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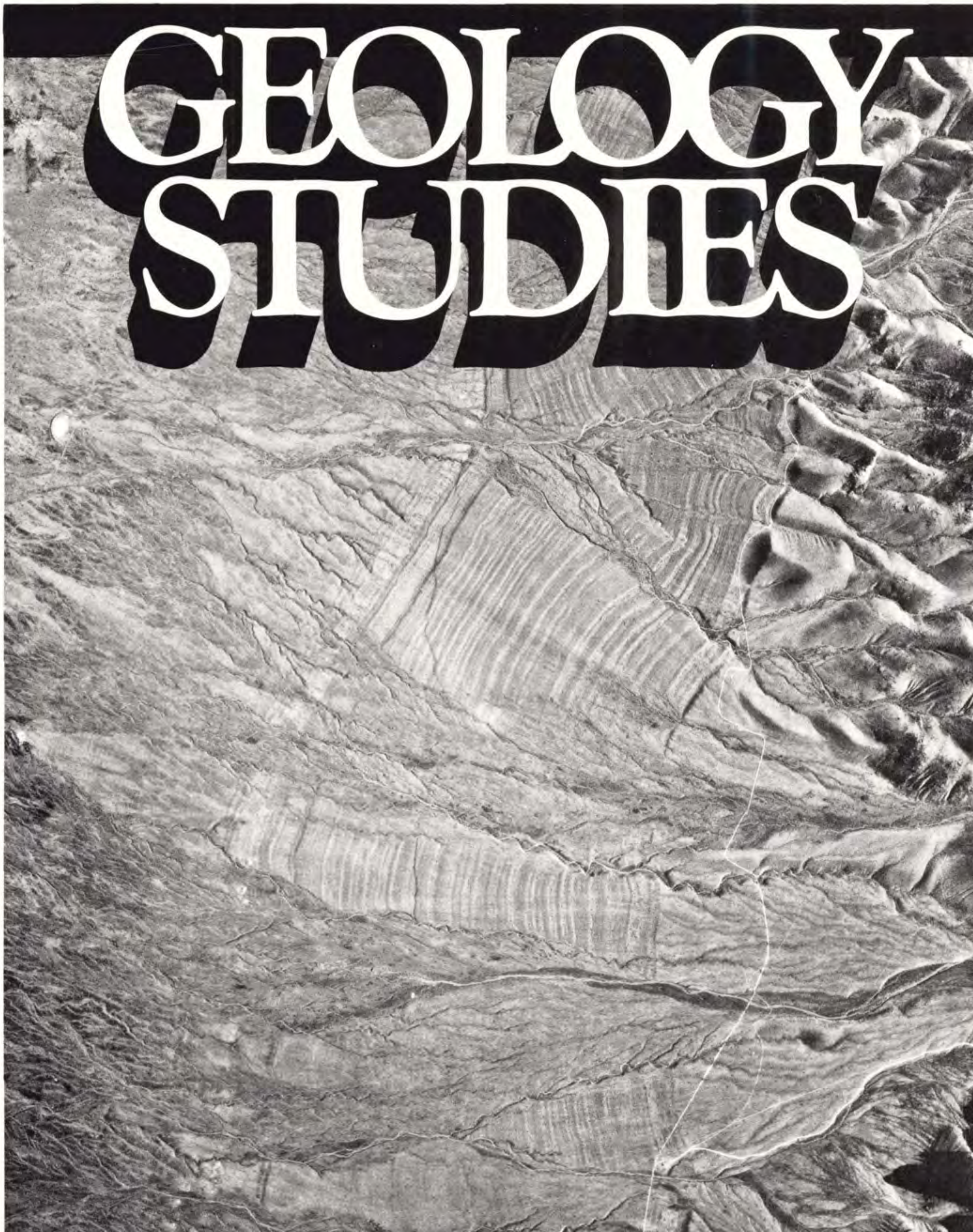

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THE GLORY OF GOD IS INTELLIGENCE

Cover: Air photo of House Range fault scarp. Courtesy of Lee Piekarski.

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Geology and Ore Deposits of Mineral Mountain, Washington County, Utah*

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ABSTRACT.–The Mineral Mountain area in the Bull Valley Mountains of southwestern Utah was mapped in order to evaluate its mineral potential. Oldest strata are late Paleozoic Callville Limestone and Supai-Coconino Sandstone which have been thrust over Mesozoic strata during the Sevier orogeny. Folding that accompanied the thrusting formed the north-trending Mineral Mountain Anticline. Late Oligocene and Miocene volcanic rocks partly cover the anticline which acted as a barrier controlling distribution of the volcanic flows. The Mineral Mountain stock, an alkali-feldspar granite porphyry, was intruded along the axis of the anticline. Associated contact metamorphism recrystallized Callville Limestone and altered the volcanic rocks. Mineralogy along the contact is indicative pyroxene hornfels facies. Three zones of alteration are recognized: marble zone, tactite zone, and an endomorphic bleach zone. Extensive argillization and minor silicification, propylitization, and pyritization are found.

Magnetite and copper oxides are located in the tactite zone on the west side of the stock. Bedded replacement, fissure fillings, and magnetite veinlets are of contact metasomatic and hydrothermal origin. On the southwest side of the stock, trace amounts of molybdenum and tungsten are associated with lamprophyre dikes. Geochemical studies indicate that gold and copper values are higher on the northwest side of the stock. Molybdenum and tungsten values are higher on the south side of Mineral Mountain. Deposits exposed on the surface and in the mines are of low tonnage and low grade.

INTRODUCTION

Mineral Mountain has had very little evaluation for mineral deposits. Evidence of iron, copper, gold, silver, molybdenum, and tungsten mineralization was found in this investigation and could provide a useful tool for future mineral exploration.

Location and Accessibility

Mineral Mountain is located in the southwestern portion of the Bull Valley Mountains (fig. 1) in the eastern part of the Basin and Range Province. Accessibility to Mineral Mountain is obtained by two routes, both of which require pickup trucks or four-wheel-drive vehicles. From U.S. 91 near Shivwits, a county dirt road extends northwest 30 km to Motoqua, then north 17 km along Slaughter Creek to Mineral Mountain. From near Gunlock a road extends up Tobin Wash for 3.2 km and then leads northwest 32 km up Grapevine Wash to the north side of Mineral Mountain (fig. 1). Accessibility is limited to the drier seasons of the year.

The Bull Valley Mountains are known for iron deposits in the Bull Valley mining district, 11 km northeast of Mineral Mountain. The Goldstrike mining camp is 3.2 km southeast of the study area. Both areas have had some mining activity, but there are no active mines at the present time.

Previous Work

Geologic literature concerning Mineral Mountain is sparse. Leith and Harder (1908) described iron deposits of the Iron Springs district and compared them with iron deposits in the Bull Valley district. They interpreted the intrusions in the Bull Valley Mountains as laccoliths similar to those of the Iron Springs district. Butler and others (1920) briefly described ore occurrence at the Goldstrike mining camp and on the north side of Mineral Mountain. Gunnell (1943) and Crawford and Buranek (1948) described and estimated tonnage of a halloysite and alunite vein on the north side of Mineral Mountain. Cook (1960) briefly discussed the Goldstrike and Mineral Mountain geology and the history of the Goldstrike mining camp. Bullock (1970) described the iron and copper occurrence of the Emma Mine area on Mineral Mountain and also provided a brief description of the structure and stratigraphy of Mineral Mountain.

The Bull Valley mining district to the northeast of Mineral Mountain has been the subject of several published works by the U.S. Geological Survey and the U.S. Bureau of Mines related to the evaluation of the iron deposits. These deposits and their origin are described by Wells (1937, 1938, 1941). Zoldok and Wilson (1953) give the results of a drilling program in the district. Blank (1959) did a detailed study of the structure and stratigraphy of the Bull Valley district.

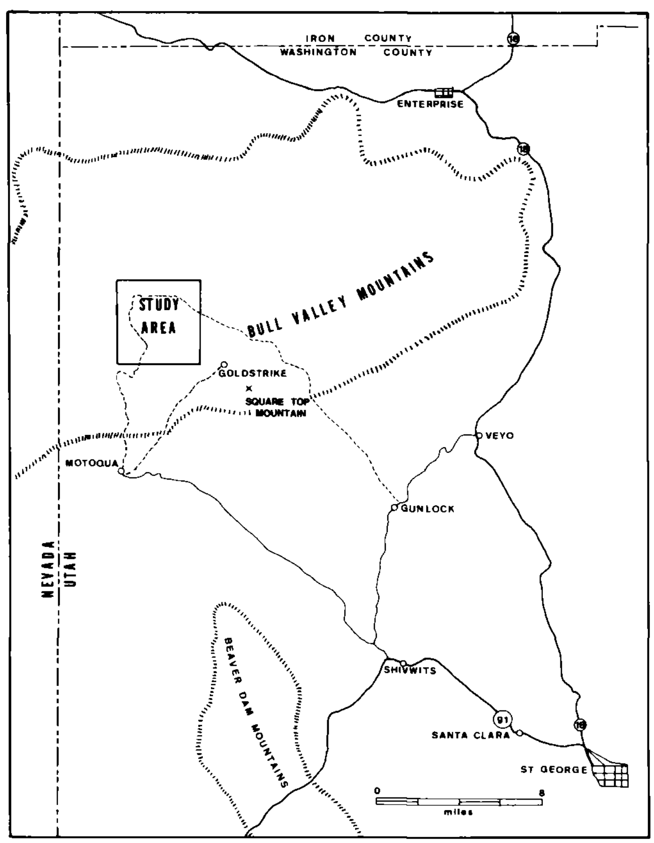

FIGURE 1.–Index map of southwestern Utah showing study area.

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, April 1980. Thesis chairman: Kenneth C. Bullock.

Methods of Investigation

Fieldwork on Mineral Mountain began in May and was completed in October 1979; it included geologic mapping, measurement of stratigraphic sections, and sample collection. Geologic mapping was done on aerial photographs and on the Goldstrike 7½-minute quadrangle which was enlarged to 1:12,000. Hand samples of rocks and geochemical samples were collected for additional study in the laboratory. Geochemical samples consisted of (1) soil samples from major drainages, tributaries, and areas of alteration; (2) rock chips of outcropping veins and other mineralized areas; and (3) dump samples of all prospect pits and major workings.

Petrographic thin sections and polished sections were prepared from the Tertiary igneous rocks, and their crystal composition percentages were estimated. Minerals that could not be identified in the field were identified by optical constraints and X-ray defraction (XRD). Geochemical analyses for 74 samples were done by Chemical and Mineralogical Services, a commercial laboratory in Salt Lake City. All samples were analyzed for gold, silver, copper, molybdenum, and tungsten. The results are discussed in the section on economic geology.

Acknowledgments

The writer expresses appreciation and thanks to Professors Kenneth C. Bullock, William Revell Phillips, Lehi F. Hintze, and Dana T. Griffen of the Geology Department, Brigham Young University, for aid and suggestion in preparation of this thesis. Acknowledgment is also given to Gulf Mineral Resources for their financial assistance which made possible the commercial analyses and thin-section preparation. Thanks to Jack Holt, Valen Ott, and Lee Perry for time spent in helping with fieldwork, and special thanks to E. Leo Leavitt and his family for financial aid and moral support during the fieldwork. Special thanks to my wife, Vicky Sue, for her able assistance and encouragement throughout the project.

SEDIMENTARY ROCKS

General Statement

Late Paleozoic strata are the only sedimentary rocks exposed in the Mineral Mountain area. Cook (1960, p. 69) described these rocks as part of the Castle Cliff thrust sheet. The sole of this thrust sheet is not exposed in the mapped area but is presumed to rest on Jurassic and Cretaceous rock as it does in areas a few miles to the south.

