GEOLOGY OF THE BOSS MOUNTAIN MINE, BRITISH COLUMBIA

by

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ABSTRACT

Detailed investigation of the Boss Mountain molybdenite deposits, which are on the northeast slope of Takomkane Mountain approximately 35 miles north-northeast of 100 Mile House, British Columbia, was undertaken to determine the origin of the deposits, controls of mineralization, effects of mineralization on the host rock, origin of the breccia bodies, and the relationship of these features to the Boss Mountain Stock.

The deposits occur in granodiorite and porphyritic biotite granodiorite phases of the composite Takomkane Batholith near an epizonal Cretaceous quartz monzonite porphyry body, the Boss Mountain Stock. Molybdenite occurs in economic concentrations in two classes of deposits: 1) Breccia Deposits, which include fracture zones, and 2) Vein Deposits, which include both single and multiple systems.

The sequence of ore formation, which includes rhyolite porphyry and rhyolite dyke emplacement, breccia formation, fracture development, mineralization, and alteration, is directly related to the oscillatory emplacement of the Boss Mountain Stock.

The Boss Breccias, including Phase I Breccia, Quartz Breccia, and Phase III Breccia, were formed by pulsating magmatic activity acting on an irregularity on the side of the magma chamber (Boss Mountain Stock). The rock above this irregularity was fractured by magmatic advances. Withdrawal of

magmatic pressure permitted collapse of the overlying fractured rock forming breccia bodies.

Rhyolite porphyry dykes, apophyses of the Boss Mountain Stock, preceded and accompanied Phase I Breccia formation. Non-porphyritic rhyolite dykes cut Phase I Breccia and have been engulfed by later breccia phases.

Four stages of rock alteration genetically related to the deposits, including (in chronological order): Stage 1, garnet-hornblende; Stage 2, biotite; Stage 3, microperthite-chlorite-sericite; and Stage 4, chlorite-talc, have been identified and delineated. Stage 1 formed in mylonite zones around the Boss Mountain Stock, Stages 2 and 3 around centres of mineralization and Stage 4 occurs in and near shear zones.

Five periods of fracture development, each of which contains quartz veins of unique mineralogy and characteristics, were interspersed with breccia formation, alteration and mineralization.

Mineralization accompanied breccia formation and fracture development. Molybdenite was introduced during three separate periods of mineralization, two of which were separated by a barren stage that produced a complex mineral assemblage. Pyrite accompanies all stages of mineralization.

Pleistocene (?) alkali basalt dykes related to Takomkane Volcano, which forms the twin summits of Takomkane Mountain,

cut all rocks and ore structures. The volcanic rocks of the volcano contain xenoliths of granodiorite, glassy black augite and peridotite.

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I. INTRODUCTION

LOCATION AND ACCESS

The Boss Mountain Mine is on the northeast slope of Takomkane Mountain (Big Timothy Mountain) at longitude 120°56', latitude 52°06' (Figure 2.1). Access to the mine and townsite is from 100-Mile House by approximately 60 miles of good road, the first 18 miles of which are hard-surfaced.

The molybdenum deposits which are in a cirque at the head of Molybdenite Creek outcrop between 5400 and 5700 feet elevation. The millsite and adit level are one mile east of the deposits at elevation 5045 feet. The townsite at Hendrix Lake is six miles east of the mine at elevation 2000 feet.

SCOPE OF PRESENT WORK

Detailed investigation of the Boss Mountain molybdenum deposits and the surrounding area was undertaken to determine the origin of the molybdenite deposits, the controls of mineralization, the effects of mineralization on the host rock, the origin of the breccia bodies, and the relationship of mineralization to the Boss Mountain Stock. Geologic data were collected during the 1963 and 1964 field seasons and during numerous brief visits to the area in 1965, 1966 and 1967. The immediate area of the mine was mapped on the surface and in the underground workings at 1 inch to 30 feet. An area within a 3000 foot

radius of the mine was mapped at 1 inch to 100 feet. Both maps were combined into Map 2 (in pocket; 1 inch to 200 feet) for this report. Mapping at 1 inch to 1000 feet covered an area three miles wide and six miles long, half of which is shown on Map 1 (in pocket). Many reconnaissance trips were made into surrounding areas to gain familiarity with rocks outside the area of study. Low-level aerial photographs (1 inch to 1000 feet) greatly facilitated field mapping.

PHYSICAL FEATURES

Takomkane Mountain, which marks the western boundary of the Quesnel Highland, rises about 2000 feet above the Fraser Plateau. The Quesnel Highland, a highly dissected part of the Interior Plateau, is the transition zone between the Fraser Plateau on the west and the Cariboo Mountains on the east. The summits of most mountains in the Quesnel Highland, including Takomkane Mountain, have been rounded by a Pleistocene ice sheet and then had their features sharpened by the development of cirques "....on the northern and northeastern sides during the late stage of glaciation." (Holland, 1964, p.73).

Molybdenite Creek and other streams north of the mine drain northward into the Horsefly River, a tributary of the Quesnel River-Quesnel Lake drainage. Boss Creek and Hendrix Creek flow southward to Canim Lake and then into the Clearwater-North Thompson drainages. Both the Quesnel and Thompson rivers are

tributaries of the Fraser River.

Bedrock is poorly exposed in most areas less than 6000 feet in elevation, but large areas are extensively exposed in cirque walls above this elevation. The rolling summit of Takomkane Mountain is locally covered with thin veneer of glacial deposits and swamps. Thick growths of trees and low brush cover most areas below timberline, except the valleys of Boss Creek and Molybdenite Creek which contain extensive swamps.

ACKNOWLEDGMENTS

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Noranda Exploration Company, Limited, generously defrayed most of the costs and provided other services. Hand specimen photographs were taken by Gordon Coots. Finally, the author

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II. PETROLOGY OF THE MINE AREA

The Boss Mountain molybdenite deposits occur in granodiorite and porphyritic granodiorite phases of a composite batholith, the Takomkane batholith, that crops out sporadically over an area of more than 500 square miles in east-central British Columbia (Figure 2.1). The batholith cuts Triassic volcanic and sedimentary rocks that probably are correlatives of the Nicola Group.

All other rocks in the map area are younger than the batholith (Table 2.1). Andesite and pegmatite dykes cut all phases of the batholith but are older than molybdenum mineralization. A complex composed of rhyolite porphyry and rhyolite dykes, three phases of breccias (Boss Breccias), and the Boss Mountain Stock is found only in the vicinity of the mine.

All rocks in the map area are cut by dykes of alkali basalt which are related to the Takomkane Volcano. The northeast side of the volcanic cone has been removed by erosion, but the remaining part is about 2,000 feet in diameter. Alkali basalt and agglomerate which form the cone contain abundant inclusions of peridotite, augite, and granodiorite. The age of the volcano is uncertain, but it appears to have been subject to alpine glaciation and in this report the age is considered to be Pleistocene.

Boss Creek and the lower part of Molybdenite Creek valleys occupy a northwesterly trending lineament that is probably the

trace of a fault or fault zone. Hendrix Creek valley, east of the map area, occupies a deeper, parallel lineament.

Glacial and stream deposits cover much of map area, especially the lower levels. The surficial deposits have not received detailed study, and will not be described.

HYPERSTHENE GABBRO

Rounded xenoliths of hypersthene gabbro occur throughout the mapped part of the Takomkane Batholith. The largest xenolith, which crops out on the west slope of the mountain (Map 1), exceeds 1,000 feet in diameter and is crudely elliptical in plan. The contact with the enclosing syenodiorite is sharp, with apophyses of syenodiorite extending several feet into hypersthene gabbro. The enclosing rock contains abundant small (six inches to three feet in length), tabular inclusions with highly rounded corners close to the large xenolith, but these become fewer and diminish to less than one percent over a distance of 15 to 20 feet.

Most xenoliths of hypersthene gabbro in other parts of the batholith, especially in the granodiorite phase, contain more orthoclase than this large xenolith, probably the result of metasomatism by the magma from which the enclosing rocks crystallized. Within the mine area the xenoliths were subjected to varying degrees of hydrothermal alteration and have undergone the same changes as other rocks. Biotitization has been extreme in some xenoliths.

In hand specimen medium-to coarse-grained hypersthene gabbro is dark grey to brownish grey. Minerals identified in thin section include antiperthitic plagioclase, augite, hypersthene, orthoclase, and biotite. Minor quantities of hornblende, quartz, apatite, chlorite, sericite, sphene, serpentine, pyrite, magnetite, ilmenite and carbonate comprise the remainder of the rock. The modes of four specimens of hypersthene gabbro, determined by point-counting thin sections, are listed in Table 2.2.

Subhedral antiperthitic plagioclase forms the framework of the intergranular texture of the rock. The subparallel laths of plagioclase are weakly zoned (oscillatory) with compositional variations from An_{43} to An_{55}. Many laths are bent.

Antiperthite is characteristic of the hypersthene gabbros. Rectangular blebs of orthoclase, are confined to ill-defined composition zones (Plate 2.3) in the enclosing plagioclase.

At high temperatures (independent of pressure) the plagioclase structure is capable of incorporating large amounts of potassium. During the cooling of the plagioclase the potassium phase may exsolve as discrete bodies of orthoclase or may be retained in an apparently homogeneous plagioclase. Sen (1959) pointed out that reheating or shearing of plagioclase with potassium in solid solution can cause exsolution of orthoclase. Reheating of the hypersthene gabbro by the Takomkane Batholith probably caused the development of anitperthite in these rocks. Restriction of orthoclase to specific zones is probably due to

ERA	PERIOD OF EPOCH	NAME	LITHOLOGY
CENOZOIC	Recent Pleistocene		Stream Sediments and Glacial deposits
	unconformity		
	Pleistocene(?)	Takomkane Volcano and related dykes	Alkali basalt
unconformable and intrusive			
MESOZOIC	Cretaceous	Boss Mountain Stock and related dykes Boss Breccias	Quartz monzonite porphyry Phase III Breccia; comminuted matrix with biotite Quartz-Breccia; quartz matrix Rhyolite dykes Phase I Breccia; comminuted matrix Rhyolite porphyry dykes
	intrusive into batholith		
			pegmatite dykes
	intrusive		
			Andesite and andesite porphyry dykes
	intrusive		
	Jurassic	Takomkane Batholith	Porphyritic granodiorite Granodiorite Syenodiorite-Diorite
	intrusive		
			Hypersthene gabbro

Table 2.1. TABLE OF FORMATIONS: BOSS MOUNTAIN MINE AREA

original compositional zoning in the plagioclase. Sen (1959) observed that the orthoclase of antiperthites which he believed to be magmatic in origin is in optical orientation with orthoclase grains adjacent to the antiperthite. Where orthoclase is observed in contact with antiperthite grains in the hypersthene gabbro of Takomkane Mountain, the optical orientations of the orthoclase are not parallel to the orthoclase within the antiperthite. If this criterion is valid, the Takomkane Mountain antiperthites are not magmatic and have formed during reheating of the xenoliths.

Specimen	Plagioclase (Antiperthitic)		Orthoclase	Quartz	Hypersthene	Augite	Hornblende	Biotite	Apatite	Sphene	Magnetite
	%	An									
7-7.2-I	68	45-50	10	x	3	14	x	3	x	-	x
7-14.2-I	73	52-53	3	-	3	16	-	5	x	-	x
9-3.1 (altered)	63	40-55	12	-	x	x	x	25	x	x	x
9-4.1	75	51-55	3	x	7	11	x	4	x	-	x

x Minor - Absent

Table 2.2. Modes of hypersthene gabbros from the Boss Mountain Mine area.

Stubby, rather equant, colourless to light green augite grains rarely are rimmed by green hornblende. Fresh hypers-

thene grains exhibit weak, light pink to colourless pleochroism. Dark brown biotite, probably of deuteric origin, occurs as radiating clusters of subhedral crystals adjacent to magnetite grains.

The origin of the hypersthene gabbro is not known. Several possible alternative origins can be postulated, but there is a lack of conclusive evidence to any single mechanism.

The gabbros may be: 1) primary igneous rocks, 2) contaminated magmatic rocks, or 3) metasomatic rocks.

If the hypersthene gabbro is a primary igneous rock, the problem arises whether it is an early phase of the Takomkane Batholith or a rock from a separate and unrelated intrusive event.

Poorly-exposed rocks east of Boss Creek, which are in contact with Nicola Group volcanic rocks suggest an origin by contamination of a primary magma. These rocks, which consist of diorite, gabbro, hornblende gabbro, anorthosite, and hypersthene gabbro appear to grade into pyroxenite near the contact with the volcanic rocks. Contamination of a syenodiorite-granodiorite magma by incorporation of andesitic volcanic rock along the contacts might possibly produce such a sequence of gabbroic rocks. Inherent features opposing this mode of origin include: 1) the high temperatures necessary to assimilate large quantities of andesites probably could not be obtained from the parent-

1 cm.

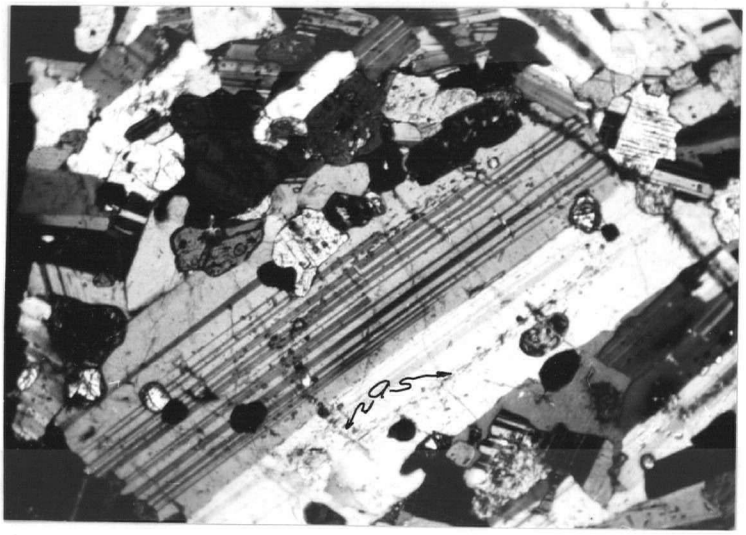


Plate 2.1. Photomicrograph (crossed nicols) of antiperthite (a) zone in plagioclase of hypersthene gabbro.

al magma, 2) the presence of anorthosites, 3) the lack of partly assimilated blocks of andesite, and 4) andesite is not basic enough to make gabbro from a syenodiorite-granodiorite melt.

The final possible origin of the hypersthene gabbro and related rocks is that they were formed through metasomatism of Nicola volcanic rocks by the intruding magma. Hornblende and augite-diopside hornfelsing of the Nicola andesites locally is extreme and rocks of almost 100 percent pyroxene are relatively common. Further speculation on this subject is not possible without much more detailed study, both in the field and in the laboratory.

TAKOMKANE BATHOLITH

Most of the rocks which crop out on Takomkane Mountain are part of a composite batholith which has not received an official name. Campbell (personal communication, 1965) has suggested the name TAKOMKANE BATHOLITH for these rocks and for ease of reference his suggestion will be followed. The area underlain by the batholith is shown in Figure 2.1.

Three phases of the Takomkane Batholith, which have been recognized and are described in this report, are 1) a syenodiorite phase, 2) a granodiorite phase, and 3) a porphyritic biotite granodiorite phase. Gradations between adjacent phases can be found. The writer does not know whether these phases are present or abundant in the main part of the batholith, but

Campbell (1961, 1963, and 1966) has mapped most of the batholith as predominantly granodiorite.

Syenodiorite

Syenodiorite is confined to the western and northeastern part of the map area (Map 1). Contacts between the syenodiorite phase and the granodiorite phase are transitional through a zone that ranges from a few tens of feet to more than 200 feet.

In hand specimens the syenodiorite is characterized by black hornblende crystals set in a grey matrix of plagioclase and orthoclase. The rock is generally massive, but locally, especially in more basic members, the mafic minerals are crudely aligned. Poikilitic orthoclase grains are conspicuous as they are in all the batholithic rocks.

The hypidiomorphic granular texture of the syenodiorite locally grades into an intergranular texture. Minerals identified in thin section include; plagioclase, orthoclase, hornblende, augite, biotite, quartz, and minor quantities of apatite, sphene, magnetite, pyrite, epidote, chlorite, and sericite, The modes of two specimens of syenodiorite determined by point counts of thin sections are shown in Table 2.3 (see also Figure 2.2).

Zoned (normal) plagioclase laths range in composition from cores of An_{51} to rims of An_{41}. Bent laths of plagioclase occur within the contact zones with other phases, but were not ob-

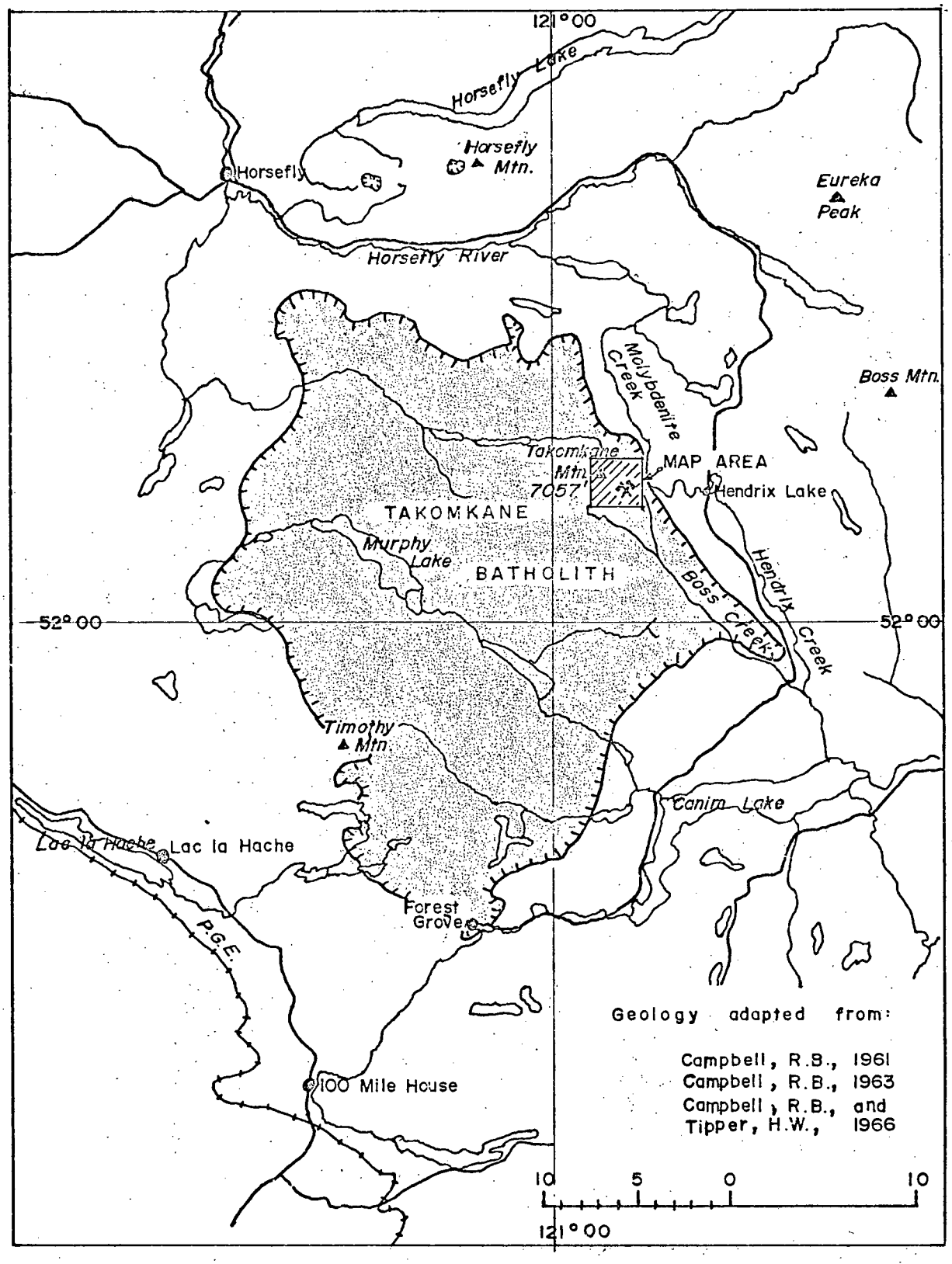


Figure 2.1. Location of area of study showing surface distribution of Takomkane Batholith.

served elsewhere in the syenodiorite. Sericite and/or epidote have replaced a small part of all plagioclase grains.

Poikilitic orthoclase, which encloses plagioclase, typically is perthitic adjacent to plagioclase grains. Orthoclase-quartz boundaries are micrographic.

Hornblende, which is the predominant mafic mineral in the rock, contains remnant patches of augite. Augite locally is as abundant as hornblende. Biotite is common and in some areas is more abundant than augite, especially near granodiorite phases.

Rounded xenoliths of hypersthene gabbro up to one foot in diameter are common throughout the syenodiorite. Dykes of andesite porphyry and andesite, pegmatite, and alkali basalt cut the syenodiorite phase of the batholith.

Granodiorite

Medium-to coarse-grained granodiorite crops out over much of Takomkane Mountain. The rock grades into syenodiorite toward the west and the northeast. The eastern contact was not observed.

In hand specimen black to greenish-black hornblende and biotite are set in a white to light-grey groundmass of plagioclase, orthoclase, and quartz. The rock generally is fresh but locally the feldspars are chalky on the surface and iron liberated from the mafic minerals during surface weathering coats some of the rock with a thin, light brown limonite stain.

Takomkane Batholith		Plagioclase		Orthoclase	Quartz	Biotite	Hornblende	Augite	Apatite	Sphene	Epidote	Chlorite	Carbonate	Sericite
Granodiorite Phase														
No.*	Sample	%	An											
1	6-26.2	60	38-48	10	14	2	12	-	x	x	x	2	-	x
2	7-10.3-1	60	36-44	12	15	5	10	1	x	x	x	x	-	x
3	7-12.1-1	55	38-42	15	10	3	17	1	x	x	x	x	-	x
4	7-12.14-1	57	33-42	14	12	6	11	-	x	x	x	x	-	x
5	8-2.11	58	39-45	13	17	4	9	-	x	x	x	x	-	x
6	8-31.2	54	35-44	19	13	10	3	-	x	x	x	x	x	x
7	36	50	38-41	8	12	8	15	-	x	x	x	x	x	x
8	BS-6	50	35-41	6	18	20	-	-	x	x	x	2	x	x
9	BS-19	56	35-42	18	11	6	7	-	x	x	x	x	x	x
10	BS-24	52	35-40	12	13	10	8	-	x	x	x	x	-	x
11	8-3.3	54	38-50	9	7	6	7	3	x	x	x	x	-	x
12	8-6.3	47	35-43	17	6	10	15	14	x	x	x	x	-	x
Porphyritic Biotite Granodiorite Phase														
13	6-27.1	58	24-39	18	10	-	12	-	x	x	x	x	x	x
14	6-27.2	55	28-34	17	17	-	10	-	x	x	x	x	x	x
15	7-7.3-1	61	22-40	25	12	1	-	-	x	x	x	x	-	x
16	8-28.2	44	23-37	15	25	16	-	-	x	x	x	-	-	x
Syenodiorite Phase														
17	7-14.3-1	61	41-51	11	2	5	16	3	x	-	x	x	-	x
18	6-25.1	60	48-50	10	1	4	12	11	x	-	x	x	-	x

x Minor - Absent * See Figure 2.2

Table 2.3. Modes of rocks from Takomkane Batholith.

The modes of several specimens of the rock, as determined from point counts of thin sections are shown in Table 2.3. Euhedral to subhedral crystals of zoned plagioclase range in composition from An_{36}(rims) to An_{50}(cores).

The orthoclase content, which varies considerably (6-19%), consists of both large poikilitic grains and smaller nonpoikilitic interstitial grains. Poikilitic microperthite grains enclose euhedral grains of plagioclase.

Quartz content ranges between 10 and 18 percent and decreases through the contact zone to less than one percent in the syenodiorite.

Hornblende is the predominant mafic mineral, comprising 5 to 7 percent of the rock. Augite remnants within the hornblende are generally rare but are common near the transition zone between the granodiorite and syenodiorite phases.

Brown biotite forms large (up to 10 mm. in length) ragged crystals that seldom comprise more than 4 percent of the rock. In specimen BS - 6 (number 8, Table 2.3) the introduction of hydrothermal biotite has raised the total biotite content to 20 percent.

The granodiorite phase of the Takomkane Batholith is cut by several other rock units. Porphyritic biotite granodiorite, a younger phase of the batholith, cuts the granodiorite in the mine area (Map 2). The granodiorite also is cut by various dykes, the Boss Breccias, and the Boss Mountain quartz monzonite stock.

Xenoliths of hypersthene gabbro are numerous within the granodiorite.

Age

A single K/Ar age from the granodiorite phase was determined as 187± m.y. by the Geological Survey of Canada (Leech et al, 1963). The sample was taken by Campbell 1800 feet east-southeast of Takomkane Volcano and well beyond the influence of the molybdenum deposits. This age would place the crystallization of the granodiorite phase of the batholith in the early Jurassic (White et al, 1967). Geologic evidence, which consists of an intrusive relationship of the batholith with Upper Triassic Nicola Group rocks, is consistent with this K/Ar age.

Porphyritic Biotite Granodiorite

A stock and several dykes of porphyritic biotite granodiorite, which are exposed on the surface and in the underground workings at Boss Mountain Mine, have intruded the granodiorite phase of the batholith.

Porphyritic biotite granodiorite crops out near the Boss Breccias as an elongate, nearly elliptical body measuring 800 feet long and 400 feet wide. The stock trends N 25° E and, as interpreted from subsurface intersections the contacts appear to be nearly vertical.

Plagioclase and biotite phenocrysts are set in a medium-

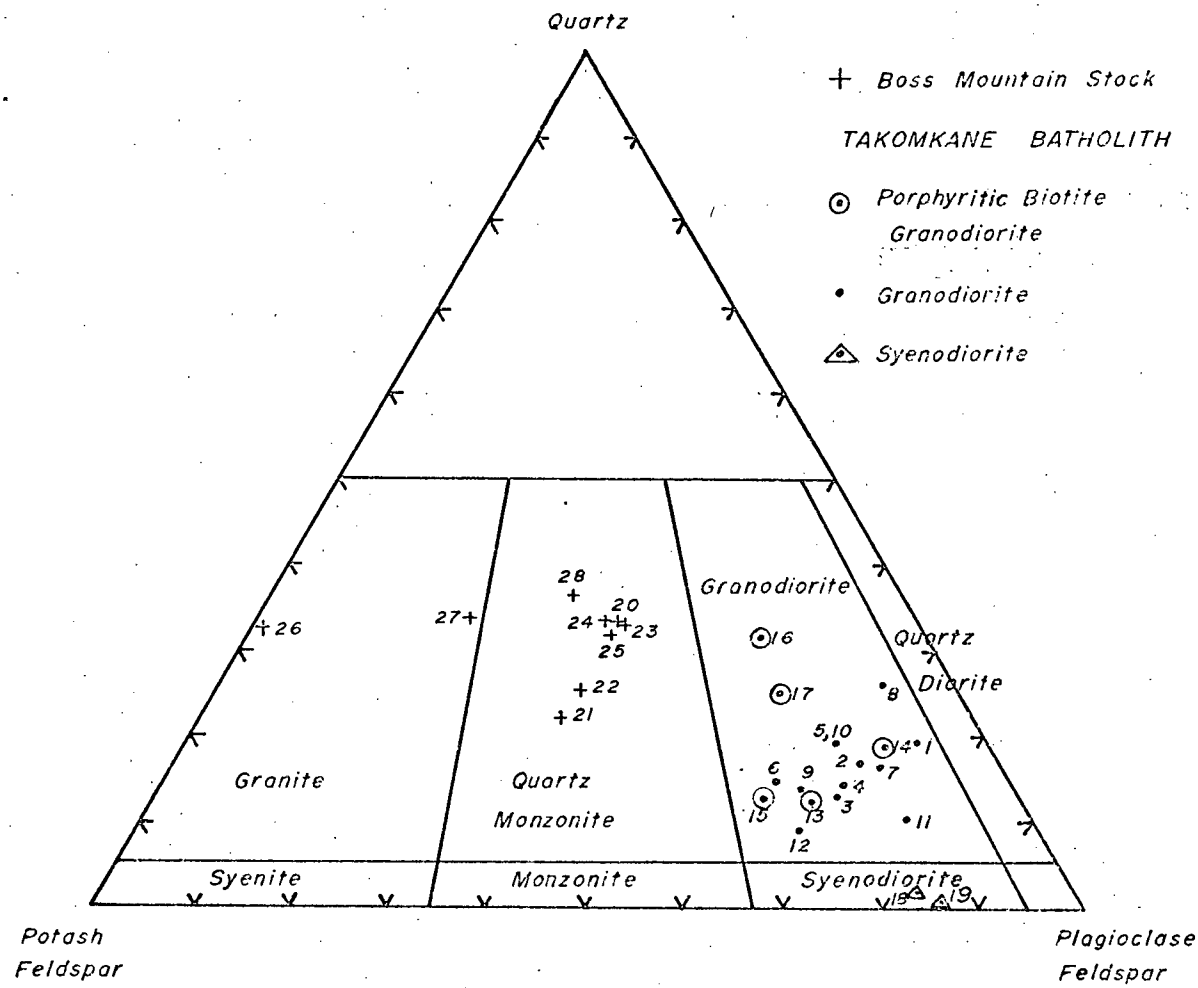


Figure 2.2. Composition of plutonic rocks from the Boss Mountain area. Numbers refer to Tables 2.3 and 2.6. (Diagram after Johannsen, 1931).

grained groundmass of interlocking quartz and orthoclase. Sphene, apatite, and zircon are the accessory minerals and chlorite, rutile, epidote, sericite, pyrite and limonite are alteration products. The modes of typical porphyritic biotite granodiorites are shown in Table 2.3 (numbers 13 through 16).

Euhedral plagioclase phenocrysts (8-15 mm. in length) display oscillatory zoning. The anorthite content increases and then decreases from the core to the rim. Combination twinning is a common feature of the plagioclase phenocrysts. Sericite has preferentially replaced certain zones in the plagioclase.

Orthoclase is perthitic and rarely forms subgraphic intergrowths along contacts with quartz grains. The grain boundaries of orthoclase and quartz are interlocking.

Brown magmatic biotite is, for the most part, replaced by mosaic masses of hydrothermal biotite. Chlorite locally has replaced much of the biotite.

Medium- to fine-grained porphyritic dykes correlative with the porphyritic biotite granodiorite were intersected in the underground workings. The dykes contain biotite, plagioclase, and orthoclase phenocrysts in a grey matrix of quartz and orthoclase.

The porphyritic biotite granodiorite body grades into granodiorite over a distance of a few tens of feet. Porphyritic biotite granodiorite dykes cut the granodiorite and are con-

sidered as the last phase of the batholith to crystallize. The Boss Breccias and several other rock units cut the porphyritic biotite granodiorite.

ANDESITE PORPHYRY AND ANDESITE

Dykes of andesite and andesite porphyry and their altered equivalents outcrop sporadically throughout the map area. There are two sets of dykes. The most prominent set strikes north 20 to 45 degrees west with dips ranging from 70 degrees east to 70 degrees west. Most of these dykes are vertical. The second set, which is subordinate in number but important from an economic viewpoint, strikes north 60 to 72 degrees east and dips 40 to 80 degrees northwest. Widths range from six inches to about ten feet, but most dykes are between two and four feet wide. The vertical extent of some andesite dykes exceeds 450 feet without visible change in trend or character. Most dykes are exposed for only a few tens of feet, but some have been traced for 100 feet or more and others have been projected by drill hole intersections for lengths exceeding 1,000 feet.

Phenocrysts of hornblende and less abundant plagioclase lie in a dark grey groundmass. The texture ranges from intergranular to trachytic with glomerophyric hornblende in porphyritic varieties. Phenocrysts of hornblende and plagioclase comprise 18 to 20 percent of the dykes and plagioclase forms the bulk of the groundmass. The modes fall within the following

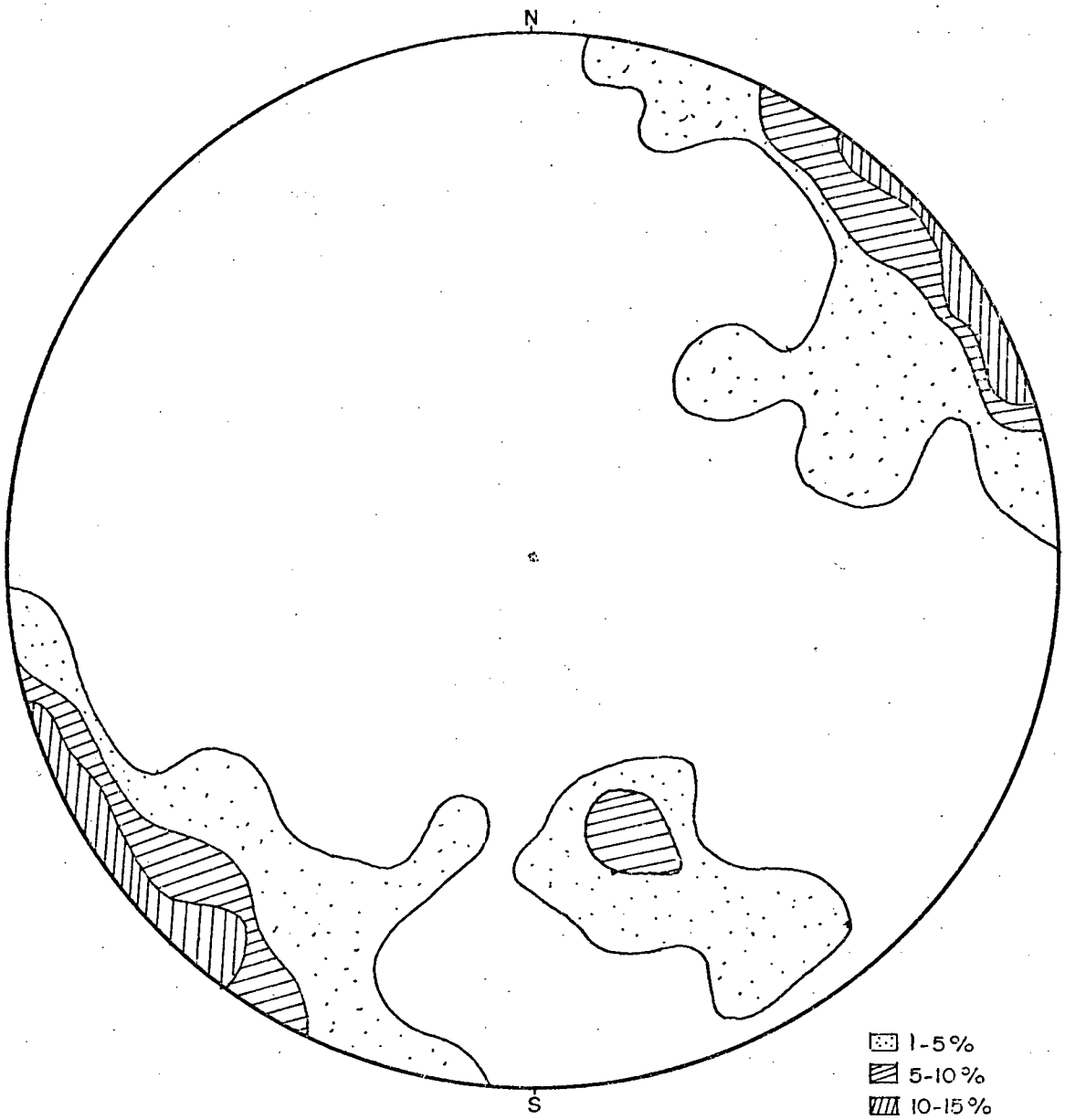


Figure 2.3. Equal-area projection (lower hemisphere) of poles to 74 andesite and andesite porphyry dykes.

limits: hornblende 15-20%, biotite 0-2%, plagioclase 78-81%, and minor amounts of quartz, apatite, zircon, chlorite, epidote, sericite, carbonate, pyrite, and magnetite.

Hornblende is strongly pleochroic (green to light brown) and individual crystals attain a maximum length of 20 mm. Phenocrysts commonly are twinned and show marked zoning. Hornblende locally has been replaced by mosaics of epidote.

Plagioclase phenocrysts attain a maximum length of five mm., but average two mm. Phenocrysts are zoned (normal) with rims of An_{40} and cores of An_{55}. Groundmass plagioclase, which comprises up to 75 percent of the rock, has a composition of An 43-45. Carbonate, sericite, and/or clay minerals locally have replaced plagioclase.

Biotite has replaced hornblende, especially on the rims of the hornblende grains. Chlorite replaced biotite and hornblende.

PEGMATITE

Pegmatite dykes crop out in the batholithic rocks throughout the map area. Some dykes are sinuous with highly irregular thicknesses. The maximum observed thickness is 14 inches and the average thickness is about 5 inches.

The grain size of the major minerals, which ranges from 5 mm. to 80 mm., generally averages 20 to 40 mm. Accessory minerals seldom exceed 10 mm. in length.

	Quartz	K-feldspar	Plagioclase	Tourmaline	Biotite (?)	Sphene	Magnetite
		Perthite					
A	41	43		12-16	-	x	x
	Graphic						
B	78		12	0-7	x	x	x

A. Dykes less than six inches in thickness.
B. Dykes greater than six inches in thickness.

Table 2.4. Modes of typical pegmatite dykes from Boss Mountain area.

The dykes fall into two broad categories. Dykes less than six inches in thickness are composed of quartz, perthite, black tourmaline, sphene, and magnetite (Table 2.4, A). Dykes greater than six inches in thickness contain graphic quartz and potash feldspar, plagioclase and a chloritized phyllosilicate (biotite?), as well as tourmaline, sphene, and magnetite (Table 2.4, B). Many pegmatite dykes are cut by narrow epidote veinlets. Modal determinations were made on hand specimens using a 2 mm. transparent grid.

A close relationship exists between pegmatite dyke orientation and geographic location on Takomkane Mountain. The most prominent strike is north 40 to 70 degrees west with dips of

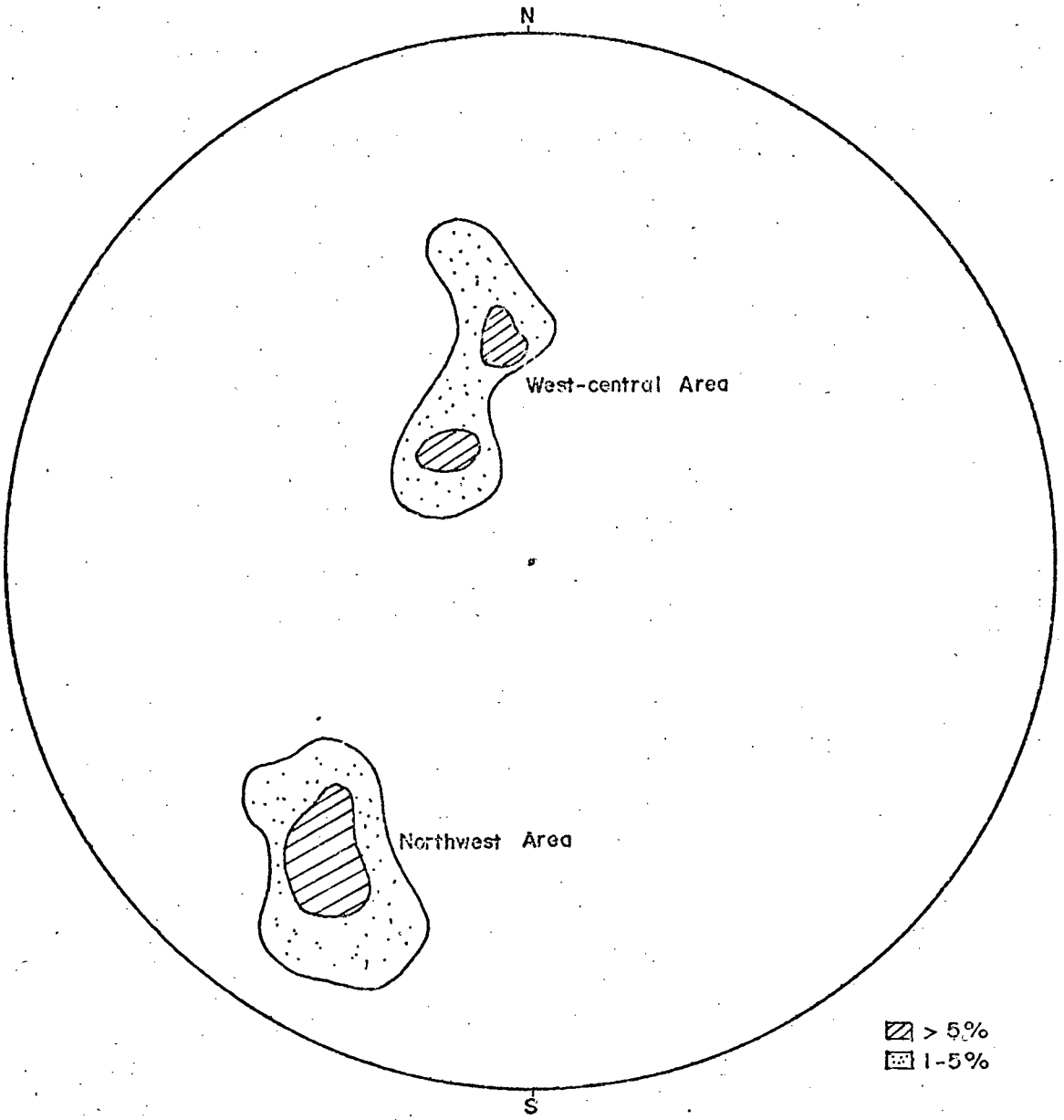


Figure 2.4. Equal-area projection (lower hemisphere) of poles to 47 pegmatite dykes. (The labels refer to parts of the map area).

