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GEOLOGY OF THE CENTRAL MINERAL MOUNTAINS
BEAVER COUNTY, UTAH

By
Bruce S. Sibbett
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*Dist-653
NTIS-22*

March 1980

Work Performed Under Contract No. AC07-78ET28392

Earth Science Laboratory
University of Utah Research Institute
Salt Lake City, Utah

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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March, 1980

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Prepared for the
DEPARTMENT OF ENERGY
DIVISION OF GEOTHERMAL ENERGY
Under Contract No. DE-AC07-78ET28392

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ABSTRACT

The Mineral Mountains are located in Beaver and Millard Counties, southwestern Utah. The range is a horst located in the transition zone between the Basin and Range and Colorado Plateau (Stokes, 1977) geologic provinces. A multiple-phase Tertiary pluton forms most of the range, with Paleozoic rocks exposed on the north and south and Precambrian metamorphic rocks on the west in the Roosevelt Hot Springs KGRA (Known Geothermal Resource Area). Precambrian banded gneiss and Cambrian carbonate rocks have been intruded by foliated granodioritic to monzonitic rocks of uncertain age.

The Tertiary pluton consists of six major phases of quartz monzonitic to leucocratic granitic rocks, two diorite stocks, and several more mafic units that form dikes.

During uplift of the mountain block, overlying rocks and the upper part of the pluton were partially removed by denudation faulting to the west. The interplay of these low-angle faults and younger northerly trending Basin and Range faults is responsible for the structural control of the Roosevelt Hot Springs geothermal system. The structural complexity of the Roosevelt Hot Springs KGRA is unique within the range, although the same tectonic style continues throughout the range.

During the Quaternary, rhyolite volcanism was active in the central part of the range and basaltic volcanism occurred in the northern portion of the map area. The heat source for the geothermal system is probably related to the Quaternary rhyolite volcanic activity.

This study did not document any additional evidence of recent geothermal activity. It has, however, documented several areas of young basaltic volcanism in the northern portion of the Mineral Mountains. In addition, a structural framework has been developed which will be of use to geothermal explorationists working in the area.

INTRODUCTION

The Mineral Mountains are located in Beaver and Millard Counties, in southwestern Utah (Figure 1). Geothermal exploration and development are currently active in the Roosevelt Hot Springs KGRA on the west-central edge of the range. At present, seven producing wells have been completed and a 20 MWe power plant is planned. The water-dominated geothermal reservoir is structurally controlled (Lenzer and others, 1976; Nielson and others, 1978, 1979).

The present study was undertaken as part of the Industry Coupled Case Studies Program of the Department of Energy, Division of Geothermal Energy. The objectives of this study are to: 1) complete a detailed geologic map of the central part of the Mineral Mountains to determine to what extent the lithologies and structure in the KGRA are unique within the range, and 2) develop a more complete understanding of the plutonic phases and structural history of the Mineral Mountains.

The geology of the Mineral Mountains has been discussed by Earl (1957), Liese (1957), and Condie (1960). Petersen (1975) published a map of the Roosevelt Hot Springs area and Evans (1977) presented a geologic compilation of previous work along with some new work. Nielson and others (1978) completed the first detailed geologic map of the Roosevelt Hot Springs KGRA, and this report is a continuation of that study. A comprehensive annotated bibliography of the geology of the Mineral Mountains was compiled by McKinney (1978).

FIGURE 1

LOCATION OF STUDY AREA AND
PHYSIOGRAPHIC SUBDIVISIONS
OF UTAH

FROM STOKES, 1977

GEOLOGY

Regional Setting

The Mineral Mountains are located west of the Marysvale volcanic pile within the transition zone between the Colorado Plateau and the Basin and Range geologic provinces (Figure 1). The range is a structural high exposing Precambrian rocks and the Mineral Mountains pluton. The regional structural setting is that of north-northeast-trending normal faults bounding horsts and grabens.

General Geology of the Mineral Mountains

The Tertiary Mineral Mountains pluton forms the bulk of the central portion of the range, but outcrops of Precambrian metamorphic rocks form some of the western foothills and Paleozoic carbonate rocks and quartzites occur on the southeast side. The north end of the Mineral Mountains consists of Cambrian sedimentary rocks (Liese, 1957), which are, in places, overlain by Cretaceous conglomerate. The southern portion of the range, the Bradshaw Mountain area, consists of Precambrian gneisses overlain by Paleozoic and Mesozoic sedimentary rocks, and Tertiary volcanic rocks (Earll, 1957). These rocks have been intruded by the Mineral Mountains Pluton. Mining activity in the range has produced gold, silver, lead, and copper from contact metamorphic deposits and associated veins in the Bradshaw Mountains.

Lithologies of the Mineral Mountains

Precambrian

The descriptions of the Precambrian units are taken from the Roosevelt Hot Springs KGRA report (Nielson and others, 1978) and the reader is referred to that report for a more detailed discussion.

Banded gneiss (P6bg)

The banded gneiss is the oldest unit exposed in the Mineral Mountains. It crops out along the western margin of the Mineral Mountains from Ranch Canyon northward to Negro Mag Wash; a few large inclusions are present in the Tertiary pluton north of Negro Mag Wash (Plate I).

The banded gneiss (P6bg) is typically fine- to medium-grained with coarser grained leucocratic layers composed of subequal amounts of quartz and K feldspar with minor biotite and plagioclase. Dark layers are composed predominantly of biotite, plagioclase, and quartz with minor hornblende and K feldspar. Rounded zircon grains and apatite are common accessory minerals.

The compositional banding represents original sedimentary bedding. Individual layers are 1 to 10 cm thick in a typical outcrop. More mafic zones and more felsic zones are a few feet to over one hundred feet thick. Biotite is the most abundant mafic mineral in the dark layers and zones, accompanied in places by minor amounts of hornblende.

Schistosity is well to poorly developed and generally parallels the banding with a typical orientation of N-S to N30E. Small-scale isoclinal folds with a NE plunge are present.

Two distinctive lithologies, a metaquartzite and a sillimanite schist, have been mapped as distinct from the banded gneiss, although they are part of the same meta-sedimentary sequence.

Quartzite (P6q)

A white metaquartzite (P6q) forms beds and lenses within the banded

gneiss and xenoliths within the hornblende gneiss between Wild Horse and Range canyons (Plate I). Bedding is visible within the quartzite and parallels the schistosity in the enclosing rocks. The rock is principally composed of quartz with about 5 percent feldspar and accessory biotite, chlorite, and apatite.

Sillimanite Schist (PGs)

The sillimanite schist (PGs) occurs as mappable inclusions within the Tertiary granite on the south side of Wild Horse Canyon. The schist is a dark gray to green, fine-grained rock with 0.5 to 1 cm layering composed of layered sillimanite-biotite-quartz schist with small garnets aligned along thin, widely separated layers. Felsic layers consisting of quartz and plagioclase separate sillimanite-biotite layers.

