ALTERATION AND MINERALIZATION OF THE
GRASSHOPPER PROSPECT, BEAVERHEAD COUNTY, MONTANA

by

Jeffrey Wayne Meyer

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STATEMENT BY AUTHOR

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SIGNED: Jeffrey Wayne Meyer

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

JOHN M. GUILBERT
Professor of Geosciences

February 29, 1980
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ABSTRACT

The Grasshopper prospect is a remarkably well zoned "porphyry"-type hydrothermal alteration and mineralization system in a fine-grained, probably shallowly emplaced, circular dacite porphyry stock which is K-Ar dated at 73.4 ± 3.5 m.y. and has not previously been recognized as an intrusion.

Alteration of the stock consists of nearly concentric zones ranging from the outside-inward from chlorite to chlorite-epidote to sericite-quartz-pyrite, and finally to biotite-magnetite-sericite. Within the two innermost alteration zones there is a centerward decrease in pyrite, sericite, and clay, and increase in silica and limonite stockworks, biotite, and magnetite. Copper, molybdenum, gold, and silver values show a clear increase toward the center of the alteration system, whereas zinc occurs mainly in intermediate alteration zones. A shallow, thin, moderately well developed supergene enriched copper blanket exists in the center of the sericite-quartz-pyrite alteration zone.

While being within the range of variation seen in "porphyry" occurrences, the Grasshopper prospect is somewhat distinctive in its near lack of orthoclase, abundance of magnetite, and presence of precious metals in the centermost alteration zone. Exploration potential exists for molybdenum, primary and supergene copper, and by-product or co-product gold and silver.
CHAPTER 1

INTRODUCTION

Purpose and Scope

It is the purpose of this thesis to define and describe the overall geology of a "porphyry" type mineralized hydrothermal alteration system with emphasis on supergene and hypogene alteration and mineralization. It is hoped that by defining alteration and mineralization, future exploration on this property will be given better direction. This work allows comparison of the Grasshopper prospect to other "porphyry" type occurrences in this region and elsewhere.

Following the introduction and description of field and laboratory techniques used in this study, the overall geology of the Grasshopper prospect is described in detail. This geologic description begins with a discussion of the regional setting, and then focuses progressively inward on the district-wide geology, the geology of the Grasshopper prospect, and finally on the alteration and mineralization seen at Grasshopper. In the conclusions, the Grasshopper prospect is compared to other "porphyry" type occurrences, and recommendations concerning future direction of exploration of this property are made.

Physiographic Features

The Grasshopper prospect lies in all or part of Sections 1, 2, 3, 10, 11, 12, 13, 14, and 15 in Township 8 South, Range 11 West, and
is located approximately 14 miles west-southwest of Dillon in Beaverhead County, Montana (Fig. 1). Access to the property is via unpaved roads extending south from County Highway 278. The property lies approximately three miles east of Bannack, an old gold and silver mining town and the first territorial capitol of Montana.

The prospect lies on hilly grasslands with occasional forested patches on steeper north-facing slopes (Figs. 2 and 3). Elevation of the property ranges from 6040 feet in Spring Creek to 7036 feet at the top of Horse Mountain. Average summer temperatures range in the 70's, and winter temperatures average in the 30's.

A dacite porphyry intrusive body and the sericite-quartz-pyrite alteration zone within the dacite porphyry make a striking crudely circular anomaly which can easily be seen from the air (Fig. 2). The chloritic alteration zones of the dacite porphyry are relatively resistant to weathering, but the sericite-quartz-pyrite alteration zone is non-resistant and is expressed by the presence of less than 5 percent outcrop (Fig. 3). The lack of significant outcrop in the sericite-quartz-pyrite alteration zone has undoubtedly resulted in a simplified geologic picture of this area.

**Previous Work and History of the Prospect**

The Grasshopper prospect lies approximately two miles east of the lode-gold Bannack Mining District, approximately two miles southeast of the lode-silver Blue Wing Mining District, and less than one mile north of the Grasshopper Creek gold placer diggings. These districts combined have produced approximately $8,000,000 in placer gold,
Fig. 1. Location and regional geologic map.
Fig. 2. Aerial photograph of the Grasshopper prospect.

Note the circular anomaly which expresses the form and differential erosion of the dacite porphyry intrusion and the light colored sericite-quartz-pyrite alteration zone. TKb=Beaverhead Formation, Tan=undifferentiated andesite, Tdp=dacite porphyry. Scale is approximately one inch equals 2,000 feet or one centimeter equals 0.24 kilometers. North is to the top of the page.
Fig. 3. View looking west from the center of the stock.

The drill rig is on hole GR-2 (Fig. 7), the wooded hill to the extreme left is Horse Mountain, and the mountains in the background are north of Bannack. Note the scarcity of outcrop.
over $2,000,000 in lode gold, and probably no more than $2,000,000 in lode silver at pre-Depression prices (Shenon, 1931). No previous mining or prospecting work has been done on the Grasshopper claim group except for a few small assessment pits.

The Grasshopper prospect was discovered by a Cities Service Corporation geologist who noted the anomalous circular pattern on aerial photographs. The property was staked by Cities Service Corporation in the summer of 1977. Geologic work by that company consisted of preliminary geologic mapping, soil and stream sediment geochemical sampling, observation of fluid inclusions in a few samples, and an Induced Polarization survey.

The property was optioned to Pillar, Lowell, and Associates in the Spring of 1978. Three shallow 300 to 600 foot rotary holes with occasional spot cores were drilled in the summer of 1978. Geologic work conducted by the author in the summer of 1978 included detailed geologic mapping of rock types, mapping of alteration types and intensities, interpretation of leached capping, measurement of numerous rock joints, and extensive surface sampling. Laboratory work conducted by the author in the Spring of 1979 included petrographic descriptions of thin and polished sections, analysis of foliation and rock jointing, fluid inclusion studies, magnetometer readings of rock specimens, and electron-microprobe studies.
CHAPTER 2

METHODS OF INVESTIGATION

Field Techniques

Mapping was carried out on Bureau of Land Management aerial photographs which were enlarged to a scale of one inch to 500 feet. Owing to scarcity of outcrop in the sericite-quartz-pyrite alteration zone, mapping of outcrop versus mantle versus float was carried out in this zone. Mantle is defined as colluvium which was probably transported less than 30 feet from point of origin. Float is thought to have been transported for greater distances. Mapping was completed for rock type distribution, alteration type and intensity, and estimated original percent disseminated sulfides as interpreted from leached capping. Bedding, rock jointing, foliation, and other interpreted structures were plotted as well.

One hundred and seventy-eight surface rock chip samples of outcrop, mantle, and float were assayed for copper and molybdenum, 26 surface samples were assayed for bismuth, fluorine, tin, and tungsten, and 13 surface samples were assayed for gold and silver. Surface samples were collected on a 500 by 600 foot grid, with some flexibility allowed for the acquisition of better samples.

A total of 1467 feet of rotary drilling was completed in three 300-600 foot holes (GR-1, 2, and 3). Spot cores were taken at the bottom of GR-1 and GR-3, but the drilling of a spot core was not
attempted on GR-2 due to poor hole condition. One hundred and fifty ten-foot composite drill cutting samples and spot cores were analyzed for copper and molybdenum, three ten-foot composite samples were assayed for bismuth, fluorine, tin, and tungsten, and six 110 to 240 foot composite drill cutting samples were assayed for gold and silver. Drill cuttings and spot cores were logged for rock type, alteration and mineralization type and intensity, vein type, and evidence of alteration and mineralization paragenesis.

Laboratory Techniques

Forty thin sections of surface samples, drill cores, and rotary chips were studied in detail for rock type, alteration type, vein type, and paragenetic relationships. Black and white prints of all thin sections were prepared by using thin sections "sandwiched" between two cross-polarized sheets of plastic as negatives in a photographic printer. These photographs were used to easily record and compare rock textures.

Whole rock alteration was summarized for each thin section using a numbering system featuring a letter and two numbers. The first letter stands for alteration intensity and usually represents the first letter of the alteration product. This letter is defined as alteration intensity as it is dependent upon the intensive variables temperature, pressure, and chemical composition of fluids. The first number represents alteration extensiveness, and is the degree on a scale of 1 to 10 to which minerals susceptible of being altered to the alteration product specified by the previous letter have in fact been altered. This value is defined as alteration extensiveness as it is dependent
on extensive variables (fluid flow rate and time). The second number represents alteration pervasiveness and is the degree on a scale of 1 to 10 to which alteration is vein controlled versus evenly disseminated throughout the rock. The number 1 describes strong vein control, and 10 represents alteration evenly distributed throughout the rock.

As an example of this system, the symbol S-3-3 would represent sericite alteration altering 30 percent of all susceptible minerals with alteration occurring as moderately restricted selvages to veins. More than one symbol can be used for one thin section to describe all alteration products. Although this alteration evaluation system should generally be used to represent alteration of the whole rock, in this case the numbering system was used only to represent alteration of phenocrysts because alteration of the matrix could not be quantitatively determined.

Ten to fifteen polished sections and polished rock slabs were studied with reflected light microscopy for metallic mineral identification, determination of metallic mineral abundances, determination of supergene mineral replacement relationships, and in search of native gold.

Orientations of high angle joints were plotted on a graph of strike of high angle joint versus bearing of location of reading from the center of the stock. This was done to try to visually determine the degree of radial and concentric fracture development.

Forty-two fluid inclusions ranging in size from 10 to 30 microns were homogenized on a standard fluid inclusion heating stage. All
homogenizations were run twice to ensure against leakage. Evidence of necked inclusions was watched for as necked inclusions would give erroneous homogenization temperatures. A significant amount of time was spent searching for associated vapor and liquid rich inclusions as evidence of boiling. All inclusions observed were determined to be secondary.