40 to 80 degrees northward (Figure 2.4). Dykes of this orientation crop out only in the northwest part of the map area and occupy pre-existing (or possibly contemporaneous) joints. Each pegmatite dyke symbol in this area of the map represents 10 dykes. Joints of this orientation also are found only in the northwest portion of the map area. The dykes range from one inch to four inches in thickness and can be traced for several tens of feet along their strike.

In the west-central part of the map area the pegmatite dykes which are few in number strike north 45 to 80 degrees east and dip 10 to 45 degrees south. The dykes are more irregular in shape and size than the northwest-trending dykes. Thickness ranges from a minimum of 3 inches to a maximum of 14 inches. The lack of observed joints of this orientation may explain the irregular form of the dykes in this specific area.

BOSS MOUNTAIN STOCK

The Boss Mountain Stock is a body of quartz monzonite and quartz monzonite porphyry which intruded the granodiorite phase of the Takomkane Batholith. The full areal extent of the stock is unknown. However, work done to date indicates a minimum east-west surface diameter of 2,500 feet. Because outcrop is poor in the area underlain by the stock, information concerning the petrography and other features of the stock has been obtained from underground exposures, and the surface contact is, in

part, projected from underground information.

Specimens from different parts of the Boss Mountain Stock appear quite different in hand specimen, but the modes are nearly the same. The differences in appearance are caused by variable degrees of sericitization and minor differences in grain size.

Boss Mountain Stock		Plagioclase		Orthoclase	Quartz	Biotite	Hornblende	Apatite	Zircon	Sericite	Chlorite	Epidote	Carbonate	Rutile
No.	Sample No.	%	An											
20	56	32	13-16	27	30	1	-	x	x	10	x	x	x	x
21	59	33	7-13	37	20	1	-	x	x	9	x	-	x	x
22	59+10	32	10-16	34	24	-	-	x	x	9	x	x	x	x
23	10-27.10	35	3-16	29	34	x	-	x	x	2	-	-	x	x
24	10-28.9	34	6-16	30	33	2	-	x	x	x	x	-	x	x
25	8-9.4	35	4-14	31	32	-	-	x	x	1	x	-	x	x
26	37a(outer chill zone)	1	-	67	32	x	x	x	x	-	-	-	-	-
27	37b(inner chill zone)	21	3-16	43	35	-	x	x	x	x	x	x	x	x
28	37	29	11-18	30	33	5	-	x	x	x	2	x	x	x

x Minor See Figure 2.2

Table 2.5. Modes of rocks from the Boss Mountain Stock.

In all parts of the stock, except in a narrow part of its chilled contact, subhedral plagioclase, orthoclase, and quartz phenocrysts characterize the rock. Pyrite is ubiquitous.

As observed in the subsurface workings the east contact of the Boss Mountain Stock with the granodiorite phase of the batholith is sharp and well-defined (Plate 2.2 and 2.3) and dips 45 to 60 degrees to the east.

Outer Chill Zone

The stock shows a chilled zone six to eight feet wide. The outer four to six inches of this chill zone are composed almost entirely of graphic intergrowths of quartz and orthoclase (Plates 2.3 and 2.4) with very minor quantities of biotite (now altered to chlorite), plagioclase, hornblende, apatite and zircon. The mode of the rocks in the outer chill zone is shown in Figure 2.2 and Table 2.5 (number 26). The rock (granophyre) in the outer chill zone is fresh and the graphic intergrowth is easily recognized with a hand lens. The outer chill zone grades rapidly into porphyritic granite with a fine-to medium-grained groundmass, the inner chill zone. The pinkish outer chill zone contrasts with the greenish to grey-green inner chill zone.

Inner Chill Zone

The inner chill zone is characterized by subhedral quartz phenocrysts, and subhedral plagioclase crystals set in a groundmass of aplitic to granophyric quartz and orthoclase with a little interstitial plagioclase. The texture of the groundmass of this phase of the stock is identical to the texture of the

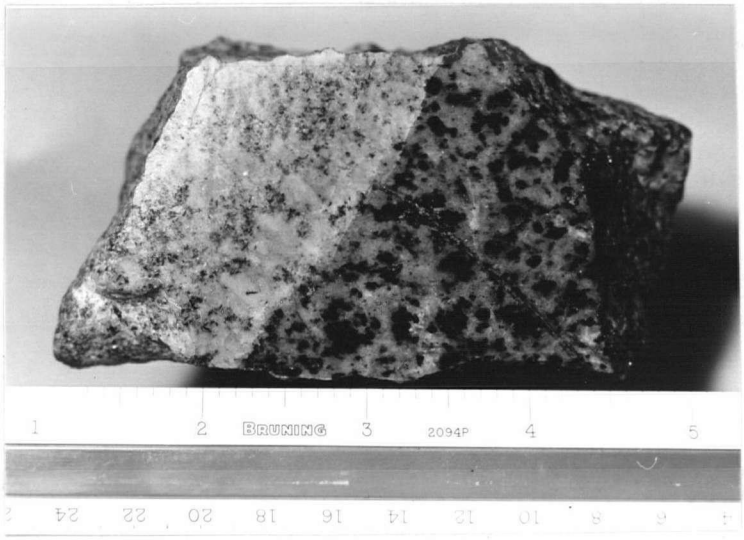


Plate 2.2 Contact between chilled margin (granophyre) of Boss Mountain Stock (left) and granodiorite phase of Takomkane Batholith (right). (Scale is in inches.)

1 cm.

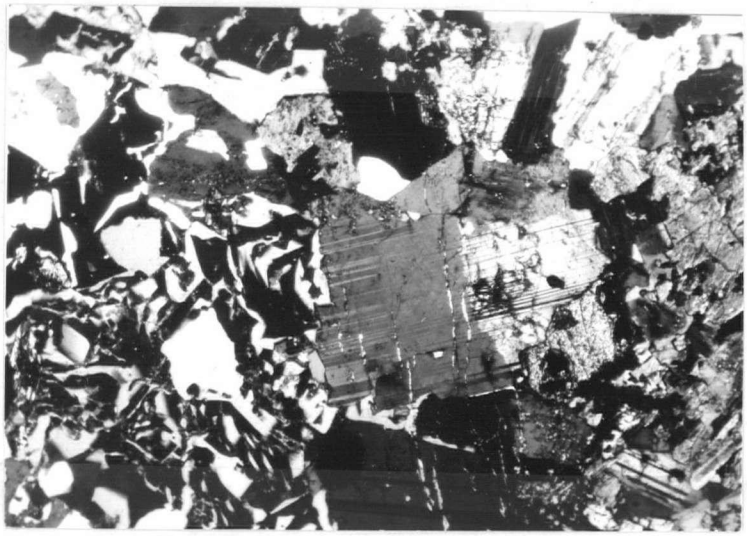


Plate 2.3. Photomicrograph (crossed nicols) of contact between chilled margin (granophyre) of Boss Mountain Stock (left) and granodiorite phase of the Takomkane Batholith (right).

rhyolite porphyry dykes. The mode of a rock from the inner chill zone is granite in composition and is shown in Figure 2.2 and Table 2.5 (number 27). The mode is almost identical to the modes of the rhyolite porphyry dykes (Table 2.6).

Glassy, clear hexagonal quartz phenocrysts are partly embayed. Extinction generally is uniform, but isolated phenocrysts exhibit weak undulatory extinction. The quartz phenocrysts measure up to 6 mm. in diameter and average 2 mm. Small phenocrysts are more nearly euhedral than are larger ones.

Sericitized, rather ragged plagioclase phenocrysts are normally zoned with cores of An_{12-16} and narrow rims of An_{3-8}. Anhedral groundmass plagioclase, which is less altered than the phenocrysts, has a composition of An_{10-12}. Plagioclase phenocrysts are up to 7 mm. in length and average about 3 mm., whereas the groundmass plagioclase seldom exceeds 0.3 mm. in length.

Orthoclase, which is confined to the groundmass of the chilled rock, occurs as granophyric to aplitic intergrowths with quartz. Biotite has been highly altered to very light green, weakly pleochroic crystals of chlorite with rutile inclusions.

Accessory and alteration minerals observed in thin sections are: zircon, apatite, chlorite (with rutile inclusions), carbonate, epidote, and pyrite. Some zircon crystals have thin overgrowths.

1 cm.

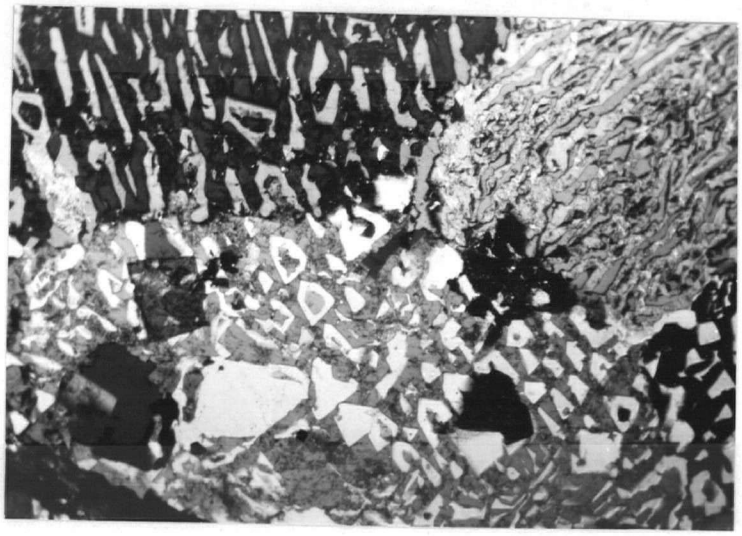


Plate 2.4. Photomicrograph (crossed nicols) of granophyre from the outer chill zone of the Boss Mountain Stock.

1 mm.

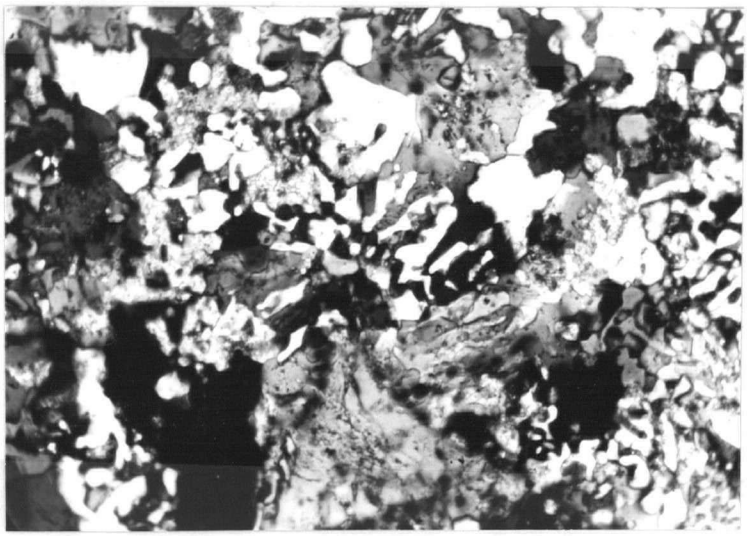


Plate 2.5. Photomicrograph (crossed nicols) of sub-granophyric texture of the groundmass of rhyolite porphyry dyke.

Quartz Monzonite Porphyry

Medium to coarse-grained quartz monzonite porphyry comprises the bulk of the Boss Mountain Stock. The core (?) of the stock, where fracturing is widely spaced, is composed of fresh, orange-coloured quartz monzonite porphyry. The orange colour is imparted by feldspar phenocrysts and groundmass. Both plagioclase and orthoclase are shades of orange.

Phenocrysts of subhedral quartz, plagioclase and orthoclase set in a groundmass of quartz and orthoclase characterize the porphyry. The texture is porphyritic with an hypidiomorphic granular groundmass. The plagioclase-orthoclase ratio of the phenocrysts (10:1) contrasts with the ratio in the groundmass (1:30). Primary minerals include: plagioclase, orthoclase, quartz, biotite, and minor quantities of hornblende, zircon, and apatite. Secondary minerals, in order of decreasing quantity, consist of: sericite, carbonate, pyrite, chlorite, rutile, epidote, and zeolite. The modes of seven specimens of quartz monzonite porphyry are shown in Table 2.5 and in Figure 2.2 (numbers 20, 21, 22, 23, 24, 25 and 28).

Subhedral to euhedral quartz phenocrysts have attained a maximum diameter of 17 mm. Small phenocrysts (less than 10 mm.) generally are nearly euhedral with well-developed crystal faces, but phenocrysts larger than 10 mm. in diameter are subhedral with highly embayed crystal faces.

Oligoclase (An_{10-18}) phenocrysts with very weakly-zoned rims of An_{3-8} exhibit varying degrees of sericite replacement. The phenocrysts range from 3 to 14 mm. in length but most measure between 4 and 8 mm. The colour of the plagioclase changes from orange in the fresh rock to greenish grey in intensely sericitized rocks. Fresh plagioclase contains irregular dark reddish patches. Cause of the orange colouration is not known.

Subhedral orthoclase phenocrysts, which are light orange in colour range from 8 to 23 mm. in length. Most crystals are fresh. Anhedral orthoclase in the groundmass seldom exceeds 2 mm. in diameter.

Mafic minerals are subordinate to other silicates in the rock. Biotite (generally bleached or altered to chlorite) and/or hornblende rarely are observed in thin section.

Sericitization of the quartz monzonite porphyry ranges from weak to intense and has preferentially affected plagioclase. Phenocrysts of orthoclase have escaped sericitization, except in the most intensely altered rocks. Orthoclase in the groundmass has been sericitized. The light orange colour of the orthoclase phenocrysts becomes more creamy with increasing sericitization of the orthoclase. Sericitization has imparted a sugary, greasy appearance to the rock.

Chlorite is present in all samples. Between crossed nicols the chlorite is an anomalous chocolate brown colour. Red,

amber, green, or black rutile inclusions occur in both chlorite and in sericite. Most chlorite is interstitial and is believed to be of hydrothermal origin. Ubiquitous pyrite forms up to 11 percent of the rock.

Throughout the quartz monzonite porphyry, widely-spaced miarolitic cavities, originally bordered by euhedral crystals of quartz and orthoclase, have been filled with sericite, chalcopyrite, and carbonate. Apatite rods occur within quartz crystals. The cavities, which generally are small (3-5 mm. in length) and irregular, obtain a maximum length of 25 mm.

Rhyolite Porphyry and Rhyolite

Rhyolite porphyry and rhyolite dykes, which occur only near the molybdenite deposits, are apophyses of the Boss Mountain Stock. Dykes range in thickness from 6 inches to 12 feet. Some have been projected along strike from intermittent outcrop and drill hole intersections for more than 1,000 feet. Vertical projections from subsurface workings, drill hole intersections, and surface outcrop exceed 500 feet. Most of the dykes strike north 35 to 50 degrees west with near-vertical dips (Figure 2.5).

The dyke-rock generally is porphyritic with phenocrysts of colourless euhedral quartz, white subhedral plagioclase, and light pinkish tan, euhedral orthoclase set in a light tan to grey, aphanitic matrix. Non-porphyritic varieties are less

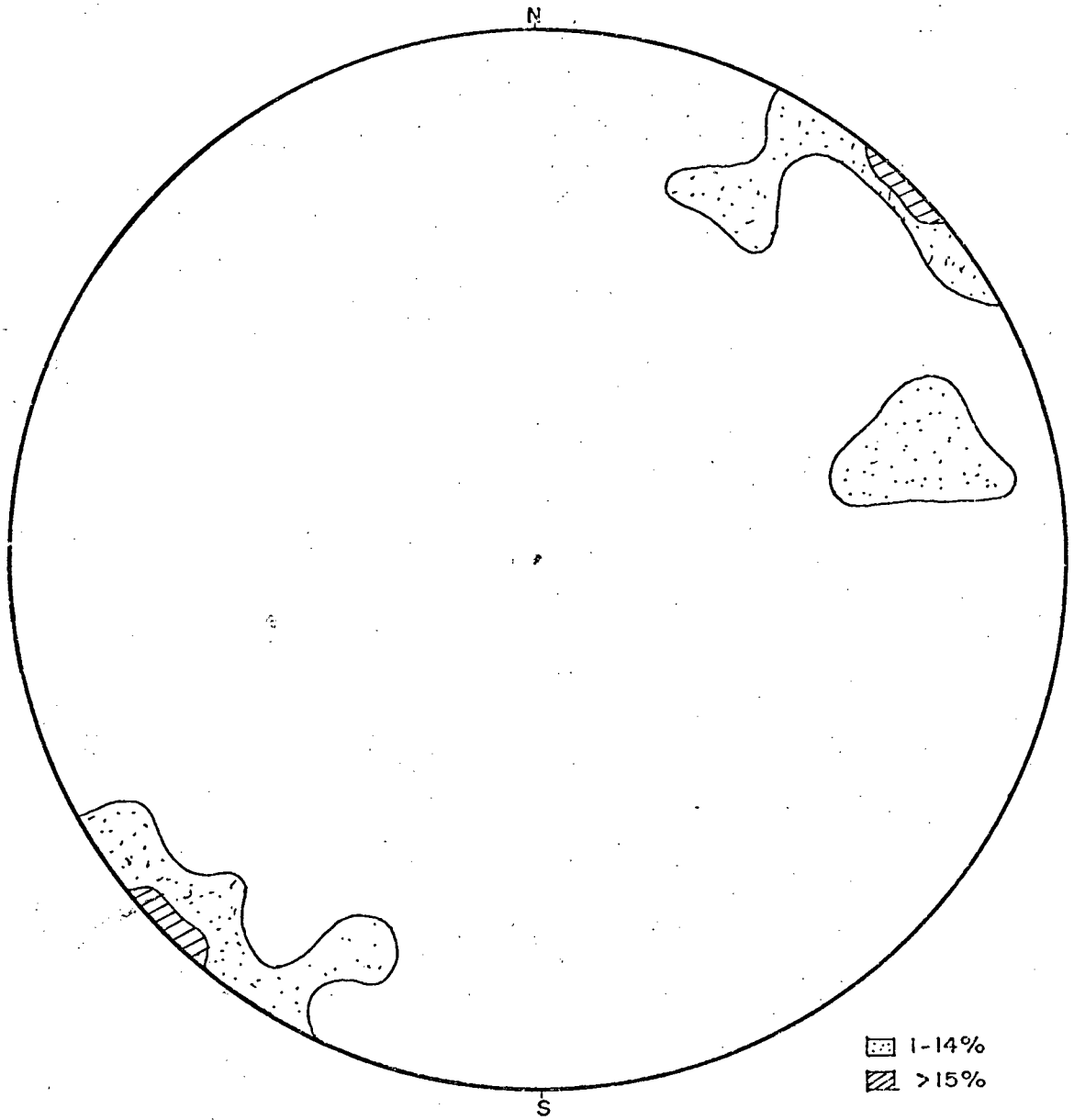


Figure 2.5. Equal-area projection (lower hemisphere) of poles to 18 rhyolite porphyry and rhyolite dykes.

common, but are identical in colour (light tan to grey) to the porphyritic dykes. Some aphanitic grey dykes are almost cherty in appearance. Phenocrysts attain a maximum length of 7 mm. and comprise up to 25 percent of the rock. The rhyolite generally is highly fractured with quartz-molybdenite veinlets, yellow muscovite, or brown stilbite coating most of the fractures.

Typical rhyolite porphyry consists of 20 to 25 percent phenocrysts of quartz, microperthite, and plagioclase in a ratio of nearly 1:2:3 set in a granophyric (Plate 2.4) to aplitic groundmass. The groundmass, which comprises 75 to 80 percent of the rock, consists of quartz, orthoclase, and plagioclase in a ratio of 3:3:1. Biotite, hornblende, sericite, apatite, zircon, chlorite, rutile, magnetite, pyrite, carbonate and molybdenite form a very minor part of the groundmass. The modes of five rhyolite porphyry and rhyolite dykes are shown in Table 2.6.

Subhedral plagioclase phenocrysts with corroded edges and anhedral crystals in the groundmass have a composition of An 7-10. Sericite alteration of the plagioclase ranges from weak to extreme. The phenocrysts have the same physical appearance and almost the same composition as plagioclase phenocrysts in the Boss Mountain Stock. Euhedral microperthitic orthoclase phenocrysts comprise up to 10 percent of the rock. The exsolved plagioclase locally is large enough to allow determination of the anorthite content (An 10-12).

Specimen		Quartz	Orthoclase (Microperthitic)	Plagioclase %	Plagioclase An	Biotite	Hornblende	Apatite	Zircon	Magnetite	Molybdenite	Chlorite	Rutile	Sericite	Pyrite	Carbonate
91	(P)	5	8	12	8-10	-	-	-	-	-	-	-	-	-	-	-
	(G)	30	34	11	8	x	-	x	x	x	-	x	-	x	x	x
91-30	(P)	4	7	10	10	-	-	-	-	-	-	-	-	-	-	-
	(G)	35	35	9	7	x	-	x	x	x	x	x	x	x	x	-
BS-17	(P)	3	5	12	9-10	-	-	-	-	-	-	-	-	-	-	-
	(G)	32	36	12	9	-	x	x	x	x	-	-	-	x	x	x
8-41	(P)	7	8	8	7-8	-	-	-	-	-	-	-	-	-	-	-
	(G)	36	32	9	7	x	-	x	x	x	-	-	-	x	-	-
BS-26		40	46	15	7-9	-	-	x	x	x	-	x	-	x	x	x

P Phenocrysts G Groundmass x Minor - Absent

Table 2.6 Modes of rhyolite porphyry and rhyolite dykes from the Boss Mountain mine area.

Quartz occurs as euhedral weakly embayed phenocrysts (Plate 2.6) and in the groundmass as granophyric and subgranophyric intergrowths with orthoclase. The total quartz content of the dykes is 35-42 percent. The quartz phenocrysts closely resemble the small phenocrysts in the Boss Mountain Stock.

Pale brown hydrothermal biotite forms up to 2 percent of the rhyolite porphyries. Biotite locally has been bleached almost colourless and contains inclusions of reticulated rutile.

1 cm.

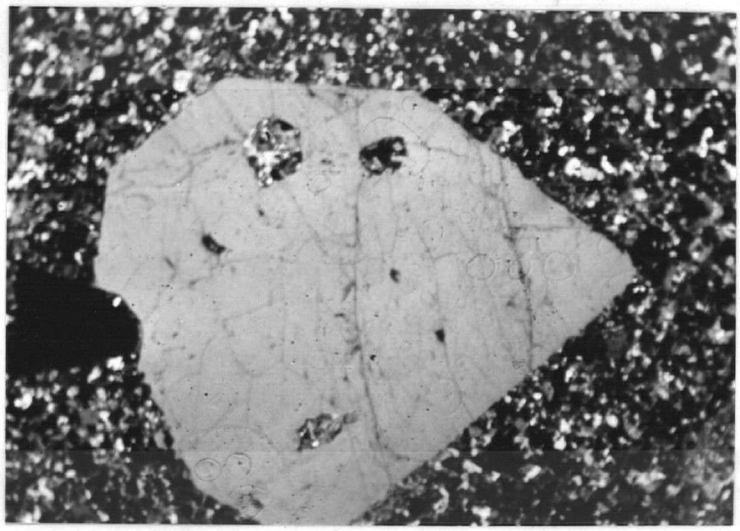


Plate 2.6. Photomicrograph (crossed nicols) of quartz phenocryst in rhyolite porphyry dyke.

1 cm.

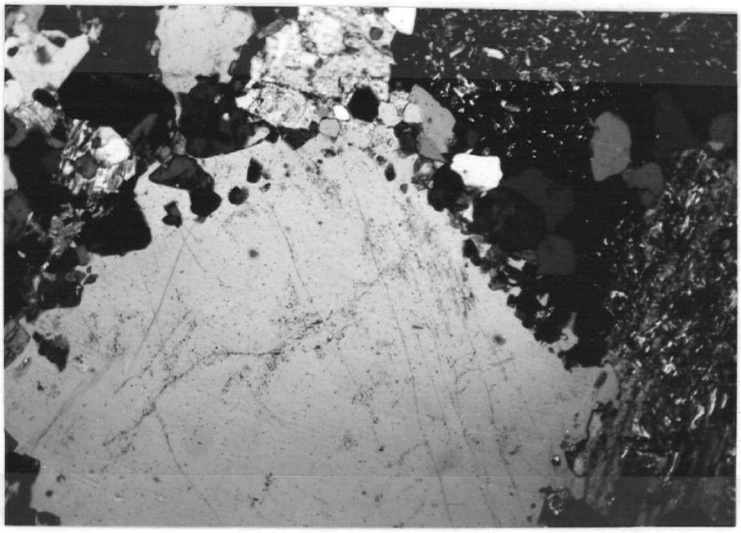


Plate 2.7. Photomicrograph (crossed nicols) of embayed quartz phenocryst in quartz monzonite porphyry.

Rhyolite porphyry dykes cut the batholithic rocks and andesite dykes, and nonporphyritic rhyolite dykes cut the Phase I Breccia (described in later section). The dykes are considered to be related to the Boss Mountain Stock. A genetic relation between these two rock units is suggested by 1) the identical composition and texture of the inner chill zone of the Boss Mountain Stock and of the dykes, 2) character and composition of the plagioclase, 3) character of the quartz phenocrysts, 4) zircon, which is the common accessory mineral in both units, and 5) geographic proximity. Grain size is the only visible difference in these two rocks.

Environment of Emplacement

General conclusions concerning the environment of emplacement of the Boss Mountain Stock can be drawn by comparing the characteristic features with Buddington's classification of plutons (1959). Many of the criteria diagnostic of epizonal plutons are characteristic of the Boss Mountain Stock. The features of the Boss Mountain Stock, which have been described, and are characteristic of epizonal plutons, are itemized below:

1) a largely or wholly discordant relation to the surrounding rocks.
2) chilled margins with sharp contact.
3) granophyric borders. Granophyre, in general, occurs exclusively in the epizone.

4) genetically related porphyry dykes.

5) no foliation; some may have primary linear structure.

6) miarolitic cavities.

7) associated breccias with the smaller plutons.

8) no contact metamorphism adjacent to porphyritic varieties.

Some features diagnostic of epizonal plutons are lacking or were not observed at Boss Mountain. These features are listed below.

1) Epizonal plutons generally contain roof pendants. (Roof pendants may have been removed by erosion; or may be present, but not observed because of the lack of exposures.)

2) Volcanic rocks of the same composition as the pluton are often present, except in plutons from the deeper part of the epizone.

3) Lamprophyre dykes generally are associated with epizonal plutons.

In summary, the observed features of the Boss Mountain Stock are diagnostic of epizonal plutons. The lack of some features is to be expected and the examples cited by Buddington (1959) do not contain all features diagnostic of epizonal plutons. However, the lack of certain features is unimportant in the classification of the pluton, the important fact is that the Boss Mountain Stock does not contain features diagnostic of plutons emplaced in the mesozone or catazone.

BOSS BRECCIAS

Breccias are geologically interesting and economically important features of the Boss Mountain mine and are referred to collectively as the "Boss Breccias". Three phases have been recognized: Phase I has a comminuted grey matrix; Quartz Breccia (Phase II) has a quartz matrix; and Phase III has a comminuted brown matrix. Only the modes of occurrence and petrography of these breccia phases will be described in this section; their genesis and relations to orebodies will be dealt with in Chapters 4 and 5.

Phase I Breccia

Phase I Breccia crops out as three apparently unconnected bodies near the molybdenite deposits (Map 2). Boundaries of the breccia bodies are based on exposures and diamond drill intersections and are somewhat conjectural because of the paucity of outcrop. Contacts between Phase I Breccia and older rocks are sharp to indistinct. The breccia grades progressively into fractured granodiorite with little matrix and then into massive granodiorite.

Three bodies of Phase I Breccia were found during the course of mapping the ore deposits. The largest body is adjacent to the breccia ore zones (described in a later section) and extends in a westerly direction for more than 1000 feet (Map 2). The west end of the breccia has amoeboid projections into the grano-

diorite, but elsewhere the contacts are regular.

A second body of Phase I Breccia lies about 400 feet south of the Phase I Breccia body described above and the two bodies are separated by an area of granodiorite and porphyritic biotite granodiorite. The body trends generally northwesterly for 500 feet, widens to the southeast, and terminates with amoeboid projections in granodiorite.

The third exposed body of Phase I Breccia, which lies about 1000 feet north of the largest Phase I Breccia body, is exposed in a few scattered outcrops over an area 120 feet long and 50 feet wide. The size and shape of this body is unknown.

Phase I Breccia consists mainly of fragments of granodiorite in grey to black matrix (Plates 2.8 and 2.9). Rhyolite porphyry, andesite porphyry, and/or sugary quartz vein fragments generally are subordinate in quantity to granodiorite and comprise less than 5 percent of the fragments. The comminuted matrix has been recrystallized in some areas and recognition in hand specimen is difficult. Zones and "veinlets" of broken plagioclase and hornblende crystals are the major indicators of recrystallized areas. Isolated dyke fragments in otherwise homogeneous granodiorite also provide clues to areas of recrystallized matrix.

The angular to subrounded fragments range in size from microscopic to several feet in diameter. Predominant range of

size is from two to ten inches. Fragment edges generally are sharp and distinct, although in places fragment boundaries seem irregular and ill-defined (possibly where the surface observed is nearly parallel to the fragment-matrix interface).

Locally, and even over distances of more than 100 feet, the proportion of matrix in the Phase I Breccia may reach 40 percent, but on the whole is about 10 percent. Microscopic examination reveals that the matrix is composed of fine-grained (.01 to 1.5 mm.) fragments of quartz, orthoclase, plagioclase, hornblende, biotite, apatite and sphene. Angular grains of orthoclase, plagioclase and apatite were observed within grains of homogeneous, unstrained, recrystallized quartz. Quartz in rock fragments has strong undulatory extinction.

In restricted areas of the Phase I Breccia the fragments are cemented by non-granulated rhyolite porphyry. Such areas have a maximum length of 40 feet (Map 2) and generally are somewhat elongate in plan.

Minute subhedral grains of light brown biotite are locally disseminated among the other minerals of the matrix and also occur in veinlets and as selvedges on recrystallized quartz and orthoclase. Evidentally such biotite is younger than Phase I Breccia.

Phase I Breccia, which contains fragments of granodiorite, porphyritic biotite granodiorite, andesite porphyry, rhyolite

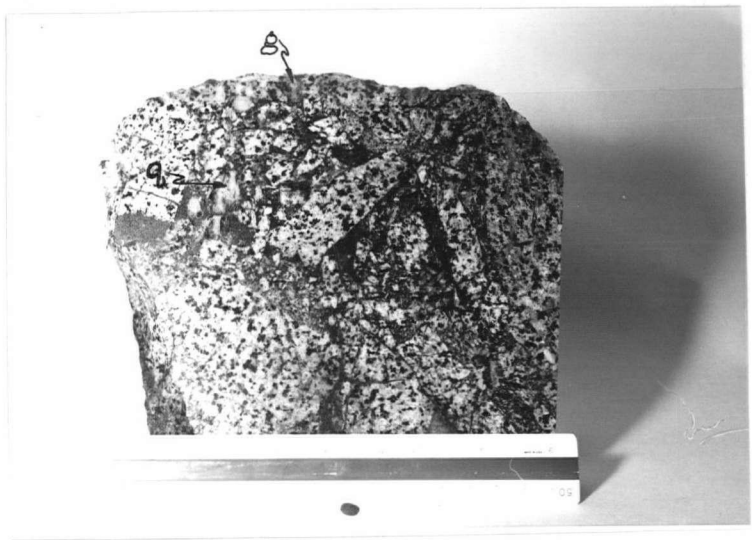


Plate 2.8. Phase I Breccia. Angular fragments of granodiorite, group 1 quartz vein (q), and garnet-hornblende veinlet (g) in comminuted matrix (black). (Scale is in inches).

Plate 2.9. Phase I Breccia. Angular fragments of granodiorite and rhyolite porphyry (r) in comminuted matrix (grey). (Scale is in inches.)

porphyry, garnet veinlets, and sugary quartz veins, must be younger than all such rock units.

Intrusion of rhyolite dykes and formation of Phase I Breccia probably are cogenetic processes. The Phase I Breccia cuts rhyolite porphyry dykes and dyke fragments are common within the breccia. Irregular bodies of rhyolite porphyry locally form part of the matrix of the Phase I Breccia (Map 2). Finally, nonporphyritic rhyolite dykes cut the Phase I Breccia and occur as fragments in the later breccia phases. In summary, dyke emplacement commenced before and continued during and after formation of the Phase I Breccia, but ceased before formation of Quartz Breccia.

Quartz Breccia

During a second phase of breccia formation, quartz was introduced as matrix between rock fragments. Quartz matrix characterizes the breccia and has given rise to the term "Quartz Breccia".

Quartz Breccia bodies are well-defined, steeply plunging lenticular or pipe-like bodies. The largest of these, part of the Main Breccia Zone (Map 2), is somewhat lenticular in surface plan. The zone trends north 35 degrees west, plunges steeply northwestwards, and dips 75 to 90 degrees eastward for the first 500 vertical feet. The north end and the southwest side of the breccia have been modified by later brecciation and

the original contacts were destroyed.

Surface exposure of the Main Breccia Zone is 500 feet long and at the maximum is 150 feet wide. The configuration of the body is well-defined by underground workings and diamond drill holes down to the 5045-foot level. Below this level, a few drill holes have defined the western contact, but not the eastern contact. The dip of the western contact remains relatively constant as far as it has been traced.

The South Breccia Zone is an ellipsoidal area of poorly-developed quartz breccia which lies 220 feet south 35 degrees east of the Main Breccia Zone. The zone strikes north 55 degrees west on surface with a length of 250 feet and a width ranging from 90 to 110 feet. The degree of brecciation increases with increasing depth.

Smaller bodies of Quartz Breccia cut the Phase I Breccia. The smaller bodies are elliptical in plan and range from 10 to 35 feet along the maximum diameter. Drill hole intersections confirm a vertical to near-vertical plunge to the pipes. Distribution of the smaller pipes is erratic and does not appear to follow any obvious controls.

Most contacts of the quartz breccia with the granodiorite are transitional; some are sharp. Transitional contacts grade from Quartz Breccia to quartz stockwork with nonrotated fragments and then into massive granodiorite with widely separated

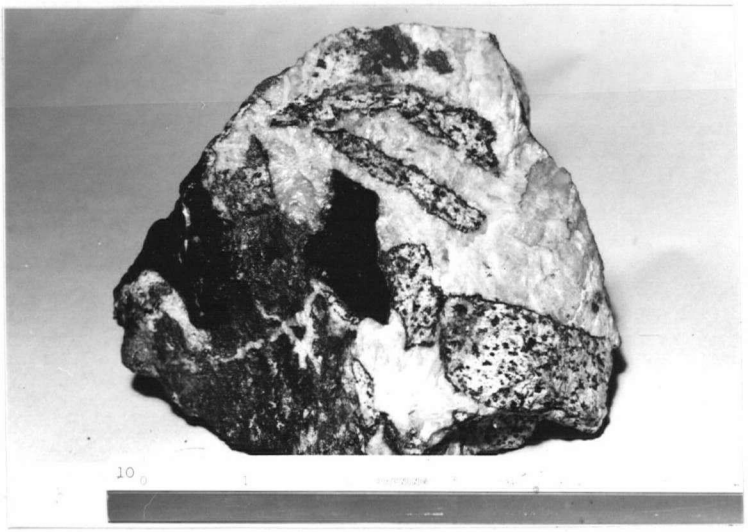


Plate 2.10. Quartz Breccia. Fragments of granodiorite and altered andesite dyke (black) in quartz matrix (white). Molybdenite forms the dark-coloured rims on the fragments. (Scale is in inches.)

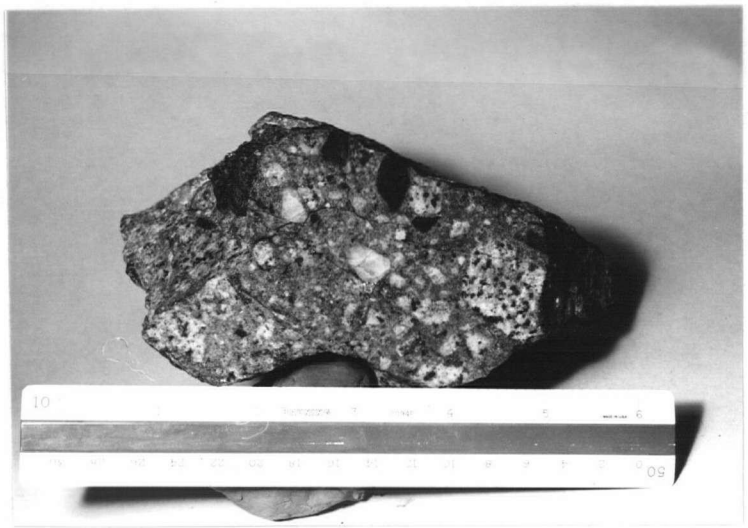


Plate 2.11. Phase III Breccia. Angular to rounded fragments of granodiorite, quartz (white), and altered andesite dyke (black) in comminuted matrix (grey). (Scale is in inches.)

quartz veins.

Sharp contacts are restricted to dyke-like bodies of Quartz Breccia. Adjacent to sharp contacts the relative movement of the fragments in the breccia has been ascertained. Along some contacts the granodiorite fragments can be reconstructed like pieces of a jigsaw puzzle (Figure 2.6). In all cases where fragments were reconstructed to original positions with the wall-rock, the fragments showed a movement downward from their point of origin. This feature is important in any interpretation of the origin of the breccias.

Most fragments are granodiorite, but porphyritic biotite granodiorite, andesite porphyry and andesite dykes, garnet veinlets, early quartz veins, rhyolite porphyry dyke, and Phase I Breccia fragments are present and locally are abundant.

Fragments range in size from a fraction of an inch to five feet, but most range from one inch to one foot in length. Abrasion between highly angular fragments has been negligible, and some fragments have retained needlesharp points. Adjacent fragments in the Quartz Breccia are rarely in contact with each other and appear to "float" in a white quartz matrix (Plate 2.10).

In drill core the differentiation between Quartz Breccia and quartz stockwork is extremely difficult.

