plate 1).

The Linchburg Quartz Monzonite has a distinctive porphyritic texture defined by rounded quartz "eyes" and by rounded to subhedral phenocrysts of plagioclase in an aphanitic matrix. The monzonite ranges in color from light greenish-gray to pinkish-gray, depending on the relative amounts of epidote, chlorite and potash feldspar in the rock.

In the Linchburg mine, the host rocks for the intrusive appear to be entirely Precambrian diabase. Contacts are gradational over distances of as much as fifteen feet. The normally dark diabase becomes increasingly bleached and silicified as the monzonite is approached. Pinkish zones within the diabase may indicate some replacement by silica and potash feldspar. Chlorite, pyrite, and rare chalcopyrite occur in variable amounts in both rock types. Hematite occurs along fractures in both host and instrusive.

Although the rock appears to be fairly fresh in hand specimen, microscopic examination reveals that it may be one of the most intensely altered of the intrusive rocks in the district. Corroded plagioclase crystals as much as seven millimeters in diameter have been so completely altered to sericite that the original composition cannot be determined in most cases. Large quartz "eyes" are thoroughly embayed and corroded. The corrosion of the plagioclase and quartz may be due to reaction of the minerals with the magma. The quartz and plagioclase phenocrysts are surrounded by a groundmass exhibiting variable textures. In most samples, the groundmass is a micrographic intergrowth of quartz and orthoclase (fig. 6). Myrmekitic textures virtually identical to the "brain coral" myrmekite described by Gilluly (1933) are common. Gilluly interpreted these textures as indicative of metasomatic replacement of original rock constituents. Cataclastic zones consisting solely of quartz and orthoclase were observed in two of the eight thin sections examined. Veinlets of quartz and orthoclase (?) were found to cut nearly all thin sections and vein-like masses of both quartz and orthoclase (?) were observed cutting and partially replacing the earlier minerals. Chlorite occurs as ragged clots that may represent original biotite, and in thin veinlets with quartz, sericite and rare sulfides.

The geometry of the Linchburg Quartz Monzonite is not known. Visible contacts in the Linchburg mine are steep and indicate that the intrusive has a dike-like form at that location. Very incomplete information garnered from drill cores and interpretive cross-sections furnished by ASARCO, which were based on four holes drilled about 500 feet south of the south end of the Linchburg workings, indicate that the porphyritic monzonite has intruded into shales of the Sandia Formation, within about 250 feet of the present surface. It is known from diamond drilling to extend at least 300 feet further west of exposures in the Linchburg and is

Figure 6a. Photomicrograph of Linchburg Quartz Monzonite showing corroded orthoclase (O) and plagioclase (P) feldspars replaced by granophyric groundmass. 1" = 0.65 mm.

Figure 6b. Photomicrograph of Linchburg Quartz Monzonite showing a quartz (Q) - orthoclase (O) - sericite (S) veinlet cutting micrographic groundmass. 1" = 0.65 mm.

exposed in the end of the Patterson adit, below the southern end of the Linchburg mine workings. The monzonite apparently has a fairly flat-lying upper contact that becomes much steeper toward the west near the Grand Ledge fault. The drill-hole data indicates that the porphyritic quartz monzonite is also dike-like in this area, as the holes passed through about 150 feet of porphyry into an equigranular quartz monzonite rock. This associated (?) intrusive is generally hypidiomorphic equigranular in character and is light buff to orange in color. Scattered clots of chlorite and veinlets of quartz and sericite are common. Sericite also replaces some of the plagioclase. Quartz and pyrite occur in thin veinlets and with chlorite in ragged patches that may represent former biotite. Microscopic examination reveals that the rock is much less altered than the porphyritic facies, with the grade of alteration corresponding to mild to moderate propylitization.

Although the actual contact between the two intrusives was not observed in the drill core examined by this writer, the disparity in textures and degree of alteration of the rocks close to their contact indicate that it may be sharp, or at most gradational over one or two feet.

ASARCO geologists considered the equigranular phase to be of possible Precambrian age, but the character of the rock, and its apparent intrusion into and west of the Grand Ledge fault zone indicates that it is probably of middle Tertiary age, similar to the Nitt and Anchor Canyon stocks.

Although the questions concerning the exact forms and relationships of the Linchburg Quartz Monzonite and the associated (?)

equigranular facies cannot be answered without additional information, this writer believes, based on the ASARCO drill cores and interpretive maps, that the porphyritic facies is a later phase that has intruded along the contact between a nearly contemporaneous quartz monzonite intrusion and its Paleozoic host rocks. The porphyritic monzonite was also injected as a thin dike along the Grand Ledge fault for an unknown distance south of the Linchburg mine.

The proximity of the porphyritic monzonite to the largest single zinc-lead orebody in the Kelly district suggests the possibility that the porphyry represents a late-stage magmatic melt injected from no great depth which had an associated post-magmatic fluid phase that was the source for the silica, sulphur and metals contained in the Linchburg orebody. The significance of this relationship and its implications regarding the discovery of new orebodies of the Linchburg type is discussed in the section of this paper dealing with economic geology.

Other Intrusive Rocks

Two additional intrusive bodies are known from exploratory drilling in widely separated parts of the district. Recent drilling in the North Baldy Peak area has revealed the presence of a monzonitic intrusive of unknown size that has stoped up through the Precambrian rocks to intrude the Kelly and Sandia Formations at approximately the 9100 elevation beneath North Baldy Peak. The monzonite is typically porphyritic with small potash feldspar and rare quartz phenocrysts set in a fine-grained matrix of plagioclase, potash feldspar and quartz. The rock has been extremely altered to chlorite, epidote, serpentine and sericite. Pyrite occurs as disseminations in fractures and as individual grains, and comprises about one percent of the rock. Quartz and carbonate veinlets are common and chalcopyrite was sparsely present in several narrow zones in the core examined. Some sections of the core resemble a healed breccia, with fragments of porphyritic monzonite and Precambrian (?) rocks surrounded by later monzonitic material. Extreme alteration of all rock types makes positive identification of these features difficult.

Porphyritic granite or quartz monzonite was penetrated in drilling approximately 500 feet south of the Vindicator shaft (plate 1). Core examined briefly by this writer revealed a sericitized, pyrite-rich, porphyritic, quartz-bearing rock that appears to have intruded the Madera Limestone and Anchor Canyon Granite. No other information about this intrusive is known, other than that it is spatially related to high grade zinc-lead-copper mineralization in a small tactite body that forms a replacement of the Madera Limestone. Figure 4 shows the locations of all known or suspected buried intrusives in the Kelly district.

Mafic Dikes

A large number of dark, aphanitic to porphyritic mafic dikes were mapped during the course of this study, especially in the northern end of the district. These dikes correspond to Loughlin and Koschmann's (1942) lamprophyre dikes and Brown's (1972) mafic dikes. The dikes are usually thin, averaging five to ten feet in width, and range in length from a few feet to over 2000 feet, averaging about 500 feet. The great majority of the dikes occur in the Stendel Ridge area, where they were emplaced along fault zones in and above the Magdalena Pluton. Most of the dikes occupy north-trending faults and fractures, but some strike towards the north-east, reflecting a transverse structural element similar to that described by Brown (1972) and Simon (1973), that appears to have had repeated influence in the area.

The dikes vary in color and general physical appearance. Because a detailed petrographic analysis of these rocks is beyond the scope of this study, the details below are derived from Brown (1972) and Loughlin and Koschmann (1942), but were confirmed by the author.

Generally, the least altered rocks are dark gray and have a basaltic appearance, but those that have been altered are green due to an abundance of chlorite. In hand specimen, they range from black to greenish-gray on a fresh surface and generally a rusty-brown or greenish-brown on the weathered surface. The dikes vary in groundmass texture and show a range in the abundance and type of phenocrysts. Some varieties are porphyritic with a fine-grained groundmass, others are only slightly porphyritic with a fine, equigranular groundmass, while still others are non-porphyritic with a very fine-grained texture. Phenocrysts generally comprise less than five percent of the rock and usually consist of plagioclase grains as much as five millimeters in length. In some dikes, the plagioclase phenocrysts are sharp and well-twinned, while in others, the plagioclase grains are irregular and greatly corroded.

Brown (1972) reports that the sharp, well-twinned plagioclase crystals have an average composition of An_{42}, while the corroded grains were zoned and exhibited undulatory extinction, with an average composition of An_{55}. He interpreted the corroded grains as being xenocrysts which were transported from depth during emplacement of the dikes. This writer has observed pockets of amethystine quartz as much as fifteen millimeters in diameter in two of the mafic dikes cutting granophyre in the northern end of Stendel Ridge. Other minerals include augite, minor oxides and some biotite and apatite (Brown, 1972).

Most of the mafic dikes in the district have been propylitized, with the mafic minerals altered to chlorite, magnetite and calcite. The phenocrystic and groundmass plagioclase are commonly completely altered to sericite and calcite. Epidote occurs as partial replacements of groundmass minerals and phenocrysts of plagioclase and augite. Pyrite is locally abundant in some dikes.

Augite Andesite

Two larger mafic intrusives were found in the Stendel Ridge area in the northern part of the district. These intrusive masses are correlative to Loughlin and Koschmann's (1942) augite andesite. They mapped a third, somewhat larger area on Stendel Ridge as augite andesite, but subsequent investigation has found this area to consist of a latitic ash-flow tuff in the upper Spears Formation.

The larger mafic intrusions are purplish-gray in outcrop and are fine-grained with scattered phenocrysts of greenish-black pyroxenes, plagioclase and hornblende. According to Loughlin and

Koschmann (1942), the augite andesites have a trachytic groundmass consisting of plagioclase laths with accessory magnetite and orthoclase (?). The rock has been somewhat altered to epidote, calcite and sericite. The plagioclase and hornblende are generally the more altered, while the pyroxene phenocrysts are reportedly quite fresh.

The augite andesite masses intrude the flow-banded unit of the A-L Peak Formation and a small outcrop of sedimentary rocks filling a paleochannel cut in the A-L Peak. The A-L Peak in this area is intensely bleached, silicified and pyritized; the augite andesite appears to be much fresher. The difference in alteration could be due to the fact that the A-L Peak ash-flow tuffs are more permeable than the andesite, but this does not seem to be entirely responsible for the great difference in alteration intensity observed. It is possible that the augite andesite masses may be younger than the alteration affecting the A-L Peak rocks, and since this alteration appears to be related to the intrusion of the Nitt stock, the andesite may be younger than the monzonite intrusions and may mark fissure vents for some of the flows of the La Jara Peak Basaltic Andesite of early Miocene age (24 m.y., Chapin, 1971 (b)). Were this to be true, the augite andesites would be among the youngest known intrusive rocks in the Kelly mining district.

White Rhyolite Dikes

The youngest intrusive rocks in the Kelly mining district are white rhyolite dikes. The dikes occupy a north-trending zone approximately 1-1/2 miles wide that extends more than six miles south of the Kelly district (Krewedl, 1974) and about four miles north of the area of this study (Brown, 1972). Most of the dikes in the Kelly district are narrow, averaging between five and ten feet in width, and are of variable lengths, ranging from a few feet to more than 1000 feet. They commonly occur en echelon, filling extensional faults and fractures. Most of the dikes dip steeply to the east or west. Loughlin and Koschmann (1942) report that "white rhyolite" forms sills in the "lower andesite" (lower to middle Spears equivalents), east of Granite Mountain, however, Chapin (personal commun., 1973) has shown these to be scattered exposures of the tuff of Nipple Mountain. One rhyolite dike with an easterly dip of 35° to 40° is known west of Anchor Canyon (Loughlin and Koschmann, 1942). Surface exposures of the dikes are restricted to the northern and extreme southern ends of the district, where they are conspicuous because of their white color. Outcrops of the dikes are notably absent from the central part of the district, but they are reported to be present in the workings of the Grand Ledge and Linchburg mines.

The dikes are grayish-white to white on weathered surfaces and are white to pinkish-gray on fresh surfaces. Outcrops are often distinctly flow-banded, which causes the dikes to weather to platy grus. The dikes are commonly speckled with limonite psuedomorphs after pyrite, which locally constitutes as much as 10 percent of the rock. Quartz phenocrysts are common, constituting as much as ten percent of the rock in some outcrops. Small orthoclase crystals are sometimes visible.

In thin section, the rhyolite has a dense, microgranular groundmass composed of irregular quartz and feldspar grains that are usually altered almost completely to sericite and carbonate. Orthoclase occurs as subhedral to euhedral phenocrysts and as broken fragments that are highly altered to sericite and carbonate. Brown (1972) describes rare biotite flakes in some of the rhyolites of his study area. Hair-like veinlets of quartz and sericite thoroughly lace many of the dikes. Loughlin and Koschmann (1942, p. 44) report a chemical analysis with 75.42 percent SiO_2 and 6.20 percent K_2O. The amount of these materials that is due to secondary alteration is not known.

The presence of white rhyolite dikes is significant in that the same extensional fault zones that are occupied by the dikes were often used as channelways for the mineralizing solutions that formed the orebodies of the district. Titley (1958) described one highly-altered rhyolite dike in the Linchburg mine that occupied a major fault zone, and believed that other rhyolite dikes might exist along the major structures, but were altered beyond positive recognition. The long, white rhyolite dike following the east side of Hardscrabble Valley marks the trace of the northern extension of the main ore zone in this area. In the area south of the Vindicator shaft (plate 1), mineralizing solutions rising along the fault occupied by the white rhyolite formed a moderate-sized body of zinc-lead mineralization in the Madera Limestone at its contact with the Anchor Canyon Granite. Another highly-altered rhyolite dike was found near the face of the Mockingbird adit on the west side of Hardscrabble Valley. There, the dike is cut by thin veinlets of quartz and carbonate that also contain some galena, sphalerite and chalcopyrite. Intensely-altered and pyritized wall rocks surrounding the dike attest to the circulation of hydrothermal fluids in this area.

Quaternary System

Landslide Deposits

Uplift of the Magdalena Range during the Miocene was apparently rapid, with the formation of steep dip slopes and fault scarps. Landslides occurred along parts of the range, and several of their remnants were mapped during the course of this study (plate 1). Most of the landslide deposits are found along the middle parts of the slopes in both the northern and southern parts of the district. Several scars indicating the source of some of the landslides are still visible in parts of the range, especially near the Woodland and Young America mines, where masses of silicified Kelly Limestone broke away and slid down the slope. Most landslides were composed of fairly homogenous material, generally either Kelly or Madera limestone. Some landslides appear to have occurred more as slumps in some areas, moving as a more-or-less coherent mass. One such example is located about 1500 feet southeast of the Waldo shaft, where a mass of Madera limestone and quartzite moved as a sufficiently cohesive mass such that gross internal relationships were maintained, even though the mass was broken into a great number of small blocks, none more than two feet in diameter. The resultant landslide body somewhat resembles a well-crumbled outcrop of Madera Limestone in which one can trace a thin, lenticular quartzite for short distances along "strike". Close examination of the mass reveals its true nature, but the body was mapped as Madera Limestone by Loughlin and Koschmann (1942, plate 2). Elsewhere in the district, some of the landslides contain blocks of altered Kelly limestone so large that prospectors drove short adits and sank shallow shafts in them in search of mineralization, only to find that the "outcrop" ended in rubble a few feet beyond. Loughlin and Koschmann (1942, p. 22) report that a small amount of ore was produced from one of the blocks, and that a 1200-foot tunnel was driven into landslide material in the southern part of the district.