Estimation of percent magnetite was obtained by direct reading of an Elliot Magnetometer Bridge on finely ground cuttings of nearly uniform size placed in a four fluid ounce plastic container. Rock chip samples were run five times per sample, and an average reading was obtained. Magnetometer readings were corrected to estimated percent magnetite by multiplication by a correction factor of 3.22 which was determined by comparing numerous magnetometer readings to magnetite weight percentages determined by point count. While it is realized that significant experimental error may have occurred due to variation in sample weight, fluctuation in magnetometer readings, and other factors, it is believed that the information is correct to a degree of certainty which allows a general comparison of overall magnetite content of the rocks.

Pyrite and chalcopyrite concentrates were obtained in two drill holes for determination of concentration factors of gold and silver in the sulfides. Sulfides were initially obtained from the cuttings ditch where drill waters concentrated the heavy particles. The concentrates were panned for further removal of silicate minerals, and then checked with a magnet for removal of magnetite. The last remaining silicates
were then floated by heavy liquids. The heavy sulfide concentrate was then run through a Franz magnetic separator, resulting in pyrite concentrates of nearly 100 percent purity and chalcopyrite concentrates of 10-20 percent chalcopyrite and 80-90 percent pyrite.

A scanning electron microscope-electron microprobe was used in an attempt to determine the mode of occurrence of gold and silver in pyrite and chalcopyrite. Pyrite and chalcopyrite grains were routinely scanned for gold, silver, arsenic, antimony, selenium, tellurium, zinc, and copper. Semi-quantitative values in parts per million and standard deviations were obtained for every element reading. Only values of at least three standard deviations were considered true readings above the detection limits of the microprobe.

All assay work was performed by Skyline Labs, Inc., of Tucson, Arizona. Atomic absorption was used for copper, molybdenum, bismuth, gold, and silver assays, emission spectroscopy was used for tin assays, the specific ion electrode method was used for fluorine determinations, and tungsten assays were determined colorimetrically. The limits of reproducibility for all of the above assay methods is estimated at 10 percent, although this range increases significantly near the lower limits of detection for each element.

Potassium-Argon age determinations were performed by Krueger Enterprises, Inc., of Massachusetts.
CHAPTER 3

REGIONAL SETTING

The Grasshopper area is underlain by a Precambrian gneiss and schist basement complex and is at the approximate eastern boundary of the Precambrian Belt Series depositional basin (Hobbs, 1968). A 6000-7000 foot thick Paleozoic section dominated by carbonate rocks and a 2000-3000 foot Mesozoic section dominated by clastic sedimentary rocks is strongly folded and faulted in a north-trending thrust belt which lies approximately two miles west of the Grasshopper prospect (Lowell, 1965). To the east of this thrust belt lies a sequence of Tertiary and Late Cretaceous sedimentary and volcanic rocks which is at least a few thousand feet thick. The Grasshopper stock intrudes a Late Cretaceous section of this sedimentary and volcanic pile (Fig. 1).

The north-trending thrust fault two miles west of the Grasshopper property is a segment of the Kelly Thrust (Myers, 1952) which extends from the Pioneer Batholith southward at least as far as Bannack (Fig. 4). The Kelly Thrust, along with other thrusts in the southwestern Montana area (Fig. 4), represents a complex and discontinuous segment of the North American Cordilleran fold and thrust belt (Snee, 1978). The general age of thrust fault activity in southwestern Montana ranges from Upper Jurassic to Eocene (Armstrong, 1974), although each thrust fault segment appears to have its own somewhat different history (Snee, 1978; Ruppel, 1978; Ryder and Ames, 1970). Models by
Plutonic rocks: PB—Pioneer Batholith (65–75 m.y.), BB—Boulder Batholith (68–78 m.y.), MMS—McCarthy Mountain Stock (71 m.y.), P—Philipsburg Batholith (70–73 m.y.), RS—Royal Stock, MPB—Mount Powell Batholith, ARP—Anaconda Range Plutons, BLIB—Bitterroot Lobe of the Idaho Batholith (80% granodiorite and granite dated at 64–95 m.y.), ALIB—Atlanta Lobe of the Idaho Batholith, TB—Tobacco Root Batholith (52 and 75 m.y.).

Volcanic rocks


Fig. 4. Tectonic map of the southwestern Montana area.

(Map and dates as reported from Snee, 1978).
Scholten (1968) and Hyndman and Chase (1975) suggest that much of the Late Cretaceous to Paleocene thrust fault activity is actually the result of eastward gravity gliding off of regional uplifts in central Idaho related to intrusion of the Idaho Batholith. Hyndman and Chase (1975) suggest that deeply penetrating thrust fault planes related to the Sapphire tectonic block (Fig. 4) may have been the major control on emplacement of nearly all of the Boulder-Batholith-related plutons. The Sapphire tectonic block is believed to be the result of Late Cretaceous gravity gliding off of the eastern end of the Idaho Batholith (Hyndman and Chase, 1975). Should this be correct, the magma of the Grasshopper and Bannack intrusions may be related to this activity. A K-Ar date on fresh hornblende in the Grasshopper dacite porphyry of 73.4 ± 3.5 million years lies within the range of ages for Boulder-Batholith-related plutons (Snee, 1978) (Fig. 4) and suggests a close relationship between the Grasshopper intrusion and the Boulder Batholith system.

The Grasshopper prospect lies on a broad trend of porphyry molybdenum deposits which follows the Rocky Mountains from Cave Peak, Texas, to Adanac, British Columbia (Fig. 5). The Grasshopper prospect also lies approximately 50 miles south of a north-east trending belt of porphyry molybdenum deposits extending from White Cloud, Idaho, to Big Ben, Montana (Armstrong, Hollister, and Harakal, 1978). The prospect can be seen on Fig. 5 to lie immediately within a -200 milligal contour. The significance of this may lie in relation to a proposal by Armstrong et al. (1978) in which positioning of molybdenum deposits
Fig. 5. Porphyry molybdenum deposits in the Rocky Mountain Region with Bouguer gravity anomalies.

(After Armstrong, Hollister, and Harakal, 1978.)
in North America is related to thickness of the earth's crust. While the validity of Armstrong's proposal may be questioned, the relation of Grasshopper to a negative gravity anomaly is clear.
CHAPTER 4

GEOLOGY OF THE BANNACK AND BLUE WING DISTRICTS

Stratigraphy

Paleozoic rocks in the Bannack and Blue Wing Districts consist predominantly of limestone units of Pennsylvanian and Mississippian age. They occur as an allochthonous belt of strongly folded sedimentary rocks which extends from north to south approximately two miles west of the Grasshopper Prospect (Figs. 1 and 6).

The Mississippian Madison Group, comprising over 95 percent of the exposed Paleozoic section near Grasshopper, consists of the basal Lodgepole Limestone and the upper and lower members of the Mission Canyon Limestone. The Madison Group consists exclusively of gray limestones; the Lodgepole is thin-bedded, the lower member of the Mission Canyon is massive and cherty, and the upper Mission Canyon member is alternately thick and thin-bedded (Lowell, 1965).

The Mississippian-Pennsylvanian Amsden Formation occurs only in a very limited area south of Bannack and is a transitional unit between the underlying Madison Group and the overlying Quadrant Sandstone. The Amsden Formation grades from basal limestones to calcareous siltstones and finally into the overlying Quadrant Sandstone. The Pennsylvanian Quadrant Sandstone is a silica-cemented sandstone which crops out south of Bannack and north of the Blue Wing Mining District in the Badger Pass area (Reynolds, 1960).
Fig. 6. Geology and metal distribution map of the Grasshopper area, Beaverhead County, Montana.
The Beaverhead Formation consists of several thousand feet of conglomerate with minor sandstone, siltstone, and limestone (Lowell, 1965) and is believed to represent eastward-directed continental deposition of debris derived from regional overthrusting (Ruppel, 1978). This unit is thought to have been deposited from Early Cretaceous to Early Eocene (Ruppel, 1978), although evidence discussed below indicates that deposition of the Beaverhead Formation in the Grasshopper area probably ended before Paleocene. The Beaverhead Formation is believed to be overlain by an unnamed sequence of tuff units, andesite agglomerates, and andesite flows which will be referred to in this report as the andesite volcanic sequence. This sequence has been tentatively given a late Paleocene or Eocene age by Lowell (1965), but evidence discussed below indicates a Late Cretaceous age. The stratigraphic relationship between the Beaverhead Formation and the presumably overlying andesite volcanic sequence is not certain, as all contacts between the Beaverhead Formation and the volcanic rock units in the Grasshopper area are poorly exposed (Lowell, 1965). In general, the andesite volcanic pile grades from basal tuff units in the west near Bannack to andesite agglomerate to the south and west of Grasshopper and into massive andesite to the north and east of Grasshopper.

The andesite volcanic sequence and Paleozoic rocks are intruded by four granodiorite stocks in the Bannack and Blue Wing Mining Districts. The Grasshopper dacite porphyry intrudes only the andesite volcanic sequence. A K-Ar date on fresh hornblende in the Grasshopper
dacite porphyry of 73.4 ± 3.5 m.y. necessitates a minimum Late Creta­
ceous age of formation for the andesite volcanic sequence. Should the
Beaverhead Formation be stratigraphically lower than the andesite
volcanic sequence, as discussed above, it would necessitate the commence­
ment of Beaverhead Formation deposition by Late Cretaceous time in the
Grasshopper area.

A probable Oligocene (Lowell, 1965) sequence consisting dominant­
ly of basalt with minor tuff and rhyolite unconformably overlies the
older volcanic sequence and the Beaverhead Formation to the south and
east of the Grasshopper Prospect. The youngest Tertiary rock unit in
the area is a thick sequence of conglomerate, sandstone, and siltstone
which lies both to the west of Bannack and approximately five miles east
of the Grasshopper Prospect (Figs. 1 and 6). This unit contains pebbles
of all of the above mentioned volcanic and Paleozoic rock types, and
contains Late Miocene vertebrate bones and teeth (Lowell, 1965). Quater­
nary alluvium lies in the broad floodplains of Rattlesnake Creek and
the Beaverhead River to the east.