The banded gneiss and sillimanite schist represent argillaceous sedimentary rocks that have undergone upper amphibolite facies regional metamorphism. In contrast, the Paleozoic and Mesozoic rocks in the area are predominantly carbonates and exhibit only contact metamorphic effects. Thus the regional metamorphism of the rocks took place in Precambrian time. Radiometric dating studies on these rocks are currently in progress.

Paleozoic and Mesozoic Sedimentary Rocks

Sedimentary rocks that have been intruded by the Mineral Mountains pluton are exposed on the southeast side of the range and in isolated outcrops southwest of the range (Plate I). Contact metamorphism and Sevier Orogeny thrusting have made determination of the stratigraphy tenuous.

The limestone, which crops out on the southeast side of the pluton, is a

medium to light gray or white dolomite and limestone with a few thin calcareous shale horizons. The dolomite is oolitic in part and crossbedded in a ten-foot-thick horizon. Worm trails are present in other horizons. There has been some recrystallization of the rock. Crawford and Buranek collected Mississippian fossils from east of the King of the Hill Mine on the east side of the range and concluded that Cambrian to Mississippian rocks were present in this area (Crawford and Buranek, 1945, p. 19). The authors were unable to relocate the Crawford and Buranek fossil locality but did collect Mississippian fossils around the Beaver View Mines (Plate I). The fossils were identified by Dr. James L. Baer of Brigham Young University as *Lithostrotion* and *Syringopora* corals, the ammonoid *Cravenoceras*, and a spirifer brachiopod which is characteristic of the Redwall Limestone. On this basis the beds by the Beaver View Mine, and east of the King of the Hill Mine, were mapped as Redwall Limestone (Plate I).

The carbonates in contact with the pluton on the southeast side are metamorphosed and some beds are recrystallized to a friable, dolomitic marble. The marble is light to medium gray and medium to massive bedded. Original bedding is preserved but most details have been destroyed. Worm trails are evident in some outcrops. The dolomitic marble may be Redwall Formation repeated by thrusting. There is a repetition of the phyllite-limestone-dolomite sequence in the King of the Hill Mine area (Plate I).

The quartzite on the southeast side of the range (Plate I) is mostly white or yellow with some areas of gray, and hematite-stained red, brown, and orange. The medium- to fine-grained quartzite is generally massive, with small scale crossbedding in some outcrops. There is a thin pebble

conglomerate at its base or east contact. The identity of these quartzites, phyllites, and carbonates was not determined due to the degree of contact metamorphism and thrust faulting, and to the limited time for studying these rocks. The quartzite and phyllites may be Mesozoic in age.

The dark brown and red phyllite on the southeast side of the range is a metamorphosed shale and siltstone sequence with thin bedding. The rock consists of rounded quartz grains with a matrix of muscovite and biotite in distinct layers. Mica cleavage is subparallel to the bedding. The rocks on the southeast side of the Mineral Mountains have been mapped as Coconino quartzite, Kaibab limestone and Moenkopi formation by Earll (1957).

However, the evidence presented above suggests that the Kaibab limestone mapped by Earll is actually Redwall limestone. If this correlation is correct, it is clear that the stratigraphy of the southeast side of the range needs to be reevaluated.

Earll (1957) mapped the limestone exposed in isolated outcrops west of the range (Plate I) as Kaibab limestone. The outcrops lack the chert nodules characteristic of this formation, however. In this study limestone, quartzite and phyllite on these inselbergs were not assigned to a named formation because their identity could not be determined.

Mafic Intrusive Rocks

Hornblende Gneiss (hgn)

The hornblende gneiss (hgn) is a coarse-grained foliated quartz monzonite that crops out in the west central part of the range, generally between the banded gneiss on the west and the Tertiary pluton on the east (Plate I). The

largest outcrop area of the hornblende gneiss is in the vicinity of Wild Horse Canyon. The unit intrudes the banded gneiss and is intruded by Tertiary plutonic rocks.

The hornblende gneiss forms massive, resistant outcrops with a weak foliation produced by the alignment of hornblende and biotite. The foliation has about the same orientation as that of the banded gneiss. Minor folds are rare but a few were observed in the hornblende gneiss. The contact between the hornblende gneiss and the banded gneiss exhibits both parallel and crosscutting relationships relative to the foliation. The foliation is parallel to that of the banded gneiss, suggesting that the hornblende gneiss crystallized in the same stress field as that in which the banded gneiss was metamorphosed. This suggests that the unit is also Precambrian, but a reliable age date is not available.

The hornblende gneiss is a light gray, coarse-grained rock with 1 cm hornblende crystals, feldspar, and finer grained quartz. Biotite content is variable and exceeds hornblende in some outcrops.

The gneiss is xenomorphic granular with intergrowths of K feldspar and plagioclase. The quartz is highly stressed and biotite occurs in weakly oriented clots. Plagioclase composition is An 26-32. The average mode for three thin-section analyses (Nielson and others, 1978) is: alkali feldspar 27.2 percent, plagioclase 25.6 percent, quartz 21.2 percent, hornblende 8.9 percent, biotite 9.2 percent, opaques 1.6 percent, and less than one percent each of clinopyroxene, apatite, zircon, sphene, actinolite, and chlorite. Sericite content averages 3.5 percent.

Biotite Granodiorite (gd)

The biotite granodiorite (gd) is a medium-grained rock that occurs as inclusions and stoped blocks within the Tertiary pluton in the west-central part of the range, and as a small stock in the eastern part of Wild Horse Canyon (Plate I). The unit is highly variable but typically has a uniform, biotite-rich, fine-grained texture with weak foliation in some exposures. Abundant 1 to 3 mm euhedral sphene and hornblende are noticeable in hand sample. The rock is dark gray, non-resistant, and forms low, rounded outcrops or fine, dark soil-covered slopes. Plagioclase is the predominant feldspar with interstitial quartz and K feldspar forming a xenomorphic granular texture. The average mode of three thin-section analyses (Nielson and others, 1978) was alkali feldspar 18.5 percent, plagioclase 34.7 percent, quartz 22.7 percent, biotite 13.3 percent, hornblende 5.2 percent, sphene 1.7 percent, opaques 1.9 percent, and less than one percent each of chlorite, apatite, sericite, and zircon. Anorthite content of plagioclase ranges between An 29 to An35. Two of the samples had a granodiorite composition and the third a quartz monzonite composition.

Field relationships bracket the relative age of the biotite granodiorite between the Precambrian banded gneiss and the felsic phases of the Tertiary pluton. The unit is lithologically similar to the Tertiary diorite (Td) in the northern part of the range.