Alluvium

Alluvial material forms the flanks of the western slope of the range, consisting of fans of debris comprised mostly of Paleozoic sedimentary and Precambrian intrusive rocks. The alluvium forms coverings on several pediment surfaces which were discussed in some detail by Koschmann and Loughlin (1934), but were not studied in detail by this writer. Thicknesses of the alluvial deposits vary from a thin veneer to greater than 100 feet, and grades into the younger valley fill. They have not been separated on the geologic map.

Talus

Talus has been mapped in several areas in the Kelly district where it obscured bedrock. The talus deposits are almost totally monolithologic and occur below well-broken or platy ash-flow tuffs in every case.

STRUCTURE

The structural history of the Kelly district is only partially understood. Several enigmatic features exist in the area that are here described for the first time, but are yet to be fully appreciated.

The district appears to be situated at the junction of three structural zones of regional extent: the WNW-trending Capitan lineament, the NE-trending Magdalena-Morenci lineament and a NNW-trending zone of extensional faults related to the Rio Grande rift zone. Some of these zones appear to have experienced repeated movements over a considerable time span and have influenced the position and shape of some of the caldera structures in the Magdalena region.

A detailed description of the structures of the Kelly district was given by Loughlin and Koschmann (1942, pp. 55-73). The accuracy of the timing and causes of their various stages of deformation was necessarily limited because of their incomplete knowledge of the stratigraphy and the ages of the various units, compounded with their relative unfamiliarity with the regional geology.

A revised structural history is presented below. A feature-for-feature comparison with Loughlin and Koschmann's earlier work is beyond the scope of this paper, and the reader is referred to their work for details of structures found in the individual mines in the district.

The major structural events that can be documented with certainty are, in chronological order: Laramide (Late Cretaceous-early Tertiary) uplift, early Tertiary transverse (NE) faulting, late Eocene-early Oligocene transverse (NE) faulting, middle Oligocene caldera collapse, and late Oligocene-early Miocene longitudinal faulting. Figure 7 illustrates the major structural features of the Magdalena region.

Local Structure

Little can be determined about the structural activity in the Kelly district prior to Laramide time. Folding of the Precambrian argillite suggests some regional compression prior to Mississippian deposition and the presence of east-trending diabase dikes cutting the Precambrian rocks indicates that faults of that trend were active sometime before the deposition of the Kelly Formation. Small-scale unconformities in the Paleozoic rocks indicate that some minor deformation occurred during the period that they were being deposited (Loughlin and Koschmann, 1942, p. 56-57).

Laramide Tectonics

No structures of definite Laramide age can be documented in the Kelly district, save the fact that erosion accompanying

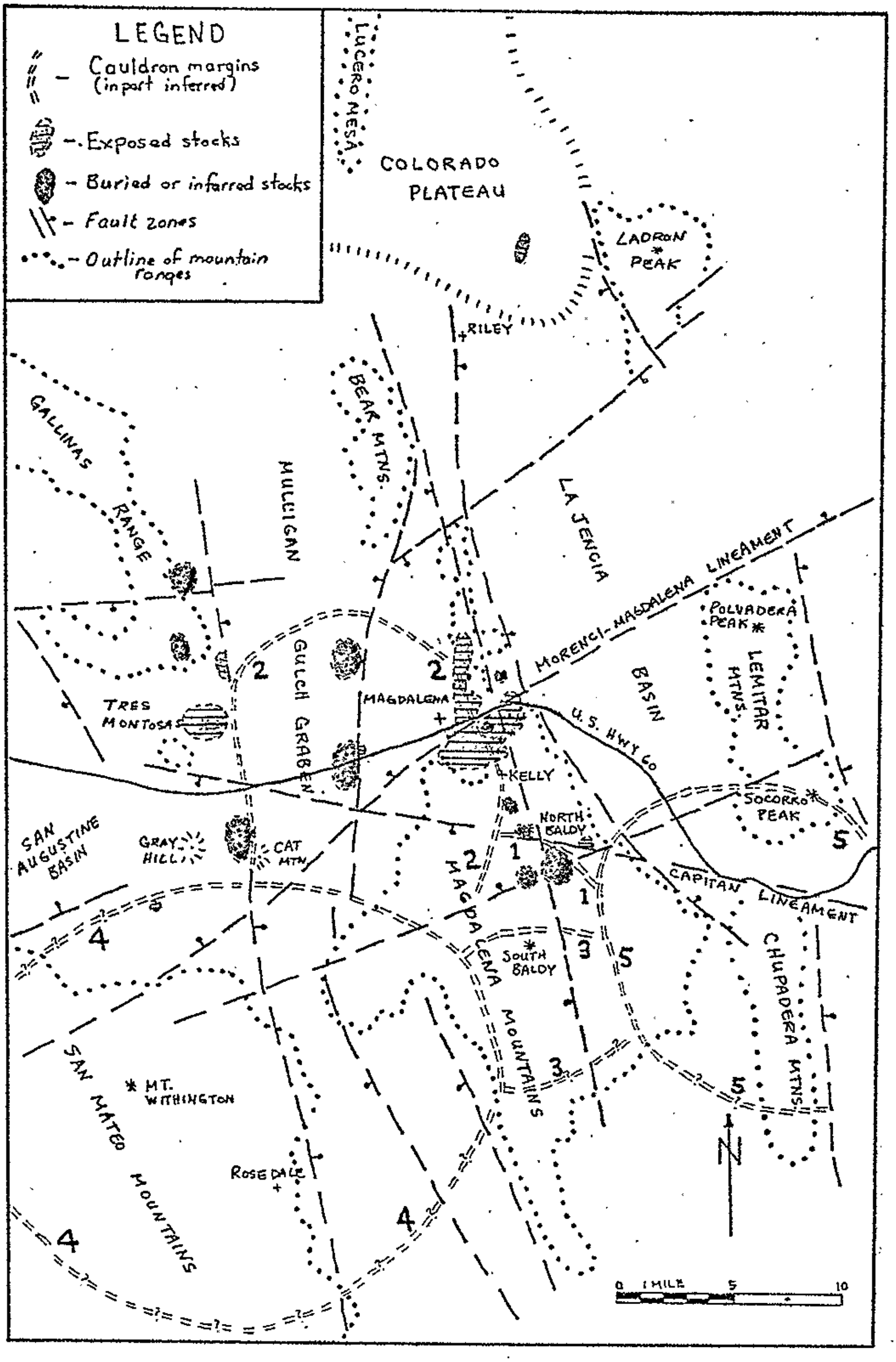


Figure 7. Major structural elements of the Magdalena area. Cauldrons are numbered in order of decreasing age: (1) North Baldy Cauldron, (2) Magdalena Cauldron, (3) Langmuir Cauldron, (4) Mt. Withington Cauldron, (5) Socorro Cauldron. Figure modified after Chapin and others (unpub.).

regional uplift beveled the pre-Spears surface down to the level of Permian strata within the area of this study. In order to place the Kelly district within the regional structural setting, a brief description of the structural features of Laramide age in the area surrounding the district is presented below.

The Kelly district is situated on the northwestern flank of a large Laramide uplift or uplifts of unknown dimensions and configuration. Chapin (pers. comm., 1974) believes that the uplift may have extended at least as far northeast as Polvadera Mountain, approximately fifteen miles ENE of Magdalena, and as far south as the southeastern flank of the San Mateo Mountains, some 30 miles south of the Kelly district. Some idea of the existence and extent of the uplift may be gained by noting that to the north of the study area, in the northern Bear Mountains, to the west, near Datil, and to the east near Carthage, the base of the mid-Tertiary volcanic pile rests on sediments of the Baca Formation of Eocene age, which in turn overlies upper Cretaceous strata. On the uplift, the Tertiary volcanic rocks rest on Paleozoic or Precambrian rocks. The precise outline of the uplift and whether it was a single swell or a series of closely-spaced smaller uplifts is not known. The core of the uplift appears to have extended from the Chupadera Mountains, south of Socorro, where ash flows similar to those in the A-L Peak Formation rest on Kelly Limestone and Precambrian rocks, northward to the Socorro and Lemitar Mountains, where Cenozoic volcanic rocks overlie lower Pennsylvanian strata (Chapin, pers. comm., 1974).

Further north, Kelley and Wood (1946) have documented a Laramide arch, the Lucero uplift, which was broken on its west flank soon after arching began, forming the Comanche thrust belt. This belt of high angle reverse faults, which is known to extend at least thirty miles southward from Lucero Mesa, generally has lower Permian and Pennsylvanian sedimentary rocks pushed up against upper Permian and Triassic rocks. Stratigraphic displacement on these faults are thought to be between 2000 and 4000 feet, with actual displacements possibly much greater. Kottlowski (pers. comm., 1975) reports the presence of possible klippe or fault slivers of Precambrian rocks in the area WNW of Ladrone Peak. The location of these outcrops indicates to Kottlowski that the strike of the Comanche thrust belt may be more southerly than interpreted by Kelley and Wood (1946), who thought that the trace of the thrust curved southeastward in the area north of Ladrone Peak.

At the present time, it is not possible to determine if the Chupadera Mountains-Socorro-Lemitar Mountains uplift is an extension of the Lucero arch or whether the Lucero arch may have forked to form two or more semi-parallel arches to the south, one of which may have extended through the Magdalena area. Sales (1968) has suggested, using the rheid concept, that large-wavelength uplifts formed by rapid tangential compression cannot sustain themselves and tend to fail, forming uplifts of smaller wavelength and amplitude. Thus a large, arching uplift that is initially several tens of miles wide would fail upon relaxation of compressive forces, forming two or more subparallel arches of smaller amplitude. Thrusting or high-angle reverse faulting could occur adjacent to the initial large uplift if compressive stresses were applied rapidly enough, or adjacent to the smaller arches (anticlines) because of failure along fold axes of isoclinally folded rocks or other mechanisms. Sales (1968) has illustrated through model experiments and field evidence similar structures resulting from left-lateral couples in the Wyoming foreland region.

Early Tertiary Faulting

Following Laramide deformation, much of the southwestern United States experienced a period of relative quiescence during which the uplifted areas were eroded and the resulting detritus was deposited in surrounding basins, creating a widespread surface of low relief (Epis and Chapin, 1973). In the Magdalena region, a broad plateau-like area adjacent to the central part of the uplift(s) was stripped of all rocks younger than the Abo Formation over much of its surface. The highest part of the uplift was eroded down to the Precambrian rocks in its core. Detrital material resulting from this erosion was deposited in the Baca basin, a narrow(?), west-trending belt of fluviatile arkosic and subarkosic sands and conglomerates that unconformably overlie upper Cretaceous strata and is overlain by volcanic rocks of the Datil volcanic pile (Snyder, 1971).

Movement along northeast-trending transverse faults related to the Morenci-Magdalena lineament broke the plateau-like area in a zone that extends northward from Hardscrabble Valley possibly as far as the southern edge of the Bear Mountains sometime during the early Tertiary. Movement along these transverse faults was graben-like, with a down-to-the-north sense in the Hardscrabble Valley-Granite Mountain area, preserving a thick section of Permian sediments, including rocks of the Abo, Yeso, Glorieta, and San Andres Formations, in the area east of Granite Mountain (Siemers, 1974). Lesser amounts of movement along faults in the central Hardscrabble Valley area resulted in the preservation of a thick section of Abo sandstones, sandy shales and limestones. Drilling by ASARCO has revealed at least 350 feet of Abo-like sediments in the subsurface at the east base of Stendel Ridge. Where exposed, the Abo south of Hardscrabble Valley averages less than 150 feet thick.

This NE-trending zone of weakness (the Morenci-Magdalena lineament) is part of a major structural feature in southwestern

New Mexico and southeastern Arizona. Faults related to this zone exerted great control over the emplacement of the copper-bearing porphyries of Laramide age in the Morenci and Safford areas (Langdon, 1973), and were later to influence the position of middle Cenozoic volcanic features as well as the southwestward bifurcation of the Rio Grande rift along the San Augustin graben during late Miocene time (Chapin, 1971).

Although the geology of the Granite Mountain area was not included in this study, it is of interest to note that Loughlin and Koschmann (1942, p. 57), based on their misidentification of the Paleozoic rock units present east of Granite Mountain, believed that the exposures there represented the beveled western limb of a northward-trending elongate dome or anticline which had been more deeply eroded in the Stendel Ridge area during prevolcanic time. Correct identification of the rocks in this area allows a different interpretation of the structural history.

Late-Eocene-Early Oligocene Transverse Faulting

Movement along faults of NE trend within and north of Hardscrabble Valley closely preceded the onset of volcanism during the latest Eocene-early Oligocene. A northeasterly-trending low area was present north of the Stendel Ridge area during the deposition of the Spears Formation. The zone apparently remained structurally, but not topographically, depressed during Eocene time from the southern part of Hardscrabble Valley, where Spears rests on middle or upper Abo rocks, northward to the southern Bear Mountains. Within the zone, middle and upper Permian rocks were preserved, but no Eocene sediments were deposited. Brown (1972) and Chapin (unpub.) have noted a thick sequence of Spears volcaniclastic sediments, lavas and ash-flow tuffs in this area that contain several features indicative of a persistent topographic low. Included among these features is the presence of conspicuous flows of "turkey-track" andesite, which Chapin (pers. comm., 1975) reports that, like the tuff of Nipple Mountain, flowed down narrow paleovallies and are therefore generally found only locally. The unusual thickness and persistence of the "turkey-track" andesite within the zone indicates that the area was topographically low during Spears time. Another unit that distinguishes the Spears section in the area described is a distinctive conglomerate composed of silicified, hydrothermally-altered fragments of volcanic rock that are coated by reddish-brown hematite. The conglomerate, which is as much as forty feet thick in the southern Bear Mountains (Brown, 1972, p. 17) and 200 feet thick at Granite Mountain (Chapin, pers. comm., 1975), was apparently deposited by streams draining an area of volcanic and hydrothermal activity to the west or southwest of the area of this study. The conglomerate is not found in the Stendel Ridge area or further south in the district, indicating that that area was on the southern shoulder of the northeast-trending lowland during Spears time.