In thin section the contact between matrix and fragments generally is sharp. Microperthite occurs exclusively along the

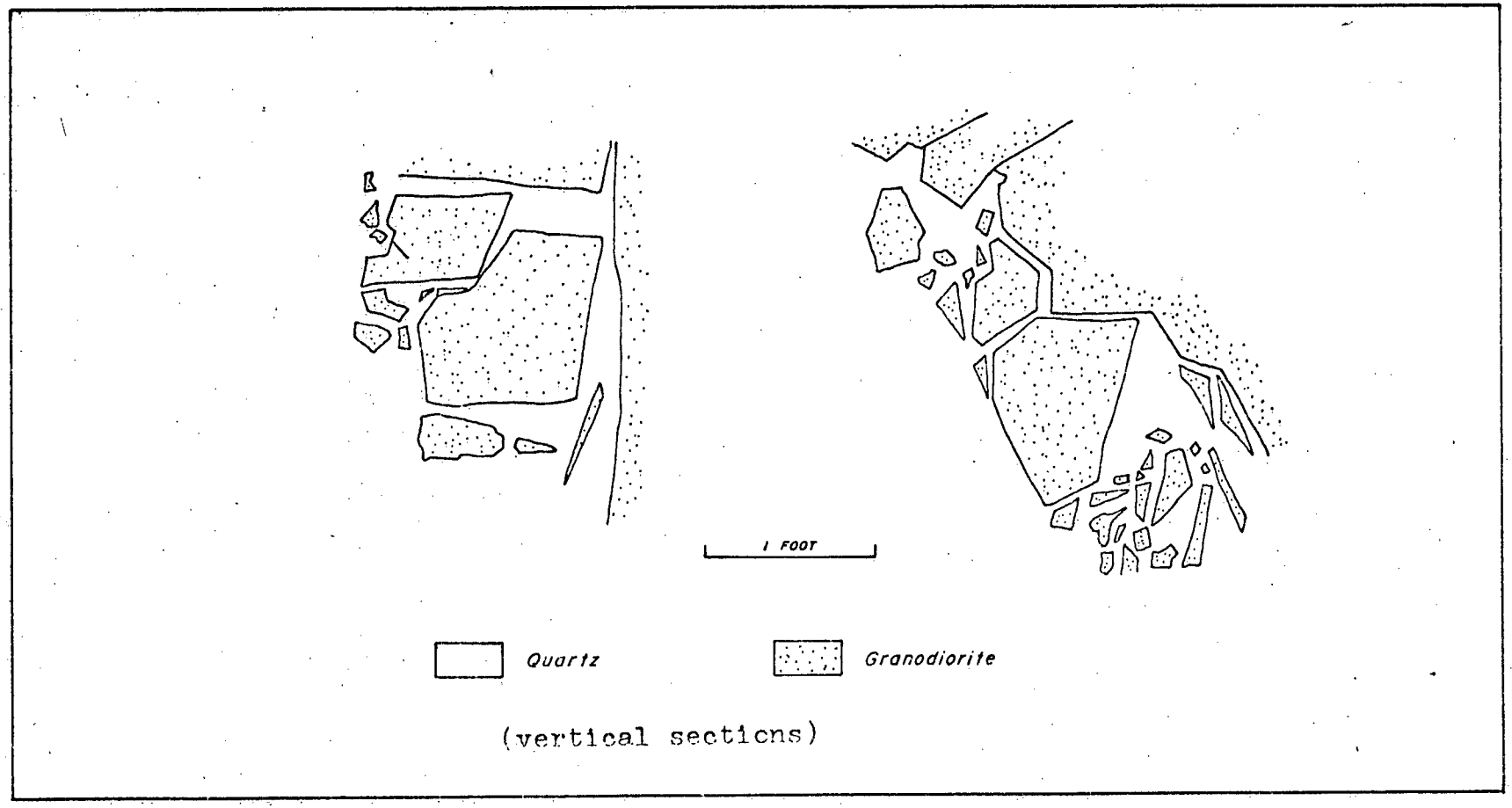


Figure 2.6. Sketches of contacts between Quartz Breccia dykes and granodiorite on the 5045 level.

edges of the quartz matrix and has replaced adjacent parts of rock fragments. The alkali feldspar in the granodiorite fragments also is microperthitic and in thin section closely resembles metasomatic microperthite, except for the poikilitic habit of the magmatic variety.

Quartz Breccia is cut by Phase III Breccia, chlorite veinlets, quartz veins, alkali basalt dykes and calcite-zeolite veinlets.

Phase III Breccia

The main body of Phase III Breccia formed within and along the southwest side of the pre-existing Quartz Breccia. The breccia is a somewhat elliptical body which extends through a known vertical range greater than 600 feet. The top of the Phase III Breccia body in the Main Breccia Zone does not reach the surface. The body is 50 to 100 feet wide and 150 to 300 feet long.

In hand specimen, Phase III Breccia is composed of angular to well-rounded fragments in grey to light brown matrix. The matrix generally is somewhat porous and contains visible creamy to salmon-coloured orthoclase crystals, secondary zeolites, and disseminated molybdenite. The siliceous matrix appears somewhat sugary when viewed with a hand lens. Much of the silica was probably derived from comminution of the quartz matrix of the Quartz Breccia.

Angular fragments of Quartz Breccia occur at the borders of the Phase III Breccia zones. However, within a foot or two of the contact the fragments of Quartz Breccia within the Phase III Breccia become well-rounded. Plate 2.11 shows a typical sample of Phase III Breccia containing well-rounded and angular fragments of quartz, granodiorite, and altered andesite dyke. Contacts between matrix and fragments generally are sharp. The proportion of martix in Phase III Breccia may exceed 70 percent of the rock over areas 30 feet or more in diameter, but generally averages 20 to 30 percent.

Petrographic study of the matrix of the Phase III Breccia reveals that the sugary texture is due in part to rounded grains of quartz in a finer-grained, more highly-comminuted groundmass. Quartz fragments show undulatory extinction. Fine-grained subhedral biotite crystals and golden brown stilbite impart the light brown colour to the matrix. Stilbite has replaced fragments of plagioclase. Creamy to salmon-coloured hydrothermal orthoclase is microperthitic and has replaced fragments of plagioclase and orthoclase in the matrix and in the grandiorite fragments.

Biotite and euhedral molybdenite crystals, which are distributed uniformly throughout the matrix of the Phase III Breccia, have partly replaced fragments of granodiorite.

Alteration of dyke and granodiorite fragments has been

more intense in the Phase III Breccia than in other breccia phases. Some granodiorite fragments have been altered to earthy, white sericite and clay minerals with light brown ovoids comprised of many, small hydrothermal biotite crystals. Other fragments which have not been altered to clay minerals locally have been replaced by creamy to salmon-coloured orthoclase accompanied by chloritization of the mafic minerals.

Phase III Breccia and Phase I Breccia are similar in appearance except for the following distinguishing features:

1. The abundance of rounded fragments in the Phase III Breccia distinguishes it from the Phase I Breccia which is comprised of angular fragments.

2. Fragments of Quartz Breccia, which is younger than the Phase I Breccia, clearly identifies the Phase III Breccia.

3. Disseminated biotite and molybdenite distinguish the matrix of the Phase III Breccia from the barren (except for biotite stringers in fractures) matrix of the Phase I Breccia.

TIME OF INTRUSION OF RHYOLITE PORPHYRY AND RHYOLITE DYKES

Intrusion of rhyolite porphyry and rhyolite dykes, which are apophyses of the Boss Mountain Stock, accompanied formation of Phase I Breccia. Rhyolite porphyry dyke fragments occur in the Phase I Breccia and locally rhyolite porphyry comprises the matrix of this breccia. Nonporphyritic rhyolite dykes cut the Phase I Breccia, but occur as fragments in later breccia phases. In summary, intrusion of rhyolite prophyry (and rhyolite) dykes

and formation of Phase I Breccia are contemporaneous processes related to emplacement of the Boss Mountain Stock.

TAKOMKANE VOLCANIC ROCKS

The Takomkane volcanic rocks, part of which forms the twin summits of Takomkane Mountain, are the youngest rocks in the map area. The volcanic rocks, which rise about 250 feet above the surrounding plateau-like upland, are part of a volcanic cone, one of several extinct volcanic centres in the Cariboo region (Figure 2.7). Lava breached the western side of the cone and flowed down a gentle depression forming a tongue-like flow some 2500 feet long and about 15 feet thick at its outer extremity. The northeastern edge of the cone was removed by an alpine glacier resulting in a 30- to 80-foot escarpment. The part of the cone that has escaped erosion measures 3000 feet (north-south) by 2000 feet (east-west). Most streams draining the area, except Ten-Mile Creek, contain little float derived from the volcano. Glacial deposits contain sporadically distributed rounded boulders and cobbles of alkali basalt, presumably derived from Takomkane Volcano.

Unconsolidated volcanic ejecta ranging in size from ash to blocks as large as 3 feet in diameter form most of the cone. Except for the tongue of lava west of the cone, flows and agglomerate are most abundant near the east edge of the cone. Volcanic bombs and bomb fragments, some with nucleii of

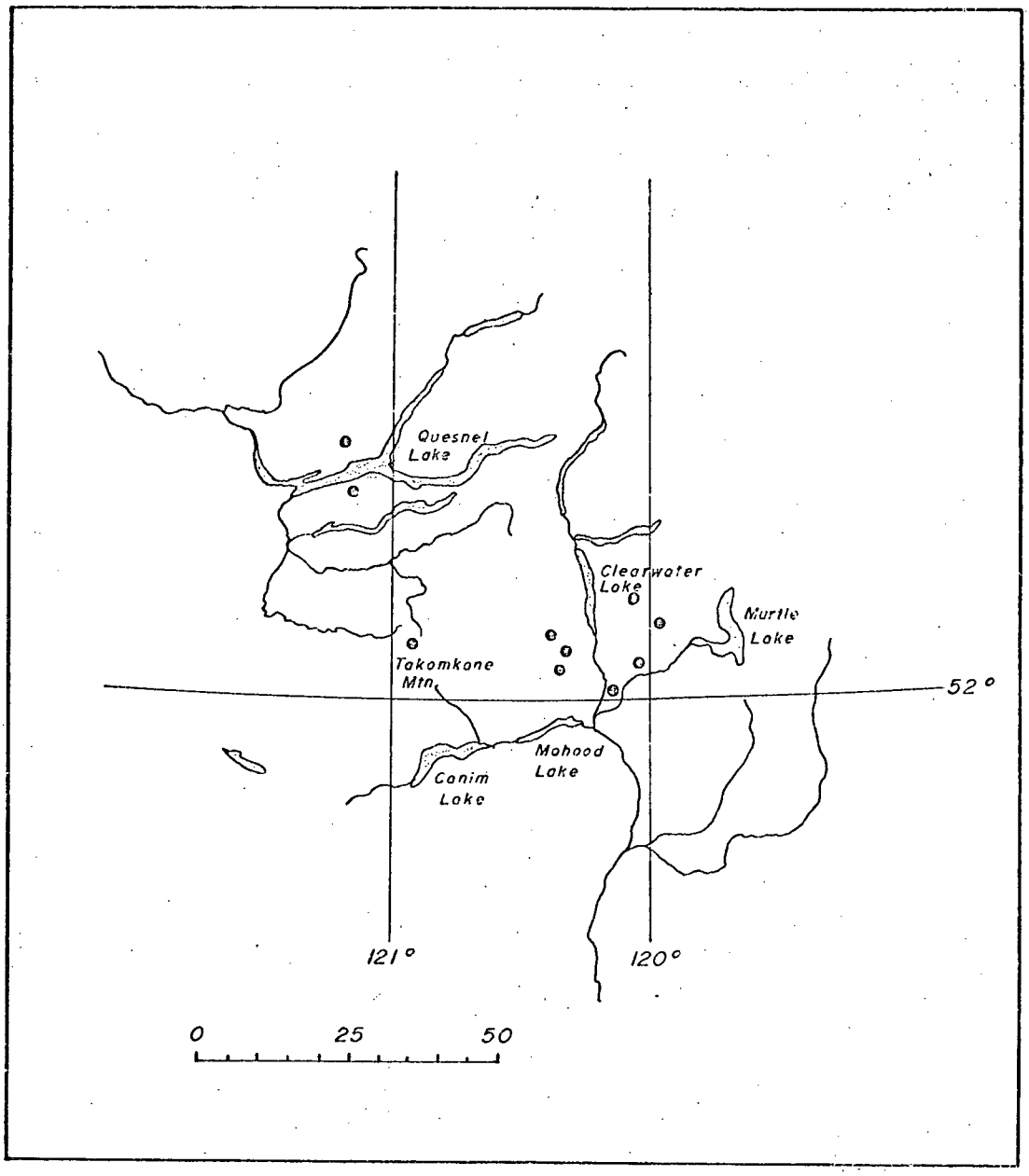


Figure 2.7. Centres of Tertiary and Recent Volcanism in the Cariboo Region (after Holland, 1964).

peridotite or alkali basalt, are abundant.

Most contacts are concealed by rubble, except on the south edge of the cone where a small rill has exposed the contact with the underlying granodiorite. Reinecke (1920, p.83) described the contact at the base of the northeast escarpment as follows:

> "On the northeast and steeper side of the hills....the actual contact between the granite and the lava is exposed at the foot of the hill, where it strikes north 10 degrees east and dips 60 degrees to the west. The granite is shattered and oxidized and the lava is dense at the contact."

Xenoliths of peridotite, glassy black augite, and granodiorite, which occur throughout the flows and ejecta, are especially numerous in the eastern exposures.

Dykes related to the volcano rarely are seen in outcrop because of their high susceptibility to weathering, but they are numerous in the underground workings of the mine. The dykes occupy two sets of vertical post-mineral fractures which strike north 10 to 25 degrees east and north 50 to 60 degrees east (Figure 2.8). Some lineaments may reflect weathered alkali basalt dykes. Columnar joints are well-developed in most dykes, but those without joints contain abundant elongated vesicles and central vesicle pipes lined with clusters of stilbite crystals. Dark greenish black glass characterizes the chilled margins of all dykes. Dykes range in thickness from 6 inches to 30 feet, but few exceed 3 feet.

A subhorizontal train of granodiorite boulders lies about

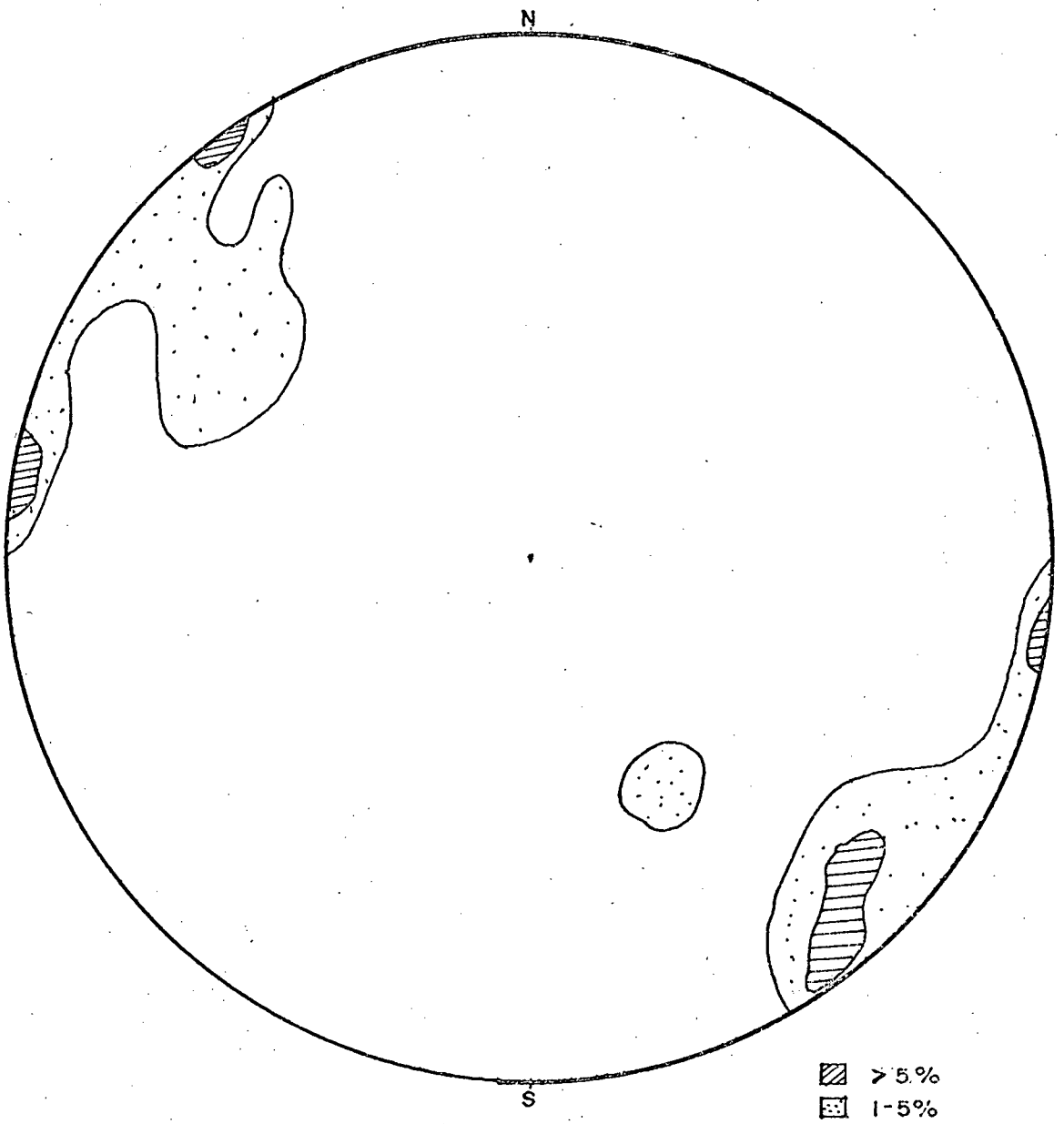


Figure 2.8. Equal-area projection (lower hemisphere) of poles to 39 alkali basalt dykes.

75 feet below the summit of the south ridge of the cone. Boulders of granodiorite are scattered over the cone below this level, but not above it. Other granodiorite fragments that have been rafted into place by volcanic action are coated with a thin rind of chilled alkali basalt. The boulders in and near the boulder train are not coated with an alkali basalt rind, and probably were deposited along the edge of a glacier.

The volcanic rocks lie upon a glaciated surface (Sutherland-Brown, 1957) and have been eroded by glacial action as shown by the abundance of glacial erratics on the cone, the boulders derived from the cone in glacial deposits, and the removal of the northeast part of the cone by an alpine glacier. Sutherland-Brown (1957) concluded from this evidence that:

> "....The mountain has obviously been glaciated before the cone was built, and the presence of erratic boulders and minor sculpturing of the cone indicate that it was also glaciated after. All facts indicate that the cone and flows were formed late in the Pleistocene epoch."

Alkali Basalt

Rocks from alkali basalt dykes and flows exhibit some differences. Dyke-rocks generally are more coarsely crystalline than flow-rocks and for this reason they have received more intensive investigation. Dykes are dark olive green to greenish black, whereas lavas are red-brown to black. Few minerals can be identified in hand specimen, except in xenoliths, which occur only in lavas and ejecta.

Weakly porphyritic alkali basalt dykes contain glomerophyric patches of augite crystals set in an intergranular to hyalophitic groundmass of plagioclase, orthoclase, biotite, olivine (?), glass, apatite, magnetite, and an unidentified mineral. The modes of three specimens of alkali basalt dyke determined by point counts of thin sections are listed in Table 2.7.

Euhedral laths of plagioclase up to 1 mm. long range in composition from An_{53} to An_{60}. The cores of most crystals are weakly altered to sericite but there is little visible zoning. Plagioclase was not identified in rocks with high glass content. Lavas contain microlites and small (0.2 mm.) crystals of plagioclase with compositions of An_{48-60}. Small, rounded grains of orthoclase occur in the groundmass.

Specimen	Plagioclase %	Plagioclase An	Orthoclase	Augite	Olivine	Biotite	Glass	Apatite	Magnetite	Unknown	Zeolite
5-25.1	65	58-60	*	25	?	2	3	*	3	2	-
5-19.4	-	-	-	26	?	4	66	*	1	1	2
10-27.11	70	53-60	*	21	?	4	3	*	2	*	-

- absent * minor ? possible

Table 2.7. Modes of alkali basalt dykes.

Augite occurs as colourless to light green euhedral crystals up to 0.1 mm. long in the groundmass and in glomerophyric patches up to 1 mm. in diameter. Serpentine and carbonate pseudomorphs of what probably were euhedral olivine crystals are sporadically scattered through the rocks. Anhedral xenocrysts of olivine are widely distributed through all lavas, but are not found in dykes.

Euhedral to subhedral plates of red-brown to light brown biotite, which comprise up to 4 percent of some rocks, occur as uniformly distributed small (up to 0.2 mm.) plates between augite and plagioclase grains.

Brown glass, which generally is weakly altered, comprises up to 66 percent of some dykes. Lavas and dykes generally contain little glass, except near their margins.

The groundmass of all rocks contain variable quantities of an unidentified colourless mineral which has low birefringence and an index of refraction less than balsam. The mineral was too small and too crowded with other minerals to permit identification, but it may be a feldspathoid, orthoclase, or possibly a zeolite.

Apatite and magnetite are ubiquitous in the alkali basalts. Stilbite occurs in vesicles and fills fractures in the rocks.

Leucite was identified with an X-ray powder photograph, but was not observed in thin section. Peach (1963, p.6) identified

leucite as a major mineral in some rocks from Takomkane volcano and states, "the lava....in places approaches leucitite in composition." Such rocks have not been identified during this brief investigation of these volcanic rocks.

XENOLITHS

Three kinds of xenoliths, excluding cognate xenoliths of alkali basalt, are widespread in the Takomkane volcanic rocks. They locally constitute up to 25 percent of the lavas in the eastern exposures, but average less than 1 percent. Peridotite xenoliths are most abundant, followed by granodiorite, and then glassy black augite.

Granodiorite and augite xenoliths, which have not been studied in detail, are briefly described below. Granodiorite xenoliths show various degrees of digestion and alteration by the enclosing alkali basalt. Primary mafic minerals in granodiorite (biotite and hornblende) were most susceptible to alteration. In some xenoliths sites previously occupied by primary mafic minerals are open vugs lined with acicular green or brown crystals of pyroxene (?). Plagioclase grains have been recrystallized along their borders to radiating groups of crystals with refractive indices less than balsam. Orthoclase has been similarly affected, but quartz rarely has been visibly altered.

Rounded, glassy black augite crystals (xenocrysts) range from 5 to 47 mm. in diameter. Cleavage is seldom discernable

in hand specimens. Most xenocrysts have subconchoidal fracture and are easily mistaken for volcanic glass. Thin section examination of one small (10 mm.) xenocryst was used to identify the mineral as augite.

Peridotite

Inclusions of peridotite, which show a wide diversity in composition, are sporadically distributed throughout the Takomkane volcanic rocks. They are especially abundant on the east edge of the cone where they comprise from 1 to 25 percent of the lavas. Most alkali basalt dykes do not contain peridotite inclusions.

The average size range of the peridotite inclusions is from 2 to 6 inches, but the total range is from xenocrysts of microscopic size to crystal aggregates 20 inches in diameter. Most inclusions are rounded, but some have subrounded shapes. The inclusions progressively decrease in size and abundance with increasing distance from the eastern edge of the cone.

The mineral composition of the peridotites consists of variable quantities of olivine, clinopyroxene, orthopyroxene, and spinel. In a world-wide survey of peridotite inclusions, Ross et al (1954) showed the clinopyroxenes of peridotite inclusions are chromian diopside and the orthopyroxenes are enstatite. In the present study, modal analyses of 30 peridotite inclusions were determined by point counting hand specimens

using a transparent grid (2 mm. spacing). Three modal analyses were made by point counts of thin sections. The coarse-grained texture and the coarse layering rendered point counts of thin sections of doubtful value. The modes of these 33 specimens are listed in Table 2.8 and the corresponding ratios of olivine, chromian diopside, and enstatite are plotted in Figure 2.9. Most inclusions contain more than 50 percent olivine and some specimens contain predominantly chromian diopside, but few specimens contain enstatite as the dominant mineral.

Layering in most inclusions is subtle, generally being expressed as thin discontinuous bands of chromian diopside. Other inclusions have coarse alternating layers of different composition.

Mineralogy

Olivine, chromian diopside, enstatite, and spinel comprise the mineral constituents of all observed peridotite inclusions. Plagioclase, a minor constituent of peridotite inclusions throughout the world (Ross et al, 1954), was reported by Reinecke (1920) as a minor constituent of some peridotites from the Takomkane lavas, but it was not observed in this investigation.

Olivine - Olivine, the most abundant mineral in the peridotite inclusions (Figure 2.9), also occurs as xenocrysts in the alkali

No.	Specimen	Olivine	Chromian Diopside	Enstatite	Spinel
1	7-14.8-I	0	98	0	2
2	9-4.5 (a)	93	4	2	1
3	(b)	82	10	6	2
4	7-17.9	0	65	30	5
5	no number	15	79	6	0
6	7-12.8-I	13	86	1	0
7	7-17.8	70	16	13	1
8	7-17.11	66	14	19	1
9	no number	96	2	0	2
10	no number	72	7	20	1
11	7-15.2 (a)	53	18	29	tr
12	(b)	59	22	17	1
13	(c)	70	7	22	1
14	(d)	61	29	10	tr
15	(e)	77	22	1	0
16	(f)	75	8	16	1
17	(g)	67	4	28	1
18	(h)	94	3	3	tr
19	(i)	70	17	13	tr
20	(j)	74	11	15	tr
21	(k)	63	29	8	tr
22	(l)	67	5	28	0
23	(m)	20	54	26	0
24	(n)	53	19	28	tr
25	7-15.3 (a)	68	14	18	tr
26	(b)	65	8	27	tr
27	(c)	67	17	16	tr
28	7-15.2	83	7	10	tr
29	7-17.10	66	16	18	tr
30	no number	2	97	0	tr
31	A*	0	40	50	10
32	B*	70	12	15	3
33	C*	11	84	4	1

* Thin section modes.

Table 2.8. Modes of peridotite inclusions from the Takomkane volcanic rocks.

basalts. The anhedral, equidimensional, transparent, light green olivine grains range in size from 1 mm. to 10 mm. Broad twin planes were observed in some olivine grains. Altered olivine grains, which are red in hand specimen, contain bright

red thread-like filaments penetrating the grains near their borders.

Olivine grains were extracted from inclusions and from the groundmass for determination of composition using the X-ray powder photograph method described by Jambor and Smith (1963). The olivines from the Takomkane volcanic rocks have compositions ranging from $Fo_{85.14}$ to $Fo_{89.91}$ (Table 2.9 and Figure 2.10). Non-filtered iron radiation was used for all determinations, except number 12 in which nickel oxide-filtered copper radiation was used. All films were corrected for shrinkage.

Number	Specimen	UBC Film No.	% Fo (calculated)
1	6-23.2 (groundmass)	4937	89.91
2	7-10.1	4805	85.14
3	7-12.2-I (groundmass)	4943	89.52
4	7-15.7	4803	87.93
5	7-15.10	4804	87.53
6	7-17.7	4819	88.09
7	7-17.11	4820	88.09
8	9-4.5 (groundmass)	4938	89.91
9	9-4.6 (groundmass)	4939	89.52
10	9-4.8 (groundmass)	4940	85.14
11	no number	4807	88.09
12	#4AS	4290	88.09

Table 2.9. Composition of olivines from peridotite inclusions and groundmass of Takomkane volcanic rocks.

Chromian Diopside - Chromian diopside occurs as emerald-green, equidimensional to lath-shaped grains ranging in size from 1 to 60 mm. Weathered specimens are dull olive green. The chromian diopside content of the inclusions ranges from 2 to 98 percent, but most inclusions contain less than 30 percent. Spectro-

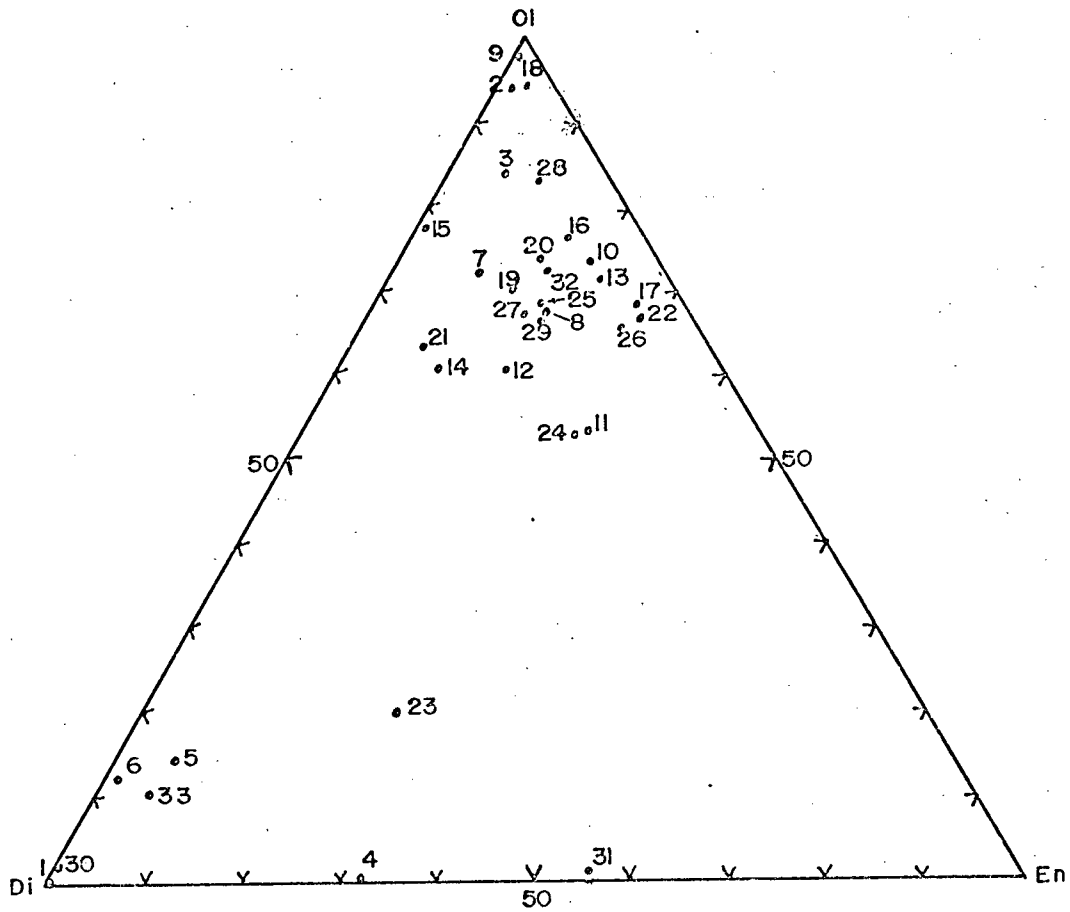


Figure 2.9. Composition of 33 peridotite inclusions from the Takomkane volcanic rocks (spinel excluded).

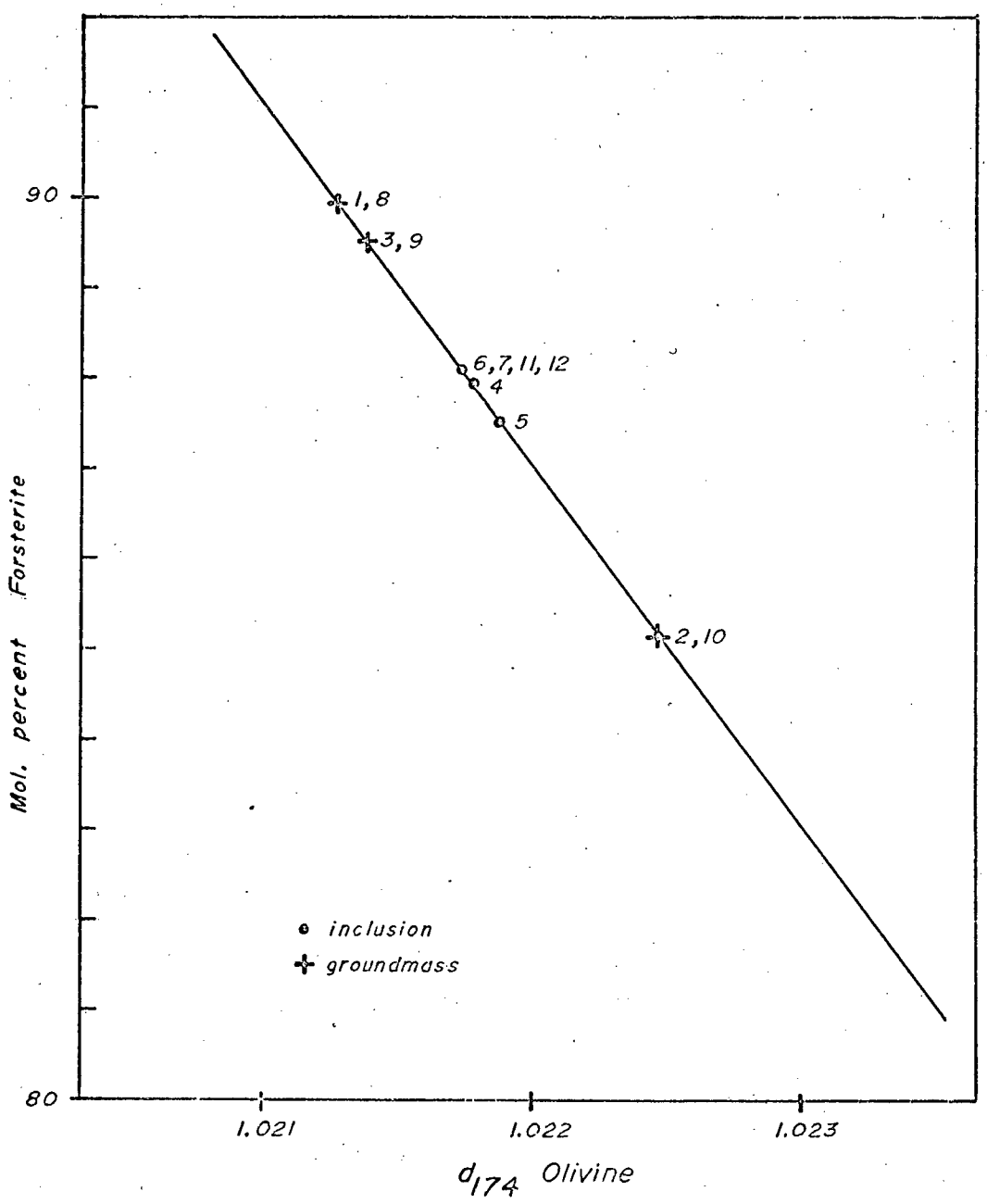


Figure 2.10. Composition of olivines from the Takomkane volcanic rocks. (Diagram after Jambor & Smith, 1963).

graphic analyses confirmed the presence of chromium (U.B.C. #1-18).

In thin section chromian diopside is green in plane polarized light and exhibits well-developed cleavage. Some grains, especially those larger than 20 mm. have diallage parting (100).

Enstatite - Enstatite occurs as translucent, equidimensional grains up to 10 mm. in diameter. Colour in hand specimen ranges from honey-yellow (number 31) to brown or greenish brown. Small exsolution lamellae of clinopyroxene were observed in some enstatite grains.

Spinel - Spinels, which comprise less than 2 percent of most inclusions, are colourless to black in hand specimen. Most are anhedral, except occasional black, submetallic grains that have subhedral form.

Spinels are colourless to tan in plane polarized light. Brown to black rims occur on spinels in contact with alkali basalt (Plate 2.12). Spinel xenocrysts exhibit various degrees of rim development. Some xenocrysts are entirely black, others have only a narrow black rim. Alkali basalt adjacent to such rimmed spinel grains is impoverished in magnetite creating a light-coloured halo around the grains (Plate 2.13). These black rims may be caused by iron replacing magnesium in the spinel structure. The liberated magnesium could then be incorporated

in the pyroxenes or biotite during crystallization of the lavas. The exchange of iron for magnesium in the spinel would result in an increased specific gravity without much increase in cell edge. Specific gravity and cell edge were measured on 11 spinel grains. Cell edges were measured from X-ray powder photographs corrected for film shrinkage. Non-filtered iron radiation was used on all samples, except number 11 which utilized nickel oxide-filtered copper radiation. Two specific gravity determinations were made on each spinel using a Berman Balance and the average of these two readings is given in Table 2.10. The results of specific gravity and cell edge determinations are plotted on the composition diagram of Deer et al (1964, vol. 5, p.61) and are shown in Figure 2.11. Compositions are grouped near the spinel ($MgAl_2O_4$) corner of the diagram. One black spinel with metallic lustre (number 5) has a composition near that of hercynite ($FeAl_2O_4$) suggesting that iron has replaced the original magnesium in the spinel.

Origin of Xenoliths

Many discussions of the origin of peridotite xenoliths in volcanic rocks are found in the literature (Ross et al, 1954; Brothers, 1960; Wilshire and Binns, 1961; Talbot et al, 1963; Jackson, 1966). The two most commonly accepted theories of origin are: 1) the xenoliths are derived from crystal cumulates of the host rocks; or 2) they are pieces of the mantle that have

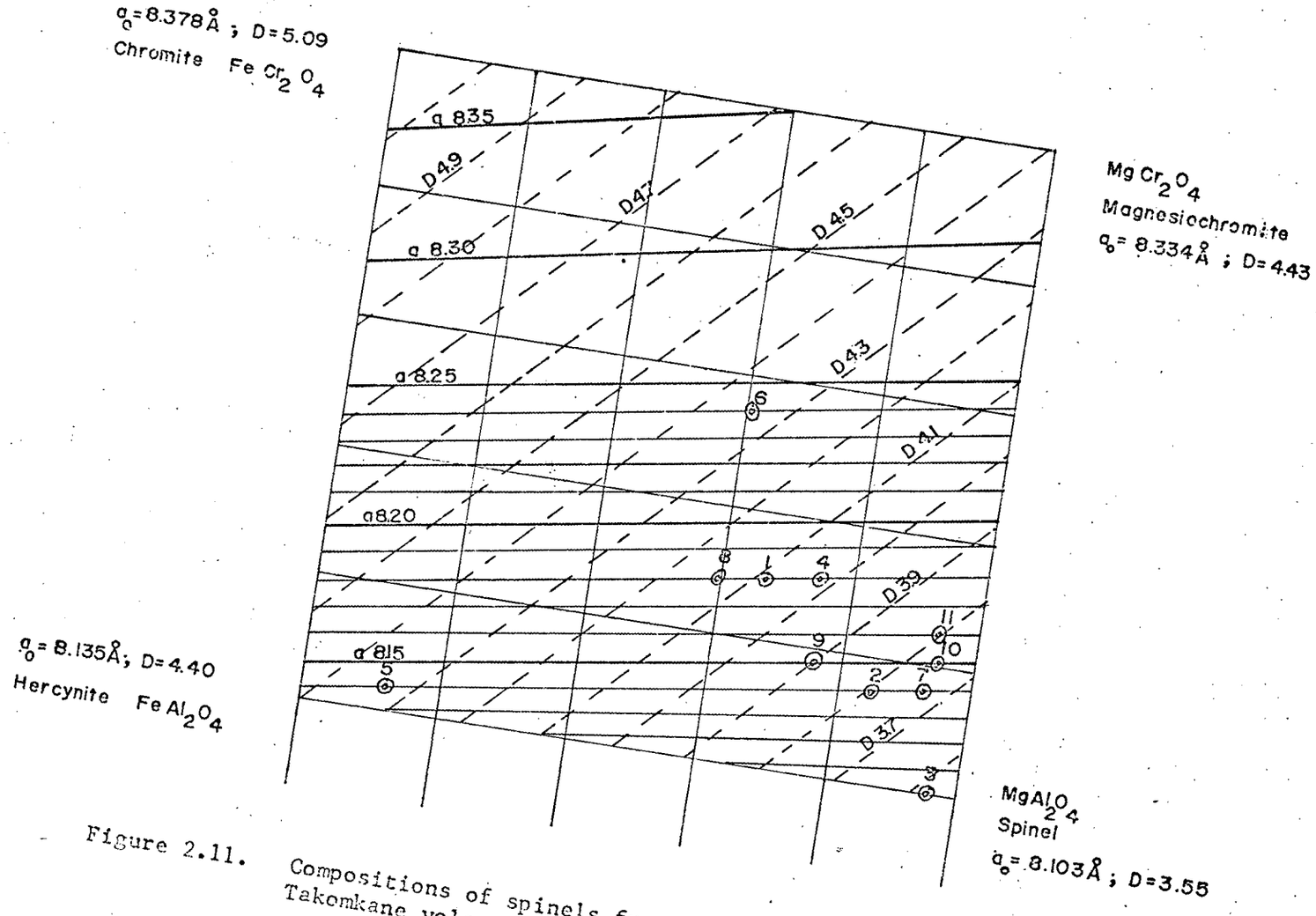


Figure 2.11. Compositions of spinels from peridotite xenoliths in Takomkane volcanic rocks. (diagram after Deer et al, 1962).

1 cm.

Plate 2.12. Photomicrograph (plane polarized light) of alkali basalt with peridotite xenoliths. Spinel (s) grains have dark rims at contact with alkali basalt. (olivine, o: chromian diopside, d)

1 mm.