Hornblende Granodiorite (hd)

A foliated medium-grained hornblende granodiorite is exposed over an area of about five square miles in the northern part of the map area. The granodiorite intrudes the Cambrian carbonates and is intruded by the biotite

quartz monzonite (Tqm) and biotite diorite (Td).

The granodiorite has a vertical, east-west foliation in some outcrops. The only post-Precambrian rocks known to be foliated in the region are Jurassic (Carl Hedge, per. comm.). The granodiorite therefore may be of Jurassic age.

The granodiorite weathers to a fine, dark grus. The slopes are generally covered with talus from the abundant porphyritic rhyolite dikes which cut the unit. The granodiorite has a hypidiomorphic texture with 2 to 6 mm euhedral plagioclase, having a composition of An 35, that constitutes 54 percent of the rock. The rock contains about 12 percent anhedral K feldspar, 12 percent quartz, 11 percent subhedral to euhedral hornblende, 9 percent subhedral biotite, 1 percent sphene, 1 percent opaques, and a trace of apatite and zircon.

Tertiary

The Tertiary pluton, which comprises most of the map area, is composed of eight major phases. The relative ages of the phases have been determined on the basis of crosscutting relationships where possible. Intrusive rocks in the San Francisco and Wah Wah Mountains, to the west, yield dates of 20 to 23 m.y. for quartz monzonite rocks and 27 to 29 m.y. for granodiorite rocks (Lemmon and others, 1973). The non-foliated rocks in the Mineral Mountains are assumed to be of similar ages. A thermal event about ten million years ago has reset biotite dates.

The eight major phases of the batholith are: diorite breccia (Tdb), biotite diorite (Td), quartz monzonite (Tqm), porphyritic quartz monzonite (Ti), biotite granite (Tbg), syenite (Ts), leucocratic granite (Tg), and fine-grained granite (Tgr). Dikes of microdiorite and diabase have intruded structures in the contact zone between Precambrian and Tertiary rocks in the KGRA. Three groups of porphyritic rhyolite dikes have intruded the range.

The coarse-grained monzonite and granite phases of the pluton have similar textures and compositions, particularly in the interior of the pluton, and contacts can be missed by a casual observer. The plutonic phases are typically medium- to coarse-grained with xenomorphic granular or granitic texture. Grain size and texture for any one unit can be quite different in the interior of the pluton compared to the periphery.

Porphyritic Andesite Flow (Tv)

A porphyritic andesite crops out on the southeast edge of the range where there is a gap in the Paleozoic carbonate rocks along the mountain front

(Plate I). The andesite has a strong flow alignment of phenocrysts and is altered to mixtures of sericite, clay, epidote, and tremolite. The unit contains accessory pyrite. The andesite is intruded by unaltered porphyritic quartz monzonite.

Biotite hornblende diorite (Td)

A large exposure of medium-grained biotite hornblende diorite is present in the northern portion of the Mineral Mountains. This rock intrudes foliated hornblende granodiorite (hd) and is intruded by biotite quartz monzonite (Tqm). In thin section this rock is an equigranular biotite hornblende diorite with apatite and sphene common. Samples from drill hole 9-1 have been correlated with this lithology and are pyroxene bearing (Glenn and others, in preparation).

Diorite Breccia (Tdb)

A heterogeneous biotite hornblende diorite breccia underlies an area of about one and one-half square miles south of Wild Horse Mountain (Plates I and II). The diorite breccia is older than, and intruded by, the leucocratic granite (Tg) and the biotite granite (Tbg) which surround it. The diorite breccia contains abundant xenoliths of biotite granodiorite (gd) and is assumed to be Tertiary in age because it is non-foliated.

The diorite breccia is an intrusive breccia with variable grain size, texture and mineral composition distinguishing clast and matrix. Generally both clast and matrix are fine-grained phaneritic, but one or both are aphanitic in some outcrops. Clast size and abundance is variable. The diorite has been pervasively sheared and chloritized after emplacement,

probably by intrusion of the younger granites. Outcrops are dark greens, grays or brown, jointed and talus forming. The diorite weathers to a fine, dark brown, mica-rich soil.

In thin section the diorite breccia is hypidiomorphic to xenomorphic with an average grain size of less than 1 mm. Clasts typically have a higher mafic content and are finer grained than the matrix. Fresh samples are about 50 percent andesine (An 35), 20 percent biotite, a trace to 15 percent hornblende, 0-15 percent K feldspar, 0-10 percent quartz and a few percent each of opaques, sphene and apatite. Samples which contain 15 percent hornblende lack quartz and K feldspar. Alteration products which compose most of the rock in some samples are chlorite, sericite, actinolite, clays, epidote, leucoxene, and calcite.

Biotite Quartz Monzonite (Tqm)

A coarse-grained biotite quartz monzonite forms most of the north half of the Mineral Mountains and has the largest outcrop area of the pluton phases (Plate I). The unit intrudes the Precambrian rocks, the hornblende diorite (hd), and the biotite diorite (Td) and is in turn intruded by most of the other Tertiary phases.

The diorite breccia and the porphyritic quartz monzonite are not in contact with the biotite quartz monzonite and their relative ages could not be determined from field relations. The quartz monzonite is massive with few joints and weathers to rounded outcrops and grus. Near the contact with the Precambrian rocks, the unit contains numerous xenoliths and in a few areas is seriate porphyritic and has a shear foliation that parallels the contact.

The average composition of the rock is 41 percent microcline, 30 percent plagioclase (An 13), 20 percent quartz, and 4 percent biotite, with sphene, opaques, apatite, and zircon as accessory minerals. The texture is generally xenomorphic granular.

Porphyritic Quartz Monzonite (Ti)

A medium-grained, porphyritic quartz monzonite is exposed on the southeast side of the range and just north of The Pass Road on the west side of the range. The unit intrudes the Paleozoic carbonate rocks on the east side of the range and is intruded by the other phases of the pluton with which it is in contact (Plate I).

The diagnostic characteristics of the porphyritic quartz monzonite are its medium grain size, relatively high content of small, anhedral biotite (7 percent), and 1 cm subhedral feldspar phenocrysts. The phenocryst content is variable however. On the east side of the range, the average grain size increases and the phenocrysts are less evident as the west contact with the leucocratic granite is approached.

The texture is xenomorphic granular with an average grain size of 2 to 5 mm. Plagioclase and K feldspar are equally abundant and form about 65 percent of the rock. The anorthite content (An 15 to 25) is in the oligoclase range. The rock contains 20 to 25 percent quartz, about 7 percent biotite, and minor amounts of sphene, opaques, and apatite.