Faults marking the southeastern edge of the NE-trending zone appear to have existed at least as far south as the Nitt shaft (plate 1) and were later obliterated by the intrusion of the Nitt Monzonite. The Kelly-Graphic cross fault (plate 1 and fig. 8; Loughlin and Koschmann, plate 20) and the Chihuahua Gulch fault may be lesser structures related to the NE-trending zone. Movement along these latter faults during the early Oligocene cannot be documented, however.

Deformation of Oligocene Age

It is probably safe to state that the major structural features of the Kelly district are of middle to late Oligocene age. During this time, the extensive ash-flow sheets of the Hell's Mesa and A-L Peak formations were erupted and were accompanied by the development of large calderas. At least five cauldrons are known or suspected to exist within a 15 mile radius of Magdalena. Most of these structures overlap and have left a perplexing puzzle to unravel, as many of the cauldrons have only recently been recognized and have not been studied in detail. The Kelly mining district appears to be situated on the margins of two overlapping cauldrons, one of which was the source of the Hell's Mesa tuff (30-32 m.y.) and the other may have accompanied eruption of one or more of the units of the A-L Peak Formation ($\sim$29 m.y.). Most of the major faulting during the Oligocene in the Kelly district appears to have ended before the Nitt and Anchor Canyon stocks (28 m.y.) were intruded, thus fixing the age of the deformations within fairly narrow limits.

Any attempt at interpreting the structural history of the district must also explain those features related to structure. It may be of some value to view the Kelly district as a whole in order to distinguish areas with similarities and to identify those features that appear anomalous or unusual.

One may define at least four north-trending zones that seem to contain similarities with regards to structure and rock units but that are distinct from the other zones. Figure 9 illustrates the various zones identified in this study. Data used in composing this figure has come from this study as well as from Loughlin and Koschmann (1942) and Iovenitti (1977) and covers most of the area originally mapped by Loughlin and Koschmann (1942), part of which was not remapped in this study. The reader is referred to plate 1 and figures 8 and 9 to aid in following the discussion below.

The easternmost of the zones consists of the crestal part of the range and is bordered on its west side by a line connecting the NNW-trending belt of Precambrian outcrops through the center of the district. East of this line, the rocks are generally of gentle to moderate westerly dips (10°-30°) and form monoclinal blocks composed of rocks of the Kelly Limestone and lower Sandia Formation. An exception to this generality is found in the large block of Madera and Sandia rocks on the west flank of Tip Top Peak (approximately 3000 feet ENE of the Waldo shaft) which is composed of younger rocks and is of generally steeper dip.

A second zone comprised of rocks having gentle to moderate dips, with local jumbling, is located to the west of the first zone and is bordered on the west by the arcuate belt of outcrops of the latite porphyry dike in the southern part of the district, by the Waldo fault north of Chihuahua Gulch, the Waldo-Madera fault zone in the vicinity of the Waldo Mine, and by the northward extension of the Waldo fault in Hardscrabble Valley. This second zone is comprised almost wholly of Paleozoic rocks and essentially defines the main ore zone of the Kelly district---that zone in which all of the major mineralization discovered to date has been found.

A third zone is found west of the main ore zone and is comprised of rocks of the Abo, Spears and Hell's Mesa Formations that form two large monoclinal blocks. One is located in the southern part of the district and is bounded on the east by the main ore zone and on the west by the Smith and South Camp faults. The second block makes up the bulk of Stendel Ridge and is bordered on the east by the main ore zone and on the west by the Nitt Monzonite and the NE-trending fault that separates the bulk of Stendel Ridge from the low hills to the northwest. The block in the Stendel Ridge area has a greater westward tilt and is more intensely altered than the block in the southern part of the district. This third zone does not form a continuous band through the length of the district, as do the first two, but is interrupted by the Kelly-Graphic fault block which is bounded on the south by the Chihuahua Gulch fault and on the north by the Nitt Monzonite.

The fourth zone is composed principally of rocks of the upper Hell's Mesa tuffs, the A-L Peak Formation and the andesite of Landavaso Reservoir. It is bordered on the east by the monoclinal blocks of the Abo and Spears rocks south of Chihuahua Gulch and by the main ore zone north of Chihuahua Gulch. The rocks of this fourth zone are characterized by intense faulting and moderate to steep dips. Silicification or other minor mineralization is found along most or all of the faults within the zone. This fourth zone does not seem to have a continuation north of the southern boundary of the Nitt Monzonite.

Rocks west of the fourth zone include what appear to be much-broken andesite of Landavaso Reservoir overlain by the Upper Tuff in the southern part of the district and by relatively unbroken, moderately to poorly-welded ash flow tuffs, volcaniclastic sediments and andesites in the area west of the Waldo and Kelly mines (plate 1) and may include the tuffs and volcaniclastic sediments that form the low hills northwest of Stendel Ridge.

The first three zones described above end abruptly against the Unity fault or the North Fork Canyon fault zone and the outcrops of the cauldron fill facies of the Hell's Mesa tuff. The fourth zone appears to continue further south beyond the area of this study.

Faults related to the North Baldy Cauldron

The Unity and North Fork Canyon faults are interpreted to be structures comprising a portion of the northern border of a caldera formed during the eruption of the Hell's Mesa tuff. The center of this caldera is believed to be located somewhere in the central or southern Magdalena Range. As the central block of the caldera subsided, displacement along the outer ring faults occurred, exposing rocks of the Spears, Abo and Madera formations along the northern wall. Some collapse of the wall must have occurred at this time to form the breccias interbedded with the Hell's Mesa tuffs south and west of North Baldy Peak. With further subsidence of the central block, settling along the Unity and North Fork Canyon faults continued, dropping the entire section of the Madera down, to be later covered by the ash-flow tuffs and interbedded landslide breccias of the caldera-fill facies of the Hell's Mesa Formation. The small size of the breccia fragments and limited extent of the individual mesobreccia units intercalated with the tuffs may indicate that a relatively small amount of topographic relief was present in this area during caldera collapse. The mixture of Spears, Madera and Abo fragments in the breccias may indicate that the lowermost Spears and upper Madera-lower Abo were exposed in the caldera wall. Alternatively, the fragments of Paleozoic rocks in the breccia may reflect only reworked material from the lower Spears. Inasmuch as the caldera-fill facies overlies directly the Abo and Madera rocks north of the North Fork Canyon fault (plate 1), the first hypothesis seems most likely. Details concerning the actual extent of the North Baldy cauldron are not known as of this writing.

Faults related to a cauldron west of the Kelly district

The four structural-lithologic zones described in the first part of this discussion are also interpreted to be related to caldera collapse centered west of the main part of the district. When viewing the district as a whole, it is apparent that each of the zones represents a belt of rocks that has been faulted down relative to the zone that borders it on the east. The zones alternate between those comprised of monoclinal, westward-dipping blocks (first and third zones) separated by somewhat narrower zones of moderately- to steeply-dipping rocks that are locally jumbled—the rocks dip at various angles with somewhat divergent strikes.

Figure 8 shows the major faults of the district and their interpreted or known offsets. The faults that separate the second from the third and third from fourth zones south of Chihuahua Gulch are of major displacement--greater than 1000 feet. North of Chihuahua Gulch and south of the Nitt Monzonite, the Waldo-Madera fault zone is also one of major offset. Faults of unknown displacement separate the zones in Hardscrabble Valley.

Within or adjacent to the second zone (the main ore zone) are the dike-like latite porphyry of Mistletoe Gulch and the Waldo-Madera fault zone--two key features which help indicate the structural environment of the district. The discontinuous line of outcrops of the latite porphyry form an arcuate band through the center of the district (plate 1), which changes in strike from NNE in the southern part of the area to northwest in the area of the Mistletoe tunnel. The northwest trend is extended by occurrences of the latite in the lower levels of the Waldo Mine (see figs. 5 and 10). The latite porphyry is interpreted to be part of a ring dike occupying a deeply-penetrating structure at the margin of the caldera. The latite intruded the fault zone shortly after collapse of the caldera, as it appears to pre-date the mineralization and alteration. Available exposures indicate that only minor post-intrusion movement has occurred along the structure.

The Waldo-Madera fault zone is one of the most intriguing features of the entire Kelly district. The 500-foot-wide zone of jumbled Madera Limestone extends approximately 2800 feet southward from Nitt Monzonite (plate 1). On the surface, the zone is expressed by a number of blocks of recrystallized and silicated limestone of various sizes that generally have a northerly strike and steep dips that range from 50° westward to 80° eastward. Small breccia zones may be observed between many of the larger blocks. The zone extends at least 1500 feet below the surface throughout most of its length and has been extensively explored above the 6500 elevation in the area of the Waldo shaft, as it contained several significant zinc-lead-copper orebodies. Figures 5, 10 and 11 are slightly modified mine maps from ASARCO files which illustrate most graphically this complex feature. Figures 5 and 10 are cross-sections whose positions are noted on figure 11.

The jumbled limestones and shales are bordered on the west by a complexly-faulted mass of Hell's Mesa and flow-banded tuffs, which also show some evidence of jumbling and brecciation. The flow-banded unit is welded to the Hell's Mesa in several locations near the Waldo Mine, indicating that it was very hot and implying that its source was nearby. Chapin (pers. commun., 1976) believes these to be the only exposures where the flow-banded unit is welded to the older rocks.

The jumbled zone is bordered on the east by a monoclinal block of Sandia shales and limestones which are capped in one area just north of the Ida Hill tunnel by a thin plate of Madera Limestone (plate 1). The contact of the plate is discordant, as shown in figure 10, and was slightly mineralized. The contact is exposed in a small prospect driven into the southern edge of the plate. Here imbricated fault breccia indicates that the relative moment of the plate at that point was eastward.

The age of these features can be closely bracketed, as they occurred shortly after or during the initial eruption of the flow-banded member of the A-L Peak Formation (29 m.y.), but before the intrusion of the Nitt and Anchor Canyon stocks (28 m.y.) and the mineralization that followed.

The origin of the Waldo-Madera fault zone is poorly understood, but several hypotheses can be presented:

(1) The zone is a broad band of faulting that has had complex movement related in part to uplift and rotation of the range during the beginning phases of basin and range deformation. Repeated movement along both the Waldo and Madera faults at different times may have caused the jumbling observed.

(2) The zone may represent some sort of chaotic breccia similar to the Armagosa Chaos in Death Valley, California, described by Noble (1941). He gave as characteristics of the chaos:

> (a) The arrangement of the blocks is confused and disordered--chaotic.
>
> (b) The blocks, though mostly too small to map (at a scale of 1:2,5000), are vastly larger than anything that could be called a breccia; most of them are more than 200 feet in length, some as much as a quarter of a mile, and a few are more than half a mile in length.
>
> (c) They are tightly packed together, not separated by much finer-grained material.
>
> (d) Each block is bounded by surfaces of movement; in other words, each is a fault block.
>
> (e) Each block is minutely fractured throughout, yet the original bedding in each block of sedimentary rock is clearly discernible and is sharply truncated at the boundary of the block. Commonly the bedding, even of incompetent beds, is not greatly distorted.

The Armagosa chaos covers a large area in the Death Valley region and occurs as the upper plate of a thrust (?) fault. The remaining thickness of the chaos does not greatly exceed 2000 feet, but Noble (*op. cit.*, p. 965) states that it may have been much greater.

Many of the characteristics of the Armagosa chaos apply to the jumbled blocks of limestone in the Waldo-Madera fault zone, and it is possible that the jumbled zone is the down-faulted and preserved remnant of a chaotic mass that had an unknown, but probably limited, extent in the Kelly district.

(3) The zone represents a large mass of caldera collapse-related landslide material similar to the megabreccia in the central San Juan Mountains of Colorado described by Lipman (1976). The zone is the result of large-scale collapse of the oversteepened cauldron walls as the central block of the cauldron subsided.

Although there may be other possible mechanisms by which features such as the Waldo-Madera fault zone may form, the three described above seem most possible, given the present state of knowledge of the geology in the Magdalena area. The first hypothesis may be discounted partly because evidence of basin and range deformation has not been documented to have begun earlier than about 26 m.y. ago in the Magdalena area (Chapin, pers. commun., 1977). Also, the sheer size of the fault zone is atypical of basin and range faults known elsewhere (Chapin, pers. commun., 1975).

The second hypothesis can also be discounted by virtue of its age (28-29 m.y.). The megabreccia could possibly have been formed along a high-angle reverse fault related to Laramide deformation, but no other evidence of structures of this type and magnitude in this part of New Mexico have been recorded.

The age of the structure and regional structural setting support the third possibility. Large cauldrons of middle or late Oligocene age surround the Kelly district and the margins of three of these features are known to exist within five miles of the Kelly townsite. The North Baldy cauldron, source of the Hell's Mesa tuff, is south of Kelly and the Socorro cauldron, source of the tuff of Allen Well, is to the east.

In the scenario suggested by this hypothesis, large-scale collapse of the area west of the Kelly district accompanied the eruption of the flow-banded member of the A-L Peak Formation. The actual locus of collapse is unknown, as the caldera is now deeply buried under later intracaldera andesites and younger tuffs, but it is believed to be located somewhere in the area west of the Kelly townsite (fig. 7).

During collapse, major movement along the Grand Ledge and Madera faults and the fault zone now occupied by the latite porphyry of Mistletoe Gulch dropped precaldera rocks down on the west. Some adjustments may also have occurred along the North Baldy and Unity faults at this time, but the North Fork Canyon fault appears to have experienced little additional movement after the deposition of the Hell's Mesa tuff. In the area of the Waldo Mine, the precaldera rocks appear to have included all rocks older than the flow-banded tuff. Rapid loss of support on the west caused oversteepening of the caldera wall along the Madera fault zone. Landslides--apparently on a spectacular scale--occurred, dumping precaldera rocks into the void. The rocks may have slipped on the Sandia shales or perhaps the thin shales in the lower Madera. The rocks may have moved as a semi-coherent mass in which the rough stratigraphic sequence was maintained. Some mixing of the rocks occurred, resulting in blocks of Hell's Mesa tuff surrounded by Madera Limestone and large pieces of flow-banded tuff enclosed(?) in blocks of Hell's Mesa tuff. The deeply-penetrating ring fracture was later intruded by masses of monzonite, latite porphyry and assorted dikes.

Lipman (1976) has described large megabreccias in the San Juan volcanic field of Colorado that in a general sense seem identical to the brecciated mass in the Waldo-Madera fault zone. Careful work is needed in the Waldo Mine to confirm or refute this tentative correlation. Masses of intermediate to silicic igneous rock that are common between the breccia fragments were previously interpreted to be dikes. Closer examination may reveal that they are, in part, volcanic rocks mixed with the limestones. Further attention should be given to the band of complexly-faulted Hell's Mesa and A-L Peak tuffs west of the Waldo fault, as these rocks also appear to be incorporated in the megabreccia. Should future work confirm this correlation, the rocks should be relegated to a separate unit, perhaps termed the Waldo Megabreccia member of the A-L Peak Formation.