Intrusive Rocks

Granodiorite crops out in four small elliptical-shaped out­
crops in the Bannack and Blue Wing Mining Districts (Fig. 6), amounting
to less than two square miles in total outcrop area. Three out of four
of the granodiorite intrusions occur at thrust plate boundaries indi­
cating probable structural control of intrusive emplacement. The in­
trusive nature of the granodiorite is evidenced by contact metamorphism
in the sediments and by the projection of apophyses into the sedimentary
rocks. The granodiorite has been assumed by Shenon (1931) to be related to the Boulder Batholith, although there are no published dates to confirm this. Chemically the granodiorite is more mafic and finer grained than the majority of the rocks of the Boulder Batholith, although it falls within the range of compositions seen (Shenon, 1931; Tilling, 1973).

The granodiorite is gray to gray-green, fine grained, and equigranular, consisting of approximately 50 percent plagioclase, 10 percent quartz, 15 percent orthoclase, 10 percent biotite, 5-10 percent hornblende, and minor accessory minerals (Shenon, 1931; Table 1). In hand specimen one can readily see fine-grained euhedral plagioclase laths with intergrown hornblende and biotite, but the quartz and orthoclase are only obvious under magnification.

The Grasshopper dacite porphyry is a brownish-gray to gray-green, medium to fine-grained porphyritic rock consisting of approximately 30 percent subhedral plagioclase phenocrysts, approximately 15 percent quartz phenocrysts, 0-5 percent hornblende phenocrysts, 3 percent biotite phenocrysts, and from 40-52 percent aphanitic to fine-grained matrix of quartz, sericite, and chlorite (Table 1). In hand specimen one can see medium to fine grained phenocrysts of rounded quartz, subhedral plagioclase, and finer grained mafic minerals in an aphanitic or fine-grained groundmass. The Grasshopper dacite porphyry differs from the granodiorite most significantly in its porphyritic texture. The similar composition, probable similar age, and close spatial association of the granodiorite and dacite porphyry bodies
Table 1. Characteristics of intrusive rocks in the Grasshopper area.

All mineral percentages of porphyritic rock types are for phenocrysts only. Mineral percentages for rhyolite are not known due to intense alteration.

<table>
<thead>
<tr>
<th>Rock Name</th>
<th>Form of Intrusion</th>
<th>Texture</th>
<th>Quartz (Vol. %)</th>
<th>Plagioclase (Vol. %)</th>
<th>Biotite (Vol. %)</th>
<th>Hornblende' (Vol. %)</th>
<th>Orthoclase (Vol. %)</th>
<th>Matrix (Vol. %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>granodiorite</td>
<td>four less than 0.5 square mile area stocks</td>
<td>fine grained, equigranular</td>
<td>10</td>
<td>50</td>
<td>10</td>
<td>5-10</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>dacite porphyry (aphanitic matrix phase)</td>
<td>outer portion of 2.6 square mile area stock</td>
<td>fine grained porphyritic</td>
<td>15</td>
<td>33</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>dacite porphyry (fine grained matrix phase)</td>
<td>inner portion of 2.6 square mile area stock</td>
<td>fine grained porphyritic</td>
<td>15</td>
<td>28</td>
<td>3</td>
<td>tr.</td>
<td>0</td>
<td>52</td>
</tr>
<tr>
<td>porphyritic andesite</td>
<td>possible dike-like intrusion</td>
<td>fine grained porphyritic</td>
<td>0</td>
<td>15-20</td>
<td>1</td>
<td>tr.</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>quartz dacite porphyry</td>
<td>unknown form, very limited surface extent</td>
<td>medium to fine grained porphyritic</td>
<td>29</td>
<td>42</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>rhyolite</td>
<td>unknown form, very limited surface extent</td>
<td>fine grained equigranular</td>
<td>present</td>
<td>present</td>
<td>0</td>
<td>0</td>
<td>present</td>
<td>0</td>
</tr>
</tbody>
</table>
indicates that these two rock units are likely part of the same overall intrusive system.

The Grasshopper dacite porphyry has not previously been recognized as an intrusive body and is shown on U.S.G.S. Map I-433 as a nearly closed crescent-shaped body of younger basalt enclosing andesite of the older volcanic sequence (Lowell, 1965). The mapped crescent-shaped body of younger basalt corresponds to the general outline of the Grasshopper dacite porphyry body while the mapped enclosed andesite generally corresponds to the sericite-quartz-pyrite alteration zone within the Grasshopper stock.

Structure

The north-north-west trending overthrust belt dominates the structure of the Bannack and Blue Wing Districts and has resulted in the movement of the Paleozoic section eastward on gentle westerly dipping fault planes to where it overlies the Beaverhead Formation and the Late Cretaceous andesite volcanic sequence. Fault movement is believed to have occurred from Early Cretaceous to Early Eocene (Ruppel, 1978). This long time span has resulted in later stage movement of the upper plate over continental detritus derived from earlier stage thrust fault activity. The low angle of the fault plane can be evidenced by the sinuous nature of the Paleozoic-Tertiary contact and by the existence of numerous klippen (Fig. 6).

The allochthonous plate is strongly folded in north-south trending anticlines and synclines whose axes generally parallel the trace of the thrust faults. The volcanics are only mildly deformed
and contain Tertiary high-angle faults which in places offset the thrust plate (Fig. 6). Thrust faults appear to have been a strong control on the occurrence of the granodiorite bodies and indirectly on mineralization; three of the four intrusions lie at thrust plate boundaries.

**Mineralization**

The Bannack and Blue Wing Districts produced predominantly gold and silver, respectively, with both districts producing minor amounts of lead, zinc, and copper (Fig. 6). In the Bannack District, gold occurs as native gold in oxidized zones or with base metal sulfides in gangue assemblages of calcite, chlorite, quartz, garnet, and specularite. The ore occurs dominantly in fractures in marbleized limestone directly outside narrow garnetized zones at the limestone-granodiorite contact (Shenon, 1931). Silver in the Blue Wing District occurs as native silver, argentite, silver-antimony sulfosalts, and in galena, with cerargyrite a common mineral in oxidized zones. Mineralization is in replacement fissures with quartz and calcite gangue in fresh limestone, marbleized limestone, and within the granodiorite (Shenon, 1931).

A number of zones of copper oxides in fault zones and disseminated in the andesite agglomerate were noted by the author immediately west and south of the Grasshopper intrusion (Fig. 6).
CHAPTER 5

GEOLOGY OF THE GRASSHOPPER PROSPECT

Country Rocks

The Grasshopper intrusion is flanked by andesite agglomerate to the south and west, andesite to the north and north-east, and by Beaverhead Formation to the east (Fig. 7, in pocket). No contact metamorphic effects were observed at the intrusive-country rock contact. Bedding dips are generally less than 30 degrees with much of the structural deformation probably caused by high angle faults, of which only a portion have been mapped. The Tertiary-Cretaceous Beaverhead Formation in the Grasshopper area consists of a pebble to cobble conglomerate with fragments consisting of limestone, quartzite, sandstone, chert, and shale in decreasing order of abundance. The matrix consists of calcareous sand or silt. The Beaverhead is only partially consolidated and is non-resistant to erosion, cropping out only rarely on hilltops and in deeply eroded gullies. The contact of the Beaverhead with other rock types is nowhere exposed in the Grasshopper area.

It has been assumed that the Beaverhead Formation is older than the andesite volcanic sequence (Lowell, 1965), and the absence of volcanic clasts in the Beaverhead would tend to support this idea. Should this age relationship be correct, it would necessitate the existence of a fault contact between the Beaverhead and the volcanic units in order to raise the Beaverhead to the same stratigraphic position. The
nature of the contact of the dacite porphyry stock with the Beaverhead conglomerate is not known.

The andesite agglomerate unit ranges from green to gray to brown to purple and consists of a medium to fine grained andesite matrix with from zero to 50 percent clasts of similar andesite (Fig. 8). Bedding thickness ranges from 20 to at least 100 feet, and dips can generally be determined only where beds of different color are in contact.

The contact of the dacite porphyry and the andesite agglomerate is intrusive and appears to dip gently into the dacite porphyry body. The contact of the andesite agglomerate with the overlying andesite is undulatory and dips at an average of 20 degrees to the east (Fig. 7). The overlying andesite is gray-green, medium to fine grained, and massive in nature (Fig. 9). The dacite porphyry is in intrusive contact with the andesite.

A small sub-outcrop of thinly laminated rhyolite tuff occurs in the south-west corner of Section 1 (Fig. 10). There is some question as to whether this unit correlates to the older andesitic or the younger basaltic volcanic sequence. In considering the sharp contrast of the tuff unit to the massive surrounding andesite and the fact that the tuff occurs on a small hill, this tuff is most likely an isolated erosional remnant of the younger basaltic volcanic sequence found more commonly to the south and east.

Intrusive Rocks

The Grasshopper intrusion is a nearly circular stock one and one-half to two miles in diameter which appears to be somewhat sill-like
Fig. 8. Andesite agglomerate.
Fig. 9. Massive gray-green andesite.

The apparent orange color is due to photography.
Fig. 10. Thinly laminated tuff.
at its outer edges (Fig. 7). The majority of the intrusion is a dacite porphyry which consists of an aphanitic and a fine-grained matrix phase. This distinction in matrix size can only be determined in thin section and for that reason the two phases have not been differentiated in mapping. In general, the aphanitic matrix phase is abundant in the chlorite and chlorite-epidote alteration zones, and the fine grained matrix phase occurs in the sericite-quartz-pyrite and biotite-magnetite-sericite alteration zones. The major characteristics of all of the intrusive rock types in the Grasshopper area are summarized in Table 1.

The aphanitic matrix phase ranges from brownish-gray to gray-green depending on the intensity of chlorite alteration (Fig. 11). It contains an average of 15 percent medium to fine grained subhedral quartz phenocrysts, 33 percent medium to fine grained subhedral plagioclase phenocrysts, 5 percent fine grained subhedral hornblende, 3 percent fine grained subhedral biotite, and minor zircon, sphene, apatite, epidote and magnetite. The matrix comprises an average of 40 percent of the rock and consists dominantly of quartz and chlorite with less than 10% calcite and sericite.

