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Petrology alteration and mineralization of the Poorman Creek-Silver Bell stock porphyry Cu-Mo deposit

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PETROLOGY, ALTERATION, AND MINERALIZATION
OF THE POORMAN CREEK-SILVER BELL STOCK
PORPHYRY CU-MO DEPOSIT

by

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ABSTRACT

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Petrology, Alteration, and Mineralization of the Poorman Creek-Silver Bell Stock Porphyry Cu-Mo Deposit (97 pp.)

Director: I. Lange

The Poorman Creek-Silver Bell stock porphyry Cu-Mo deposit (15 km southeast of Lincoln, Montana and 25 km south of the 44 m.y. Heddleston porphyry Cu-Mo district) is a composite granite to monzonite intrusive which cuts the Empire and Helena formations of the Precambrian Belt Supergroup. The Empire Formation, a 330 m thick green argillite, is overlain by the 1700 m thick Helena Formation, a silty carbonate. At least six phases, including granite, granodiorite, quartz monzonite, granite porphyry, quartz monzonite porphyry, and andesite porphyry have been identified within the stock and associated conjugate dikes. The N-S Rochester Gulch fault and breccia zone cuts the stock, was active before, during, and post intrusion and mineralization, and has at least 300 m of vertical, west side down, displacement.

Mineralization includes both disseminated Cu+Mo and Pb-Zn-Ag veins cutting quartz monzonite and hornfels. Coextensive with late(?) phases of the stock is pervasive phyllic alteration, disseminated chalcopyrite, and molybdenite along some fractures. Potassic alteration is noted along molybdenite bearing veinlets, however, no large zone of K-silicate alteration is exposed. Low angle igneous contacts and numerous outcrops of roof pendants within the pluton suggest that only the top of the system has been exposed by erosion. Gold, copper, and silver mineralization is irregularly distributed in overlying skarn rocks. Placer gold and lead-silver veins were mined in the 1930's.

ACKNOWLEDGMENTS

Many thanks to Dr. Ian Lange for suggesting the project and visiting the field area. I am indebted to many people for thoughtful conversations about the project including Marshal Himes, Dick Thompson, Dr. R. Berg, Dr. Henry McClernan, Neil Desmarais, and Gil Wiswall. I am very grateful to Don Winston for encouragement and guidance when it was most needed. Field work was supported in part by Utah International Company and by a summer fellowship provided by the Montana Bureau of Mines and Geology.

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CHAPTER I

INTRODUCTION

General Statement

Many porphyry copper-molybdenum deposits in the Pacific Northwest have not been extensively studied. Field, et al., 1974, 1975, and A. S. Brown, 1976, have contributed much by tabulating information available concerning these deposits. The Poorman Creek-Silver Bell stock porphyry copper-molybdenum deposit provides an excellent opportunity to study a mid-Tertiary (?) deposit. I have studied the intrusive and extrusive rocks, and the extent and characteristics of the alteration and mineralization. These characteristics are similar to characteristics of well-known and described porphyry ore deposits such as the Kalamazoo ore body (Lowell and Guilbert, 1970). I hope this study will increase the understanding of igneous activity and porphyry ore mineralization in this region, thus aiding in future mineral exploration both in the Silver Bell area and in the Pacific Northwest.

Location

The study area is located approximately 22 km southeast of Lincoln, Montana (Fig. 1). It is within Range 7 and 8 West, township 13 North, Lewis and Clark County. The area is accessible by

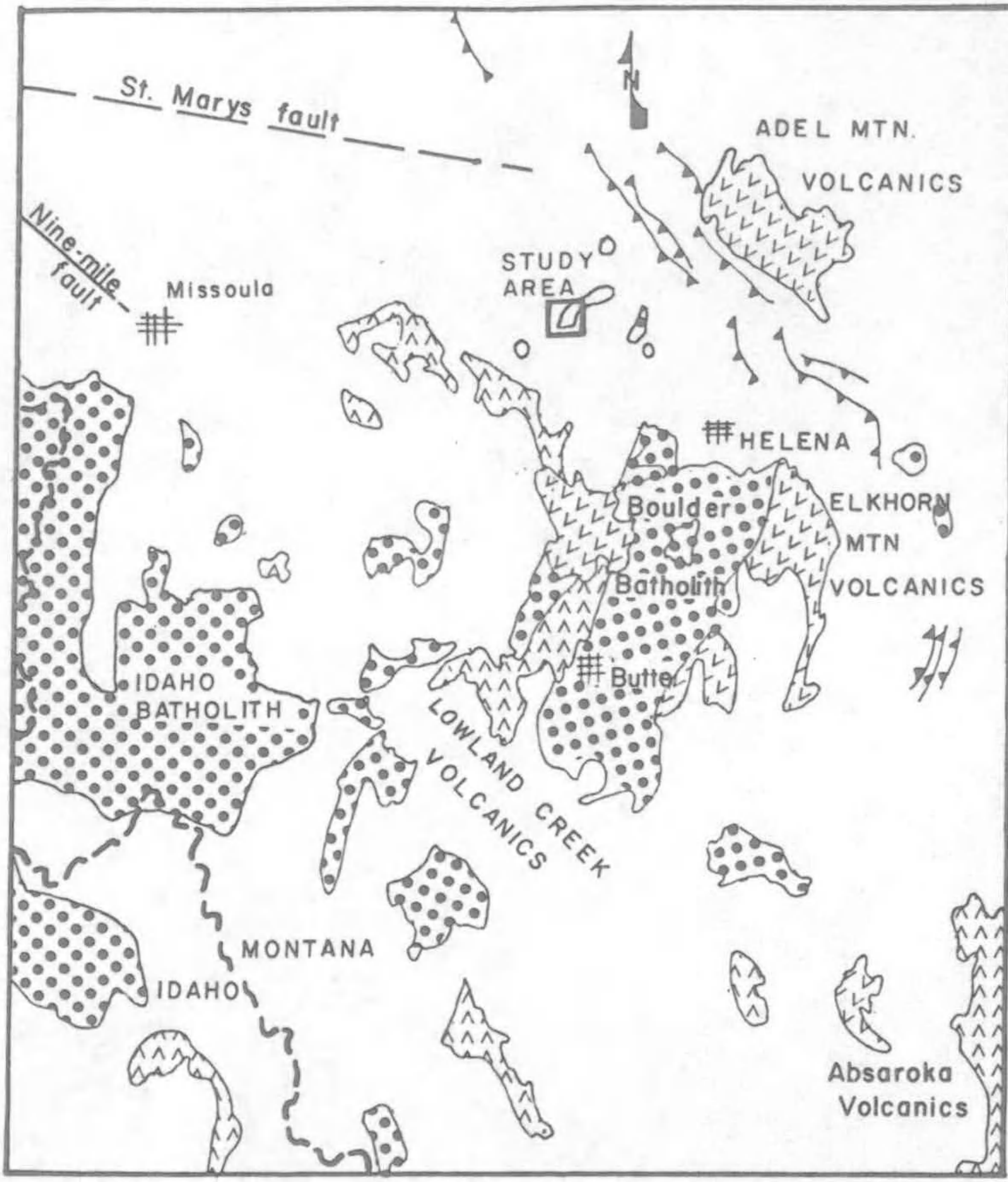


FIGURE I - LOCATION MAP

LEGEND

Cretaceous - Tertiary "granitic" Rocks

Cretaceous/Tertiary Volcanic Rocks

0 25 50 km

traveling south from Lincoln along Forest route 689 of the Helena National Forest.

Previous Work

Many studies have been done in the Lincoln area. The studies which have proven most helpful to this study include: Barrell, 1907; Knopf, 1913; Pardee and Schrader, 1933; Melson, 1964, 1971; Kleinkopf and Mudge, 1973; Miller et al., 1973; and McClernan, 1974.

Barrell (1907) studied the Marysville mining district approximately 32 km south and east of the Silver Bell stock. He described Belt rocks, mineral deposits, and intrusive rocks. He proposed a genetic correlation with the intrusive rocks of the Boulder batholith.

Knopf, 1913, and Pardee and Schrader, 1933, described mineral deposits of the greater Helena area including the Poorman Creek area. Their descriptions are useful for comparing the Silver Bell with nearby mineral deposits including those within the northern part of the Boulder batholith.

Melson, 1964, carefully mapped the Lincoln area including the Poorman Creek drainage. His work provided a good general map for this study as well as good descriptions of nearby intrusive and extrusive igneous rocks, and a general description of Belt rocks and their metamorphic derivatives.

Kleinkopf and Mudge, 1973, provide regional aeromagnetics (Appendix A) and interpretations. McClernan, 1974, conducted a soil sample geochemistry study over the Silver Bell stock (Appendix A). Miller, et al., 1973, described the Heddleston porphyry system which is located approximately 25 km to the northeast along U.S. 200.

The Utah International Company conducted rock and soil sample geochemistry, induced potential, and ground geomagnetics and gravity studies over the Silver Bell stock (Appendix A). Also, they provided diamond drill core for examination.

Regional structural studies including the Lincoln area are being conducted by Mike Stickney and Don Winston. Their information aided in regional interpretations. Finally, Fission-track age dating is being conducted by C. Naeser, I. Lange and J. McKee on the Silver Bell stock and nearby igneous rock and will be published at a later date.

CHAPTER II

REGIONAL SETTING

The study area includes the western two-thirds of the Silver Bell stock which intrudes the Precambrian Belt Supergroup. The Silver Bell stock is spatially associated with many other Cretaceous and Tertiary igneous rocks including the Boulder batholith, small granitic stocks, and andesitic to latitic volcanic rocks (Fig. 1). Nearby mineral deposits include porphyry ore deposits, base metal bearing quartz veins, and placer gold deposits. The tectonic setting of the Silver Bell stock is poorly understood; however, the stock appears to have been emplaced post-orogenically.

Sedimentary Rocks

The Lincoln area is underlain by Precambrian sedimentary rocks belonging to the Belt Supergroup. These rocks have experienced only low grade, greenschist facies regional metamorphism except near the Idaho batholith. Local exceptions include contact metamorphism and hydrothermal alteration near Tertiary stocks.

The Belt Supergroup was first described in this area by Walcott (1898). Melson (1964, 1971) and Beirwagen (1964) described in detail the Belt rocks in the Lincoln area. The reader is referred to these papers for a more lengthy discussion of the regional aspects of the Belt rocks.

Four major Belt units whose total section is approximately 4572 meters (Melson, 1964) are exposed in the Silver Bell area. These formations, starting from the lowest, are the Spokane, Empire, Helena and Marsh formations. These rocks and their contact metamorphic equivalents are discussed in Chapter III.

Within the Belt Basin, anomalous amounts of copper (100 ppm or more) occur in virtually all units except the Pilcher and the Bonner formations (Harrison, 1972). The principal copper minerals include chalcopyrite, chalcocite, digenite (?), and bornite (Trammell, 1970; A. L. Clarke, 1971). Anomalous amounts of silver and mercury occur with the copper anomalies (Harrison, 1972). Notably, in the Lincoln area, anomalous amounts of copper occur in the green beds of the Spokane, Empire, and Helena formations (Harrison, 1972). The copper occurs as syngenetic minerals concentrated along bedding planes, in minor sedimentary structures, and in water escape structures (Harrison, 1972; Lange, 1975). Another curious occurrence is the chalcopyrite replacement of oolites in the Helena Formation (Lange and Eby, 1978). The origin of these metals is a subject of debate and is discussed in the three papers just cited.

Igneous Rocks

Igneous rocks in the Lincoln area range in age from Precambrian to mid- to late-Tertiary in age. Volumetrically, Laramide or post-Laramide intrusive and extrusive rocks prevail and are the subject of this study.

Boulder Batholith

The Boulder batholith, which lies 30 km south of the Lincoln area, is a late Cretaceous composite mass of at least a dozen plutons. It varies in composition from syenogabbro to alaskite, however, most of it is quartz monzonite (Klepper et al., 1971). Significant papers on the batholith include Knopf, 1957; Hamilton and Myers, 1974, 1974a; Klepper et al., 1971, 1974; Tillings, 1973, and many others. Some authors, notably Knopf, 1913, feel the stocks in the Lincoln area are derived from the Boulder batholith. However, I feel the disparity in age, composition, and areal distribution argue against this view.

Other Granitic Rocks

In addition to the Silver Bell stock, other "granitic" rocks in the Lincoln area include the Granite Peak, Dalton Mountain, and Heddleston stocks. These range from quartz diorite to granite in composition and, where studied, are composite. Significant features the stocks have in common include:

(1) strongly discordant contacts

(2) large contact aureoles

(3) lack of chilled contacts

(4) massive unfoliated, unlineated "granitic" rocks

(5) association with mineral deposits.

The Silver Bell and Heddleston stocks differ from the others in being hydrothermally altered and very porphyritic.

Stratigraphic reconstruction suggests a maximum depth of emplacement of 4.8 to 6.4 km (Melson, 1964). Thus, they are clearly epizonal (Buddington, 1959).

Extrusive rocks are areally associated with the Tertiary stocks in the Lincoln area (Fig. 1). The Adel Mountain volcanics outcrop to the northeast of the Silver Bell. The Lowland Creek and Elkhorn Mountain volcanics outcrop near and on top of the Boulder batholith. Many authors, including Smede, 1962; and Tillings, 1973; have described these volcanics.

Regional Structure

Five structural events are recognized in the Lincoln area (Melson, 1964). First, the development of a structural basin allowed the accumulation of Belt sediments. In this region, the basin probably formed in response to east-west faults (Winston, oral communication, 1978). Secondly, a late Precambrian (East Kootenai) tilting and low grade metamorphism followed by erosion created low angle unconformities (Melson, 1964). Third, a laramide folding event produced broad open folds like the Black Mountain Syncline (Beirwagen, 1964). Fourth, normal faulting occurred along with emplacement of "granitic" stocks, (this study). Fifth, mid- to late-Tertiary faulting offset Tertiary volcanics and formed present valleys (Melson, 1964).

Regional Distribution of Mineral Deposits

Metallic mineral deposits in the Lincoln area include high temperature disseminated copper and molybdenum deposits, epithermal base metal containing quartz veins, and placer deposits. Of these, the placer deposits were the highest dollar producers.

Several disseminated and/or stockwork "porphyry" copper-molybdenum deposits occur in the greater Lincoln area. These include the Heddleston, Big Ben, Corbin Wicks, Bald Butte, and Silver Bell prospects. The Heddleston property is controlled by Anaconda Company and has been extensively prospected (Miller et al., 1973). The other prospects have not been thoroughly studied; however, they are thought to be porphyry ore deposits. References for these deposits are: Bald Butte (Rostad, 1964), Big Ben (Schafer, 1935).

These porphyry ore deposits lie along the White Cloud-Cannivan Northeast trending Porphyry Molybdenum Belt of Idaho and Montana (Armstrong et al., 1978).

Quartz veins containing base metals have been mined in the Lincoln area since the turn of the century. Pardee and Schrader, 1933, described the mineral deposits of the greater Helena region. Melson, 1964, included a study of the base metal veins near the Silver Bell stock in his study. This paper discusses in detail the characteristics of the quartz veins. Distribution of the epithermal veins around the Silver Bell stock is shown in Figure 2.

FIGURE 2- Epithermal Veins near the Silver Bell (from Melson, 1964)

Tectonic Setting

The tectonic setting of the Silver Bell stock, spacially related intrusive and extrusive rocks, and indeed of the nearby Boulder batholith is an enigma. The Boulder batholith is probably genetically related to the Idaho batholith (Hyndman et al., 1975). This is borne out by radiometric age dates. The Idaho batholith was generated over a paleosubduction zone which was operative during Triassic through late Cretaceous in the Seven Devils region (Burchfiel and Davis, 1975). The subduction zone shifted to the present day Washington-Oregon coast during late Cretaceous or early Tertiary time (Burchfiel and Davis, 1975).

The mid-Tertiary intrusive and extrusive rocks of the Lincoln area postdate this event by approximately 40 million years or so. Therefore, no direct correlation with subduction can be presently made. However, some of the porphyry copper-molybdenum deposits of the southwestern U.S., also postdate the cessation of nearby subduction by 40 million years (Lowell, 1974). Although the exact tectonic mechanism is not known, the igeneous history in this region is similar to those in other porphyry ore deposit districts.

CHAPTER III

DETAILED GEOLOGY

Map Area, Geomorphology

The mapped area is approximately square (3048 meters on a side) and ranges in elevation from 2004m in the northeast to 1524m in the Poorman Creek drainage near the west end of the map area. The north and east facing exposures support heavy lodgepole pine stands and reveal little outcrop. No evidence of glaciation was noted within the map area. In general, outcrop is restricted to ridgetops, stream channels and cuts, and road and cat cups. Approximately 4 percent of the map area exposes bedrock. Therefore, geologic observations are limited. Many crucial areas (contacts, faults, etc.) are the sites for advanced weathering and are not exposed. Information from diamond drill hole cores and rotary drill hole chips were used to augment surface geologic observations.

Float supplemented bedrock observations in areas of little outcrop. Scattered float in upper soil horizons was not found to be a good indicator of bedrock-type. However, within certain constraints, float can be used. I used the following criteria for using float as an indicator of bedrock-type: To be valid the float must meet conditions 1, 2, and 3 or 4.

1. significant amount of float (more than 10 percent of soil)
2. predominance of one rock-type (greater than 90 percent)
3. at or near ridge or top of hill
4. if not 3, then:
   a. compatible with surrounding outcrops
   b. soil at least 50 percent float and
   c. predominance of one rock-type (99 percent).

Geomorphological considerations supplemented bedrock field observations. Straight stream valleys, saddles along ridges, and abrupt breaks in slope were used as guides for locating faults. Poorman Creek, Rochester Gulch and several tributary drainages appear to be controlled by major or minor faults. In general, the ridges are held up by the more resistant hornfels and volcanic rocks while the granite weathers more deeply. Hydrothermal alteration of the granite may be in part responsible for its deeper weathering.

Sedimentary Rocks

Precambrian Belt Supergroup

Four formations of the Belt Supergroup, the Spokane, Empire, Helena, and Snowslip formations, outcrop within the map area and are the only pre-Tertiary sedimentary rocks mapped. Hydrothermal alteration, bleaching, contact metamorphism, and tectonic brecciation followed by silification produced varying degrees of alteration and metamorphism. Upper hornblende hornfels facies metamorphism has developed on the rocks adjacent to the stock. With distance from the stock, contact metamorphism decreases. A contact metamorphic aureole, rarely extending more than .8 km from the outcrop of the stock, forms an irregular outline around the stock (Figure 3). The Belt rocks are folded with dips rarely exceeding 30 degrees, and wavelengths of hundreds of meters.

Descriptions

The stratigraphically lowest formation exposed in the map area is the Spokane Formation. Within the map area, the Spokane is in fault contact with the Helena and underlies the Empire Formation. The bottom of the Spokane is not exposed; however, its thickness in the region is estimated to exceed 1525 meters (Melson, 1964). The Spokane Formation, as exposed in the map area, is a light to medium gray and red argillite with centimeter scale micro couplets of fine horizontally laminated sand and silt grading upward to clay at the couplets top. Metamorphic sericite, 1 to 2 percent in sample 184, occurs in the Spokane Formation within the contact metamorphic aureole.