Most of the faults within the Waldo-Madera fault zone resulting from the caldera collapse originally were probably vertical or dipped steeply westward. Later rotation of the range during basin and range deformation has resulted in the present configuration by steep, east-dipping faults and fractures within the zone bordered by steep, westward-dipping basin and range faults (see figs. 5 and 10).

The plate of flat-lying Madera Limestone overlying steeply-dipping Sandia rocks north of the Ida Hill tunnel (plate 1, fig. 10) is also interpreted to be a landslide feature, although the apparent eastward movement indicated by the imbricated fault breccia fragments presents an enigma. Apparently the precaldera rocks above the Sandia in this area had already collapsed into the caldera and the Sandia was tilted westward somewhat at the time the limestone block was emplaced. The source of the limestone was probably to the east or north, as a source to the west does not fit with present interpretations. The apparent eastward movement indicated by the fault breccia may be due to counter-clockwise rotation of the limestone mass as it slid downslope.

Structural Adjustments During and After Stock Intrusion

Some structural activity seems to have accompanied the period of stock intrusion that immediately followed collapse of the cauldron centered west of the Kelly district. Slight doming of the Abo rocks may have occurred as the latite porphyry of Mistletoe Gulch intruded the area between the Chihuahua Gulch and O.C.O. faults (plate 1, fig. 8). Intrusive pressure may also have formed the two horsts of Precambrian rocks east of the Kelly and Waldo Mines (plate 1). These blocks occur along one of the margin fault zones of the Magdalena cauldron. Intrusion of the Nitt monzonite or latite porphyry, or both, along the zone in this area may have caused differential uplift of the blocks.

Minor adjustments along NNW-trending faults appears to have immediately followed stock intrusion. The mafic and white rhyolite dikes were intruded at that time and were closely followed by mineralizing solutions.

Miocene Faulting

Structural activity following the intrusion of the Nitt and Anchor Canyon stocks was dominated by basin and range-type faulting. In the central and southern parts of the Kelly district, the South Camp fault appears to be the range-bounding structure. South of Chihuahua Gulch, rocks of the A-L Peak Formation are in juxtaposition with rocks that are progressively higher in the Spears Formation as the South Camp fault is traced southward until it intersects and truncates the northwest-trending Smith fault. South of this point, rocks of the Andesite of Landavaso Reservoir and Potato Canyon Rhyolite were faulted against A-L Peak units. The similarity of the andesites in the two groups caused Loughlin and Koschmann (1942) to miss the faulting in this area.

Displacements across the South Camp fault is estimated to be about 1100 feet in the area south of Chihuahua Gulch and about the same at the southern edge of the mapped area. The fault continues southward for several miles near the western crest of the Magdalena Range (Krewedl, 1974).

The range-bounding fault cannot be traced with certainty north of Chihuahua Gulch. Some post-intrusive movement on the Waldo and Madera faults is evident, and it appears that the Waldo fault may have experienced the greater displacement. Movement along the Waldo fault appears to have resulted in the truncation of the limestone megabreccia in the Waldo mine and juxtaposed A-L Peak rocks against lower Madera limestones just north of Kelly (plate 1) and brought middle(?) Abo rocks against lower Madera just south of the townsite. Near the Waldo mine, thick, jumbled Hell's Mesa and A-L Peak rocks were faulted against the limestone megabreccia (fig. 11). Movement along the Waldo fault zone further sheared and deformed the Abo sandstones to such a degree that ASARCO geologists did not recognize the unit.

The displacement on the Waldo fault during the Miocene is uncertain because the thickness of the jumbled Hell's Mesa and A-L Peak rocks is not known and the amount of displacement of the precaldera rocks during caldera collapse has not been ascertained. It would be reasonable to assume that at least 500 to 1000 feet of displacement has occurred, however.

In the Stendel Ridge area, the trace of the range-bounding fault is not exposed. It is inferred to be an extension of the Waldo fault and to run along the eastern base of Stendel Ridge, cutting off the Stendel fault, and to separate Abo sandstones from the steeply-dipping Madera Limestone west of the Vindicator fault (plate 1). Assuming a thickness of 1800 feet for the Madera, displacement on the Waldo fault in this area may exceed 1500 feet.

Further north, simultaneous movement on faults of the Magdalena-Morenci lineament dropped the ground between the Magdalena Range and the main part of the Bear Mountains. Faulting along the zone resulted in the formation of the San Augustin graben, a southwestward bifurcation of the Rio Grande rift (Chapin, 1971a).

Uplift of the range was accompanied by westward rotation. The average rotation in the northern part of the Magdalena Range appears to be about 30°, based on the uniform tilt of the Spears in the southern part of the district. Differential rotation may have occurred in blocks bordered by the larger transverse faults, such as the O.C.O. and Chihuahua Gulch faults, resulting in an apparent right lateral offset in the range-bounding fault as it crosses those structures (plate 1).

Uplift was apparently rapid at times, as oversteepening induced large landslides throughout the district. Several remnants of these landslides were mapped during this study (plate 1). Loughlin and Koschmann (1942, pp. 73-75) identified six pediment surfaces in the district, resulting from different stages of post-intrusion uplift. They have elaborated on these pediments in another paper (Koschmann, and Loughlin, 1934).

Uplift of the Magdalena Range persists today. Sharp fault scarps along the east face of the mountains attest to recent and continuing activity.

ECONOMIC GEOLOGY

The Magdalena district has been one of the foremost producers of zinc and lead in New Mexico, having produced at least $52 million worth of metals (at original prices). Partial production records compiled by Loughlin and Koschmann (1942, pp. 84-85) indicate that the district produced more than 230 million pounds of zinc, 100 million pounds of lead and 11 million pounds of copper during the years 1881 to 1940. Subsequent production to date might increase these figures 50 to 100 percent.

Mining activity in the district was essentially continuous from 1875 to about 1960. Sporadic production occurs today from the Linchburg mine and there is renewed exploration activity in and around the Kelly district.

The largest mines in the district are the Nitt-Graphic, Waldo, Kelly and Linchburg, from which at least 95 percent of the total production has come. Loughlin and Koschmann (1942) gave a detailed historical sketch of the area and discussed at some length the developments in the various mines prior to 1940. The reader is referred to their paper and its bibliography. Because Loughlin and Koschmann (1942) and Titley (1958, 1961) have given fairly detailed descriptions of most of the mines of the district and have gone to considerable lengths describing the various gangue and ore minerals found throughout the area, the remainder of this paper will deal with a description of the controls of mineralization, some of the aspects of the distribution and controls of certain features of the hydrothermal alteration found in the district, and suggestions for future prospecting in the immediate area.

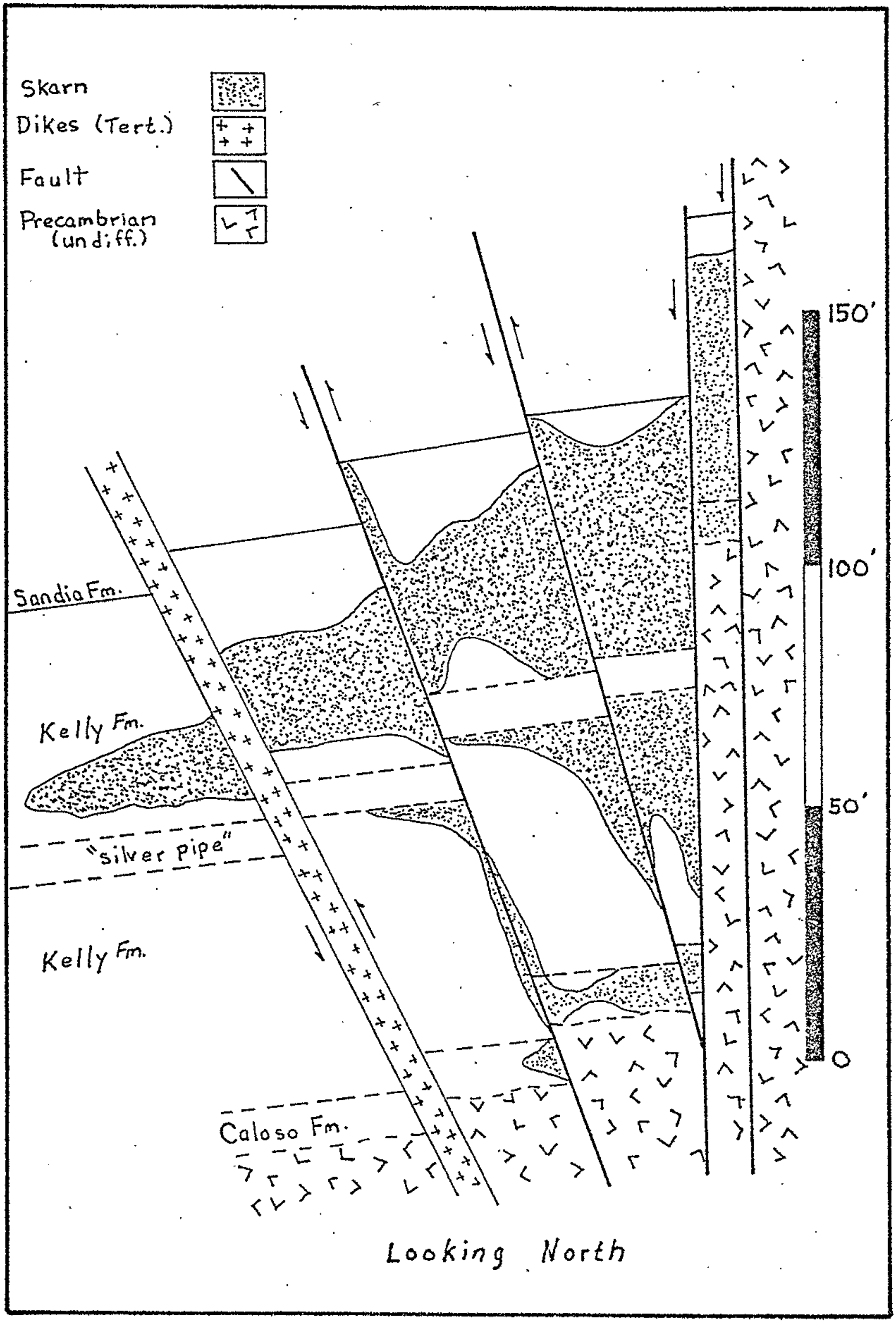
Ore Controls

Several factors are responsible for the positions and types of orebodies found in the Kelly district. All of these factors have been described in some detail by Loughlin and Koschmann (1942) and Titley (1958, 1961, and 1963) and are summarized below.

The main ore control in the district is the intersection of faults with reactive limestones, especially those of the Kelly Formation. Essentially all late Oligocene pre-ore faults were conduits for hydrothermal fluids, although the intensity of mineralization varies widely among individual faults and along strike of any individual structure. The intensity of mineralization also appears to be a function of the proximity to a large intrusive body. The largest orebodies in the Graphic, Waldo and Linchburg mines are all within a few hundred feet of major intrusive bodies, and although no such relationships are known from the Kelly mine, the presence of a large mass of latite porphyry in the lower levels of the southern end of the Waldo may indicate a similar situation.

The Sandia Formation may have been an additional control over the shape of some of the orebodies as the relatively impermeable and unreactive shales may have acted as a dam over the more permeable and reactive Kelly Limestones. This relationship is suggested by the manto shape of several of the deposits (see fig. 12), although Titley (1958, p. 28) believes that the shales should not be considered an ore control in this way.

Figure 12. Generalized cross-section across the Linchburg orebody illustrating relationship of ore to the major structures and to the Kelly Limestone. Modified slightly after Titley (1958).


Skarn
Dikes (Tert.)
Fault
Precambrian (undiff.)
150'
100'
50'
0
Sandia Fm.
Kelly Fm.
"silver pipe"
Kelly Fm.
Caloso Fm.
Looking North

Titley (1958, 1961, and 1963) has described the controls over sulfide deposition and orebody zoning that certain silicate minerals had in the Linchburg mine. In short, his studies indicate that crystallization of silicate minerals including garnet and pyroxenes only slightly preceded, or were contemporaneous with, sulfide deposition. As the sulfides were deposited sphalerite preferentially replaced garnet and galena replaced both sphalerite and pyroxene. He also noted a regular sulfide zoning, with sphalerite most abundant closest to the fault and galena more common towards the outer edges of the orebody. The reader is referred to Titley's works cited above for details.

Rock Alteration

Propylitization is the most widespread type of alteration found in the Kelly district, affecting to some degree almost all of the volcanic and intrusive rocks. Minerals characteristic of propylitization include quartz, calcite, chlorite, epidote and sericite (Creasey, 1966), which occur in veinlets and as replacements of original rock minerals. Within the Kelly district, propylitic alteration has had significant effects on the volcanic rocks, especially the Spears Formation. Intense propylitization has changed the original purple and red colors of the Spears Formation to shades of green and gray in the Stendel Ridge area. Propylitic alteration of the Abo Formation at the eastern base of Stendel Ridge bleached the normally red sandstones and siltstones to shades of green and gray and prompted Loughlin and Koschmann (1942) to correlate these rocks with the Sandia Formation.

Propylitization has strongly affected the volcanic and intrusive rocks north of Chihuahua Gulch. In this area, chlorite has replaced biotite and hornblende in the dike rocks to various degrees and epidote, quartz and calcite occur in veinlets and as replacements of plagioclase and groundmass. Some areas contain large amounts of pyrite, which, when oxidized under supergene conditions, forms sulfuric acid; the acid has bleached the rocks and transformed much of the sericite into clays. Pyritization is most intense in the volcanic rocks west of the Waldo-Madera fault zone, north of the Waldo tunnel (see fig. 13) and in the area bordering the pass between the main part of Stendel Ridge and the low hills to the northwest. Disseminated pyrite is also common in the sedimentary rocks and ash flow tuffs of the intracaldera rocks that constitute the small crescent-shaped hill approximately one mile west of Kelly (plate 1). As a result of the oxidation of the pyrite, the rocks are generally mottled brown and white, and many of the details or rock texture have been partially destroyed.