The fine grained matrix phase ranges from off white to dark gray depending on intensity of sericite-quartz-pyrite or biotite-magnetite-sericite alteration (Figs. 12 and 13). It contains an average of 15 percent medium to fine grained subhedral quartz phenocrysts, 28 percent medium to fine grained subhedral plagioclase phenocrysts, only a trace of hornblende, and minor zircon, apatite, and
Fig. 11. Aphanitic matrix phase of the dacite porphyry.

Sample is from the southern edge of the intrusive body and is lightly chloritized. Note the flattening of xenoliths and the parallel alignment of plagioclase and mafic minerals.
Fig. 12. Sericite-quartz-pyrite altered fine-grained matrix phase of the dacite porphyry.

Note the off-white color and minor transported iron oxides.
Fig. 13. Biotite-magnetite-sericite altered fine-grained matrix phase of the dacite porphyry with cross-cutting sericite-quartz-pyrite-(chlorite) alteration.
magnetite. The matrix comprises approximately 52 percent of the rock and consists dominantly of quartz and sericite with minor secondary biotite, chlorite, calcite, leucoxene, montmorillonite, possible kaolinite, and possible orthoclase.

Xenoliths can be found in both phases of the dacite porphyry but are more common in the aphanitic phase, especially near the edge of the intrusion. Xenoliths can account for up to 15 percent of the rock, are generally no more than pebble-sized, and consist dominantly of andesite and tuff with minor shale, limestone, chert, and quartzite. Xenoliths were most likely emplaced by magmatic stoping, the volcanic fragments derived from the older andesite sequence, and the sedimentary fragments derived from either the Beaverhead Formation or the Paleozoic section. Near the dacite porphyry-volcanic rock contact, the xenoliths are usually foliated with plagioclase and mafic minerals commonly aligning their long axes parallel to foliation as well (Fig. 11).

Porphyritic andesite occurs in three isolated outcrops in the west-central portion of the sericite-quartz-pyrite alteration zone (Fig. 7). Contacts between the andesite and the dacite porphyry are concealed by alluvium, but it is believed that the andesite is a later-stage dike-like intrusive body. Strongly sericite-quartz-pyrite altered samples of porphyrytic andesite are light gray and consist of an average of 15-20 percent medium to fine grained subhedral plagioclase phenocrysts, one percent medium to fine grained subhedral biotite phenocrysts, a trace of hornblende, and approximately 80 percent fine grained matrix consisting dominantly of quartz and sericite.
(Fig. 14). The porphyritic andesite is distinguished from the dacite porphyry by the absence of quartz phenocrysts.

A single isolated outcrop of quartz dacite porphyry occurs near the center of the stock (Fig. 7), and is believed to be a later-stage intrusion. The outcrop is strongly sericite-quartz-pyrite altered, is off-white, and consists of 29 percent medium to fine-grained subhedral quartz phenocrysts, 42 percent medium to fine-grained subhedral plagioclase phenocrysts, 4 percent coarse to medium-fine-grained biotite phenocrysts, and approximately 25 percent fine-grained matrix of quartz, sericite, and iron oxides (Fig. 15). The quartz dacite porphyry is distinguished from the dacite porphyry by more abundant and larger quartz phenocrysts, and by coarse-grained biotite books.

A single outcrop of rhyolite near the center of the stock represents an intrusive body of unknown extent (Fig. 7). This outcrop is totally sericite-quartz-pyrite altered and consists of at least 50 percent quartz veins and veinlets with minor magnetite. The original composition of the rhyolite is indeterminate, but it appears to have consisted of fine-grained, equigranular quartz, plagioclase, and orthoclase in a seriate texture (Fig. 16).

Although the form and extent of the porphyritic andesite, quartz dacite porphyry, and rhyolite bodies are not well known, they appear to be only small in volume in comparison to the two-phase dacite porphyry (Fig. 7). This conclusion is supported by the fact that the only rock type encountered in drilling is the fine-grained-matrix phase of the dacite porphyry.
Fig. 14. Porphyritic intrusive andesite.

Off-white color is due to sericite-quartz-pyrite alteration.
Fig. 15. Quartz dacite porphyry.

Note the off-white color caused by sericite-quartz-pyrite alteration. The gray spots are quartz phenocrysts.
Fig. 16. Rhyolite with quartz-magnetite veining.
Whether one considers only the dacite porphyry or all of the porphyritic rock types, including the dacite porphyry, the porphyritic andesite, and the quartz dacite porphyry, an overall increase in quartz phenocryst abundance and size toward the north-central portion of the quartz-sericite-pyrite alteration zone is evident (Figs. 17 and 18). Quartz phenocryst abundance ranges from 0-29 percent while quartz phenocryst size ranges from 0-3.9 millimeters.

**Structure**

Foliation in the dacite porphyry occurs as a parallel alignment of disc-shaped xenoliths and of long axes of minerals such as plagioclase, hornblende, and tabular biotite (Fig. 11). Foliation is most common within about 1000 feet of the edge of the intrusion and almost without exception dips at angles less than 45 degrees toward the center of the stock (Figs. 7 and 19). Foliation is most likely the result of friction at the intrusion-country rock contact, and is probably approximately parallel to the strike and dip of this contact. This shallowly inward dipping foliation pattern and the observed shallowly inward dipping contacts on the south side of the intrusion strongly suggests that the edges of the Grasshopper intrusion are sill-like as shown on Fig. 7.

A weakly developed concentric and radial joint pattern is present in the Grasshopper stock and is revealed in a plot of strike of steeply dipping joints versus bearing of joint reading from the center of the stock (Fig. 20). This pattern is best seen by the northwest to westerly striking joints in the south-west half of the stock (Figs. 7 and 20). The radial and concentric fracture pattern and the
Fig. 17. Quartz phenocryst abundance distribution.

All samples are outcrops. Numbers are quartz phenocryst abundance in volume percent of the whole rock.
Fig. 18. Quartz phenocryst size distribution.

All samples are outcrops. Phenocryst size is in millimeters.
Fig. 19. Foliated dacite porphyry near its contact with andesite.

The foliation parallels the rock hammer handle and is gently dipping into the stock. The view is at the north end of the intrusion looking west.
strike of joints with greater than 60 degree dip

Fig. 20. Plot of strike of high angle joints versus bearing from center of stock.
nearly circular overall shape of the stock indicate that regional stresses were probably at near negligible levels at the time of stock emplacement.

To the west of the Grasshopper intrusion a number of high-angle faults disrupt the volcanic section (Figs. 6 and 7). These faults are believed to have only minor displacement. In many cases they contain copper oxides. The faults recognized in mapping probably represent only a portion of the structural disturbance in the volcanic section, a great deal of which is likely caused by unrecognized high-angle faults. In the eastern half of Section 12, a high angle fault with apparent left lateral displacement is inferred and appears to be the only fault of significance which offsets the intrusive body (Figs. 6 and 7). Another set of apparent high angle faults is inferred at the Beaverhead Formation-volcanic rock contact and appears to have uplifted the stratigraphically lower Beaverhead Formation to the same position as the andesite and andesite agglomerate.

**Fluid Inclusion Data**

Forty-two successful fluid inclusion homogenizations were performed from a one-inch-thick-quartz vein which contains minor pyrite and has a one-half inch thick sericite alteration halo. The vein sample is from a spot core in GR-1 at a depth of 367 feet, and appears to represent a late, non-pervasive, sericite-quartz-pyrite-(chlorite) alteration and mineralization stage. All fluid inclusions observed were determined to be secondary. Due to the limited number of homogenization temperatures, this study should only be considered "tentative". A clear
understanding of the fluid inclusions present can only be determined by a very extensive fluid inclusion study of a type which is beyond the scope of this thesis.

All fluid inclusion homogenization temperatures are plotted on Fig. 21. Four different groups of inclusions observed are summarized below:

1. Type 1 inclusions consisting of approximately 15 percent vapor phase and 85 percent liquid phase. While this inclusion type is common, only one successful homogenization was performed with the inclusion turning into the liquid phase at approximately 305°C.

2. Type 2 inclusions consisting of an average of 90 percent vapor and 10 percent liquid. Twenty-four successful homogenizations were performed. The inclusion fillings turned into a vapor phase between 350°C and 445°C, with an average of 405°C.

3. Type 3 inclusions consisting of an average of 25 percent vapor, 25 percent NaCl, occasional very fine hematite, and 50 percent liquid. Fourteen successful homogenizations were performed with the vapor phase homogenizing to liquid at an average temperature of 404°C within the range of 365°C to 445°C. NaCl homogenization ranged between 230°C and 390°C and averaged 329°C.

4. Type 3 inclusions consisting of approximately 20 percent NaCl, 15 percent KCl, 15 percent vapor, less than one percent hematite, and 50 percent liquid. Only three successful homogenizations were performed with NaCl homogenizing to a liquid phase
Fig. 21. Histogram of observed fluid inclusion homogenization temperatures.
at an average of 488°C with a range between 467°C and 502°C. The vapor homogenized to a liquid phase at an average of 408°C with a range of 395°C to 430°C and the KCl homogenized to a liquid phase at an average of 209°C with a range of 180°C to 250°C.

Approximate NaCl and KCl weight percentages were obtained for the salt-rich inclusions by plotting homogenization temperatures on a phase diagram for part of the system NaCl - KCl - H₂O (Fig. 22). For the Type 3 inclusions consisting of NaCl, vapor, and liquid, the approximate fluid composition is 41 weight percent NaCl, 0-7 weight percent KCl, and 52-59 weight percent H₂O. For the Type 3 inclusions consisting of NaCl, KCl, hematite, vapor, and liquid, the approximate fluid composition is 42 weight percent NaCl, 23 weight percent KCl, and 35 weight percent H₂O.