The Callville Limestone makes up the southern ridge of Mineral Mountain and most of the flanking contacts with the Mineral Mountain granite porphyry stock. The Supai-Coconino Sandstone is exposed only as an erosional remnant on the top of the Callville Limestone. An angular unconformity exists between late Paleozoic rocks and Tertiary volcanic rocks (fig. 2).

Pennsylvanian System

Callville Limestone

The Callville Limestone was named by Longwell (1921, p. 47) from Callville Mountain, Clark County, Nevada. Reber (1951, p. 27) identified the Callville Limestone in the Beaver Dam Mountains, Utah. Cook (1960, p. 69) mapped part of a thrust sheet on Square Top Mountain and Mineral Mountain as Callville Limestone. Fossils collected from the Callville Limestone on Mineral Mountain were identified by H. J. Bissell (personal communication) as *Fusulinella* of Derryen (lower Middle Pennsylvanian) age. This age is compatible with ages assigned to the Callville Limestone in other areas.

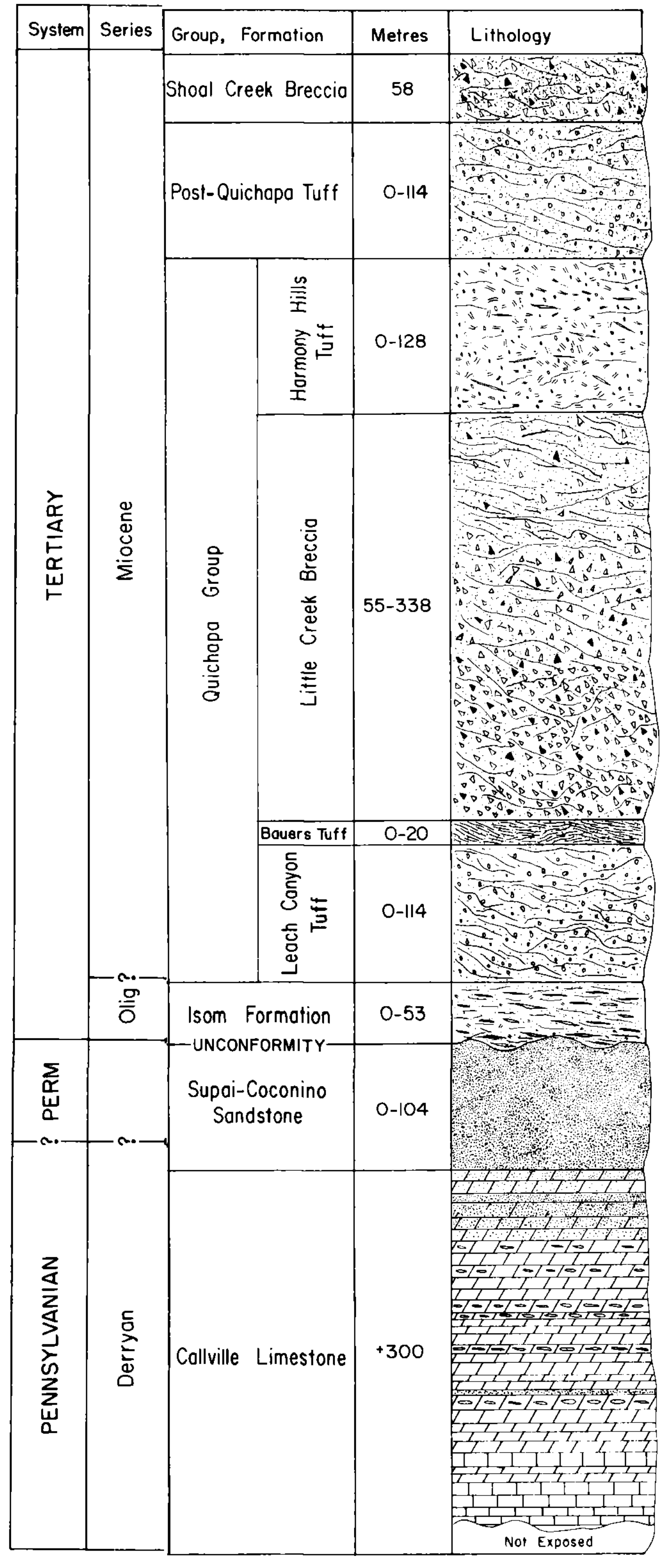

FIGURE 2.–Stratigraphic section in the Mineral Mountain area.

No complete section of the Callville Limestone is exposed on Mineral Mountain. Its base has been assimilated by the intrusive rock and it is mostly altered to dolomitic marble. Unaltered portions consist of dolomite and limestone with lenses of chert. A partial section of Callville Limestone measured on Square Top Mountain is shown in appendix A.

Pennsylvanian and Permian Systems

Supai-Coconino Sandstone

Because of the absence of a mappable break between the Supai Formation and the Coconino Sandstone, both are shown as a single map unit in the Beaver Dam Mountains (Reber 1952, p. 104), and Cook (1960, p. 69) mapped the Supai-Coconino as one unit on Square Top Mountain. In the thesis area no distinctions could be made in lithology to justify separating the Supai and Coconino Sandstone Formations. The undivided Supai-Coconino Sandstone is exposed on the south end of Mineral Mountain near Potter Peak where it consists of 0 to 104 m of fine- to medium-grained, dusky yellow to yellowish gray, calcareous, cross-bedded sandstone. The Leach Canyon Tuff and the Little Creek Breccia unconformably overlie the Supai-Coconino Sandstone.

TERTIARY VOLCANIC ROCKS

General Statement

The Tertiary volcanic rocks in the Mineral Mountain area are part of a long and complex history of Tertiary volcanism in southwestern Utah and southeastern Nevada. The volcanic rocks are mainly ignimbrites; however, some local andesite flows and tuffs are also present.

Isom Formation

The oldest volcanic formation recognized on Mineral Mountain is the Isom Formation, a sequence of ignimbrites first described by Mackin (1960, p. 89) in the Iron Springs district. Blank (1959, p. 38) described three members of the Isom Formation in the Bull Valley Mountains, only one of which, the basal vesicular flow member, is exposed on Mineral Mountain. The Bald Hills Tuff Member and the Hole-in-the-Wall Tuff Member are not present because of either erosion or nondeposition.

The vesicular flow member is exposed along the west side of Butcher Knife Canyon, where it unconformably overlies the Callville Limestone. Its upper contact is with the Leach Canyon Formation of the Quichapa Group.

The vesicular flow member is 0 to 53 m thick where measured in Butcher Knife Canyon. It consists of several flows of andesite which contain from 0 to 40 percent phenocrysts of which 65 percent are plagioclase, 25 percent pyroxene, 5 percent sanidine, and 5 percent magnetite. Plagioclase crystals, 4 to 10 mm long, are common in the more crystalline flows. The vesicular flow member has distinctive elongated vesicles often filled with secondary calcite. The member is more vesicular toward the top, and only the lower flows are porphyritic.

Quichapa Group

The Quichapa Group was first described as three ignimbrite units in the Pine Valley Mountains by Cook (1957, p. 53–57). It was named by Mackin (1960, p. 89, 97) from exposures in Quichapa Canyon in the Iron Springs district. The Quichapa Group is a sequence of ignimbrites of varied lithology extending over much of southwestern Utah and southeastern Nevada. In the Bull Valley Mountains, four formations of the Quichapa Group are recognized: (1) Leach Canyon Tuff, (2) Bauers Tuff Member of the Conder Canyon Formation, (3) Little Creek Breccia, and (4) Harmony Hills Tuff.

Leach Canyon Tuff

The basal formation of the Quichapa Group is the Leach Canyon Tuff. It consists of 0 to 114 m of pale yellow and bluish gray moderately welded vitric crystal latite tuff. The Leach Canyon Tuff is 30 to 40 percent crystals of which 40 percent is quartz, 25 percent plagioclase, 25 percent sanidine, and 10 percent biotite. Abundant red lithic fragments about 3 cm across are present.

The Leach Canyon Tuff lies variously on Isom Formation, Supai-Coconino Sandstone, and Callville Limestone. The most complete section of the Leach Canyon Tuff is exposed on the east side of Butcher Knife Canyon.

Bauers Tuff Member

Bauers Tuff and the Sweet Hills Tuff are members of the Conder Canyon Formation found in southwestern Utah, but the Sweet Hills Tuff is not present in the Bull Valley Mountains (Blank 1959, p. 45). Bauers Tuff is the only member found there.

Bauers Tuff is the upper member of the Conder Canyon Formation. In the Bull Valley Mountains it overlies the Leach Canyon Tuff and underlies the Little Creek Breccia. It is a red or pink welded vitric crystal latite tuff with eutaxitic fabric. The Bauers Tuff is 30 percent crystalline, of which 50 percent is plagioclase, 30 percent sanidine, and 20 percent biotite. Pumice fragments in the Bauers Tuff are drawn out into schlieren structures. The eutaxitic appearance and schlieren structures are distinctive and helpful for field identification. In Butcher Knife Canyon the Bauers Tuff is 0 to 20 m thick. The basal contact with Leach Canyon Tuff is marked by, 5 m of dense black glassy rock. In some locations along Butcher Knife Canyon and west of Potter Peak, the Bauers Tuff is absent, and the Little Creek Breccia rests directly on Leach Canyon Tuff

Little Creek Breccia

Blank (1959, p. 45–48) named a thick sequence of andesite flows and breccia flows, overlying the Bauers Tuff, the Little Creek Breccia. It consists of 55 to 338 m of massive andesite flows. Flows at the base of the formation are brecciated. The fragments are angular to subrounded and are composed of the same material as the matrix. The brecciation of the flow rock was probably not tectonic but rather autobrecciated. Brecciation grades vertically into unbroken rocks. The breccia is best exposed on the north and west sides of Mineral Mountain. Variations of texture and color of this formation are spectacular. Fresh surfaces of the Little Creek Breccia are usually grayish purple to very dark red, but dark browns and greens are also common Fresh outcroppings are massive, but weathered outcrops are reduced to platy chips and fragments which are iron stained and earthy.

The Little Creek Breccia ranges from porphyritic (up to 35 percent phenocrysts) to aphanitic. Phenocrists are 60 percent plagioclase (labradorite), 35 percent pyroxene, and 5 percent magnetite. One flow contains 15 percent biotite and 10 percent quartz.

Harmony Hills Tuff

Harmony Hills Tuff is a biotite hornblende quartz crystal dacite tuff. It is 40 to 50 percent crystal of which 60 percent is plagioclase, 20 percent biotite, 15 percent quartz, and 5 percent sanidine. Lithic fragments of felsite are present but not abundant.

The Harmony Hills Tuff overlies Little Creek Breccia and underlies the post-Quichapa tuff. It is exposed along the southern border of the mapped area. On the northwest side of Mineral Mountain the tuff is exposed between a normal fault and a strike-slip fault. The formation is 128 m thick on the south side of Mineral Mountain.

Post-Quichapa Tuff

Overlying the Harmony Hills Tuff are 114 m of moderately welded biotite quartz pyroclastic latite tuff. The post-Quichapa tuff is 40 percent crystals of which 20 percent is quartz, 30 percent plagioclase, 35 percent sanidine, and 15 percent biotite. Lithic fragments of red and brown felsite are present but sparse. The post-Quichapa tuff is found north of Mineral Mountain, but most exposures are altered and weathered. Quartz is the most distinguishable mineral and occurs commonly as broken clasts. Biotite is altered but recognizable. Post-Quichapa tuff is stratigraphically where the Bull Valley suite rocks are in the Bull Valley district. The Bull Valley suite was described by Blank (1959, p. 51–55) as eruptive rocks from a center in the Bull Valley district. The rocks are described as a quartz monzonite intrusive, quartz latites, and quartz latite tuffs. Blank (1959, p. 61–69) reports that although the extrusive phases are quartz latites and quartz latite tuff, no quartz phenocrysts are present.