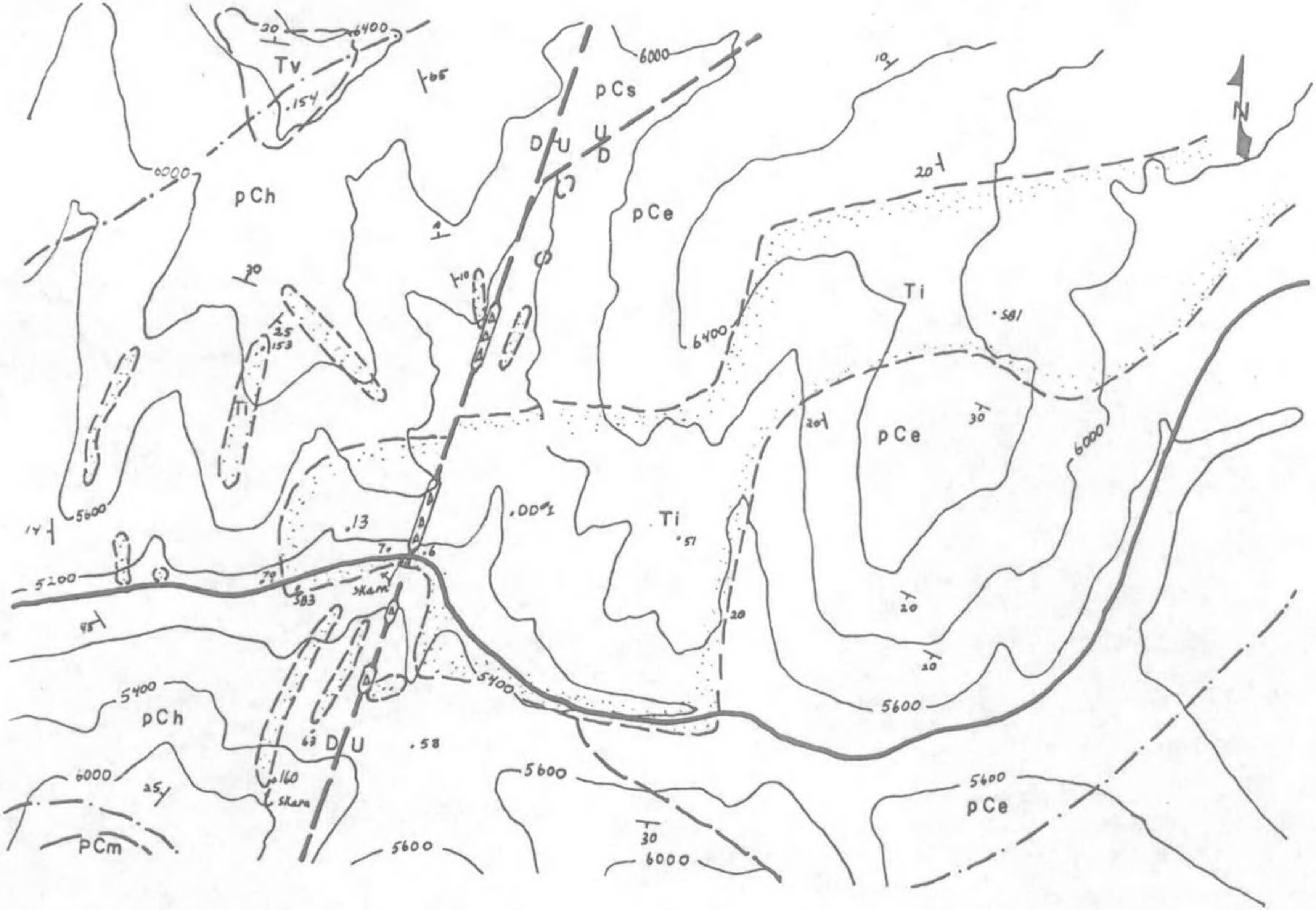
The Empire Formation, which overlies the Spokane Formation, outcrops over a large portion of the east half of the map area (Figure 3). The base of the Empire Formation is placed at the lowest dominantly green argillite beds overlying red or gray argillite. Melson, 1964, estimates that the Empire thickness in this region approximates 305 meters. The Empire, in outcrop, is a green, fine grained, planar

FIGURE 3- GEOLOGIC MAP

LEGEND

Tv	Tertiary volcanics		
Ti	Tertiary intrusives	20	Dip and Strike of beds
pCm	Precambrian Marsh Fm.		Contacts
pCh	Precambrian Helena Fm.		Fault with breccia
pCe	Precambrian Empire Fm.		Limit of contact aureole
pCs	Precambrian Spokane Fm.		Road

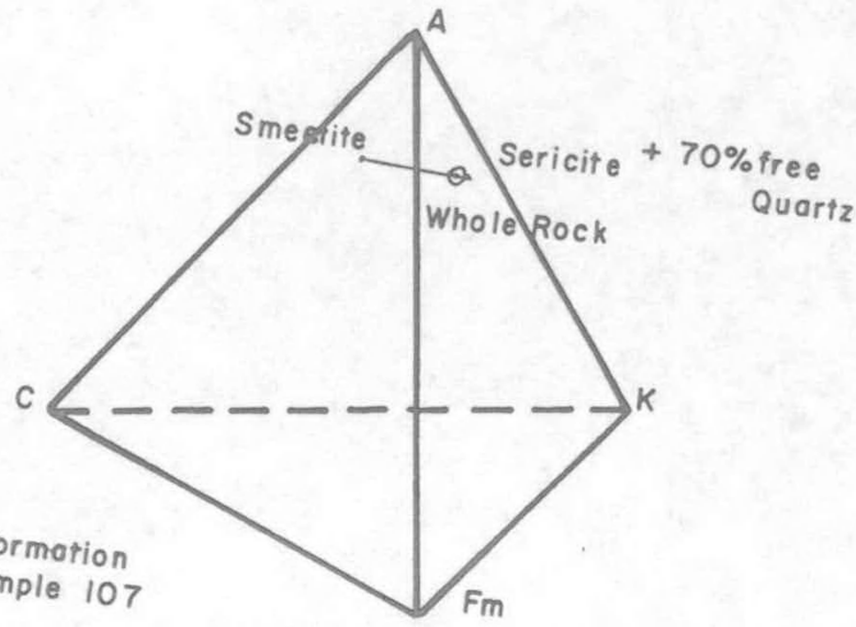
0 .5 1 km.


Tv
pCs
pCh
pCe
Ti
PCm
D U
U D
N
6400
6000
5600
5400
5200
.154
.581
.51
.58
.13
.6
383
.160
Skarn

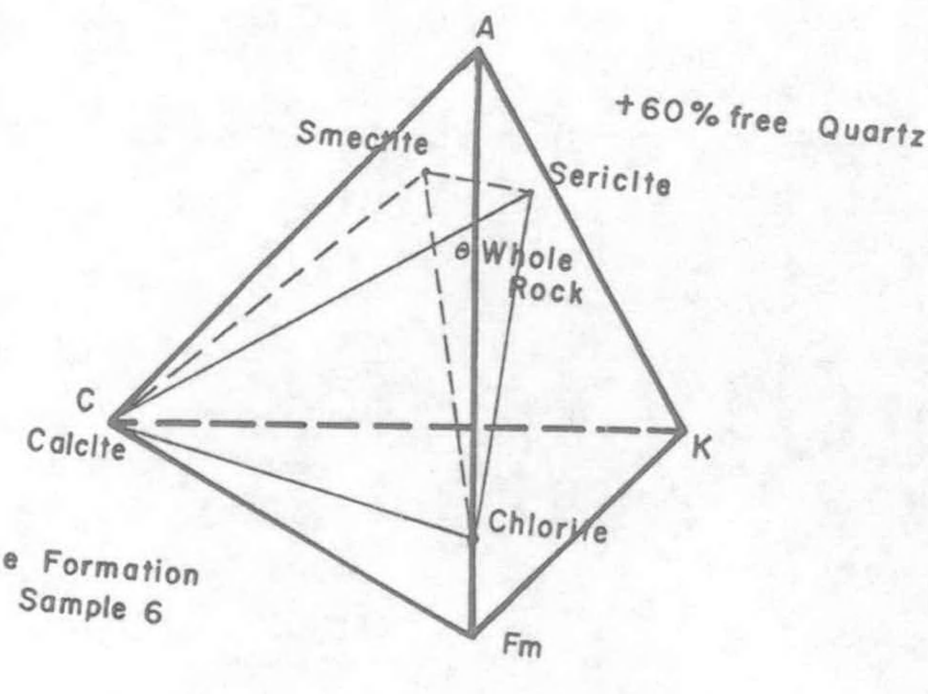
laminated argillite with centimeter scale micro couplets in thin silt laminae grading upward to green chloritic mud laminae. In thin section, the Empire is composed of very fine subangular to subrounded quartz grains with interstial clay and chlorite (sample 79). The metamorphic grade of the Empire Formation depends upon its proximity to the contact of the stock. Near the contact, the Empire outcrops as a white to light green, crudely laminated hornfels. Microscopically, the hornfels contain quartz, sericite, calcite, and more rarely epidote. The larger sericite flakes are aligned with the layering, however, most of the sericite is randomly oriented. This implies a contact metamorphic origin for the finer sericite grains. Sample 104 is Empire Formation from this zone. Its mineralogy corresponds to at least albite-epidote grade metamorphism, (Figure 4a). Further from the contact, metamorphism becomes less intense. Sample 6 contains 60 percent subangular quartz grains, 28 percent very fine randomly oriented sericite grains, 4 percent fine chlorite, and 6 percent calcite concentrated mostly in small quartz calcite veins (Figure 4b). This composition also corresponds to albite-epidote facies metamorphism (Hyndman, 1972). With the exceptions of common quartz-calcite-epidote veins, Ca metasomatism near these veins, and common small calcite pods, the Empire Formation is distinguished from the overlying Helena Formation by lesser amounts of calcium bearing minerals.

Overlying and in fault contact with the Empire Formation is the calcareous Helena Formation. The Helena is exposed over large areas

FIGURE 4- ACFmK DIAGRAMS



A, Empire Formation
Sample 107



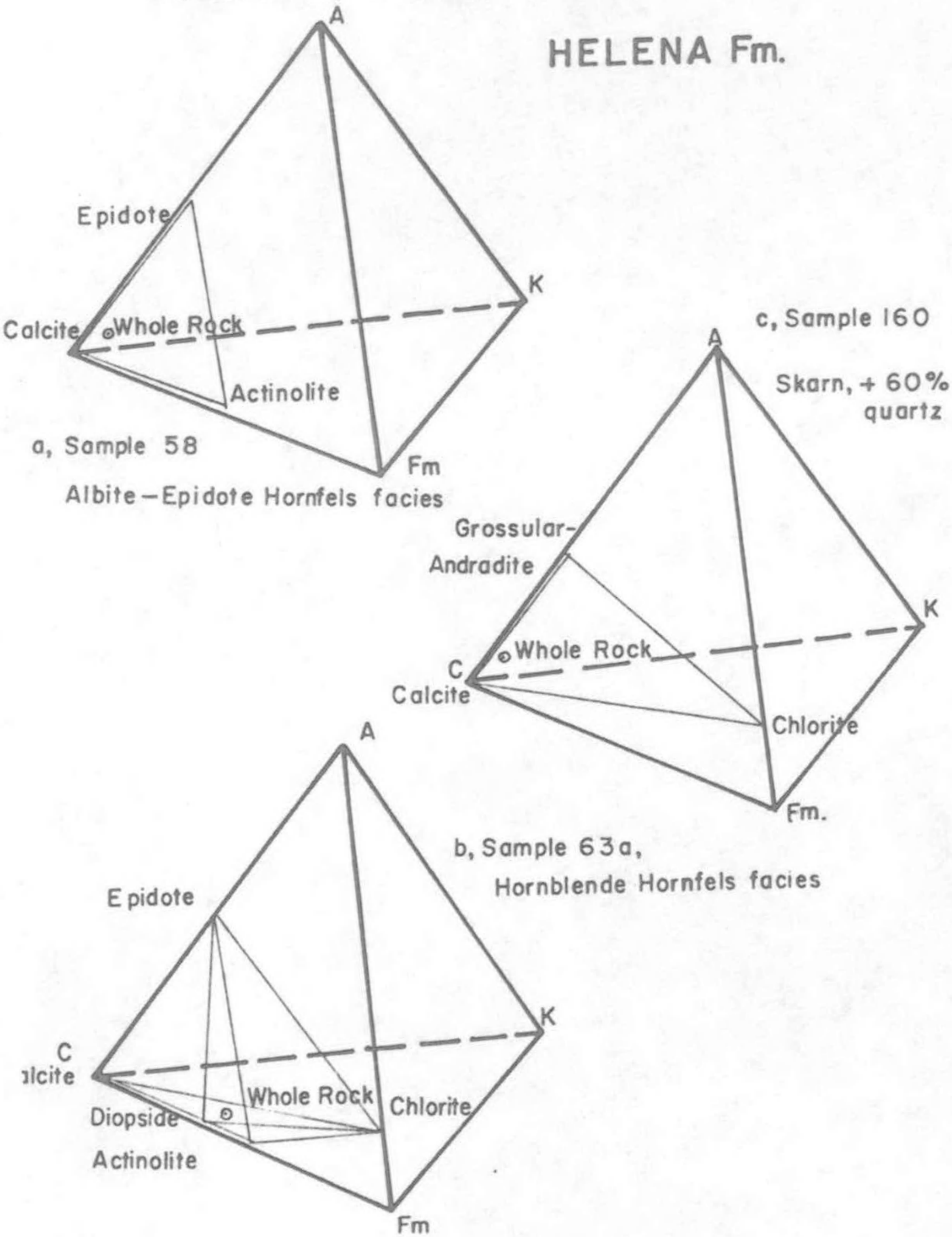
B, Empire Formation
Sample 6

in the southwest and north-central portions of the mapped area (Figure 3). The thickness of 1524-2286 m estimated by Melson, 1964, is compatible with field observations.

The unmetamorphosed Helena Formation outcrops as a dark gray to buff weathering horizontally layered and ripple cross-bedded Quartzite interstratified with calcareous and dolomitic mudstone. Cyclic layering was observed in some outcrops east of the map area. A scour surface marks the base of the cycle. The scour surface is overlaid by a calcareous, medium grained, planar laminated siltstone which grades upward into a more dolomitic, finer grained mudstone with no visible lamination. Near the top of the cycle, "molar tooth" structure and stromatolites become common. The top of the cycle is then marked by a disconformity (scour surface). The typical Helena Formation hand sample is a gray green, planar laminated, calcareous siltstone with 10-80 percent calcite, 10-75 percent subangular to subrounded quartz grains, and 10-50 percent mud (clay) matrix.

Contact metamorphism of these units produced a hornblende hornfels grade hornfels near the contact which grades into albite-epidote facies hornfels with increasing distance from the stock. Sample 58 demonstrates albite-epidote facies contact metamorphism (Figure 5a). Distinct layering from calcite rich to a calcite poorer region is still visible. Calcite, 80 percent has been recrystallized and forms coarse grains where the rock was originally coarser and finer grains where originally fine. Quartz, 10 percent, forms fine anhedral grains with

FIGURE 5 ACFmK DIAGRAMS, HELENA Fm.



sutured grain boundaries. Actinolite, 3 percent, and epidote, 7 percent, form fine needles and medium grained anhedral crystals respectively. This sample outcrops 150m from the nearest intrusive contact.

Nearer the contact, the metamorphic grade increases to the hornblende hornfels facies. The Helena Formation samples from this zone contain garnet, calcite, epidote, diopside, tremolite or actinolite, and minor quartz. Sample 63a contains 45 percent colorless anhedral diopside, 40 percent actinolite needles mostly along fractures and in veins, and minor quartz (5%), chlorite (1%), and pyrite (2%). When plotted on a ACFm diagram (Figure 5b) the diopside-chlorite and actinolite-epidote lines cross. Also, chlorite does not exist stably into the hornblende hornfels facies. Therefore, I believe that chlorite and actinolite occur as retrograde or alteration minerals after a stable assemblage of diopside-epidote-quartz-pyrite was reached.

Another type of metamorphism is exemplifed by sample 160 which is a coarse grained skarn containing andradite-grossular garnets (2%), calcite (15%), chlorite (5%), quartz (65-70%), and specular hematite (1%). This corresponds to hornblende hornfels facies contact metamorphism (Hyndman, 1972). On the ACFmK diagram (Figure 5c) the tie lines do not cross. However, chlorite must be an alteration or retrograde mineral since it cannot exist into the hornblende hornfels facies (Hyndman, 1972). Two localities contain skarns (Figure 3). Both are near the contact of the Helena Formation, the Silver Bell stock, and the Rochester Gulch fault zone. The greater availability of hydrothermal solutions, due to the proximity of the Rochester Gulch quartz breccia zone, increased metasomatism and ion transport and decreased crystal nucleation thus producing a skarn.

The Snowslip Formation overlies the Helena Formation and is 1800-3000m thick in this region (Melson, 1964). The lower contact is defined by the first appearance of a light gray, fine-grained, horizontally laminated siltstone. It outcrops only in the southwestern most portion of the map area and appears unaffected by contact metamorphism.

Phanerozoic Sediments

The only other sediments in the map area are recent gold-bearing unconsolidated sands and gravels. They have been extensively placer mined in the Western-most part of the district. The sediments are restricted to the stream bottoms. No glacial deposits were observed within the map area.

Tertiary Volcanic Rocks

Minor amounts of Tertiary, Oligocene (?), volcanic rocks outcrop along ridge crests within the map area (Figure 3). However, they are quite extensive to the north and northeast of the map area. They unconformably overlie the Belt Supergroup. (Volcanic rocks, not as yet correlated with volcanic rocks in the map area, overlie granitic stocks to the south (Bierwagen, 1964). Two distinct volcanic series, a lower volcanic series and an upper volcanic series, are recognized in this region (Melson, 1964).

Lower Volcanic Series

Sample CM2 is an Andesite from Crater Mountain, north of the map area, which is representative of the lower volcanic series.

Sample CM2

Mineralogy	Percent	Description
Plagioclase, phenocrysts	20	An_{39}
groundmass	60	euhedral laths
Biotite	1	anhedral grains
Chlorite	1	felty
Groundmass	18	dark gray, holocrystalline (?)

Sample CM2 is porphyritic, and plagioclase laths in the groundmass exhibit a distinct flow lineation (Figure 6a). Alteration is very weak and may be deuteric.

Sample 154 is from the lower volcanic series from within the contact aureole of the stock (Figure 3). This sample shows considerable effects of hydrothermal alteration and contact metamorphism. It contains plagioclase phenocrysts (An_{29}) in a felty plagioclase bearing

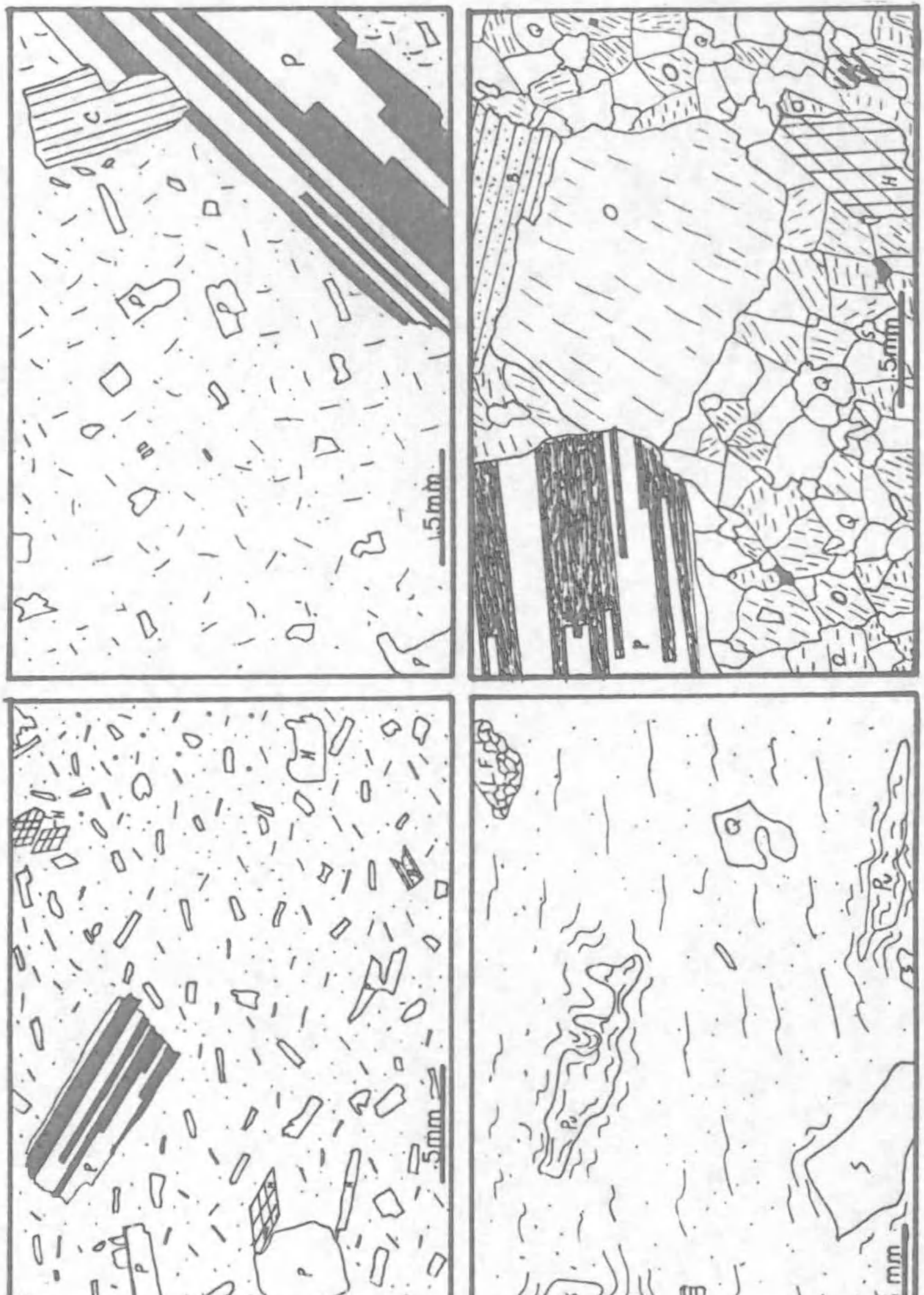
Figure 6

a, Sample CM2
- P - Plagioclase, phenocrysts, An_{39}, normal zonation
- H - Hornblende - subhedral to euhedral crystals
- Groundmass - dark brown, aphanitic, and contains minor biotite, chlorite, and plagioclase laths
- Sample shows a distinct flow lineation

b, Sample 154
- Q - Quartz, anhedral
- P - Plagioclase, subhedral phenocrysts that are highly altered and euhedral laths in groundmass
- C - Chlorite, pseudormorphs after biotite and fine grains in groundmass
- Groundmass, felty intergrowth of secondary chlorite, sericite, calcite, and minor epidote.
- Accessory mineral: apatite

c, Sample CM1
- Q - Quartz phenocrysts, rounded and embayed
- S - Sanadine, subhedral phenocrysts
- B - Subhedral Biotite
- Pu - Collapsed pumice fragments
- F - Lithic fragment, argillite
- Groundmass is dark brown, aphanitic, and contains glass shards, quartz, and minor magnetite and sanadine

d, Sample SB1
- P - Plagioclase, subhedral, zone from An_{29} in the core to An_{22} at the rim
- O - Orthoclase, anhedral-subhedral
- Q - Quartz, anhedral
- B - Biotite, anhedral
- H - Hornblende, anhedral accessory, magnetite, sphene, apatite, zircon, slightly porphyritic
- Alteration minerals: chlorite, epidote, clays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5mm
5 mm

groundmass which has been mostly chloritized. Other alteration minerals include sericite, chlorite, and calcite. Relic structures in the groundmass have been largely destroyed (Figure 6b).