Silicification is also a widespread alteration feature in the Kelly district. Large volumes of Kelly Limestone have been transformed to jasperoid in the eastern and southern parts of the district. Almost every exposure of the Kelly Limestone found along either side of the crest of the range has been at least partially replaced by light-gray, yellowish or reddish-brown jasperoid. This jasperoid often has a banded appearance, with layers of dense siliceous rock coated on both sides by masses of drusy quartz crystals (see fig. 14). The banding may be largely a reflection of the original thin bedding of the Kelly. Many of the bands are

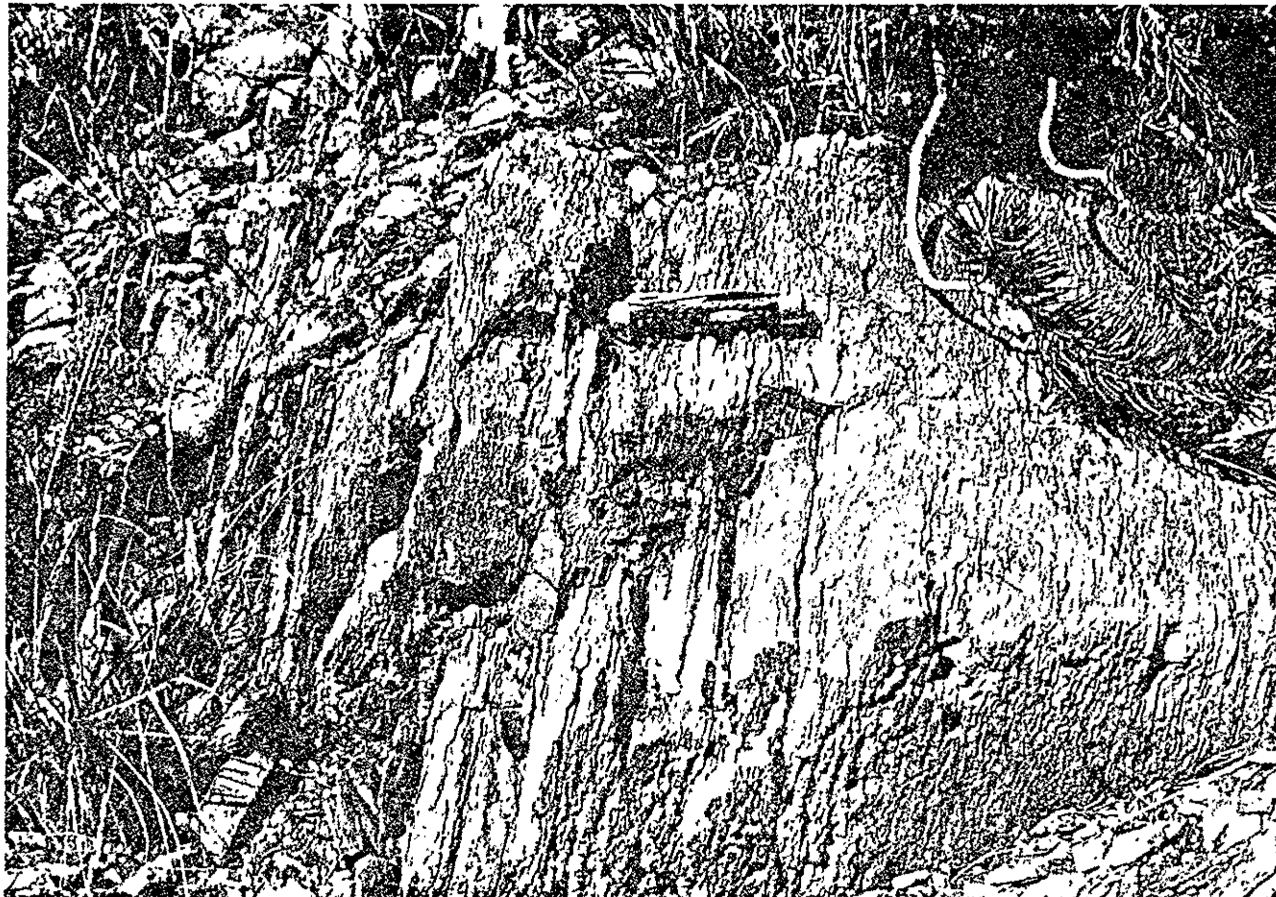


Figure 13. Photograph of the altered and bleached Pinnacles member of the A-L Peak Tuff northwest of the Waldo mine portal. Note the large silicified pumice fragments below and to the left of the knife.

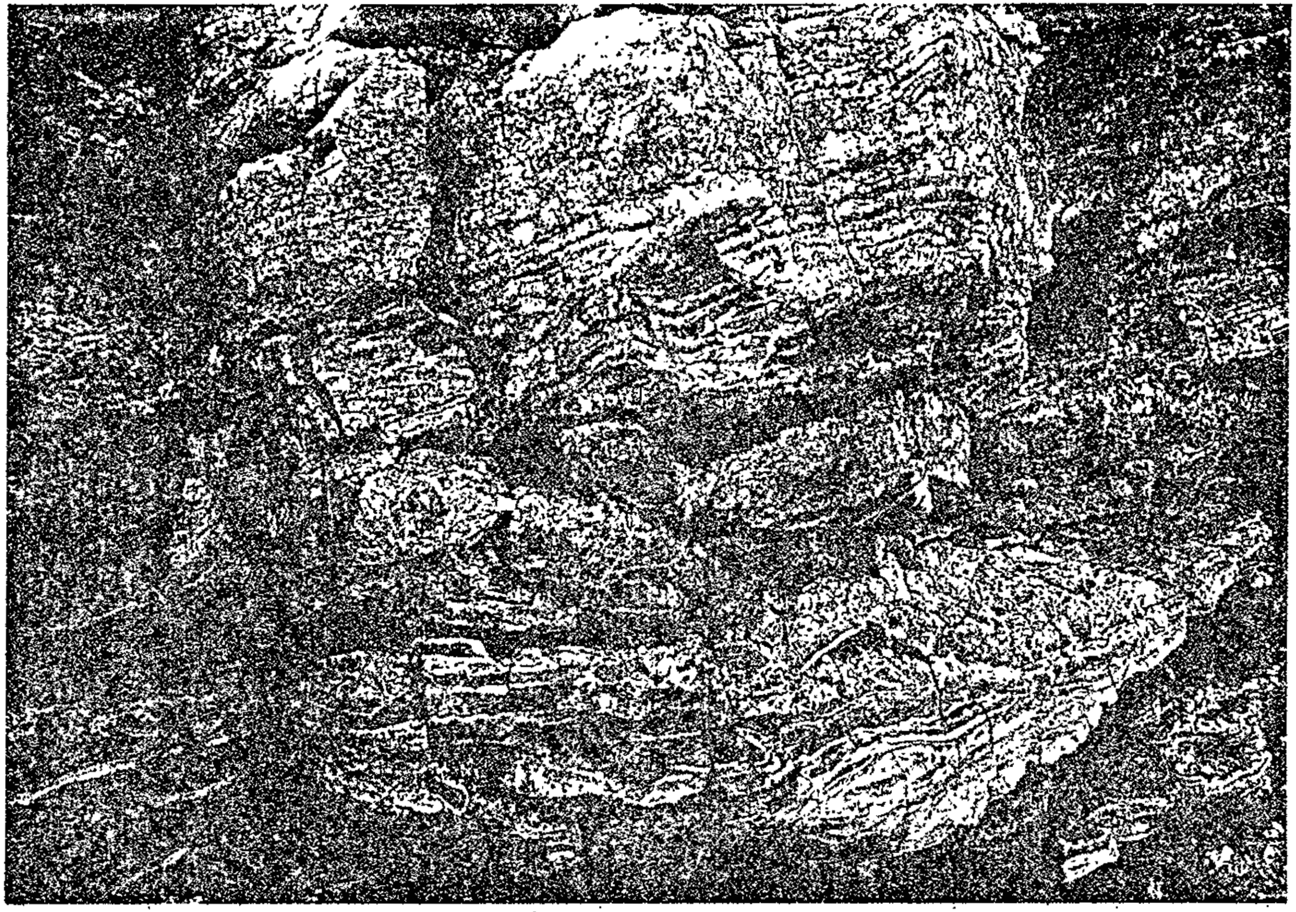


Figure 14. Photograph of jasperoidal Kelly Limestone exposed in outcrops on the crest of the range. Silica-rich solutions permeating the rock along bedding planes has resulted in a multi-colored jasperoid rich in accessory minerals.

irregularly contorted, which may indicate some change in volume of the original rock mass during silicification.

The fluids responsible for silicification of the Kelly appear to have been controlled by some of the north-trending, late-Oligocene extensional faults that in part preceded intrusion of the stocks and controlled ore deposition. The most intensely-altered Kelly is adjacent to these faults and to several transverse structures that connect individual strands of the system. The fluids responsible for silicification were probably related to those that created the large skarn ore bodies found in the district. The jasperoid commonly has small pods of lead and zinc mineralization, some of which have yielded a few tons of ore in the past. Sparsely disseminated pyrite, and occasionally, argentiferous galena, are common in the jasperoid, especially in the more intensely altered areas. Barite, calcite, fluorite and dolomite are common accessory minerals, especially in the area east of Kelly, and some gold and silver is apparently scattered throughout the mass. Recent widespread bulk sampling indicates that the amounts are sub-economic even at the present (1974) higher prices for the two metals.

An area of intense silicification is found near the Grand Ledge tunnel, where rocks of the Kelly Limestone and the underlying Pre-cambrian granite and argillite have been so intensely silicified as to render them indistinguishable. The area, which is up to 100 feet wide, extends along the Grand Ledge fault for several hundred feet. A roughly circular area of the most intensely silicified rock appears to be a breccia, as faint outlines of angular fragments can be distinguished in the mass. The area of this intense silicification lies at the southern end of the Linchburg orebody and directly above the quartz monzonite exposed in the Linchburg mine.

Silica-rich hydrothermal fluids have also affected the Paleozoic limestones and siltstones in Hardscrabble Valley. In contrast to the general silicification of the Kelly Limestone in the central and eastern parts of the district, the Madera Limestone has been converted to a dense mass of calc-silicate minerals over large areas in the northern part of the district. The limestones south and west of the Vindicator Mine (plate 1) have been largely replaced by an aggregate of diopside, chlorite, garnet, carbonate and quartz. The alteration is especially intense in the limestones west of the Vindicator and those nearest the projection of the Waldo fault to the west and north. Minor lead-zinc mineralization occurs in veins and as disseminations in the silicated rocks throughout the area. Of interest is the fact that the most intense silication occurs in limestones away from its contact with the Anchor Canyon stock.

A wide band of sanded, recrystallized limestone separates the silicated rocks from the stock north and west of the Vindicator Mine. The intensity of alteration is generally seen to increase near inferred or projected faults. Recent work has shown that a large area of skarnified, locally mineralized Paleozoic rocks also exists east of Granite Mountain, north of the Hardscrabble Valley area. If these rocks are part of a continuous zone of alteration and mineralization under the intervening alluvial cover, the belt of silicated sediments could extend for some 2-1/2 miles northward from the Vindicator area.

Suggested Areas for Additional Prospecting

<u>Hardscrabble Valley</u>. Excellent potential exists for the discovery of new orebodies in the Hardscrabble Valley area. The presence of high-grade zinc-lead-copper mineralization in the Vindicator Mine is ample indication that the conditions for the formation of ore deposits were present in the area. Drilling by ASARCO and the New Jersey Zinc Company has indicated approximately 25,000-35,000 tons of material grading 8 to 10 percent combined zinc, copper and lead. This mineralization occurs along the Vindicator fault, in Madera(?) limestones, about 500 feet south of the Vindicator shaft. High-grade mineralization is also known to occur in the Vindicator itself, where approximately 5,700 tons of ore containing about 25 percent of the combined metals was produced (Loughlin and Koschmann, 1942, p. 161). The ore occurs in the southern part of the mine workings. Significantly, the ground below the mine workings and between the mine and the mineralization further south has not been explored. The area includes the possible intersection of the Vindicator fault with an inferred transverse fault approximately 300 feet south of the Vindicator shaft, which should be an especially favorable area for exploration.

The area of possibly greatest potential for the development of substantial amounts of mineralization in the entire district is in the belt of moderately to intensely silicated limestones and siltstones that extends northward from the Vindicator mine area. The distribution of the skarn and associated minor sulfide mineralization indicates that the mineralization could be related to one or more intrusive bodies located at moderate depths along the Waldo and/or the Vindicator faults. Exploration efforts should be directed towards defining the possible centers of mineralization. Special attention should be given to areas of intense silication that also contain scattered zinc, lead or copper mineralization at surface. Such areas are found near the Vindicator Mine and near some short prospect shafts approximately 1,500 feet NNW of the Vindicator. Similar areas are found east of Granite Mountain, north of Hardscrabble Valley.

Azurite Mine area. Significant copper mineralization is found in the Azurite Mine, located approximately 3,600 feet south of Vindicator Mine (plate 1). At the Azurite, the Nitt monzonite has been intensely shattered, altered and locally mineralized over a zone known to be at least 300 feet wide. Lesser, scattered copper mineralization can be found in altered monzonite at least 1,000 feet north and 2,000 feet south of the mine. Chalcopyrite and rare bornite occur with pyrite, pyrrhotite, galena and shalerite in quartz and carbonate veins and veinlets in monzonitic rock that has been altered to a mixture of chlorite, sericite, serpentine, quartz and carbonate. Some possible secondary biotite and orthoclase may be present in veinlets or as local replacements of earlier minerals. The mineralized zone appears to extend westward under the alluvium for an unknown distance. Structures on the east side of the zone appear to dip consistently toward the east, while those on the west side dip generally west, implying that the zone of favorable breakage may widen with depth.

The mineralization at the Azurite is typical of that found in "porphyry copper"-type deposits. A channel sample cut in the walls of the main drift in the mine averaged approximately 0.25 percent copper over a length of 250 feet. The zone of mineralization is virtually untested to depth and in the adjoining alluvium-covered areas.

Exploration Possibilities in the South End of the District. The southern end of the Kelly district remains relatively unexplored, despite numerous indications that significant mineralization may be present. The zone of greatest potential is necessarily restricted to the areas of Madera Limestone outcrop south and west of the Linchburg Mine (plate 1). Ground west of the line of exposures of Mistletoe latite is unfavorable because faulting has dropped the host limestones too deeply for practical exploration at this time. Ground east of the Grand Ledge fault and north of the Unity fault appears to have been unfavorable for the formation of pyrometasomatic mineral deposits, perhaps because the Kelly Limestone was not buried as deeply as it was to the west at the time of mineralization.

Several areas are worthy of detailed scrutiny in this southern part of the district, including the area west of the Linchburg mine, the margin of the concealed Linchburg stock, and the Kelly and Madera Limestone near North Baldy Peak.