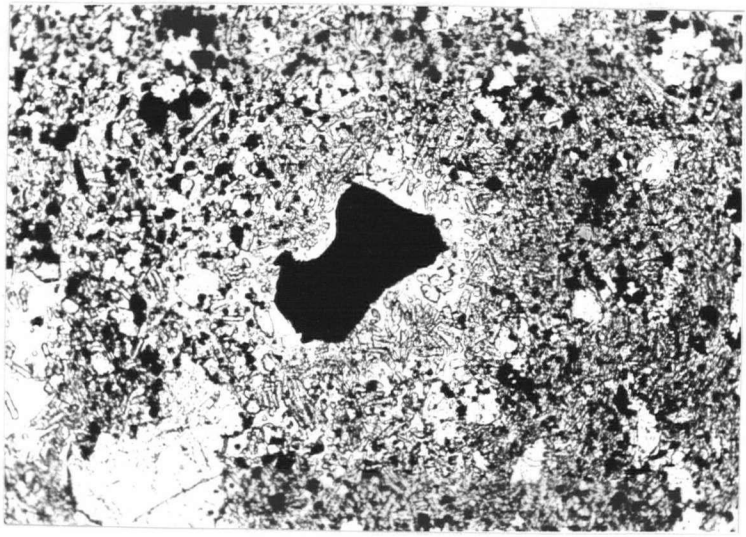


Plate 2.13. Photomicrograph (plane polarized light) of a spinel (centre) grain in alkali basalt. Note the alkali basalt adjacent to the spinel is impoverished in magnetite near the spinel grain.

Number	Specimen	UBC Film No.	Cell Edge (measured)	Specific Gravity
1	7-15.8	4910	8.18Å	4.09
2	7-17.10	4812	8.14	3.79
3	7-27.3	4802	8.10	3.59
4	9-4.6	4966	8.18	4.02
5	#2AES	4814	8.14	4.33
6	#3AES	4808	8.24	4.35
7	#1RMT	4965	8.14	3.74
8	#2RMT	4972	8.18	4.13
9	#3RMT	4978	8.15	3.90
10	#4RMT	4976	8.15	3.76
11	no number	4072	8.16	3.80

(Numbers 7, 8, 9, and 10 from samples collected by R. M. Thompson)

Table 2.10. Cell edge and specific gravity measurements of spinels from peridotite xenoliths in Takomkane volcanic rocks.

been brought to the surface along volcanic conduits. The following features of peridotite xenoliths can be explained by either theory of origin.

Peridotite xenoliths:
1. are world-wide in occurrence.
2. occur almost exclusively in alkali basalts.
3. have identical mineralogy throughout the world.
4. are layered.

Detailed investigation of one or more of these features has led various authors to opposing conclusions. It is beyond the scope of the present study to try to resolve the origin of peridotite xenoliths through an exhaustive literature survey. The data from this preliminary study of the Takomkane volcanic rocks and associated peridotite xenoliths agrees with published data, but are not adequate to explain their origin.

III. STRUCTURE

Structural features of the Boss Mountain Mine area include joints and faults, as well as a myriad of quartz veins. Some of these features are of different ages and older structures may be greatly dislocated or otherwise concealed by younger structures. Those features unrelated to ore deposition are described under the section on General Structure and those related to ore deposition under Local Structure.

GENERAL STRUCTURE

Faults

All faults in the area surrounding the Boss Mountain Mine can be grouped into five sets based on attitude. Most faults are of post-mineral age.

Molybdenite Creek Fault

The broad valleys of Boss Creek and Molybdenite Creek form a continuous lineament trending north 35 to 40 degrees west which is inferred as the trace of a fault, the Molybdenite Creek Fault (Map 1). It cuts the Takomkane Batholith within the map area and continues through Nicola Group volcanic rocks to the north (personal observation). In the map area there are no marker units that can be used to measure displacement. From its topographic expression the fault is believed to have a steep dip. Although the age of the Molybdenite Creek fault is unknown,

it probably is one of the oldest fractures in the area. A fault along Ten-Mile Creek causes a right-lateral separation of the Molybdenite Creek fault of the order of 1000 feet.

Post-Mineral Faults

Four sets of post-mineral faults have been recognized on Takomkane Mountain. The abundance of outcrop near the summit of the mountain has permitted establishment of the following chronological sequence of post-mineral faults (oldest to youngest): (1) strikes north 60 degrees west with a vertical dip, (2) strikes north 50 to 58 degrees east with a vertical dip, (3) strikes north 10 to 30 degrees east with a vertical dip, and (4) strikes north 70 degrees east to south 80 degrees east with dips from 69 degrees south to vertical.

The faults are expressed by pronounced lineaments, some of which extend for thousands of feet. For the most part, these faults have had little visible effect on adjacent rocks, although shear fractures have developed parallel to some faults.

Most fault surfaces are obscured by debris, but where visible, as in cirque walls, the adjoining rock is intimately fractured with many slickensided surfaces.

Faults that strike north 60 degrees west are well developed in the northwestern and in the southern part of the map area, but are weak or absent in the central part. These faults are

cut by sinistral faults striking north 50 to 58 degrees east.

Faults striking north 50 to 58 degrees east are the most abundant post-mineral faults in the map area. Numerous joints (shear fractures) parallel faults of this set.

A third set of post-mineral faults, which strikes north 10 to 30 degrees east with vertical dips, cuts the north 50 to 58 degree east faults. Faults of this age are seldom detected in surface exposures, but are prominent in the mine workings.

Faults of the youngest set strike from north 70 degrees east to south 80 degrees east and dip from 69 degrees south to vertical. These easterly striking faults cut all others in the map area and form the most prominent and most continuous lineaments. The most prominent of these faults is the Ten-Mile Creek Fault which extends across the entire map area and offsets the Molybdenite Creek Fault. Evidence of displacement is based upon the separation of two ridges east of Molybdenite and Boss Creeks. The break between these ridges coincides with the probable trace of the Ten-Mine Creek Fault. Joints are moderately well-developed adjacent to Ten-Mile Creek Fault.

All post-mineral faults are older than the Takomkane Volcano, but only faults striking north 50 to 58 degrees east and north 10 to 30 degrees east commonly contain basalt dykes.

Joints

Several prominent joint sets, which exhibit a striking control of topography, cut the rocks in the map area. Figure 3.1 is an equal-area projection (lower hemisphere) of poles to joints. Three of these joint sets are found in almost all exposures, although the degree of development is not always equal. These joints, marked 1, 2, and 3 in Figure 3.1, have the following average attitudes: (1) strikes north 42 degrees west and dips 42 degrees south, (2) strikes north 45 degrees west and dips 48 degrees north, and (3) strikes north 41 degrees west and dips vertically. The first set is most abundant.

The strike of joint set 2 (N45^{o}W) is more westerly (N58^{o}W) with steeper dips (60°N) in the north part of the map area (Figure 3.1, number 2a).

Superimposed on joint sets 1, 2, and 3 is another set striking north 56 degrees east with dips that are predominantly vertical but range from 60 degrees south to 70 degrees north (Figure 3.1, number 4). This joint set parallels post-mineral faults. Other joint sets are local in distribution and generally parallel faults.

LOCAL STRUCTURE

Local structures include garnet-hornblende veinlets, which occupy narrow mylonite zones, quartz-filled fractures and

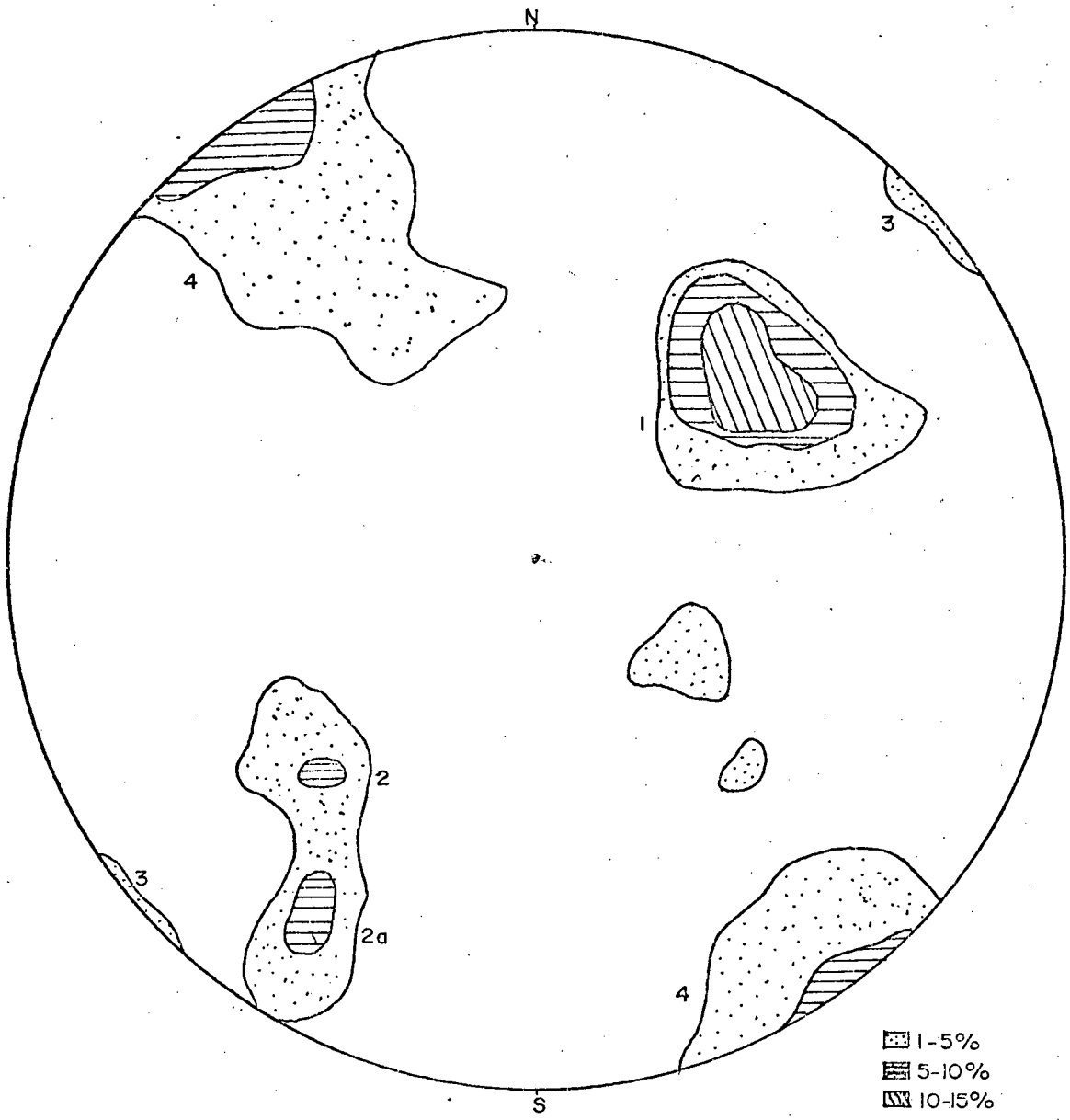


Figure 3.1. Equal-area projection (lower hemisphere) of poles to 321 joints on Takomkane Mountain.

unfilled fractures. The fractures, both quartz-filled and barren, have been studied in detail on the 5045 level of the mine which provides several thousand feet of continuous 3-dimensional exposure through all known geological features, except the Takomkane volcano. Sublevels are restricted to ore-bearing areas and are useful for comparative purposes. Surface exposures are too few and discontinuous to provide data as meaningful as that obtained on the 5045 level.

Garnet-Hornblende Veinlets

Along the 5045 main haulage level, both east and west of the Boss Mountain Stock, granodiorite and andesite dykes are cut by numerous garnet-hornblende veinlets. These occupy narrow mylonite zones which are interpreted as shear fractures.

Attitudes of 123 veinlets east of the stock and of 48 veinlets west of the stock are shown on stereograms in Figure 3.3. Three sets of fractures that seem to be present in each area have average attitudes summarized as follows:

East of Boss Mountain Stock	West of Boss Mountain Stock
1. strike N58°W; dip vertical	1. strike N72°E; dip vertical
2. strike N12°W; dip 71°E	2. strike N20°E; dip vertical
3. strike N68°E; dip 63°S changing to strike N56°E; dip vertical	3. strike N34°W; dip vertical

Sets 1 and 2 are interpreted as conjugate shears so oriented that the bisectrix of the acute angle is roughly normal to the surface of the Boss Mountain Stock in each area. Set 3, roughly

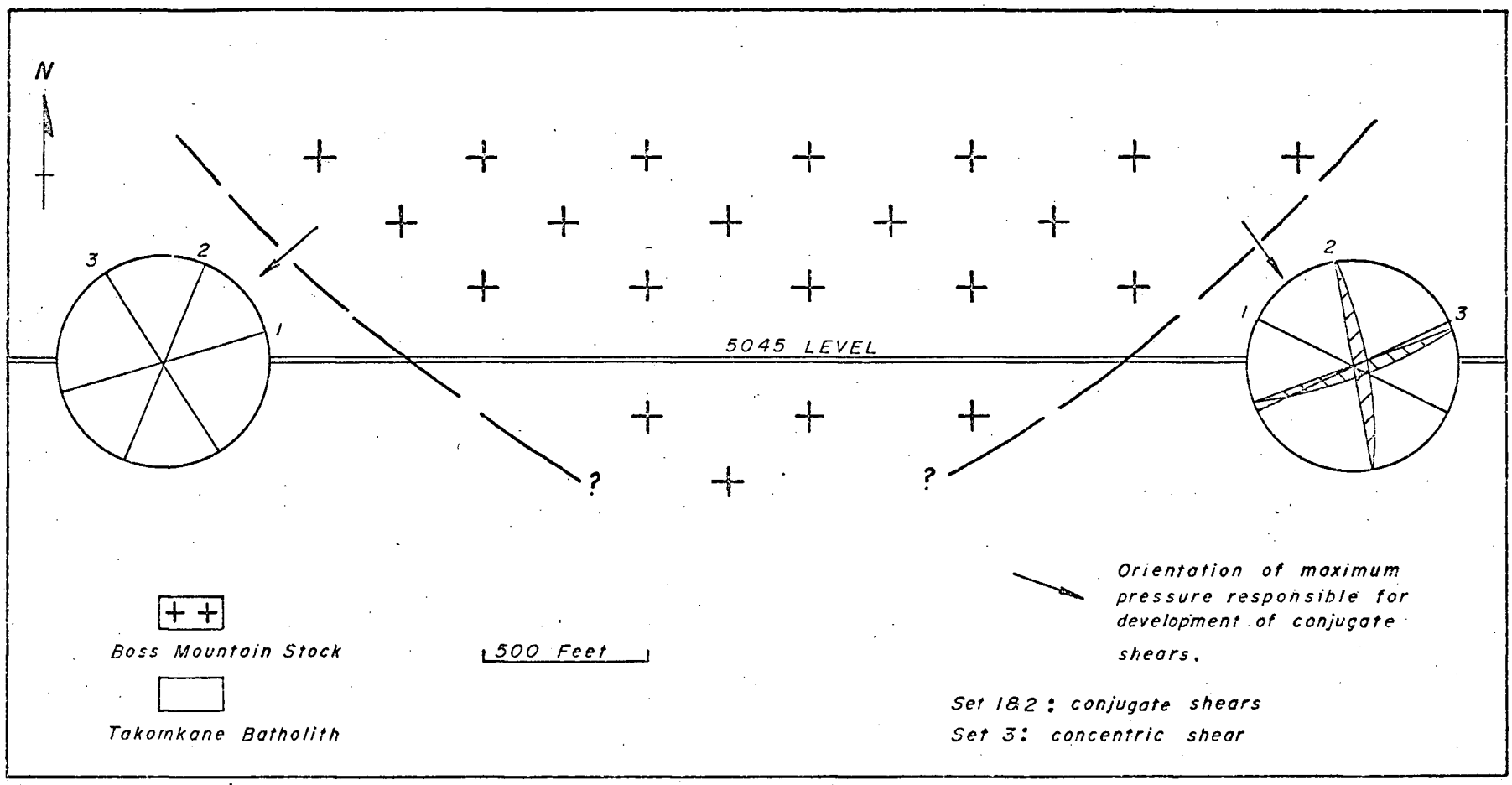
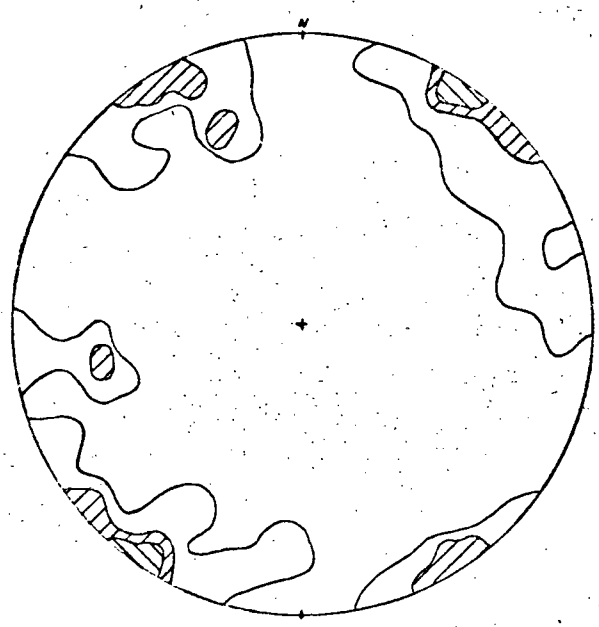
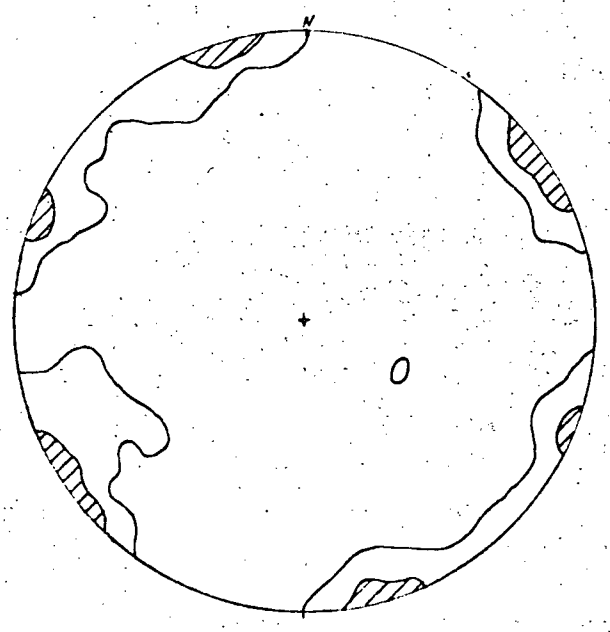


Figure 3.2. Idealized plan of part of the 5045 level showing attitudes of garnet-hornblende veinlets and their relationship to the Boss Mountain Stock.



East of Boss Mountain Stock
(123 points)

> 10%
6–10%
1–5%



West of Boss Mountain Stock
(48 points)

Figure 3.3. Equal-area projections (lower hemisphere) of poles to garnet-hornblende veinlets (5045 level).

parallel to the surface of the stock in each area, is interpreted as a concentric shear. This analysis of the fracture pattern is justified by field observations. Fractures of sets 1 and 2 cross without offset, whereas fractures of set 3 are cut by those of sets 1 and 2.

Figure 3.2 is an idealized representation of the relation of these fracture sets to the Boss Mountain Stock. When the stock was intruded the wall-rock was disrupted first by shearing parallel to the contact and later by conjugate shears so oriented that the axis of maximum stress was normal to the contact.

Ore Fractures - 5045 Level

A detailed analysis of both barren and mineralized fractures in the underground workings was made in an effort to help explain the genesis of the Boss Breccias and ore deposits. The eight groups of fractures identified in this study include pre-mineral, contemporaneous and post-mineral fractures.

Recognition and correlation of fractures of a given age is dependent upon cross-cutting relations, attitudes of fractures, and upon the character and mineralogy of quartz veins which fill most of the fractures. In most cases the character and mineralogy of the quartz veins is the only reliable feature for correlation in different areas of the mine.

The underground workings of the 5045 level were divided into eight areas based upon proximity to geologic features such as the

Fracture	Attitude	Area	Character	Genetic affinity
8	N5°W to N10°E; 90°	all	Barren; calcite-zeolite	Post-mineral: Unknown
7	N50-60°E; 90°	all	Barren; calcite-zeolite	Post-mineral: Unknown
6	N78-82°E; 40-48°N	all	Barren; chloritized	Post-mineral: Unknown
5	N70-74°W; 20-30°S N19°E; 20°N N47°E; 30°S N5°E; 20-35°S N75-80°E; 40-45°N N75°E; 30°N N48°W; 20°S	C,D,E D,G E F G H H	Quartz-molybdenite veins.	Reduction of pressure at depth - High-Grade Vein and Stringer Zones.
4	Early: N5°W; 50°S N45°E; 20°S N30°E; 45°S Late: N12-20°E; 60-68°S N30°E; 15°N Composite: N20-30°W; 18°S N10°W; 15-25°S N60°E; 40-70°N	 A C E A,B,C C D F,G G	Quartz veins, (composite) Complex mineralogy.	End of Phase III Breccia formation and crystallization of the Boss Mountain Stock.
3	N40-45°E; 30°S N50-70°E; 60-65°S	F D,G	Quartz-molybdenite veins	Phase III Breccia
2	N28-43°W; 75N to 90°	C,G H	Quartz veins in some	Quartz Breccia
1 (oldest)	N40-60°E; 90°	All*	Quartz veins in some	Unknown

(* except B)

Table 3.1. Chronological chart of fractures on the 5045 level; Boss Mountain Mine.

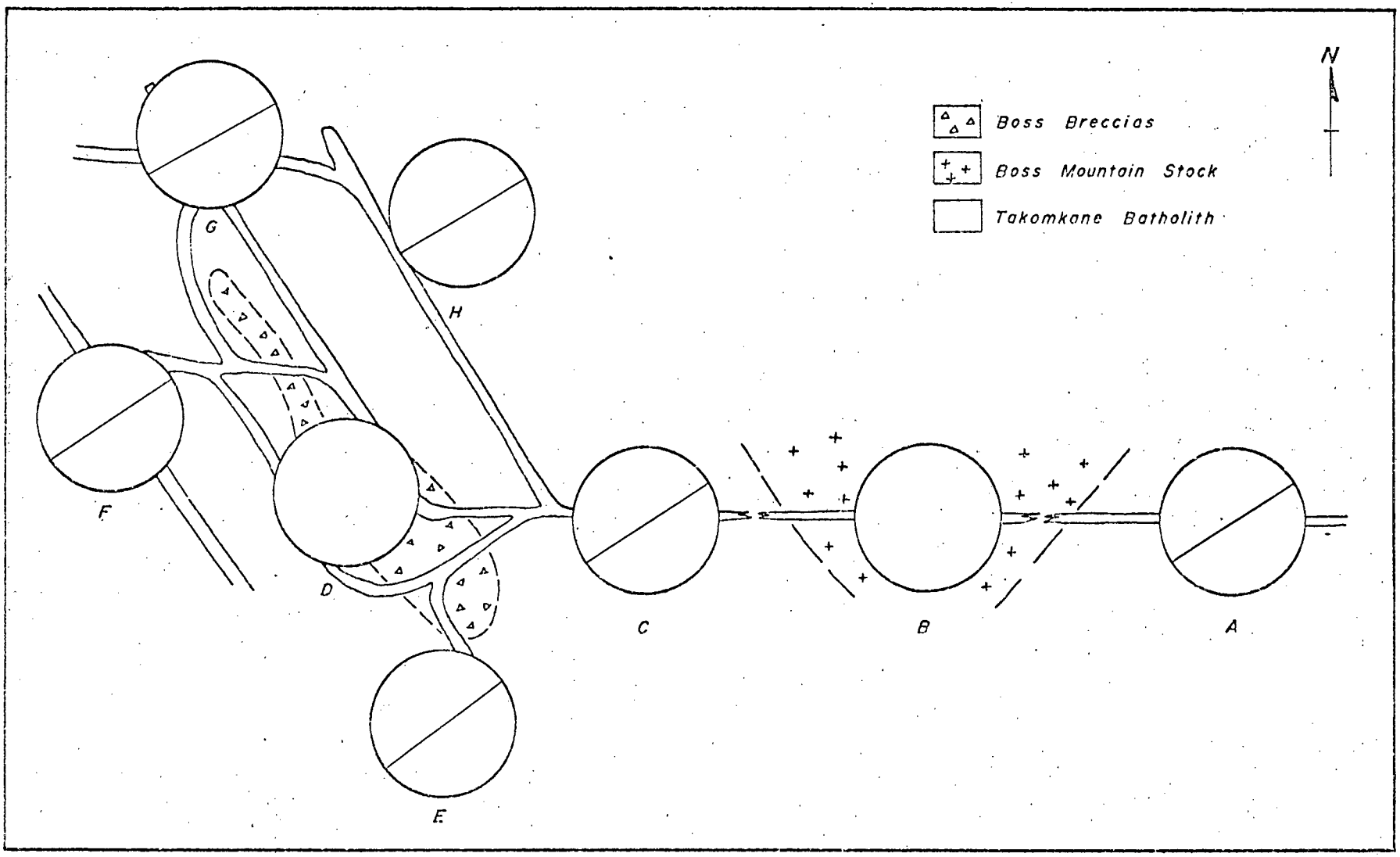


Figure 3.4. Stereographic projections (lower hemisphere) of group 1 fractures in different areas of the 5045 level (see Appendix I for contoured equal-area projections).

Boss Breccias and the Boss Mountain Stock. These areas have been designated A, B, C, D, E, F, G, and H on the accompanying figures.

Few fractures, especially those filled with quartz veins, show evidence of movement. Apparent displacement, where visible, seldom exceeds one foot. Some fractures of each age offset older fractures, dykes, etc. and some fracture surfaces are slickensided.

Table 3.1 is a summary of the relative age, orientation, character, and possible genetic significance of all fracture sets, which are discussed individually below. Equal-area stereograms (lower hemisphere) from which the following attitudes were derived are shown in Appendix I.

Group 1 Fractures

Group 1 fractures, the oldest recognized group, occur throughout the mine area, except in the Boss Breccias and the Boss Mountain Stock (Figure 3.4). Attitudes of the fractures, which are surprisingly consistent, range from north 40 to 60 degrees east and all dip vertically or very nearly so. After quartz was deposited in the fractures they were sheared, giving the quartz veins a sugary appearance with weakly banded structure parallel to the fractures. Near the Main Breccia Zone, in area C, molybdenite was added to the veins at some later time. Pyrite is disseminated through the veins.

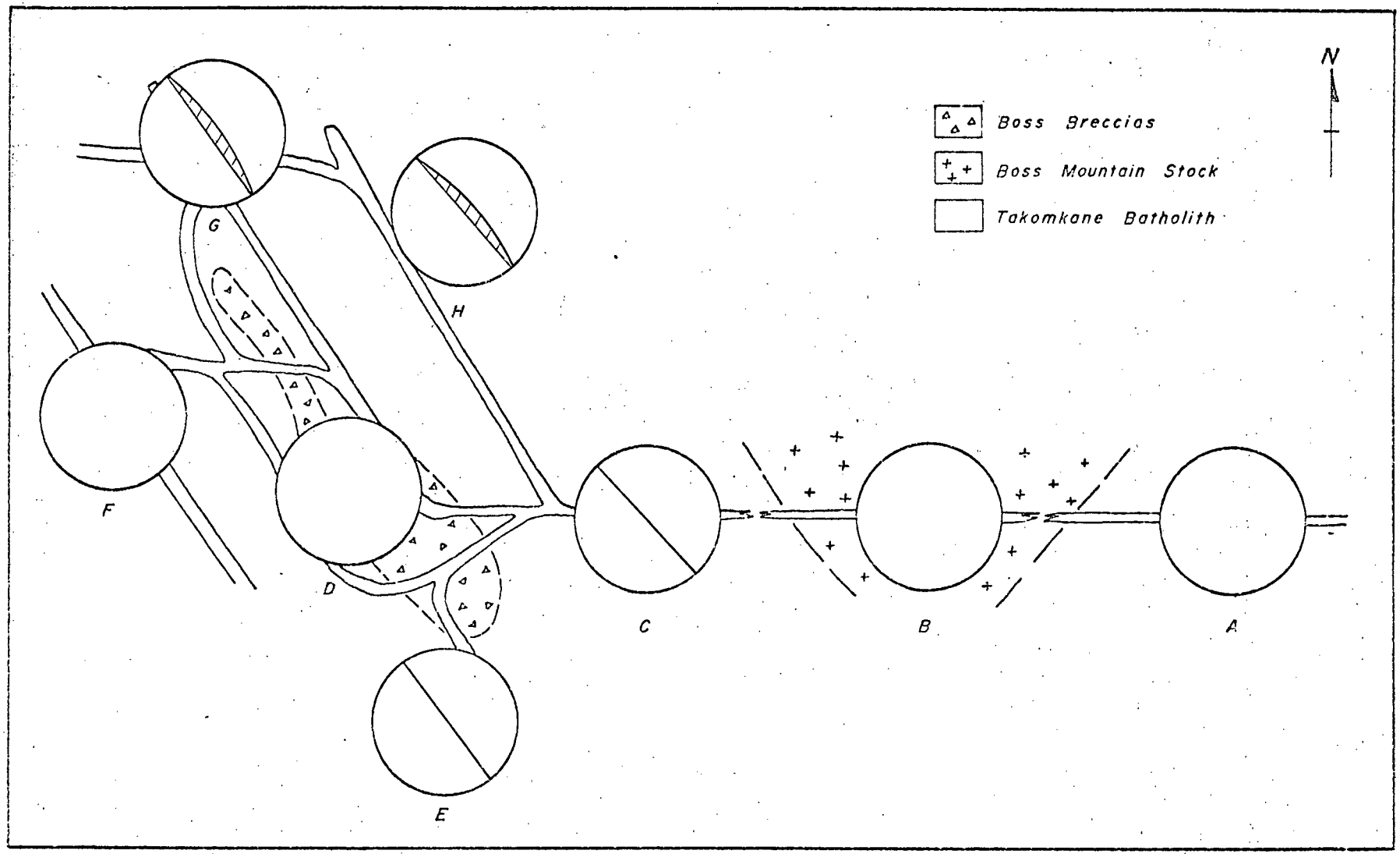


Figure 3.5. Stereographic projections (lower hemisphere) of group 2 fractures in different areas of the 5045 level (see Appendix I for contoured equal-area projections).

Group 1 fractures which cut granodiorite, andesite dykes and garnet-hornblende veinlets, are in turn cut by the Boss Breccias, Boss Mountain Stock and related dykes, together with all other quartz veins and alkali basalt dykes.

Group 2 Fractures

Group 2 fractures, which occur near but not in the Boss Breccias (Figure 3.5, areas C, E, G. and H), strike north 28 to 50 degrees west and dip 75 degrees north to vertical. Some fractures are filled with barren quartz veins that contain minor amounts of pyrite and microperthite.

The attitudes of the fractures are subparallel to the strike of the Quartz Breccia (Main Breccia Zone). North of the Main Breccia Zone (Figure 3.5, areas G and H) the attitudes of the fractures parallel the Quartz Breccia (north 35 degrees west, dip 75 to 80 degrees north).

Group 2 fractures cut group 1 fractures, granodiorite, Phase I Breccia, and andesite dykes and are cut by later quartz veins.

Group 3 Fractures

Group 3 fractures are restricted to areas north and west of the Phase III Breccia, (Figure 3.6, areas D, F, and G,). The fractures, which are nowhere abundant, generally are filled with quartz-molybdenite veins.

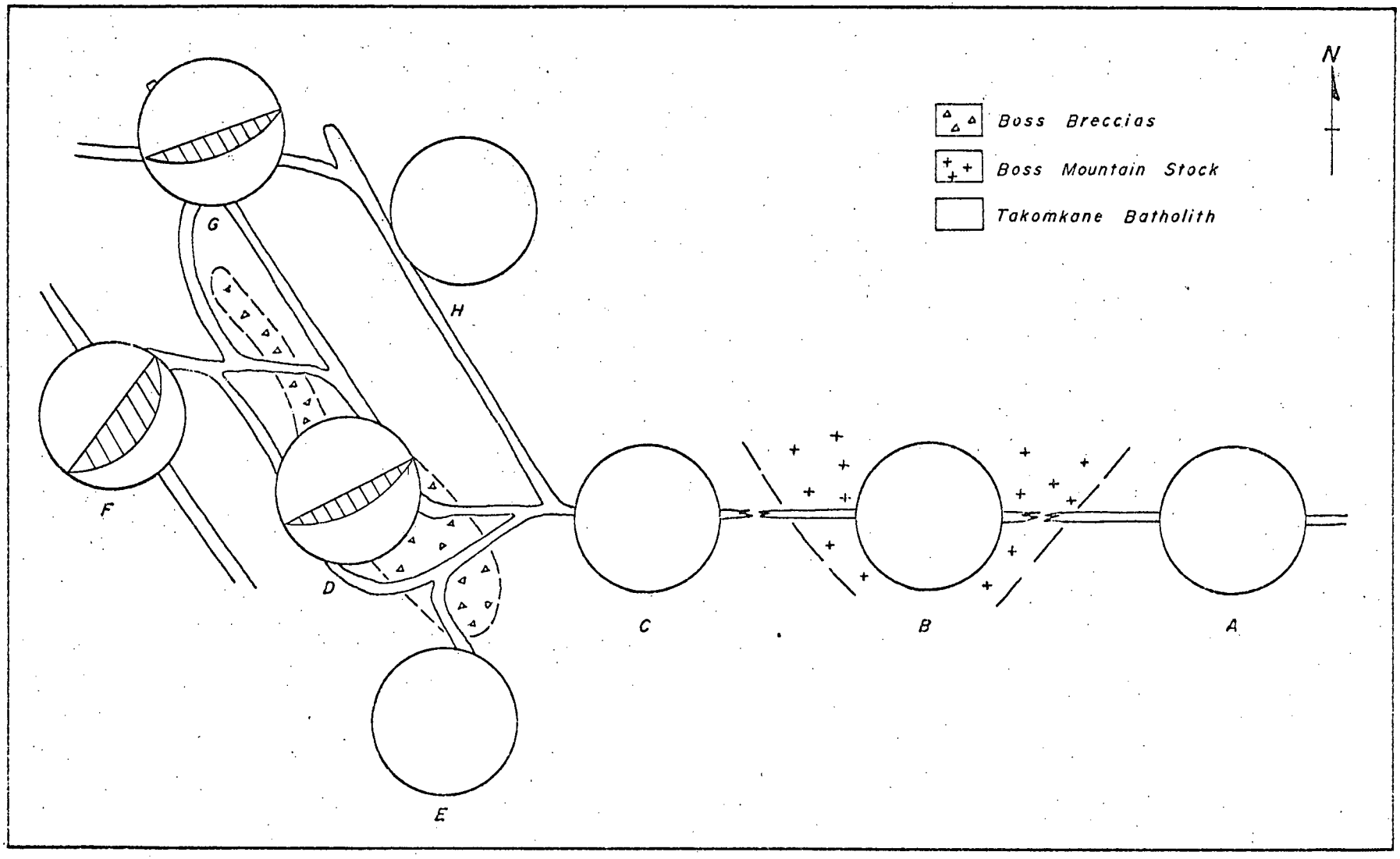


Figure 3.6. Stereographic projections (lower hemisphere) of group 3 fractures in different areas of the 5045 level (see Appendix I for contoured equal-area projections).

Group 3 fractures strike north 50 to 67 degrees east and dip 60 to 65 degrees south in areas D and G. In area F the veins strike north 40 to 45 degrees east and dip 30 degrees south. Reverse movement of a few inches occurs on some fractures.

The relative geologic age of the fractures is well-documented. Group 3 fractures cut granodiorite, Quartz Breccia, and group 1 fractures adjacent to Phase III Breccia. Both group 4 and group 5 fractures cut group 3 fractures.

Group 4 Fractures

Group 4 fractures have been observed in most areas of the underground workings (Figure 3.7). The attitudes of the fractures and quartz veins in different areas of the 5045 level are listed in Table 3.1. Quartz veins in group 4 fractures are composite west of and in the Boss Breccias (Figure 3.7, areas D, E, and G), but occur as two separate sets east of the breccias (areas A, B, and C). Early stage veins contain quartz, molybdenite, microperthite, chlorite, pyrite, and rutile. Late stage quartz veins, which have a mineralogy similar to early stage quartz veins (quartz, microperthite, chlorite, and pyrite) are recognized by their accessory minerals such as: aikinite, bismuthinite, chalcopyrite, sphalerite, magnetite, scheelite, sericite, fluorite, calcite, and anatase. Late stage quartz veins in group 4 fractures have been superimposed upon and are

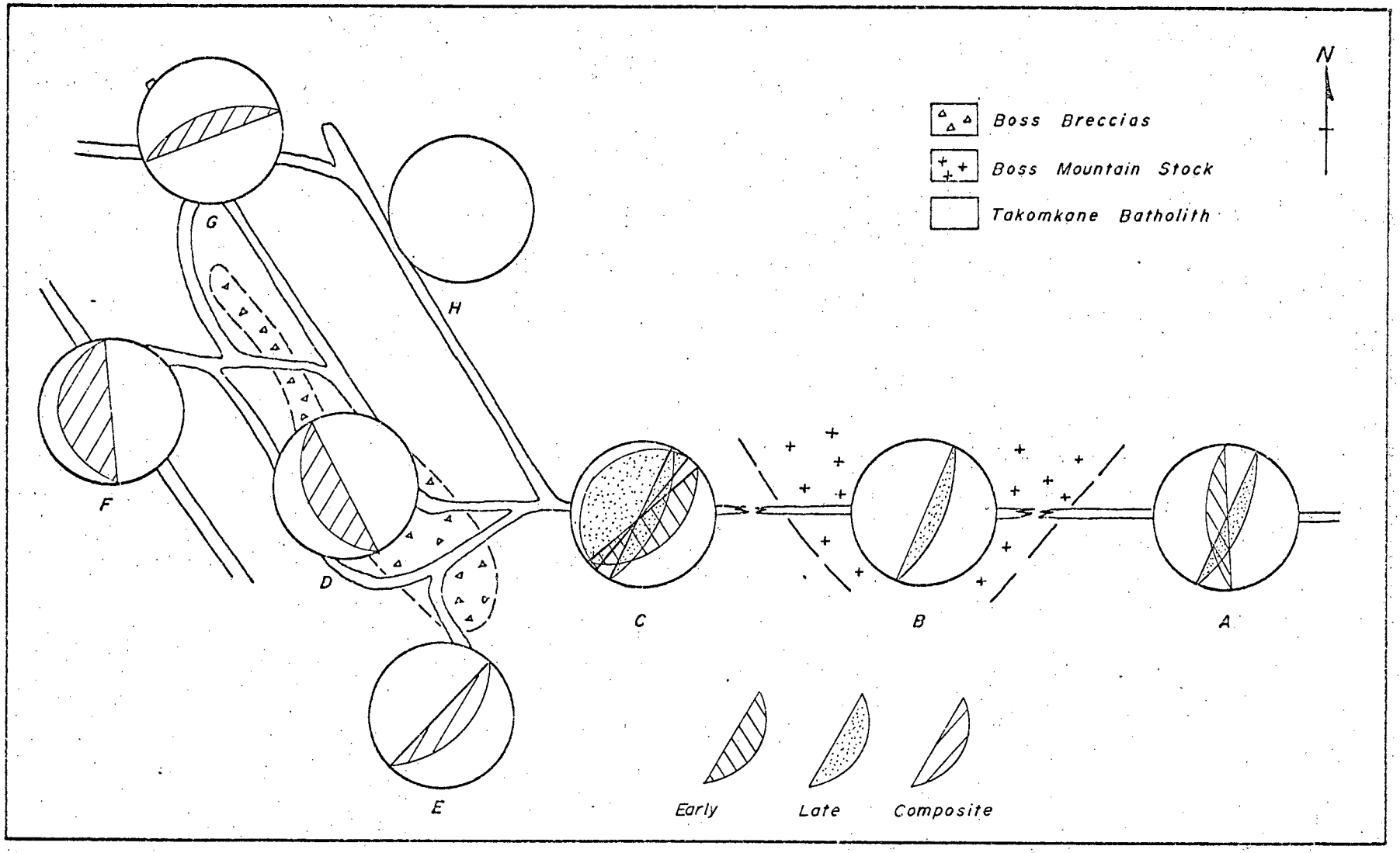


Figure 3.7. Stereographic projections (lower hemisphere) of group 4 fractures in different areas of the 5045 level (see Appendix I for contoured equal-area projections).

confined to the vein boundaries of early stage quartz veins in areas D, F, and G. In area A, B, and C early and late group 4 quartz veins occupy separate fracture sets.