Sample 154

Mineralogy	Percent	Description
Quartz	5	anhedral, undulose
Plagioclase, phenocrysts	20	euhedral
groundmass	30	laths
Groundmass	20	dark gray-black holocrystalline
Chlorite	15	anhedral
Sericite	5	anhedral
Calcite	8	anhedral
Apatite	1	anhedral

The strong alteration of the lower volcanic series within the contact aureole of the stock indicates that the lower volcanic series erupted prior to the emplacement or at least the cooling of the Silver Bell stock.

Upper Volcanic Series

The upper volcanic series is composed of latitic welded tuffs. Sample CM1 is a light brown to buff, trachyoid, latitic welded tuff from Crater Mountain (Figure 6c). It is characteristic of the upper volcanic series and appears identical to samples of the upper volcanic series found within the map area. The absence of hydrothermal alteration or metamorphism within the contact aureole of the stock indicates a post intrusive date for the upper volcanics.

Sample CM1

Mineralogy	Percent	Description
Quartz	2	phenocrysts are rounded and embayed
Sanadine	22	subhedral phenocrysts
Biotite	2	subhedral
Lithic fragments	10	angular argillite and volcanic fragments
Pumice fragments	2	
Groundmass	52	very fine-grained, contains anhedral quartz and sanadine

Intrusive Rocks

"Granitic" rocks of the Silver Bell stock outcrop over 5.1 Km^2 within the map area. Several dikes derived from the stock intrude the country rocks. The stock ranges in composition from porphyritic andesite to porphyritic alkali feldspar granite. I identified six phases using distinctive mineralogical and textural criteria together with field and drill core relationships. The outcrop pattern of these phases is shown on Figure 7. Small mineralogical or textural differences were considered to be variations of the six major phases and were not used to discriminate between phases. However, because some of them may represent distinct phases some similar phases may have been grouped as a single phase.

Silver Bell Phase

The Silver Bell phase is widespread in the eastern part of the map area and extends for approximately 3.2 km farther east. It varies little in composition. However, the quantity of phenocrysts ranges from 5 to 20 percent and their size ranges from 3 cm to approximately groundmass size, 3mm. Hydrothermal alteration is not widespread and is restricted to fractures and fault zones; Copper, lead, and silver-bearing quartz veins crosscut this phase near the Silver Bell Mines. Composition of the Silver Bell phase varies as follows:

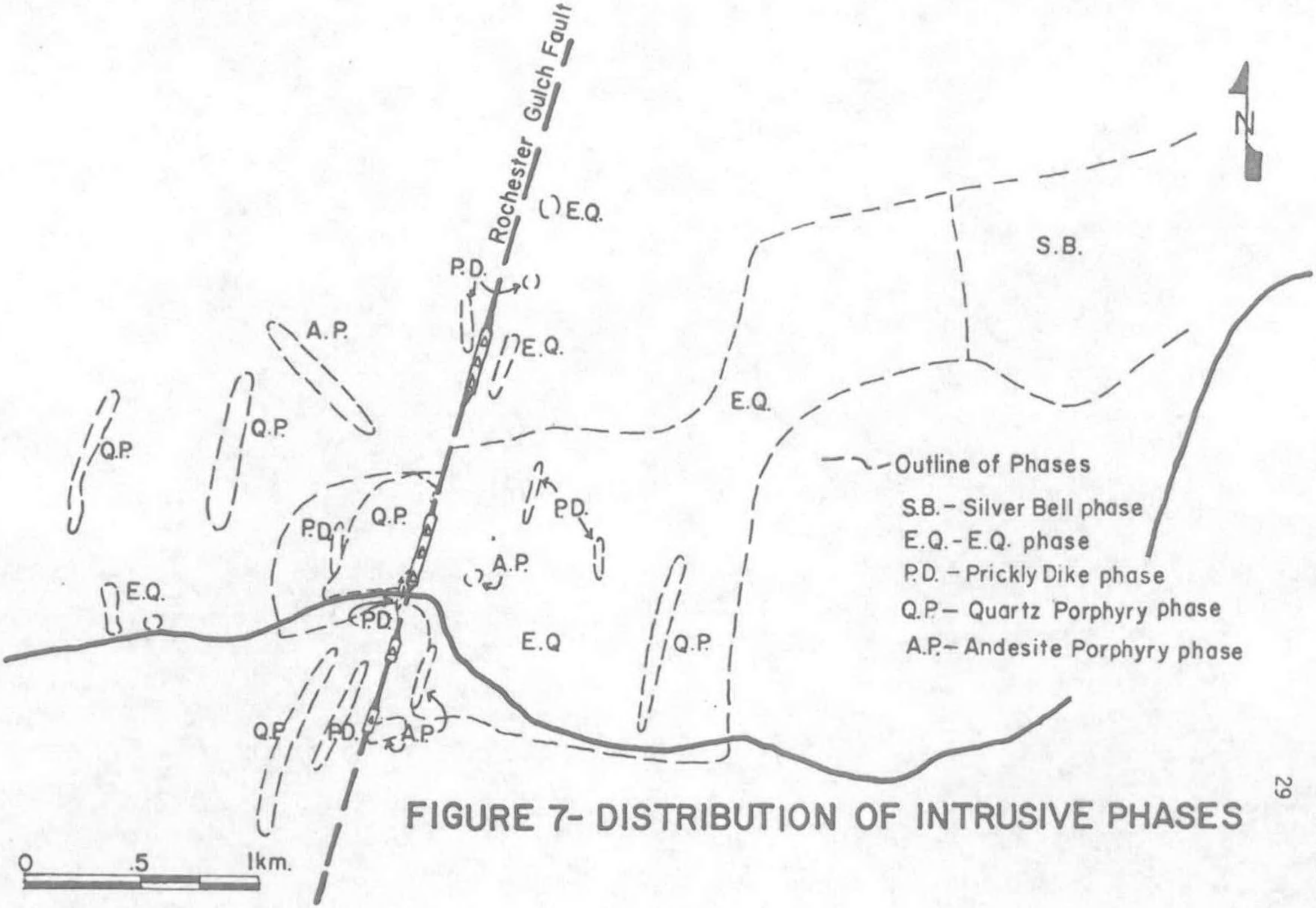


FIGURE 7- DISTRIBUTION OF INTRUSIVE PHASES

Mineral	Range	Mean Percent
Quartz	40-60	45
Plagioclase, phenocrysts	5-20	15
groundmass	5-15	7
Orthoclase, phenocrysts	0-20	5
groundmass	5-25	18
Biotite	tr-5	2
Hornblende	0-2	1

Trace accessory: Zircon, sphene, apatite, rutile

Alteration Minerals: Chlorite, epidote, clay group minerals

Texture: Porphyritic to slightly porphyritic, massive, medium grained

Sample SB1, representative of the Silver Bell phase, is a light pink or gray, medium grained, porphyritic granite (Figure 6d). It has the following composition:

Sample SB1

Mineral	Percent	Description
Plagioclase, phenocrysts	10	subhedral, normal zoned, 1-1.5cm
groundmass	10	anhedral
Orthoclase, phenocrysts	5	euhedral, 1.3cm
groundmass	25	anhedral
Quartz	40	fine grained, anhedral
Biotite	4	no orientation, subhedral
Hornblende	1	euhedral

Accessory minerals: Sphene, apatite, zircon, rutile, magnetite

Alteration minerals: Chlorite, calcite, clay (kaolinite) epidote

Texture: Porphyritic, massive, directionless

The plagioclase phenocrysts are normally zoned from An_{29} at the core to An_{22} at the rim. Some are broken exposing the core against the groundmass. SB1 is weakly propylitically altered. Biotite is partially altered to chlorite. Hornblende and plagioclase are partially altered to calcite, epidote, and chlorite. Clay (kaolinite?) dusts the plagioclase crystals. Orthoclase appears unaffected by alteration.

Alteration of this phase is rarely more intense than in SB1 except near the larger quartz veins. Some samples collected from the Silver

Bell Mine dumps were sericitically altered where in contact with quartz veins. Although, the hydrothermal alteration is ubiquitous in this phase, alteration minerals present total less than a percent away from the epigenetic veins.

E. Q. Phase

The E-Q phase is a widespread, equigranular to slightly porphyritic granitic rock which comprises the bulk of the intrusive rocks within the mapped area. It appears to be crosscut by all other phases with the possible exception of the Silver Bell phase. The relationship between the Silver Bell phase and the E-Q phase is unclear because the contact is nowhere exposed and their outcrop areas do not overlap. Compositionally, they are similar, although the Silver Bell phase contains larger and more abundant phenocrysts of plagioclase and orthoclase. Relative to other phases the E-Q phase was emplaced early. Composition of the Silver Bell phase varies as follows:

Mineral	Range Percent	Mean Percent
Quartz	10-50	25
Plagioclase, phenocrysts	0-10	5
groundmass	10-45	35
Orthoclase	10-40	27
Biotite	0-7	3
Trace accessory minerals: Sphene, zircon, apatite		1

Secondary alteration minerals:		
Sericite	Tr-20	1
Calcite	Tr-5	1
Pyrite	Tr-5	Tr
Epidote, clay, chalopyrite	Tr-4	Tr

Sample SB3 is a typical example of the widespread E-Q phase. It is a light gray to slightly green, medium grained, slightly porphyritic granodiorite (Figure 8a).

Sample SB3

Mineral	Percent	Description
Plagioclase	45	subhedral, An_{22}, normal zonation
Orthoclase	15	anhedral-subhedral
Quartz	30	anhedral
Biotite	5	euhedral
Accessory minerals: Chlorite, magnetite, apatite, sphene		

Alteration intensity ranges from essentially fresh rock to intense phyllic alteration. Propylitic alteration affects most of the phase, however, and phyllic alteration is restricted to vein margins. Sulfide minerals, up to 5 percent pyrite and trace amounts of chalcopyrite, replace magnetite and mafic minerals within the phyllic

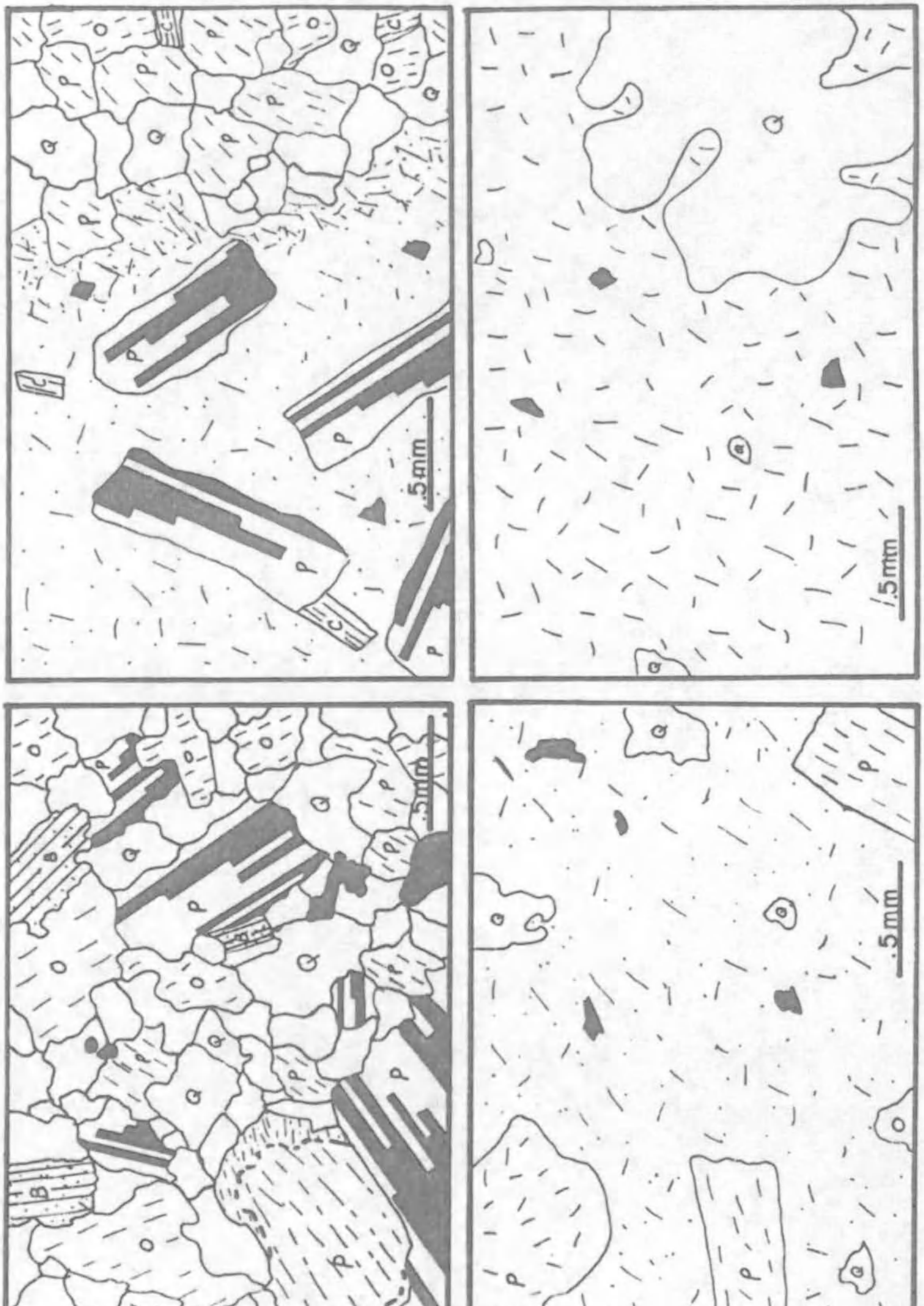
Figure 8

a, Sample SB3
P - Plagioclase - subhedral grains, An_{22} normal zonation
O - Orthoclase - anhedral-subhedral grains
Q - Quartz anhedral grains
B - Biotite subhedral nonaligned grains
Black grains are magnetite
Alteration minerals: chlorite
Accessory minerals: apatite, sphene
Texture, massive, directionless

b, Sample 197.5
P - Plagioclase, on the left phenocrysts of An_{27}, normal zonation and euhedral fine grained laths. On the right, anhedral, highly altered grains
O - Orthoclase - anhedral grains
Q - Quartz - anhedral grains
C - Chlorite - replacing biotite
Accessory minerals: sphene, zircon
Alteration minerals: sericite, calcite, clays, pyrite
This sample shows a contact between the Andesite Porphyry phase on the left and the E.Q. phase on the right. The contact is highly altered and contains appreciable sericite. Chlorite is abundant throughout the sample

c, Sample 51
P - Plagioclase - subhedral phenocrysts which are highly altered and subhedral laths in groundmass
Q - Quartz, phenocrysts which are rounded and embayed
O - Orthoclase - subhedral phenocrysts, highly altered
Groundmass - intergrowths of chlorite, sericite and smectite
Accessory minerals: sphene, zircon, apatite
Texture - massive, directionless

d, Sample 153
Q - Quartz, rounded and embayed phenocrysts
Groundmass contains sericite, quartz and pyrite
Texture - massive, directionless



alteration halos around some veins. Molybdenite and chalcopyrite in small amounts are associated with quartz-orthoclase veins west of the Rochester Gulch fault.

Andesite Porphyry Phase

The volumetrically small andesite porphyry phase outcrops along Poorman Creek east of the Rochester Gulch zone and in Prickly Creek (Figure 7). Several meters of drill core are andesite porphyry also. Contacts between the andesite porphyry and the E-Q phase are generally gradational over .3-2.2m, however, some are very sharp. Compositional variations of the Andesite Porphyry phase are large, (see next page); however, the porphyritic texture is distinctive. Phenocrysts of orthoclase and plagioclase, which are commonly altered to sericite, epidote, chlorite, and calcite, occur in a fine grained, directionless groundmass of quartz, plagioclase laths, orthoclase (?), chlorite, and clay (kaolinite(?)) minerals.

Mineral	Range Percent	Mean Percent
Plagioclase, phenocryst	20-45	37
groundmass	25-30	28
Orthoclase	Tr-20	11
Quartz	Tr-15	5

Accessory minerals: zircon, magnetite, apatite

Mineral	Range Percent	Mean Percent
Secondary Minerals		
Epidote	Tr-7	4
Sericite	Tr-15	8
Chlorite	Tr-8	7
Calcite	Tr-4	3

Sample 197.5 demonstrates the sharp contact relationship between the E-Q phase and the andesite porphyry phase (Figure 8b). The andesite porphyry occurs here as a fine grained, porphyritic, gray green andesite which is propylitically altered.

Sample 197.5

Mineral		Percent	Description
Plagioclase,	phenocrysts	13	An_{27}, normal zonation
	groundmass	8	fine grained, non-aligned laths
Orthoclase		10	anhedral, in groundmass
	groundmass	39	dark gray, holocrystalline, chloritic?

Accessory minerals sphene, zircon
Secondary alteration minerals: calcite, sericite, chlorite, clays (kaolinite), pyrite--32%

All samples of this phase were propylitically altered. Phyllic alteration may be present but has not been recognized. Sulfide mineralization is weak. Minor amounts of pyrite replaces magnetite and biotite in some samples.

Quartz Porphyry Phase

The quartz porphyry phase is largely restricted to the west side of the Rochester Gulch fault zone. It also outcrops in three dikes west of the stock and in one outcrop east of the Rochester Gulch fault (Fig. 7). Its original texture and composition is commonly masked by intense sericitic hydrothermal alteration. Rounded and embayed phenocrysts of quartz are ubiquitous. The groundmass is commonly very fine grained. In outcrop it is white to light green in color and locally red, where weathered, due to the oxidation of pyrite. The composition ranges from sericitically altered granite to a propylitically altered granodiorite.

Mineral	Range Percent	Mean Percent
Quartz	40-80	57
Plagioclase	0-55	5
Orthoclase	0-30	7
Biotite	0-2	Tr

Trace accessory minerals: sphene, zircon, apatite

Mineral	Range Percent	Mean Percent
Secondary alteration minerals		
Sericite	Tr-45	30
Calcite	Tr-5	1
Pyrite	Tr-8	5
Epidote, chalcopyrite, clay (kaolinite + smectite) all tr - 4		

The extreme range in amount of feldspars reflects differences in intensity of feldspar destroying alteration. In some samples, the entire rock has been altered to quartz, sericite, and pyrite destroying the original texture and composition. Other samples have less pervasive alteration.

Sample 51 is representative of the quartz porphyry phase. It is a white, fine grained, propylitically altered granitic with quartz phenocrysts (Fig. 8c).

Sample 51

Mineral	Percent	Description
Quartz, phenocrysts	2	rounded and embayed
groundmass	50	anhedral, very fine
Plagioclase phenocrysts	5 (originally 25)	phenocrysts are highly altered to sericite, clay
Orthoclase phenocrysts	15	subgrained, highly altered to sericite clay
trace accessory minerals: sphene, zircon, apatite		
Secondary minerals		
Sericite	26	anhedral
Chlorite	12	anhedral
Smectite	5	anhedral

Quartz is strongly augmented. Feldspar phenocrysts are altered to chlorite, sericite, and smectite. Chlorite and sericite are alteration products of biotite.

Alteration within the quartz porphyry phase is usually pervasive. As in sample 153 (Figure 8d), secondary sericite, quartz, and pyrite are the main constituents of the rock and the primary texture is lost. Only the rounded and embayed quartz phenocrysts reveal the original rock type. Even where only propylitically altered (sample 51), the alteration is pervasive. Nearly all of the quartz porphyry phase is sericitically altered.

The quartz porphyry phase contains the most disseminated sulfide mineralization. No epithermal vein-type mineralization crosscuts this phase. Pyrite, up to 8 percent, and chalcopyrite, Tr-1 percent, replace mafic minerals, are disseminated, or are concentrated along fractures. Molybdenite is rare and occurs within quartz-orthoclase veins. Mineralization is further discussed below.

Prickly Dike Phase

The Prickly dike phase outcrops in the western and central portions of the map area notably along the west side of the Rochester Gulch fault zone. This phase intrudes both country rocks and the earlier phase of the stock (the E.Q. phase) as dikes. Three distinct dikes, Figure 7, occur west of the Rochester Gulch fault. Compositional variations are large, as tabulated below. However, its porphyritic nature permits positive identification.

Mineral	Range Percent	Mean Percent
Plagioclase, phenocrysts	5-25	18
groundmass	15-45	38
Orthoclase	Tr-15	8
Biotite	1-12	7
Quartz	1-30	28

Accessory minerals: magnetite, sphene, zircon, apatite
Secondary alteration minerals: sericite, chlorite, epidote, clay group 12%

Porphyritic texture is characteristic of the Prickly dike phase. Phenocrysts of plagioclase, orthoclase, and biotite occur in a fine grained groundmass containing quartz, orthoclase, and plagioclase. In most samples, the biotite flakes are aligned reflecting a flow structure. Groundmass typically has poorly aligned felty plagioclase laths.

Sample 13 is representative of this phase (Figure 9a).