Biotite Granite (Tbg)

A coarse-grained biotite granite forms the southwest quarter of the

Mineral Mountains (Plate I). Granite Peak, the Milford Needle and other massive outcrops, prominent in the south half of the range, consist of this unit. It intrudes the Precambrian rocks, the hornblende gneiss, and porphyritic quartz monzonite. Dikes of the granite intrude the diorite breccia and the biotite quartz monzonite. The biotite granite is intruded by the leucocratic granite and the syenite phases of the pluton.

The granite is coarse grained with a xenomorphic granular texture in the interior of the pluton and forms massive, rounded outcrops. Near the contact with Precambrian rocks on the west edge of the range and where it occurs as a dike, it is medium grained with 1 to 3 cm euhedral K feldspar phenocrysts.

The K feldspar content of the granite averages 50 percent. Plagioclase with a composition of An 21 constitutes about 13 percent of the rock. The granite contains about 27 percent quartz and 7 percent biotite, with sphene, opaques, apatite, and zircon as accessory minerals.

Syenite (Ts)

A medium-grained syenite forms an elongate stock in the west central part of the Mineral Mountains. The syenite intrudes the biotite quartz monzonite and the biotite granite and is intruded by the leucocratic granite and the fine-grained granite dikes.

The syenite is coarse- to medium-grained xenomorphic granular and weathers to grus. The average composition is microcline 65 percent, plagioclase 19 percent (An 10), quartz 7 percent, biotite 1 to 2 percent, sphene 2 percent, and opaques, apatite, hornblende, and zircon as accessory minerals.

Leucocratic Granite (Tg)

A medium- to coarse-grained granite composes most of the southeast quarter of the pluton, from The Pass Road to Bearskin Mountain (Plate I). This granite intrudes the syenite, the biotite granite, and the porphyritic quartz monzonite, and is intruded by the fine-grained granite and younger mafic dikes. The granite has the same textural and outcrop characteristics as the syenite but can be distinguished by its abundant quartz. Distinguishing the unit from the biotite quartz monzonite and the biotite granite is very difficult in outcrop, but the leucocratic granite has a lower biotite content and generally larger quartz grains than either of these units.

The average mineralogic composition of the leucocratic granite is microcline 53.8 percent, plagioclase 16.2 percent (An 11), quartz 23.4 percent, biotite 3.7 percent, and one percent or less of sphene, opaques, apatite, and zircon.

Fine-Grained Granite (Tgr)

A fine- to medium-grained granite occurs as a major dike-forming unit in the west central part of the range within the contact zone between the batholith and the Precambrian rocks (Plate I). The unit intrudes all the major phases of the pluton with which it is in contact and is intruded by the diabase and microdiorite dikes. The unit forms resistant, jointed outcrops, with blocky to rounded talus. Limonite staining on joints and fractures is more common in this unit than in other phases of the pluton. Aplitic and pegmatite dikes have been included with this unit.

The fine-grained granite is xenomorphic granular and the quartz grains

are strained. The mineralogic composition is K feldspar 57 percent, plagioclase about 9 percent, quartz 29 percent, biotite 3 percent and 1 percent each of sericite and chlorite. Unlike the other phases of the pluton, the granite contains only a trace of sphene.

Mafic Dikes (Tmd, Tds)

Fine-grained to aphanitic microdiorite (Tmd) and diabase (Tds) form thin dikes in Precambrian and Tertiary plutonic rocks in the west central part of the range. These dikes cut the fine-grained granite. The microdiorite has intruded faults, particularly the low-angle fault in the Roosevelt Hot Springs KGRA.

The microdiorite forms resistant dark green to black outcrops and has a subdiabasic texture. The unit typically contains 40 percent andesine, 0-6 percent K feldspar, 0-1 percent quartz, 25 percent hornblende, 15 percent actinolite, 6 percent biotite, and 1 to 3 percent each of sphene, opaques, apatite, orthopyroxene, and alteration minerals.

The diabase dikes are 71 percent andesine, 1 percent K feldspar, 2 percent quartz, 17 percent chlorite which has replaced pyroxene, and 1 to 3 percent each of opaques, apatite, hematite, and sericite.

Rhyolite Dikes (Trd, Tpr)

Three groups of rhyolite dikes occur in the Mineral Mountains and cut the pluton phases. Their structural style, chilled margins, and granophyric texture indicate that they were intruded after the major phases of the pluton had cooled. One group of rhyolite dikes (Trd) forms one to twenty-meter wide,

resistant outcrops in the area north of Ranch Canyon, on the west side of the range (Plate I). Another group of porphyritic dikes (Tpr) crops out in the southeast part of the study area. These dikes generally strike northwest and dip 18 to 30 degrees to the south (Plate I). The third and most extensive group (Tpr) forms a swarm of porphyritic rhyolite dikes striking north-northwest from the east-central portion of the range to the north end of the pluton.

Phenocryst size, 2-4 mm, and composition is similar in all the dikes. They contain 10 to 14 percent K feldspar phenocrysts, 5 to 14 percent quartz, a trace to 3 percent biotite, and a few plagioclase phenocrysts. The dikes on the south and north end of the map area have a matrix of granophyric intergrowths.

Lava Flows (Tlf)

A porphyritic quartz latite flow caps two small hills along Corral Canyon, about two miles west of the range front. The flow overlies a coarse boulder alluvium different from the surrounding finer grained alluvium. On the west end of the larger hill, the basal contact is above the level of the current bajada but dives below the bottom of Corral Canyon on the southeast side of the hill (Plate 1). The southeast end may be the source, or alternatively, the flow filled a paleocanyon which was deeper than Corral Canyon. The base of the flow forming the west hill also slopes to the level of Corral Canyon on the south side. The flow has been dated by the K-Ar method to be 7.9 ± 0.2 m.y. old (Evans and Nash, 1978, p. 9).

A small exposure of a second flow crops out in Ranch Canyon at the

western end of bedrock exposure. The flow overlies chloritized and faulted biotite granodiorite and Tertiary syenite, and is overlain by obsidian-bearing alluvium. The rock has a poorly defined flow structure, irregularly shaped vesicles, and vapor phase crystals of quartz and feldspar. The rock contains a few small feldspar and biotite crystals.

The unit contains about 2 percent 1 mm plagioclase phenocrysts (An 25-30), 1 percent K feldspar, a little less than one percent each quartz and biotite, and a trace of hornblende and opaques in a felsic matrix.