Linchburg Mine Area. Over four hundred thousand tons of high-grade (+13% combined) zinc-lead-copper ore has been mined from a pyrometasomatic deposit along the Young America-Grand Ledge fault zone. As the mine has been worked almost wholly by lessees who were forced to ship ore directly to a mill at Hanover, New Mexico, only the higher-grade material was mined. Substantial amounts of low to medium-grade (5% to 7% combined zinc-lead-copper) is thought to be readily accessible in the mine. Also, little systematic exploration was done to test for mineralization in Kelly Limestone in the down-faulted blocks west of the mine workings. The intensity of the mineralization in the mine is a good indication that the Kelly may be mineralized wherever it was cut by pre-mineral faults in the area.

The character of the Linchburg stock has never been determined since its discovery nearly 30 years ago. Four shallow holes were drilled south and west of the south end of the Linchburg workings in an attempt to determine the extent of this body. All four holes penetrated the sparsely mineralized equigranular monzonite, but the southern and western contacts were never delineated. The Kelly Limestone around the periphery of this intrusive body should be an excellent prospecting target, as the contact would provide a good channelway to the Kelly for any mineralizing fluids.

<u>North Baldy Area</u>. Zinc-lead mineralization in hedenburgite-garnet skarn replacing the Kelly Limestone on the southern flank of North Baldy Peak indicates another possible center of mineralization similar to that at the Linchburg. Silicate minerals have replaced the upper part of the Kelly Limestone adjacent to white rhyolite dikes in this area (see figs. 15 and 16). A small outcrop of similar mineralization is also to be found adjacent to the west trending latite dike along the North Fork Canyon fault zone. A recent wagon-drilling project has indicated approximately 50,000 tons of material grading 5 percent combined zinc and lead is present and is confined to a thin zone in the upper Kelly. The northern and western limits of the mineralization were not defined. More recent core drilling on the western and southern flanks of the peak was

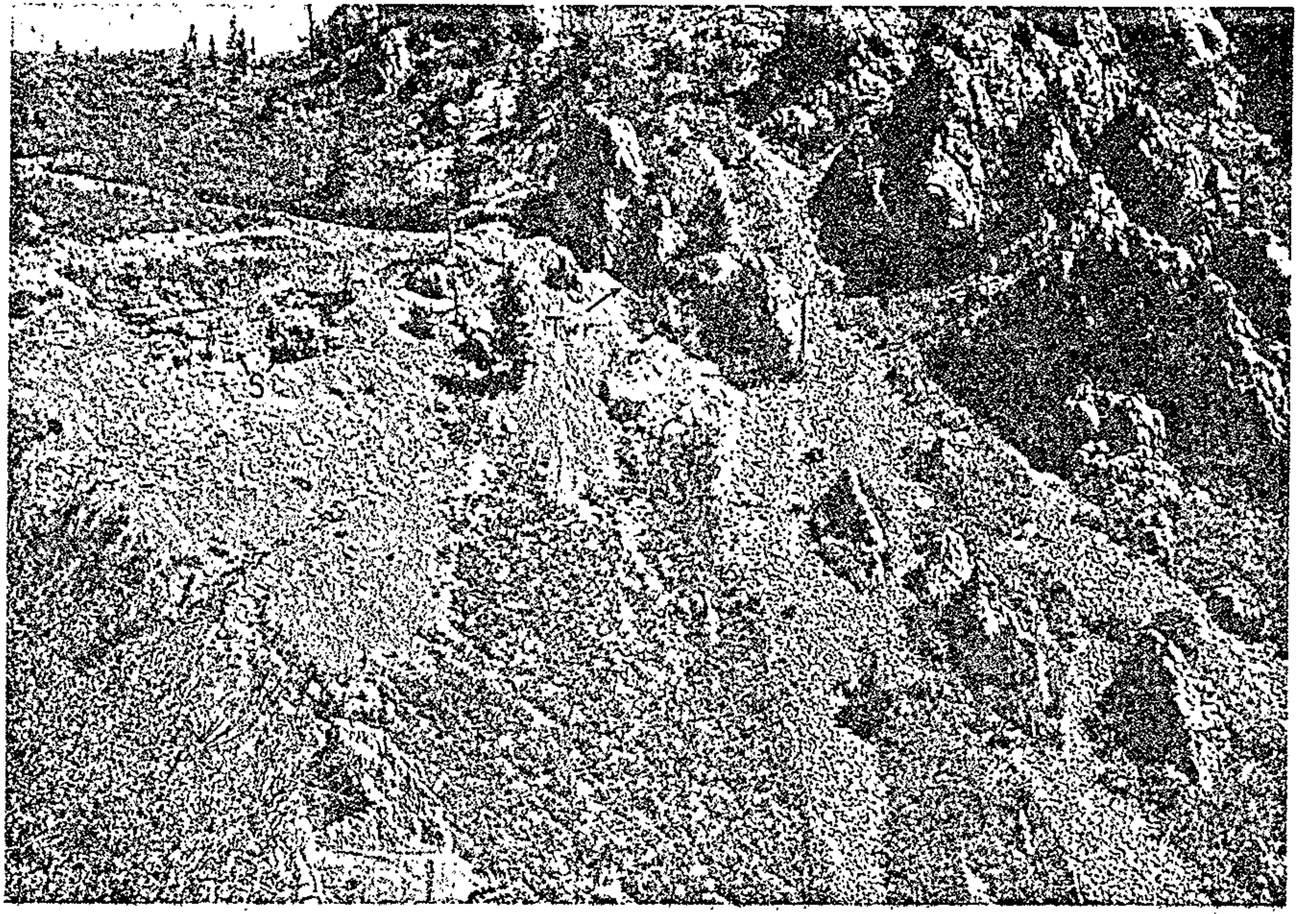


Figure 15. Photograph of the skarn occurrence east of North Baldy Peak showing the relationship of the skarn(s) to the white rhyolite dike (Twr).

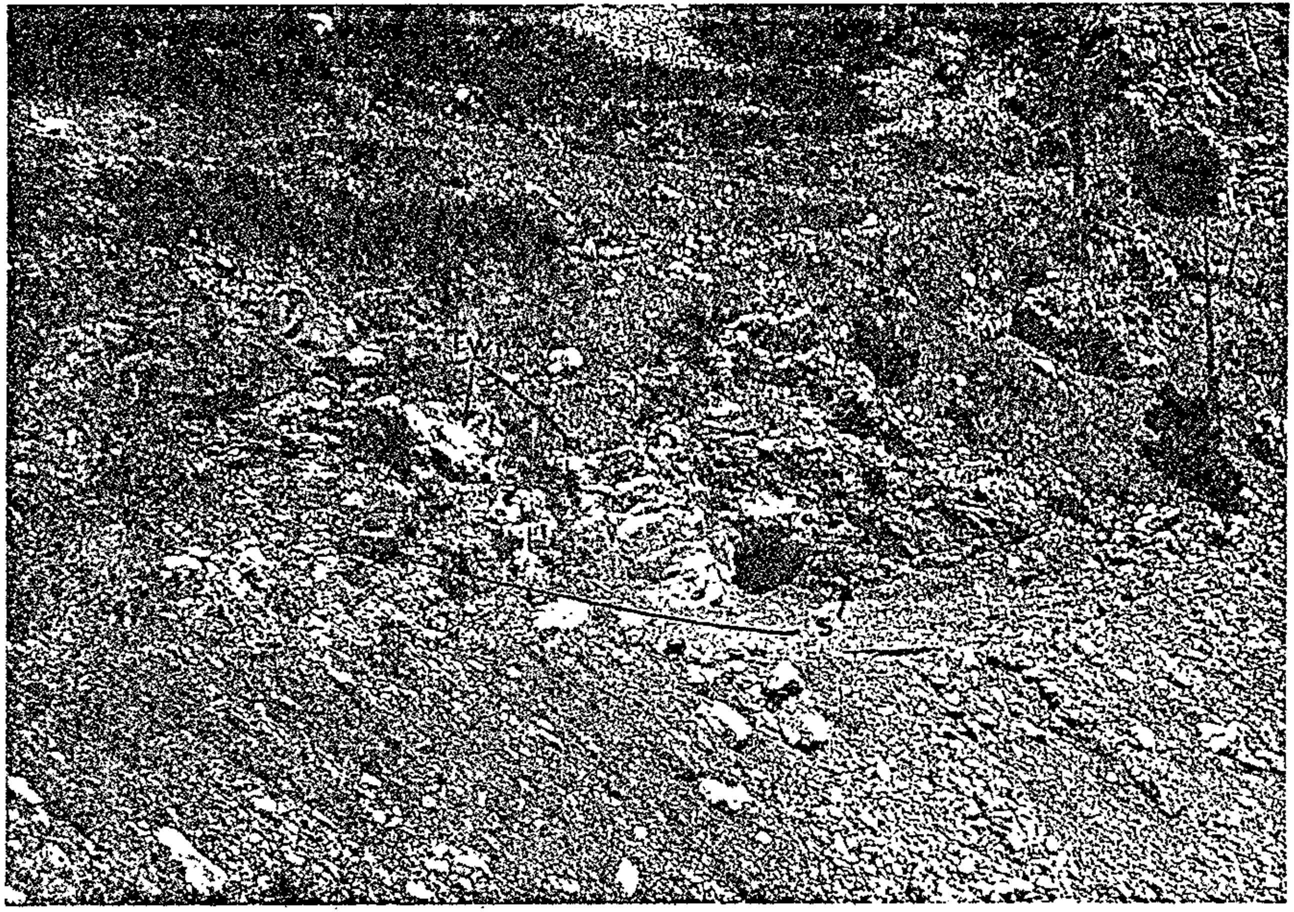


Figure 16. Close-up of the skarn occurrence east of North Baldy Peak. Skarn(s) is dark-brown material surrounding adit in photograph. A rhyolite dike (Twr) cuts the rock just to the left of the adit opening. Looking NNE.

aimed at exploring the Kelly Limestone along the major fault zones in hopes of discovering more substantial mineralization. This drilling resulted in the discovery of a monzonitic intrusive body that had penetrated the Paleozoic section under the peak to an altitude of approximately 9,100 feet. The body appears to be in part an intrusive breccia composed of fragments of foliated Precambrian greenstone or argillite in a fine-grained intrusive matrix. All rocks appear to be intensely altered to sericite, chlorite and serpentine with some possible secondary potash feldspar and quartz flooding and veinlet development. Pyrite and chalcopyrite are sparsely disseminated in the rock and several narrow, strong lead-zinc veins cut the mass. The monzonitic mass had stoped out the Kelly Limestone along the western side of the peak and the Sandia shales had locally been strongly altered to a talc-chlorite mass in three of the four holes. Approximately 10 feet of low-grade zinc-lead mineralization was cut in a hole drilled on the south flank of the peak. The mineralization was in a chloritized hedenbergite(?) skarn in the upper part of the Kelly Limestone. Below this was silicified and recrystallized limestone containing minor mineralization which was in contact with the intrusive.

The exploration program did not fully evaluate the mineralization in the North Baldy area, but has indicated that good potential exists for the discovery of substantial amounts of pyrometasomatic ores in the Kelly around the margin of the monzonitic intrusive and to the north along the North Baldy fault. Should later exploration efforts find ore in these areas, attention should be directed towards the Kelly and Madera limestones on the western (downfaulted) side of the North Baldy fault. The excellent structural preparation and abundant silicification and low-grade mineralization along the fault zone bodes well for the discovery of mineralization at depth.

The presence of strong, north-trending quartz veins containing lead, zinc and copper cutting the cauldron fill facies of the Hell's Mesa Formation west of North Baldy Peak (fig. 17) indicates that conditions may be favorable for the discovery of replacement deposits in the Kelly or Madera limestones along the North Fork Canyon fault. The monzonitic intrusion discovered recently under North Baldy Peak appears to be controlled by the margin faults of the North Baldy Cauldron and may extend westward along the ring fault. Deep exploration may be required, but the rewards could be substantial.

Figure 17. Photograph of veins cutting the cauldron-fill facies of the Hell's Mesa Formation west and south of North Baldy Peak. Looking SSW. v = veins.