Group 5 Fractures

More detail has been obtained about group 5 fractures and their associated quartz-molybdenite veins than any others. The ribbon-like character of the veins is significant to their recognition. The veins form an important part of the Stringer Zones and the High-grade Vein system. Fractures of this age have not been recognized in or east of the Boss Mountain Stock, but are prominent and abundant in and near the Main Breccia Zone where much data has been collected regarding orientations. When these data were plotted on equal-area stereonets (Appendix I) the following fracture sets became evident:

Area	Attitude of Sets	
	Strike	Dip
C	N75°W	20°S
D	N19°E	20°W
	N74°W	30°S
E	N47°E	30°S
	N75°W	30°S
F	N18°E	25°W
G	N13°E	30°W
	N79°E	43°N
H	N48°W	20°S
	N76°E	30°N

It is noted that two sets appear in areas D, E, G, and H. Because fractures of these sets have mutual intersections it is concluded that they represent pairs of conjugate shear planes.

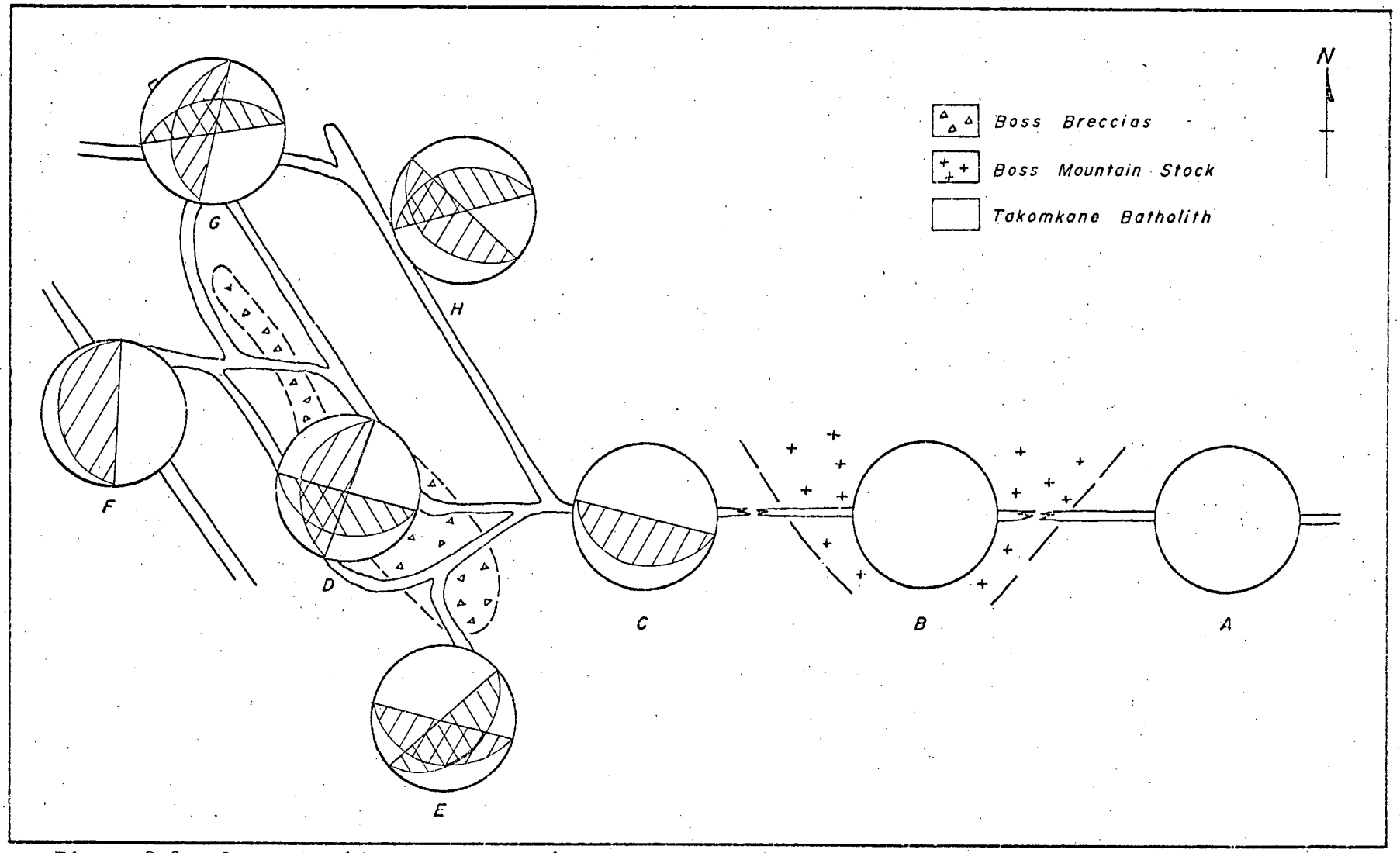


Figure 3.8. Stereographic projections (lower hemisphere) of group 5 fractures in different areas of the 5045 level (see Appendix I for contoured equal-area projections).

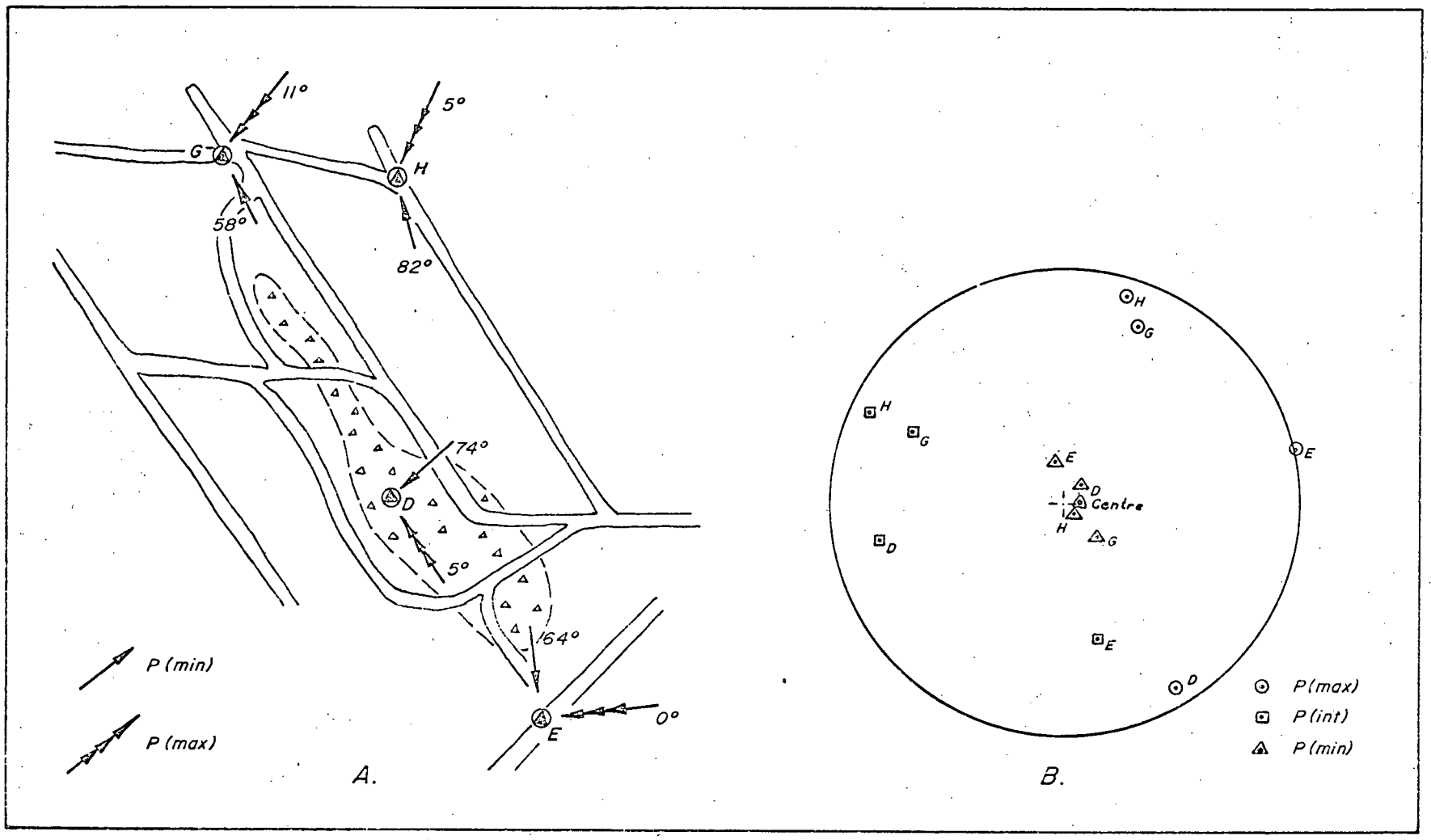


Figure 3.9. Stress elements of group 5 quartz veins. A: Orientation and attitudes in specific areas.
B: Stereographic projections (lower hemisphere) of stress elements (note that P(min) defines a great circle).

If Hartman's Law that the axis of maximum pressure (P max) bisects the acute angle between shear planes is accepted, then the stress distribution is as shown in Table 3.2.

Area	P(max)	P(int)	P(min)
D	S32°E at 5°	S76°W at 16°	N48°E at 74°
E	N77°E horizontal	S17°E at 28°	N14°W at 64°
G	N32°E at 11°	N65°W at 30°	S39°E at 58°
H	N25°E at 5°	N65°W at 6°	S26°E at 82°

Table 3.2 Group 5 fractures. Orientations of stress elements.

Such a stress distribution is illustrated by Figure 3.9. From a composite stereogram plot of these structural elements, it is noted that P(max) and P(int) have random orientation but the P(min) are concentrated in a small area, the centre of which lies in a north 74 degrees east direction at 83 degrees (Figure 3.9, B). The genetic implications of this stress distribution pattern is dealt with in a later section.

Post-Ore Fractures - 5045 Level

Group 6 Fractures

Group 6 fractures have been recognized in all rocks, except the Boss Mountain Stock and some contain post-mineral alkali basalt dykes. The fractures strike north 78 to 82 degrees east, dip 40 to 48 degrees north (Figure 3.10) and persist over lengths exceeding 500 feet. Much shearing and intense chloritization has occured along such fractures.

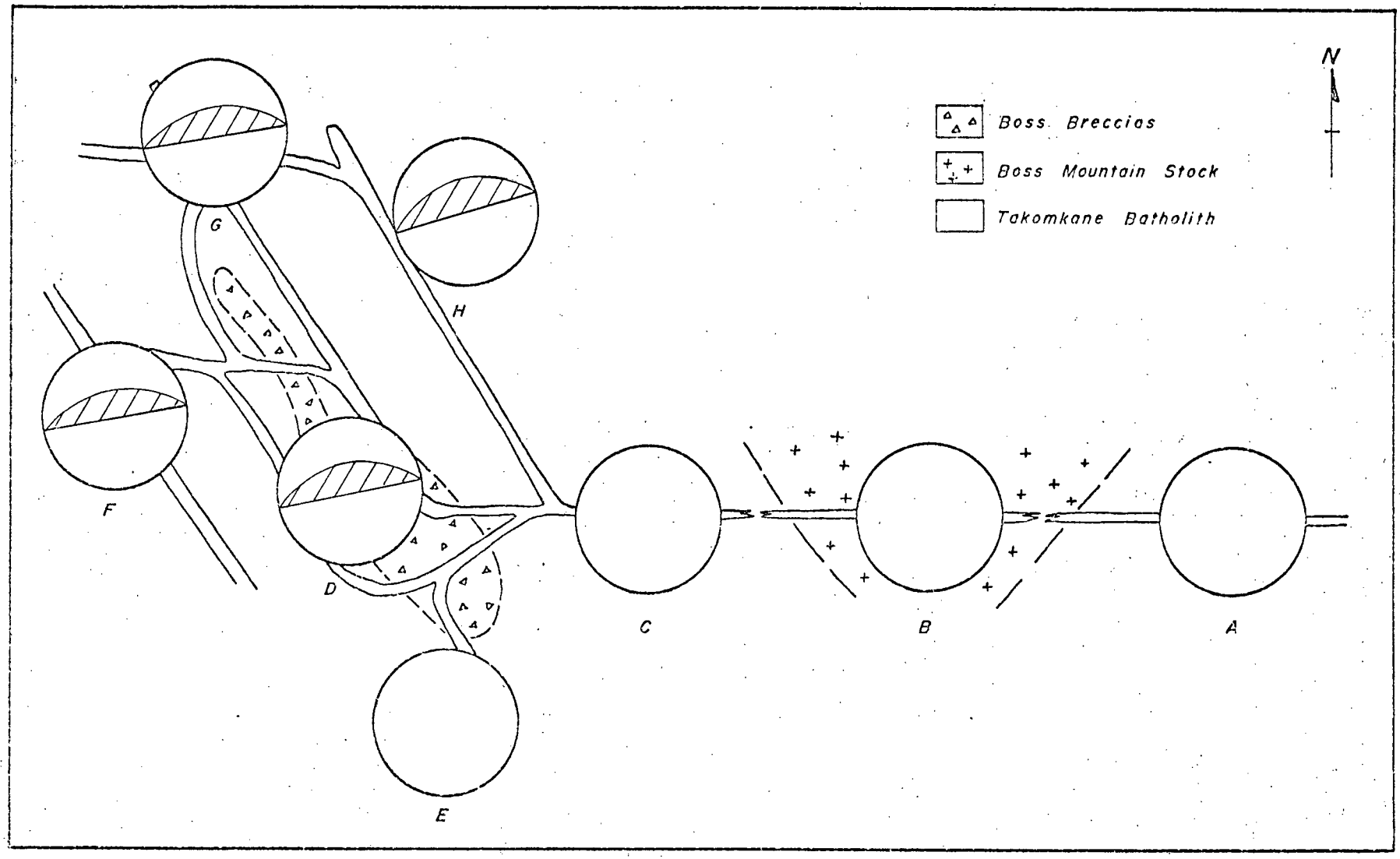


Figure 3.10. Stereographic projections (lower hemisphere) of group 6 fractures in different areas of the 5045 level (see Appendix I for contoured equal-area projections).

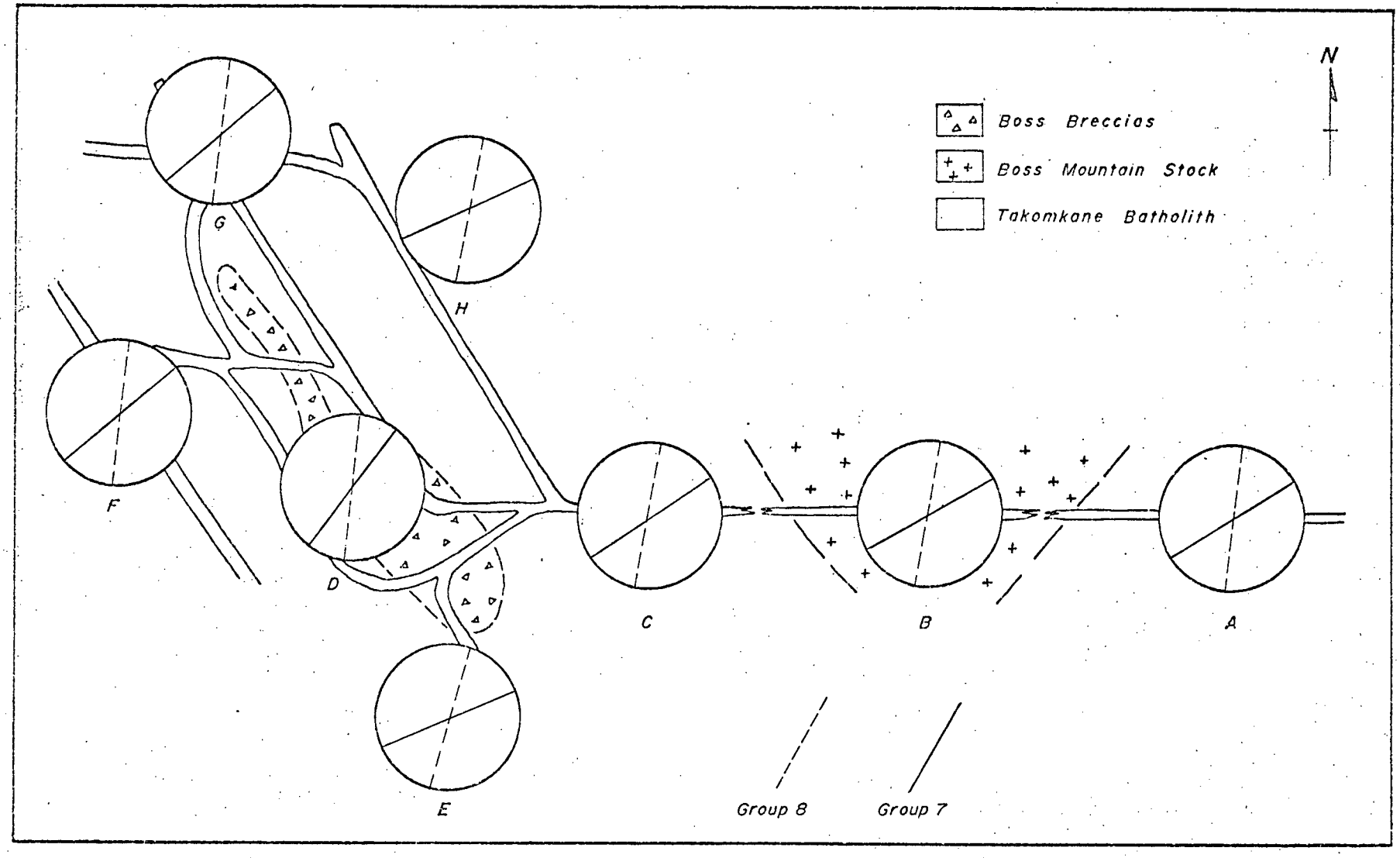


Figure 3.11. Stereographic projections (lower hemisphere) of group 7 and group 8 fractures in different areas of the 5045 level (see Appendix I for contoured equal-area projections).

Wallrock adjacent to such fractures is altered to clay minerals. Fractures of this set are clearly post-mineral. They cut and offset quartz-molybdenite veins in all ore bodies and produced drag-folds in the quartz of the High-Grade Vein. All observed displacements indicate normal faulting.

Group 7 and Group 8 Fractures

Fractures of groups 7 and 8 (Figure 3.11), also post-mineral in age, offset all ore-bearing structures and have no genetic relationship to mineralization. The fractures of group 7 strike north 50 to 60 degrees east and dip vertically. Group 8 fractures, which offset group 7 fractures, strike north 5 degrees west to north 20 degrees east and dip vertically.

Both sets of fractures contain abundant, water-bearing open spaces, filled or partly filled with calcite and zeolites. Many group 7 fractures contain alkali basalt dykes. Group 7 and 8 fractures are prominent outside the immediate mine area and were described in the section on General Structure.

One set of fractures found only east of the Boss Mountain Stock strikes north 38 degrees east and dips 55 degrees northwest. The significance of this fracture set, which does not fit into the pattern of fractures described above, is unknown.

GENETIC IMPLICATIONS OF FRACTURE PATTERNS

The garnet-hornblende veinlets surrounding the Boss Mountain Stock occupy primary fractures that formed during its intrusion. The concentric set represents adjustment of the country rock by reverse faulting above a rising pluton as illustrated by Figure 3.12; A. The conjugate sets represent lateral expansion of the pluton probably at horizons near its upper surface.

Barren and quartz-filled fractures (Group 2 Fractures) represent adjustments by fracturing closely related in time and space to development of quartz breccia. The fractures are subparallel to a prominent joint set that may have had some control on fracture development.

The position, attitude and relative age of group 3 quartz-molybdenite veins suggests that they were formed during Phase III Breccia development. During the initial stage of Phase III Breccia development, pressure directed upward resulted in reverse faulting (accompanied by quartz-molybdenite introduction) in the surrounding rock (Quartz Breccia and granodiorite) in a manner illustrated by Figure 3.12; A.

Group 4 fractures and quartz veins probably were formed by a decrease in the vertical component of stress which accompanied crystallization and subsidence of the outer part of the Boss Mountain Stock (Figure 3.12; B). As this decrease took

place, first early group 4 veins formed followed by late group 4 veins. Early group 4 veins were reopened during late group 4 development and late group 4 minerals were superimposed on the earlier-formed suite.

Group 5 quartz-molybdenite veins occupy fractures that formed as the result of pressure reduction at depth in a manner suggested by Anderson (1936) for the development of ring dykes (Figure 3.12; B). In this fracture system maximum stresses (P(max)) are everywhere nearly horizontal (see Table 3.2 and Figure 3.9). Minimum stresses (P(min)), which are steep in all areas, are concentrated around a point which lies in a north 74 degrees east direction at 83 degrees. The maximum stresses represent the normal inherent confining pressures of the rock which became maximized by a reduction in pressure below and resulted in the development of fractures now occupied by the group 5 quartz-molybdenite veins.

In summary, the development of garnet-hornblende veinlets and quartz veins can be explained by increase or decrease in pressures from below. The ultimate source of this pressure variation, which is also related to breccia development, probably was the Boss Mountain Stock.

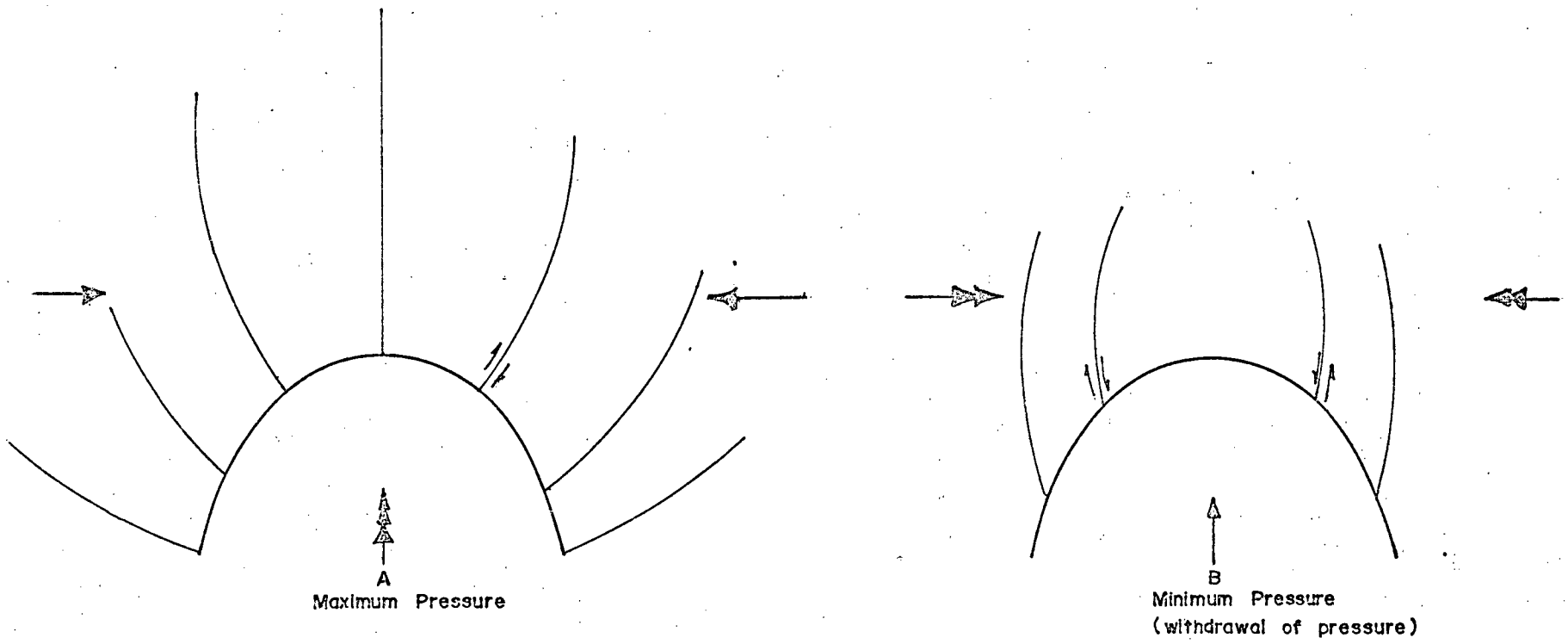


Figure 3.12. Formation of fractures. (A, forceful injection. B, withdrawal of pressure). Modified after Anderson, 1936.

IV. ROCK ALTERATION

Rock alteration in the Boss Mountain mine area resulted in the appearance of many different mineral assemblages, some genetically related and some unrelated to ore deposition. The degree of alteration ranges from very weak to intense.

ALTERATION UNRELATED TO ORE DEPOSITION

Alteration unrelated to ore deposition includes propylitization and a zeolite-calcite-clay assemblage.

Propylitic Alteration

Widespread propylitic alteration generally is restricted to the proximity of fractures but locally is more pervasive. Irregular, discontinuous and randomly-oriented fractures throughout the area contain epidote and the adjoining rock has been chloritized and saussuritized for a few inches from fractures. Three areas of more pervasive propylitic alteration are indicated on Map 3.

Area I is north of Takomkane Volcano near some old copper showings; area II, west of the mine, is the largest and most intensely altered; and area III is exposed on a bench below the cirque walls south-southwest of the mine.

In these areas epidote veinlets are two inches to one foot apart and the intervening rock is completely or partly chlor-

itized and saussuritized. Minor amounts of pyrite occur in both the veinlets and in the rock, but may not be part of the propylitic alteration. Pyrite which forms a halo around the molybdenum mineralization is clearly superimposed upon and is therefore younger than the propylitic alteration.

Zeolite-Calcite-Clay Assemblage

Post-mineral fractures throughout the area commonly contain fillings and encrustations of zeolite and calcite which represent the last stage of rock alteration. This alteration, presumably related to Takomkane Volcano, is too erratic in distribution to be shown on Map 3. Within the mine the zeolite-calcite-clay assemblage occurs not only in post-mineral fractures, but is found also as crystalline growths in vugs in Phase III Breccia and quartz veins and in vesicles in alkali basalt dykes.

Four zeolites, stilbite, chabazite, sodium harmotome, and heulandite, were identified by X-ray powder photographs. Stilbite is the most abundant and most widespread zeolite. Chabazite is relatively common and sodium harmotome and heulandite are rare.

Euhedral golden yellow to golden brown crystals and crystal aggregates of stilbite line open fractures and vugs. Individual crystals, which range in length from a fraction of a millimeter to 10 mm, were deposited in sub-radiating and randomly oriented

groups in open spaces. Anhedral masses of stilbite also replace plagioclase in the matrix and fragments of the Phase III Breccia, imparting a brownish colour.

Chabazite is more restricted in distribution than stilbite. Transparent to translucent honey-brown rhombohedra of chabazite occur in vugs in Phase III Breccia and in quartz-microperthite-pyrite veins. Stilbite generally occurs with chabazite, in places as encrustations. Angles between rhombohedral faces of chabazite crystals are almost 90 degrees and the crystals appear nearly cubic, resembling fluorite. Cleavage, visible in most crystals, is parallel to crystal faces $(10\bar{1}1)$. The size of the chabazite rhombohedra averages 3 mm., but crystals as large as 15 mm. have been found.

In thin section, chabazite appears isotropic and resembles fluorite except for cleavage. In plane polarized light chabazite is colourless to light pink and has a refractive index less than orthoclase. Chabazite rarely replaced plagioclase and orthoclase (microperthite) in the Phase III Breccia. Some garnet-hornblende veins contain chabazite.

Sodium harmotome was observed only in the Boss Mountain Stock. Veinlets generally are less than $\frac{1}{2}$ inch wide, but locally swell to 2 inches. Wider sections of the veins are vuggy and lined with white euhedral crystals up to 5 mm. in length. Sodium harmotome occurs only near alkali basalt dykes and development probably is related to dyke intrusion. The

mineral was not studied in thin section.

Colourless crystals of heulandite were observed in narrow, somewhat vuggy veinlets which cut alkali basalt dykes. Vuggy parts of veinlets are lined with euhedral heulandite crystals and white calcite scalenohedra. The nearly equant heulandite tablets have perfect 010 cleavage. Cleavage faces have a pearly lustre. Crystals range in size from 0.05 mm. to 0.5 mm. The mineral was identified by use of X-ray powder photographs.

Calcite occurs in a myriad of forms, but only those associated with zeolites will be described. Scalenohedrons, rhombohedrons, and hexagonal prisms of golden calcite were deposited on the walls of open fractures. Individual crystals reach a length of 40 mm. and generally are completely coated with randomly oriented aggregates of stilbite. Colourless hexagonal plates, golden scalenohedrons, and other more complex forms were deposited upon stilbite. In any individual vug all crystals of the same age have the same form. When more than one age of calcite occur together, they generally differ in morphology.

Clay minerals, which developed in plagiocalse and microperthite only adjacent to fractures containing zeolites and/or calcite, probably are another product of this last stage of alteration. Varieties of clay minerals were not identified.

ALTERATION GENETICALLY RELATED TO ORE DEPOSITION

Four distinct stages of hydrothermal alteration can be recognized in the Boss Mountain mine area.

(1) Garnet-Hornblende
(2) Biotite
(3) Microperthite-Chlorite-Sericite
(4) Chlorite-Talc

The distribution and limits of each stage, except the last, are shown on Map 3.

Stage 1: Garnet-Hornblende

The garnet-hornblende mineral assemblage is the initial stage of alteration related to ore deposition and is important in the interpretation of the genesis of the ore deposits. The assemblage occurs in narrow veinlets which occupy mylonite zones in granodiorite and in andesite porphyry dykes around the Boss Mountain Stock. Garnet and hornblende have replaced the host rock in and near the mylonite zones.

Distribution of the veinlets, as shown on Map 3 (in pocket), is based upon observations in underground workings and in diamond drill intersections. The veinlets occupy a zone as much as 2500 feet wide around the stock. Immediately west of the stock there is an apparent lack of veinlets. However, on closer examination veinlets of hornblende (without garnet) were found in narrow mylonite zones (up to ¼ inch wide) which parallel garnet-hornblende veinlets farther west.

Attitudes of the garnet-hornblende veinlets differ east and

west of the Boss Mountain Stock. In both areas, there are three prominent attitudes which correspond to a set of conjugate shears and a concentric shear around the stock. Development of these fractures was discussed in Chapter 3.

Garnet-hornblende veinlets range in thickness from a fraction of an inch to six inches and average less than one inch. Individual veinlets can be traced along strike for several tens of feet. The thickness varies greatly within individual veinlets and most veinlets grade into narrower mylonite zones. Typically, each veinlet is characterized by a core of red-brown garnet bordered by a black to bluish black selvedge of hornblende and magnetite (Plate 4.1). Epidote forms an important part of some veinlets, but is lacking in others. Distribution of epidote, both areally and within individual veinlets, is very erratic.

Granodiorite adjacent to garnet-hornblende veinlets is weakly mylonitized for a width up to two inches. These mylonitized areas, which are readily visible in hand specimen, generally are altered to fine-grained sericite. Some veinlets grade laterally into mylonite zones without garnet-hornblende development.

Aggregates of anhedral garnet crystals form the cores of the veinlets. Individual garnet anhedra do not exceed 0.2 mm. in diameter. Several specimens of garnet were selected for

Plate 4.1. Mylonitized granodiorite containing veinlets of garnet (grey) with hornblende selvedges (black). (Scale is in inches).

measurement of refractive index, specific gravity and cell edge. Fourteen samples were of sufficient purity to measure index of refraction and cell edge, but were too small for specific gravity measurement. Refractive index and cell edge data are plotted on Winchell's diagram (1958, p.597) resulting in a concentration of points near the andradite corner of the diagram (Figure 4.1). Index of refraction measurements (measured with an Abbey refractometer) range from 1.869 to 1.873. Cell edge determinations alone (12.00-12.03 Å) indicate a garnet rich in the andradite molecule. Determinations of cell edge were made from X-ray powder photographs corrected for film shrinkage.

Green hornblende forms a selvedge of subhedral crystals up to 0.1 mm. in length adjacent to the garnet core. Identification is based on external form, pleochroism, and cleavage. Disseminated euhedral magnetite accompanies the hornblende. Locally, aggregates and veinlets of anhedral magnetite cut the hornblende selvedge but little magnetite occurs in the garnet cores.

Chabazite, which was noted near the center of the garnet core in two thin sections, probably replaces plagioclase.

Stage 2: Biotite

Biotite is the most widespread product of potassium metasomatism. With the exception of the Boss Mountain Stock and the alkali-basalt dykes, hydrothermal biotite occurs in all rocks

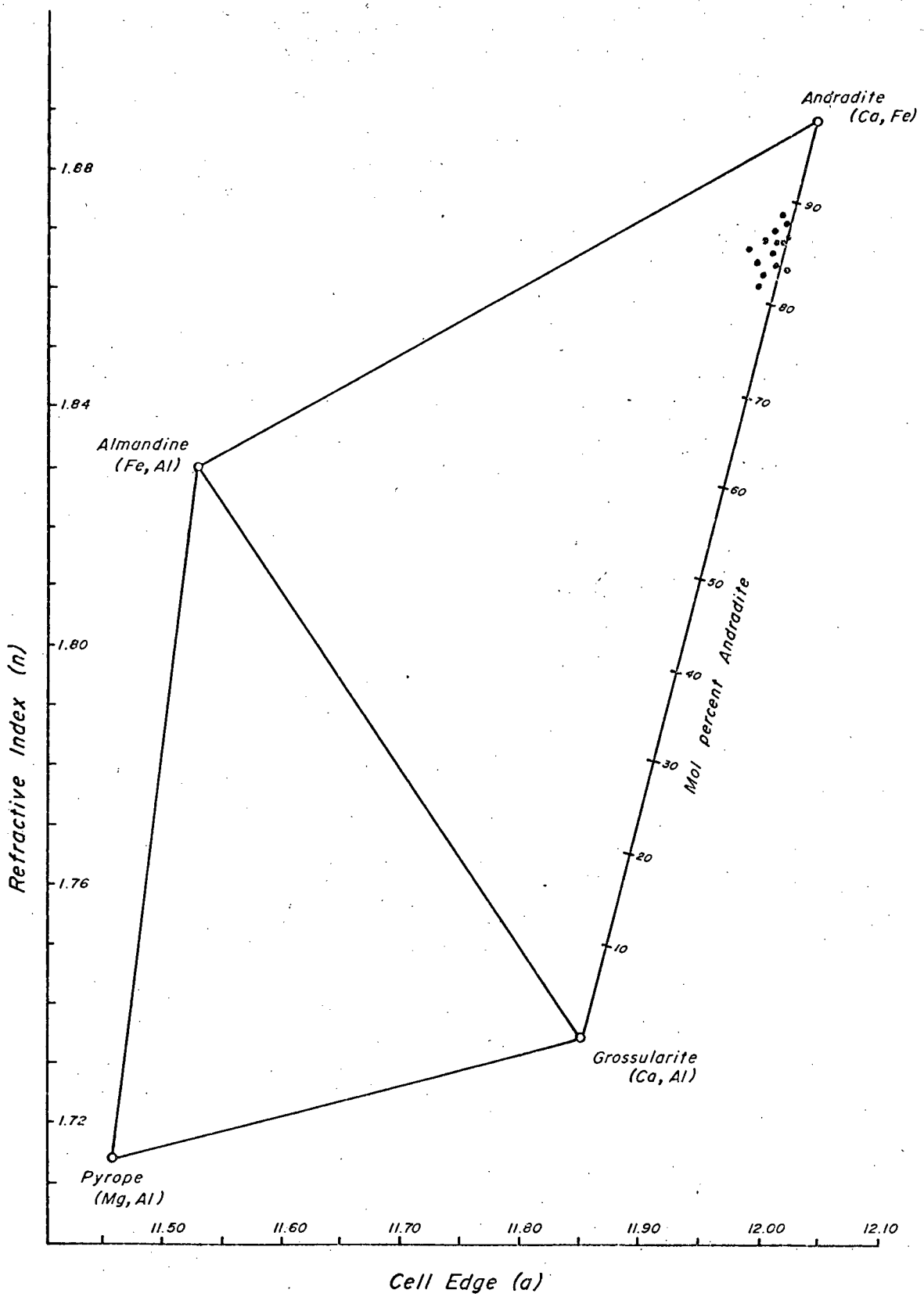


Figure 4.1. Composition of 14 garnets; Boss Mountain Mine. (Diagram modified from Winchell, 1958, p. 597).

throughout the mine workings. The western limit of the biotite zone has been traced on the surface approximately 1,000 feet west of the underground workings. Map 3 (in pocket) shows the distribution of hydrothermal biotite as determined from underground workings, scattered outcrops, trenches, roadcuts, and diamond drill intersections. Limits of alteration to the northeast and south could not be established because of the lack of rock exposures. The western limit is near the base of cirque walls which rise 1,500 feet above the valley floor.

Biotite metasomatism is most intense in and near the breccias. The degree of metasomatic replacement generally decreases with increasing distance from the breccias, except in andesite dykes which are intensely biotitized everywhere within the biotite zone.

The presence of hydrothermal biotite in granodiorite or porphyritic biotite granodiorite has not altered the overall appearance of the rock, which has a fresh appearance in hand specimen. Hydrothermal biotite can be readily identified in hand specimen with the aid of a hand lens. Apparently homogeneous primary mafic minerals (hornblende and biotite) are composed of aggregates of fine-grained black to greenish black biotite crystals. Weakly altered specimens from peripheral areas require thin section examination for identification of hydrothermal biotite. Actinolite is

locally abundant with the biotite in altered andesite dykes.

The biotite is olive-green to pale brown in plane polarized light. Olive-green biotite occurs as mosaic ovoids, irregular patches, pseudomorphs and veinlets of randomly oriented crystals and as single crystals in altered andesite dykes. Pale brown biotite occurs as single crystals in the matrix of the Phase III Breccia and as aggregates of euhedral crystals replacing andesite dyke fragments in Phase III Breccia. Individual biotite crystals range from 0.1 to 0.5 mm. in length.

Microfractures and the arrangement of mafic minerals of magmatic origin determine the distribution of hydrothermal biotite. Ovoids of biotite crystals generally are of the same size as primary mafic minerals in the host rock (1 to 4 mm). Many pseudomorphs of hydrothermal biotite after magmatic hornblende and less commonly, hydrothermal hornblende, have retained the external morphology of the host (Plate 4.3). Replacement of magmatic biotite generally results in irregular masses and patches of biotite crystals, some with thin bands of magnetite grains oriented parallel to the cleavage of the original magmatic biotite. In the initial stages of biotite metasomatism only the edges of magmatic crystals are replaced (Plate 4.2). Rocks which contain abundant microfractures have abundant hydrothermal biotite along the fractures as well as replacements

of primary mafic minerals. In some highly altered rocks even the feldspars have been partly altered to biotite.

Introduction of hydrothermal biotite into the granodiorite and other rocks resulted in other more subtle changes within the rocks. Plagioclase grains contain very small amounts of sericite where they are in contact with hydrothermal biotite but not elsewhere in the grain. This may have been caused by diffusion of potassium during development of hydrothermal biotite. Chloritization of hydrothermal biotite released potash and further contributed to the sericitization of plagioclase. In rocks which contain visible chlorite, sericitization has imparted a chalky appearance to the plagioclase.

The type of host rock has played an important role in the intensity of biotite metasomatism. Most of the above descriptions of biotite metasomatism apply to granodiorite and porphyritic biotite granodiorite because these rock types form the bulk of the altered rock. Other rocks, though of less quantitative importance, have in some cases been more intensely metasomatized.

Xenoliths of hypersthene gabbro were highly sensitive to biotite alteration. Some xenoliths have been so intensely altered that their original composition is difficult to ascertain except by the texture of the remaining plagioclase. Biotite preferentially replaced mafic minerals; hence, distribution of

primary mafic minerals in the gabbro has largely determined the distribution of hydrothermal biotite.

Rhyolite and rhyolite porphyry dykes, which contain few mafic minerals contain little hydrothermal biotite. Hydrothermal biotite occurs as evenly distributed euhedral grains in the matrix of Phase III Breccia. In contrast hydrothermal biotite occurs in stringers in the Phase I Breccia. Adjacent to such stringers, biotite replaces and transects feldspars in the matrix.