Quaternary

Rhyolites (Qrf, Qrd, Qra)

Rhyolitic volcanism produced flows, pyroclastic rocks, and domes in the Minerals Mountains between 0.8 m.y. and 0.5 m.y. ago (Lipman and others, 1978). Lipman and others (1978), and Ward and others (1978) have summarized the studies of these rhyolites. Studies on the petrology and petrochemistry of the rhyolites have been presented by Nash (1976), Nash and Smith (1977), and Evans and Nash (1975, 1978)

The activity started with the obsidian-rich, non-porphyritic flows of Bailey Ridge and Wild Horse Canyon (Plate I). The next stage of eruptions produced pyroclastics which formed non-welded ash flow tuffs, air-fall, water-lain, and surge deposits. These rocks contain a few sanidine and quartz microphenocrysts and are principally exposed in Ranch Canyon. Twelve domes formed during the final stage of rhyolitic activity.

Basalt Flows and Vents (Qb)

Five small outcrops of vesicular, porphyritic basalt are present near the north end of the map area (Plate 1). The three outcrops on the west side of the range are small flows with ropy flow tops partially preserved. Two small spatter cones overlie bedrock and alluvium on the east edge of the range. The northern cone includes a lava flow.

On the east side of the range, the leucocratic granite and alluvium are overlain by basaltic andesite lava flows of the Cove Fort volcanic field (Clark, 1977). Condie and Barsky (1972, Figure 1) believe the Cove Fort lava flows are post-Lake Bonneville but group the small northernmost basalt vent in

the Mineral Mountains with the Black Rock field which is pre-Lake Bonneville and over 70,000 years old. The basalt vents in the northern part of the range are little eroded however, and ropy flow tops and spatter cinders are well preserved, suggesting that most of these basalts are less than 10,000 years old. The northernmost lava flow and spatter cone on the east side is more eroded and may be older than the others.

There are flows of several ages in the Cove Fort volcanic field and the extensive flow shown on the east edge of Plate 1 is deeply eroded and faulted, with all of the original flow top textures eroded off. This flow is probably several tens of thousands of years old and not post-Lake Bonneville. The petrography and chemistry of these basalts are discussed by Condie and Barsky (1972).

Hot Springs Deposits (Qs, Qcal)

Hot springs deposits of both siliceous sinter and silica-cemented alluvium occur around Roosevelt Hot Springs and along the Opal Mound Fault to the south (Nielson and others, 1978; Parry and others, 1976). Both of these areas have opaline and chalcedonic sinter. Calcite is a major part of the cement at a few outcrops of cemented alluvium. It has not been determined whether the calcite was deposited by cooler thermal water or normal ground water. A small exposure of manganese oxide-cemented alluvium and a bed of hematite- and opal-cemented alluvium are present along Negro Mag Wash. Both of the manganese oxide and hematite-opal sinter deposits are about three feet thick and twenty feet long.

Alteration and Mineralization

The first lead-silver production in Utah came from the Mineral Mountains during the 1850's (Earll, 1957, p.99). Most of the base metal mining in the range started in the 1870's in the Bradshaw Mountain area, in the southern Mineral Range. This area was not included in the current study and the reader is referred to Earll, (1957) for information on the geology and mineral deposits. Antelope Mountain, on the north end of the Mineral Mountains, is also outside the current study and the reader is referred to Liese (1957) for the geology and mineral occurrences of this area.

Granite District

Within the study area, most of the mining has been along the pluton-carbonate contact on the southeast side of the range. This area comprises Granite and North Granite mining districts, organized in the 1860's (Earll, 1975, p. 93). The district produced \$50,000 worth of base metals and copper, most of it from the Beaver View Mine in the SE 1/4 of section 31, T28S, R8W. The second largest producer of base metals was the Blue Star Mines, also called the Big Pass Mine, just north of The Pass Road (Plate 1).

During World Wars I and II tungsten was produced from some of the base metal mines and new mines were opened. Tungsten production was valued at \$18,600 for 634 tons of ore from the Garnet Mine (Plate 1) and 279 tons from the Big Pass Mine (Earll, 1957, p. 97) as of 1957. The Miller Mine was under development and the only active property in 1957. There is no current activity in the district.

All of the mineralization in the district is in tactite zones within

favorable carbonate beds and is related to the pluton. At the pluton-carbonate contact a calc-silicate assemblage is usually present. This zone is generally only a few feet wide with epidote and garnet the dominant minerals. The carbonate rocks within a thousand feet or so of the contact are marbleized and some beds are sanded and bleached. The largest exposure of skarn is at the Blue Star Mine. The mines and alteration were not examined in detail for this report. More detailed coverage of the district is given by Crawford and Buranek (1945), and Earll (1957). Hobbs (1945) includes a detailed map of the Garnet Mine.

Shag Hollow Area

The diorite breccia in the Shag Hollow area is intensely sheared and chloritized. Many small prospect pits are located on quartz veins or veinlets along the ridge crest. The visible mineralization in these pits is copper associated in places with galena, barite, and molybdenite and ferrimolybdenite.

Other Mineralization

There are several isolated mines and mineral occurrences spread throughout the Mineral Mountains. Shallow shafts are located on faults one half mile north of the mouth of Ranch Canyon and on the section line between sections 26 and 35, T27S, R9W. These shafts explored pyrite-chalcopyrite mineralization in the fault zone. Several prospect pits have been excavated on copper occurrences in altered mylonites in the KGRA.

Two areas of intense brecciation are exposed at fault intersections on the east side of the range directly east of Negro Mag Wash (Plate I). Some of the breccia has undergone propylitic and argillic alteration. Minor copper

mineralization and a prospect adit are present in the breccia area in the SE 1/4, section 33.

Intense faulting within the Roosevelt Hot Springs KGRA and on the east edge of the map area was accompanied by hydrothermal alteration. The cataclasite zones display assemblages that are characteristic of greenschist facies or propylitic alteration (Nielson and others, 1978, p. 41). The faults are commonly silicified in the KGRA and euhedral quartz crystals have formed as open-space filling in a few places.

Small skarn deposits have been explored on the inselbergs along the Upper Ranch Canyon Road. On the hill in the SE 1/4, section 10, T25S, R9W, a skarn deposit, developed around a vertical bed of marble, was worked for copper and possibly for precious metals. The age of the marble is uncertain due to the extensive faulting in the area.

A chlorite deposit occurs on the east side of the range at the north end of the study area along the hornblende granodiorite-Cambrian carbonate contact. This occurrence has been exposed by a trench and road cut in the hillside. Tremolite deposits are also present along this contact in the same part of the range (Crawford and Buranek, 1942).

Albitization

Albitization affects several major pluton phases. The alteration occurs along a structure to the south and east of Wild Horse Mountain, but in all other areas it does not seem to be related to major structures. Areas of alteration are located on the east and west sides of Wild Horse Mountain and

the eastern part of Negro Mag Wash (Plate 1). The altered to unaltered transition is often very sharp in outcrop and resembles a contact between different rock units.

The albitized rock has a chalky texture with green or black mafic clots composed of chlorite and variable amounts of calcite, and some specular hematite. A trace amount of epidote may be present. Zoisite is present and more abundant than epidote in some samples. The mafic areas are less resistant and weather out, giving the rock a spongy appearance. The quartz is usually removed, but some outcrops have quartz with secondary overgrowths.