One of the quartz latite tuffs which outcrops over a large area of southwestern Utah and southeastern Nevada is called the Rencher Formation (Blank 1959, p. 51–55). The Rencher Formation is stratigraphically between the Harmony Hills Tuff and the Shoal Creek Breccia in the Bull Valley district, and the post-Quichapa tuff lies between the Harmony Hills and Shoal Creek Breccia in the thesis area. The correlation of the Rencher Formation with other extrusive phases of the Bull Valley suite is uncertain, but the abundance of fragmental quartz in the post-Quichapa tuff and the absence of quartz in the Rencher Formation in the Bull Valley district make the correlation of the two seem unlikely.

Shoal Creek Breccia

Overlying the post-Quichapa tuff is a sequence of andesite and dacite flows called the Shoal Creek Breccia. Blank (1959, p 108–10) named and described the Shoal Creek Breccia from exposures in Shoal Creek in the Bull Valley district. The breccia is predominately a massive dark brown to dark maroon color, but variations are common. Breccia clasts and matrix material are of the same general composition, but phenocrysts appear larger in the matrix than in the breccia clasts

The Shoal Creek Breccia is 25 to 35 percent visible crystals, of which 35 percent is hornblende, 50 percent plagioclase, and 15 percent pyroxene. It looks similar to the Little Creek Breccia. Distinguishing the two in the field is difficult, but the distinction can be made by stratigraphic positions and the presence of hornblende in the Shoal Creek Breccia, which is absent in the Little Creek Breccia. The Shoal Creek Breccia is 52 m thick north of Mineral Mountain and Marble Mountain and overlies the post-Quichapa tuff.

TERTIARY INTRUSIVE ROCKS

General Statement

Intrusive activity postdates all the extrusive rocks in the area. The major intrusive events baked, altered, and deformed rocks which were deposited earlier. The alkali-feldspar granite porphyry makes up the major portion of the Mineral Mountain Stock. An alaskite intrusion, porphyritic granite dikes, and lamprophyre dikes cut the alkali-feldspar granite porphyry. The alkali-feldspar granite porphyry intrudes along the axis of the Mineral Mountain Anticline which probably served as a structural control for the emplacement of the alkali-feldspar granite porphyry. The other intrusive rocks resulted from the differentiation of the alkali-feldspar granite porphyry.

Alkali-Feldspar Granite Porphyry

An alkali-feldspar porphyry makes up the major peaks of Mineral Mountain (fig. 3). The northern portion of the intrusive body is displaced laterally to the east approximately 1,280 m, by a right lateral strike-slip fault. Marble Mountain has been partially formed on the displaced northern portion of the stock If the displaced part of the stock were restored to its original position, the intrusive body would be roughly elliptical, elongated parallel to the axial trend of the Mineral Mountain Anticline. The fault has almost displaced the stock into two separate bodies. The surface area of the Mineral Mountain is 6.3 km².

The alkali-feldspar granite porphyry has intruded into the Pennsylvanian Callville Limestone which was arched, brecciated, and recrystallized into marble.

The alkali-feldspar granite porphyry is leucocratic, commonly light gray to very light gray. Weathered surfaces are pale grayish orange to pale yellowish orange. Generally, the finer the matrix, the darker the rock. Typically, the granite porphyry outcrops are spheroidally weathered Slopes around the stock are usually platy chips of the intrusive rock and grus overgrown by dense brush

Mineral percentages of the granite were determined by visual and thin-section measurements. Samples were selected from various locations and provided an average mineral percentage·

K-feldspar	55%
Quartz	30%
Plagioclase	7%
Hornblende	5%
Magnetite	3%
Apatite	Trace

UGS Classification, alkali-feldspar granite porphyry (Streckeinsen 1975, p 27)

In the main body of the Mineral Mountain Stock the alkali-feldspar granite porphyry has a phaneritic matrix. The phaneritic crystals of quartz and K-feldspar have an average diameter of 0.2 mm.

An apophysis of granite porphyry extends into the Little Creek Breccia on the southwest side of the stock. Here the phenocryst percentages are the same as the main stock, but the phaneritic matrix is finer grained Crystals of the matrix from this area are 0.05 mm in diameter. In Butcher Knife Canyon east of the Marble Mine, samples of granite porphyry have an aphanitic matrix. Changes in crystal size take place over very short distances indicating rapid temperature changes within the stock during its emplacement. The decrease in matrix grain size does not necessarily occur along the contact but usually does occur within 300 m of it. Marginal cooling may contribute to decreasing crystal size, but the drastic changes noted are more likely a result of near-surface emplacement.

K-feldspar and quartz phenocrysts are a distinctive feature of the granite porphyry rock and are rather uniform throughout the intrusive body. Along contacts with the country rock, the phenocryst percentage of the granite porphyry is less than near the center of the stock. It is common to find a noticeable decrease in phenocrysts 9 to 15 m from the contact.

K-feldspar phenocrysts are usually elongated laths 3 to 4 mm long. Along the contacts with the Callville Limestone and Tertiary volcanic rocks the K-feldspar phenocrysts are altered to clay minerals. Plagioclase is often observed within K-feldspar phenocrysts.

Short stubby dipyramidal quartz phenocrysts about 7 mm across are the most easily recognized feature of the alkali-feldspar granite porphyry. All quartz phenocrysts are corroded and embayed. Quartz is most deeply embayed along contacts and in areas of the stock where the matrix is finer. Phenocrysts of quartz are often fractured with a void in the center, and secondary magnetite and other iron oxides are often deposited in the voids. The short stubby nature and the fracturing of the quartz phenocrysts are characteristic of beta quartz inverted to alpha quartz.

Alaskite Intrusion

On the southern slope of Marble Mountain, southwest of the marble quarry, is an elliptical alaskite intrusion which measures 120 m by 210 m and is completely contained within the alkali-feldspar granite porphyry. A narrow chill margin has formed along the contacts.

The alaskite has a fine equigranular texture of K-feldspar and quartz. Its average mineralogical composition is as follows:

K-feldspar	75%
Quartz	20%
Magnetite	4%
Plagioclase	Trace
Hornblende	Trace

UGS Classification, alaskite (Streckeinsen 1975, p. 13)

The alaskite looks stony in hand sample and is void of mafic minerals. It is younger than the alkali-feldspar granite and is likely a late phase of the major intrusive activity. Mineral composition of both alaskite and alkali-feldspar granite is similar, but lack of phenocrysts and absence of mafic minerals indicate a different petrologic history for the alaskite.

Lamprophyre Dikes

Augite Kersantite Dike

On the ridge that extends southeast from the marble quarry on Marble Mountain is an augite-rich lamprophyre dike. The dike is completely within the stock and trends north 34° east and is nearly vertical. The dike runs perpendicular to the ridge and is exposed for 60 m across the crest before being lost under float and brush. The dike is 1.4 m wide at the crest, decreasing to .5 m down each slope.

In hand sample the dike rock is dark green and aplitic. The rock is largely augite with minor plagioclase and traces of quartz, biotite, and hornblende (USG Classification, augite kersantite [Streckeinsen 1979, p. 331]).

Hornblende Kersantite Dike

At the Pickadilly Mine two hornblende kersantite dikes cut the recrystallized Callville Limestone along relic bedding planes. They are exposed at the portals of the two main drifts and trend north 60° west, dipping 70 to 80° west. The lower drift follows one dike into the hill 19 m, and the upper drift follows the other dike 21 m where the dike swings to the north. This drift continues north 60° west into barren marble. The dike of the upper drift is exposed on the hill above the mine where small prospect pits appear all along the outcrop of the dike. The two dikes at the Pickadilly Mine are petrographically identical and possibly join at depth.

Plagioclase grains are subhedral phaneritic intergrowths, and anhedral hornblende fills spaces between. Magnetite and pyrite are minor minerals. The pyrite was probably introduced by late hydrothermal activity (UGS Classification, hornblende kersantite [Streckeinsen 1979, p. 331]).

Just south of the granite porphyry-Callville Limestone contact on the south ridge of Mineral Mountain is another hornblende kersantite dike. This dike is not well exposed. It is

FIGURE 3.—Mineral Mountain looking northwest from Butcher Knife Canyon, where g marks the granite porphyry which makes up the highest peaks of Mineral Mountain. The Callville Limestone, altered to marble, is marked m. Leach Canyon Tuff is in the foreground.

found only in shallow prospect pits on the ridge and can be traced for only a few meters. This dike is finer grained than the two at the Pickadilly Mine but compositionally the same

Porphyritic Granite Dikes

Along the west side of the alkali-feldspar granite porphyry stock are many small (1 m to a few cm) porphyritic granite dikes, which are finer grained than the main intrusion. These dikes follow a dominant north-south joint set within the stock. None could be traced into the country rock although most are near the margins of the stock. One dike was traced 12 to 18 m by discontinuous outcrops in the float.

The dike rocks contain phenocrysts of K-feldspar and equal amounts of subhedral quartz and K-feldspar in the matrix with minor plagioclase and a trace of magnetite (UGS Classification, granite [Streckeinsen 1975, p. 13–27]).

Some leucogranite dikes cut the post-Quichapa tuff in the northwest corner of the mapped area These dikes are thin (1 to 10 cm) and weather to form resistant low ridges about 10 cm high which can be traced several meters. All have a north-south trend and dip nearly vertically. Composition and texture are similar to dikes in the stock and may be extensions of them; however, correlation is impossible because of ground cover and displacement by the right lateral strike-slip fault.

Age Relationships of the Igneous Rocks

Much work has been done on the geochronology of Tertiary igneous rocks in southwestern Utah, although no specific radiometric dating has been done on volcanic rocks in the Mineral Mountain area. The same volcanic formations as in the Mineral Mountain area, however, have been dated radiometrically from areas close by.

Samples of the Bald Hills Tuff Member of the Isom Formation from the Iron Springs district have been established by K-Ar dating to be 25.0 ± 0.5 m.y Armstrong (1970) considered the Bald Hills Tuff to be late Oligocene or early Miocene. Although the Bald Hills Tuff is absent from Mineral Mountain area, Blank (1959, p. 38–41) mapped it resting on the vesicular flow member of the Isom Formation in the Bull Valley Mountain district; hence the age of the Isom Formation's vesicular flow member should be late Oligocene.

Several age dates have been obtained from the various formations which make up the Quichapa Group. The Bauers Tuff Member of the Condor Canyon Formation has been well dated radiometrically as early Miocene by Armstrong (1970, p. 208–9) and by Fleck and others (1975, p. 56–58) Armstrong obtained dates of 21.3 ± 0.5 and 21.6 ± 0.4 m.y. from samples of Bauers Tuff from Nevada, and Fleck and others (1975, p. 55–59) obtained dates of 22.1 ± 0.6 m.y. near Panguitch, Utah. The Harmony Hills Tuff is also Miocene, dated at 19.8 ± 0.4 in Nevada and 21.3 ± 0.4 m.y. at Sweet Hills, Utah (Armstrong 1970, p. 208–9).

The alkali-feldspar granite porphyry has effectively baked, altered, and brecciated all ages of rocks that surround it. The intrusive is assumed to have been emplaced during the Miocene age.