In one case, evidence of boiling was observed in the form of a vapor-rich inclusion seen immediately adjacent to and in the same plane as a Type 3 inclusion containing NaCl, liquid, and vapor. The vapor-rich and Type 3 inclusions homogenized at 400°C and 390°C respectively. Overall, the vapor-rich inclusions and the Type 3 inclusions containing NaCl, liquid, and vapor had average homogenization temperatures of 405°C and 404°C respectively. While this may be strong evidence for boiling, it cannot be considered "proof" as only one pair of apparent boiling inclusions was observed. The wide range in NaCl homogenization temperatures for the Type 3 inclusions containing NaCl, liquid and vapor is puzzling as well.
Fig. 22. Phase diagram for part of the system NaCl-KCl-H₂O.

(After Roedder, 1971.)
Under the assumption that boiling is present, plotting of homogenization temperature and salinity on a pressure-temperature diagram of the $\text{H}_2\text{O}-\text{NaCl}$ system gives a formation pressure of 200 bars (Fig. 23). This pressure can be translated into depth of formation by the following equation from Bodnar (1978):

$$Z = \frac{P}{K\rho}$$

where $Z =$ depth in centimeters, $P =$ pressure in bars, $\rho =$ density in gm/cm$^3$, and $K =$ a constant $= 9.12 \times 10^{-4}$ cm$^2$/gm relating density and depth to the pressure in bars. Assuming a hydrostatic overburden, the depth of burial would be:

$$Z = \frac{200 \text{ bars}}{(9.12 \times 10^{-4} \text{ cm}^2/\text{gm})(1. \text{ gm/cm}^3)} = 2.19 \times 10^5 \text{ cm} \approx 2.2 \text{ KM}$$

Assuming a lithostatic overburden, the depth of burial would be:

$$Z = \frac{200 \text{ bars}}{(9.12 \times 10^{-4} \text{ cm}^2/\text{gm})(2.67 \text{ gm/cm}^3)} = 8.21 \times 10^4 \text{ cm} \approx 0.8 \text{ KM}$$
Fig. 23. Pressure-temperature diagram of the H$_2$O-NaCl system.

Point A = homogenization temperature and salinity of possible boiling inclusions. (After Cunningham, 1978.)
CHAPTER 6

ALTERATION AT THE GRASSHOPPER PROSPECT

General

Alteration and mineralization at Grasshopper appear to have occurred relatively soon after emplacement of the main intrusive body. A sericite concentrate collected from rocks at 367 feet depth in drill hole GR-1 is dated at 71.6 ± 2.8 m.y. while the aphanitic phase of the dacite porphyry is dated at 73.4 ± 3.5 m.y. The alteration zoning pattern at Grasshopper is not unlike that of many porphyry copper systems in calc-alkaline rocks. From the outside inward, the alteration zoning pattern consists of nearly circular, concentric zones of chlorite, chlorite-epidote, sericite-quartz-pyrite, and biotite-magnetite-sericite alteration.

Field and laboratory observations of numerous hand samples taken on a 500 by 600 foot grid were most useful in delimiting alteration zones while thin section studies of selected hand samples were most useful in accurately defining the alteration seen. The distribution of petrographically determined alteration numbers for surface and shallow drilling samples is shown on Fig. 24.

Chloritic Alteration

Chloritic alteration is present to some degree throughout the entire 2.6 square mile area of the stock except for the central sericite-quartz-pyrite alteration zone (Fig. 7). The most intense
Fig. 24. Petrographic alteration numbers.

All samples are of outcrops. For a complete description of alteration numbers see text under Laboratory Techniques. $S = \text{sericite}, C = \text{chlorite}, E = \text{epidote}, K = \text{kaolinite},$ and $B = \text{secondary biotite}.$
chlorite alteration occurs near the outer edge of the sericite-quartz-pyrite alteration zone, resulting in alteration to chlorite of nearly all of the mafic minerals and most of the matrix. Chlorite alteration intensity decreases toward the outer edge of the intrusion and approaches near negligible levels at the extreme west and north-west edges of the stock. Strongly chloritized dacite porphyry is gray-green while relatively unaltered outcrops are brownish-gray (Fig. 11).

In the chloritic alteration zone, original biotite is approximately 94 percent altered to 85 percent chlorite, 8 percent magnetite, 5 percent sericite, and 2 percent epidote, and original hornblende is approximately 77 percent altered to 90 percent chlorite, 8 percent magnetite, 1 percent epidote, and minor quartz and calcite. Original plagioclase is approximately 12 percent altered to 58 percent sericite, 25 percent chlorite, 8 percent epidote, and minor magnetite, jarosite, and secondary plagioclase. The matrix appears to be altered dominantly to chlorite with minor quartz, magnetite, calcite, and sericite.

**Chlorite-epidote Alteration**

The chlorite-epidote alteration zone is the result of a gradational increase in epidote alteration of plagioclase and mafic minerals with continued chlorite alteration of biotite, hornblende, and the groundmass. Epidote alteration can be seen in Fig. 25 to be erratically increasing toward the outer edges of the sericite-quartz-pyrite alteration zone to a maximum of about 12 percent of the whole rock.
Fig. 25. Epidote alteration distribution.

All samples are of outcrops and there is no epidote in the sericite-quartz-pyrite alteration zone. 
N = no epidote, L = estimated 1-3% epidote, LM = estimated 3-6% epidote, M = estimated 6-8% epidote, MH = estimated 8-10% epidote, H = estimated 10-12% epidote, and V = presence of epidote in veinlets.
In the chlorite-epidote alteration zone, original biotite is totally altered to an average of 60 percent chlorite, 30 percent epidote, and 10 percent magnetite, and original hornblende is totally altered to an average of 55 percent chlorite, 18 percent epidote, 15 percent magnetite, 10 percent calcite, and 2 percent leucoxene. Original plagioclase is approximately 35 percent altered to 71 percent epidote and 28 percent sercite with a trace of calcite and magnetite. The matrix appears to be altered dominantly to chlorite with minor epidote, quartz, calcite, sercite, and magnetite. Rare epidote veinlets are present, usually near the inner edge of the chlorite-epidote alteration zone in moderate to heavily chlorite-epidote altered rock (Fig. 25).

Sericite-quartz-pyrite Alteration

The sericite-quartz-pyrite alteration zone is the highest intensity alteration zone exposed at the surface of Grasshopper (Fig. 7). This alteration type has resulted in a non-resistant light gray to off white rock which contrasts sharply to the resistant darker colored rocks of the two outermost alteration zones (Figs. 2 and 12). The sericite-quartz-pyrite alteration zone has original plagioclase phenocrysts approximately 86 percent altered to 75 percent sercite, 14 percent kaolinite and montmorillonite, 10 percent quartz, and minor chlorite, leucoxene, and jarosite. Original biotite phenocrysts are approximately 75 percent altered to 64 percent sercite, 20 percent kaolinite and montmorillonite, and 14 percent leucoxene with minor chlorite and quartz. The matrix appears to be altered to
dominant quartz and sericite with significant amounts of kaolinite and montmorillonite, and with minor chlorite, calcite, leucoxene, and iron oxides.

In the sericite-quartz-pyrite alteration zone, 100 percent of the quartz and only about 50 percent of the plagioclase, biotite, and hornblende phenocrysts are present, as compared to all other alteration types. The absence of many of these phenocrysts is believed to be due to their alteration beyond the limits of recognition.

In a general way, both sericite and clay contents are slightly higher above the zone of enrichment than in primary mineralized rocks. Also, a general trend is noted in increased clay and sericite content toward the outer edge of the sericite-quartz-pyrite alteration zone. Whether these trends are a function of primary vertical and lateral alteration zoning, of supergene alteration effects, or a combination of these two is not known.

The great majority of the iron oxides in the leached capping at Grasshopper are jarositic, although minor geothitic limonite is present, especially in veins and veinlets near the center of the sericite-quartz-pyrite alteration zone. The abundance of jarosite indicates a relatively high pyrite to chalcopyrite and magnetite ratio, especially in the outer portions of the sericite-quartz-pyrite alteration zone. The geothitic limonite veins and veinlets could likely be after chalcocite, although no well-preserved boxworks indicative of chalcocite were noted.
Estimations of original percent disseminated sulfides as interpreted from leached capping range from zero to 5 percent and show an overall decrease in disseminated sulfides toward the center of the sericite-quartz-pyrite alteration zone (Fig. 26). Much of this decrease in disseminated limonite after sulfides is made up for by an increase in limonite veins and veinlets.

Quartz, quartz-limonite, limonite, and quartz magnetite veins and veinlets can account for as much as 50 percent of the total rock volume (Fig. 16), although they generally occur in much lower amounts. A plot of combined quartz and limonite stockwork density as visually approximated from hand samples reveals a well-displayed increase in stockwork density toward the center of the sericite-quartz-pyrite alteration zone (Fig. 27).

**Biotite-magnetite-sericite Alteration**

Biotite-magnetite-sericite alteration is the highest intensity alteration seen at Grasshopper and is encountered in drill holes GR-1 and GR-2 (Fig. 7). The contact with the sericite-quartz-pyrite alteration zone is gradational, and it is possible that only the outside edge of the biotite-magnetite-sericite alteration zone was intercepted in drilling. At the bottom of drill hole GR-1, in the highest intensity biotite-magnetite-sericite alteration intercepted, original plagioclase is approximately 33 percent altered to 57 percent sericite and 38 percent secondary biotite with minor quartz, chlorite, calcite, pyrite, magnetite, kaolinite, and leucoxene. Original biotite is approximately 88 percent altered to 81 percent secondary biotite and
Fig. 26. Original percent disseminated sulfides as estimated from leached capping.

Samples are of mixed outcrop and mantle. N = estimated 0-0.5% disseminated sulfides, L = estimated 0.5-2.0% disseminated sulfides, M = estimated 2.0-5.0% disseminated sulfides.
Fig. 27. Combined silica and limonite stockwork distribution.