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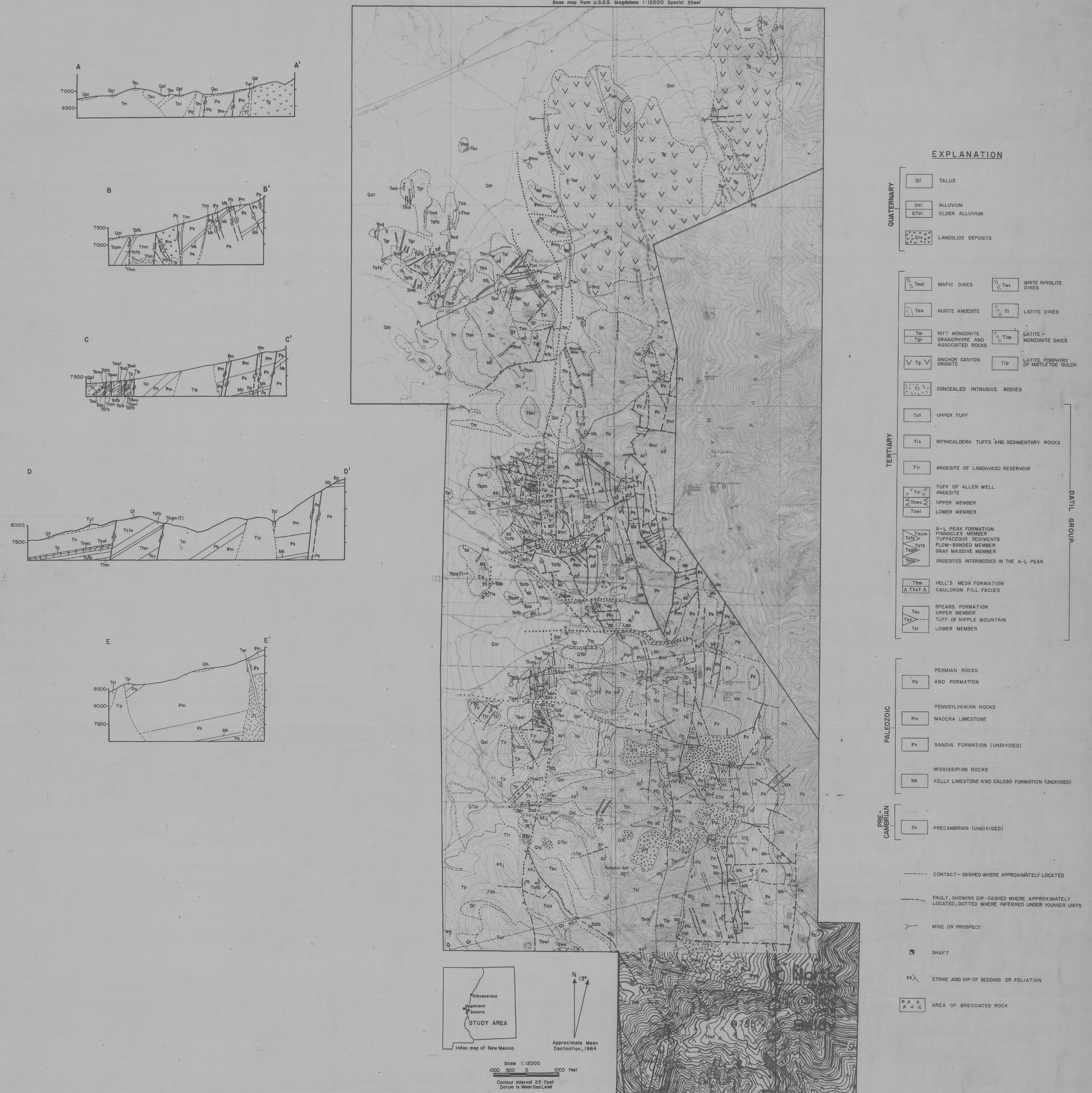
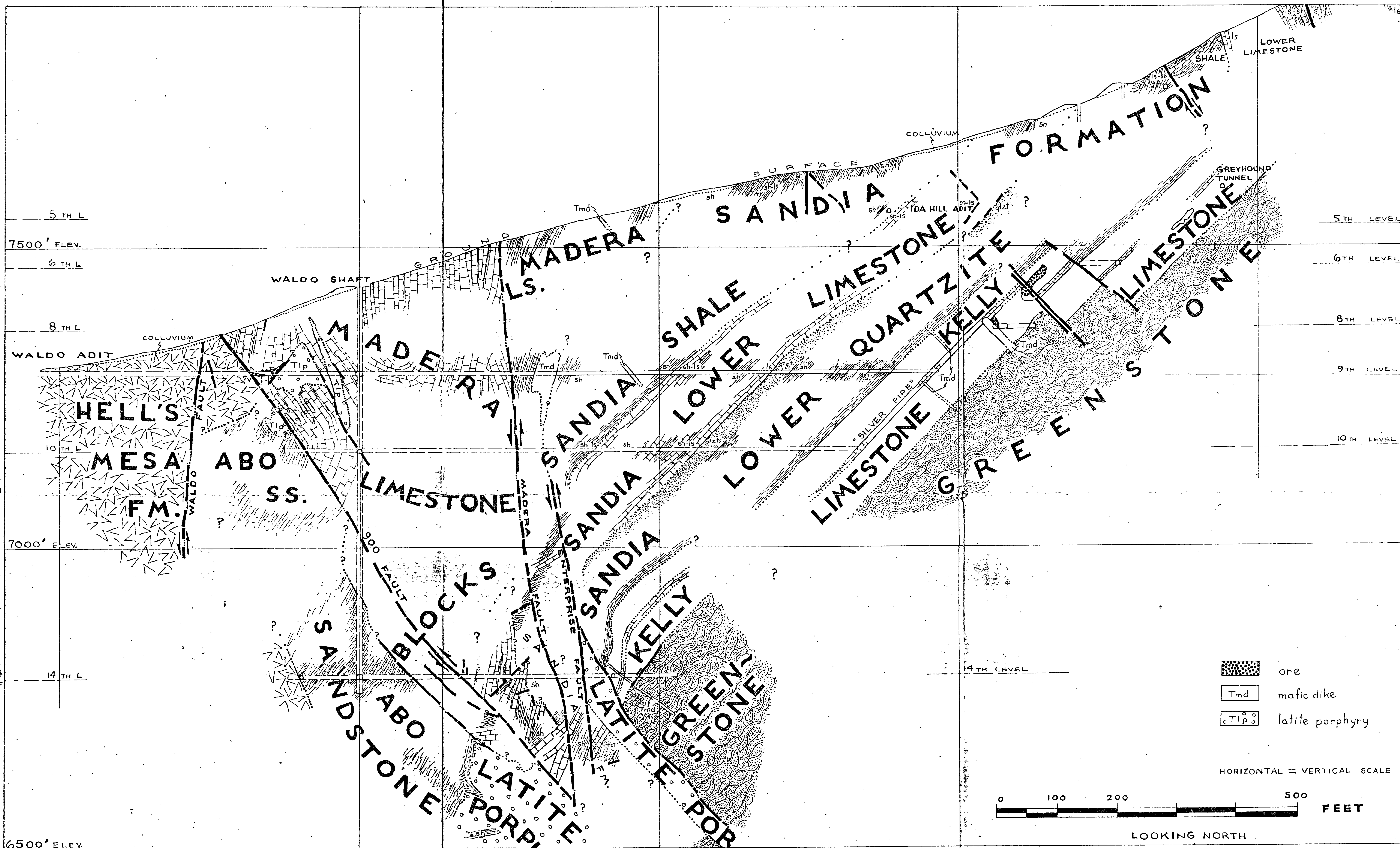


GEOLOGIC MAP AND SECTIONS OF THE KELLY MINING DISTRICT
SOCORRO COUNTY, NEW MEXICO

by

Robert B. Blakestad, 1978

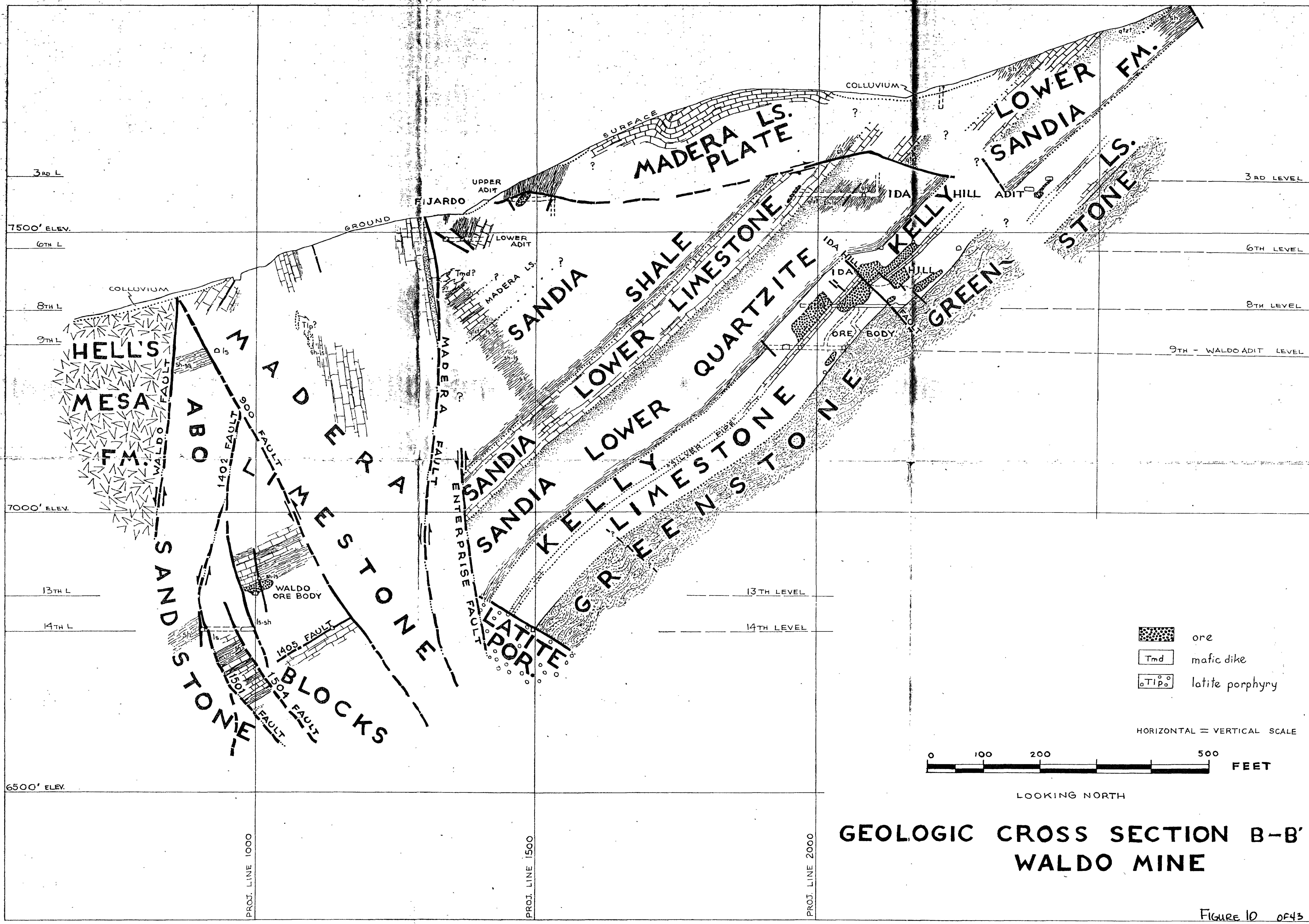


GEOLOGIC CROSS SECTION A-A'
WALDO MINE

FIGURE 5 OF 43

Fig. 8. Map showing the major faults in the Kelly District, some estimated displacements, and relationships to exposed intrusive rocks.

Fig. 9. Map showing the various structural-lithologic zones in the Kelly District.



GEOLOGIC CROSS SECTION B–B'
WALDO MINE

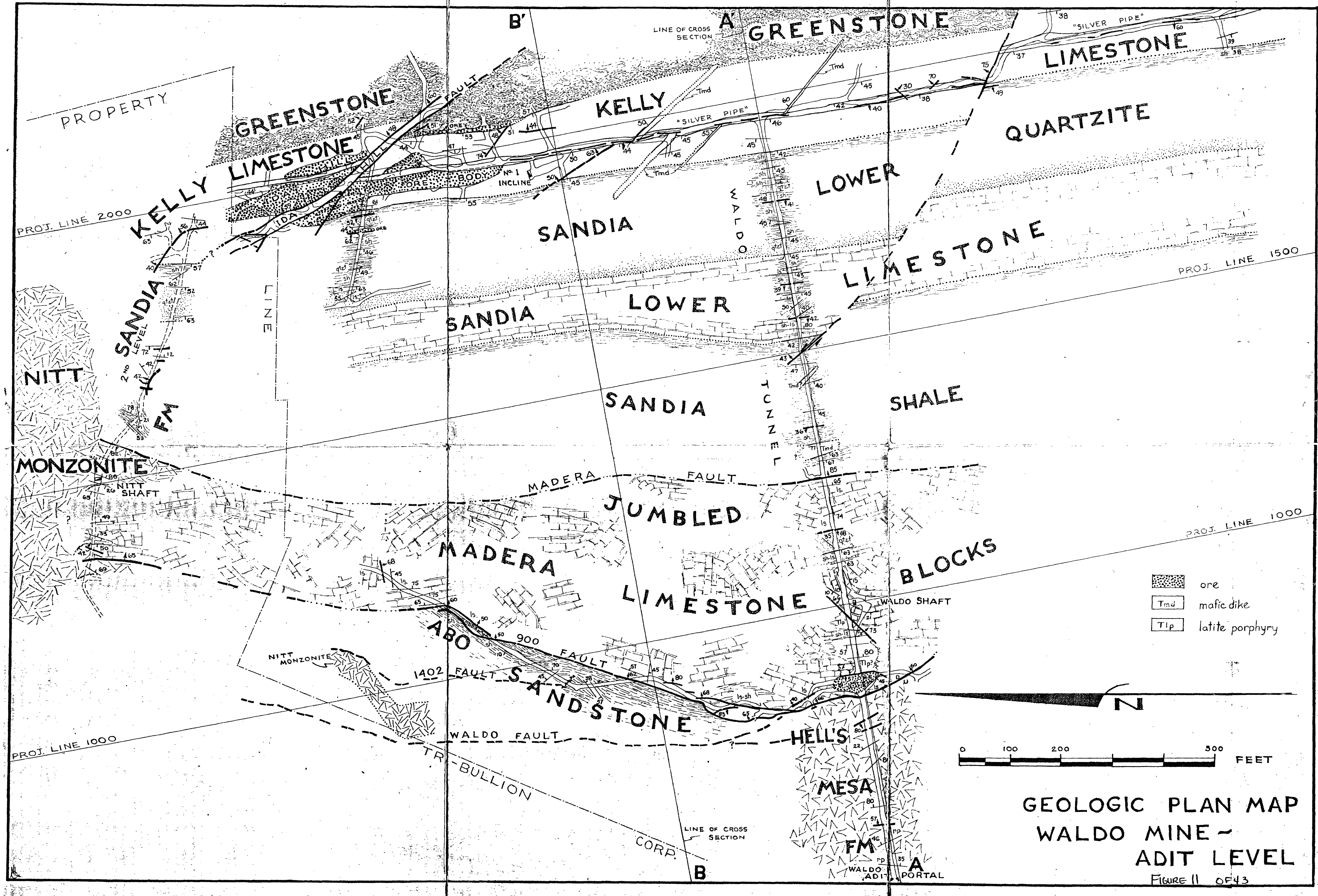


FIGURE 11 OF 43

OLOGIC MAP AND SECTIONS OF THE KELLY MINING DISTRICT
SOCORRO COUNTY, NEW MEXICO

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PRELIMINARY GEOLOGIC MAP OF THE
~~MAGDALENA~~ KELLY MINING DISTRICT, SOCORRO COUNTY, NEW MEXICO

by Robert B. Blakestad, 1974

43

EXPLANATION

Qt
Talus

Qal
QTal
Qal- Alluvium
QTal- Older Alluvium

Qls
Qls- Landslide deposits

TERTIARY INTRUSIVE ROCKS

Tmd
Mafic dikes

Twr
White rhyolite dikes

Taa
Augite Andesite

Tl
Latite dikes

Tm | Tgr | Tmb
Tm- Nitt Monzonite
Tgr- Granophyre
Tmb- Mafic border facies

Tlm
Latite-monzonite dikes

Tg
Anchor Canyon Granite

Tlp
Latite porphyry of Mistletoe Gulch

Ti
Concealed Intrusive Bodies

TERTIARY ROCKS

Tut
Upper Tuff

Tis
Intracaldera tuffs and sedimentary rocks

Tlr
Andesite of Landavaso Reservoir

Ta
Tawu
Tawl
Tuff of Allen Well
Tawu- upper member
Tawl- lower member
Ta- andesite

Tapm
Tats
Tafb
Tagm
Tala
A-L Peak Formation
Tapm- pinnacles member
Tats- tuffaceous sediments
Tafb- flow-banded member
Tagm- gray massive member
Tala- andesites interbedded in the A-L peak

Thm | Thcf
Hell's Mesa Formation
Thcf- Cauldron fill facies

Tsu
Tsn
Tsl
Spears Formation
Tsu- upper member
Tsn- Tuff of Nipple Mountain
Tsl- lower member

