CONTENTS

Geology of the Mineral Mountains Intrusive Complex, Beaver County, Utah

by

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ABSTRACT

The Mineral Mountains form a horst block located in the transition zone between the Basin and Range and the Colorado Plateau (Stokes, 1977). A Tertiary intrusive complex 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).

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. The Mineral Mountains intrusive complex is the largest exposed pluton in Utah.

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 east-west and north-south-trending Basin and Range faults is responsible for the structural control of the Roosevelt Hot Springs geothermal system.

During the Quaternary, rhyolite volcanism was active in the central part of the range and basaltic volcanism occurred in the northern portion of the

Mineral Mountains. The volcanic rocks of this period reflect the latest of the igneous episodes and are probably the heat source for the geothermal system.

INTRODUCTION

The Mineral Mountains intrusive complex is the largest body of plutonic rock exposed in the state of Utah. The complex forms the central portion of the Mineral Mountains (Figure 1) located in Beaver and Millard counties. The geologic work presented here was done to establish a structural setting for the Roosevelt Hot Springs geothermal system which is located on the western flank of the Mineral Mountains. Rocks of the Mineral Mountains intrusive complex form the hosts for portions of the geothermal resource.

Previous geologic mapping in the area includes the work of Liese (1957), Earll (1957), Condie (1960), Petersen (1975), and Evans (1975). This paper is based on the 1:24,000 scale geologic mapping of Nielson et al. (1978) and Sibbett and Nielson (1980a). These results have also been reported in Sibbett and Nielson (1980b). As a result of interest in the Roosevelt Hot Springs geothermal system, an abundant and diverse geoscience data base exists for the Mineral Mountains area. These data have been summarized in McKinney (1978) and Ward et al (1978). An update of the data base summary is now in preparation (Ross et al., in prep.).

GEOLOGY

General Geology of the Mineral Mountains

The Tertiary Mineral Mountains intrusive complex forms the major part of the central portion of the Mineral Mountains (Figure 2), with outcrops of Precambrian metamorphic rocks forming some of the western foothills and Paleozoic carbonate rocks and quartzites occurring on the southeast side of the range (Sibbett and Nielson, 1980a, 1980b). High-grade regionally metamorphosed Precambrian rocks are exposed on the west side of the Mineral Mountains (Figure 2). A banded gneiss comprises most of these rocks with limited outcrops of quartzite and sillimanite schist also present (Nielson et al., 1978). The northern end of the Mineral Mountains consists of Cambrian sedimentary rocks (Liese, 1957) which are, in places, overlain by Cretaceous conglomerate. The Cambrian carbonates were intruded and contact metamorphosed on the north by the intrusive complex.

On the southeast side of the central Mineral Mountains beds of limestone, dolomite, quartzite and phyllite flank the pluton. The fossil-bearing carbonates have been identified as Redwall Limestone (J. Baer, personal communication). Near the pluton contact the beds have been turned on end and metamorphosed to marble and phyllite. The repetition of a phyllite-limestone-dolomite sequence and drag folding along the base of the phyllite suggest that a thrust fault is present.

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 intrusive complex. Mining activity in the range has produced gold, silver, lead, and copper from contact metamorphic deposits and associated veins in the Bradshaw Mountains.

Early Intrusive Sequence

The older phases of the Mineral Mountains intrusive complex include five stocks of diorite to quartz monzonite composition. The average mineralogic compositions of these and the other phases of the complex are listed in Table 1.

A coarse-grained, foliated, hornblende quartz monzonite (hgn) intruded the Precambrian rocks on the west side of the range. The contact between the foliated quartz monzonite and the banded gneiss exhibits both parallel and crosscutting relationships relative to the foliation. The foliation in the stock is sub-parallel to the contact with the banded gneiss. We feel that this is a flow foliation developed during the intrusion of the pluton.

A medium-grained hornblende granodiorite (hd) is exposed over an area of about five square miles in the northern part of the map area (Figure 2). This body 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 most outcrops. It has a hypidiomorphic texture and its average mineralogic composition is listed in Table 1.