Samples are of mixed outcrop, mantle, and float, and value ranges are crude estimates from field observations. N = less than 2 percent stockworks, L = approximately 2–6 percent stockworks, and M = greater than 6 percent stockworks. Less than 2 percent stockworks occur outside the sericite-quartz-pyrite alteration zone.
16 percent chlorite with minor sericite, quartz, magnetite, pyrite, chalcopyrite, kaolinite, and leucoxene. The matrix is weakly to moderately altered to secondary biotite and sericite with minor quartz, chlorite, pyrite, chalcopyrite, magnetite, kaolinite, and leucoxene. Biotite-magnetite-sericite alteration is crosscut by non-pervasive sericite-quartz-pyrite-(chlorite) alteration which occurs as alteration selvages up to 4 inches wide around quartz-pyrite veins (Fig. 13). Chlorite commonly occurs between sericite-quartz-pyrite alteration selvages and pervasive biotite-magnetite-sericite alteration and can clearly be seen to be altering the pervasive secondary biotite. This overprinted alteration makes up from 15 to 30 percent of the rock volume.

An average of 95 percent of the magnetite, 75 percent of the chalcopyrite, and 28 percent of the pyrite is associated with pervasive biotite alteration, occurring commonly as replacement of mafic minerals. The majority of the pyrite occurs as pyrite and quartz-pyrite veins and veinlets, and as alteration selvages to these veins. Magnetite and chalcopyrite occur only rarely in veins or veinlets with or without quartz.

Magnetite Distribution

The distribution of percent magnetite as determined in surface samples by an Elliot Magnetometer Bridge is shown in Fig. 28. Underground, drill hole GR-1 has an average of 0.5 percent magnetite in the weathered and enriched zones to 180 feet and an average of 1.2 percent magnetite in the primary zone from 180 to 370 feet. Drill
Fig. 28. Surface magnetite distribution.

Samples are mixed outcrop, mantle, and float. Values are weight percent magnetite and were obtained by using a correction factor (3.22) on readings from an Elliot Magnetometer Bridge.
hole GR-2 has an average of 1.0 percent magnetite in the weathered and enriched zones to 160 feet and an average of 1.9 percent magnetite in the primary zone from 160 to 542 feet. Drill hole GR-3 encountered only a trace of magnetite in predominantly sericite-quartz-pyrite altered rock. It is obvious from Fig. 28 that there are two distinct assemblages which involve magnetite; the peripheral chlorite and chlorite-epidote zones, and the central biotite-magnetite-sericite zone, the two clearly separated by the magnetite free sericite-quartz-pyrite zone. In both cases the magnetite appears to have been produced by hydrothermal alteration, although in the chlorite and chlorite-epidote zones some original rock forming magnetite may have been present.

It is not known, because of limited drill exposures, if the general decrease in magnetite content in the weathered and enriched portions of the drill holes is a function of vertical alteration zoning or of oxidation of magnetite. The occurrence of magnetite on the surface supports the idea that the biotite-magnetite-sericite alteration zone may extend all the way to the surface but is not easily recognized due to supergene effects.

**Paragenetic Relationships of Alteration Assemblages**

The only paragenetic relationship that can be defined with certainty is the overprinting of veinlet-controlled sericite-quartz-pyrite-(chlorite) alteration which occurs as selvages to quartz-pyrite veins over the pervasive biotite-magnetite-sericite alteration (Fig. 13). In this alteration relationship, secondary biotite can be seen
to be altered to chlorite and sericite, and rare magnetite veinlets are cross-cut by quartz-pyrite veins.

The relationship of the non-pervasive sericite-quartz-pyrite-(chlorite) alteration to the pervasive sericite-quartz-pyrite alteration zone is not known. Should they be cogenetic, a younger age of alteration for the entire sericite-quartz-pyrite alteration zone would be inferred. Within the sericite-quartz-pyrite and the biotite-magnetite-sericite alteration zones, many cross-cutting relationships exist between quartz, quartz-pyrite, and pyrite veins but no discernible paragenetic pattern is evident.
MINERALIZATION AT THE GRASSHOPPER PROSPECT

Copper Mineralization

Sub-economic copper mineralization both as primary and supergene enriched copper is intercepted in drilling. Drill hole GR-1 intercepted a 90 foot weathered and leached zone averaging 0.02 percent copper, an 80-foot zone of enrichment averaging 0.33 percent copper, and finally 200 feet of 0.13 percent primary copper. Drill hole GR-2 intercepted a 40-foot weathered and leached zone averaging 0.05 percent copper, a 100-foot zone of enrichment averaging 0.19 percent copper, a 260 foot zone of primary 0.12 percent copper, and finally 120 feet of primary 0.09 percent copper. Drill hole GR-3 intercepted 170 feet of leached capping averaging 0.01 percent copper, 90 feet of very weak enrichment averaging 0.05 percent copper, and finally 285 feet of primary 0.03 percent copper.

Values of copper in surface samples (Fig. 29) range from 5 to 620 ppm copper and show a very well displayed concentric anomaly in the center of the sericite-quartz-pyrite alteration zone. Nearly all of the copper in the leached capping is apparently contained in the iron oxides, as discrete copper oxide minerals are only very rarely encountered.

A comparison of rock type to copper content reveals no im-  
portant trends. All rock types appear to be equally susceptible to copper
Fig. 29. Surface copper distribution.

Samples are mixed outcrop, mantle, and float, and copper values are in parts per million. Contours are 20, 100, 200, 300, 400, 500, and 600 parts per million.
mineralization as their distribution causes no significant deflections of the concentric pattern shown on Fig. 29.

Primary copper mineralization occurs dominantly as fine-grained chalcopyrite which is relatively evenly distributed throughout the rock and is commonly associated with mafic minerals. Significant primary copper is present only in the biotite-magnetite-sericite alteration zone with copper grade apparently being a function of intensity of biotite alteration. A summary of over 12,000 point counts on 11 polished thin sections and rock slabs from the bottoms of the drill holes shows best the relationship of copper mineralization to alteration (Table 2). Note the near 1-to-1 pyrite to chalcopyrite ratios in biotite-magnetite-sericite alteration and the fact that the majority of the copper is contained in the biotite-magnetite-sericite alteration type. Also note the low total sulfide values for GR-1 and GR-2, in biotite-magnetite-sericite alteration, in comparison to GR-3 in sericite-quartz-pyrite alteration.

Electron microprobe analysis of four pyrite grains from the bottom of GR-2 reveals an average copper content in pyrite of 230 ppm with a range of from 210 to 250 ppm copper. The copper is relatively evenly distributed in the pyrite, and therefore appears to occur in ionic substitution of copper for iron in the pyrite structure.

The supergene enrichment zone occurs as a relatively thin, very flat lying unit (Fig. 7) which lies either at or slightly above the present day water table. It is apparent that little structural disturbance has occurred since development of the blanket and it is
Table 2. Summary of pyrite, chalcopyrite, and magnetite point count data corrected to weight percentages.

<table>
<thead>
<tr>
<th>Location</th>
<th>Alteration Type</th>
<th>Pyrite (Weight %)</th>
<th>Chalcopyrite (Weight %)</th>
<th>Magnetite (Weight %)</th>
<th>Total Sulfides (Weight %)</th>
<th>Pyrite/Chalcopyrite</th>
<th>Chalcopyrite/Magnetite</th>
<th>Pyrite + Chalcopyrite/Magnetite</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR-1, 370 ft.</td>
<td>Non-pervasive sericite-quartz-pyrite-(chlorite) (28% of rock volume)</td>
<td>2.70</td>
<td>0.05</td>
<td>0.25</td>
<td>2.75</td>
<td>54/1</td>
<td>0.2/1</td>
<td>11/1</td>
</tr>
<tr>
<td>GR-1, 370 ft.</td>
<td>Biotite-magnetite-sericite (72% of rock volume)</td>
<td>0.49</td>
<td>0.51</td>
<td>1.77</td>
<td>1.00</td>
<td>1/1</td>
<td>0.3/1</td>
<td>0.6/1</td>
</tr>
<tr>
<td>GR-1, 370 ft.</td>
<td>Overall rock average</td>
<td>1.11</td>
<td>0.38</td>
<td>1.34</td>
<td>1.49</td>
<td>3/1</td>
<td>0.3/1</td>
<td>1.1/1</td>
</tr>
<tr>
<td>GR-2, 542 ft.</td>
<td>Non-pervasive sericite-quartz-pyrite-(chlorite) (23% of rock volume)</td>
<td>1.56</td>
<td>0.62</td>
<td>0.38</td>
<td>2.18</td>
<td>2.5/1</td>
<td>1.6/1</td>
<td>6/1</td>
</tr>
<tr>
<td>GR-2, 542 ft.</td>
<td>Biotite-magnetite-sericite (77% of rock volume)</td>
<td>0.15</td>
<td>0.24</td>
<td>2.18</td>
<td>0.39</td>
<td>0.6/1</td>
<td>0.1/1</td>
<td>0.2/1</td>
</tr>
<tr>
<td>GR-2, 542 ft.</td>
<td>Overall rock average</td>
<td>0.47%</td>
<td>0.33</td>
<td>1.77</td>
<td>0.80</td>
<td>1.5/1</td>
<td>0.2/1</td>
<td>0.5/1</td>
</tr>
<tr>
<td>GR-3, 555 ft.</td>
<td>Pervasive sericite-quartz-pyrite</td>
<td>4.97</td>
<td>trace</td>
<td>trace</td>
<td>4.97</td>
<td>&gt;30/1</td>
<td>-</td>
<td>&gt;30/1</td>
</tr>
</tbody>
</table>
quite possible that the enrichment process is continuing at present. Enrichment is due to replacement of pyrite and chalcopyrite by chal-
cocite and minor covellite. Chalcopyrite is by far the preferred
mineral for replacement with pyrite generally only developing thin
replacement coatings. Covellite is commonly observed either replacing
chalcopyrite or pyrite or being replaced by chalcocite.