Sample 13

Mineral	Percent	Description
Quartz	25	anhedral
Plagioclase, phenocrysts	22	An_{28} 3-8mm euhedral crystals
groundmass	18	poorly aligned euhedral laths
Orthoclase, phenocrysts	4	euhedral-subhedral
groundmass	11	anhedral fine
Biotite	2	flakes, poorly aligned

Accessory minerals: sphene, apatite

Alteration minerals: epidote, chlorite, sericite, clay group minerals 11%

Propylitic alteration affects all samples of the Prickly dike phase studied. Even where this phase borders the sericitic alteration

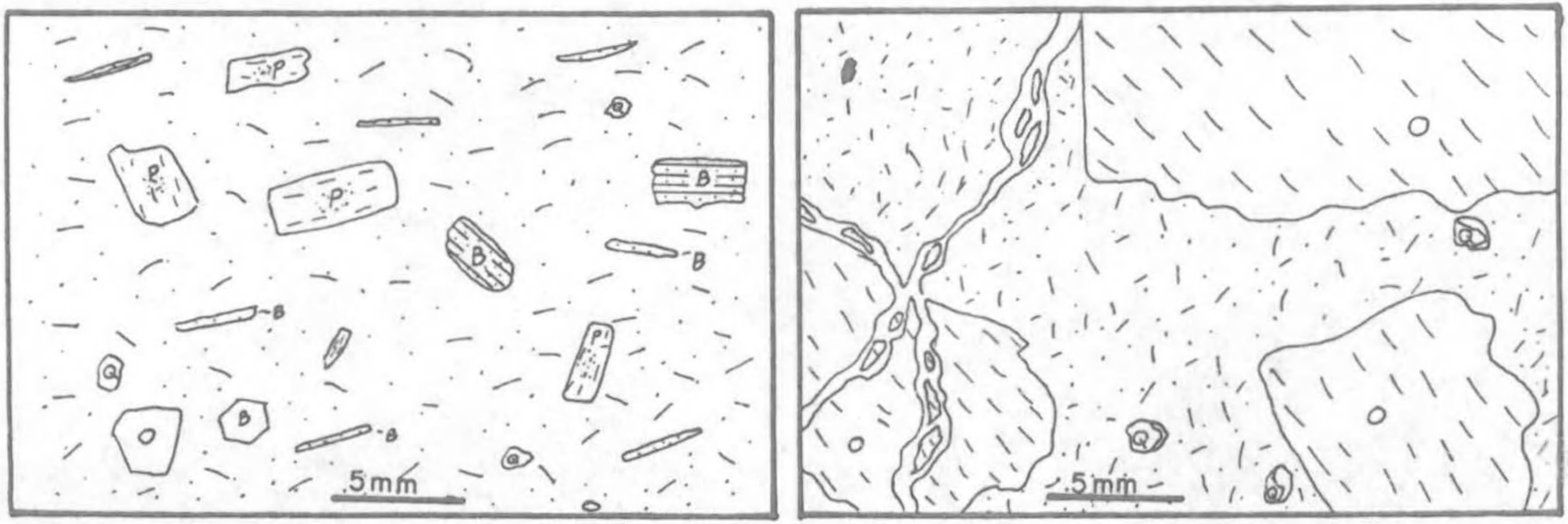


Figure 9

a, Sample 13
P - Plagioclase; phenocrysts, euhedral-subhedral, An_{28}, and poorly aligned euhedral laths
O - Orthoclase - subhedral-euhedral phenocrysts and anhedral grains in groundmass
Q - Quartz - anhedral grains
B - Biotite, euhedral grains
The Biotite grains in this sample show a distinct lineation

b, Sample 533
Q - Quartz - small, augmented
O - Orthoclase phenocrysts, subhedral
Groundmass consists primarily of quartz and sericite

zone (Figures 7, 14), the samples are propylitically altered. Therefore, the Prickly dike phase was intruded later than the hydrothermal event which formed the sericitic alteration zone or the rocks of the Prickly phase were less susceptible to alteration. The later proposal is supported by lower fracture density within the Prickly dike phase than in adjoining sericitically altered rocks. The lower fracture density would reduce the permeability of the rocks thus making them less susceptible to hydrothermal alteration. However, the Prickly dike phase does crosscut the sericitic alteration zone and no mineralization or alteration characteristic of sericitic zone occurs within the dike. Furthermore, contact relationships between the quartz prophyry phase and Prickly dike phase indicate the Prickly dike phase was later. Therefore, I propose that the Prickly dike phase postdates the phase of sericitic alteration.

The Prickly dike phase contains little mineralization. Minor amounts of pyrite replaced magnetite in some locations. Small pyrite-quartz fissure filling veins crosscut these rocks near the Rochester Gulch quartz vein breccia zone.

Alkali Feldspar Granite Phase

The alkali feldspar granite phase only is recognized in dikes in the drill core from DD #1, (Figure 3). It varies in thickness from 1-3.5m and is a very prophyritic, light gray-green granite. It characteristically contains orthoclase phenocrysts 1.4m long in a mostly seriticized groundmass. Sample 522 is representative of this phase (Figure 9b). It is light green, porphyritic, sericitically altered, alkali feldspar granite.

Sample 533

Mineral	Percent	Description
Quartz	45	greatly augmented, fine, anhedral
Orthoclase	35 (originally)	phenocrysts, completely sericitized
Trace accessory minerals:	sphene, apatite	
Secondary alteration minerals		
Sericite	45	fine needles
Smectite	5?	very minor peak on x-ray
Chlorite, calcite	5	anhedral grains

Alteration imparts a pale green color to this sample suggesting the presence of phengitic sericite. This is confirmed by optical and x-ray data. Sericite alteration affects most samples of this phase. However, no mineralization is recognized. The age relationships of this phase are unclear because of its limited exposure. However, it postdates the E.Q. phase.

Structure

Within the map area, I have delineated several sets of faults. Major and minor faults are expressed by topographic breaks, valleys, saddles, breccia zones, or by displacement of country rocks. A major north-south fault zone, the Rochester Gulch fault, outcrops as a quartz vein breccia containing argillite fragments. The major inferred faults are the Poorman Creek, and Prickly Creek faults (Figure 10).

Early N45E and N45W faults are crosscut by major N-S and E-W faults and are the most subtly expressed faults. They control minor tributary drainages in the eastern part of the map area. The presence of NE faulting was confirmed by examination of a cut east of Rochester Gulch (M. Himes, per. comm., 1977).

The Rochester Gulch fault trends N10E, offsets all rocks intersected in the map area, and extends several kilometers north and south of Poorman Creek (Figures 3, 10). On the surface, it is expressed by a quartz vein breccia zone, discussed below. The fault brings the Empire and Spokane formations on the east up relatively to the Helena on the west. Where the Spokane Formation is in fault contact with the Helena Formation in Rochester Gulch, there is at least 330 meters of west side down displacement along the fault. Displacement decreases to the north and south and disappears below Tertiary basin fill (Melson, 1964). Many smaller NE and NW faults terminate in the Rochester Gulch fault and apparently do not offet it suggesting the

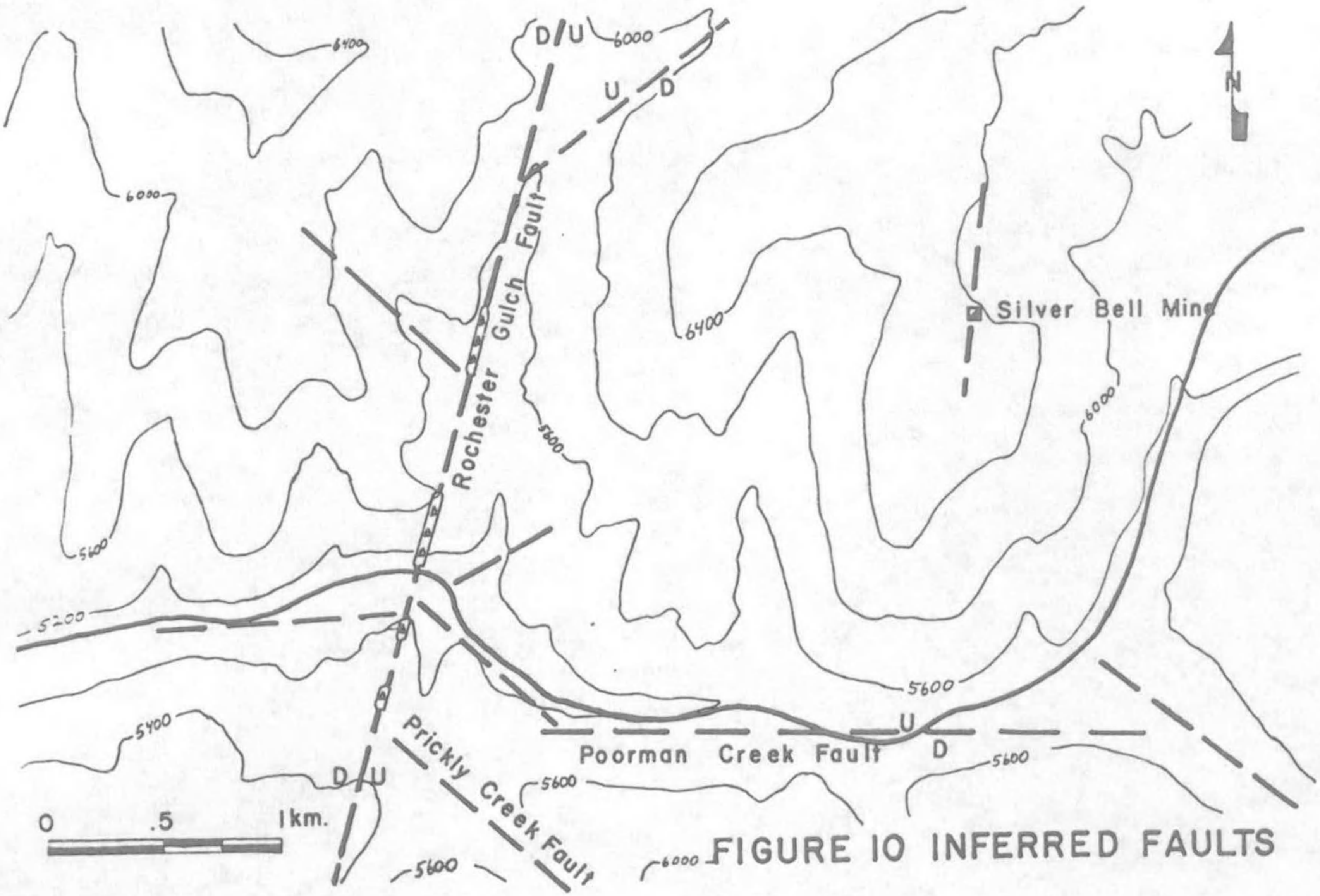


FIGURE 10 INFERRED FAULTS

Rochester Gulch fault postdates the NE and NW faults.

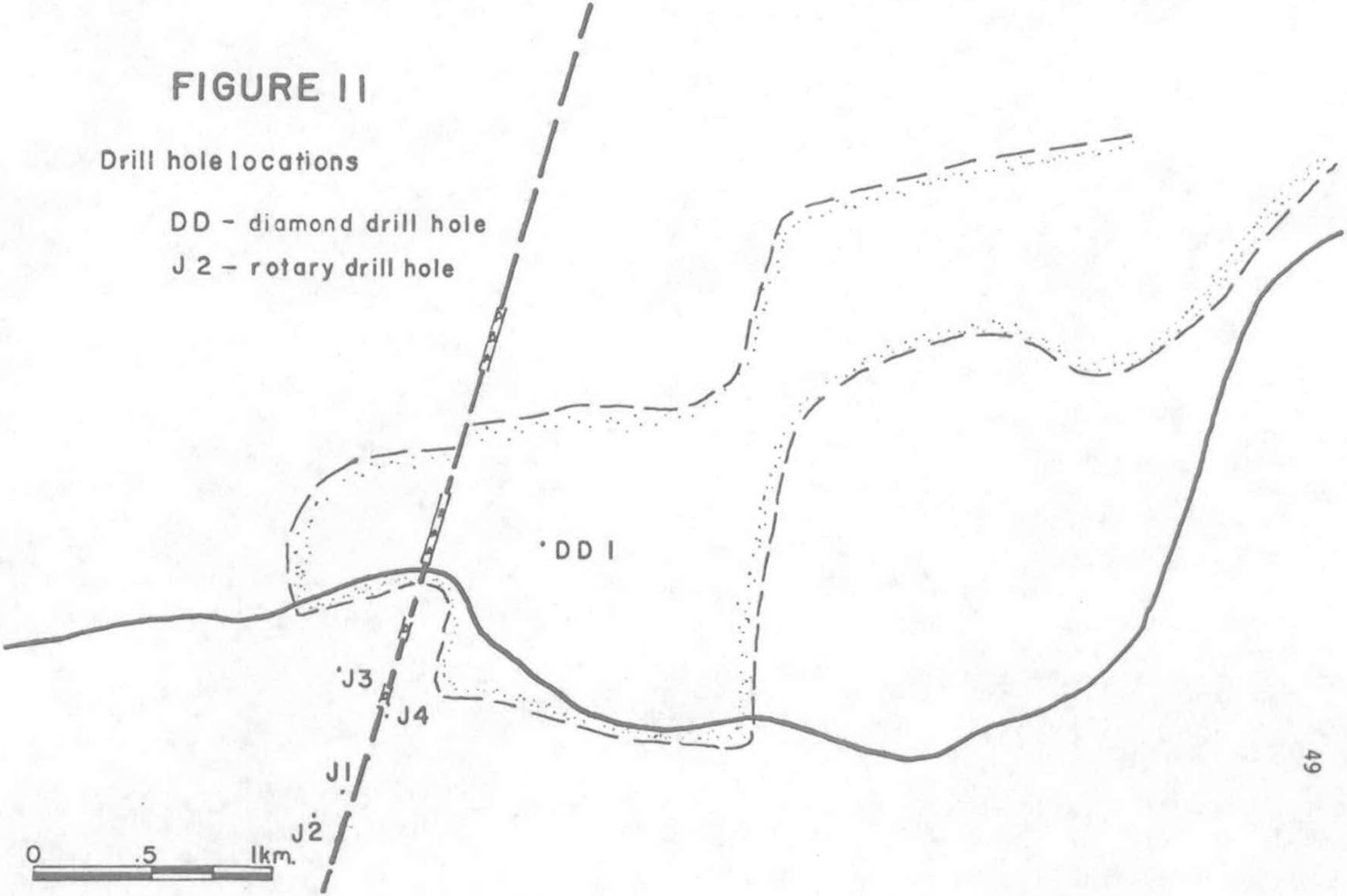
An inferred fault with probable south side down dip slip displacement is the east-west Poorman Creek fault. Two lines of evidence support the existence of this fault. South side down displacement along Poorman Creek is suggested by the abrupt southern limit of the stock along Poorman Creek (Figure 3). None of the four rotary drill holes, up to 150m deep, drilled south of Poorman Creek (Figure 11) intersected the stock. An independent line of evidence supporting the existance of the Poorman Creek fault is an abrupt change in character of the quartz vein breccia zone where it crosses the Poorman Creek fault. North of Poorman Creek the resistant quartz vein averages 3-15 meters wide while directly south of the creek it does not outcrop suggesting it is absent. Farther south (.5 km) small outcrops of quartz breccia along the proposed extension of the fault indicate the Rochester Gulch fault does continue on strike across the Poorman Creek fault. However, the relationship between the Rochester Gulch fault and the inferred Poorman Creek fault is not as clear. Although the Rochester Gulch fault is not laterally offset, the decrease in width and pervasiveness of the quartz vein breccia to the south of the Poorman Creek drainage (Figure 10), infers Poorman Creek fault is later, vertically offsetting the Rochester Gulch quartz vein zone. Many drainages within the map area have a N10E trend indicating the pervasive nature of this direction of faulting and jointing.

FIGURE 11

Drill hole locations

DD - diamond drill hole

J 2 - rotary drill hole



Therefore, crosscutting relationships imply that the earliest faults are the N45W and N45E faults. Displacement is unknown and I suggest it is minor because the Belt units show no significant offset. The N10E (Rochester Gulch) direction of faulting crosscuts the NW and NE faults. The inferred Poorman Creek fault represents the final stage of fault movement.

Quartz Vein Breccia Zone

Within the Rochester Gulch fault zone is a quartz vein breccia which strikes N10E and dips 75 to 90 degrees west. It continues sporadically for about 2 km north and 1.6 km south of Poorman Creek road and contains breccia fragments of white to light green Empire hornfels in a quartz matrix. The Empire fragments are typically sericitically altered (see Sample 107). Commonly, the quartz is vuggy and shows open space filling textures. The vein contains less than 1 percent total sulfides. The quartz vein breccia is best observed just north of the Poorman Creek road and in Rochester Gulch. Here, outcrops of highly fractured but not displaced Empire formation occur at the outside edges of the breccia zone (Figure 12). Open space filling quartz veins fill the fractures and increase in size and number toward the fault center. At the point where the quartz veins exceed 50 percent of the outcrop, the hornfels fragments are displaced from their original position. However, the fragments would fit together if the quartz vein material were removed. Closer to the center,

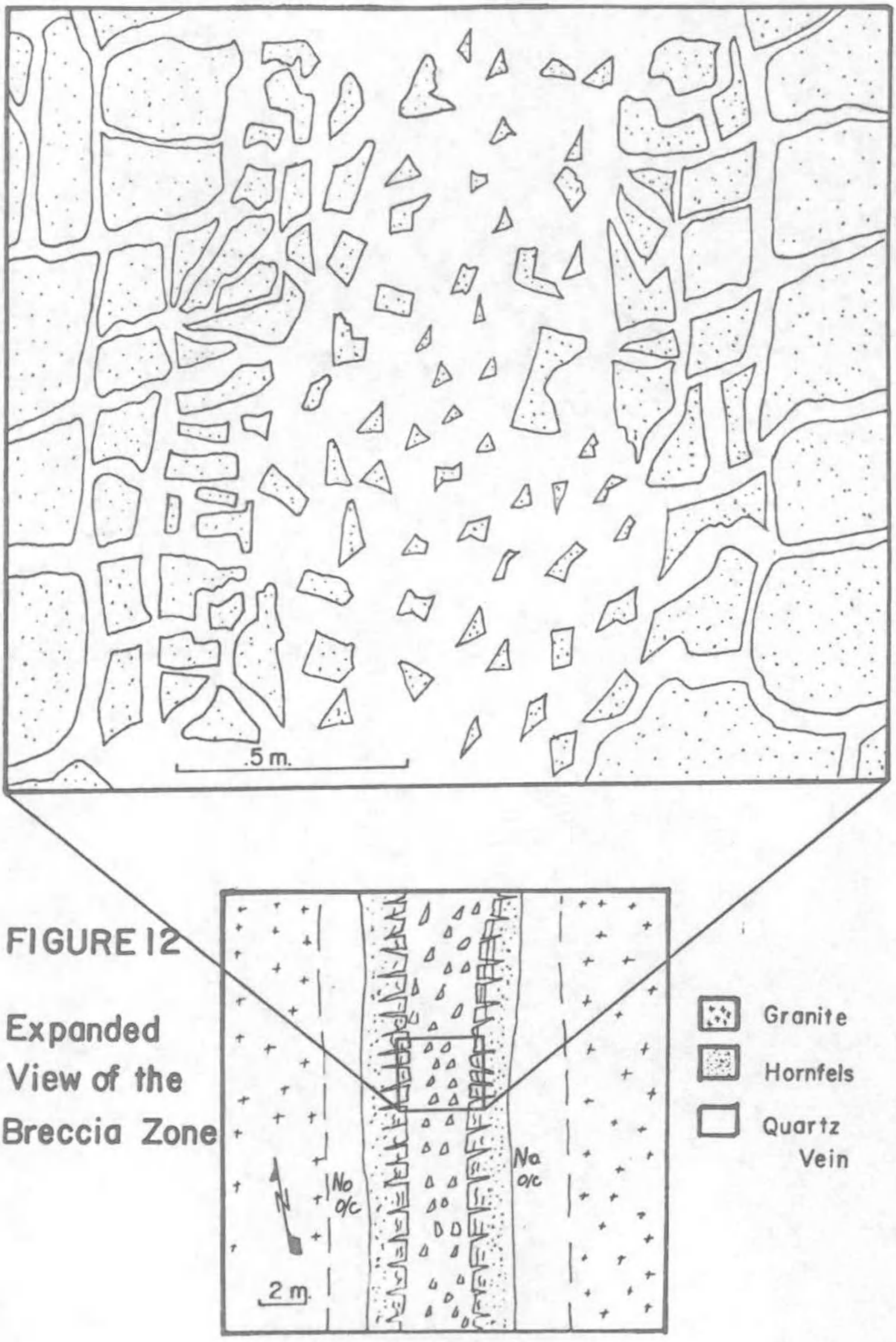


FIGURE 12

Expanded View of the Breccia Zone

movement and rotation of the breccia fragments becomes extreme. The fragments float in a quartz vein matrix. I recognized at least four and as many as twelve filling episodes on the basis of inward growing, open space filling quartz veins within the breccia zone. The quartz vein breccia zone weathers resistantly to form ridges up to 15 m wide in places.

The quartz vein breccia zone does not change in character as it crosscuts the main body of the stock. It contains hornfels fragments in a quartz matrix grading outward to solid Empire hornfels even where it is apparently within the stock. Possible explanations for this feature are discussed in Chapter IV.