The effect of biotite alteration on andesite and andesite porphyry dykes and dyke fragments in the breccias ranges from weak to extreme. Table 4.1 shows the modes of unaltered and altered andesite and andesite porphyry dykes. In weakly altered dykes (Table 4.1, number 3) biotite is not discernable with the naked eye.

Several pronounced changes occur in andesite dykes with increase in the quantity of hydrothermal biotite. As the biotite content increases the rock becomes progressively more schistose in appearance until the end-product is a biotite "schist" composed almost entirely of biotite (Table 4.1, number 11). The colour of the dykes generally becomes greener with increasing alteration and dyke fragments in the breccias are dark greenish black or light brown. Veinlets of biotite and/or actinolite also occur in weakly altered dykes.

1 cm.

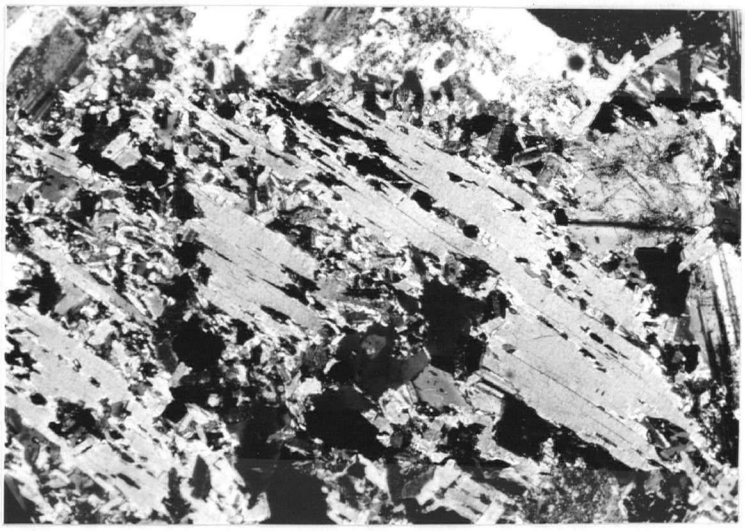


Plate 4.2. Photomicrograph (crossed nicols) of hydrothermal biotite which has partly replaced magmatic biotite.

1 cm.

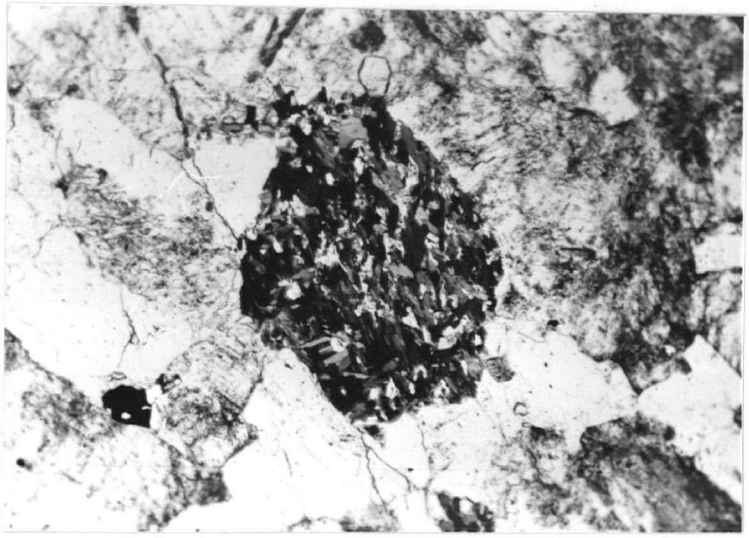


Plate 4.3. Photomicrograph (plane polarized light) of pseudomorphic hydrothermal biotite which has replaced magmatic hornblende.

Figure 4.2 is a plot of mineral variations in andesite dykes with increasing biotite content. Formation of biotite and actinolite rims on primary hornblende in the dykes are the first effects of Stage 3 alteration (Table 4.1, number 3). Once hornblende is completely altered, plagioclase is progressively replaced by biotite and actinolite. Actinolite increases at a more rapid rate than biotite until the actinolite content reaches about 55 percent of the rock. Biotite then replaces actinolite until the rock consists of essentially 100 percent biotite. Samples of altered andesite dykes containing greater than 90 percent biotite occur only as fragments in the breccias. Such samples may have never contained actinolite as a mineral phase.

A close correlation exists between the ratio of actinolite and quartz. Rocks that contain the highest percentage of actinolite also have the highest quartz content.

It appears that plagioclase becomes more sodic as actinolite and biotite begin to replace it. Apatite and zircon content of all samples remains constant throughout the alteration process.

The mineral changes outlined above are summarized in Table 4.1 and illustrated by Figure 4.2.

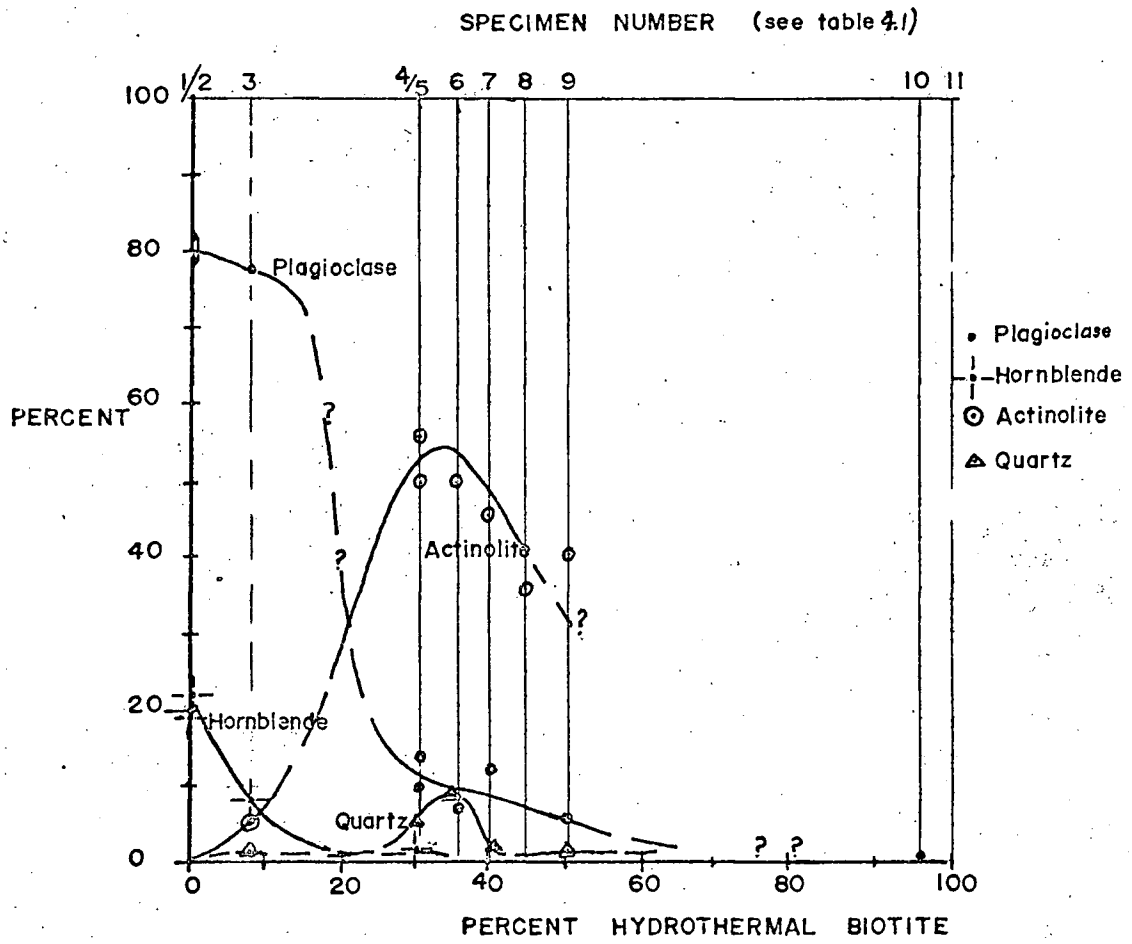


Figure 4.2. Mineral variations in altered andesite and andesite porphyry dykes in relation to increasing biotite content.

		Primary								Alteration									
		Plagioclase		Quartz	Hornblende	Biotite	Zircon	Apatite	Magnetite	Plagioclase		Quartz	Biotite	Actinolite	Talc	Epidote	Chlorite	Sericite	Carbonate
No.	Specimen	%	An							%	An								
1	6-23.1 (P)	6	40-55	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	(G)	75	43-44	x	-	-	x	x	x	-	-	-	-	-	-	-	x	x	x
2	8-6.2 (P)	8	40-45	-	18	2	-	-	-	-	-	-	-	-	-	-	-	-	-
	(G)	70	45	x	2	-	x	x	x	-	-	-	-	-	-	x	-	-	-
3	1-19.2-I (P)	8	36-42	-	10	-	-	-	-	-	-	-	6	5	-	-	-	-	-
	(G)	71	-	-	-	-	x	x	x	-	-	-	-	-	-	x	x	-	x
4	10-28.4	-	-	-	2	-	x	x	-	14	10-12	4	30	50	-	x	-	-	x
5	8-11.2	-	-	-	-	-	x	x	x	10	13	4	30	56	x	-	x	-	x
6	10-27.12	-	-	-	-	-	x	x	x	7	11	8	35	50	-	-	-	-	x
7	502	-	-	-	-	-	x	x	-	13	10	2	40	45	-	-	-	-	x
8	8-1.3	-	-	-	-	-	x	x	x	x	-	2	45	35	8	-	x	-	10
9	BS-15	-	-	-	-	-	x	x	x	6	8	1	50	40	-	-	x	-	3
10	9-3.4	-	-	-	-	-	x	x	-	2	-	2	96	-	-	-	-	-	-
11	10-27.1	-	-	-	-	-	x	x	-	-	-	x	100	-	-	-	-	-	-

P Phenocrysts G Groundmass x minor - absent

Table 4.1. Modes of andesite porphyry dykes and their altered equivalents; Boss Mountain mine area.

Stage 3: Microperthite-Chlorite-Sericite

The Stage 3 alteration assemblage generally is moderately to intensely developed in Phase III Breccia, the Stringer Zone, and the Boss Mountain Stock (Map 3). Widely scattered occurrences of Stage 3 alteration, not shown on Map 3, are associated

with quartz veins throughout the mine area.

Creamy to salmon-coloured microperthite developed as subhedral to euhedral crystals in the matrix and in open vugs in Phase III Breccia and as anhedral grains in breccia fragments. Granodiorite fragments were most susceptible to feldspathization and locally are intensely altered to masses of microperthite, chloritized mafic minerals, and sericite. Pyrite is ubiquitous.

Stage 3 alteration in the Stringer Zone and in the Boss Mountain Stock is slightly different in character and is more intense than that in the Phase III Breccia. Microperthite, chlorite, and sericite envelope quartz-microperthite veins (Group 4 veins) for widths up to seven feet, but generally the granodiorite host rock is altered for about 18 inches on both sides of the veins. Chlorite formed at the expense of mafic minerals and as vug-filling crystal aggregates in and near the veins. Sericite occurs in vugs and as an alteration product of magmatic feldspars.

Metasomatic microperthite is readily distinguished from magmatic microperthite in this area. The creamy to salmon-coloured metasomatic variety contrasts sharply with the white magmatic microperthite in the granodiorite and the orange orthoclase of the Boss Mountain Stock. Exsolved plagioclase is more irregular in shape and distribution in metasomatic than in magmatic microperthite. Replacement of plagioclase is a feature common to

both microperthites. Much magmatic microperthite in granodiorite is poikilitic, a feature not shared by metasomatic microperthite.

Individual crystals of hydrothermal microperthite, ranging in size from 5 to 10 mm., formed in vugs as euhedral, equant grains. Anhedral microperthite ranges from 1 to 8 mm. in diameter. Veinlets of molybdenite cut metasomatic microperthite. Minor quantities of chalcopyrite and sphalerite occur in parts of the Phase III Breccia that are rich in metasomatic microperthite.

Chlorite associated with Stage 3 alteration has either epigenetic or pseudomorphic form. In its epigenetic form chlorite occurs as radiating aggregates of subhedral crystals in vugs (Plate 4.6). Between crossed nicols this chlorite is chocolate brown in colour. Some, but not all, grains contain inclusions of translucent golden brown to deep red rutile crystals (Plates 4.6 and 4.7).

Chlorite also occurs as pseudomorphs of mafic minerals, particularly hydrothermal biotite (Plate 4.4). In thin section the colour and habit of pseudomorphic chlorite contrasts sharply with epigenetic chlorite. The colour (crossed nicols) is anomalous purple to yellowish. Chlorite pseudomorphs after biotite contain inclusions of very dark brown to opaque rutile. Sphene occurs as minute crystals in chloritized hornblende. Rocks

affected by Stage 3 alteration contain both forms of chlorite. The epigenetic form predominates in the Phase III Breccia and in the Boss Mountain Stock and the pseudomorphic form in the Stringer Zone. Some of the properties of the two chlorites are compared in Table 4.2.

Epigenetic Form	Pseudomorphic Form
1. As radiating and single subhedral crystals in vugs.	1. Assumes form of original mafic mineral.
2. Some, but not all, contain translucent rutile inclusions	2. Always contain opaque to weakly translucent rutile or sphene inclusions.
3. Rutile not confined to chlorites.	3. Rutile only in chlorite.
4. Chocolate brown(crossed nicols).	4. Purple to yellowish (crossed nicols).
5. Little or no effect on adjacent feldspars.	5. Halo of sericite in adjacent feldspars.

Table 4.2. Comparison of chlorites produced during Stage 3 alteration.

Feldspars, particularly plagioclase, where in contact with chloritized hydrothermal biotite contain sericite adjacent to the contact. Such sericite has been superimposed on sericite associated with hydrothermal biotite development. Apparently the chlorite structure could not accommodate potassium which was expelled, forming sericite in the adjoining feldspar grains.

Titanium, which apparently is less mobile than potassium, remained with the chlorite, forming discrete grains of rutile or sphene. Rutile formed only in chloritized hydrothermal biotite,

1 cm.

Plate 4.4. Photomicrograph (plane polarized light) of chloritized biotite with rutile inclusions (black).

1 mm.

Plate 4.5. Photomicrograph (plane polarized light) of hydrothermal biotite cut by molybdenite (black).

indicating the biotite probably was titaniferous. Magmatic hornblende was also titaniferous and chloritized specimens contain grains of sphene.

Schwartz (1958) described the development of rutile inclusions during chloritization of biotite and concluded that rutile in chlorite indicates the chlorite was derived from biotite. This does not appear to be the situation at Boss Mountain (Table 4.2).

Sericite occurs as yellow to yellow-green subhedral crystals and crystal aggregates in vugs and in the groundmass of the granodiorite and the Boss Mountain Stock. It also occurs in feldspars accompanying chloritization. Sericitization shows an affinity for plagioclase in preference to orthoclase.

Except in certain weakly or moderately altered zones, sericitization of the Boss Mountain Stock is extreme. The alteration is most intense adjacent to quartz-microperthite-pyrite veins (group 4 quartz veins). Relative proportions of quartz, microperthite and pyrite in the veins vary considerably along strike and dip.

The degree of sericitization of the stock is readily discernible by rock colour. Weakly sericitized rocks are pink to orange and appear relatively fresh in hand specimen, except for a waxy appearance of the plagioclase. Moderately altered rocks are white to grey-green and contain unaltered cream-coloured

1 mm.

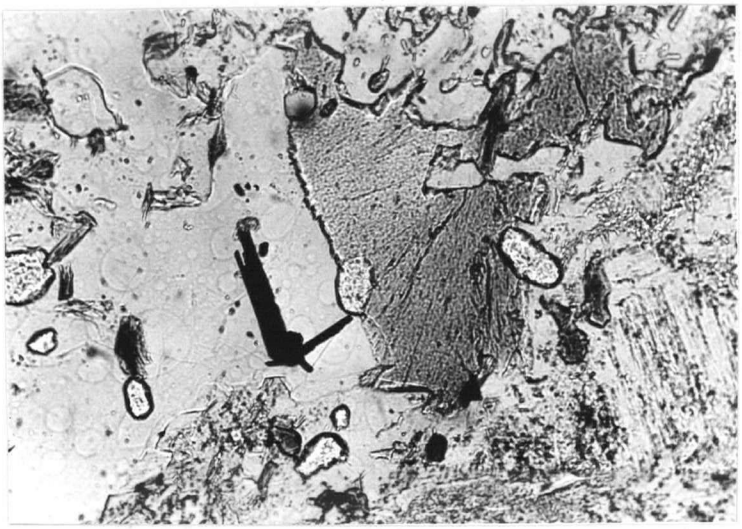


Plate 4.6. Photomicrograph (plane polarized light) of rutile (black) in quartz near epigenetic chlorite (grey).

1 mm.

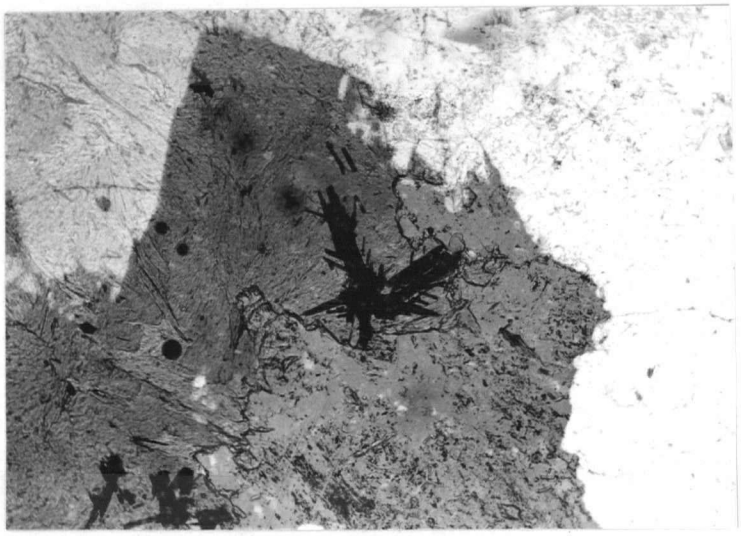


Plate 4.7. Photomicrograph (plane polarized light) of rutile (black) in epigenetic chlorite.

orthoclase and glassy quartz in a matrix of white to olive green sericite. Intensely sericitized quartz monzonite is olive green in colour and only quartz has escaped alteration. Chlorite and epidote occur in areas of intense sericitization. Ubiquitous pyrite and minor chalcopyrite occur throughout the stock without apparent quantitative relationship to intensity of alteration.

Stage 4: Chlorite-Talc

Chlorite and talc characterize the Stage 4 alteration assemblage. The assemblage is restricted to dyke-like and vein-like bodies filling fractures which cut the Boss Breccias and surrounding rocks in a north 76 to 85 degrees east direction with dips 45 to 60 degrees northward. The High-grade Vein which parallels this fracture set, has been highly sheared and altered. Andesite dykes which were intensely altered by biotite metasomatism also have been especially susceptible to Stage 4 alteration. Most altered andesite dykes trend north 30 to 50 degrees west but some trend north 75 to 82 degrees east. Easterly trending dykes have been intensely altered to masses of chlorite and talc. Carbonate generally accompanies alteration. Stage 4 alteration is not shown on Map 3 because the assemblage is restricted to narrow dykes and shear zones.

Northwesterly trending altered andesite dykes contain much chlorite and talc where cut by easterly trending fractures related to the Stage 4 alteration.

Patches of brown carbonate were observed in some dykes. Talc veinlets occur in carbonate-rich areas. In thin section the chlorite is very pale green in colour. Narrow fractures (less than $\frac{1}{4}$ inch) coated with chlorite are common throughout the mine area and are related to Stage 4 alteration. Orientations of these fractures were not measured. Irregular vein-like bodies of Stage 4 alteration which cut the breccias seldom exceed five inches in thickness. The schistose character of these vein-like bodies is caused by shearing. Shearing related to development of the alteration has folded and fractured pre-existing group 5 quartz veins.

V. ORE DEPOSITS

HISTORY AND MINE DEVELOPMENT

The first prospecting activity reported in the Takomkane Mountain area was in 1914 when claims were staked on the north flank of the mountain. Several mineralized zones containing chalcopyrite, pyrite, galena, and sphalerite with sporadic precious metal values were discovered and prospected for a few years before the claims were abandoned.

In 1917, W. J. Ryan and John Foster discovered and staked molybdenite showings on the east slope of the mountain. In the fall of the same year several hundred pounds of molybdenite ore was hauled to Lac la Hache by pack-mule. The fate and total amount of ore shipped from the claims is somewhat obscured by history, but Eardley-Wilmot (1925, p.33) gives the following description of ore from Takomkane Mountain:

> "Early in 1918, Mr. Ryan sent 761 pounds of hand-picked ore to the Mines Branch, Ottawa, from which 210 pounds of pure molybdenite was recovered and sold to the Canadian General Electric Company. In addition 200 pounds of 75 percent ore was sold elsewhere".

Following the shipment of ore, subsequent activity on the claims was not recorded until 1930 when Consolidated Mining and Smelting Company of Canada, Limited, began exploring the property. Several trenches were excavated on a quartz-molybdenite vein system south of Molybdenite Creek and on a breccia zone.

In 1942 the British Columbia Department of Mines and

Petroleum Resources took an X-ray diamond drill to the property by pack-horse and drilled a total of 1363 feet. Further drilling and exploration of the breccia zone were recommended, but the work was not performed.

In 1955 H. H. Heustis and associates of Vancouver acquired the claims at a tax sale after examination and resampling of the property by W. H. White. The property was optioned to Climax Molybdenum Company in 1956. Between 1957 and 1960, when the option was dropped, Climax Molybdenum Company and Southwest Potash Company, Limited, completed 37,000 feet of diamond drilling; dug several trenches; completed geological, geochemical, and geophysical surveys; and constructed a fair-weather road suitable for four-wheel drive vehicles to connect with a road to Horsefly.

In March 1961, Noranda Exploration Company, Limited, optioned the property from H. Heustis and associates. Two men were dropped near the property by helicopter to relog the available drill core. When the snow melted, geological mapping, geochemical sampling, trenching, and drilling programs were initiated to confirm interpretations based upon drill core studies. Construction of an all-weather road to connect the property with the Hendrix Lake Forestry Access Road six miles to the east commenced during the summer of 1961 and was completed in 1962.

An adit site was selected approximately one mile east of the showings at the edge of a broad, relatively flat valley which forms the head of one branch of Boss Creek. A camp was erected near this site and in 1962 and 1963 a 6000-foot exploration adit was driven at elevation 5045 feet to intersect the Main Breccia Zone. From this adit a vertical raise was driven through the orebody to the surface and a sub-level and second raise were driven for sampling and drilling purposes.

Further underground exploration and sampling resulted in a decision in late 1963 to bring the mine to production. The following spring construction of concentrating plant, storage bins, office buildings, townsite, and other structures commenced and in March, 1965, production was attained at 1000 tons of ore per day.

Underground development and exploration continued through 1965, 1966, and 1967 and in early 1968 plans were being considered for an internal shaft to provide access to ore below the 5045 level of the mine. Bulk sampling of an area of possible open-pit ore was carried on in 1967, but the results of these tests have not been made public.

During nine months in 1965, the concentrator treated 259,000 tons of ore from which 1429 tons of concentrates containing 1,585,000 pounds of molybdenum were produced (Noranda Mines, Limited, Annual Report, 1965). The following year (1966),

during the first full year of production, the concentrator treated an average of 1190 tons of ore per day with a 95.8 percent recovery to produce 3,069 tons of concentrates containing 3,576,000 pounds of molybdenum (Noranda Mines, Limited, Annual Report, 1966). During 1967, 1286 tons of ore per day were mined and treated with total production at 469,000 tons of ore averaging 0.35 percent molybdenum. The concentrate contained 3,130,000 pounds of molybdenum.

> In 1967; "Ore reserves above the adit level were maintained at 2,475,000 tons, with average grade reduced to 0.28 percent molybdenum." (Noranda Mines, Limited, Annual Report, 1967).

FORM OF MINERAL DEPOSITS

The bulk of the molybdenite ore of the Boss Mountain deposits is contained within breccia bodies or vein systems. Ore deposits generally are defined by assay boundaries. In the breccia deposits these boundaries are sharp and can be visually established before the completion of assays. Ore boundaries in vein systems, which require more detailed analysis, are defined by the distance between the veins and the grade of the component veins. Some of the ore bodies are shown in plan, cross-section, and longitudinal section in Figures 5.1, 5.2, and 5.3.

The Main Breccia Zone is a crudely lenticular, nearly vertical body that strikes north 35 degrees west and plunges steeply northwestward. The zone is 200 to 400 feet long,

30 to more than 100 feet wide, and has been traced from the surface to a vertical depth exceeding 1100 feet where it terminates against the Boss Mountain Stock. Mineralization boundaries of the Main Breccia Zone as shown in Figures 5.1, 5.2 and 5.3 represent a grade of 0.4 percent molybdenum. Downward the ore zone separates into two roots. The northernmost root bottoms between elevations 5045 feet and 4900 feet, but the south root extends downward without change to the contact with the Boss Mountain Stock.

For mining purposes the Fracture Ore Zone, which is along the upper edge of the Quartz Breccia, is considered part of the Main Breccia Zone; however, this zone is structurally different and deserves special description. The Fracture Ore Zone, a bulbous hood that envelopes the upper edge of the Main Breccia Zone, is a body of breccia with closely spaced, unoriented fractures filled with molybdenite and a little quartz (Figures 5.1, 5.2, and 5.3). Along its plunge of 45 degrees northwestward, this body extends from the surface downward for 400 feet. The zone attains a maximum width of 130 feet and a horizontal length of more than 300 feet.

Four other mineralized breccia zones are known, but have not been extensively explored. All are roughly vertical, pipe-like bodies, ovoid to circular in plan. The largest of these, the South Breccia Zone, is 250 feet long in a direction north

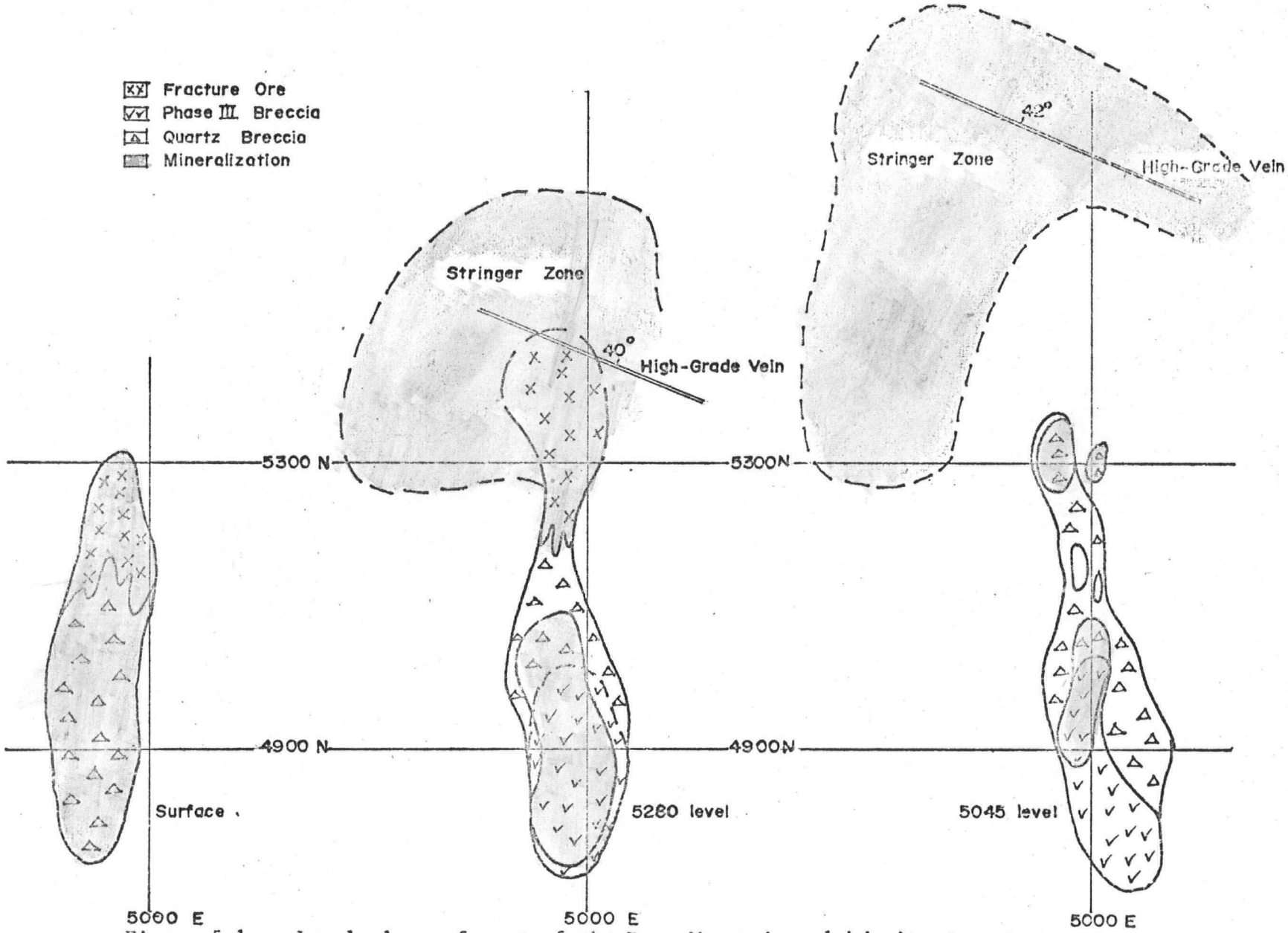


Figure 5.1. Level plans of part of the Boss Mountain molybdenite deposits.

55 degrees west with a maximum width of 110 feet. It has been traced by a few drill holes to a depth exceeding 1000 feet and is currently being more thoroughly explored. Other breccia pipes range from 15 to 25 feet in diameter and are known to persist for depths exceeding 200 feet.

Hundreds of quartz veins, some of which contain molybdenite and are of economic significance, occur in the mine area. Most veins are narrow and somewhat isolated and are individually of no economic interest, but where they occur in subparallel swarms or lodes, referred to as stringer zones, they constitute low-grade mineral deposits. The most important and best-known of these, the Stringer Zone, forms a flat-lying quarter-cone, tabular in cross-section that skirts the west side and north end of the Main Breccia Zone and the Fracture Ore Zone (Figures 5.1, 5.2, and 5.3). With a thickness ranging from 100 to 300 feet, this zone has an arc length in excess of 600 feet and an explored dip length of at least 500 feet. From its southwest end the Stringer Zone trends northerly and then swings easterly around the Fracture Ore Zone. Dips in the western part are 20 to 30 degrees to the west and in the easterly trending part are 35 to 45 degrees northwestward. Because the dip is low, the Stringer Zone intersects the Fracture Ore Zone and the Main Breccia Zone at and above the 5100-foot elevation. Boundaries of the zone are determined by the spacing and molybdenite

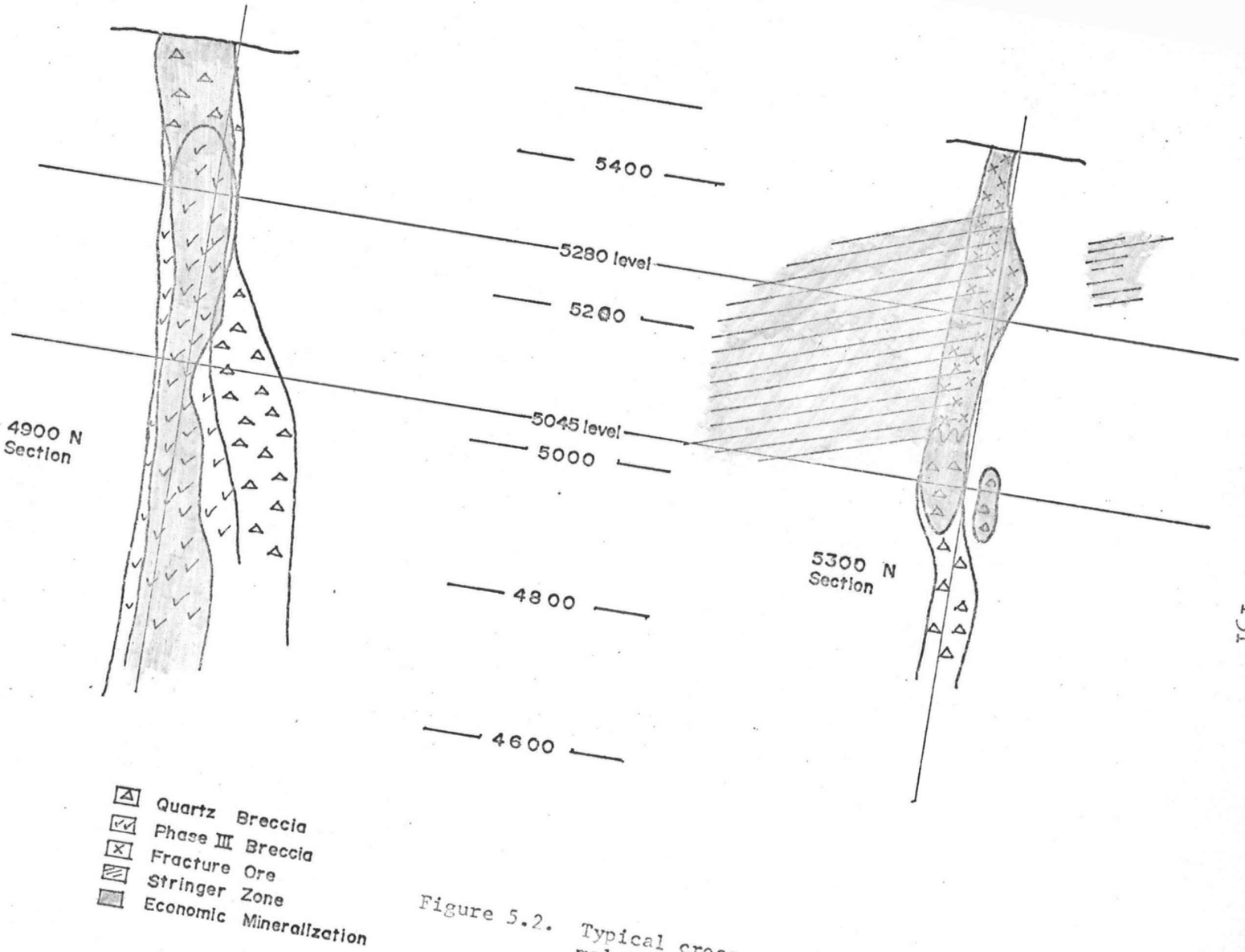


Figure 5.2. Typical cross-sections of the Boss Mountain molybdenite deposits (looking grid north - N35°W).

content of the component veins.

West and southwest of the Stringer Zone is another zone of subparallel molybdenite-bearing quartz veins which constitute the West Stringer Zone. Although only partly explored, this zone has a possible horizontal extension exceeding 3000 feet in a general north to north 35 degrees west direction. Dips of individual veins range from 15 to 35 degrees southwestward.

Sketchy diamond drill data suggest a complementary stringer zone east of the Fracture Ore Zone. The orientation and extent of veins in this zone, the East Stringer Zone, is not known, but they may be up-dip extensions of veins which form the Stringer Zone.

One vein of economic importance, known as the High-Grade Vein, has an explored length exceeding 400 feet and a width ranging from 4 to 10 feet. It is a composite vein that follows a sheared and altered andesite dyke over most of its length. The High-Grade Vein strikes north 76 to 80 degrees east and dips 42 to 48 degrees north. Molybdenite, which is erratically distributed, comprises 0.X percent to a maximum of 10 percent of the vein.

CHARACTER OF MINERALIZATION

The character of mineralization in the various ore zones is grossly similar, but differs in detail. All ore zones are composed of more than one stage of molybdenite mineralization.

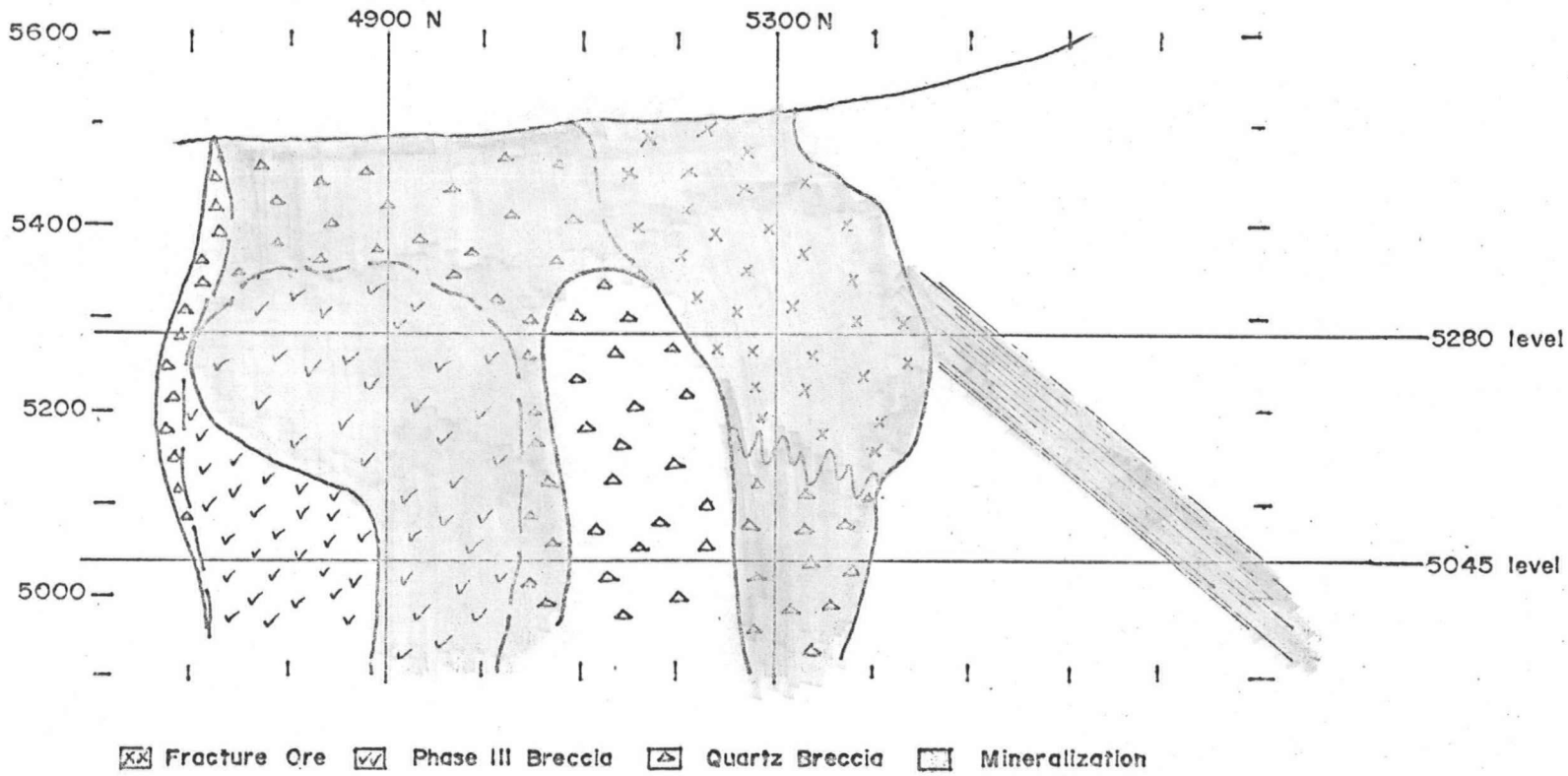


Figure 5.3. Longitudinal section (projected to 5000 E grid line) through part of the Boss Mountain molybdenite deposits (looking west).

Areas of single-stage molybdenite mineralization generally are not economically significant, except in areas of particularly intense pre-mineral fracturing.

Molybdenite deposited during the initial stages of mineralization was finely crystalline (± 1 mm.) and generally became progressively more coarsely crystalline with each successive stage. Molybdenite crystals deposited in the final stage of mineralization range from 5 mm. to 20 mm. in diameter. The exception to this generality is the mineralization in the Fracture Ore Zone which contains finely crystalline molybdenite that was deposited during intermediate and late stages of mineralization.