The theoretical thickness of leached capping required to account
for the observed enrichment can be calculated by the following equation:

\[ Lt = \frac{(Et)(Eg-Pg)}{(Pg-Lg)} \]

where \( Lt \) = necessary leached capping thickness in feet, \( Et \) = enrichment
zone thickness in feet, \( Eg \) = enrichment zone grade, \( Pg \) = primary zone
grade, and \( Lg \) = leached zone grade. The use of this equation for GR-1
gives:

\[ Lt = \frac{(80 \text{ feet})(0.330 - 0.130)}{(0.130 - 0.024)} \approx 150 \text{ feet} \]

Similar calculations for GR-2 and GR-3 give necessary leached capping
thicknesses of 110 feet and 105 feet respectively.

**Molybdenum Mineralization**

Minor molybdenum is noted in both drilling and surface samples
(Fig. 30). Drill holes GR-1, GR-2, and GR-3 average 27, 10, 19 ppm
molybdenum respectively, with no important change in grade throughout
the length of the holes. Two 10-foot-interval assays of 250 and 120
ppm molybdenum in GR-3 may represent small veins. Surface samples
range from less than 2 to 55 ppm molybdenum and show a well displayed
Fig. 30. Surface molybdenum distribution.

Samples are mixed outcrop, mantle, and float and molybdenum values are in parts per million. Contours are at 10, 20, 30, 40, and 50 ppm.
molybdenum anomaly in the center of the sericite-quartz-pyrite alteration zone (Fig. 30). Comparison of rock types to molybdenum content reveals no trends as each rock type appears to be equally susceptible to molybdenum mineralization. All of the molybdenum is believed to be present as molybdenite which occurs as disseminations and in small veinlets with or without quartz.

**Molybdenum Related Trace Elements**

Levels of occurrence of a number of elements commonly found as halo elements dispersed around porphyry molybdenum deposits were determined by assay. Surface samples at a grid spacing of approximately 1200 by 1000 feet and samples from the bottom of each drill hole were assayed for fluorine, tungsten, tin, and bismuth. There are no discernible trends in distribution of any of these elements, and all values are well below what one would consider "interesting" in evaluating a potential molybdenum prospect (Sharp, 1978; Wallace et al., 1968). Fluorine averages 410 parts per million with a range from 190 to 920 parts per million. Tungsten averages 3 parts per million with a range from <2 to 8 parts per million. Bismuth and tin are both below their limits of detection at <2 and <10 parts per million respectively.

**Gold and Silver Mineralization**

Minor gold and silver values were found in both drilling and surface samples. Drill hole intercepts are summarized in Table 3, Column C. No important change in gold and silver grade occurs throughout the depth of the holes. Surface and drill hole samples show a
Table 3. Summary of gold and silver assays and concentration factors.

<table>
<thead>
<tr>
<th>(A) Drill Hole</th>
<th>(B) Precious Metal</th>
<th>(C) Precious Metal assay in whole rock (ppm)</th>
<th>(D) Precious Metal assay in pyrite (ppm)</th>
<th>(E) Precious Metal concentration factor in pyrite</th>
<th>(F) Precious Metal concentration factor in chalcopyrite</th>
<th>(C) Precious Metal content contained in sulfides (ppm)</th>
<th>(I) Estimated percent of whole rock precious metal contained in sulfides</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR-1</td>
<td>Au</td>
<td>0.18</td>
<td>1.0</td>
<td>6X</td>
<td>67X</td>
<td>0.057</td>
<td>31%</td>
</tr>
<tr>
<td>GR-1</td>
<td>Ag</td>
<td>0.2</td>
<td>2.0</td>
<td>10X</td>
<td>410X</td>
<td>0.334</td>
<td>166%</td>
</tr>
<tr>
<td>GR-2</td>
<td>Au</td>
<td>0.23</td>
<td>2.4</td>
<td>10X</td>
<td>91X</td>
<td>0.080</td>
<td>35%</td>
</tr>
<tr>
<td>GR-2</td>
<td>Ag</td>
<td>0.8</td>
<td>1.0</td>
<td>1X</td>
<td>58X</td>
<td>0.157</td>
<td>20%</td>
</tr>
<tr>
<td>GR-3</td>
<td>Au</td>
<td>0.035</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GR-3</td>
<td>Ag</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
well-defined increase in gold and silver toward the center of the sericite-quartz-pyrite alteration zone (Figs. 31 and 32).

Gold and silver assays of pyrite and chalcopyrite concentrates (Table 3, Columns D and E) for GR-1 and GR-2 allow the calculation of concentration factors for gold and silver in pyrite and chalcopyrite (Table 3, Columns F and G). By knowing the grade of gold and silver in pyrite and chalcopyrite and knowing percent pyrite and chalcopyrite in the rock (Table 2), one can calculate total gold or silver contained in the sulfides by the equation:

\[ Ms = \frac{(Pg \times Pp) + (Cg \times Cp)}{K} \]

where \( Ms \) = total gold or silver contained in the sulfides, \( Pg \) = grade of gold or silver in pyrite, \( Pp \) = weight percent pyrite in rock, \( Cg \) = grade of gold or silver in chalcopyrite, \( Cp \) = weight percent chalcopyrite in rock, and \( K = 100 \), a correction factor to change percentage to fractional terms.

Using this equation for gold in GR-1 gives:

\[ Mg = \frac{(1.0 \text{ ppm} \times 1.11\%) + (12.0 \text{ ppm} \times 0.38\%)}{100} = 0.057 \text{ ppm} \]

Similar calculations for silver in GR-1 and gold and silver in GR-2 give the values in Table 3, Column H. By knowing the amount of precious metals in the sulfides and comparing this to total precious metals in the rock, the estimated percent of the precious metals in the rock that are contained in the sulfides can be determined (Table 3, Column I).
Fig. 31. Distribution of gold on surface and in drilling.

Samples are outcrop, mantle, float, and drill cuttings, and gold values are in parts per million.
Fig. 32. Distribution of silver on surface and in drilling.

Samples are of mixed outcrop, mantle, float, and drill cuttings, and silver values are in parts per million.
While one must remember that there is considerable room for error in calculations of this sort, it is apparent that a significant amount of the gold and silver is concentrated in the sulfides and that chalcopyrite is significantly more enriched in gold and silver than pyrite.

An electron-microprobe was used to scan a number of pyrite and chalcopyrite grains for gold and silver in an attempt to determine how evenly gold and silver are distributed throughout the grains. This attempt proved futile, however; gold and silver were never detected since the lower limits of microprobe detection for gold and silver are approximately 150 ppm, nearly twice the highest value obtained from assaying. The absence of gold or silver in pyrite and chalcopyrite in excess of 150 ppm helps to indicate the probable even distribution of gold and silver in the sulfides. It is believed that the most likely mode of occurrence of gold and silver in the sulfides is as substitution for the iron and copper ions in the lattice of the pyrite and chalcopyrite structure (Vincent and Crockett, 1960).

**Zinc Mineralization**

Zinc occurs at values ranging from 5 ppm to 680 ppm and can be seen in soil and stream sediment samples taken by Cities Service Corporation (Schell, 1977) to be erratically distributed about the outer edges of the sericite-quartz-pyrite alteration zone and the inner portion of the chlorite and chlorite-epidote alteration zones (Fig. 33). Electron-microprobe scans of four chalcopyrite grains found three to contain detectable zinc averaging 460 ppm and ranging from 370 to 540...
Fig. 33. Surface zinc distribution.

Samples are of soil and of stream sediment and values are in parts per million. Only values greater than 99 ppm are plotted. (Data is from Schell, 1977.)
ppm zinc. Four scans of pyrite grains for zinc proved to be below the lower limits of detection of the probe, approximately 300 ppm.
CHAPTER 8

REVIEW OF ZONING PATTERNS

The Grasshopper porphyry system shows remarkable zoning in rock composition, alteration, and mineralization. It should be realized, however, that as samples of mixed outcrop, mantle, and float were used, many of the apparent very regular and concentric patterns displayed on the surface may not accurately represent the true zoning in the rock. The most important zoning patterns are summarized below.

1. Matrix. Although it is not mappable, the aphanitic matrix phase of the dacite porphyry is generally in the outer portions of the stock while the fine-grained matrix phase is generally central.

2. Quartz phenocrysts. Within the fine-grained matrix phase of the dacite porphyry, quartz phenocryst abundance and size generally increase toward the north-central portion of the sericite-quartz-pyrite alteration zone. These quartz phenocryst trends become even more pronounced when all porphyritic rock types are considered (Figs. 17 and 18).

3. Overall alteration. The overall pattern of alteration consists of four roughly concentric zones ranging from outermost chlorite alteration to innermost biotite-magnetite-sericite alteration (Fig. 7).
4. Sulfide distribution. Total sulfide percentages, as seen both in leached capping interpretations and in drilling, show a continued inward decrease from a maximum of at least 5 percent in the outer portions of the sericite-quartz-pyrite alteration zone to a low of less than 1 percent in biotite-magnetite-sericite alteration (Fig. 26 and Table 2). Sulfide percentages also decrease drastically outward from the outer portions of the sericite-quartz-pyrite alteration zone into the two outermost chloritic alteration zones.

5. Stockworks. Silica and pyrite stockwork development shows a marked increase toward the center of the annular sericite-quartz-pyrite alteration zone (Fig. 27). Stockworks range from less than two to as much as 50 volume percent of the rock.

6. Magnetite. Magnetite shows a distinct twofold distribution pattern. It occurs in the two peripheral chloritic alteration zones in amounts ranging from zero to 1.9 weight percent, and is absent from the outer portions of the sericite-quartz-pyrite alteration zone (Fig. 28). Magnetite shows an increase from the center of the sericite-quartz-pyrite zone into the biotite-magnetite-sericite alteration zone, reaching a maximum of 1.9 weight percent in hole GR-2.