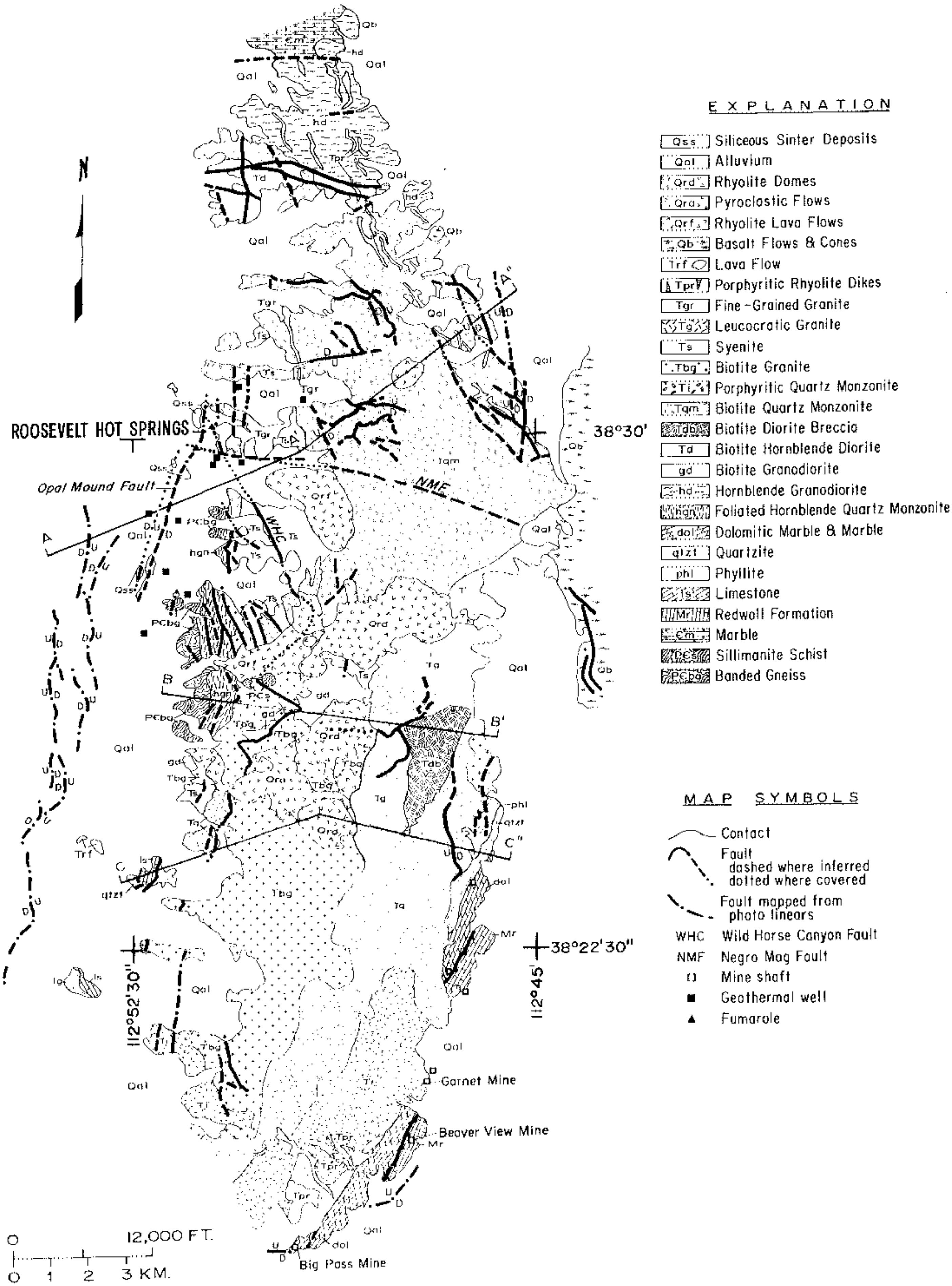
A biotite granodiorite stock outcrops in the central part of the range (gd, Figure 2). The unit typically has a uniform, biotite-rich, fine-grained texture with weak foliation in some exposures. The rock is dark gray and forms low rounded outcrops or fine, dark soil-covered slopes. The average