In the Main Breccia Zone molybdenite occurs in three different modes, introduced during two different stages of mineralization. Most molybdenite was introduced during Phase III Breccia development as part of the matrix of the breccia and also along fractures and matrix-fragment boundaries in the adjacent Quartz Breccia. Group 3 quartz veins, which developed during Phase III Breccia formation, and group 4 quartz veins also contribute to part of the ore zone. Molybdenite deposited during Phase III Breccia development is finely crystalline, whereas molybdenite in group 4 quartz veins is coarsely crystalline. Andesite dyke fragments and mafic minerals in other fragments were especially favorable sites of molybdenite

deposition. In all places molybdenite seems to occupy open spaces, such as grain contacts, vugs and fractures, and few replacement textures have been observed.

Details of the mineralization of the South Breccia Zone are scanty, but the data indicate a similar mineralization history.

The Fracture Ore Zone, which for mining purposes is considered as part of the Main Breccia Zone, is composed of two modes of molybdenite from two stages of mineralization. Finely crystalline molybdenite, which forms the matrix of the Fracture Ore (Plates 5.1 and 5.2), was deposited during group 4 and group 5 quartz vein development. Molybdenite in the accompanying quartz veins, such as the High-Grade Vein, is coarsely crystalline.

Molybdenite in the High-Grade Vein System and in the Stringer Zones is entirely in quartz veins, except very locally in the High-Grade Vein where molybdenite occurs without quartz. The Stringer Zones consist of group 3, group 4 and group 5 quartz veins and commercial ore boundaries reflect the density of quartz veins.

MINERALOGY

Most minerals in the Boss Mountain deposits were identified in hand specimen, or in thin section; others required polished section and/or X-ray powder photographs for identification. Nonmetallic, metallic and secondary minerals are considered in this section.

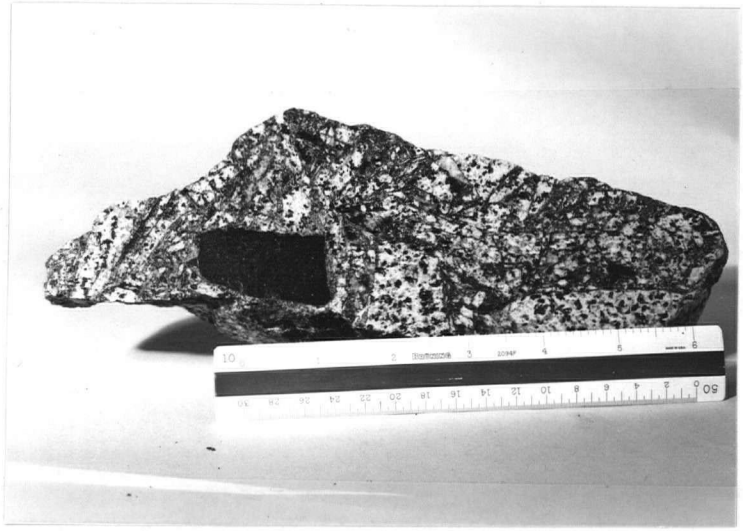


Plate 5.1. Fracture Ore. Angular fragments of granodiorite and altered andesite dyke (black) in molybdenite matrix (grey). (Scale is in inches).

Plate 5.2 Fracture Ore. Angular fragments of granodiorite and quartz (white) in molybdenite matrix (grey). (Scale is in inches).

Nonmetallic Minerals

Nonmetallic minerals in the Boss Mountain deposits include gangue and alteration minerals (Table 5.1). Some minerals, such as biotite, microperthite, sericite, and chlorite, occur as both gangue and alteration minerals.

Alteration Minerals*	Gangue Minerals
Actinolite	Biotite
Biotite	Calcite
Calcite	Chlorite
Chlorite	Fluorite
Clay minerals	Microperthite
Epidote	Quartz
Garnet	Sericite
Hornblende	
Microperthite	
Sericite	
Talc	
Zeolites:	
Chabazite	
Stilbite	
Heulandite	
Sodium Harmotome	

* Described in Chapter 4.

Table 5.1. Nonmetallic minerals of the Boss Mountain molybdenum deposits.

Alteration minerals were described in Chapter 4, and will not be repeated. Gangue minerals are described below.

Biotite.-- Biotite, the most abundant and widespread nonmetallic mineral associated with the molybdenum deposits, was described in Chapter 4. The biotite occurs as a gangue mineral in the matrix of the Phase III Breccia and replaces magmatic

hornblende and biotite in the host rocks.

Calcite.-- Calcite occurs in several ways: 1) in calcite-zeolite veins, 2) as a constituent of fault gouge, 3) in vugs and replacing feldspars in the Boss Mountain Stock, and 4) as a primary mineral in quartz veins. The first three occurrences were described in Chapter 4.

Calcite in quartz veins show a wide range of colour and habit. Colour ranges through colourless, white, pale green, and pink. Most veins contain little calcite. Single subhedral rhombohedra completely embedded in quartz suggest that calcite was a primary constituent of the veins.

Pink calcite is found only in late group 4 quartz veins. The curved cleavage surfaces suggest a dolomitic composition, but X-ray powder photograph identification confirms a calcite composition. External form of the calcite is controlled by quartz and pyrite crystals. Veinlets of sericite cut the calcite.

Group 5 quartz veins also contain calcite as a primary, but very minor, constituent.

Chlorite.-- Chlorites were described in considerable detail in Chapter 4.

Fluorite.-- A few small anhedral masses of fluorite, closely associated with microperthite, were observed in group 4 quartz veins and in altered sections of the Phase III Breccia.

The grains, which range from 0.5 to 2 mm. in maximum diameter, have dark purple cores that grade rapidly outward to almost colourless rims. Grains less than 1 mm. in diameter are nearly colourless and are easily overlooked. Thus, fluorite may be more common in the deposits than has been recognized. Identification was confirmed with X-ray powder photographs.

Microperthite.-- See Chapter 4.

Quartz.-- Quartz, closest associate of molybdenite, occurs in veins and as matrix in Quartz Breccia. Several ages of quartz veins have been recognized in the mine area. The structural relations of these veins were discussed in Chapter 3. Recognition of quartz veins from different age groups is dependent upon the mineralogy, orientation of the veins, and upon the character of the quartz in the veins (Plates 5.3 and 5.4). Table 5.2 is a summary of the mineralogy and character of the veins.

Sericite.-- Sericite was described in Chapter 4.

Metallic Minerals

Thirteen metallic minerals have been identified in the Boss Mountain deposits. The minerals represent several different stages of mineralization and some minerals appear at more than

Group	Mineralogy	Character
5	Quartz, molybdenite, pyrite, white orthoclase (?), calcite, magnetite, chalcopyrite.	Massive to coarsely banded-many fractures normal to vein walls. Molybdenum in irregular and discontinuous bands and lenses. Tendency to pinch and swell, (Plate 5.4)
4	Late: quartz, microperthite, sericite, calcite, pyrite, bismuthinite, aikinite, magnetite, anatase, fluorite.	Amethystine overgrowths on early quartz crystals. Mineralization cuts early quartz veins.
	Early: quartz, microperthite, chlorite, pyrite, molybdenite, rutile.	Vuggy veins. Colourless quartz crystals. Mineralization patchy and irregular.
3	Quartz, pyrite, molybdenite, microperthite.	Uniform, massive quartz with irregular distribution of other minerals.
2	Quartz, pyrite, microperthite.	Massive quartz with minor pyrite and microperthite.
1	Quartz, pyrite	Sugary, banded veins. Other sulfides added locally during later stages of mineralization (Plate 5.3)

Table 5.2. Mineralogy and character of quartz veins.

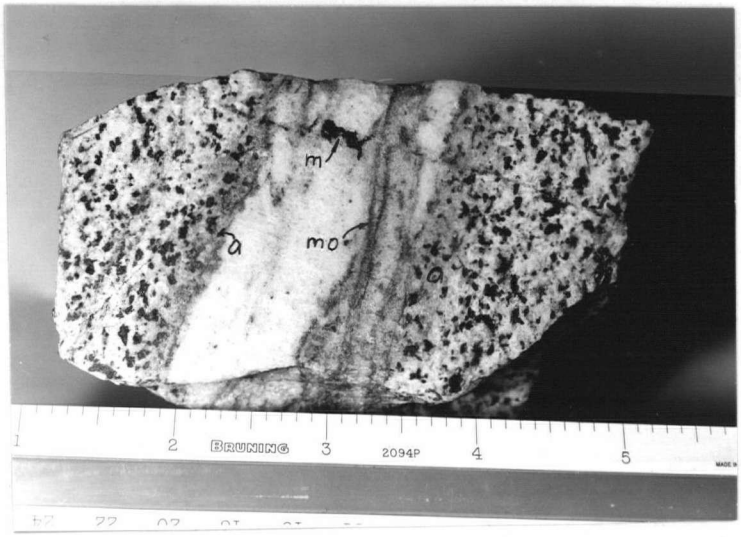


Plate 5.3. Group I quartz vein cut by molybdenite veinlets (mo) and a quartz-magnetite veinlet (m). Note the sugary texture of the quartz vein and the weak alteration (a) of the granodiorite adjacent to the vein. (Scale is in inches).

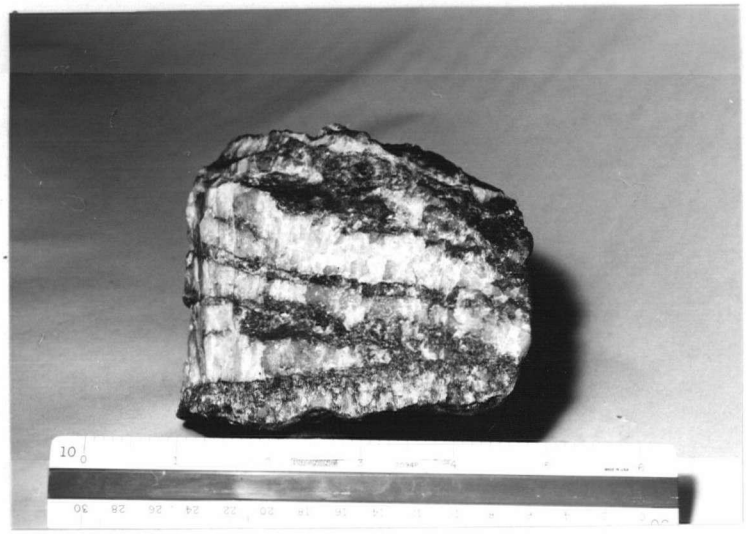


Plate 5.4. Banded group 5 quartz vein with characteristic fractures normal to the vein walls. Grey bands are molybdenite. (Scale is in inches).

one stage. Table 5.3 is a list of the metallic minerals in order of abundance.

Pyrite	FeS_2 (most abundant)
Molybdenite	MoS_2
Rutile	TiO_2
Magnetite	Fe_3O_4
Chalcopyrite	$CuFeS_2$
Sphalerite	$ZnFeS_2$
Scheelite-Powellite	$CaWO_4$-$CaMoO_4$
Aikinite	$PbCuBiS_3$
Bismuthinite	Bi_2S_3
Pyrolusite	MnO_2
Specular Hematite	Fe_2O_3
Tetrahedrite	$Cu_3(Sb,As)S_3$
Anatase	TiO_2 (least abundant)

Table 5.3. Metallic minerals of the Boss Mountain molybdenite deposits.

Pyrite.-- Pyrite is the most abundant and the most widespread mineral associated with the molybdenite deposits. It is a primary constituent of all quartz veins, occurs in quartz-free fractures, and is disseminated through all rocks in the mine area, except the alkali basalts. The ore deposits are encompassed by an extensive aureole of pyrite (Map 3, in pocket) that exceeds 8,000 feet in diameter.

Most pyrite in quartz veins is euhedral, the common form being the cube modified to varying degrees by pyritohedral and/or octahedral forms. Pyrite related to a specific age of quartz generally exhibits the same external crystal characteristics. For example, euhedral pyrite of early group 4 quartz

veins is modified by pyritohedral forms, is deeply striated, and has well-developed octahedral cleavage. Pyrite in other quartz veins does not have these characteristics.

The pyrite in quartz-free fractures occurs as thin films of tabular and irregular masses bounded by crystal faces.

Disseminated pyrite assumes a wide variety of forms, but generally occurs as irregular anhedral patches. These patches attain a maximum diameter of 23 mm. in the Boss Mountain Stock, but in most other rocks their diameter is less than 10 mm. Pyrite disseminated through rhyolite porphyry dykes and andesite dykes commonly is euhedral to subhedral. In the batholithic rocks disseminated pyrite is accompanied by small epidote grains.

Pyrite ranges in colour from yellow-white to brass-yellow to golden yellow, but there is no apparent correlation between colour and occurrence, age or position.

Pyrite from early group 4 quartz veins is unique among the Boss Mountain pyrites because of the large size of the crystals (up to 4 inches along the cube face) and especially because of the well-developed octahedral cleavage. It was thought that the cleavage might be caused by impurities incorporated during crystal growth or by chemical composition that might be expressed by a variation in the size of the cell edge. Polished sections of several single cyrstals revealed a lack of impurities that could be resolved with a microscope. A single X-ray

powder photograph of the pyrite gave a cell edge of 5.405Å which is in agreement with the value of 5.40667±00007 reported for pyrite by Kerr et al (1945, p.498) for pyrite from Leadville, Colorado. Berry and Thompson (1962) report the cell edge of pyrite as 5.419Å.

Much pyrite exposed on the surface at the Boss Mountain deposits is altered to limonite and jarosite which have coloured the rocks rusty brown to yellow-brown.

Molybdenite.-- Molybdenite, the only economic mineral at Boss Mountain is second in abundance among metallic minerals. Pyrite, along with the nonmetallic minerals biotite and quartz, exceeds molybdenite in total abundance. Three periods of molybdenite mineralization have been recognized, two or which are separated by a barren quartz vein phase. Generally molybdenite in the earliest period of mineralization was fine grained and grain size increased with each period of mineralization until the molybdenite in the final period of mineralization was very coarse grained.

Molybdenite characteristically forms thin selvedges along the edges of quartz veins and breccia fragments (see Plate 2.12, Chapter 2), discontinuous bands within some quartz veins (Plate 5.4), and less commonly rosettes of coarse crystals. Mafic minerals were favoured sites of molybdenite deposition.

In the High-Grade Vein molybdenite characteristically fills

open fractures in a comb texture. Veinlets as much as four feet in length are composed of groups of molybdenite crystals up to 20 mm. across that extend from opposing vein walls into the openings (Plates 5.5 and 5.6). Most openings are completely filled with molybdenite, but in some a medial opening remained that was filled with quartz and pyrite. In some veinlets the medial part contains fragments altered wall rock. The veinlets, which are insecurely fastened to vein walls, are easily separated from the altered andesite host rock.

Traill (1963) reported a rhombohedral polytype of molybdenite that is easily identified with X-ray powder photographs. X-ray powder photographs of molybdenite from all three periods of molybdenite mineralization at the Boss Mountain deposits show the molybdenite is the common hexagonal polytype.

Molybdenite in surface exposures has been largely altered to ferrimolybdite and more rarely to powellite.

Rutile.-- The occurrences and types of rutile were described in Chapter 4.

Magnetite.-- Granular hydrothermal magnetite, which is erratically distributed throughout the deposits, generally occurs in and near group 4 and group 5 quartz veins. Subhedral magnetite dodecahedra associated with radiating clusters of chlorite crystals line vugs in group 4 veins and in the Phase III Breccia.

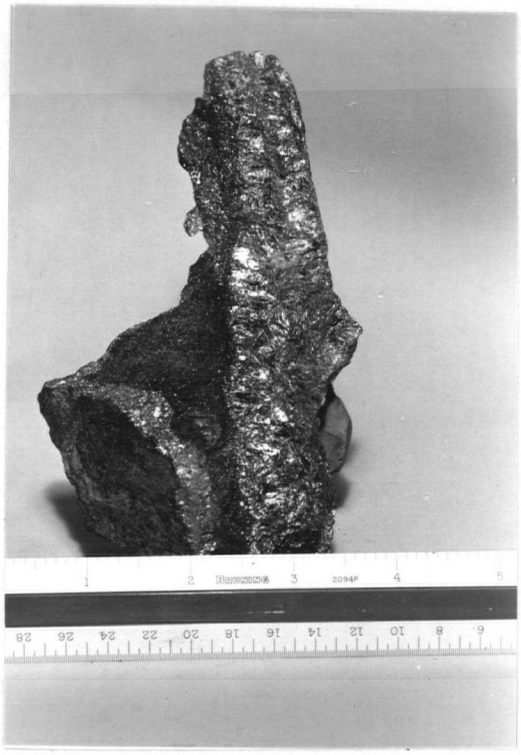


Plate 5.5. Coarsely crystalline molybdenite from the High-Grade Vein. Black fragment is altered andesite host rock. (Scale is in inches).

Plate 5.6. Characteristic texture of coarsely crystalline molybdenite in the High-Grade Vein. (Scale is in inches).

Magnetite appears to have crystallized contemporaneously with chalcopyrite and with pyrite. Pyrite of an earlier stage of mineralization is cut by magnetite which in turn is cut by later stages of pyrite. Similar relations are shown between magnetite and molybdenite.

Chalcopyrite.-- Irregular masses of anhedral chalcopyrite, which are sparsely and erratically distributed throughout the Boss Mountain deposits, occur in miarolitic cavities in the Boss Mountain Stock, in group 4 and group 5 quartz veins, and disseminated through parts of the Phase III Breccia zone. Pyrite, microperthite and chlorite are constant associates of chalcopyrite. Magnetite, specular hematite, and sphalerite are common associates and in the Boss Mountain Stock tetrahedrite occurs with the chalcopyrite.

Widely spaced miarolitic cavities in the Boss Mountain Stock, which are lined with euhedral quartz, microperthite, and sericite, have been filled with chalcopyrite. Several samples of highly sericitized rock from the stock, which were found on the waste dump, contain an estimated 20 to 50 percent total sulfides comprised of 10 to 15 parts chalcopyrite to 1 part tetrahedrite. The source of the samples was not found. Polished section study of the chalcopyrite-tetrahedrite shows that both minerals are for the most part free of impurities, except along mutual contacts where the chalcopyrite contains rounded

blebs of tetrahedrite.

Chalcopyrite was introduced with late group 4 quartz veins and more rarely with group 5 quartz veins. It occurs as disseminated grains and stringers in the veins and was introduced into pre-existing structural or textural features, such as quartz veins, breccias and fractures, during development of the late group 4 and group 5 veins. The chalcopyrite in parts of the Phase III Breccia zones was introduced during this stage of mineralization.

Polished section study of chalcopyrite from the Boss Mountain deposits has shown that the mineral is free from exsolved impurities, except locally in samples from the Boss Mountain Stock. Pyrite, magnetite, and molybdenite cut chalcopyrite. Few other minerals were observed in contact with chalcopyrite. Some pyrite from an earlier stage of mineralization is cut by chalcopyrite.

Chalcopyrite in minute quantities was found in several localities outside the molybdenite deposits. Most noteworthy of these is north of Takomkane Volcano in some old workings where chalcopyrite and pyrite in quartz vein material was found on the dump of a water-filled shaft. Reinecke (1920, p.97) and Galloway (1917, p.135) described these occurences when the workings were accessible. Nothing of significance can be added to their observations.

Sphalerite.-- Sphalerite was observed with chalcopyrite in Phase III Breccia. Aggregates of euhedral crystals and anhedral masses of sphalerite, which generally are small (less than 2 mm.), locally exceed 7 mm. in diameter. Individual crystals range from 0.5 mm. to 1.5 mm. in diameter. Large grains have a dark, iridescent tarnish that imparts a black colour to the mineral, but smaller crystals and fragments are yellow to light brown in colour. Cleavage fragments exhibit the characteristic resinous lustre.

A polished section examination disclosed that the sphalerite is free of impurities. A grain of dark sphalerite and a grain of yellow sphalerite were selected for cell edge measurement with X-ray powder photographs. The measured cell edge of both grains are identical ($a=5.412\mathring{A}$) and corresponds to a FeS content of 6 mol percent (Skinner, 1961, p.1406).

Orange microperthite and dark green chlorite (Stage 3 alteration) are closely related to sphalerite-chalcopyrite occurrences and all are genetically related to group 4 quartz vein development.

Scheelite-Powellite.-- Late group 4 quartz veins contain minor and irregularly distributed quantities of scheelite-powellite. The euhedral to subhedral creamy to golden yellow crystals range in size from 2 to 24 mm. Fluorescence of most crystals is light blue (scheelite), but the outer parts of some

crystals fluoresce yellow (powellite). In one large crystal the inner core (17 mm.) fluoresces light blue and the rim (5-7 mm.) fluoresces yellow. The colour change is sharp and is marked by a weak physical discontinuity in the crystal. Other crystals do not display such well-defined relations between yellow and light blue fluorescence.

Spectrographic analyses of bulk samples from the deposits indicates the presence of small quantities of tin. It was noted that tin and tungsten appear to be mutually dependent. Two samples of scheelite, the only tungsten mineral in the deposits, were selected for semi-quantitative spectrographic analyses to confirm this apparent interrelation. The analyses clearly show that scheelite carrys small quantities of tin (Table 5.4).

	Sample 1	Sample 2	
Ca	VS	VS	VS=Very Strong
W	S	S	S=Strong
Mo	M	M	M=Moderate
Sr	M	M	WM=Weakly Moderate
Sn	WM	WM	W=Weak
Ti	W	W	VW=Very Weak
Bi	VW (?)	VW (?)	
Si	M	M Impurity (?)	
Fe	W	W	
Mg	W	W	

Table 5.4. Semi-quantitative spectrographic analyses of scheelite.

Aikinite.-- Bright, metallic grey, subhedral to euhedral crystals of aikinite comprise a minute part of late group 4 quartz veins. The aikinite occurs as well-developed ortho-

rhombic prisms (110) which exhibit perfect cleavage parallel to the b-pinacoid (010). Terminations are rare. Observed crystals, which range from 2 to 180 mm. in length, have a greyish black streak and are very soft (H=2). The measured specific gravity (7.09) is comparable to Peacock's (1942, p.63) measurements of 7.07 and 7.08.

Aikinite and bismuthinite both are found in group 4 quartz veins closely associated with scheelite and pyrite, but have not been observed together. Aikinite occurs only near the Main Breccia Zone and bismuthinite was found only in late group 4 quartz veins cutting the Boss Mountain Stock. The two minerals appear to be mutually exclusive.

Bismuthinite.-- Subhedral masses of bismuthinite were found in late group 4 quartz veins in the Boss Mountain Stock. The metallic grey masses have grown upon euhedral pyrite crystals and are closely associated with scheelite. Identification of the mineral was established with X-ray powder photographs. Because of the erratic distribution of the material and its small size (less than 5 mm.) and quantity, bismuthinite could be easily overlooked.

Pyrolusite.-- Velvety black manganese oxide coats quartz crystals in some of the group 4 quartz veins on the 5045 level of the mine. Colourless calcite crystals were deposited upon the black oxide. Manganese oxide films seldom exceed

0.5 mm. in thickness. X-ray powder photographs of the material were poor but were sufficient to identify the material as pyrolusite.

Genetic relationship of the pyrolusite is problematical. Pyrolusite, which may be of secondary origin, is found as thin films within unoxidized quartz veins on the 5045 level. Other occurrences of secondary manganese minerals were observed only in surface exposures. For this reason, the pyrolusite is believed to have formed during the late stages of group 4 quartz vein development.

Specular Hematite.-- Specular hematite, a rare mineral in the Boss Mountain deposits occurs in and near group 4 quartz veins and in Phase III Breccia as euhedral to subhedral plates spatially related to chalcopyrite. Triangular markings on the plates, red internal reflections, hardness (about 6), and brownish streak were the identifying properties of the mineral. Polished section examination shows plates of hematite cutting anhedral grains chalcopyrite.

Tetrahedrite.-- Tetrahedrite, which was observed only in samples from the Boss Mountain Stock, occurs as anhedral masses intimately associated with chalcopyrite. The tetrahedrite is greyish black with a brown streak. Cell edge as determined from one X-ray powder photograph is 10.30Å (measured). Textural relations suggest that the tetrahedrite and chalcopyrite crystallized simultaneously. Chalcopyrite rarely contains rounded blebs of tetrahedrite at mutual boundaries. Tetrahedrite was not

observed in place, but was found on the waste dump.

Anatase.-- Anatase occurs with yellow sericite which cuts group 4 quartz veins. The euhedral honey-brown crystals average 0.2 mm. in diameter and have a maximum diameter of 0.5 mm. The bipyramidal crystals, which are striated parallel to the base, show various degrees of modification by a second bipyramid, a prism, and basal pinacoid. Other modifications may be present, but were not recognized on the small, rough crystals.

Anatase and rutile are polymorphs of TiO_2 and do not form simultaneously. Schröder (1928, p.54) has shown that anatase is a lower temperature polymorph than is rutile. Anatase which is genetically related to late group 4 quartz veins may have formed at the expense of pre-existing rutile.

Products of Weathering

The minerals included in this section are those which formed during weathering. Only two secondary minerals, limonite and ferrimolybdite, are abundant and widespread; all other minerals are rare. Table 5.5 is a list of secondary minerals from the Boss Mountain deposits in order of decreasing abundance (top to bottom).

Limonite	hydrous iron oxides (most abundant)
Ferrimolybdite	$Fe2(MoO4)_3 8H20$
Manganese oxide	
Jarosite	$KFe_3(SO_4)2(OH)_6$
Powellite	$CaMoO4$
Leucoxene	hydrous titanium oxides (?)
Hematite	Fe_2O_3
Malachite	$Cu_2(OH)_2CO_3$(least abundant)

Table 5.5. Secondary minerals of the Boss Mountain molybdenum deposits.

Limonite.-- Limonite, as used here, is a general term applied to brownish hydrous iron oxides. No attempt was made to identify the mineral constituents of the limonite.

Limonite, the most abundant and widespread secondary mineral in the Boss Mountain deposits, formed from the oxidation of pyrite, chalcopyrite, and magnetite, as well as from mafic minerals. Pervasive limonite stain was found on all fractures in the rocks to a depth of 40 feet in the underground workings. Active water courses (open fractures) 500 feet below the present ground surface contain limonite, but the occurrence at this depth is highly restricted. Many rock faces in the underground workings, which were fresh and unaltered when exposed, have had limonite deposited on them within two years after their exposure.

Ferrimolybdite.-- The alteration of molybdenite to ferrimolybdite is apparent in most surface exposures which contain molybdenite. Fibrous, felty, yellow patches and pseudomorphs after molybdenite characterize the ferrimolybdite. In many exposures much molybdenum apparently has been removed by

weathering. Hexagonal molds of former molybdenite crystals in quartz veins now contain a few acicular crystals of ferrimolybdite or are completely barren. The rocks around these areas are stained with limonite. Titley (1963, p.204) has shown that conditions under which limonite forms are not conducive to ferrimolybdite development.

Acicular ferrimolybdite crystals have attained a maximum length of 1.5 mm. Many occurrences are so fine grained that individual crystals were not recognized. Ferrimolybdite is essentially a surface feature and was not observed more than 5 feet below the surface of the ground. Limonite is the only abundant secondary mineral at greater depths.

Manganese oxide.-- Thin, discontinuous films and dendritic forms of black manganese oxide are relatively common on fractures in the surface exposures of the mine area, but are not prominent. Locally the manganese oxide has been deposited on limonite, but relation to other secondary minerals could not be determined. Attempts to identify the black oxide by use of X-ray powder photographs were unsuccessful.

Jarosite.-- A yellowish, earthy alteration product of pyrite was determined as jarosite with the aid of X-ray powder photographs. The mineral is not abundant, but is so fine grained and inconspicuous that it can easily be overlooked.

Powellite.-- Powellite was first observed in the oxidized

part of the molybdenum deposits when several samples were exposed to ultraviolet radiation. Under ultraviolet radiation the powellite fluoresces creamy yellow. Positive identification was made with an X-ray powder photograph. Secondary powellite, a rare mineral at Boss Mountain, forms thin, inconspicuous, light grey to white films on quartz and other minerals adjacent to altered molybdenite grains.

Leucoxene.-- Leucoxene is widely distributed over Takomkane Mountain, but it is not an abundant mineral. The mineral occurs as a light brown to yellowish alteration product of titanium-bearing minerals, such as rutile and sphene. Sphene, the most abundant accessory mineral in the rocks of the batholith, generally is fresh and unaltered. Locally the sphene is weakly altered to leucoxene.

Rutile developed by hydrothermal solutions and deposited with quartz veins seldom exhibits alteration, but some of the rutile, especially the opaque, black variety, is weakly altered to leucoxene. Chloritized magmatic hornblende contains sphene which commonly is weakly altered to leucoxene.

Hematite.-- Bright red, earthy hematite was formed as a minor alteration of pyrite in the underground workings of the mine. It occurs most often in and near altered andesite dykes as thin coatings on narrow pyrite veinlets. When the hematite is removed from the mine it quickly alters to light brown limonite.

Malachite.-- Malachite, a rare mineral in the Boss Mountain deposits occurs as thin, green crusts on chalcopyrite grains. The only malachite found in the mine area was found in the surface exposures of the Main Breccia Zone. Several shear zones in the surrounding areas on Takomkane Mountain contain minute quantities of malachite, especially north of the volcano.

Paragenesis

The paragenetic sequence of minerals genetically related to the Boss Mountain molybdenite deposits is shown on Table 5.6. Many minerals, such as pyrite, molybdenite, quartz, microperthite, sericite, chlorite, and calcite, appear more than once in the sequence and exhibit conflicting evidence in a paragenetic study. The mineral relations were discussed in foregoing sections.

CLASSIFICATION

The most widely accepted and most easily understood classification of ore deposits in use today in North America is the Lindgren classification as modified by Graton (1933) and Buddington (1935) (Park, 1964, p.213). A deposit requires much investigation before it can be categorized into this classification. The following data from the Boss Mountain deposit bear on its classification.

The Boss Mountain Stock, the igneous body most closely associated with the molybdenite deposit, is clearly epizonal

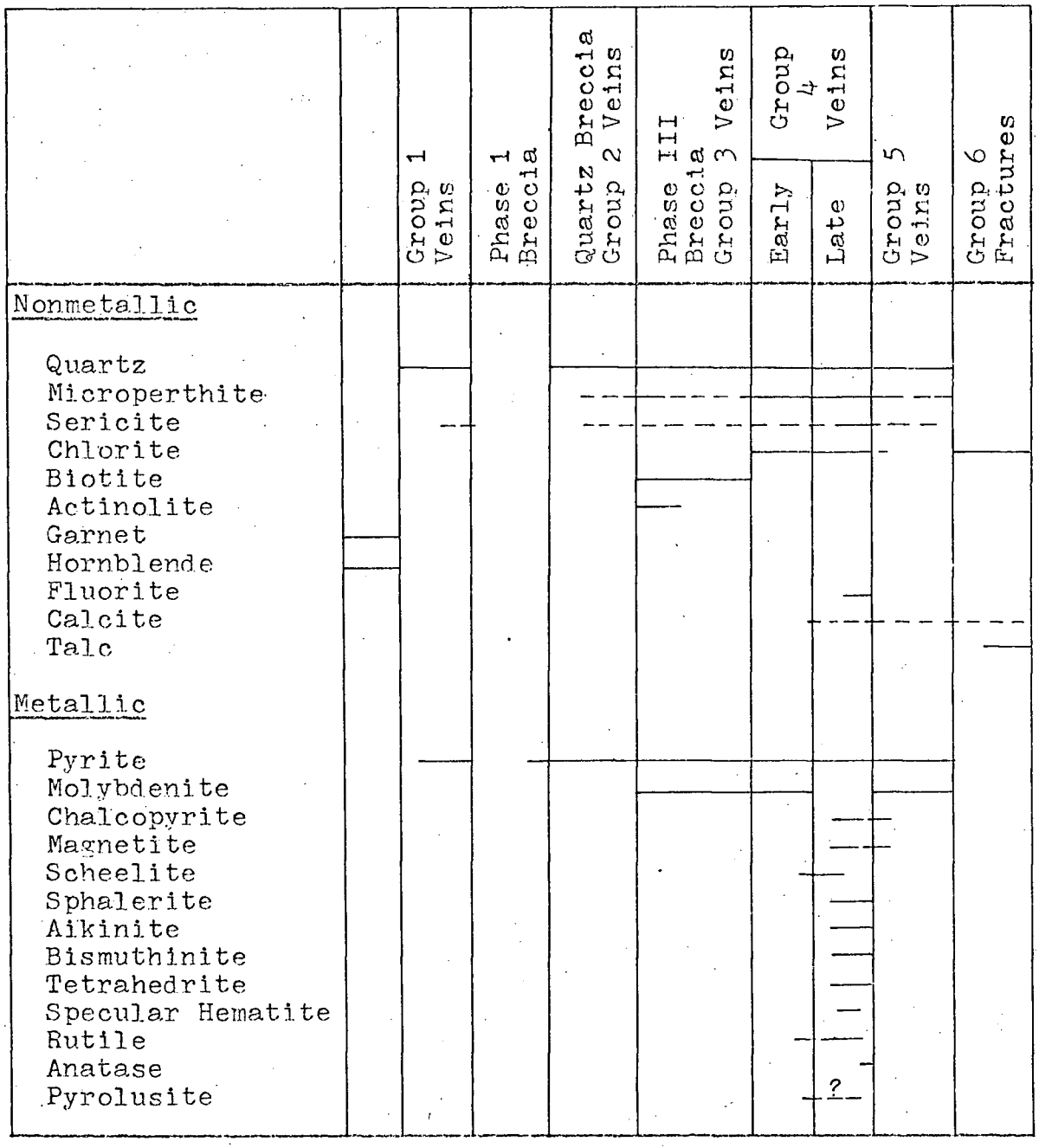


Table 5.6. Paragenetic sequence of Minerals genetically related to the Boss Mountain deposits.

(Chapter 2) and consequently lithostatic pressure would be low. Breccia pipes and the dominance of open-space filling over replacement at Boss Mountain imply a near-surface environment of low pressure. Park (1967, p.347) states, "Telescoping and dumping characterize xenothermal deposits." Telescoping is the superposition of high-and low-temperature minerals with retention of recognizable paragenetic sequence. Dumping, the simultaneous crystallization of minerals that are not ordinarily found together, is the result of sudden loss of temperature or pressure. Group 4 quartz veins at the Boss Mountain deposit show telescoping of a low temperature mineral suite upon a high temperature suite. Dumping is exhibited in the late group 4 quartz veins.

Temperature limits may be inferred from the following mineral relations.

1. The presence of amethystine quartz in late group 4 quartz veins indicates a temperature near 250°C (Frondel, 1962).

2. The coexistence of sphalerite and chalcopyrite with a lack of exsolved chalcopyrite in the sphalerite places an upper limit on crystallization of these sulfide minerals at 350°C (Park, 1964, p.200).

3. Some minerals, such as garnet, hornblende, and magnetite are considered to form at high temperatures (Bateman, 1956, p.40). Minerals such as molybdenite, bismuthinite, biotite, and

rutile probably formed at high temperatures. Stringham (1952, p.663) has shown that biotite crystallizes above 375°C in acid solutions.

4. Incomplete data obtained by Sinclair (personal communication, 1968) from fluid inclusions in quartz indicate a minimum temperature of formation between 300 and 380°C.

To summarize the above data, the Boss Mountain molybdenite deposits were formed in a near-surface environment at temperatures ranging from 250°C to greater than 380°C. Deposits formed at shallow depths and at high to low temperatures, such as the Boss Mountain molybdenite deposits, are classified as xenothermal.

AGE OF THE DEPOSITS

Samples of grandiorite, Phase III Breccia, and altered andesite dyke, all of which contain hydrothermal biotite, were selected from different areas of the Boss Mountain Mine for K/Ar dating at the University of British Columbia. Unaltered samples of the Boss Mountain Stock suitable for dating could not be found. The leucocratic nature of the rhyolite porphyry and rhyolite dykes rendered them unsuitable for K/Ar dating. Rocks outside of the limits of hydrothermal alteration (Map 3) were not analysed.

Hydrothermal biotite, which was introduced during Phase III Breccia formation, and the entire sequence of ore formation are

genetically related to the Boss Mountain Stock and, therefore, the age of the hydrothermal biotite represents the age of the Boss Mountain Stock, the Boss Breccias, and the ore deposits.

The K/Ar age of the hydrothermal biotite in three samples is 105 ± 2 million years (middle Cretaceous) (White et al, 1967). This age is in close agreement with those obtained by the Geological Survey of Canada (Wanless et al, 1966 and 1967) from molybdenum-bearing batholithic rocks in the Clearwater-North Thompson River area (Figure 5.4).

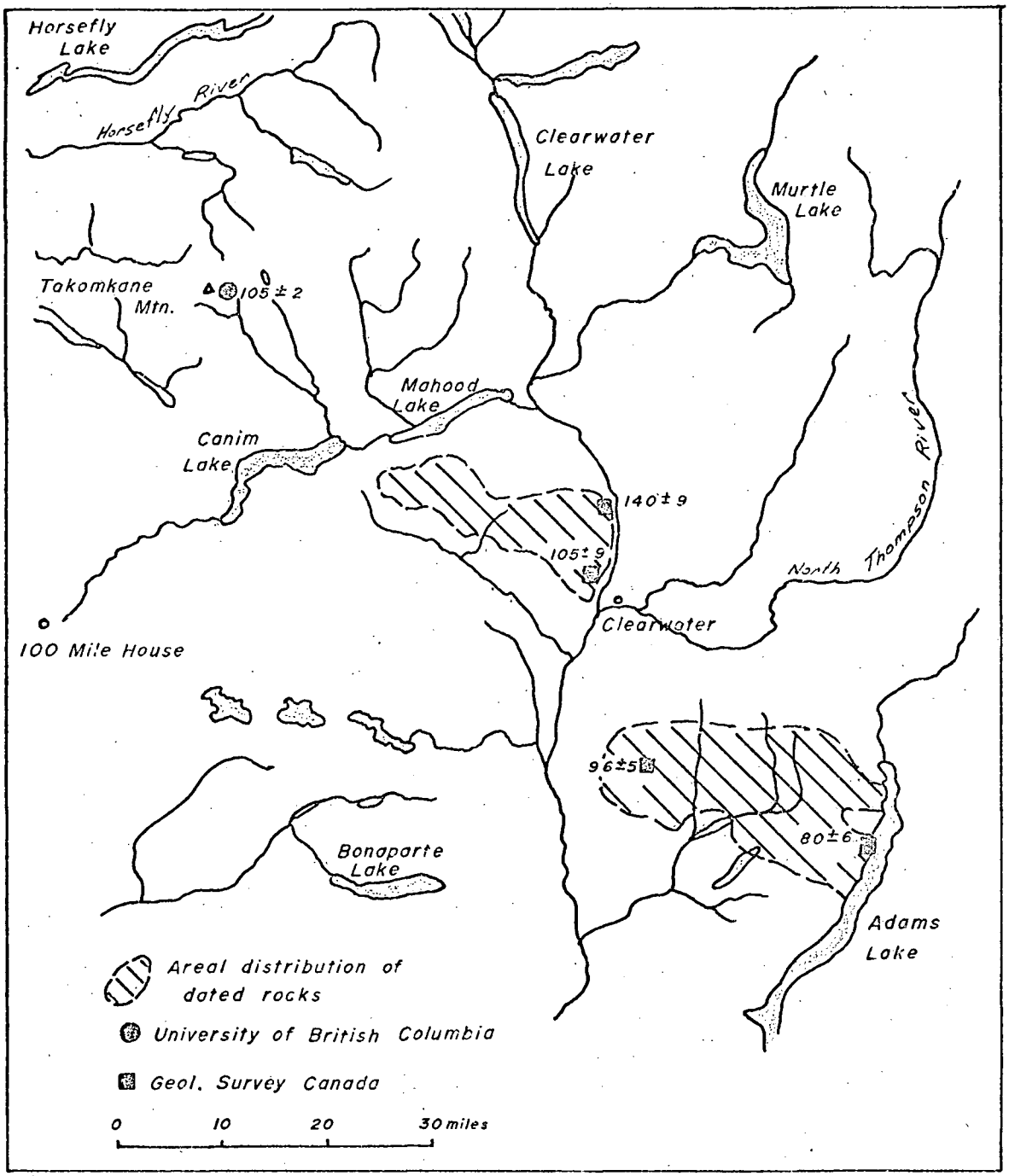


Figure 5.4. Published potassium-argon dates of molybdenum-bearing and related rocks in east-central British Columbia.

VI. GENESIS OF THE ORES

ORIGIN OF THE BOSS BRECCIAS

Various combinations of volcanic or sub-volcanic explosions and/or intrusive activities have been used to explain the origin of breccia pipes. Most authors recognize an associated acidic magma as the source of the activity that resulted in the development of breccia pipes. Breccias formed by volcanic explosions related to more basic lavas are not considered in the following discussions.