STRUCTURE

The Mineral Mountain Anticline

The major structural feature of the mapped area is a south-trending anticline, here named the Mineral Mountain Anticline The north end of the anticline is displaced by the right lateral strike-slip fault and covered by Tertiary volcanic rocks (fig. 4).

The oldest formation exposed in the anticline is Callville Limestone which plunges under Tertiary volcanic rocks south of Mineral Mountain. Callville Limestone has been intruded by the granite porphyry that forms the highest peaks of Mineral Mountain. It is altered to dolomitic marble around the intrusion, and in some places the granite has assimilated the carbonate completely

Evidence indicates that the anticline was present prior to the deposition of the Tertiary volcanic rocks and had renewed arching during the emplacement of the granite porphyry. On the east flank of the Mineral Mountain Anticline, the Isom Formation and the Leach Canyon Tuff are resting on the Callville Limestone. On the west flank, Little Creek Breccia rests on Callville Limestone (fig. 4, cross section B-B′). Across the crest of the anticline north of Potter Peak, Supai-Coconino Sandstone is overlain by Leach Canyon Tuff and Little Creek Breccia. The Leach Canyon is thinned from 115 m in Butcher Knife Canyon to 40 m just north of Potter Peak If the anticline formed a topographic high during Isom time, the deposition of the Isom would have been controlled by it. The hill would have acted as a barrier, restricting or preventing deposition of the Isom on the west flank. During Quichapa time, the topographic barrier could have been filled, allowing the Leach Canyon Tuff to flow across lower areas of the topographic high By then the topography was more or less flat, except for the highest portion of the hill formed on the anticline. The Little Creek Breccia was then able to cover the structure. If this model is correct, the difference of the volcanic stratigraphy found on the east and west flanks of the anticline would be explained by the existence of a topographic barrier formed by the Mineral Mountain Anticline before the deposition of the Isom Formation

The Callville Limestone and Supai-Coconino Sandstone are segments of the Castle Cliff Thrust on Mineral Mountain Cook (1960, p 67) indicates that the Castle Cliff Thrust formed during the late Cretaceous and Eocene The compressional forces which formed the Mineral Mountain Anticline are considered to be contemporaneous with those which caused the thrusting events during the Sevier orogeny and would be prior to Isom time, which is late Oligocene or early Miocene (Anderson and Rowley 1975, p. 19–20).

Callville Limestone on the flanks of the anticline dips from 63 to 30° whereas the Tertiary volcanic rocks along the flank dip 16 to 10° off the structure (fig. 4, cross section B-B′) The angular unconformity between the Paleozoic rocks and the Tertiary volcanic rocks indicates additional arching during the Tertiary, possibly caused by emplacement of the Mineral Mountain Stock.

Faults

Thrust Faults

Pre-Tertiary structures are mostly covered by Tertiary volcanic rocks in the Bull Valley Mountains but can be seen on Square Top Mounatin 10 km southeast of Mineral Mountain. Here the Callville Limestone and Supai-Coconino Sandstone have been thrust over Jurasic and Cretaceous rocks (Cook 1960, p. 69). Callville Limestone can be traced from Goldstrike on Square Top Mountain to Mineral Mountain. This is the easternmost exposure of Paleozoic rock in the Bull Valley Mountains.

The largest segment of Dobbin's (1939, p. 129–31) Castle Cliff Thrust is found on Square Top Mountain On Mineral

Mountain the Castle Cliff Thrust appears as outcrops of Callville Limestone and Supai-Coconino Sandstone (Cook 1960, p. 69), but the sole of the thrust is not exposed.

Right Lateral Strike-Slip Fault

On the north side of Mineral Mountain is a right lateral strike-slip fault that strikes north 65° west and has approximately 1,280 m of lateral displacement. The fault can be seen distinctively on aerial photographs but is rather difficult to locate on the ground. The fault is younger than any other major geologic feature in the thesis area. The northern part of the granite porphyry stock has been displaced to the east by the strike-slip fault until it is almost completely separated from the rest of the intrusion.

In Slaughter Creek Canyon the fault is exposed where it crosses the stream gorge. A broad breccia and gauge zone 9 m wide is present where the Little Creek Breccia has been brought in contact with the granite porphyry intrusion. In Butcher Knife Canyon the fault has brought the granite porphyry intrusive on the north side of the fault in contact with the Leach Canyon Tuff on the south side (fig. 5).

The strike-slip fault movement displaced the north side of the intrusion and the mineralization on its west contact eastward relative to the main intrusion. The Emma Mine is located on the displaced eastern segment.

Normal Faults

On the northwest side of Mineral Mountain, a normal fault and the strike-slip fault form the boundaries of a graben of granite porphyry, marble, and Harmony Hills Tuff. The normal fault is south of the strike-slip fault and strikes north 86° west (fig. 6). It is assumed that the normal fault joins with the strike-slip fault to the east.

The graben has dropped the Harmony Hills Tuff into contact with the Callville Limestone, granite porphyry, and the Little Creek Breccia.

CONTACT METAMORPHISM AND METSOMATISM

General Statement

The alkali-feldspar granite porphyry stock is in contact with the Callville Limestone along 90 percent of its margin where the carbonate rock is altered by pyrometamorphism and metasomatism. Three zones of alteration are recognized: (1) the outermost zone is a broad band of dolomite and calcite marble, formed by recrystallized Callville Limestone; (2) directly along the granite porphyry-marble contact is a discontinuous zone of tactite—both these alteration zones are caused by exomorphic reactions; and (3) granite porphyry near the contact has been altered by endomorphism, which is not continuous but is generally associated with areas where exomorphic alteration is most intense.

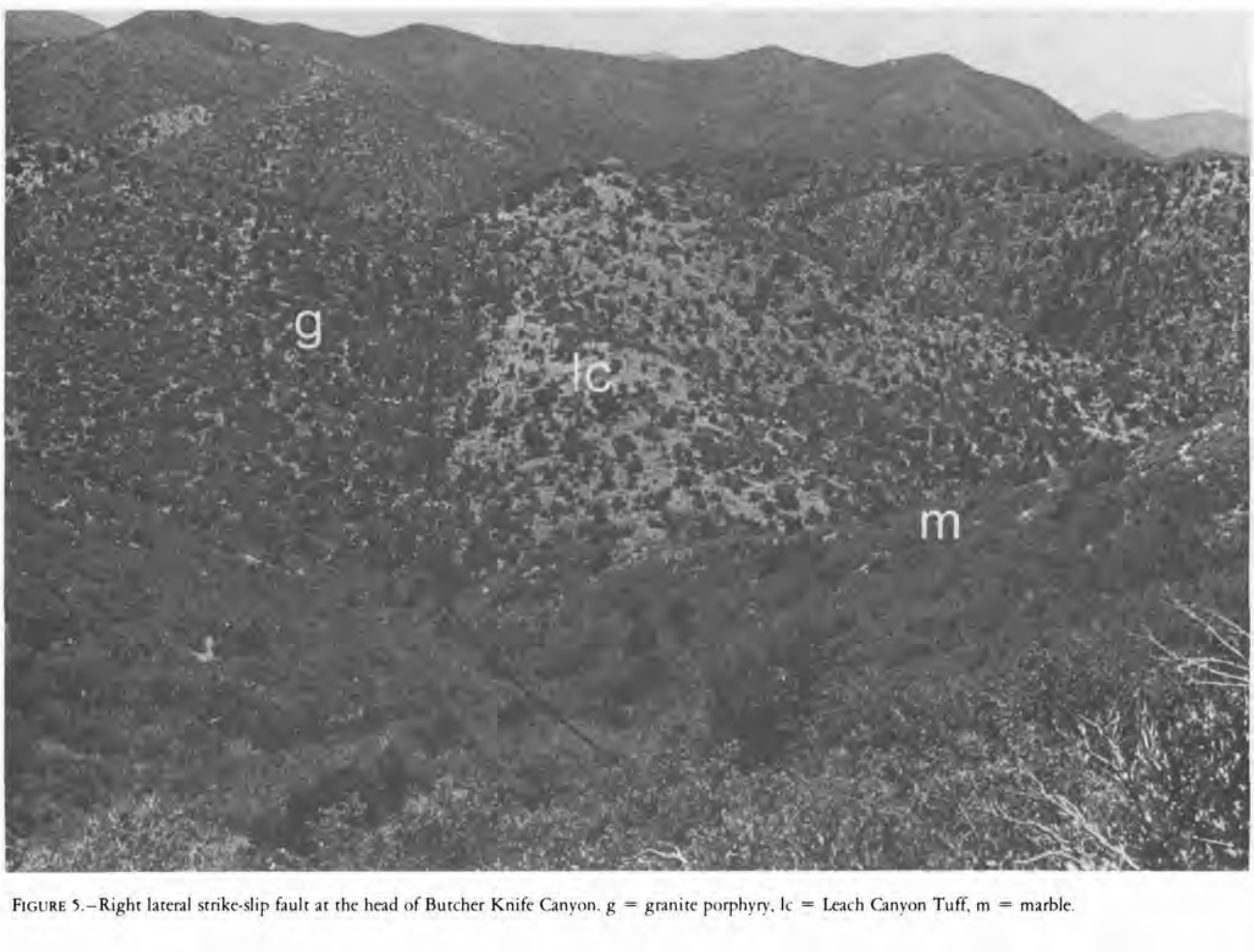

FIGURE 5.—Right lateral strike-slip fault at the head of Butcher Knife Canyon. g = granite porphyry, lc = Leach Canyon Tuff, m = marble.

The Marble Zone

The marble zone is due to heat from the intrusion. On the south side of Mineral Mountain marmorization extends 90 to 1,100 m into the limestone. Wider marble zones suggest the intrusion extends out under the Callville at depth. On the western and northern sides of the intrusion the marble zone is not so wide, grading into unaltered dolomite within 200 m from the stock.

In most areas of marmorization, relic bedding of the carbonate rocks is discernable and dips away from the granite porphyry contact. Alteration in the more dolomitic beds can be traced further from the intrusive contact than that in the limestone layers, and the dolomite marbles tend to be coarser grained than limestone marbles. Closer to the intrusive contact, where marmorization is most intense, the marble is coarser, and small amounts of brucite, epidote, and antigorite are present. The marble zone is a controlling factor of the location of the endomorphic bleach zone and to some extent the tactite zone.

Tactite Zone

A zone of tactite occurs along the contact between the intrusion and the marble zone. The tactite forms discontinuous bodies elongated parallel to the boundaries of the intrusion, usually along the contact area (fig. 7), but also off the contact in the marble zone. The tactite is poorly developed on the eastern and southern sides of the intrusion where it is commonly less than 1 m wide or completely absent. Where the tactite zone is absent, a coarse-grained marble rests directly in contact with the intrusion. The largest tactite bodies are exposed along Slaughter Creek, on the western and northern sides of the stock. Some mining has taken place in these larger bodies for iron and copper minerals. The tactite zone just west of Slaughter Creek is more continuous than in other areas. The trend of this zone is terminated by the right lateral strike-slip fault and displaced some 1,280 m east on the north side of the Mineral Mountain. The Emma Mine is located on the displaced portion of the western tactite zone. The northern side of the intrusion which has been displaced by the strike-slip fault has a tactite zone, but it is not nearly so well developed as at the Emma Mine or along the western side of the stock.

Mineralogy of the tactite seems to be consistent throughout all the areas observed. The major minerals which comprise the tactite are brucite (nemalite), magnetite, antigorite, calcite, and quartz, suggesting conditions common to a pyroxene hornfels facies. Minor amounts of monticellite, augite, forsterite, spinel, garnet, and sphene are also present. Fractures and shears are filled with calcite, aragonite, antigorite, and copper oxides.