Both feldspars are sieved and albite patches are usually present in any remaining potassium feldspars. The more advanced stage of alteration is indicated by rocks in which the potassium has been totally replaced by sodium and the only mafic minerals are zircon and rutile. The feldspars are altered, lack gridiron twinning, and the quartz is either replaced by albite or has secondary overgrowths. The plagioclase is 91 to 95% albite. There is no sulfide mineralization associated with the albitization and it is thought to have been produced during the final stage of magma crystallization.

Hot Springs Alteration

Hydrothermal alteration associated with hot springs deposits is minimal at the surface and is confined to areas of recent hot spring activity and sinter formation along fault zones in the KGRA. This alteration and the more extensive subsurface alteration has been described by Bryant and Parry (1977), Ballantyne and Parry (1978), Parry (1978), and Hulen (1978). The results are summarized by Ward and others (1978).

Structural History

The structure of the Mineral Mountains reflects regional and contact metamorphism, thrusting, intrusion, uplift, and several periods of normal faulting. These structural features will be discussed in chronological order.

Metamorphism and Intrusion

During Precambrian time, east-west compression and regional metamorphism produced isoclinal folds with north to northeast axes in the banded gneiss. Field evidence suggests that the hornblende gneiss was intruded during this metamorphic event and consequently developed foliation similar to that of the banded gneiss.

After erosion of the Precambrian rocks and deposition of Paleozoic rocks, the hornblende granodiorite intruded Cambrian carbonate rocks in the north end of the range. As discussed above, the age of the granodiorite is not known, but it may be Jurassic.

Thrust Faulting

During the Sevier Orogeny, thrusting from west to east occurred in the region (Hintze, 1973). Thrusts involving Cambrian carbonate and quartzite rocks were mapped on the north end of the range by Liese (1957). Crawford and Buranek (1945) recognized thrust faulting in the Bradshaw Mountain area and at the Big Pass Mine in the southern part of the range. The present study has delineated thrust faults in the sedimentary rocks on the east side of the range. The Redwall limestone is thrust over itself at the Beaver View Mine (Plate I). Three miles north of the Beaver View Mine the stratigraphic section has been repeated by thrust faulting (Plate 1). Emplacement of the

pluton has upturned the beds and thrust faults on end, so the upper plate is now to the east. Other thrusts may be present in the section.

Pluton Emplacement

The Mineral Mountains Pluton consists of several phases with ages ranging from Oligocene to Late Miocene. Potassium-argon dates of 9 to 15 million years have been obtained for felsic phases (Park, 1968; Armstrong, 1970; Bowers, 1978). The intrusions were emplaced by a combination of stoping and forceful intrusion. On the west-central side of the pluton, in the Roosevelt Hot Springs KGRA, stoped blocks and partially assimilated xenoliths of Precambrian rock and older intrusive rocks occur one to two miles from the contact into the biotite quartz monzonite, biotite granite, and syenite. Chilling zones in the pluton and baking of the country rock near the contact are generally absent, suggesting emplacement of these phases occurred at depth in hot rocks primarily by stoping and assimilation. Growth of K feldspar porphyroblasts in the metamorphic rocks within a few feet of the contact was the most noticeable effect on the Precambrian country rock.

In contrast, the pluton intruded the Paleozoic rocks by uplift and shouldering aside with little evidence of stoping or assimilation. The sediments are arched up on the north and south end of the pluton and the beds on the east side are vertical and overturned near the contact (Plate I and II).

Evidence of faulting between emplacement of the major monzonite and granite phases or faults along their mutual contacts is very limited. Also their contacts, when exposed, do not show contact bake or chill effects, which

suggests that the early phases were still relatively hot when the subsequent phases were emplaced. All of the phases younger than the biotite quartz monzonite have outcrop patterns that are elongate north-south (Plate 1), suggesting a N-S structural control of pluton emplacement, perhaps an early reflection of Basin and Range structures.

The fine-grained granite (Tgr) was the last of the major felsic phases to be emplaced. The younger dike units, such as the microdiorite, have chilled contacts and typically intrude faults, suggesting the pluton had cooled and faulting had occurred before their emplacement. Uplift in connection with Basin and Range faulting produced the fault system into which the microdiorite dikes were intruded.

Denudation Faulting

As a result of uplift, low-angle normal faults or denudation faults which dip west and north were formed. A major denudation fault with normal offset of about two thousand feet has been documented by Nielson and others (1978) in the Roosevelt Hot Springs KGRA (cross section B-B' Plate II). The first low-angle faults probably formed near the pluton-country rock contact, or a few feet below this along cooling fractures within the pluton. One such fault, with a breccia zone about 40 feet thick, is exposed in Corral Canyon (Plate I) and shown in cross section C-C' (Plate II). A few feet of granite, too thin to be shown in the cross section, is in intrusive contact with the quartzite and limestone above the thick breccia zone. Other denudation faults formed deep within the pluton (Plate II). The best exposed denudation fault is in the KGRA. At its center, south of Wild Horse Canyon, this fault has a dip of

about 17° to the west. The dip steepens and the fault trace curves to the west both north and south of Wild Horse Canyon. The fault dips 65° west, south of Negro Mag Wash and 46° west on the west end of an inselberg south of Corral Canyon.

Thin sections of the fault breccia and mylonite suggest more than one period of movement and alteration. At several localities the quartz-sericite alteration is cut by chlorite veinlets that in places include quartz and sulfide. Some clasts within the breccia are breccia from an earlier movement. Microdiorite dikes within the fault zone are both sheared and unsheared suggesting a repetition of faulting and intrusion.

Two and possibly three denudation faults are exposed one above the other in the eastern part of the Negro Mag Wash (Plate I and cross section A-A'-A", Plate II). The upper fault dips 22° to the north and a porphyritic biotite granite dike and two fine-grained granite dikes are offset 1000 feet to the northwest. The lower fault dips about 5° to the west and offsets an albitized zone 1000 feet in a westerly direction. Both of these faults have chlorite and hematite-stained, silicified breccia zones 4 to 10 feet thick.

A third low-angle fault is exposed in the drainage south of the road, NW1/4, section 6, T27S, R2W. Exposure was not adequate to determine if this is a separate fault or a down-dropped segment of the denudation fault to the north.

Most of the low-angle faults dip west-to-northwest, but two dip to the north and one to the south. All of the demonstrated offset is westerly, however.

Normal Faulting

Northwest- and east-west-trending normal faults formed small grabens within the north half of the range. The denudation faults are preserved in these grabens and mostly removed by erosion outside the grabens in the upper part of the range. Weathering and erosion of fractured rock within and adjacent to the denudation faults have resulted in areas of sparse outcrop and deep grus development. These areas have the appearance of fossil erosional surfaces.