TABLE 1

Average percent of major minerals

Map Unit	K-Feldspar	Plag	Quartz	Hornblende or amphiboles	Biotite	Sphene + apatite	Opaques + zircon	Pyroxene + epidote	Chlorite + sericite	% Anorthite	No. Samples averaged
Foliated quartz monzonite* (hgn)	27.2	25.6	21.2	9.6	9.2	1.1	1.6	0.4	4.1	32	3
Hornblende granodiorite† (hd)	12	54	12	11	9	1	1	---	---	35	2
Biotite granodiorite*(gd)	18.5	34.7	22.7	5.2	13.3	2.5	2.0	---	1.1	32	3
Biotite diorite breccia† (Tdb)	5	50	10	5	20	2	3	---	5	35	5
Biotite quartz monzonite* (Tqm)	41.2	30.5	19.9	Trace	4.3	2.1	1.2	0.1	0.7	13	4
Porphyritic quartz monzonite†(Ti)	33	32	23	---	8	1.5	2.5	---	---	20	3
Biotite granite*(Tbg)	49.7	12.9	27.4	---	7.3	0.8	0.6	---	1.3	21	4
Syenite†(Ts)	65.5	19.5	7.0	0.4	2.0	2.5	1.1	---	2.0	10	3
Leucocratic granite*(Tg)	53.8	16.2	23.4	---	3.7	1.4	0.8	---	0.7	11.5	4
Fine-grained granite*(Tgr)	57.1	8.7	29.0	---	2.9	Trace	1.0	---	1.3	---	2
Microdiorite dikes†	4	40	---	40	7	2.8	3.0	0.3	3.0	41	2
Diabase dikes*	1.2	70.7	2.0	---	---	0.8	6.7	0.1	18.5	35	1
Porphyritic rhyolite dikes† (phenocrysts) (Tpr)	12	1	10		1	(76% granophyric matrix)					3

* from Nielson et al., 1978.
† from Sibbett and Nielson, 1980.



ROOSEVELT HOT SPRINGS
Opal Mound Fault
WHC
NMF
Garnet Mine
Beaver View Mine
Big Pass Mine
38°30'
38°22'30"
112°52'30"
112°45'
N
0
12,000 FT.
0 1 2 3 KM.
EXPLANATION
Qss Siliceous Sinter Deposits
Qal Alluvium
Qrd Rhyolite Domes
Qra Pyroclastic Flows
Qrf Rhyolite Lava Flows
Qb Basalt Flows & Cones
Trf Lava Flow
Tpr Porphyritic Rhyolite Dikes
Tgr Fine-Grained Granite
Tg Leucocratic Granite
Ts Syenite
Tbg Biotite Granite
Ti Porphyritic Quartz Monzonite
Tqm Biotite Quartz Monzonite
Tdb Biotite Diorite Breccia
Td Biotite Hornblende Diorite
gd Biotite Granodiorite
hd Hornblende Granodiorite
hgn Foliated Hornblende Quartz Monzonite
dol Dolomitic Marble & Marble
qtzt Quartzite
phl Phyllite
ls Limestone
Mr Redwall Formation
Єm Marble
PЄs Sillimanite Schist
PЄbg Banded Gneiss
MAP SYMBOLS
Contact
Fault
dashed where inferred
dotted where covered
Fault mapped from
photo linears
WHC Wild Horse Canyon Fault
NMF Negro Mag Fault
Mine shaft
Geothermal well
Fumarole

Figure 2. Geology map of the Mineral Mountains intrusive complex, Beaver County, Utah

mode of three thin-section analyses (Nielson et al., 1978) is given in Table 1.

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.