7. Biotite. Secondary biotite occurs in the most central alteration zone amounting up to as much as 10 volume percent of the whole rock in hole GR-1.

8. Copper and molybdenum show well-defined increases toward the center of the sericite-quartz-pyrite alteration zone ranging
from near negligible background levels to central highs of 620 parts per million copper and 55 parts per million molybdenum (Figs. 29 and 30). This trend continues into the biotite-magnetite-sericite alteration zone where hole GR-1 averages 0.13 percent primary copper and 0.002 percent molybdenum.

9. Gold and silver. Both gold and silver show marked increases toward the center of the sericite-quartz-pyrite alteration zone (Figs. 31 and 32) and on into the biotite-magnetite-sericite alteration zone. Gold and silver values range from near negligible levels in the outer portions of the system to values of 0.23 parts per million gold and 0.80 parts per million silver in hole GR-2.

10. Zinc. Although rather erratically distributed, zinc occurs dominantly near the outside edge of the sericite-quartz-pyrite alteration zone and in the two chloritic alteration zones (Fig. 33). Zinc values range from 5 to 680 parts per million.
CHAPTER 9

CONCLUSIONS

General Observations

The most significant contribution of this thesis is that a detailed description of a porphyry system has been presented which allows comparison of the Grasshopper prospect to other porphyry systems and which can be used to give direction to any possible future exploration on this property. The Grasshopper porphyry system falls within the range of geologic variations described in North American porphyry systems, yet has distinct deviations from the norm in probable depth of formation, rock type composition, alteration style, mineralization style, and mineralization zoning. Among the similarities of Grasshopper to a "typical" porphyry system as defined by Lowell and Guilbert (1970) are a common relationship of mineralization and alteration to a porphyritic intrusion, the common occurrence of mineralization and alteration in a passively emplaced stock, and the distribution of alteration zones from a "potassic" core to an outermost "propylitic" alteration zone. The approximately two mile diameter size of the Grasshopper alteration system is about the average size described by Lowell and Guilbert (1970), and the distribution of sulfide minerals from a low total sulfide core to an intermediate high sulfide zone, and finally to an outermost low total sulfide zone, is common to both systems.
Among the most important deviations of the Grasshopper system from "typical" porphyry models is its probable shallow depth of formation. The intrusive complex at Grasshopper is believed to represent the epizonal roots of a stratovolcano. Lines of evidence for this conclusion are:

1. the fine grain size of the two phase dacite porphyry and of the subordinate intrusive rocks;
2. the nearly circular outline of the dacite porphyry body in map view;
3. the concentric zoning pattern of rock textures within the dacite porphyry;
4. the apparent sill-like nature of the intrusive body near its edge;
5. the fact that the stock intrudes a Cretaceous volcanic sequence; and
6. the apparent radial and concentric fracture pattern.

Lines of evidence for alteration and mineralization of the Grasshopper intrusion occurring at relatively shallow depths are that:

1. the host intrusive body was probably shallowly emplaced (1-6 above);
2. isotopic dates of 73.4 ± 3.5 m.y. for the intrusion and 71.6 ± 2.8 m.y. for alteration micas indicate that alteration occurred soon after emplacement of the main intrusive body;
3. the zoning patterns of alteration and mineralization are strikingly concentric; and
4. fluid inclusion evidence, although non-conclusive, points to a depth of formation between 0.8 and 2.2 kilometers.

Other important deviations of the Grasshopper system from the Lowell and Guilbert model are the lack of regional structural control of the Grasshopper intrusion and the occurrence of the Grasshopper system in a dacite porphyry versus a quartz monzonite for the "typical" porphyry system. The extremely disseminated nature of mineralization, the occurrence of up to two weight percent magnetite, and the near lack of orthoclase in the centermost alteration zone are other features uncommon the the "typical" porphyry system. Finally, the Grasshopper system contains approximately one-half the amount of total sulfide minerals described in the "typical" porphyry system and is somewhat anomalous in its containing positive gold and silver values in the centermost alteration zone.

Many of the above-mentioned deviations in alteration and mineralization from the model of Lowell and Guilbert (1970) are more common in porphyry systems in calc-alkaline rock suites as at Safford, Arizona (Robinson and Cook, 1966), in many British Columbia deposits (Hollister, 1978; McMillan, 1976), and in many southwest Pacific porphyry systems (Gustafson, 1978; Loudon, 1976; Wolfe, Manuzon, and Divis, 1978; Ashley et al., 1978; Kósaka and Wakita, 1978; Baldwin, Swain, and Clark, 1978; Titley, 1975). In many respects, the Grasshopper system falls into the category of the diorite model of Hollister (1978) which was used to describe certain deposits in British Columbia.
Features of the Grasshopper system common to the model of Hollister include abundance of secondary biotite, lack of orthoclase, and relative abundance of gold in the centermost alteration zone.

The approximately 73 million year age of emplacement of the Grasshopper stock is simultaneous with that of the Boulder Batholith (Meyer et al., 1968), and falls within the range of ages for deposits in the porphyry molybdenum belt approximately 50 miles north of Grasshopper (Fig. 5) (Armstrong, Hollister, and Harakal, 1978; Schmidt and Worthington, 1977). The pervasive biotite-magnetite-sericite alteration and associated mineralization at the Grasshopper prospect has many similarities to the early pervasive biotitic alteration event at Butte (Roberts, 1973). In early alteration at Butte, mafic minerals are altered to secondary biotite, and chalcopyrite, pyrite, and bornite are disseminated throughout the rock, occurring chiefly in the mafic mineral sites. This alteration assemblage occurs as an elongate dome approximately 1 by 3 miles in diameter. Intensity of biotitization, total sulfide content, chalcopyrite to pyrite ratios, and copper and molybdenum values all increase toward the center of the core of this subsurface alteration zone (Roberts, 1973). Should the biotite-magnetite-sericite alteration zone at Grasshopper follow the pattern of early biotitic alteration at Butte, one would expect to find similar improvements in alteration and mineralization centrally and at depth in the Grasshopper porphyry system.

Late-stage, non-pervasive sericite-quartz-pyrite-(chlorite) alteration and the associated mineralization at the Grasshopper prospect
is similar in some respects to the main stage mineralization and alteration event at Butte. In main stage mineralization at Butte (Meyer et al., 1968; Thompson, 1973), veins are strongly regionally structurally controlled and consist dominantly of quartz, pyrite, and copper sulfide fillings with zinc and manganese minerals becoming increasingly important toward the outer portions of the system. Alteration selvages to these veins consist of outwardly progressing zones of sericite-quartz-pyrite, kaolinite-montmorillonite, and fringe "propylitic" alteration. These selvages range from less than an inch to a few feet in width with alteration becoming pervasive in areas of high vein density. While the late stage alteration event at the Grasshopper prospect contains only very minor copper sulfide mineralization and is not nearly as well developed or structurally controlled as the main mineralization stage at Butte, an overall similarity in alteration style is evident.

**Exploration Potential**

In evaluating the exploration potential of the Grasshopper prospect, one must first consider that drilling has not yet penetrated beyond 555 feet in depth and that no significant vertical changes in primary alteration or mineralization have been seen. It is hardly excluded that only the outside edge of the biotite-magnetite-sericite alteration zone has been cut and that stronger biotite alteration could be encountered laterally or at depth. Although the approximate lateral extent of the biotite-magnetite-sericite alteration zone is probably
roughly equivalent to the area of the central surface magnetite anomaly (Fig. 28), only the north side of this alteration zone has been defined by drilling.

Exploration for more important primary grade copper values could follow two courses of logic. If one considers the similarities of this system to early pervasive alteration at Butte, as discussed above, the best exploration target would be to drill the core of the biotite-magnetite-sericite alteration zone in hopes of finding more intense biotitization, higher total sulfide content, improved chalcopyrite to pyrite ratios, and higher copper grade centrally and at depth. This possibility would best be tested by one or two deep drill holes in the center of the biotite-magnetite-sericite alteration zone as defined by surface magnetite distribution (Fig. 28). Should the Grasshopper prospect follow the general trends described by Lowell and Guilbert (1970), drilling of the core of biotite-magnetite-sericite alteration would not be expected to find significant improvement in primary copper grade as the total sulfide content of the rock would become too low to contain significant copper, even with improved chalcopyrite to pyrite ratios. By this model, the best exploration strategy would be to drill the lateral outer portions of the biotite-magnetite-sericite alteration zone and the transition zone between biotite-magnetite-sericite and sericite-quartz-pyrite alteration in hopes of finding favorable chalcopyrite to pyrite ratios in a part of the system with a higher total sulfide content.

The possibility of lateral improvement in supergene enriched copper grade can easily be tested by a number of shallow, less than
200 foot deep drill holes. Drilling would best be directed over the area of biotite-magnetite-sericite alteration as defined by surface magnetite distribution (Fig. 28), and in the transition zone between the biotite-magnetite-sericite and sericite-quartz-pyrite alteration zones. While the probability of a large, rich, supergene enriched deposit is small, the possibility of small, medium grade enrichment blanket segments at shallow depth exists.

The molybdenum potential of this property would best be tested by one or two deep drill holes located in the center of the biotite-magnetite-sericite alteration zone. This exploration theory would be based on the idea that copper, gold, silver, and zinc mineralization represents a base and precious metal "halo" related to a deeper porphyry molybdenum system. One would hope to find deep molybdenum mineralization associated with a hidden, more differentiated intrusion, possibly a larger intrusive body related to the rhyolite seen on the surface.

One should not forget the possible contribution to be made by gold and silver as by-products or even co-products. The significant concentration of these metals in the sulfides would make their recovery relatively easy.
LIST OF REFERENCES


Thompson, B. T., 1973, Distribution of primary mineralization and hydrothermal alteration within the Berkley Pit, Butte District, Montana: Guidebook for the Butte Field Meeting of Society of Economic Geologists, Butte, Montana, pp. L-1-1.


Figure 7. Geologic Map and Cross-Sections of the Grasshopper Prospect, Beaverhead County, Montana.