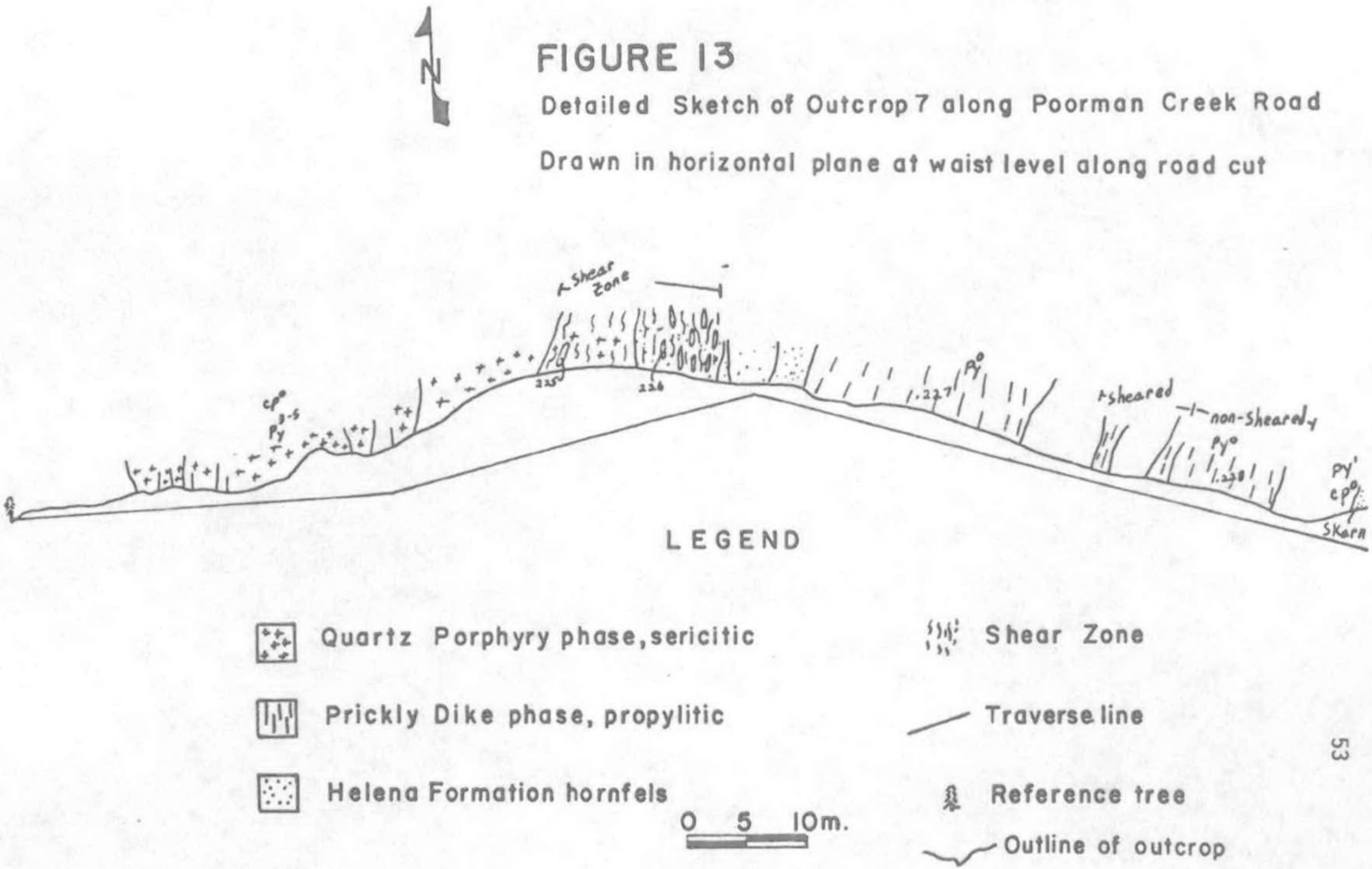
The sequence of events within the Rochester Gulch Breccia Zone are not completely understood. Granite fragments in a granitic and siliceous matrix, samples 222A, 222B, respectively, outcrop south of Poorman Creek (Figure 3). This indicates movement after crystallization of a granitic intrusive. However, no major offset of the "granitic" rocks has been observed along the Rochester Gulch fault. Therefore, I suggest the major movement along the Rochester Gulch fault was prior to and during the emplacement of the stock. Minor displacement along the fault after the emplacement of the stock is suggested by N10E trending fractures and gouge zones within the stock.

Outcrop 7, Figure 13, is a road cut along Poorman Creek road which contains information concerning the timing of Rochester Gulch fault, the hydrothermal alteration, and the emplacement of the

FIGURE 13

Detailed Sketch of Outcrop 7 along Poorman Creek Road

Drawn in horizontal plane at waist level along road cut



Prickly dike phase. The shear zone between the Helena hornfels and the phyllically altered granite suggests the contact is a tectonic one. The sense of displacement is uncertain but the most likely displacement would be west side relatively up. However, this conflicts with the sense of displacement of the Rochester Gulch fault. The sharp, non sheared but also non exposed, contact between the Prickly dike phase and the hornfels suggests the dike intruded the hornfels. The Prickly dike phase does have a local shear zone within it which suggests some post intrusive fault movement. The hornfels near the Rochester Gulch quartz vein breccia zone are skarnified and contain pyrite and chalcopyrite while the quartz vein breccia contains none. The quartz porphyry phase exposed is phyllically altered while the Prickly dike phase shows only porphylitic alteration. The most likely scenario begins with the intrusion of the quartz porphyry phase. This phase carried the hydrothermal solutions which formed the alteration and mineralization zones. Secondly, fault movement along the Rochester Gulch and parallel zones then produced shear zones and tectonically emplaced the phyllic zone against the Helena hornfels. Thirdly, the Prickly dike phase was then intruded along this zone of weakness. More fault movement and the development of propylitic alteration and the quartz vein breccia occurred during the late (cooler) stages of hydrothermal alteration.

Alteration

Hydrothermal alteration is widespread throughout the stock and contact metamorphic zone. Alteration mineralogy and intensity define distinct mineral assemblages. The most intense hydrothermal alteration is restricted to the late stage quartz porphyry intrusive and major structures such as the Rochester Gulch fault zone. X-ray diffraction studies combined with optical microscopy are necessary to identify major sheet silicates in the altered zones.

Alteration Mineralogy

Predominant alteration (secondary) minerals include quartz, sheet silicates, calcite, the epidote group, orthoclase, albite, pyrite, chalcopyrite, and rarely molybdenite. Secondary quartz, the most abundant alteration mineral, strongly augments primary quartz in intensely altered rocks. Of the sheet silicates, the following are present in order of decreasing abundance; chlorite, sericite, kaolinite and smectite. Sericite has two common meanings to petrologists. It is used widely as a textural term to describe fine-grained secondary white micaeous silicates. The other meaning defines a mineral with the same chemistry and structure as muscovite. "Sericite" is used here to describe a fine-grained, secondary, dioctrahedral, 2 m. mica, which has 10 Å peaks on an X-ray diffraction pattern and does not expand upon glycolation. Its chemistry, structure, and optical properties are inferred to be identical to muscovite. Chlorite, kaolinite, and smectite were also identified by X-ray diffraction techniques. The epidote group minerals (including epidote and clinozoisite), calcite, orthoclase and albite as well as the sulfides were identified optically. Whether albite occurs as a primary or secondary mineral is not known. Relatively unaltered samples contain plagioclase An_{20} while a few samples from altered zones were An_5. Textural evidence is conflicting. Some albite crystals appear to be primary while others show the patchy texture of secondary albite.

Alteration Mineral Assemblages

Secondary alteration mineral assemblages occur within the map area. These mineral assemblages are distinct mineral packages which grade into one another over large distances and are thereby zoned with respect to the stock. Alteration zones are compressed around quartz veins where the sericitic halo extends only 1-3 meters from the vein. Recent discussions in the literature propose that the mineral assemblages form by either metamorphism or alteration due to changes in hydrothermal solution temperature and chemistry (Burnham, 1962; Lowell and Guilbert, 1970, 1974). In this area, the strong control of the mineral assemblages by fractures and faults indicates a hydrothermal origin for the mineral assemblages. Identification of equilibrium mineral assemblages is difficult because the alteration events were too brief to allow all reactions within the system to go to completion. Therefore, equilibrium assemblages were extrapolated on the basis of textural evidence and my interpretations. The equilibrium minerals at the Silver Bell, Table 1, are similar to those described at the Kalamazoo deposit by Lowell and Guilbert, 1970, Table 2. This similarity suggests a common hydrothermal origin for the alteration assemblages in both the Kalamazoo and Silver Bell deposits.

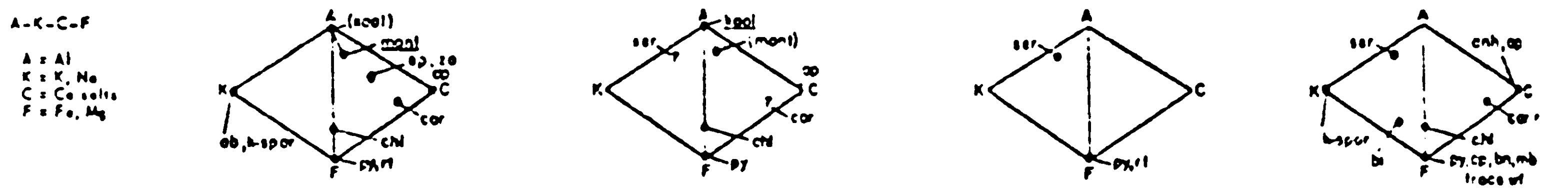
Propylitic alteration is the most widespread alteration assemblage and affects all intrusive rocks in the area not affected by more intense alteration. The stable assemblage consists of quartz, chlorite, calcite, and epidote group minerals and to a lesser extent sericite, kaolinite pyrite and chalcopyrite. Not all of these minerals need be present. Their presence depends to some extent upon the availability of their chemical constituents. Within this assemblage (zone) primary quartz is stable and may be slightly augmented. Orthoclase is stable or may be partially altered to sericite. Plagioclase is unstable and is altering to or aiding in the formation of calcite, epidote or clinozoisite, chlorite and sericite. Biotite and hornblende are unstable and alter to chlorite, epidote and to a minor extent kaolinite. Pyrite and chalcopyrite may replace mafics. Quartz, calcite, epidote, and pyrite veins are common and alteration is locally more intense near them. As noted, secondary minerals of more intense alteration assemblages (sericite and clays) commonly occur in minor amounts in the propylitic zone. Thus, boundaries between alteration zones are gradational. The boundaries will be discussed in detail below. The

Table 1. Summary of hydrothermal alteration assemblages at the Silver Bell

Fresh Qm, Porphyries	Propylitic Zone I	Propylitic Zone II	Phyllic Zone
Quartz	No change	Slightly augmented	Augmented
Orthoclase	No change	Minor sericite	Sericitized
Plagioclase (An_{25-45})	Trace kaolinite, flakes of sericite, chlorite	Kaolinite, smectite, chlorite	Sericitized
Biotite	Chlorite	Chlorite	Sericite, rutile(?) pyrite
Hornblende	Epidote, calcite	Chlorite, epidote calcite	
Magnetite	Trace pyrite	Pyritized	Pyritized

Table 2. Summary of hydrothermal alteration assemblages at San Manuel--Kalamazoo. (Lowell and Guilbert, 1970)

FRESH QM, PORPHYRIES	PROPYLITIC ZONE	ARGILLIC ZONE	PHYLLIC ZONE	POTASSIC ZONE
Quartz	No Change	Augmented	Augmented	Augmented
Orthoclase-Microcline	No Change	Flecked with Sericite	Sericitized	Recrystallized in part replaced by alteration K-feldspar-quartz
Plagioclase ($An_{35.45}$)	Tr.Mont, flecks & granules ep, zois, car, chlorite, kaol.	Montmorillonite Kaolin	Sericitized	Fresh to completely replaced by brn-grn alt'n biotite, K-spar ser.
Biotite	Chlor, zois, car, leucoxene	Chloritized, + leucoxene, qtz	Sericite, pyrite, rutile	Fresh or recrystallized to sucrose brn-grn granules, + chlorite
Hornblende	Ep, car, mont, chlor (2 types)	Chloritized	Sericite, pyrite, (rutile?)	Biotite, ± chlorite, rutile
Magnetite	trace pyrite	Pyritized	Pyritized	Pyritized



distinction between the propylitic alteration and deuteric alteration is unclear. Both originate from the same process of late stage hydrothermal solution release from a crystallizing magma and both produce similar mineralogy. I feel the distinction is one of scale. Propylitic alteration is more prevasive whereas deuteric alteration is generally weak and restricted to fractures.

I recognize two zones within the porpylitic alteration assemblage which reflect different intensities of alteration. Propylitic zone I is the lower intensity assemblage which involves only hydrogen metasomatism. Chlorite occurs as a replacement of biotite and hornblende. Calcite and rarely epidote form as alteration products of plagioclase. Orthoclase is stable. Quartz is not augmented. Sample SB1 is from the propylitic zone I. Propylitic zone II is a higher intensity zone which contains appreciable metasomatism and leaching. Chlorite replaces not only biotite and hornblende, but also plagioclase. The metasomatism becomes obvious upon examination of the chemical reactions. The chloritization of biotite requires only the exchange of the hydrogen ion for other cations.

$$2K\,(Mg,\,Fe)_3\,AlSi_3O_{10}(OH)_2 + 4H^+ = Al(MgFe)_5\,AlSi_3O_{10}(OH)_8 + (MgFe^{+2}) + 2K^+ + 3\,SiO_2$$

However, the chloritization of albite requires the introduction of

Mg^{+2}, Fe^{+2+3}, and Al^{+3} as well as H_2O.

$$2NaAlSi_3O_8 + 4\ (MgFe)^{+2} + 2\ (FeAl)^{+3} + 10H_2O =$$

$$(MgFe)^{+2}_4\ (FeAl)_2\ Si_2\ O_{10}(OH)_8 = 4SiO_2 + 2Na^+ + 12H^+$$

Thus it is evident that more complex metasomatic reactions are required for the propylitic zone II reactions. Also, within zone II, orthoclase is unstable and alters to sericite. Quartz is augmented by secondary quartz probably because of the release of quartz by the above chloritization reactions. Sample 51 shows the features of the propylitic zone II. Argillic assemblage mineralogy is not present in sufficient amounts in any samples investigated to justify classifying the rock as argillic. Kaolinite, up to 5 percent, and smectite, in trace amounts, have been identified by X-ray diffraction; however, either propylitic or sericitic assemblage minerals always dominated. Therefore, no argillic zone has been established. The significance of this is discussed in Chapter IV.

Sericitic (phyllic) alteration is the most intense alteration noted in the area. The assemblage consists of quartz, pyrite, and sericite. The original quartz is stable and may be greatly augmented. Sericite is the second most abundant mineral in this assemblage comprising 5 to 40 percent of the rock. It generally is both disseminated throughout the rock and forms pseudormorphs after relic phenocrysts of feldspars.

Pyrite (3-8%) occurs as disseminated grains, concentrated along fractures, or replacing mafics. Chalcopyrite, and molybdenite are other common sulfides. Smectite is rare in this assemblage. Secondary minerals of the propylitic zone are absent in this assemblage.

Sample 153 is characteristic of this zone (Fig. 8d). Quartz phenocrysts (5%) are rounded and embayed. Quartz occurs as anhedral grains in the groundmass and is strongly augmented by secondary quartz (60%). Sericite occurs as very fine, felty flakes in the groundmass and as pseudormorphs after biotite and feldspar. Trace amounts of clay (kaolinite) are confirmed by X-ray data. Pyrite (1%) is disseminated and occurs along fractures.

Potassic Alteration

No zone of potassic alteration was observed. However, the development of secondary orthoclase near quartz-orthoclase veins was noted both in outcrop and drill core. Secondary biotite later altered to chlorite is suspected in one location of drill core (Sample 459.5). This rock appears to be recrystallized and foliated. Chlorite pesudomorphs after biotite occur in the foliated part. I believe the biotite was secondary and obtained a foliation during recrystallization of the granite. The chlorite then replaced the biotite during a later propylitic event.

Alteration Zone Boundaries

The lower boundary of the propylitic alteration zone is taken to be those rocks containing measurable amounts of secondary minerals such as chlorite, calcite, and/or epidote group minerals. The rock generally has a light green tint. The transition between the propylitic and sericitic alteration is considered, in this study, to be the point where the quantity of secondary smectite-sericite exceeds that of all alteration minerals of the propylitic zone. Within the sericitic zone, the rocks are white (or red, where oxidized), very fine grained, and are composed primarily of quartz, sericite, and pyrite. Remnant primary minerals include quartz, sphene, apatite, and zircon. As previously mentioned, no argillic zone has been observed.

Alteration Zonation

The areal distribution of the alteration zones is shown on Figure 14. Near the center of the area is a small sericitic alteration zone which has an irregular outline. This zone roughly corresponds to the outcrop pattern of the quartz porphyry phase (Fig 7). Outward and surrounding this zone is the propylitic alteration zone. This essentially takes in the entirety of the stock exclusive of the phyllic zone. Note that no argillic zone exists. This will be discussed further in Chapter IV. An interpreted cross-section of the alteration patterns along with mineralization zonation is shown on Figure 15. Note the similarities of alteration and mineralization zonation described by Lowell and