The fourth stock of the early intrusive sequence is a medium-grained biotite hornblende diorite (Td) in the northern portion of the Mineral Mountains. This rock intrudes the foliated hornblende granodiorite and is intruded by biotite quartz monzonite. In thin section this rock is an equigranular biotite hornblende diorite with apatite and sphene common.

A heterogeneous biotite hornblende diorite breccia (Tdb) underlies an area of about one and one-half square miles in the central part of the range (Figure 2). The diorite breccia is intruded by the granites which surround it. This stock is an intrusive breccia with variable grain size, texture and mineral composition distinguishing clasts and matrix. Generally both clasts 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. In thin section the diorite breccia is hypidiomorphic to xenomorphic with an average grain size of less than 1 mm. Alteration products which compose most the rock in some samples are chlorite, sericite, actinolite, clays, epidote, leucoxene, and calcite.

Principal Felsic Sequence

The six felsic phases compose over three-fourths of the Mineral Mountains intrusive complex and are thought to be 20 to 23 m.y. old (Sibbett and

Nielson, 1980a). This sequence consists of two quartz monzonite and two granite plutons plus a syenite stock and a granite stock. These plutonic phases are typically medium- to coarse-grained with xenomorphic granular texture. Grain size and texture for any one unit can be quite different in the interior of the plutonthan at the margins. The coarse-grained monzonite and granite phases have similar textures and compositions, particularly in the interior of the pluton. The average mineralogic compositions for each phase are listed in Table 1.

A coarse-grained biotite quartz monzonite (Tqm) forms most of the north half of the Mineral Mountains and has the largest outcrop area of the plutonic phases (Figure 2). The unit intrudes the Precambrian rocks, the hornblende diorite and the biotite diorite and is in turn intruded by most of the other felsic phases.

A medium-grained, porphyritic quartz monzonite (Ti) 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 (Figure 2). The porphyritic quartz monzonite is not in contact with the biotite quartz monzonite (Tqm) and their relative age could not be determined from field relations.

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.

A coarse-grained biotite granite forms the southwest quarter of the Mineral Mountains (Tbg, Figure 2). The granite is coarse grained in most of its area, but 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. It intrudes the foliated quartz monzonite and the 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.

A medium-grained syenite (Ts) 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.

A medium- to coarse-grained leucocratic granite composes most of the southeast quarter of the pluton (Tg, Figure 2). This granite intrudes the syenite, the biotite granite, and the porphyritic quartz monzonite, and is intruded by porphyritic rhyolite dikes. The granite has the same textural and outcrop characteristics as the syenite but can be distinguished by its abundant quartz and differs from other phases in its lower biotite content.

A fine- to medium-grained granite occurs as a major dike-forming unit and a small stock in the west central part of the range within the contact zone between the batholith and the Precambrian rocks (Tgr, Figure 2). The unit intrudes all the major phases of the pluton with which it is in contact and is intruded by diabase and microdiorite dikes. The granite 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.

Dikes

Fine-grained to aphanitic microdiorite and diabase form thin dikes in

Precambrian and Tertiary plutonic rocks in the west-central part of the range. These dikes cut the fine-grained granite (Tgr). The microdiorite has intruded faults, particularly the low-angle fault in the Roosevelt Hot Springs KGRA (Nielson et al., 1978).

Porphyritic rhyolite dikes cut the pluton phases in the north and south end of intrusive complex (Tpr, Figure 2). Their structural style and chilled margins indicate that they were intruded after the major phases of the pluton had cooled. Phenocryst size, 2-4 mm, granophyric matrix, and composition are similar in all of the rhyolite dikes.

The rhyolite dikes in the southeast part of the study area generally strike northwest and dip 1 to 30 degrees to the south. The more extensive group 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 (Figure 2). Field relationships demonstrate that these dikes were Tertiary lava flows emplaned along pre-existing fault zones.