East-west structures are important in the Mineral Mountains but poorly exposed. A few have been mapped in the northern half of the range and there may be an east-west structure in Wild Horse Canyon, under the Quaternary rhyolites. East-west structures perhaps control basalt vents in the northern portion of the map area.

The structural control of the Quaternary rhyolite domes and flow vents has not been defined. It should be noted that all but one of the vents are located on or near a contact between phases of the pluton. Zones of weakness along lithologic contacts may have in part controlled the location of the Quaternary vents.

The most recently active faults are along the range front. These faults trend north-south but a few such as the Opal Mound Fault and faults on the east side of the range diverge 20° or more from the north. A fault mapped in the alluvium, a mile west of the Opal Mound and extending south to The Pass Road (Plate 1), is believed to be the main range front fault on the west side (Gertson and Smith, 1979). Offset of the alluvial surface on Ranch Canyon

Road is about 11 feet down to the east on the west fault. The magnitude of displacement decreases to the north. The extent of erosion of the fault scarp is about the same as for the Bonneville level beach escarpment, two and a half miles to the west, and is therefore thought to be of comparable age.

A detailed study of joints and in-situ analyses of strain has been completed by Yusas and Bruhn (1979). Their study determined that steeply dipping joint sets, trending east-west and north-south, are roughly uniform throughout the central Mineral Mountains. Joint densities are strongly affected by lithology and proximity to faults. They concluded that these joint sets were probably formed by cooling and contraction of the pluton.

The Mineral Mountains are a fault-bounded horst and parts of the bounding faults have been mapped on both the east and west sides of the range (Plates I & II). No evidence of significant tilting of the range has been found. The geomorphic profile of the central part of the range is distinctly asymmetric with short, steep drainages on the east side and long, more gentle drainages on the west (Plate II, cross section BB'). This central part extends from Negro Mag Wash south to a little south of Ranch Canyon. The asymmetric drainage divide may have formed due to structural control or an ancestral drainage system. The denudation faults and the shallow dipping joint set in the range generally dip to the west (Yusas and Bruhn, 1979). These structures may favor development of western drainage, but the northern and southern parts of the study area have comparable joints and an asymmetric drainage system has not developed.

A west-flowing ancestral drainage system from the Beaver Valley and the

Tushar Mountains may have crossed the Tertiary pluton before the Mineral Mountains were uplifted relative to the Beaver Valley. This theory would explain two interesting but inconclusive observations; the east ends of both Negro Mag Wash and the left fork of Ranch Canyon seem to be truncated. The second observation concerns the presence of cobbles of vesicular, porphyritic basalt which are present along the range crest northeast of Salt Cove (Plate I). The basalt cobbles are far south and at higher elevation than the small basalt occurrences in the northern end of the study area. The cobbles occur on areas that could be interpreted as paleo-erosional surfaces. There is no intrusive basalt on the range crest which could have been a source vent. These cobbles may have been left by the ancestral drainage system which crossed the Tertiary pluton.

GEOTHERMAL SYSTEM

Examination of subsurface data indicates that geothermal fluid production comes from fault and fracture zones within the crystalline rocks of the Mineral Mountains. On the basis of these subsurface data and detailed mapping within the KGRA, Nielson and others (1978, 1979) proposed a model to explain the locations of the producing zones in the Roosevelt Hot Springs geothermal field. The present mapping has not resulted in substantial modification of that working model.

The model of Nielson and others (1978, 1979) was based on the observation that geothermal production is located in areas where structures extrapolated from the Mineral Mountains block are intersected by the Opal Mound Fault and Faults that are parallel to the Opal Mound Fault. The faults which were

extrapolated from the Mountain block are of two types. In the northern portion of the producing area these structures have been termed the Negro Mag fault zone. Two steeply dipping normal faults have been mapped, and where exposed in the range, they are characterized by the presence of cataclasite. In the southern portion of the geothermal field, the faults exposed in the range were formed by denudation faulting. Although low-angle structures are present, the predominant faults are high-angle northwest-trending faults which have developed by brecciation of the hanging wall of the denudation fault.

The Opal Mound and associated faults are steeply dipping and control the obvious surface thermal manifestations of the district. Thus it is suggested that they are responsible for channeling the geothermal fluids from depth. In the southern portion of the area, these fluids enter other fault zones in the hanging wall of the denudation fault. In the northern portion of the area, the fluids may enter similar structures in the hanging wall of the low-angle fault or structures associated with the Negro Mag fault zone. The only producing well outside these two areas is 12-35. Well 12-35 may produce from a zone which is defined by the intersection of an E-W structure through Salt Cove and the N-S normal faults which have been mapped in the vicinity of the well.

Where observed in the field, the cataclastic zones are fine-grained, silicified, and impermeable. However, the rocks adjacent to these zones are often highly fractured and commonly show evidence of hydrothermal alteration. It is our speculation that a large reservoir volume was not developed until these cataclasites and adjacent fractured zones were intersected by faults of

the Opal Mound trend which served to rebrecciate the cataclasites and open the adjacent fractured zones. It is interesting to note that the fine-grained granite (Tgr) is the most strongly jointed and iron oxide-stained of the felsic phases in surface outcrop, and a thick hematite-stained and sheared intercept of the fine-grained granite correlates with an important hot water entry in Utah State 14-2 (Glenn and Hulen, 1979).

The heat source for the geothermal system is probably the partially crystallized igneous intrusion which fed the Pleistocene extrusive centers. Recent evidence for this interpretation has been presented by Robinson and Iyer (1979). These workers have identified two low-velocity zones beneath the Mineral Mountains which they interpret to be produced by bodies of magma. The deeper zone extends from the mantle to approximately 10 km depth. A smaller low-velocity zone is found at a depth of 5 km or less.

CONCLUSIONS

The central part of the Mineral Mountains was mapped in the same detail as the Roosevelt Hot Springs KGRA (Nielson and others, 1978). From an examination of Plate I it can be seen that the KGRA is distinctly more complex in both structure and lithology than the rest of the range. Within the KGRA the structures have been formed by the combination of denudation faulting and other faulting. The lithologic complexity has resulted from the intrusion of five major phases of the pluton into Precambrian rocks. Comparable structures, that is denudation faults affected by later graben formation, are exposed in the central part of the range north of Negro Mag Wash. These are much smaller in area, occur at a shallower depth, and lack the diverse

lithologies of the KGRA.

The relative ages and mineralogic make-up of the pluton phases are consistent with a typical magmatic evolution from calcium and iron-rich diorites to potassium-rich, leucocratic granites.