FIGURE 6.–Graben in Slaughter Creek Canyon looking west, bounded by strike-slip fault (right) and normal fault. g = granite porphyry, m = marble, h = Harmony Hills Tuff, and l = Little Creek Breccia.

Brucite (nemalite) is the most abundant tactite mineral. It is dark gray to black and fibrous, and it has a somewhat greasy feel. Weathered surfaces are light gray to chalk white. Fibrous brucite is formed quite often by hydration of periclase (Deer and others 1975, p. 403), and the brucite on Mineral Mountain is probably formed by such an alteration. The fibers of brucite are often oriented perpendicular to the dolomite bed it has replaced. Antigorite has formed by the hydration of forsterite.

Magnetite is found as veins, as replacement deposits, and as pods of isolated magnetite along shear zones. Where tactite is most extensive, magnetite has replaced dolomite beds, and stringers and veinlets of magnetite in the marbles are associated with these replacement deposits.

Tactite is best developed on the west side of the intrusion in marble; however, some tactites are found in the Little Creek Breccia.

Bleach Zone

The granite porphyry intrusion in contact with the Callville Limestone has been endomorphically altered. In areas of well-developed tactite, the granite is usually bleached chalky white, and it is difficult to distinguish marble from bleached granite. The width of the bleached zone varies from a few centimeters to 140 m. Along the western side of the intrusion the bleach zone is most continuous and averages 60 m wide. Some wider bleach zones, such as at the Emma Mine area, suggest that the contact is dipping quite shallowly. Erosion of the contact has exposed a broad zone beneath it.

FIGURE 7.–Tactite resting (t) on granite porphyry (g) 50 m north of Gregerson Mine.

In the bleach zones the mafic minerals are absent or replaced by clay minerals and sericite, and the K-feldspars and matrix minerals are also altered to argillic minerals. Quartz phenocrysts are more deeply embayed in the bleach zone than in the main intrusive body, and xenoliths of marble bounded by reaction halos are sometimes found. The halos are dark calc-silicate minerals and magnesium oxides such as forsterite, sphene, diopside or augite, and periclase.

Along 10 percent of its exposed margin the intrusive stock intrudes Tertiary volcanic rocks. In Butcher Knife Canyon, on the east side of the stock, the Isom Formation and the Leach Canyon Tuff are in contact with the granite porphyry, and the bleach zone is absent. That only minor alteration of the mafic minerals occurs in the granite is evident.

The endomorphic bleach zone is best developed where tactite is present, but it is also present where granite is in contact with marble. Wide bleach zones not related to tactites are present on the north side of the granite porphyry, suggesting erosion of flat-lying contacts.

HYDROTHERMAL ALTERATION

Hydrothermal alteration occurs near the granite porphyry contact with both Callville Limestone and Tertiary volcanics. Four types of alteration are found: (1) argillization, (2) silicification, (3) propylitization, and (4) pyritization. Argillic alteration is most widespread and extends farther from the intrusive than do the other three types. Silicification is close to the intrusion contact, and propylitization and pyritization are found only in isolated areas.

The Little Creek Breccia on the western and northern sides of Mineral Mountain is extensively altered where the argillic alteration has rendered the Little Creek Breccia more susceptible to weathering and erosion. Outcroppings are friable and rubbled with detritus containing clay minerals and iron oxides. Slopes on the north side of Mineral Mountain are covered with soft red clay soils and rock chips weathered from the altered breccia.

The post-Quichapa tuff on the north side of the Mineral Mountain Stock is also intensely altered to argillic minerals with only broken quartz phenocrysts remaining unaffected.

Silicification of the Callville Limestone has occurred on the south ridge of Mineral Mountain. Silica replacement of the limestone has rendered it a dense, siliceous, dark gray outcrop.

On the northern side of the stock narrow quartz veins extend from the intrusion into the post-Quichapa tuff, which has been silicified up to 0.5 m from the veins. In one location many quartz veins are close together, and the entire outcrop is silicified.

Butcher Knife Canyon the rocks of the Isom Formation show propylitic and pyritic alteration. Most of the outcrops have been thoroughly altered to clays, epidote, and chlorite, with some replacement by pyrite. In one location, pyrite has replaced the amygdaloidal fillings in a vesicular flow member of the Isom. Plagioclase phenocrysts are partially replaced by pyrite and epidote, and propylitic alteration halos surround the replaced phenocrysts. Epidote and chlorite have replaced the ferromagnesium minerals. In Butcher Knife Canyon the Leach

Canyon Tuff has also been altered to argillic minerals but not so intensely as the Isom, and propylitic and pyritic alteration is absent.

The lamprophyre dikes on the southwest side of Mineral Mountain, at the Pickadilly Mine, have pyritic, hematitic, and argillic alteration. Pyrite occurs primarily along a shear zone in the hanging wall of the dike, and veinlets and disseminations of pyrite are also found in the dike rock. Argillic and hematitic alteration has replaced breccia along the hanging wall shear zone between dike and marble. Calcite and quartz veins cut the lamprophyre dike, but no wall rock alteration was observed.

ECONOMIC GEOLOGY

Mining History

Mining on Mineral Mountain has been spotty and sporadic since it began in the late 1800s. Interest in the mineral potential of Mineral Mountain was no doubt influenced by gold discoveries in the nearby Goldstrike camp. The three areas of the most extensive mining activity were the Pickadilly, Emma, and Gregerson Mines. Each area has several prospects and some drifts.

The Pickadilly Mine was worked prior to 1899, but to what extent is not known. Around the turn of the century the Emma claim was located. In 1903 samples from the Emma Mine were reported to run $12.90 per ton of gold and 11.5 percent copper (Salt Lake Mining Review 1903, p. 30). In 1904 a ledge (vein) of aluminium ore (alunite) was found cross cutting the drift. It was reported to assay at 50 percent aluminium (Salt Lake Mining Review 1904, p. 27).

Interest in the mining on Mineral Mountain declined because of the lack of high-grade ores and poor accessibility, and since that time the area has had periodic activity. Some drilling and mining were done in the mid-1960s in the Emma and Gregerson mines, but no ore was produced (Jack Holt personal communication). The area has been idle since then except for some marble quarrying on Marble Mountain. No records of ore production are known, and it is doubtful that any ore was ever shipped.

Magnetite Deposits

Bedded Replacement Bodies

The largest magnetite deposits are of pyrometasomatic origin. They occur as bedded replacements of marmoritized Callville Limestone. Magnetite, brucite, and antigorite are the major minerals with minor quartz, chlorite, spinel, periclase, and forsterite. Quartz and calcite veins cut the ore body. The calcite veins often contain chrysocolla, malachite, and azurite. The presence of antigorite and brucite in the ores indicates that dolomitic beds of the Callville Limestone are the most favorable host rocks.

The west side of the Mineral Mountain Stock has the largest bedded replacement deposits. The Gregerson and Emma Mines are both located along this side; the Emma Mine on the north side of the right lateral strike-slip fault is displaced to the east. The other contact areas have only minor deposits.

The dolomite marbles along the contact of the Mineral Mountain Stock have been pyrometasomatically replaced by periclase and forsterite. Iron-rich hydrothermal solutions replaced the dolomitic marbles, oxides, and silicates with magnetite along the bedding planes. Presumably, copper was associated with the magnetite as chalcopyrite. Fracturing of the deposits by either solution pressure or intrusive activity allowed later solutions to move through the deposits. The solutions hydrated periclase to brucite and forsterite to antigorite. The fractures were filled with quartz and antigorite, forming a network of thin veinlets.

Groundwater moving through these bedded replacement deposits has oxidized the chalcopyrite and relocated the copper along open shears and fractures as azurite, malachite, and chrysocolla. In the larger deposits and in some of the minor ones, quartz boxwork structures have formed around unreplaced brecciated marble. The removal of carbonate material between the quartz framework has left open voids. Some of the septus retain relict rhomboheldral cleavage shapes.

Fissure Fillings

Fissure veins within the tactite zone in volcanic rocks and marble are primarily magnetite and hematite with minor amounts of quartz. Fissures of magnetite are much smaller than the bedded replacement deposits and have been formed by fracture filling and some wall rock replacement. Typically fissure veins are less than 0.5 m wide and can be traced on the surface for only a few meters before they pinch out.

At one location north of the Pickadilly Mine, a magnetite vein is exposed in the roadcut (fig. 8). The vein strikes north 5° east and dips near vertically. Slickensides along the vein indicate ground movement since deposition of the ores. The magnetite has replaced part of the Little Creek Breccia along the vein. The prospect on the southeast side of Mineral Mountain is located on a small magnetite vein in the marble zone. These are small shoots of magnetite extending along the bedding planes or shears from the bedded replacement deposit. Magnetite fissure fillings are usually associated with areas of brecciation close to the intrusive contact. Fissure fillings are typically associated with the bedded replacement deposits. Fissure-filling veins exposed near the surface may indicate bedded replacement deposits near by.

Magnetite Veinlets

Along the western side of the Mineral Mountain Stock in the endomorphic bleached zone are sheeted veinlets of magnetite less than 3 cm wide which can be traced for several meters (fig. 9). These veinlets are nearly pure magnetite and are paral-

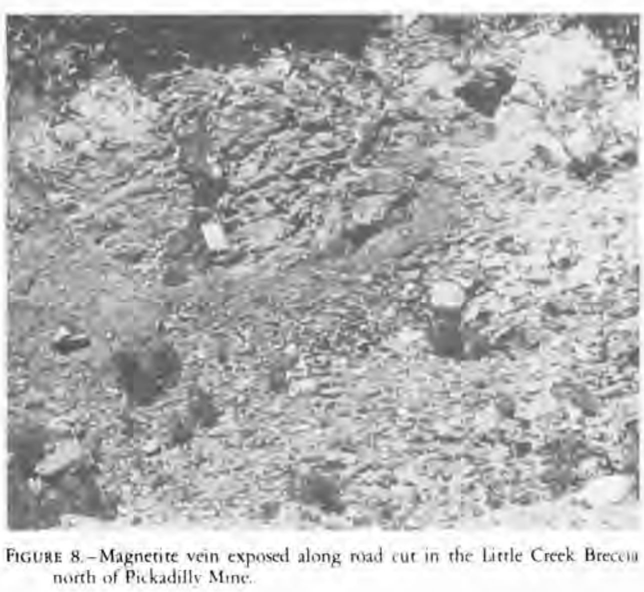

FIGURE 8.–Magnetite vein exposed along road cut in the Little Creek Breccia north of Pickadilly Mine.

leled by veinlets of quartz. Both magnetite and quartz veinlets closely parallel a dominant joint direction of the granite porphyry which strikes north 15° west and dips 75° east. The quartz veinlets are younger, crosscut, and parallel, and they intertwine with the magnetite veinlets. Just south of the Emma Mine are similar magnetite and quartz veinlets in the recrystallized dolomites and marbles of the Callville Limestone. The magnetite and quartz veinlets strike north 80° east and dip near vertically. In both the granite porphyry and marble where the quartz veinlet crosses or joins with a magnetite veinlet, the magnetite is replaced by quartz.

Mineralization Associated with the Lamprophyre Dikes

Lamprophyre dikes at the Pickadilly (Humbug) Mine contain veins of magnetite, limonite, pyrite, and disseminated pyrite. The magnetite veins are 4 to 8 cm wide and cut across the dike. Along the hanging wall contact between dike rock and marble are veins of magnetite and pyrite, with secondary limonite. Traces of tungsten and molybdenum are present but are detected only by assay. One sample collected from the dump of the lower drift of the Pickadilly Mine assayed at one-half ounce per ton of silver.