A porphyritic quartz latite flow (Tlf) caps two small hills about two miles west of the range front in the southern part of the study area. The flow overlies a coarse boulder alluvium different from the surrounding finer-grained alluvium. The flow has been dated by the K-Ar method to be 7.9 ± 0.2 m.y. old (Evans and Nash, 1978).

A small exposure of a second flow (not shown on Figure 2) crops out on the western end of bedrock exposure to the northeast. The flow overlies chloritized and faulted biotite granodiorite and 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 porphyritic flows 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 Rhyolite and Basalt

Rhyolitic volcanism produced flows, pyroclastic rocks, and domes in the Minerals Mountains between 0.8 m.y. and 0.5 m.y. ago. Lipman et al. (1978) and Ward et al. (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. The next stage of eruptions produced pyroclastics which formed non-welded ash flow tuffs, air-fall, water-lain, and surge deposits. Twelve domes formed during the final stage of rhyolitic activity.

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). There are flows of several ages in the Cove Fort volcanic field and the extensive flow shown on the east edge of Figure 2 is deeply eroded and faulted, with all of the original flow top textures eroded off. This flow is probably pre-Lake Bonneville. The petrography and chemistry of these basalts are discussed by Condie and Barsky (1972). The two small outcrops of basalt on the north-east edge of the range (Figure 2) are spatter cones.

Alteration and Mineralization

The first lead-silver was produced from the Mineral Mountains during the 1850s (Earll, 1957). Most of the base metal mining in the range started in the 1870s in the Bradshaw Mountain area, south of the current study area and the reader is referred to Earll (1957) for information on the geology and mineral deposits.

Within our study area, most of the mining has been along the contact with the carbonates on the southeast side of the range. This area comprises Granite and North Granite mining districts, organized in the 1860s (Earll, 1957). The district produced $50,000 worth of base metals and copper, most of it from the Beaver View Mine. The second largest producer of base metals was the Big Pass Mine (Figure 2).

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 (Figure 2) and 279 tons from the Big Pass Mine (Earll 1957) as of 1957.

All of the mineralization in the district is in tactite zones developed within favorable carbonate beds during the emplacement of the intrusive complex. The carbonate rocks within a thousand feet or so of the contact are marbleized and some beds are sanded and bleached. 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.

Many small prospect pits are located on quartz veins or veinlets within the diorite breccia. The visible mineralization in these pits is copper associated in places with galena, barite, molybdenite and ferrimolybdite.

There are several isolated mines and mineral occurrences spread throughout the Mineral Mountains. Shallow shafts are located on faults on the west side of the range along the pluton contact. These shafts explored pyrite-chalcopyrite mineralization in the fault zones. A more detailed account of fault-controlled alteration and mineralization is given in Nielson et al. (1978) and Sibbett and Nielson (1980a). Small skarn deposits have been explored for copper and magnetite on the inselbergs southwest of the range.

Structural History

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

During Precambrian time, east-west compression and regional metamorphism produced isoclinal folds with north to northeast axes in the banded gneiss. The regional metamorphism climaxed in the upper amphibolite facies producing lithologies similar to those found in the Farmington Canyon complex of northern Utah.

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. Emplacement of the pluton has upturned the beds and thrust fault so the upper plate is now to the east.

Isotopic dating of the complex is incomplete, but initial data in conjunction with the geologic evidence suggests that the complex was being rapidly uplifted during the intrusion of the various phases. The oldest phases are both coarse grained and highly foliated, suggesting a deeper zone of emplacement than subsequent phases. The main mass of the pluton is composed of coarse- to medium-grained rocks that only display foliation along contact zones. The youngest phases are fine grained and occur as dikes. These units were emplaced when the previous phases had cooled to the extent that they would support brittle fracture. Initial dating suggests that this entire sequence took place over the relatively short time span of about 13 m.y. with the initial diking events being emplaced about 12 m.y. ago. By approximately 8 m.y. ago the intrusive complex had been exposed by erosion as indicated by the rhyolite flows mapped in the vicinity of Corral Canyon.