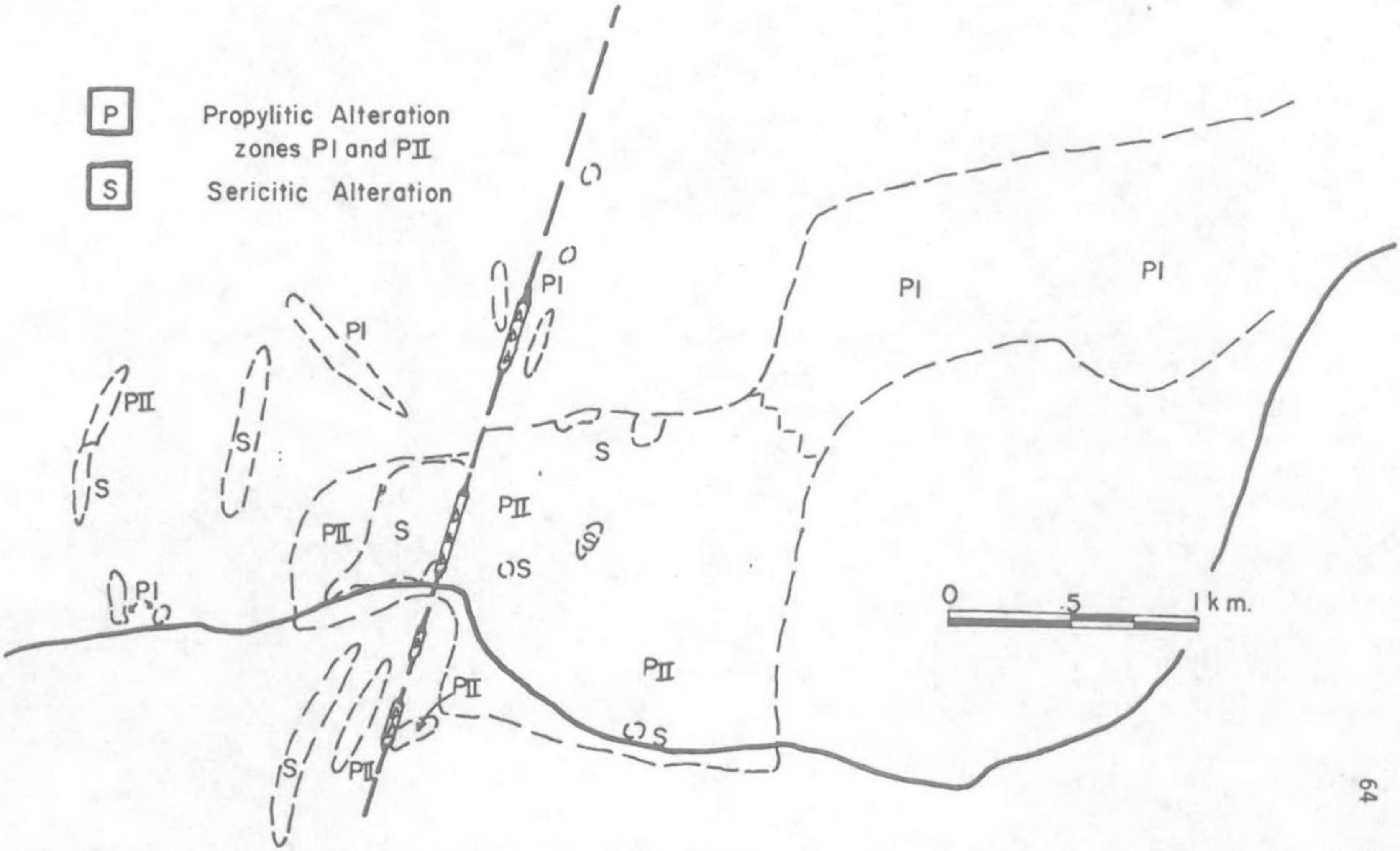


FIGURE 14 – DISTRIBUTION OF ALTERATION TYPES

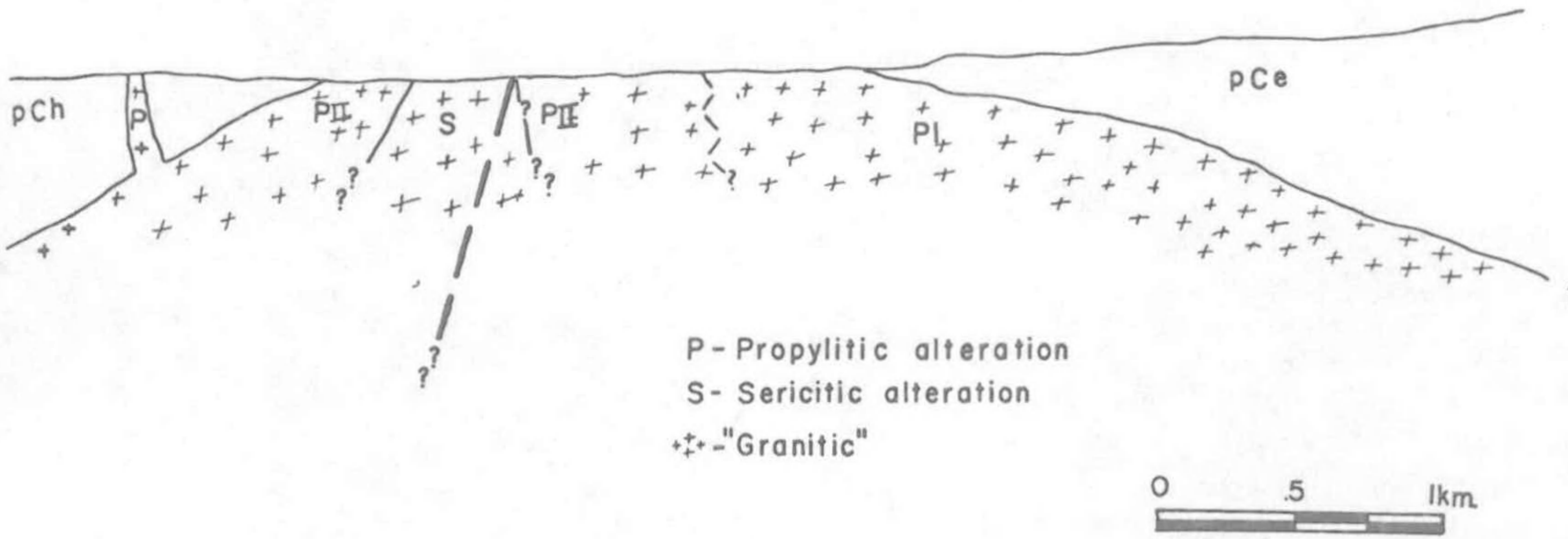
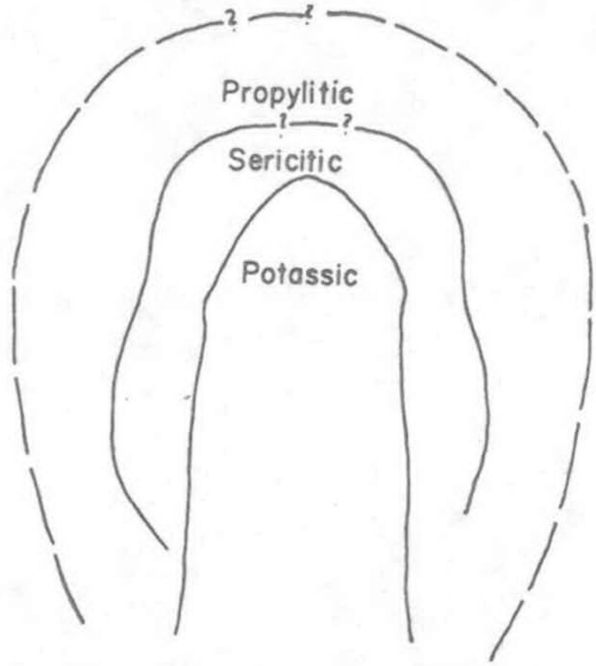


FIGURE 15 - SCHEMATIC CROSS-SECTION OF ALTERATION

Drawn along the Poorman Creek Road, looking North

FIGURE 16

SCHEMATIC CROSS-SECTION OF ALTERATION AT THE KALAMAZOO ORE BODY



from LOWELL AND GUILBERT, 1970

Guilbert, 1970, for a typical porphyry copper deposit (Fig. 16). The significance of this is described in Chapter V.

Mineralization

Two distinct types of mineralization are recognizable within the district and are not found together. One is pyrite and chalcopyrite-bearing epithermal quartz veins. These crosscut all rocks within the map area, and, except for the phyllic alteration zone, outcrop in all alteration zones.

The other type of mineralization is disseminated pyrite and chalcopyrite, and rarely molybdenite, along fractures. The disseminated mineralization is restricted to the phyllic alteration zone. The zonation of mineralization is shown in Figure 17.

Base Metal Containing Quartz Veins

Pyrite, chalcopyrite, and other base metal sulfides occur with quartz and calcite in epigenetic, epithermal fissure filling quartz veins. They fill tension fractures and dip between 50 and 90 degrees although rarely some are horizontal. The veins most commonly follow one of the predominant fracture trends; N10E, N45E, or N90W. The veins are rarely traceable for more than 300 meters and more commonly are traceable for less than 100 meters. Notable exceptions include the Swansee Mine vein system and the Rochester Gulch quartz vein breccia zone. The width of the common quartz veins ranges from 2 cm to 1.5 m.

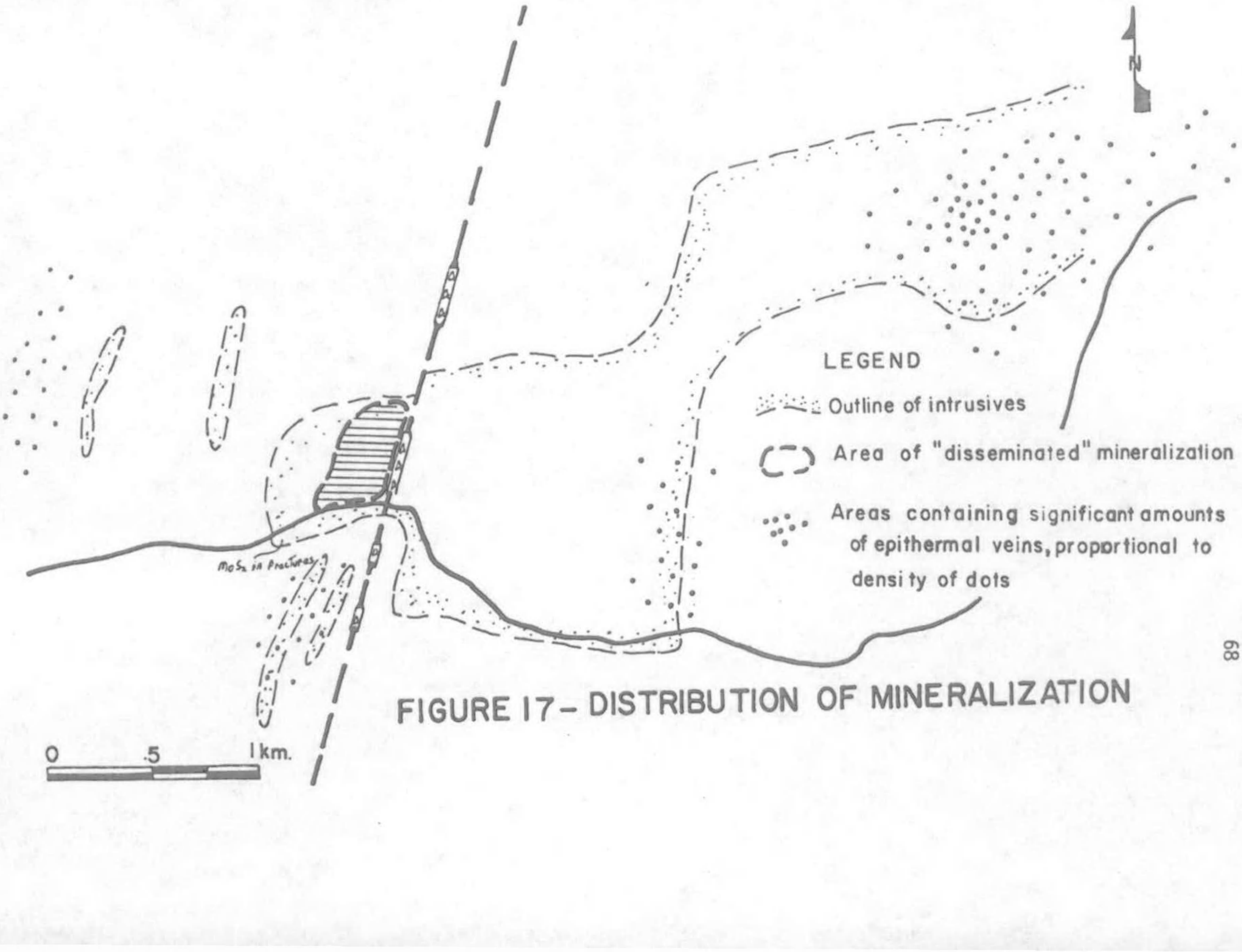


FIGURE 17 - DISTRIBUTION OF MINERALIZATION

Characteristically, the veins contain breccia fragments which are a simple fragmentation of the enclosing host rocks. Origin of the fissure fractures is uncertain; however, they may be simply cooling joints.

The Silver Bell Mine is developed on Cu-Ag-Au bearing fissure filling quartz veins (Fig. 18). This system has produced silver, lead, copper and some gold and was mined near the turn of the century.

Disseminated Mineralization

"Disseminated" pyrite, chalcopyrite, and molybdenite occur primarily within the Quartz Porphyry phase of the Silver Bell stock and are generally restricted to sericitically altered zones. Sample 7 contains "disseminated" pyrite (5%), and chalcopyrite (1%) in a groundmass of sericite (35%) and quartz (65%). Closer examination shows that chalcopyrite and to some extent pyrite occur in only two associations. Some of the sulfides replace mafics, i.e., biotite, which are now sericitized. Other sulfides occur in or near fractures.

Sample 575, from the drill core, further demonstrates fracture control of secondary sulfides (Fig. 19). Molybdenite (1%), and chalcopyrite (5%), are found along steeply dipping fractures in a sericitically altered granite.

Therefore, the term "disseminated" mineralization is not strictly applicable to mineralization at the Silver Bell. Fracture control is very important. However, the term is used because it generally describes the hand sample appearance. Geochemical surveys including

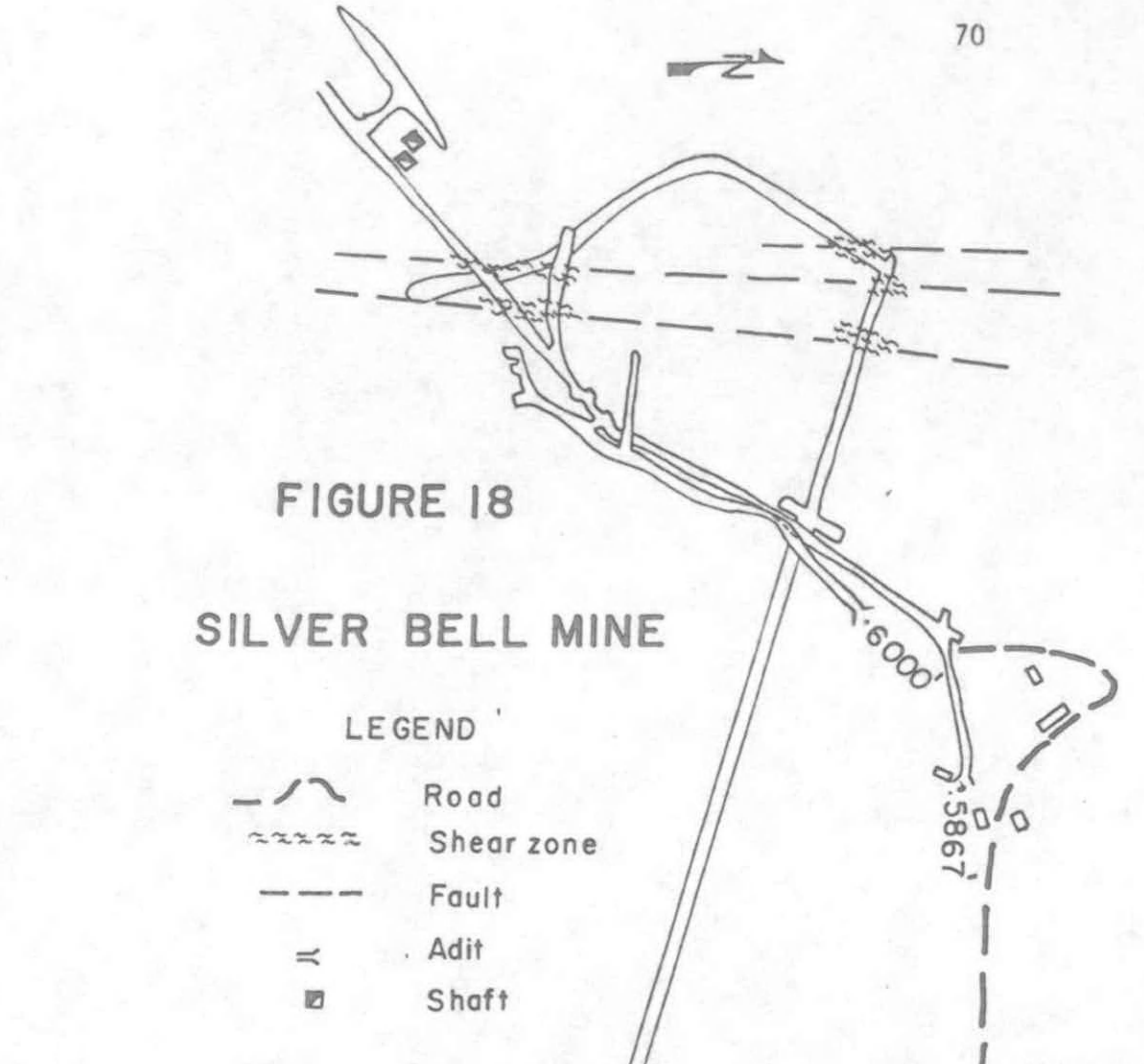


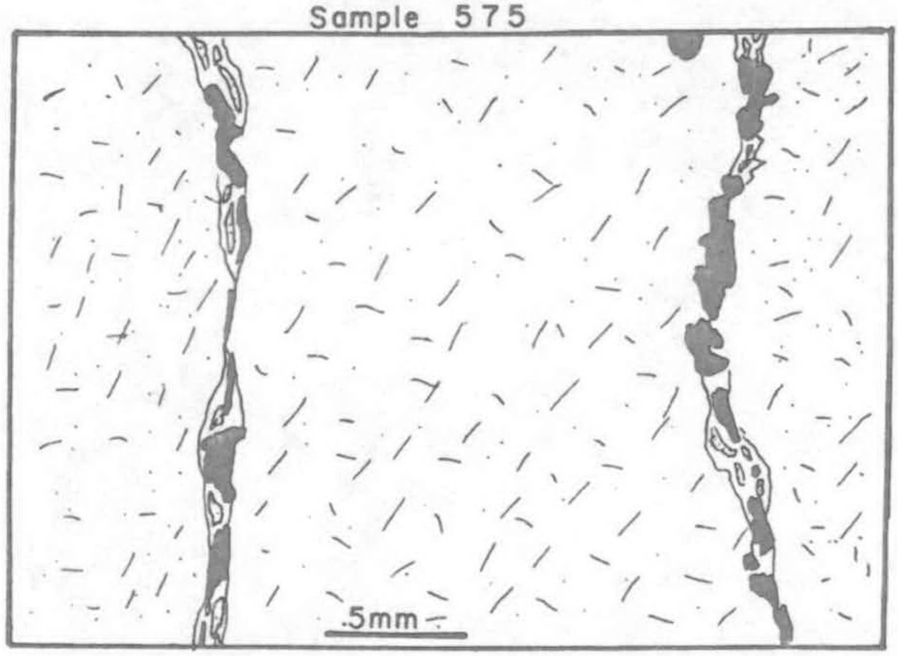
FIGURE 18

SILVER BELL MINE

FIGURE 19

Fracture Control of Mineralization

Sample 575



Sericitically altered granite

Fracture

Molybdenite

rock chip and soil sample assays demonstrate the correlation of high metal values with phyllic alteration. In general, the highest copper and molybdenum anomalies are found within and around the phyllic zone of alteration (Appendix A).

CHAPTER IV

DISCUSSION AND INTERPRETATIONS

Level of Emplacement

Field and petrographic relationships indicate an epizonal level of emplacement of the Silver Bell stock. Several independent lines of evidence proposed by Melson, 1964, support this interpretation including:

1) large contact aureole
2) lack of chilled contacts
3) highly fractured country rocks
4) discordant contacts
5) small scale magmatic stoping
6) massive, unfoliated granite to granodiorite, except for the Prickly dike phase
7) composite stock
8) occasional miarolitic cavities
9) extreme porphyritic nature of some phases

Additional evidence includes:

10) venting of the magma chamber to surface forming welded tuff.

Also, field relationships suggest a shallow level of exposure of the stock. Roof pendants are very common. Most exposed contacts between the stock and country rocks are at an extremely low angle (10-30 degrees). Therefore, on the basis of the above discussion, I feel the present level of exposure represents only the upper part of a large intrusive.

Control of Alteration by Fractures and Faults

The most pervasive and most intense alteration coincides highly fractured rock. Intense and pervasive hydrothermal alteration requires many avenues of transport. Fracture densities in the highly altered sericitic zone, range from 10 m to 25 m while in the propylitic zone they range from 2 m to 8 m. This demonstrates a strong control of alteration by fractures.

Several examples of zonation of hydrothermal alteration around veins and/or faults are recognized within the map area. Outcrop 96 demonstrates this relationship well (Figure 20). Here a 30 cm quartz vein carrying minor pyrite and chalcopyrite cuts a granite dike which is propylitically altered. Near the vein, the rock is sericitically altered, 96A, and beyond 1-1.5 m from the vein the rock becomes only propylitically altered. Pyrite content of the granite dike also decreases from 5 percent near the vein to trace amounts 1-1.5 m from the vein. Fracture density is higher near the vein. Several interpretations concerning hydrothermal alteration can be made. First, sericitic alteration is a more intense, higher temperature form of alteration. It may require more highly fractured rock which allows more solution movement than does propylitic. Secondly, hydrothermal solutions are channeled by major and minor fractures and faults and disseminate in

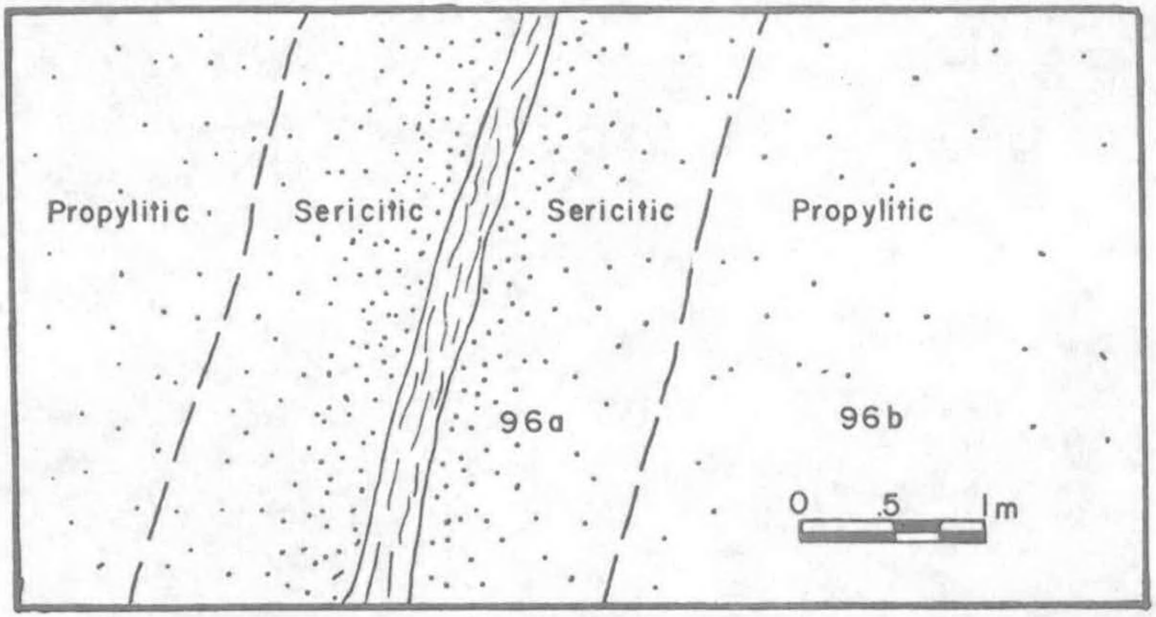


FIGURE 20- OUTCROP 96

Sketch of a cat cut, Fracture control of Alteration

LEGEND

- Granite
- Quartz Vein
- Alteration intensity, proportional to density of dots

highly fractured zones. Thirdly, "disseminated" mineralization is spacially related to specific alteration (sericitic) assemblages.

Relationship of Intrusion, Alteration, and Mineralization

As previously discussed, the Silver Bell stock is a shallowly emplaced composite stock. No igneous differentiation trend is recognizable; still, several observations about the individual phases can be made. Some contacts between two phases, recognizable in drill core, are gradational in some locations and sharp in others. Gradational contacts may occur either within an inhomogeneous magma or at the boundaries of separate intrusions into a partially solidified magma forming incomplete mixing near the boundaries. Sharp contacts imply intrusion of a molten phase into a partially or completely solidified phase. Suppose a later phase intruded an earlier phase which was crystallized near the boundaries and molten towards the core. Then sharp boundaries could exist against the crystallized portion and gradational boundaries could exist near the core of the older phase. Therefore, I suggest the time lapse between the E.Q. and the Andesite Porphyry phases was not great enough to allow complete crystallization.