The general outcrop configuration of the major pluton phases suggest a change in structural control during pluton emplacement. The earlier diorites and biotite-quartz monzonite phases have approximately equidimensional outcrop patterns (Plate I). The later pluton phases are elongate north-south, suggesting Basin and Range structural control.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to our colleagues at the Earth Science Laboratory for their careful reviews of the manuscript. We also wish to express our thanks to Dr. James Baer, Department of Geology, Brigham Young University, for identifying the fossils collected and the Redwall Limestone.

Conversations in the field with T. A. Steven, C. Hedge, and H. Morris of the U.S.G.S. added greatly to our understanding of the regional geologic relationships. Susan Samberg provided some assistance in the field mapping.

The drafting was done by D. D. Cullen and P. Daubner and the typing by Lucy Stout and Sue Moore.

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PLATE I TOP

EXPLANATION

QUATERNARY	Qls	Landslide
	Qs	Opaline and chalcedonic sinter
	Qcal	Silica-cemented alluvium
	Qh	Hematite-cemented alluvium
	Qm	Manganese oxide-cemented alluvium
	Qal	Alluvium
		Basalt Lava flows and spatter cones.
	Qrd	Rhyolite Domes Glassy, 1-5% phenocrysts, perlite and pumice mantles.
	Qra	Pyroclastics Air fall and non-welded ashflow tuff. White to light tan. Weakly consolidated,
	Qrf	Rhyolite Flow Non-porphyrritic glassy, gray, flow-banded lava and obsidian. Perlitic rubble on flow tops.
	Tlf	Lava Flows Pink to tan, sparsely porphyritic felsite with flow structure.
	Tpr	Porphyritic Rhyolite Dikes Resistant, brown to pink dikes containing 20% 2 mm phenocryst in a granophyric matrix.
TERTIARY	Trd	Rhyolite Dikes Aphanitic, gray rhyolite dikes with approximately 5% k-feldspar phenocrysts and minor biotite. Often silicified and typically strongly jointed.
	Tds	Diabase Dikes Aphanitic, light brown or light gray green, with 3% plagioclase phenocrysts. Typically strongly jointed.
	Tmd	Microdiorite Dikes Dark green, dark gray, or black fine-grained dikes, plagioclase phenocrysts often present.
	Tgr	Granite Dikes Fine-grained phaneritic, resistant, dark brown, closely joined outcrops, forming blocky to rounded talus. Joints are typically limonite-stained. Unlabeled dikes are Tgr.
	Tg	Granite Coarse- to medium-grained, leucocratic with large quartz grains. Forms massive rounded outcrops, weathers to grus.
	Ts	Syenite Medium-grained, xenomorphic, with 1 to 3% sphene. Forms white or very light brown stained, massive, rounded outcrops, weathers to grus.
	Tbg	Biotite Granite Coarse- to medium-grained, forms massive, rounded outcrops and weathers to grus. Porphyritic in NW contact zone.
	Ti	Porphyritic Quartz Monzonite Medium-grained, biotite-rich with 1 cm feldspar phenocrysts. Forms resistant, massive outcrops.
	Tqm	Quartz Monzonite Coarse-grained, massive, rounded, light brown outcrops. Flow foliation and mafic xenoliths typical in the contact zone. Forms some talus in the contact zone, but weathers to grus in the interior of the pluton.
	Tdb	Diorite Breccia Fine- to medium-grained intrusive breccia with abundant biotite and hornblende. Forms dark colored outcrops or weathers to fine, brown soil.
	Td	Diorite Fine- to medium-grained biotite and hornblende diorite. Forms dark gray outcrops.
	Tv	Porphyritic Adesite Flow Greenish gray to brown; propylitized; 2 mm plagioclase laths.
	hd	Hornblende Granodiorite Medium-grained, weakly foliated in some outcrops. Forms grus-covered slopes.
	gd	Biotite Granodiorite Highly variable biotite and biotite-hornblende granodiorite. Typically massive to weakly foliated, dark colored, sphene-rich and fine-to medium-grained. Non-resistant, forming dark micaceous soil.

AGE UNCERTAIN	hgn	Hornblende Gneiss Medium-grained gneissic hornblende quartz monzonite. Forms resistant outcrops.
	qtzt	Quartzite White, yellow to red, massive, medium- to fine-grained quartzite. Small scale cross bedding in some outcrops.
	phl	Phyllite Dark brown to red, thinly bedded argillite.
	dol/l	Dolomite and Limestone Light to dark gray, massive to thick bedded.
	dm	Dolomitic Marble White or yellow to medium gray, friable.
MISS.	mb1	Marble Light- to medium-gray, generally massive.
	Mrd Mr1s	Redwall Limestone Light- to medium-gray dolomite (Mrd) and limestone (Mr1s), massive to thick bedded with a few pink to tan argillaceous zones.
CAMBR.	Emb	Marble Light- to medium-gray marble, undifferentiated Cambrian carbonate rocks.
PRECAMBRIAN	PEs	Sillimanite Schist Dark gray to green, fine-grained, finely laminated schist containing abundant biotite, fibrolitic sillimanite, and minor garnet porphyroblasts.
	PEq	Quartzite White, bedded metaquartzite containing minor biotite and feldspar.
	PEBg	Banded Gneiss Gray to white, conspicuously layered biotite gneiss, schist and migmatite. Highly variable in composition. Well developed isoclinal and pygmatic folding.
	---	Contact, dashed where approximate.
	---	Fault, intruded by microdiorite dike.
	---	Fault, dashed where inferred, dotted where covered. Breccia zones shown where mappable.
	---	Fault, mapped from linears on aerial photos, may have some topographic relief.
	90	Joints
	80	Foliation
	65	Dip and strike
	41	Dip of dike, thickness not shown to scale. Unlabeled dikes are Tgr.
	41	Albitized rock and other altered areas.
	▲	Fumarole
	■	Geothermal well
	◇	Thermal gradient hole
	✕	Prospect pit
	■	Shaft, with symbols of know metal values beside mine or mine name.
	Y	Adit

PLATE I
MIDDLE

LOCATION MAP

EARTH SCIENCE
LABORATORY

UNIVERSITY of UTAH
RESEARCH INSTITUTE

GEOLOGY OF THE CENTRAL MINERAL MOUNTAINS BEAVER COUNTY, UTAH

GEOLOGY, 1980, BY
BRUCE S. SIBBETT AND DENNIS L. NIELSON

PLATE I
BOTTOM

PLATE II

EARTH SCIENCE
LABORATORY

UNIVERSITY of UTAH
RESEARCH INSTITUTE

GEOLOGIC CROSS SECTIONS OF THE CENTRAL MINERAL MOUNTAINS

GEOLOGY, 1980, BY
BRUCE S. SIBBETT AND DENNIS L. NIELSON