FIGURE 9.–Magnetite veinlets (m) and quartz veinlets (q) in granite porphyry.

Paragenesis of Ores

Mineralization is localized along the contact zone, between carbonate rocks and the Mineral Mountain Stock. The Callville Limestone was recrystallized to dolomite marble along the contact and continued interaction with the intrusion-altered marble to periclase and forsterite. Iron-rich solutions from the intrusion metasomatically replaced marble and skarn minerals with magnetite. Deposited with the magnetite were chalcopyrite, gold, silver, and molybdenum. This period of metalization produced bedded replacement bodies, fissure-filling veins, and magnetite veinlets. Following metalization, the mineralized areas were shattered and sheared by either solution pressure or additional intrusive activity. Thermal solutions moved along fractures and shears, hydrating periclase to brucite (nemalite) and forsterite to antigorite. Quartz and antigorite were deposited along fractures within the brucite and magnetite bodies in the bedded replacement deposits. Solutions have removed unreplaced brecciated marbles, leaving an open boxwork structure. Quartz forms the thin septus of the boxworks.

Magnetite veinlets in granite porphyry and marble zone parallel, join, and intertwine with quartz veinlets. Segments of the quartz veinlets which cross or join magnetite veinlets have replaced the magnetite. The presence of quartz in sheared bedded replacement deposits and of quartz veinlets replacing magnetite indicates addition of quartz in the mineralized areas following metalization.

Groundwater moving through the magnetite deposits oxidized chalcopyrite and relocated the copper in shears as chrysocolla, azurite, and malachite. One vein at the Emma Mine contained mainly calcite, chrysocolla, and malachite and assayed 1.42 percent copper, 21.0 ppm silver, and 4.2 ppm gold. The unusually high values for copper, gold, and silver indicate relocation of these metals.

Geochemistry

Areas of alteration and suspected mineralization were sampled for geochemical analysis. Dump samples were taken from mines and prospect dumps. Rock chip samples were collected from outcroppings of veins and altered rocks. Soil samples were collected from drainages and soil-covered surfaces in areas of possible mineralization. Figure 10 shows the location and types of samples collected. Each sample was analyzed for gold, silver, copper, molybdenum, and tungsten by Chemical and Mineralogical Services (CMS) in Salt Lake City, Utah. Samples collected from areas that were influenced by the same geologic conditions, such as soil samples, collected from the same area were plotted as $\log_{10}$ mean ppm (part per million) for the gold, silver, copper, and molybdenum values in the histograms in figure 11. Tungsten values were not shown in figure 11 but are covered briefly in this section. All geochemical data is shown in appendix B.

Samples represented in histograms A–D (fig. 11) are located along the west side of Mineral Mountain in the major mineralized areas. Histograms A–C (fig. 11) show the result of geochemistry values obtained from samples collected along the west side of the Mineral Mountain Stock on the major trend of the magnetite deposits. Histograms D–F (fig. 11) show results from Pickadilly Mine (histogram D) south to Potter Peak. Comparison of mean values shown on histograms A–D indicate the following: (1) gold and copper values are higher in the north, (2) molybdenum values are higher in the south, and (3) silver values show no detectable pattern. Of the three major mines, the Emma Mine showed the highest values for gold and copper. The Pickadilly Mine showed the highest molybdenum

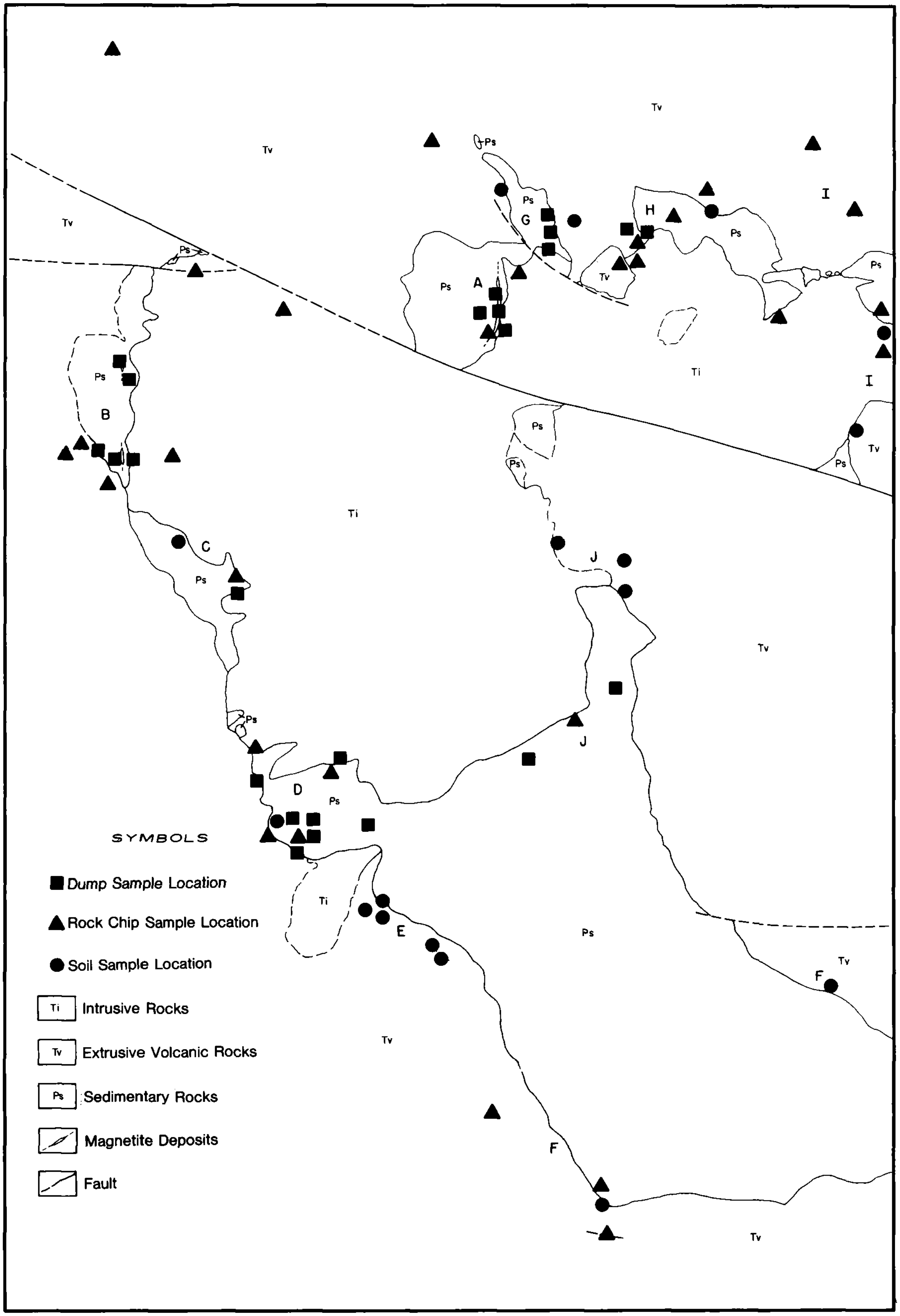

FIGURE 10.–Location map of geochemical samples. Block letters correspond to histograms in figure 11.

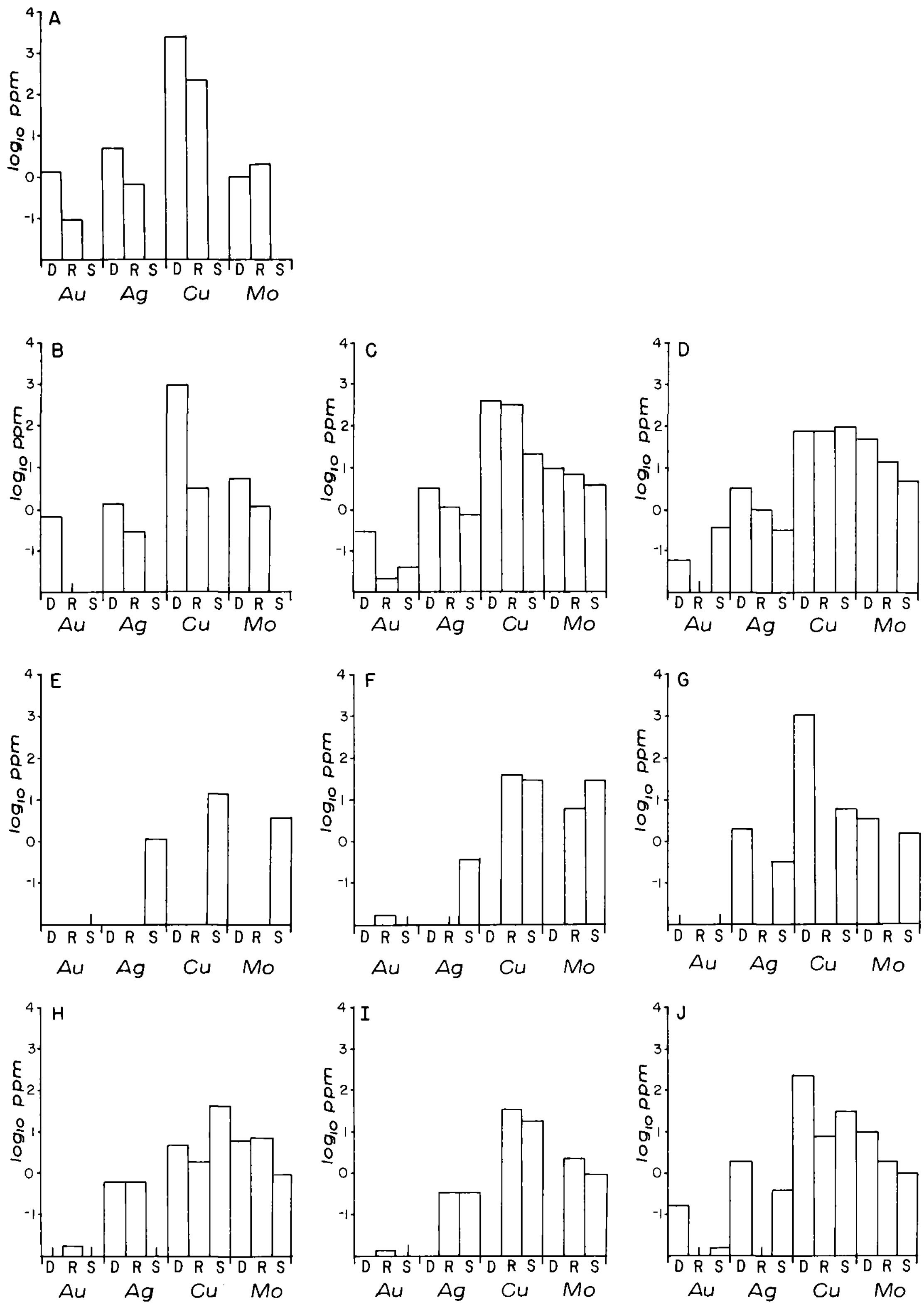

FIGURE 11.–Histogram of geochemical results. Block letters on the upper left of histograms correspond to block letters in figure 10, indicating area from which samples were collected. The $\log_{10}$ ppm for the mean of each type sample in areas designated on sample location map, figure 10. Each bar represents the $\log_{10}$ mean ppm for either dump samples, rock chip samples, or soil samples. Each is designated by D, R, or S, respectively, for the type sample. A dash mark indicates that the average ppm for that element is below its detection limit. No bar indicates no samples were taken of that type in that area.

values and traces of tungsten. The areas sampled from the Pickadilly Mine south to Potter Peak showed higher molybdenum values than samples collected elsewhere. Traces of tungsten are also present.