The quartz porphyry phase of the Silver Bell stock may be a late stage differentiate. Relative to the other phases, the quartz porphyry melt contained significantly more quartz, metallic sulfides, and possibly volatiles. It contains rounded and embayed quartz phenocrysts in most samples. This implies that the magma became supersaturated with quartz first. Corrosion of the early formed quartz phenocrysts indicates an as yet unexplained change in the character of the melt. This phase also shows the most hydrothermal alteration and metallic sulfide content. The concentration of hydrothermal alteration within this phase may have been aided by late magmatic shattering of the crystallized magma. Fracture control has been discussed above. Fracturing was caused by the explosive character of the concentrated volatites within the magma. This highly fractured rock would then allow the transport of heated magmatic or hydrothermal groundwater. Probably coincident with alteration was the deposition of metallic sulfides. The concentration of metals and volatiles in a late stage differentiate is well documented. Hyndman (1972), states "...ions that do not easily substitute for the ions in common rock-forming minerals are concentrated in the residual melt along with silica, alkalis, and water." Thus, if a melt were originally somewhat enriched in metals, they would be concentrated along with silica, alkalis, and water in a residual melt. This corresponds well to the observations made.

Another line of evidence supporting the correlation of hydrothermal alteration with the quartz porphyry phase concerns time and spatial distribution. Although the sericitic alteration affects more than the quartz porphyry phase, it is restricted to the general area of outcrop of this phase (Figs. 7 & 12). The time of alteration had to be post-crystallization to alter primary minerals and yet pre-cooling. If the stock had completely cooled then a thermal event would have been necessary to increase the temperature of the country rock to a point where intense pervasive alteration could take place. This is generally taken to be between 200° and 350° C (Meyer, et al., 1968). No evidence exists which indicates a later thermal event. It is likely, therefore, that alteration is most closely tied, in both time and space, with the crystallization of the late stage differentiate, the quartz porphyry phase.

The absence of the argillic zone of alteration in the Silver Bell stock is not understood. Two possibilities seem likely. Two stages of alteration may be present. The early alteration event would have formed a normal zonation of alteration, phyllic at the core rimmed by argillic and argillic rimmed by propylitic. A later alteration event would expand the phyllic zone at the expense of the argillic zone (Meyer and Hemley, 1967). If this model is valid, then some argillic alteration should have been preserved. Since this is not the case, I feel this possibility is unlikely. A second model would have no argillic zone forming because a lack of sufficient chemical constituents to form the necessary mineralogy. The argillic zone is "...least well developed and is most likely to be absent in any given penetration of the ore deposit" (Lowell and Guilbert, 1970). The second model is also supported by the lack of argillic alteration near veins (Fig. 20).

Independent evidence supporting the second model deals with the zonation of alteration. The intensity of alteration is proportional to the distance from the sericitic alteration zone. The sericitic zone is rimmed by the propylitic zone II which is in turn rimmed by propylitic zone I which grades into fresh rock. Therefore, the alteration zones probably formed concurrently by an advancing front of hydrothermal solutions which emanated from the quartz porphyry phase. The solutions altered the rocks through a combination of leaching and introduction of chemicals, and temperature and pressure effects. The solutions evolved with distance from their source and became less reactive with the wall rocks. Thus the reaction was least intense (propylitic) farthest from the center, and most intense (sericitic) near the hydrothermal source. The presence of one main locality of sericitic alteration suggests one main source for the hydrothermal solutions. The patches of sericitic alteration found away from this center formed along major solution passageways (i.e., joints and fractures).

Chemical Changes During Alteration

The particular mineral assemblage found within a hydrothermal alteration zone is, in part, representative of the rock chemistry. Therefore, chemical changes during alteration are identified by studying coincident mineralogical changes. A graphic representation of the mineral assemblages in terms of their common chemical constituents allows visualization of the chemical changes during alteration. A four component (A, C, Fm, K) diagram is used. The four components are approximated as:

$$A = Al_2O_3 + Fe_2O_3 - Na_2O - K_2O$$

$$C = CaO$$

$$Fm = (Fe, Mn, Mg)\ O$$

$$K = K_2O$$

Quartz saturation is assumed.

The situation described above (Fig. 20) where a sericitic alteration halo encloses a small vein in an otherwise propylitically altered rock provides a good study area. Variables, such as different intrusive phases or different amounts of weathering, are not present, so definite statements can be made about chemical changes related to hydrothermal alteration.

Samples 96a and 96b, the sericitic and propylitic samples, respectively, are plotted on ACFmK diagrams (Fig. 21). Sample SB1 is also plotted on a ACFmK diagram (Fig. 21). Sample SB1 represents a slightly altered sample of the same rock type as 96a and b. A smooth trend towards depletion of CaO, and (Fe, Mn, Mg) O, in more intensely altered rock is evident. Also a coincident increase in K_2O is apparent. This agrees with chemical reactions proposed in Chapter III. The reactions require the release of Ca, Fe, and Mg and the fixation of K_2O during prograde alteration reactions. Two chemical reactions

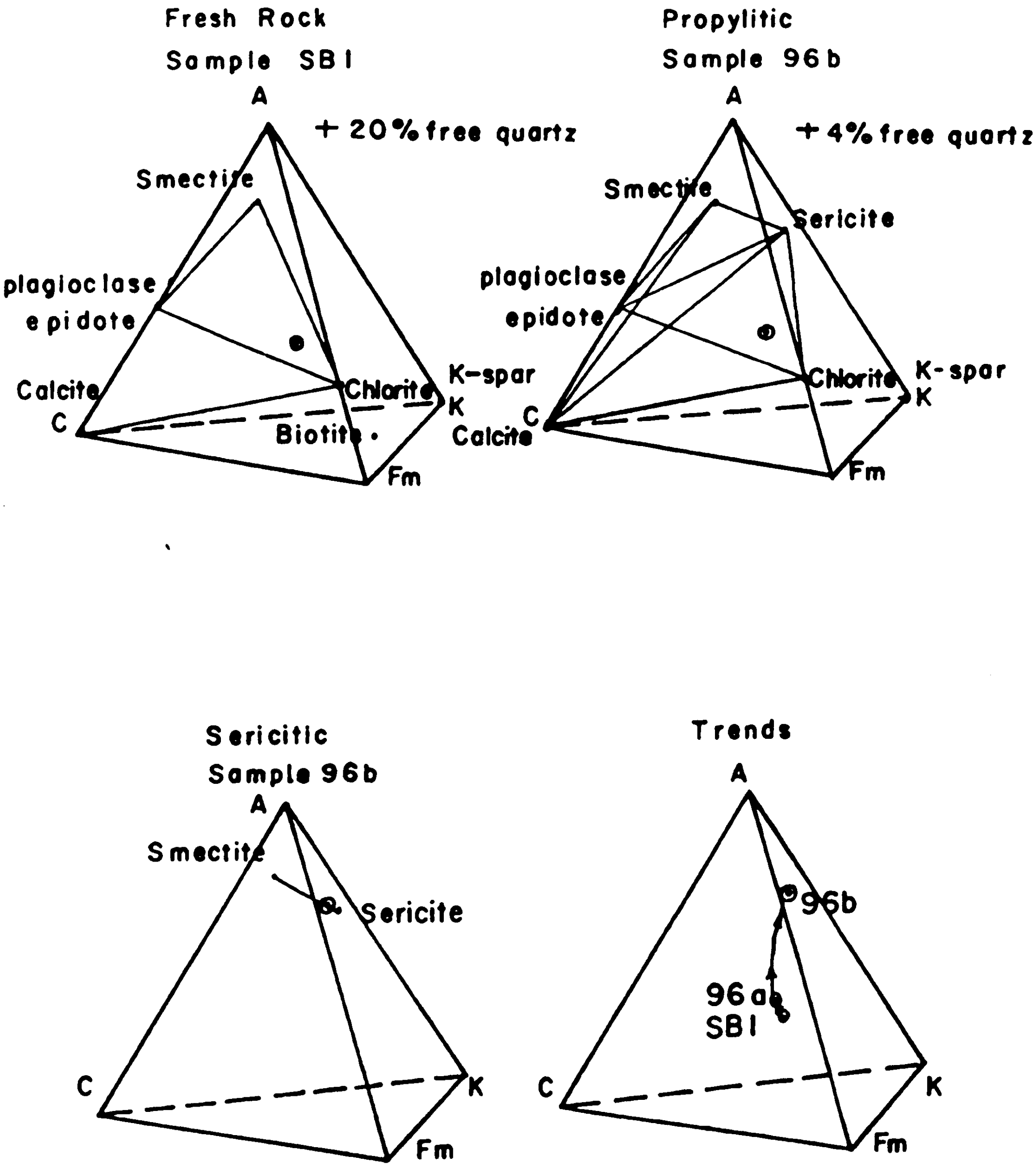


FIGURE 21 - ACFmK DIAGRAMS

which are not evident from the A C Fm K diagrams involve the fixation of H^+ at the expense of the base cations. And SiO_2 is greatly augmented in the sericitic alteration zone.

Relationship of Intrusive and Extrusive Rocks

Two series of volcanic rocks occur in the Lincoln area. The lower series consists primarily of dark gray andesite flows (cm 2) which are aphanitic to porphyritic with plagioclase, An_{39}, phenocrysts. The andesites are mostly unaltered north and east of the Silver Bell stock. However, propylitic alteration within the andesites is found north of Crater Mountain near other Tertiary intrusives (Melson, 1964). Hydrothermal alteration and/or metamorphism is observed in this unit within the Silver Bell contact aureole. It is therefore inferred that the lower volcanic series is earlier than the Silver Bell stock and was intruded and metamorphosed by the stock. Possible vents for this series are found along the Hambug contour road west of the map area, at the head of Prickly Gulch, and along the Blackfoot River to the north of the map area. These are isolated outcrops of andesitic material which occur as dikes or plugs.

The upper volcanic series is composed primarily of quartz latite crystal welded tuffs, Chapter III. These tuffs are remarkably unaltered except near younger Tertiary intrusive centers such as Crater Mountain. No alteration exists within the Silver Bell stock contact aureole, which demonstrates a later or contemporaneous time of eruption. The lower contact of the upper volcanic series unconformably overlies the lower andesite series and Belt rocks. North of the map area, the upper volcanic series lies upon a conglomerate containing fragments of the lower series and of Belt rocks inferring a significant time lapse between eruption of the lower and upper volcanic series.

I suggest that the Quartz Porphyry phase is the source of the Upper Volcanic series. Compositionally they are similar:

	Quartz Porphyry Phase	Upper Volcanic Series
Quartz -	rounded and embayed phenocrysts, 1-5%	rounded and embayed phenocrysts 1-3%
Potassium feldspar	orthoclase phenocrysts 0-10%	sanadine 2-5%
Groundmass	mostly hydrothermal sericite and quartz	crystal welded tuff, light brown aphanitic groundmass containing quartz, glass shards, and collapsed pumice fragments.

No other vent for these tuffs has been previously recognized. Melson, (1964), suggests that the rhyolitic domes may have been a source. However, hydrothermal alteration genetically associated with the intrusion of the rhyolitic domes affects the lower volcanic series (Melson, 1964) which makes this alternative seem unlikely. Also, rhyolitic domes are considered to be the result of emplacement of a dry rhyolitic magma whereas tuffs are considered to be formed by the explosive characteristics of water saturated or supersaturated magmas (Smith, 1960). If the Silver Bell stock is considered as a vent for the upper volcanic series then this would help explain characteristics of the stock including the composite nature, porphyritic character, lack of pegmatites, and intrusive breccias.

CHAPTER V

CONCLUSIONS

Geologic History

The Geologic History of the Silver Bell area as surmised from field, petrographic, and literature research is:

1. Deposition of Belt rocks during the Precambrian
2. Late PreCambrian, pre-Flathead, tilting and minor uplift and erosion
3. "Laramide" fracturing, faulting, folding, and uplift and erosion
4. Extrusion of lower Volcanic series - lower Tertiary (Pre-Oligocene)
5. Minor erosion
6. Intrusion of Silver Bell stock, development of contact aureole, extrusion of upper volcanic series (post-Oligocene), and movement along Rochester Gulch fault. During very late stages of crystallization of stock; hydrothermal alteration and mineralization developed and the Rochester Gulch quartz breccia zone formed.
7. Faulting (Poorman Creek fault, etc.) erosion, exposure of Silver Bell
8. Supergene weathering.

Classification

The classification of metallic mineral deposits is of genetic, economic, and academic interest. Two classification schemes, not mutually exclusive, apply to the Poorman Creek-Silver Bell deposits. One, the Lowell and Guilbert model (Lowell and Guilbert, 1970), describes a low grade disseminated copper and/or molybdenum deposit. Characteristics of this model include genetically related porphyritic "granitic" rocks and zoned hydrothermal alteration and mineralization assemblages. The Silver Bell satisfies these criteria. Porphyritic "granitic" rocks are very abundant. Alteration mineral assemblages correspond well with the Lowell and Guilbert model (Tables 1 and 2). Zonation of alteration and mineralization of the Silver Bell also corresponds to the Lowell and Guilbert model (Figs. 14, 16). The lack of an argillic alteration zone is a significant variant from the model; however, it is not an uncommon ore (Lowell and Guilbert, 1970). In the second model, (Brown, 1976), porphyry ore deposits are classified by their relative symmetry, age, and depth of emplacement. According to Brown, phallic porphyry deposits are emplaced post-orogenically and very shallow depths. Also, they have a high degree of symmetry. If the Silver Bell is post-Oligocene, then it certainly is post-orogenic. The Silver Bell deposit also satisfies the other two criteria as discussed above. Therefore, the Poorman Creek-Silver Bell stock deposit appears to be a phallic porphyry copper-molybdenum deposit.

Economic Potential

Extent and economic potential of the system is not fully understood. No ore grade rock has been found. Field evidence suggest a shallow level of exposure of the stock. If the Silver Bell stock, as presently exposed, simply represents only the upper extension of a much larger pluton then perhaps the mineralization we see represents only the upper extensions of a larger hydrothermal ore deposit. This is borne out by the presence of molybdenite-bearing quartz orthoclase veins and molybdenite-bearing fractures which are found sparingly within the deposit. Also, Induced Potential data indicate an anomaly, possibly a sulfide ore body, widening with depth.

All available information suggests that the most favorable location for a drill hole would be in the center of the phyllic alteration zone along Poorman Creek road, Figure 14. A diamond drill hole would provide additional information needed to clarify geologic interpretations such as the extent of the quartz porphyry phase, the existence of ore body, the character of the Rochester Gulch quartz vein breccia zone, and extent and character of hydrothermal alteration. I would expect the drill hole to intersect pervasive phyllic alteration at depth possibly grading into potassic alteration and an ore grade sulfide body of unknown extent.

BIBLIOGRAPHY

Armstrong, R.L., Hollister, V.F., and Harakal, J.E., 1978, K-Ar Dates for Mineralization in the White Cloud-Cannivan Porphyry Molybdenum Belt of Idaho and Montana, scientific communication, Econ. Geol. v. 73, no. 1, p. 94-95.

Barrell, J., 1907, Geology of the Marysville mining district, Montana: U.S. Geol. Survey Prof. Paper 57.

Beirwagen, E., 1964, Geology of the Black Mountain area, Montana: Unpub., Princeton Ph.D. thesis.

Brown, A.S., 1976, Morphology and Classification in Porphyry Deposits in the Canadian Cordillera, ed. A. S. Brown, C.I.M. Sp. Vol. 15, p. 45-51.

Buddington, A.F., 1959, Granite Emplacement with special reference to North America: Geol. Soc. Am. Bull., vol. 70, p. 671-747.

Burchfiel, B.C., and Davis, G.A., 1975, Nature and Controls of Cordillera Orogenesis, Western United States - Extension of an Earlier Synthesis: Am. Jour. Sci. Vol. 275-A, p. 363-396.

Burnham, C.W., 1962, Facies and Types of Hydrothermal Alteration: Economic GEology, Vol. 57, p. 768-784.

Field, D.W., Jones, M.B., and Bruce, W.A., 1974, Porphyry Copper-Molybdenum Deposits of the Pacific Northwest, A.I.M.E. Transaction, Vol. 225, p. 9-22.

Field, C.W., Briskey, J.A., Henricksen, T.A., Jones, M.B., Schmuck, R.A., Bruce, W.A., 1975, Chemical Trends in Mesozoic Plutons Associated with Porphyry-Type Metallization of the Pacific Northwest, A.I.M.E. preprint number 75-L-359, 25 p.

Hamilton, W., and Meyers, W.B., 1974a, Nature of the Boulder batholith of Montana: Geol. Soc. Am. Bull., Vol. 85, p. 365-378.

__________, 1974b, Nature of the Boulder batholith: Reply: Geol. Soc. Am. Bull., Vol. 85, p. 1958-1960.

Harrison, J.E., 1972, Precambrian Belt Basin of Northwest United States: Its geometry, sedimentation, and copper occurrences: Geol. Soc. America Bull., Vol. 83, p. 1215-1240.

Hyndman, D.W., 1972, Petrology of Igneous and Metamorphic Rocks: McGraw Hill Book Co., N.Y., 533 p.

_____, Talbot, J. L., and Chase, R.B., 1975, Boulder batholith: A Result of Emplacement of a Block Detached from the Idaho batholith Infrastructure?, Geology, Vol. 3, No. 7, p. 401-404.

Kleinkopf, M.D., and Mudge, M.R., 1973, Aeromagnetic, Bouguer gravity, and generalized geologic studies of the Great Falls-Mission Range Area, Northwestern Montana: U.S. Geol. Surv. Prof. Paper 726-A, 19 p.

Knopf, A., 1913, Ore deposits of the Helena mining region, Montana, U.S. Geol. Survey Bull. 527.

_____, 1957, Boulder bathylith of Montana: Am. Mineralogist, Vol. 255, p. 81-103.

Lamarre, A.L., and Hodder, R.W., 1978, Distribution and genesis of flourite deposits in the Western United States and their significance to metallogeny, Geology, Vol. 6, no. 4, p. 236-238.

Lange, I.M., 1975, Revett-sulfide deposits and sandstone-type red-bed copper deposits of the southwestern United States: Northwest Geology, Vol. 4, p. 59-76.

_____, and Eby, D.E., 1978, A Chalcopyrite-bearing Oolite Bed in the Helena Formation, Belt Super-Group (Precambrian-Y), near Lincoln, Montana, Geol. Soc. Am. Abstr. Vol. 10, No. 4, p. 219.

Klepper, M.R., Robinson, G.D., and Smedes, H.W., 1971, On the Nature of the Boulder batholith of Montana: Geol. Soc. America Bull., Vol. 82, p. 1563-1580.

_____, 1974, Nature of the Boulder batholith of Montana: Discussion: Geol. Soc. Am. Bull., Vol. 85, p. 1953-58.

Lowell, J.D., 1974, Regional Characteristics of Porphyry Copper Deposits, Econ. Geol., Vol. 69, No. 5, p. 601.

_____, and Guilbert, 1970, Lateral and Vertical Alteration - Mineralization Zoning in Porphyry Ore Deposits, Econ. Geol. Vol. 65, p. 373-408.

Lowell, J. D., and Guilbert, 1974, Variations in Zoning Patterns in Porphyry Ore Deposits, C.I.M. Bull. No. 2, p. 99-109.

McClernan, H., 1974, Geochemical Exploration of the Stemple Pass Area, Lewis and Clark County, Montana. Montana Bur. of Mines and Geol. Sp. Pub. 64.

Melson, W.G., 1964, Geology of the Lincoln Area, Montana, and Contact Metamorphism of Impure Carbonate Rocks, Princeton Univ., Ph.D. Thesis, Unpub.

_____, 1971, Geology of the Lincoln Area, Lewis and Clark County, Montana, Smithsonian Contr. to Earth Science, No. 7, Smithsonian Inst. Press.

Meyer, C., and Hemley, J.J., 1967, Wall Rock Alternation, in Barnes, H.L., editor, Geochemistry of Hydrothermal Ore Deposits; Holt, Rinehart and Winston, Inc., N.Y., p. 166-232.

_____, E. P. Shea, C. C. Goddard, Jr., and staff, 1968, Ore Deposits at Butte, Montana in Ridge, J.D., editor, Ore Deposits of the United States, 1933-1967, Graton-Sales Volume, A.I.M.E., N.Y., Vol. 2, p. 1373-1416.

Miller, R.N., Shea, E.P., Goddard, C.C., Potter, C.W., and Bronx, G.W., 1973, Geology of the Heddleston Copper-Molybdenum Deposit, Lewis and Clark County, Montana, A.I.M.E. Pacific Northwest Metals and Minerals Conference, Coeur d'Alene, Idaho, 33 p.

Pardee, J.T., and Scharder, F.C., 1933, Metalliferous deposits of the greater Helena Mining Region, Montana: U.S. Geol. Survey Bull. 842.

Schafer, P.A., 1935, Geology and ore deposits of the Neihart mining district, Cascade County, Montana, Mont. Bur. Mines and Geol. Mem. 13, 62 p.

Smedes, H.W., 1962, Lowland Creek Volcanics, an upper Oligocene Formation near Butte, Montana: Jour. Geology, Vol. 70, No. 3, p. 259-266.

Smith, R.L., 1960, Ash Flows: Geol. Soc. America Bull., Vol. 71, p. 795-842.

Tilling, R.I., 1973, Two Contemporaneous but Chemically and Isotropically Distinct Magma Series: A Model for the Boulder batholith, Montana: Geol. Soc. America Bull., Bol. 84, p. 3879-3900.

Walcott, C.D., 1899, Precambrian fossiliferous formations: Geol. Soc. America Bull., Vol. 10, p. 199-244.