From this evidence it is proposed that the Mineral Mountains intrusive complex was emplaced in a block which was ascending through the crust in a diapiric fashion. The boundaries of this block are larger than the present Mineral Mountains and must await additional data from the adjacent Beaver and Milford Valleys for complete definition. The ascending diapir did involve the Precambrian gneisses, which are unique to the Mineral Mountains in central and southern Utah. Structural and fission track studies presently underway will result in a further refinement of this hypothesis.

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 600 meters has been documented by Nielson et al. (1978) in the Roosevelt Hot Springs KGRA (cross section B-B' Figure 3). This fault is herein named the Wild Horse Canyon fault. The first low-angle faults probably formed near the pluton-country rock contact along cooling fractures within the pluton. One such fault, with a breccia zone about 40 feet thick, is exposed on the west side of the range and shown in cross section C-C' (Figure 3). A few meters of granite, too thin to be shown in the cross section, is in

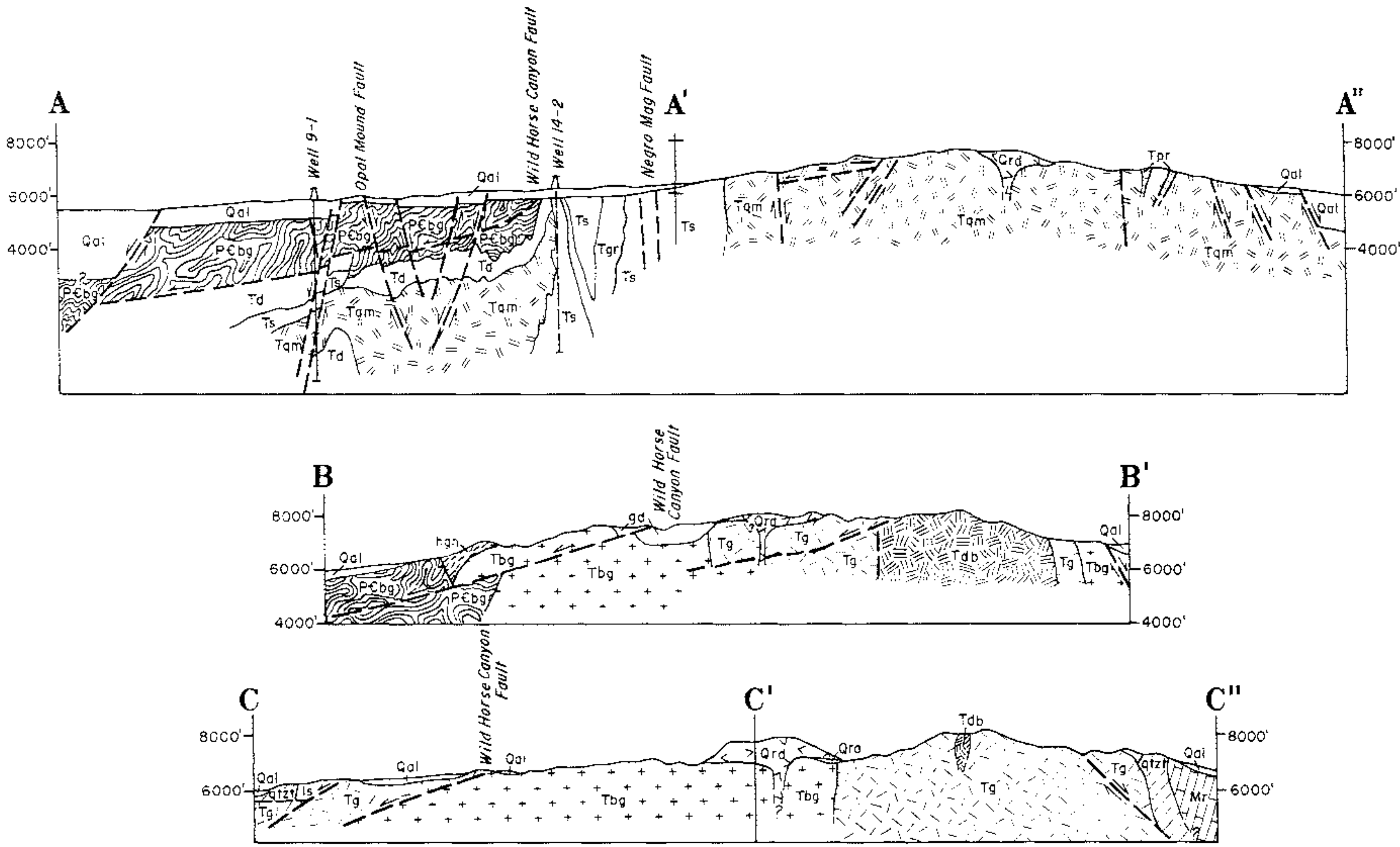

A
A'
A''
B
B'
C
C'
C''
8000'
6000'
4000'
Well 9-1
Opal Mound Fault
Wild Horse Canyon Fault
Well 14-2
Negro Mag Fault
Qal
PЄbg
Td
Ts
Tqm
Tgr
Crd
Tpr
hgn
Tbg
gd
Qrd
Tg
Tdb
Wild Horse Canyon Fault
qtzt
ls
Qra
Mr

Figure 3. Geologic cross sections of the Mineral Mountains intrusive complex.

intrusive contact with the quartzite and limestone above the thick breccia zone. Other denudation faults formed deep within the pluton. The Wild Horse Canyon fault is the best exposed denuation fault and has a dip of about 17° to the west along its central part. The dip steepens and the fault trace curves to the west both north and south (Figure 2).

Thin sections of cataclasite from the fault zone 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. A more complete discussion of the denudation faulting can be found in Nielson et al. (1978) and Sibbett and Nielson (1980a).

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.

The most recently active faults are the north-south-trending range front faults. A fault system mapped in the alluvium on the west side of the range (Figure 2) is believed to be the main range front fault on the west side (Gertson and Smith, 1979). The alluvial surface is offset as much as 11 feet and a fault-line graben is evident. 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.