Samples represented in histograms G–J (fig. 11) came from the north and east side of Mineral Mountain where only trace amounts of gold were detected. The trend of copper values is not as uniform as on the western side of Mineral Mountain; however, copper values are high on the northern side (histogram G) and on the eastern side (histogram J) of the mountain. Samples from the northeast side of the stock (histograms H–I) are slightly lower. No significant differences in silver and molybdenum are shown in histograms G–J.

MINES AND PROSPECTS

Emma Mine

The Emma Mine is located on the north side of Mineral Mountain. Claims covering the Emma Mine and surrounding area are currently held by LeRoy Holt of St. George, Utah. Several prospect pits on the ridge above the main drift have uncovered a magnetite replacement deposit traceable for 46 m. The deposit is brucite, magnetite, and antigorite. The ore body and surrounding wall rock are broken and shattered because of postmineralization tectonic movement. Secondary calcite, chrysocolla, and malachite cover fracture and shear surfaces. The ore body dips between 75° and 56° to the west. The magnetite has metasomatically replaced the marble along bedding planes.

On the west slope below the exposed lode deposits are the main workings of the Emma Mine (fig. 12), where a drift extends 77 m into the mountain. The drift runs almost due east perpendicular to the strike of the replacement body and crosscuts several brecciated shears and fissures, separating wedges of marble and massive brucite and antigorite replacements. Sixty-four meters into the drift, a 2.4-m-wide body of magnetite is encountered. The footwall of this deposit is a brecciated shear zone with blocks and fragments of serpentine and marble, and the hanging wall is a massive brucite replacement.

Along the walls of the drift, copper oxides in fractures are common. Twenty-nine meters into the drift, a shallow winze 7.3 m deep follows some of the calcite-copper-filled fractures. The winze is flooded, making access to deeper workings, if any, impossible.

At the time of my visit to the Emma Mine, the first 15.2-m section of the drift was caved. Access to the workings was reached by a small opening behind the caved portion.

The Emma Mine has had no record of ore production although reports of rich gold and silver exist. Assayed samples from the dumps indicate only trace amounts of gold and silver; however, the Emma has the largest iron deposits on Mineral Mountain. A magnetometer survey across the magnetite body (Bullock 1970, p. 95) revealed only a small anomaly and indicated that the ore body is shallow and dipping steeply. Bullock concluded from geology and geophysical data that the iron ore reserves are less than 1,000 tons.

Gregerson Prospects

The Gregerson prospects are located on the west side of Mineral Mountain. Claims covering the Gregerson prospects are also held by LeRoy Holt of St. George, Utah. Several pros-

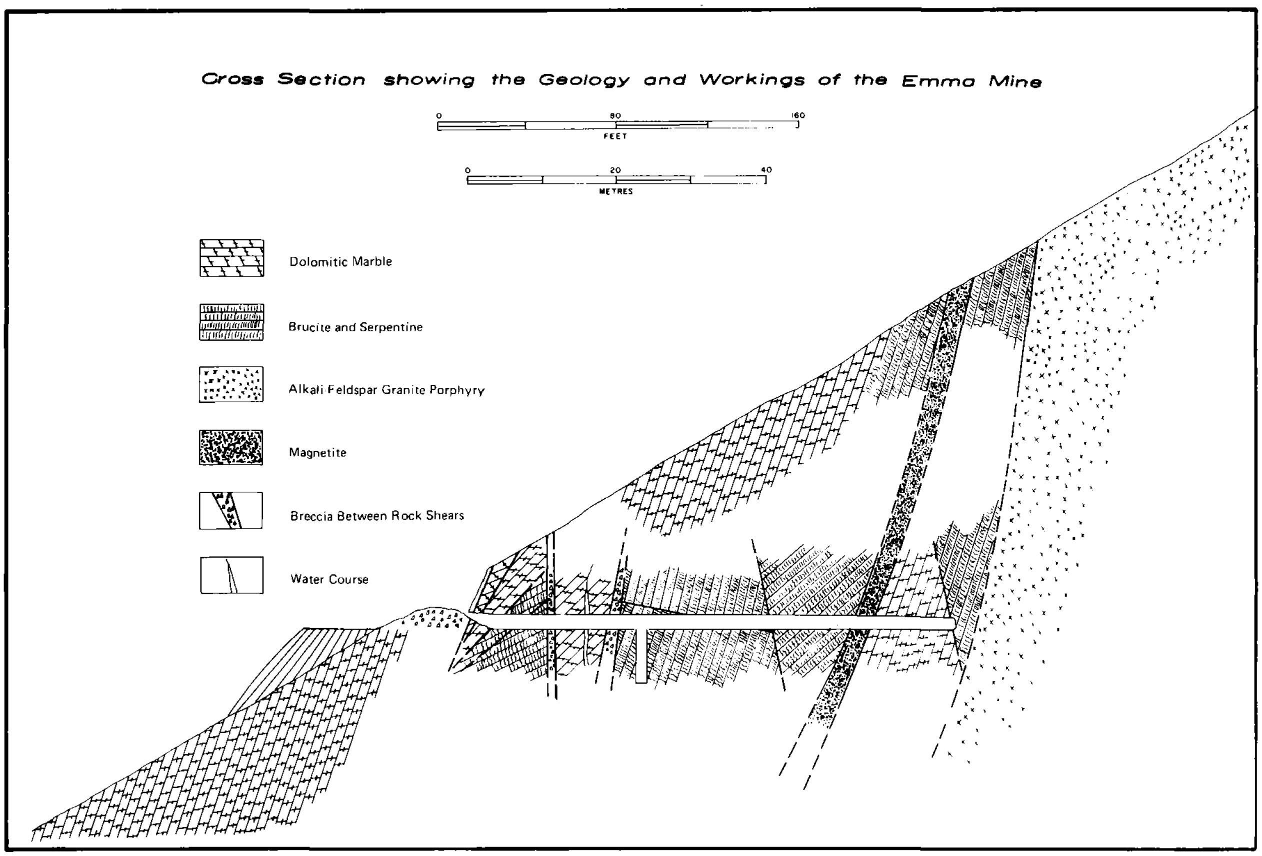

FIGURE 12.–Geology map and workings of the Emma Mine.

pect pits, a bulldozer cut, and two short drifts represent all work done on the property. Mineralization at the Gregerson is similar to that of the Emma Mine but less extensive. No magnetite deposit can be traced on the surface as a continuous body, and magnetite appears only as discontinuous pods along bedding planes. Copper oxides occur with calcite in fractures in the tactites.

Both drifts at the Gregerson property are caved, but the northernmost drift can be entered by a small opening behind the caved portal. The northern drift extends east 24.4 m, and the entire drift is in brecciated brucite, serpentine, and marble. Magnetite appears on the dump, but none was found in the mine. Assayed samples from the dumps show traces of gold, silver, and molybdenum.

LeRoy Holt (personal communication), owner of the Gregerson prospects, recalls that drilling in the 1960s encountered granite porphyry beneath the property. No record or log data of the drilling was kept, and no ore production has been recorded from the Gregerson prospects.

Pickadilly (Humbug) Mine

The Pickadilly (Humbug) Mine is on the southwest side of Mineral Mountain. The property has several prospect pits, two drifts, and two shafts. All the workings are grouped around the two lamprophyre dikes exposed on the hillside. The dikes are approximately parallel and strike north 30° west. The western dike is exposed only at the portal of the lower drift. The east dike is exposed at the lower drift and can be traced up the hill 76 m. On the hill, north of the two drifts, are several prospects and two shafts following the trend of the dike. One shaft is inclined and connects with workings of the upper drift.

The only accessible workings are two drifts into the lamprophyre dikes. The lower drift extends 19 m along the strike of the smaller western dike. Along the hanging wall of the dike is a magnetite and pyrite fissure vein. Disseminated pyrite is found all through the dike rock.

The upper drift follows the other lamprophyre dike along strike 21 m then swings out into the unmineralized marble. At 31 m the drift intercepts a natural cavern which has formed along a bedding plane shear in the marble. Some minor dripstone deposits line vugs and walls of the cavern. At the cavern the drift forks, the left fork leading to an inclined shaft from the surface and the right fork following minor iron stains along a shear zone.

The Pickadilly Mine has had no known production of ore. Dump and rock chip samples from the mine show only traces of gold, silver, molybdenum, and tungsten.

The Marble Mine

A marble quarry on top of Marble Mountain, opened by Milton Holt of Gunlock, Utah, is mined for white, green, and red marbled stone. No economic minerals are found in the quarry, and the mine has produced less than 10 tons of marble (Milton Holt personal communication). Marble is the only economic commodity currently being mined from the Mineral Mountain area.

Other Prospects

Between the Emma Mine and Marble Mountain several small prospects are located on minor showings of chrysocolla and malachite in the fractured marble. On the south ridge of Mineral Mountain on the west flank of the Mineral Mountain Anticline are three prospects located on areas of limonite stains and argillic alteration.

SUMMARY

Stratigraphy of the Mineral Mountain area consists of Late Paleozoic rocks from the Callville Limestone and Supai-Coconino Sandstone Formation and Tertiary volcanic rock. Late Paleozoic rocks are part of an allochthon of the Late Cretaceous Sevier orogeny. The Mineral Mountain Anticline is the major structure in the mapped area and acted as a topographic barrier during deposition of the Tertiary volcanics. The volcanic tuffs and flows thin and lap on the crest and flanks of the Mineral Mountain Anticline. Intrusion of alkali-feldspar granite porphyry along the axis of the anticline causes renewed arching and brecciation of the country rock. Alkali-feldspar granite porphyry forms the bulk of the rock in the Mineral Mountain Stock which makes up the major part of Mineral Mountain.

Along contacts of the Mineral Mountain Stock the rocks are altered by pyrometamorphism and metasomatism, producing a contact metamorphic aureole that contains an exomorphic bleach zone in the granite porphyry. Mineralogy of the rock along the contact suggests conditions common to a pyroxene hornfels facies.

Mineral deposits are in the tactite zone along the west side of the Mineral Mountain Stock. Magnetite is the most common ore mineral and is found in three types of deposits: (1) bedded replacements, (2) fissure fillings, and (3) magnetite veinlets. Bedded replacement deposits are the largest type of magnetite deposit and have replaced the marbles along relict bedding planes. Fissure-filling veins are associated with and extend from the bedded replacement deposits. Small magnetite veinlets in the granite porphyry and marble are also associated with the other types of magnetite deposits. Chalcopyrite associated with the magnetite has been oxidized by meteoric waters and mobilized and deposited as azurite, malachite, and chrysocolla in fractures in the tactite and marble zone.

Minor amounts of pyrite and magnetite and traces of tungsten and molybdenum are found in fissures along the hanging wall contact of the lamprophyre dikes at the Pickadilly (Humbug) Mine.

Paragenesis of ores involved first the marmorization of the dolomite beds of the Callville Limestone and later continued alteration to periclase and forsterite. Iron-rich solutions from the intrusion metasomatically replaced the marbles and other minerals with magnetite. Deposited with the magnetite were chalcopyrite, gold, and silver. Solution pressure or additional intrusive activity shattered the tactites, allowing solutions to hydrate the periclase and forsterite and deposit quartz and antigorite. Groundwaters oxidized the chalcopyrite and relocated the copper as copper oxides. After the mineralization and metalization, the north end of the Mineral Mountain Stock was displaced by the right lateral strike-slip fault.

Geochemistry indicates that gold and copper mineralization is more pervasive on the northern end of the tactite zone on the west side of Mineral Mountain Stock. Molybdenum and tungsten values are generally higher at the Pickadilly Mine area and on the south side of the Mineral Mountain Stock.