PALEOZOIC ROCKS

Permian Rocks

Pa
Pa- Abo Formation

Pennsylvanian Rocks

IPm
IPm- Madera Limestone

IPs
IPs-Sandia Formaion (undivided)

Mississipian Rocks

Mk
Mk- Kelly Limestone and Caloso Formation (undivided)

Precambrian Rocks

PЄ
PЄ-Precambrian (undivided)

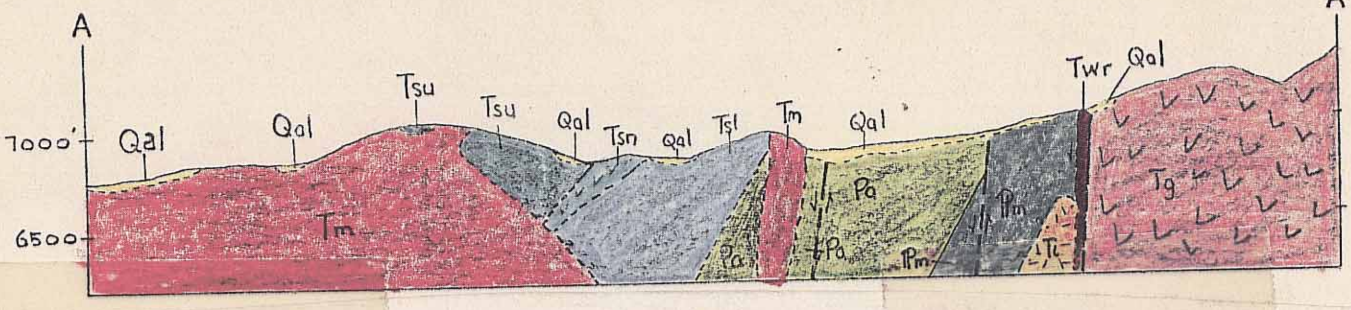
- Contact-dashed where approximately located

75 - Fault, showing dip; dashed where approximately located, dotted where inferred under younger units

- Mine or prospect
- Shaft

65 - Strike and dip of bedding or foliation

- Area of brecciated rock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Tsn
Tsl
Tm
Twr
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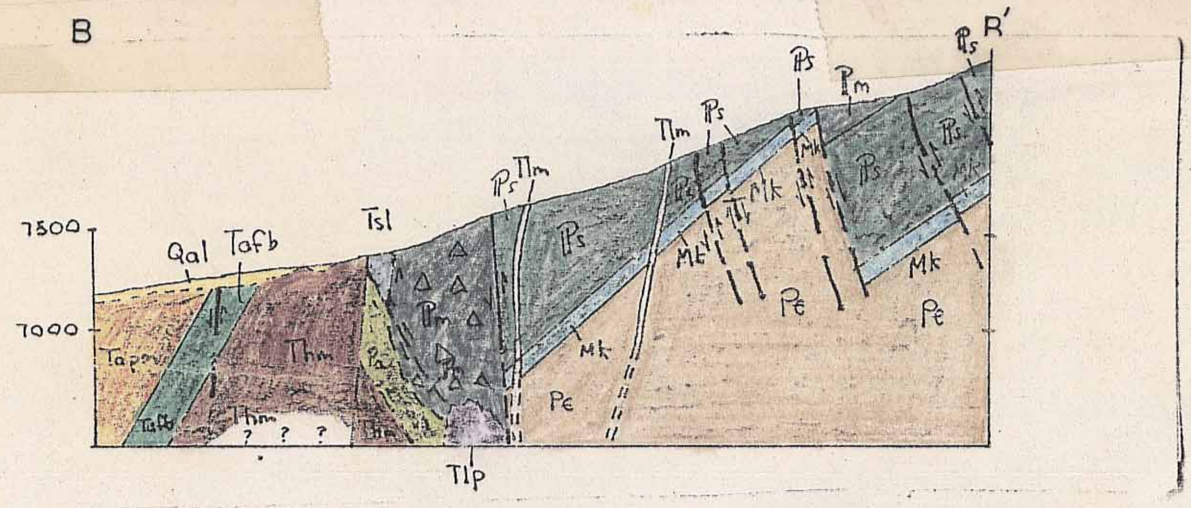
Pa
Ti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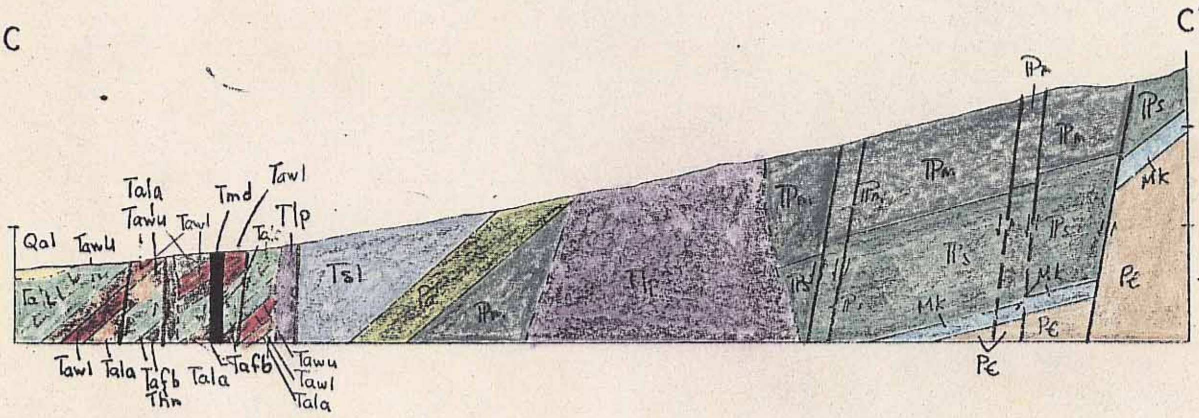
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Tsl
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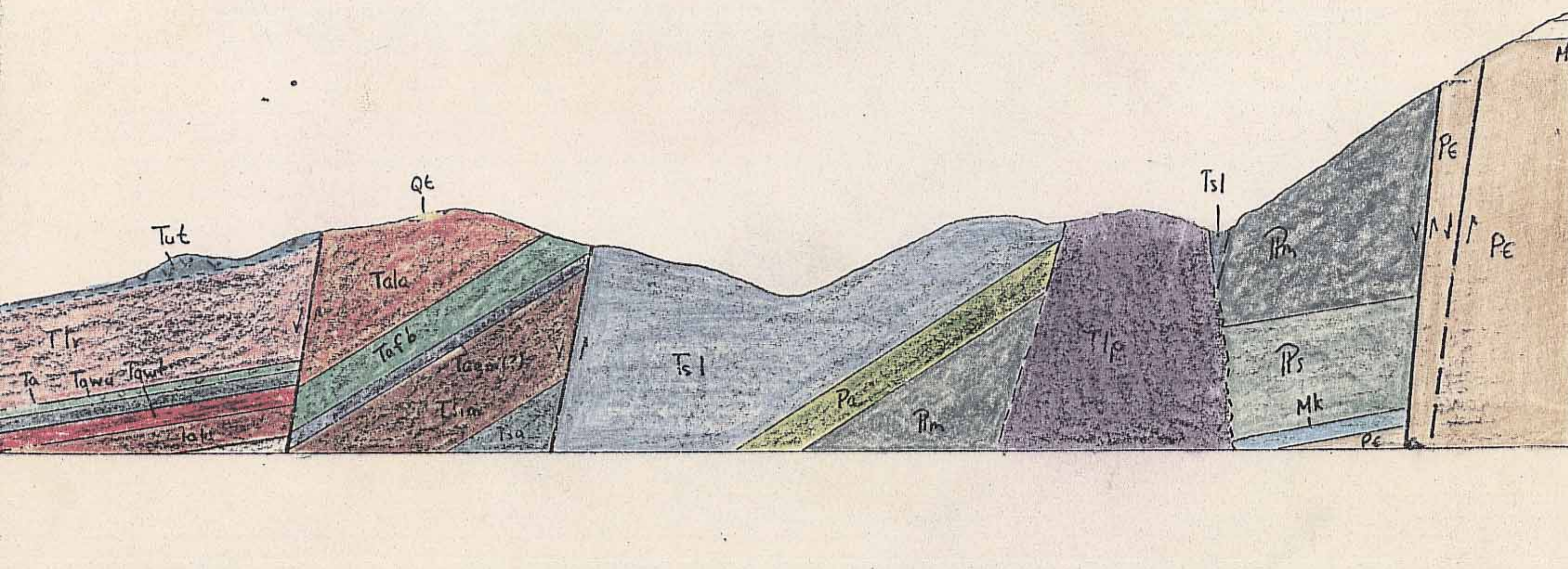
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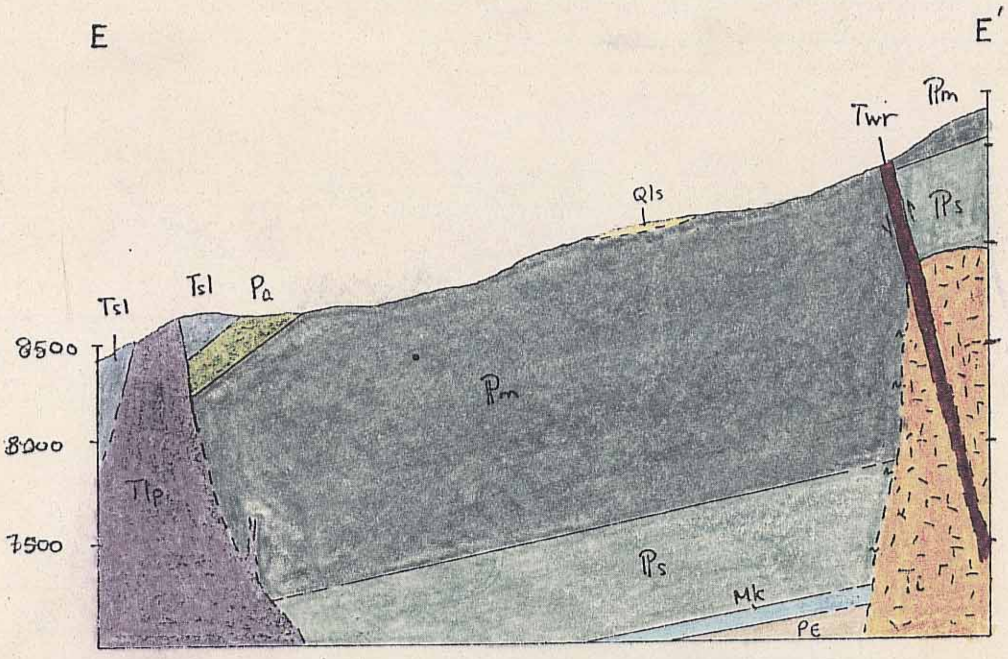
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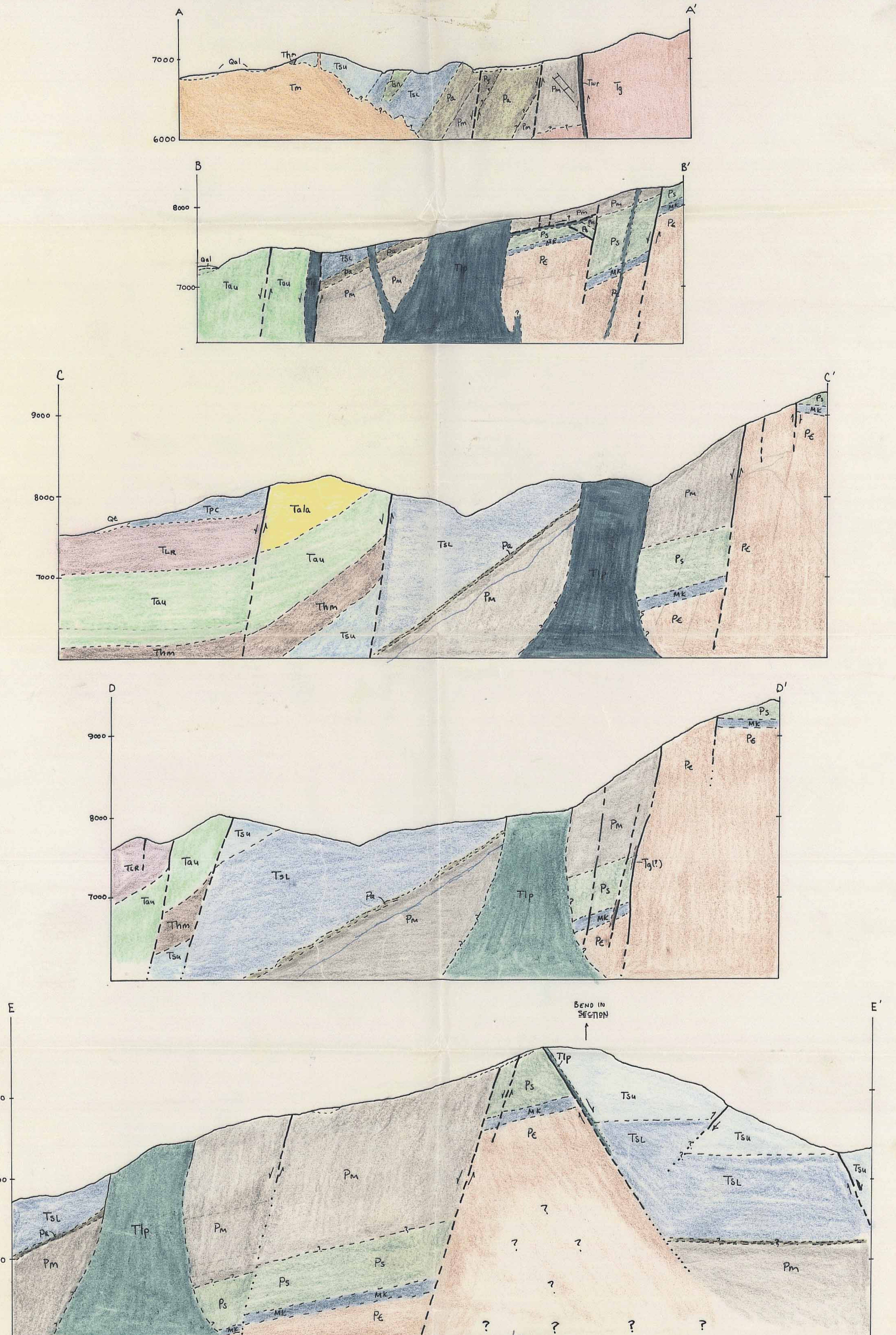

PRELIMINARY GEOLOGIC CROSS SECTIONS, ~~MAGDALENA~~ KELLY MINING DISTRICT,
SOCORRO COUNTY, NEW MEXICO
SCALE: 1"=1000'