APPENDIX

Geochemical and Geophysical Studies

Prior to this study, soil sample geochemistry by McClernan (1974) for copper and molybdenum resulted in the discovery of anomalous amounts of these metals near the southwest end of the stock (Fig. 22). The anomalous metal values were measured over both the igneous and hornfels rock.

Utah International Company has supplied induced potential data for the Silver Bell prospect (Fig. 23, 24, 25, 26). The level of penetration is:

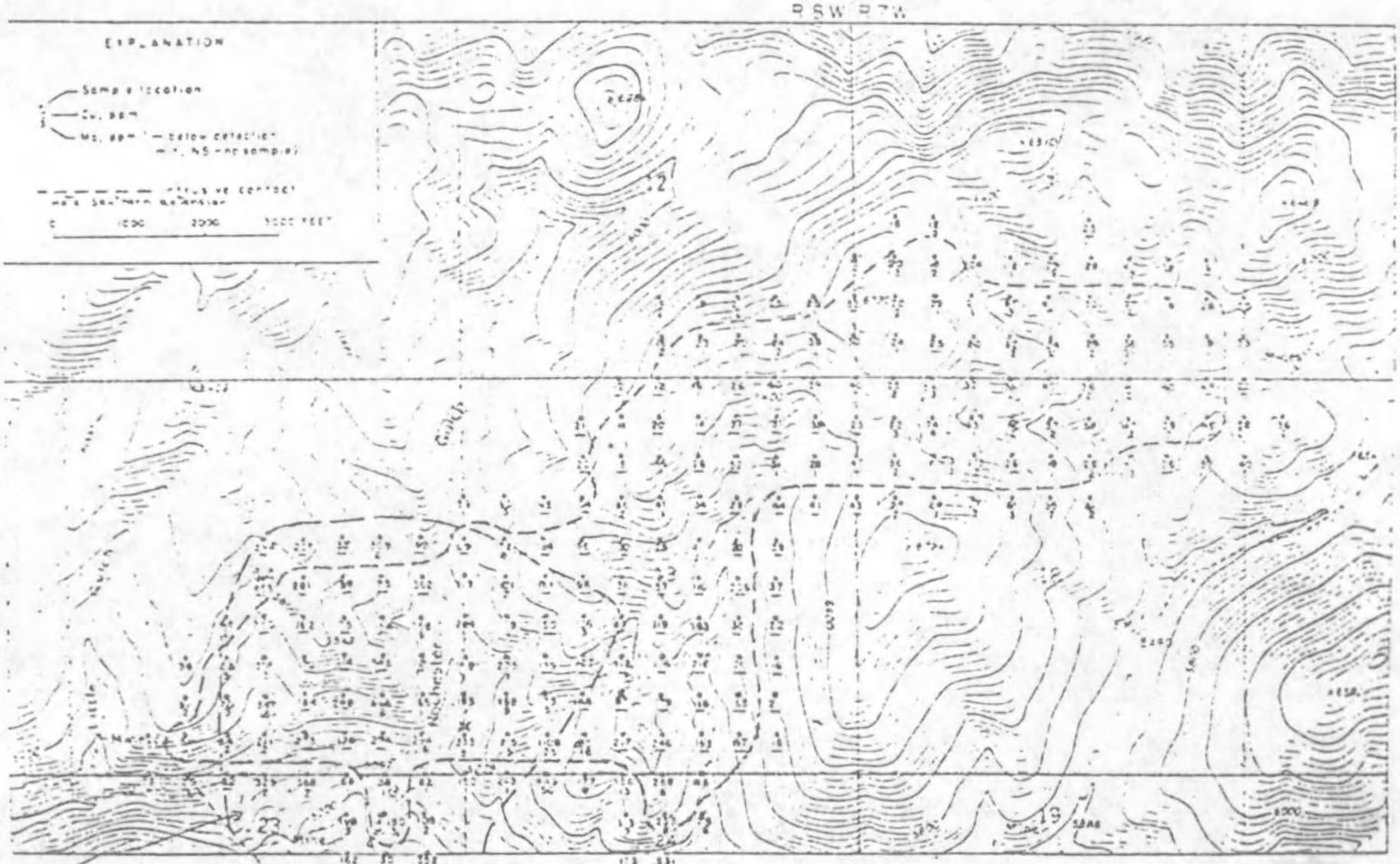
N - 1 400'"A"- 133.3 feet

N - 3 400'"A"- 300 feet

N - 5 400'"A"- 566.6 feet

The figures show an anomaly (≥ 40 Ms) widening with increasing depth. This most likely is a metal sulfide body, however, whether it is pyrite or chalcopyrite cannot be ascertained.

Another geophysical study is the aeromagnetic and Bouguer gravity study of the Great Falls to the Mission Range area by Kleinkopf and Mudge (1972). They delineated a pronounced magnetic anomaly over the western portion of the Granite Peak stocks. However, no strong magnetic anomaly is recognized over the Silver Bell stock. Kleinkopf and Mudge believe that the lack of a strong anomaly is possibly due to the late magmatic hydrothermal alteration and mineralization which is prevalent in the Silver Bell stock.



Cmpx sericite-quartz alteration within the boundary
propylitic alteration in intrusive beyond quartz-sericite alteration

Figure 3.–Copper and molybdenum values in soil, Silver Bell stock, Lewis and Clark County, Montana
Base from U.S. Geol. Surv. Swede Gulch Quadrangle

contact

Modified after Figure 3, McClernan, 1974

FIGURE 22

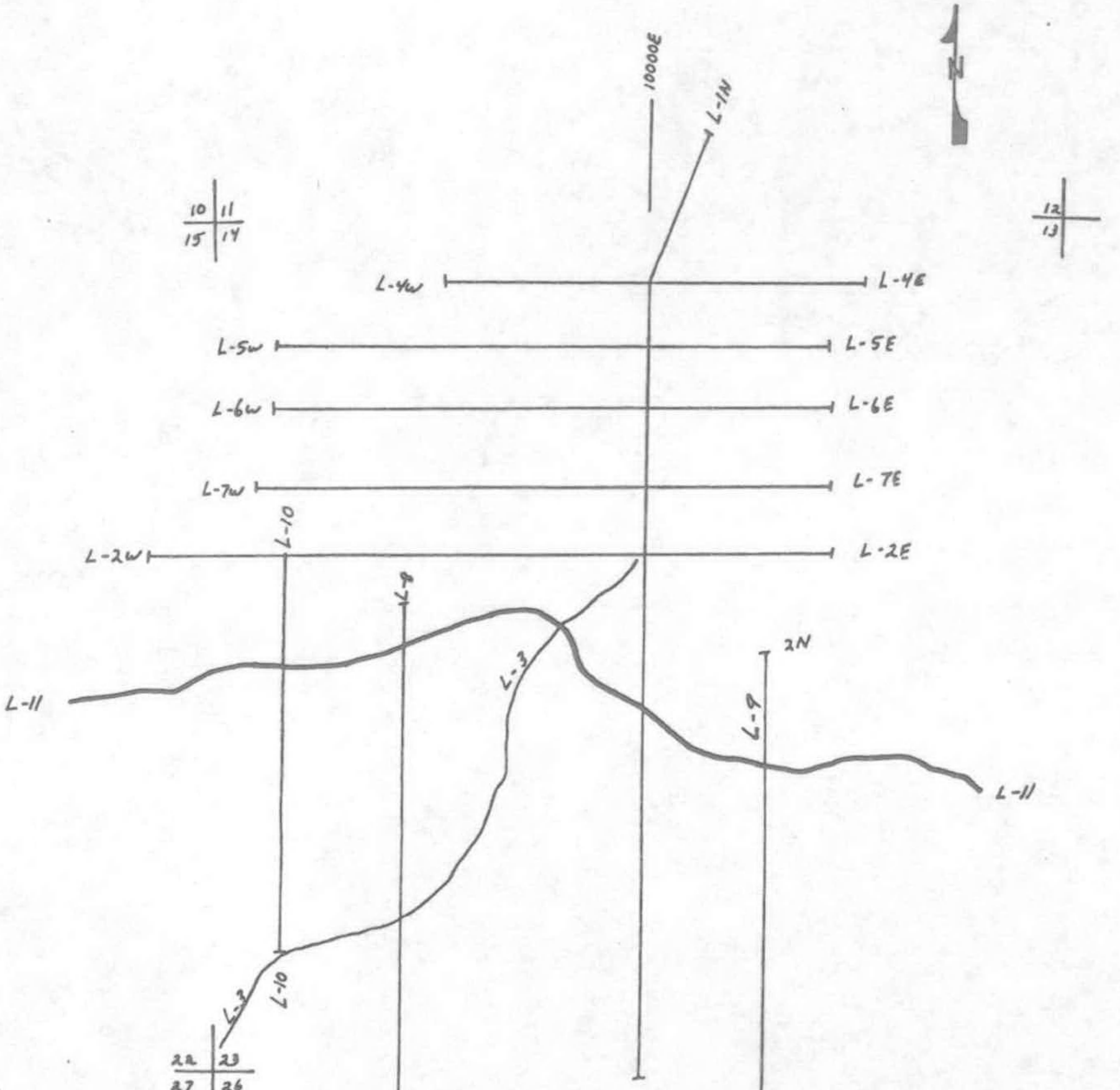

N
10000E
L-1N
10 11
15 14
12
13
L-4w
L-4E
L-5w
L-5E
L-6w
L-6E
L-7w
L-7E
L-10
L-2w
L-2E
L-8
L-3
2N
L-11
L-9
L-11
L-10
L-3
22 23
27 26
L-15
L-8
L-9
I.P. Lines
Silver Bell
from
Utah International Co.

Figure 23

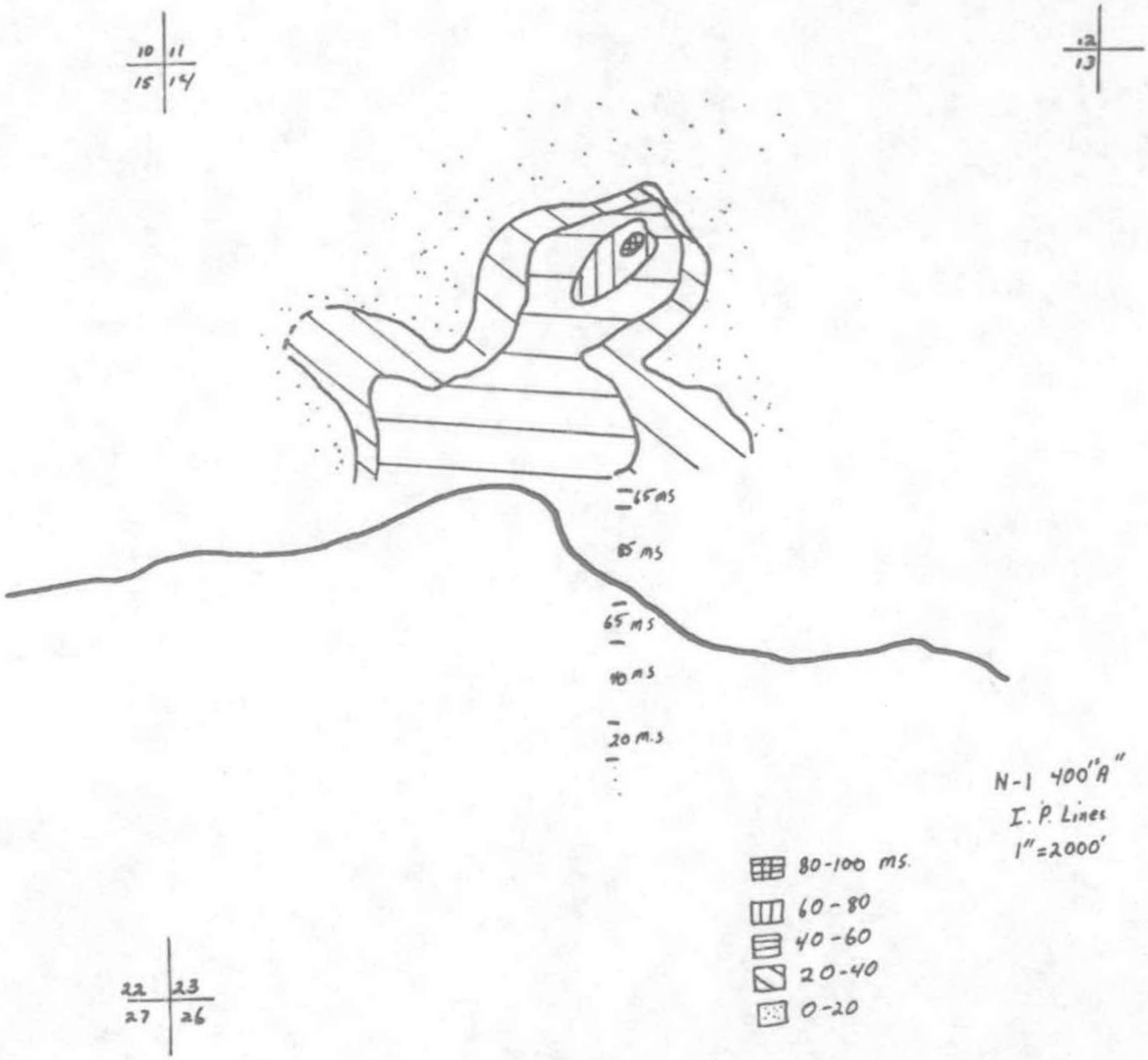

10
11
15
14
12
13
65 ms
85 ms
65 ms
40 ms
20 m.s
N-1 400'A"
I. P. Lines
1"=2000'
80-100 ms.
60-80
40-60
20-40
0-20
22
23
27
26

Figure 24

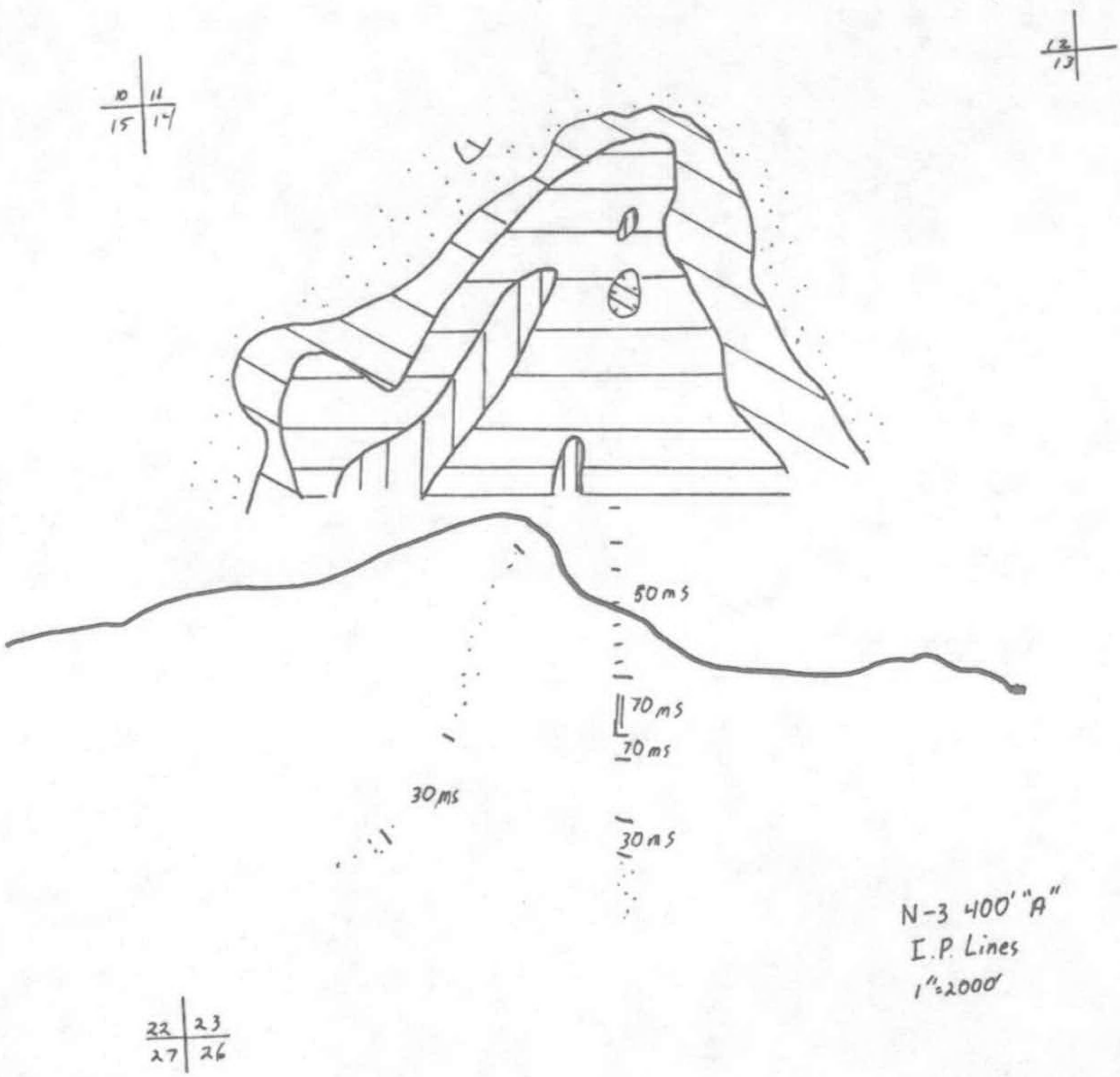
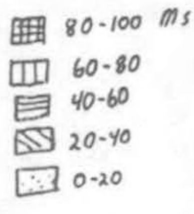

10 11
15 14
12
13
50 ms
70 ms
70 ms
30 ms
30 ms
N-3 400' "A"
I.P. Lines
1"=2000'
22 23
27 26

Figure 25


80-100 ms
60-80
40-60
20-40
0-20

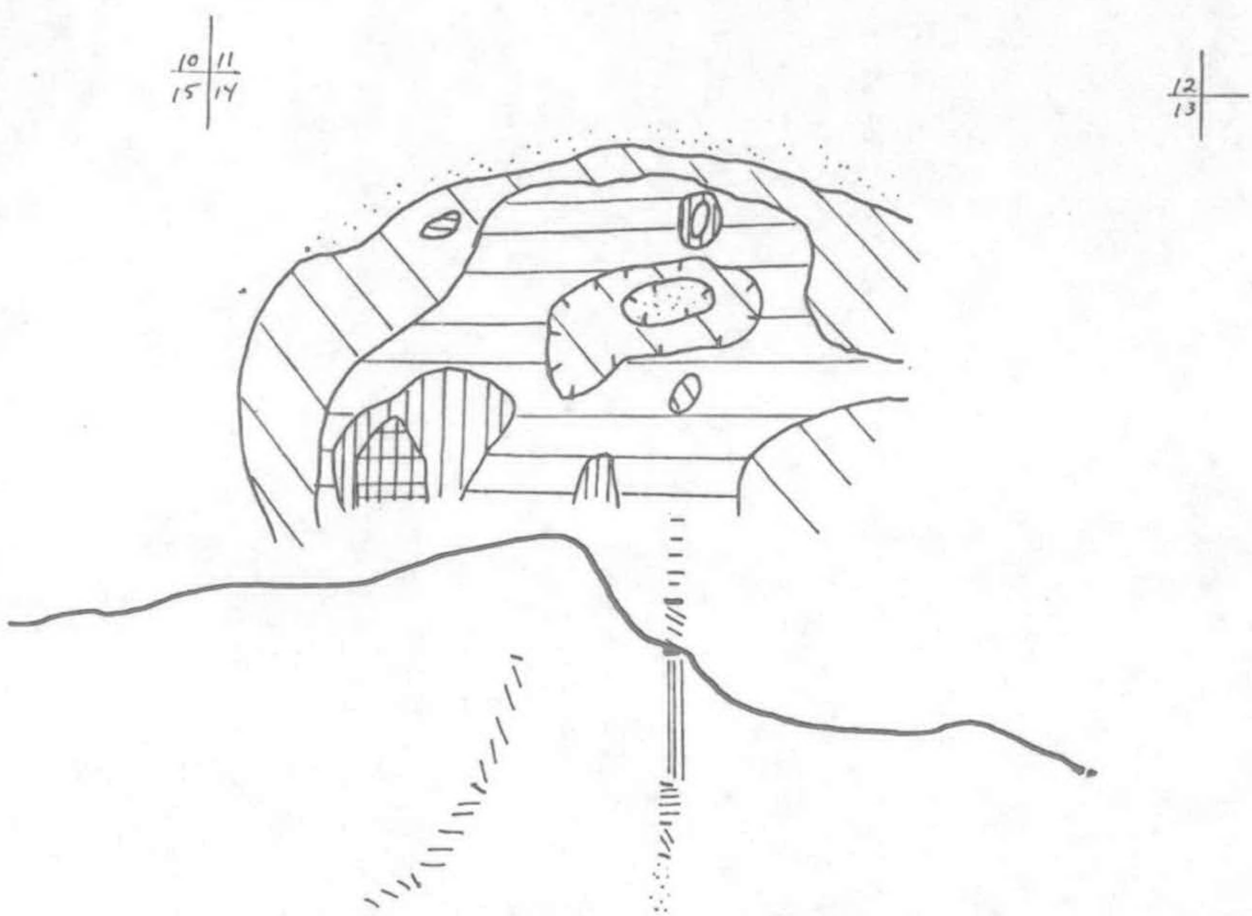


Figure 26

N-5 -400' "A"
I. P. Lines
1"=2000'

80-100 mS
60-80
40-60
20-40
0-20