ECONOMIC POTENTIAL

Mineral deposits on Mineral Mountain are small and near the surface. No exploration has been done at any significant depth. Patterns from the geochemical investigation indicate that copper and gold mineralization is associated with magnetite deposits on the west side of the Mineral Mountain Stock. The highest molybdenum and tungsten values came from the lamprophyre dikes at the Pickadilly (Humbug) Mine on the south side of Mineral Mountain.

A wide marble zone, hydrothermal alteration, and higher molybdenum and tungsten values to the south suggest that the Mineral Mountain Stock extends along the Mineral Mountain Anticline at depth. Detailed geologic mapping, close-spaced geochemical sampling, and a shallow drilling program in areas of alteration along the anticline would be useful for determining possible ore targets.

Deposits currently exposed on the surface and in the mines are low tonnage and low grade. Difficult accessibility makes these deposits impractical to mine.

APPENDIX A

Stratigraphic Section of the Callville Limestone

Measured by Stuart K Morris and Lee Perry in the northwest corner of section 6, Township 40 south and Range 18 west, on November 23, 1979

Unit Number	Description	Unit Thickness in Meters	Cumulative Thickness in Meters
	Supai-Coconino Sandstone dusky yellow to yellowish gray, fine-grained, cross-bedded, slightly calcareous sandstone		
	Conformable and gradational contact		
	Callville Limestone		
39	Covered slope Yellow sandstone and dolomite float	10 6	319 5
38	Dolomite Light gray, fine grained with minor amounts of interbedded chert	2 5	308 9
37	Dolomite Medium dark gray with thin beds, gray sandstone, slope former	4 4	306 4
36	Dolomite Light bluish gray, fine grained	4 0	302 0
35	Dolomite and sandstone Yellowish gray and white sandy dolomite and calcareous sandstone	5 1	298 0
34	Sandstone Light olive brown to dusky yellow, fine grain and calcareous, minor interbedded limestone	5 1	292 9
33	Dolomite Light gray, fine to medium grain	0 6	287 8
32	Covered slope Float of sandstones and dolomite	15 2	287 2
31	Dolomite Light gray, fine grained, minor amounts of chert	6 9	272 0
30	Sandstone Light red to light brown, fine grained, thinly bedded and calcareous, minor amounts of chert	40 6	265 1
29	Dolomite and sandstone Light gray, fine-grained with 1-m bed of light brown, fine- to medium-grained calcareous sandstone	7 6	224 5
28	Covered slope Float of light gray dolomite	12 5	216 9
27	Dolomite Light gray, fine grained	2 4	204 4
26	Covered slope Float of light gray dolomite	19 6	202 0
25	Dolomite Light gray to white, fine grained	1 3	182 4
24	Dolomite Medium light gray, medium grained, interbedded light yellow chert	4 8	181 1
23	Dolomite Light gray, fine grained	5 3	176 3
22	Covered slope Light gray soil and dolomite float	5 4	171 0
21	Dolomite White to very light gray, fine grained	2 1	165 6
20	Dolomite Light bluish gray, fine to medium grained, interbedded chert beds	20 1	163 5
19	Limestone Grayish yellow, medium grained, sandy	0 3	143 4
18	Dolomite Light gray to medium gray alternating beds, fine grained	7 1	143 1
17	Dolomite White to very light gray, fine to medium grained	5 9	136 0
16	Dolomite Light gray to medium gray beds, fine grained, some interbedded dolomite breccia	7 9	130 1
15	Dolomite Light gray, fine grained with minor amounts of chert	5 7	122 2
14	Dolomite White to light gray, fine grained with some interbedded breccia	10 1	116 5
13	Dolomite White to medium gray, fine to medium grained, fossil fragments and minor amounts of chert	13 4	106 4
12	Dolomite and limestone Dark gray to medium gray, coarse-grained dolomite grading to medium-grained very light gray limestone	13 8	93 0
11	Limestone Light gray to white, medium to coarse grained, some fossil fragments	5 1	79 2
10	Covered slope Light gray soil and dolomite float	2 7	74 1
9	Dolomite Very light gray, fine grained	1 0	71 0
8	Covered slope Light gray soil and dolomite float	5 4	70 4
7	Dolomite and limestone Interbedded light gray dolomite and light bluish gray limestone, the dolomite beds are partly shattered	22 3	65 0
6	Covered slope Light gray and red soils with limestone and dolomite float	2 4	42 7
5	Limestone Light gray, fine grained, massive bed	2 9	40 3
4	Limestone Light gray fine to medium grained, minor chert nodules and fossil fragments	7 6	37 4
3	Covered slope Light gray and yellowish soils	0 8	29 8
2	Limestone Light blue, fine grained, minor beds and nodules of chert, some thin light brown, fine-grained sandy beds	12 5	29 0
1	Limestones Brecciated and deformed limestones	16 5	16 5
	Thrust fault		

The partial section of the Callville Limestone measures 319 5 m (1048 ft) The rest of this section is not present because of thrusting of part of the Callville Limestone over the Mesozoic Navajo Sandstone

APPENDIX B

Methods of Geochemical Sampling

All mine dumps were sampled by taking fines from small (0.2 m) pits dug at one-meter intervals just below (0.5 m) the crest of the dump. Stockpiles of high grade ores were not sampled, so the sample would be representative of the wall rock mineralization.

Rock chip samples.
Several (more than two) rock chips were taken from around the outcrop of interest. Weathered surfaces were chipped away from the samples, if possible.

Soil samples.
Two types of soil samples were taken: (1) soil samples and (2) drainage samples. Soil samples were taken from the "B" soil horizon, if present, and if not present samples were taken from deeper parts of horizon "A". Drainage samples were taken from the fine silts in the stream bottom above major bifurcations.

Geochemical Results

The geochemical results are listed in ppm. The location of the samples is shown by section number and feet east of the west section line and feet south of the north section line. Results are also grouped under the graph area.

Section	Feet east from west section line	Feet south from north section line	Sample type	Au	Ag	Cu	Mo	
			Graph A					
34	100	4,900	Dump	0.08	0.6	375	1	
"	300	5,000	"	2.25	8.0	4020	1	
"	300	5,000	"	1.50	3.2	3060	1	
"	300	5,000	"	0.81	5.5	3040	1	
"	600	4,200	Chip	0.01	0.5	65	3	
"	200	5,100	"	0.15	0.8	325	1	
			Graph B					
5	3,400	400	Dump	0.31	1.4	1050	4	
"	3,600	600	"	0.17	1.2	295	7	
"	3,500	1,900	"	0.35	0.8	385	3	
"	3,400	1,900	"	1.38	1.7	880	9	
"	3,300	1,900	"	1.38	3.4	3320	7	
"	2,600	1,800	Chip	0.01	0.3	11	1	
"	2,700	1,800	"	0.01	0.3	25	1	
"	3,300	3,200	"	0.01	0.3	50	2	
			Graph C					
4	0	3,900	Dump	0.30	3.2	415	9	
"	0	3,800	Chip	0.02	22.8	650	4	
5	4,300	1,700	"	0.02	0.3	25	9	
"	4,400	3,200	Soil	0.04	0.8	20	4	
			Graph D					
9	400	2,200	Dump	0.23	1.2	220	7	
"	900	2,800	"	0.01	2.0	25	1	
"	200	2,900	"	0.01	2.0	17	1	
"	1,200	3,000	"	0.01	0.8	50	17	
"	1,200	2,900	"	0.02	1.5	215	20	
"	1,600	1,900	"	0.01	1.5	13	1	
"	1,000	3,000	"	0.10	14.0	40	310	
							25	W
"	1,200	3,000	Chip	0.01	1.8	330	45	
"	600	4,900	"	0.01	0.3	4	14	
"	400	1,700	"	0.01	0.3	4	1	
"	1,500	2,000	"	0.01	1.5	10	1	
"	700	2,800	Soil	0.35	1.0	110	5	
			Graph E					
9	2,400	4,300	Soil	0.01	0.4	14	13	
"	2,100	4,200	"	0.01	0.5	25	1	
"	2,300	4,200	"	0.01	0.9	18	1	
"	3,200	4,900	"	0.01	1.2	10	1	
"	3,100	4,800	"	0.01	2.2	7	1	
			Graph F					
15	4,100	2,100	Chip	0.01	0.3	25	2	
"	600	3,300	"	0.03	0.3	4	15	
"	700	4,100	"	0.01	0.3	10	2	
"	600	3,600	Soil	0.01	0.4	35	30	
"	300	2,900	"	0.01	0.3	17	35	
							2	W
			Graph G					
34	1,200	3,300	Dump	0.01	0.6	50	1	
"	1,100	3,800	"	0.01	4.1	3200	1	
"	1,300	3,900	"	0.01	0.8	400	9	
"	300	2,900	Soil	0.01	0.3	20	1	
"	1,500	3,400	"	0.01	0.3	16	2	
			Graph H					
34	2,500	3,700	Dump	0.01	1.0	40	8	
"	2,500	3,600	"	0.01	0.3	13	3	
"	2,200	3,900	Chip	0.01	0.3	6	1	
"	2,900	3,300	"	0.03	0.9	11	1	
"	3,600	2,800	"	0.01	0.3	30	1	
"	2,500	3,700	"	0.01	0.8	35	30	
"	2,200	4,000	"	0.02	0.8	16	2	
"	3,800	3,200	Soil	0.01	0.3	40	1	
			Graph I					
34	4,800	4,900	Chip	0.01	0.3	25	3	
35	1,100	4,800	Chip	0.02	0.8	20	3	
"	0	2,100	"	0.01	0.3	50	1	
"	700	3,200	"	0.01	0.3	35	1	
"	1,300	5,200	"	0.01	0.3	65	3	
"	1,300	5,200	Soil	0.01	0.3	25	1	
3	4,700	1,400	"	0.01	0.3	15	1	
			Graph J					
9	4,700	1,800	Dump	0.01	1.0	30	13	
4	0	3,900	"	0.30	3.2	415	9	
10	200	1,200	Chip	0.01	0.3	8	2	
4	5,100	3,200	Soil	0.01	0.4	13	1	
3	900	3,500	"	0.01	0.3	40	1	
"	900	4,000	"	0.03	0.4	45	1	

APPENDIX C

Uranium Mineralization Investigation

A scintillometer survey was made over the north, west, and south sides of Mineral Mountain, including the Emma, Gregerson, and Pickadilly mining areas. The investigation was done to determine if any uranium mineralization is present.

The results obtained from the investigation are listed below:

Location	Rock type or formation	Count/minute
Marble Mountain	Marble	9,000
Northeast of Emma Mine	Post-Quichapa tuff	25,000
Northeast of Emma Mine	Marble	9,000
Emma Mine area	Marble-granite porphyry	25,000
Emma Mine	Tactite	19,000
West side of Mineral Mountain Stock (North of Gregerson Mine)	Marble-granite porphyry contact	24,000
Gregerson Mine	Marble and tactite	16,000
Area south of Gregerson Mine	Little Creek Breccia	15,000
Pickadilly Mine area	Marble	10,000
Pickadilly Mine	Lamprophyre dike	14,000
South ridge of Mineral Mountain	Callville Limestone	8,000
Potter Peak area	Little Creek Breccia	15,000

No high anomalies were encountered during the survey. The scintillometer readings did indicate a uniform count for each formation or rock type. The uniform readings obtained from the volcanic formations could be a useful tool in determining the local stratigraphy. The information from this brief study indicates that no near-surface uranium mineralization is present in the areas investigated.

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