GEOTHERMAL SYSTEM

The Roosevelt Hot Springs geothermal system is a structually controlled fracture reservoir (Nielson et al., 1978, 1979). Open breccia and fractures have formed along fault intersections when block faulting rebrecciated silicified cataclasite of the denudation faults. This has occurred in a small graben bounded on the west by the Opal Mound fault. This fault controls most the surface thermal manifestations of the district. Some of the better production wells are located near the Negro Mag fault where it crosses the graben and the fine-grained granite dikes (Nielson et al., 1978). An important hot water entry in Utah State 14-2 is within a highly fractured fine-grained granite intercept (Glenn and Hulen, 1979). As stated previously, this rock unit is notably more fractured and hematite stained at the surface than other phases of the pluton. The granite may, therefore, be a major factor in reservoir formation near and to the north of Negro Mag Wash where the granite is the principle rock type.

The heat source for the geothermal system is probably the crystallized igneous intrusion which fed the Pleistocene extrusive centers.

CONCLUSIONS

The Mineral Mountains intrusive complex consists of two intrusive sequences. The older sequence includes four stocks of diorite to granodiorite composition and a foliated meta-quartz monzonite. The age of these stocks is uncertain because a thermal event about 10 m.y. age has reset the biotites.

The principal felsic sequence includes two quartz monzonite phases, three granite phases and one syenite stock. These six intrusions are all part of one magmatic event probably during early Miocene.

The general outcrop configuration of the major pluton phases suggests a change in structural control during pluton emplacement. The earlier diorites and biotite-quartz monzonite phases have approximately equidimensional outcrop patterns (Figure 2). The later pluton phases are elongate north-south, suggesting Basin and Range structural control. Igneous activity on a reduced scale has continued into the Quaternary in the range. Denudation faults and later graben formation on the west side of the Mineral Mountains are the major structures forming the Roosevelt Hot Springs geothermal reservoir.

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