Breccias developed by explosive eruptions accompanying Tertiary volcanism in Scotland have been described by Tyrrell (1928), Richey (1932 and 1940) and other authors. These breccias "....are clearly associated with rising acidic magmas and are located along ring dykes" (Gates 1959, p.807).

In 1941 Burbank and H. Cloos independently explained the cause of breccia development and accompanying volcanic explosion by the action of gases forced into fractures above a rising magma.

Reynolds (1954) further emphasized the importance of gases and applied fluidization, the mobilization of a body of fractured rock by the violent agitation of fragments caused by the action of gas flowing through the fractures, to the formation of intrusive breccia "pipes".

Many authors have called upon volcanic and/or sub-volcanic

explosions to explain some breccia bodies related to mineral deposits, especially those which rapidly diminish in cross-section with increasing depth. Breccias associated with the Bethlehem copper deposits in the Highland Valley of British Columbia have been explained in this manner (White et al, 1957; Northcote, 1968).

Carr (1960) believed these same breccias resulted from explosions caused by vapor pressure increases accompanying chilling and rapid crystallization of porphyry dykes. Other authors (Gates, 1959; Perry, 1961; Kents, 1964) have attributed such pipes to the late-magmatic phase of development, some of which clearly post-date metallic mineralization (Perry 1961).

Locke (1926) proposed that the Pilares breccia pipe of Sonora, Mexico, was formed by mineralization stoping, the subsidence of rock fragments being a result of the corrosive action of ascending hydrothermal solutions. Alteration of andesite rock fragments accompanied the corrosive action and was further accentuated by a cycle of mineral deposition.

Gas-action accompanying intrusion of acidic magma has been called upon to explain many breccias (Tweto, 1951; Gates, 1959; Perry, 1961; Kents, 1964). Such theories of origin do not require escape of gases to the surface, and thus differ from the sub-volcanic and volcanic explosion theories.

Tweto (1951) suggested that brecciation associated with

the Pando sills of Colorado were formed as the result of marginal chilling and concomitant expulsion of gas that caused brecciation ahead of an advancing magma.

Gates (1959) concluded that breccia pipes in the Shoshone Range, Nevada, were formed by oscillatory intrusion of magma and described their formation as follows:

> "Assume a rising cupola of magma which is crystallizing and building up pressure of volatiles and is perhaps preceded by a vapor aureole of gas....The pressures of magma and gas open cracks overhead; gas rushes into some of these, tearing fragments from the walls which, in turn, assist in further brecciation by abrasion, attrition, and wedging; magma rushes into others, quickly chills and evolves more gas which brecciates the rocks ahead; still others may be filled with breccia formed by rock-bursts. Rapid heating of the rocks and conversion of included water to steam may add to the fragmentation.
>
> ....Once the pressures have been diminished by eruption, a period of subsidence follows, accompanied by slumping, collapsing, and perhaps rock-bursting....As the magma continues to cool and crystallize, gas pressure builds up again. Another cycle of eruption, brecciation, and intrusion of magma and gas follows."

Perry (1961) expanded upon the idea of breccia pipes developing as a result of oscillatory magmatic intrusion. He believes that breccia pipes form by foundering of the roof above a magma chamber caused by decrease in magma pressure at localized points. He cites two critical features which require breccia development in this way (p.369):

> 1. "....some of the pipes show remarkable large downward displacement of fragments. This fact, combined with the great volume increase due to brecciation, calls for removal of large volumes of material."

> 2. "Second, the closed tops of certain pipes demonstrate that these large volumes were not excavated from the top of the pipe; the inescapable conclusion is that withdrawal must have occurred at the bottom."

Decrease in magma pressure has been explained by differential movement of magma to another part of the chamber or by withdrawal of magma during volcanic eruption. Successive advances and withdrawals of "quartz porphyry magma" produced the La Colorada pipe and its related copper-molybdenum deposits.

The importance of quartz porphyries in the sequence of breccia and ore deposit formation are stressed by Perry (1961) who summarizes Sales (1954) views on these rocks as follows:

> "He considers the first break through of quartz porphyry a critical step in setting up a focal point for differentiation of aqueous fluids within the magma. Subsequent crystallization of the quartz porphyry closed the magma system, permitting further segregation and concentration of the ore fluids."

In 1964 Kents published a theory that he considers applicable to the formation of several different types of breccias. Magmatic pulsations provide forces which cause hydraulic ramming of hydrothermal solutions into overlying rocks. His theory is as follows:

> "....It is quite possible that hydrothermal solutions separated from the cooling magma during the ebbing phase of magmatic pulsations; because of their lesser density and viscosity they may gather on top of a batholith, and form there a wet cap of volatiles. Such accumulated solutions will be at the fore-front of the next magmatic onrush, to become rammed into the enclosing rocks above the batholith, which they may then permeate....The solutions by wedging fractures open, divide or break up the enclosed rocks to fragments, and envelope them....The

fragments may shift, tumble, and become abraded, which results in the formation of different types of breccias.

Kents' theory requires a "tight cap above the hydrothermal development to compel the solutions to remain confined" (p.1554). During magmatic subsidence the fractured rocks collapse under their own weight to form breccias. The initial breccia-type developed in this process in the "rupture breccia" or stockwork, which become breccias if they subside and are shifted.

The breccia bodies of Boss Mountain which were described in Chapter 2, can be briefly summarized as follows:

1. Three phases of breccia were developed at three different times in the sequence. The earliest breccia (Phase I) has a matrix of comminuted rock with local patches of rhyolite porphyry. The second breccia, the Quartz Breccia, has a matrix of quartz with minor amounts of pyrite and microperthite and contains Phase I Breccia and rhyolite dyke fragments. The Phase III Breccia contains fragments of Quartz Breccia and granodiorite in a matrix of comminuted rock along with quartz, biotite, and molybdenite. Altered andesite dyke fragments occur in all three breccias.

2. Fragments in Phase I Breccia are dominantly angular; those in Quartz Breccia are entirely angular; and those in the Phase III Breccia are angular near the contacts, but are dominantly rounded throughout the remainder of the body.

3. Relative displacement in the Phase I Breccia was probably slight because fragments of rhyolite porphyry dykes are crudely aligned with their source in the wall rock. Granodiorite, andesite dyke, and quartz vein fragments in Quartz Breccia have all moved downward from their place of origin in the wall rock. Indications of the relative displacement of fragments within the Phase III Breccia were not obtained, but the analysis of structural features (group 3 fractures and quartz veins) developed during breccia formation indicates an upward direction of stresses. These upward-directed stresses

also caused intense fracturing along the upper edge of the Quartz Breccia which was later mineralized with molybdenite (Fracture Ore Zone).

4. The contacts of the breccias with the surrounding host rock are highly variable. Contacts between Phase I Breccia and the wall rock are everywhere highly gradational; whereas the contacts between Quartz Breccia and the older rocks are abrupt to gradational through stockwork to non-brecciated rock. Phase III Breccia contacts with Quartz Breccia and granodiorite are gradational over a few feet.

Sub-volcanic explosions and fluidization are not applicable to the origin of the Boss Breccias for the following reasons. There are (is):

1. no associated extrusive rocks.
2. little rounding of fragments, except in the Phase III Breccia which is capped by overlying rocks and, therefore, did not reach the surface.
3. no intrusive features such as intrusive breccia dykes. All breccia dykes show downward movement of fragments.
4. no evidence of any upward movement of fragments.

Mineralization stoping is not favoured as a mode of origin because of the nature of the host rock, dominance of comminuted matrix (except in the quartz breccia), and the lack of intense alteration or replacement of the breccia fragments.

Eastwood (1964, p.78) suggested that the quartz breccias were formed by replacement of the matrix of an older breccia. The presence of angular fragments of older breccia, which show no evidence of replacement, within the quartz breccias

precludes this mode of origin.

The theories proposed by Gates (1959), Perry (1961), and Kents (1964) in which breccia pipes are formed above columns of pulsating acidic magma are directly applicable to the Boss Breccias. All three authors require the presence of volatiles at the top of the column to assist in fracturing the overlying rocks by various methods. Rock is fractured by upward surge of magma and collapses in response to the force of gravity during magmatic withdrawal.

Kents (1964) has applied different names, such as rupture, subsidence, heave, kneaded, milled, late-magmatic, and burst breccias, to breccias with differing physical characteristics and slightly different modes of origin.

The Phase I Breccia and the Phase III Breccia at Boss Mountain are "kneaded breccias". Kneaded breccias are comprised of a chaotic array of angular to subangular fragments not far removed from their place of origin and set in a matrix of comminuted rock.

The Quartz Breccias are "subsidence breccias" which are characterized by: angular fragments; downward displacement of fragments; heterogeneous fragment size; relatively undisturbed contacts (stockworks) that progressively grade into completely mixed rocks; and the interstices between fragments filled with hydrothermal minerals such as quartz. Subsidence breccias are

formed by the "sinking of hydrothermally affected rocks in response to withdrawing of some magma" (Kents, 1964, p.1557).

Conclusions drawn from detailed study of the Boss Breccias and related fracture systems confirm a close genetic relationship with the Boss Mountain Stock. Intrusion and crystallization of rhyolite phorphyry magma apophyses from the Boss Mountain Stock initiated breccia formation at Boss Mountain. Sales (1954) and Perry (1961) concluded that quartz porphyry (rhyolite porphyry) intrusions are the "vanguard of the mineralization process" a fact borne out in the Boss Mountain deposits where rhyolite porphyry and rhyolite magmas were intruded before, during and after formation of the Phase I Breccia.

Most breccia pipes have formed at the apex of a magma column (Perry, 1961; Kents, 1964), some have formed along ring dykes (Gates, 1959). The apex of the Boss Mountain Stock, which has been removed by erosion, does not appear to have been the locus of breccia development, mineralization, or alteration. The locus of such processes lies approximately 2000 feet west of the centre of the Boss Mountain Stock and requires special conditions for development.

Anderson's (1936) explanation of the fracturing of rocks by forceful injection of magma were discussed in Chapter 3 (see Figure 3.12). The application of his conclusions to an irregular magma chamber might well result in particularly numerous

fractures locallized above such an irregularity as shown in Figure 6.1, A. Subsidence of the magma column would then result in collapse of the fractured rock, forming breccia in that area (Figure 6.1, B). Diamond drilling early in 1968 confirmed that the contact of the Boss Mountain Stock flattens below the 5045 level, terminating the downward continuation of the Boss Breccias (Figure 6.2). The Boss Mountain Stock below the breccias is chilled at the contact as it is in the adit. Drill hole 5214 penetrated about 430 feet beyond the chilled contact into non-chilled quartz monzonite porphyry without visible change in character of the rock. The stock below the Main Breccia Zone, as shown by core from diamond drill hole 5216, contains large fragments of granodiorite that have subsided during breccia development (Figure 6.2).

Details of the formation of the Boss Breccias are outlined below. Fluid emanations, either gaseous or liquid, have played an important role in breccia formation as shown by the abundance of hydrothermal minerals such as quartz, pyrite, biotite, microperthite and molybdenite which accompanied breccia formation. The importance of such emanations in the development of fractures during magmatic surges has been emphasized by several authors (Gates, 1959; Perry, 1961; and Kents, 1964).

Magmatic advance fractured the rock above an irregularity in the magma chamber. These fractures were initially filled with

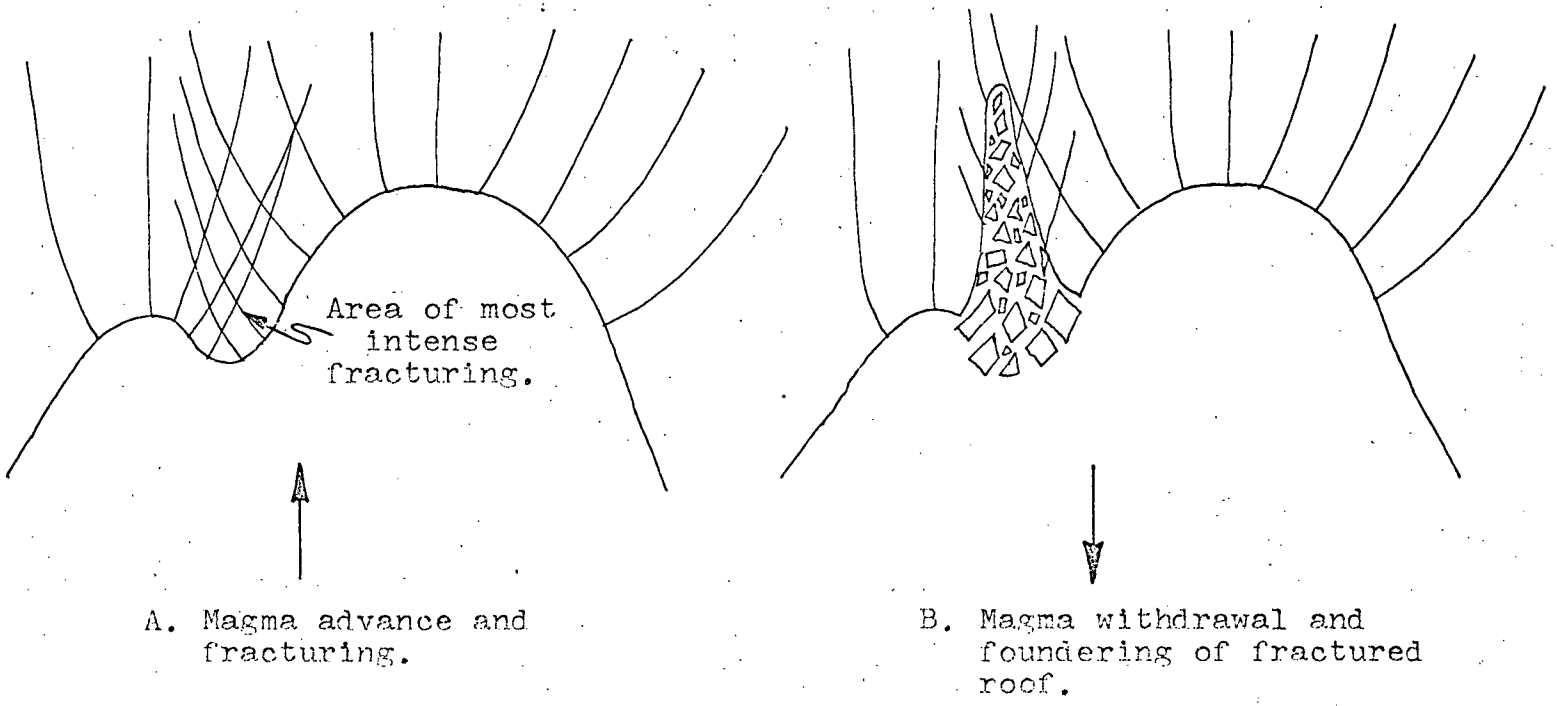


Figure 6.1. Formation of breccia bodies.

rhyolite porphyry dykes. With increased pressure a large block of overlying rock, including the rhyolite porphyry dykes, became intensely fractured with much comminution of larger fragments. Magma of rhyolite porphyry composition introduced during breccia formation caused recrystallization of the comminuted matrix to such a degree that decrease of magmatic pressure was accompanied by little downward movement of the fragments. In the resulting Phase I Breccia, fragments have not moved far from their place of origin although there is abundant evidence of mixing, such as comminuted matrix and heterogeneous mixtures of fragments.

A later magmatic surge produced fracturing in more confined areas. Slow withdrawal of magmatic pressures and concomitant collapse of the fractured rock accompanied by introduction of quartz between the fragments resulted in breccia in which individual fragments seldom are in contact with or can be matched with adjacent fragments. The resulting quartz breccias are characterized by angular fragments of granodiorite, Phase I Breccia, and dyke rocks that appear to "float" in a matrix of quartz. These Quartz Breccia bodies are circular, oval or lensoid in plan and form nearly vertical pipes. Collapse started at the bottom of the fractured column of rock and progressed upward and outward resulting in a chaotic mixture of fragments in the centre of the pipes and relatively undisturbed

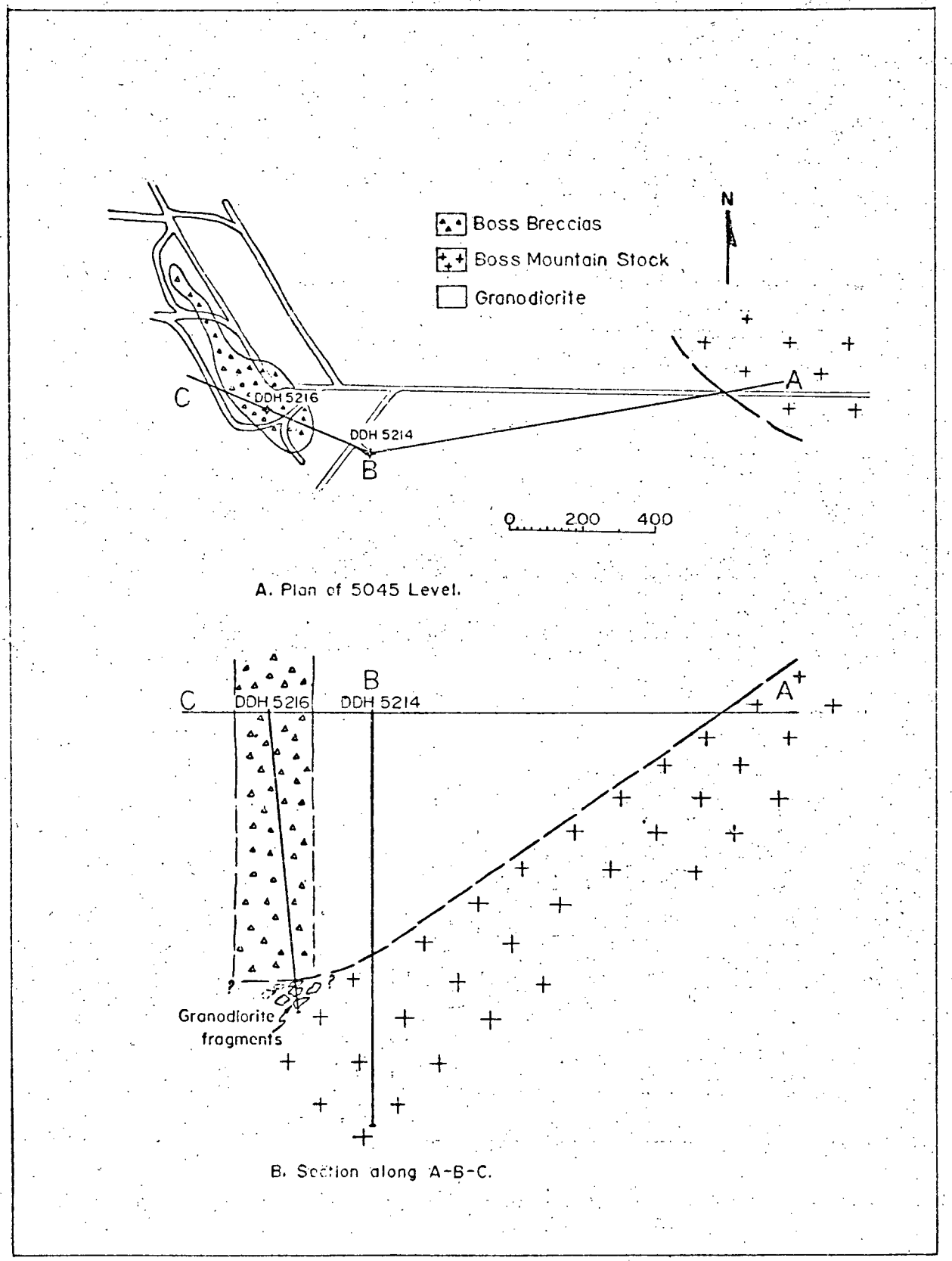


Figure 6.2. Plan and section illustrating the relationship between the Boss Breccias and the Boss Mountain Stock.

stockworks near the margins.

A third upward surge of the magma column resulted in intense fracturing and comminution of the Quartz Breccia in the Main Breccia Zone. The upper surface of this Quartz Breccia body was also shattered but not comminuted during this magmatic surge. Reduction of magmatic pressures was accompanied by collapse of the column of fractured rock and by the introduction of materials which formed quartz, biotite, and molybdenite in the matrix of the breccia. This pipe of Phase III Breccia is capped by Quartz Breccia. The shattered rock above the Quartz Breccia, which was later mineralized to form the Fracture Ore Zone, did not collapse completely during decrease of pressure because of the support by the underlying weakly fractured Quartz Breccia.

In conclusion, the formation of the Boss Breccias resulted from the action of a pulsating magma column. An irregularity on the west side of the magma chamber resulted in accentuation of fracturing around and above the irregularity and produced a series of breccia bodies of different ages and different characteristics. Further magmatic pulsations produced other structural features in the same area.

SEQUENCE OF ORE FORMATION

Phenomena related to ore formation, including igneous activity, breccia formation, fracture and vein development,

alteration, and mineralization, have been discussed in preceding sections. This section synthesizes all phenomena into a chronological sequence as shown in Table 6.1. Some repetition of earlier conclusions is unavoidable.

All phenomena in the sequence of ore formation can be directly or indirectly correlated with oscillatory magmatic activity. The initial event in this sequence was recorded by development around the Boss Mountain Stock of concentric and conjugate shears now filled with garnet and hornblende.

Group I quartz veins, the origin of which is unexplained, cut garnet-hornblende veinlets and are cut by all other features related to the sequence of ore formation.

A second magmatic surge and withdrawal was accompanied by rhyolite porphyry dyke emplacement and formation of Phase I Breccia.

Another magmatic advance formed fractures, now occupied by group 2 quartz veins. With continued magmatic advance, followed by reduction of pressures accompanied by introduction of quartz, the Quartz Breccia pipes were formed.

Magmatic surge again fractured the rocks. The earliest fractures formed during this surge were filled with quartz-molybdenite veins. The upper edge of the Main Breccia Zone (Fracture Ore Zone) was intensely fractured by this upward magmatic push. Reduction of magmatic pressures resulted in

IGNEOUS ACTIVITY	BRECCIAS & ORE DEPOSITS	FRAC-TURES	ALTERATION & MINERALIZATION
		6	
	High-Grade Vein	5	
	Stringer Zone		
Crystallization of Stock		4 late / early	
	Phase III Breccia (Fracture Zone)	3	
	Quartz Breccia	2	
Rhyolite			
Rhyolite Porphyry	Phase I Breccia	1	
Initial Magmatic Advance			

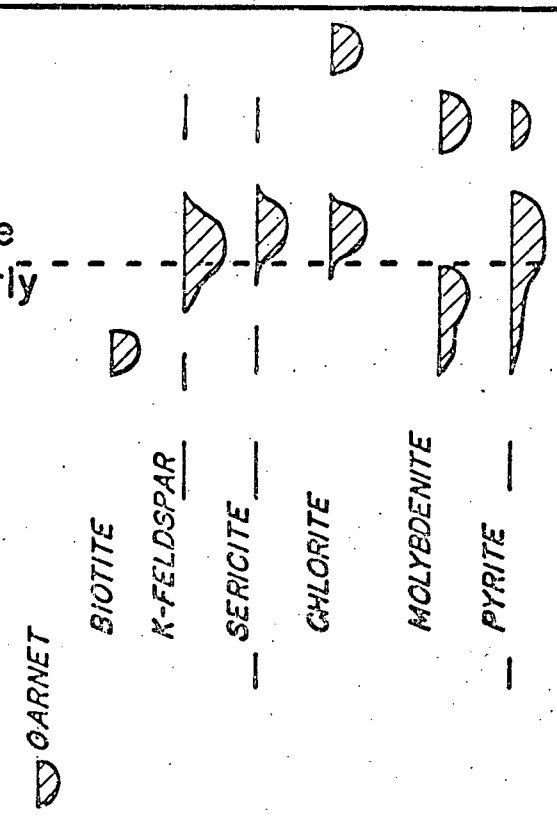


Table 6.1. Chronological chart of phenomena related to ore formation.

collapse and formation of Phase III Breccia accompanied development of hydrothermal biotite.

After Phase III Breccia formation, further reduction in pressure resulted in the development of early group 4 quartz veins followed by crystallization of the upper part of the Boss Mountain Stock. Adjustments deeper in the stock caused development of late group 4 quartz veins, the first structures to cut the stock. This was the time of maximum potash feldspar and sericite alteration (Stage 2) as well as the time of maximum pyritization (Table 6.1).

Further reductions in pressure from the deeper, unconsolidated parts of the magma chamber caused the development of fractures and the filling of these fractures by group 5 quartz veins. Molybdenite was introduced into the Fracture Ore Zone at this time.

The final event recorded in the sequence of ore formation was continued fracturing parallel to the High-Grade Vein accompanied by moderate to intense chloritization.

In summary magmatic pulsations of the Boss Mountain Stock caused the formation of ore structures and provided the mineralization that constitute the Boss Mountain molybdenite deposits.

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APPENDIX I

CONTOURED EQUAL-AREA PROJECTIONS OF FRACTURES: 5045 LEVEL

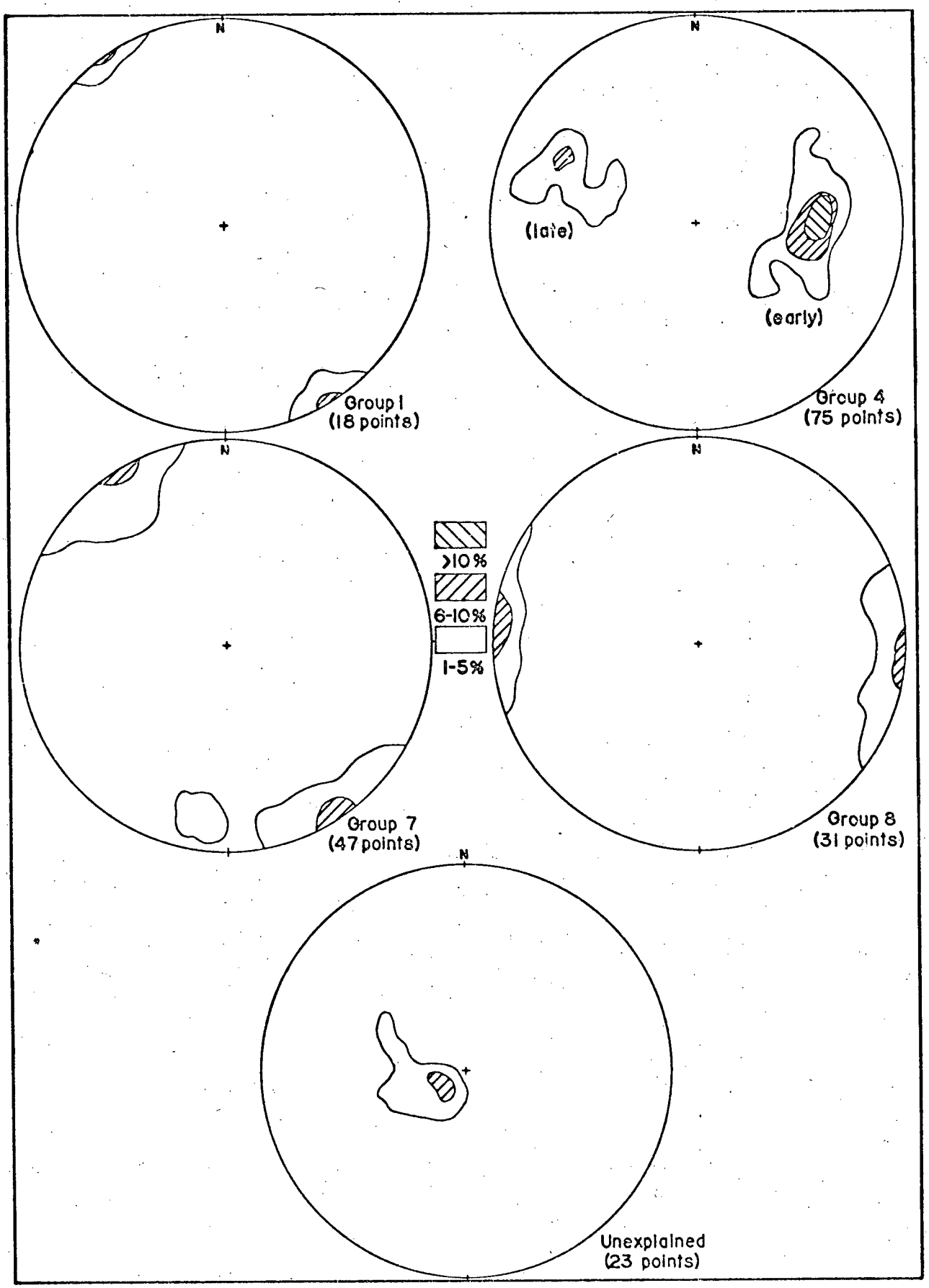


Figure I.1. Contoured equal-area projections (lower hemisphere) of poles to fractures in Area A; 5045 level.

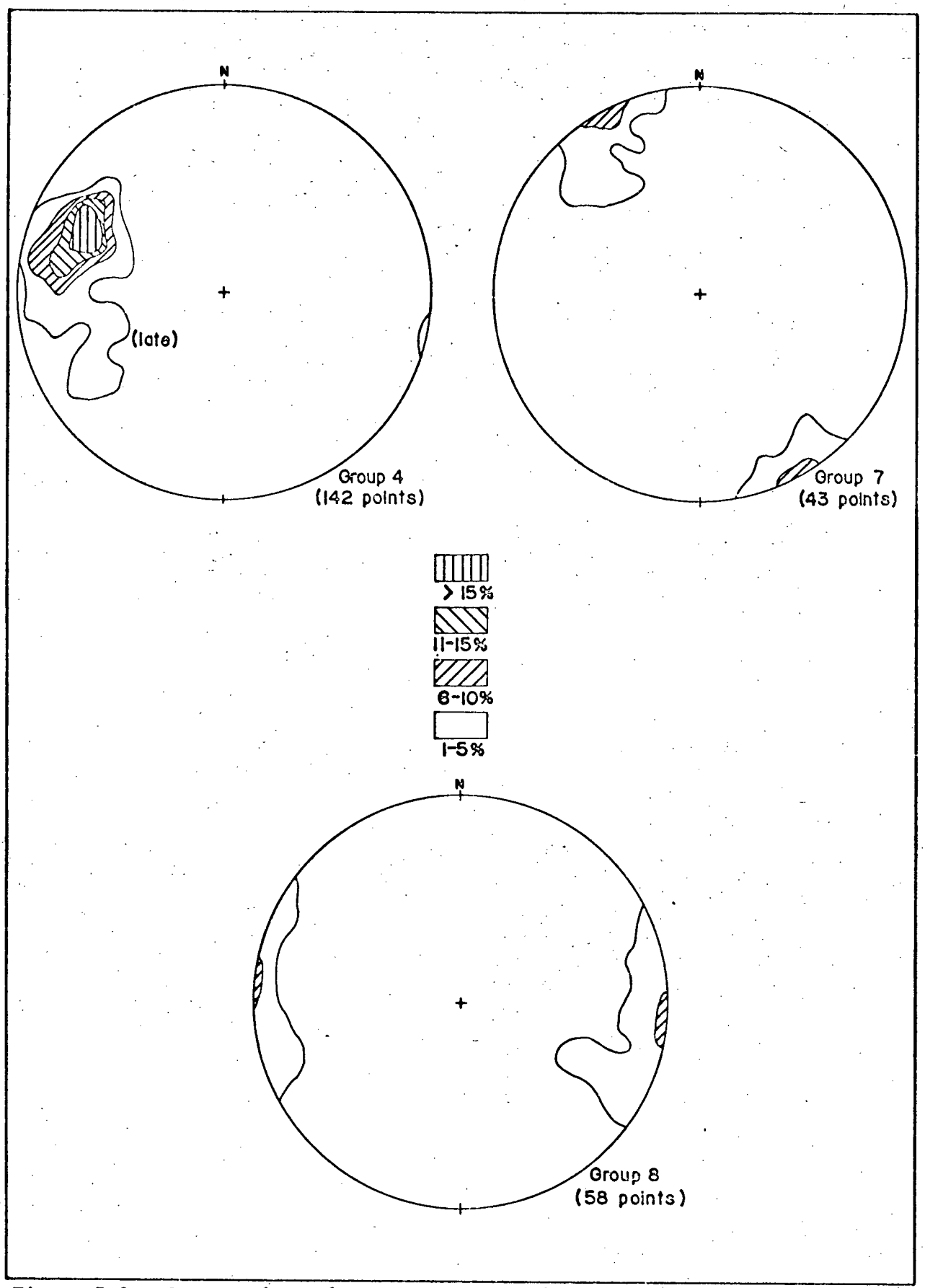


Figure I.2. Contoured equal-area projections(lower hemisphere) of poles to fractures in Area B; 5045 level.

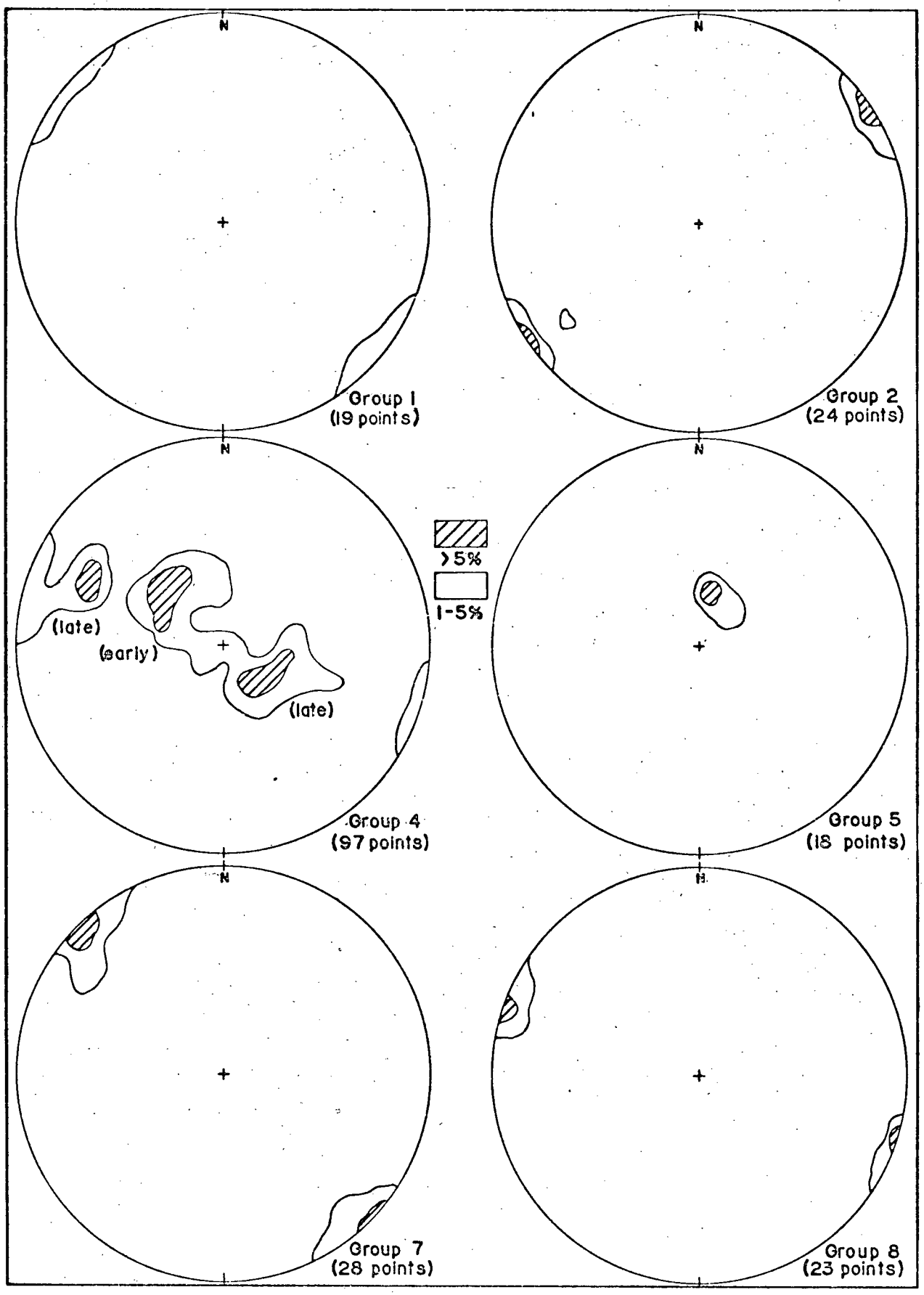


Figure I.3. Contoured equal-area projections(lower hemisphere) of poles to fractures in Area C; 5045 level.

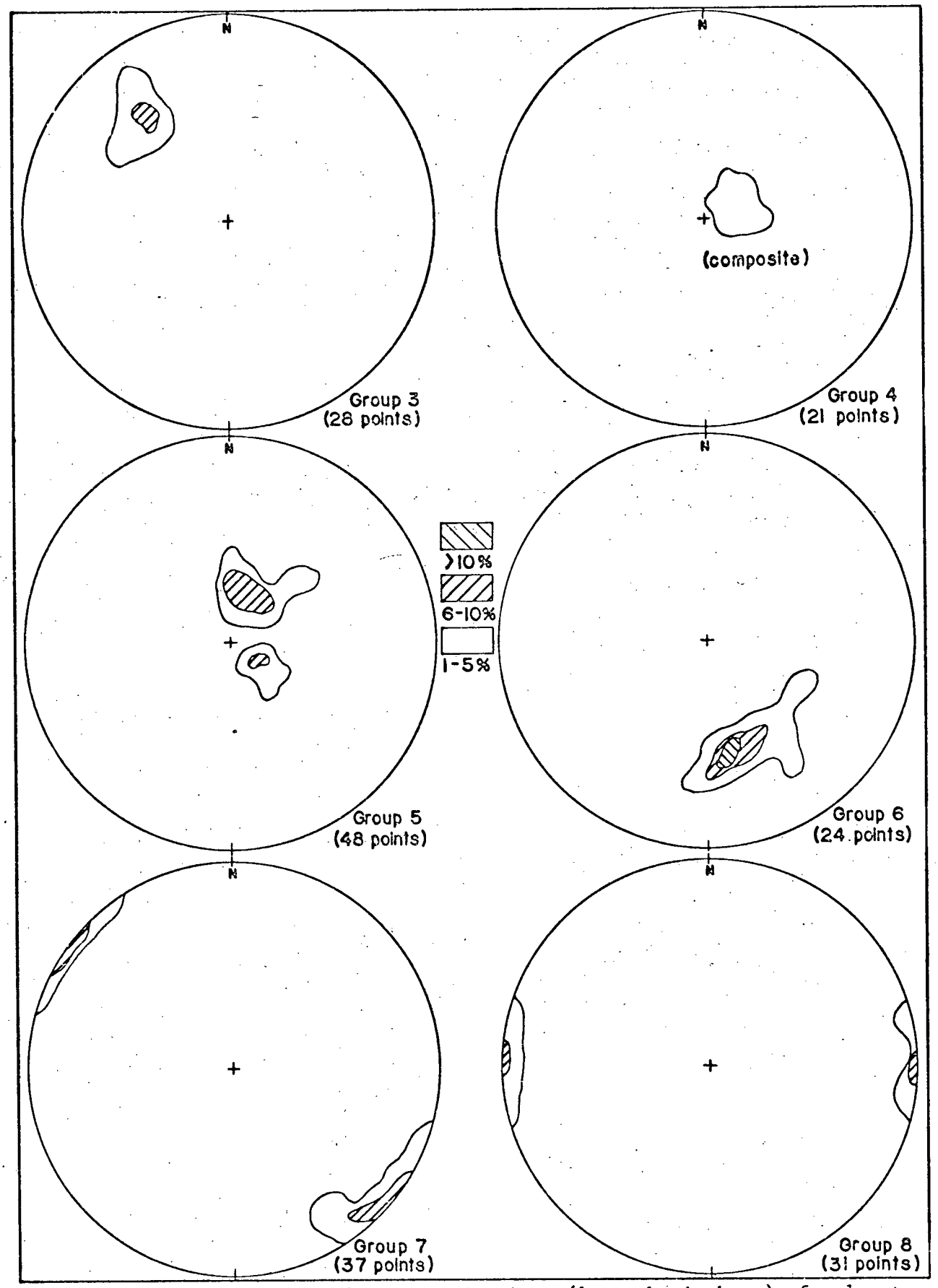


Figure I.4. Contoured equal-area projections (lower hemisphere) of poles to fractures in Area D; 5045 level.

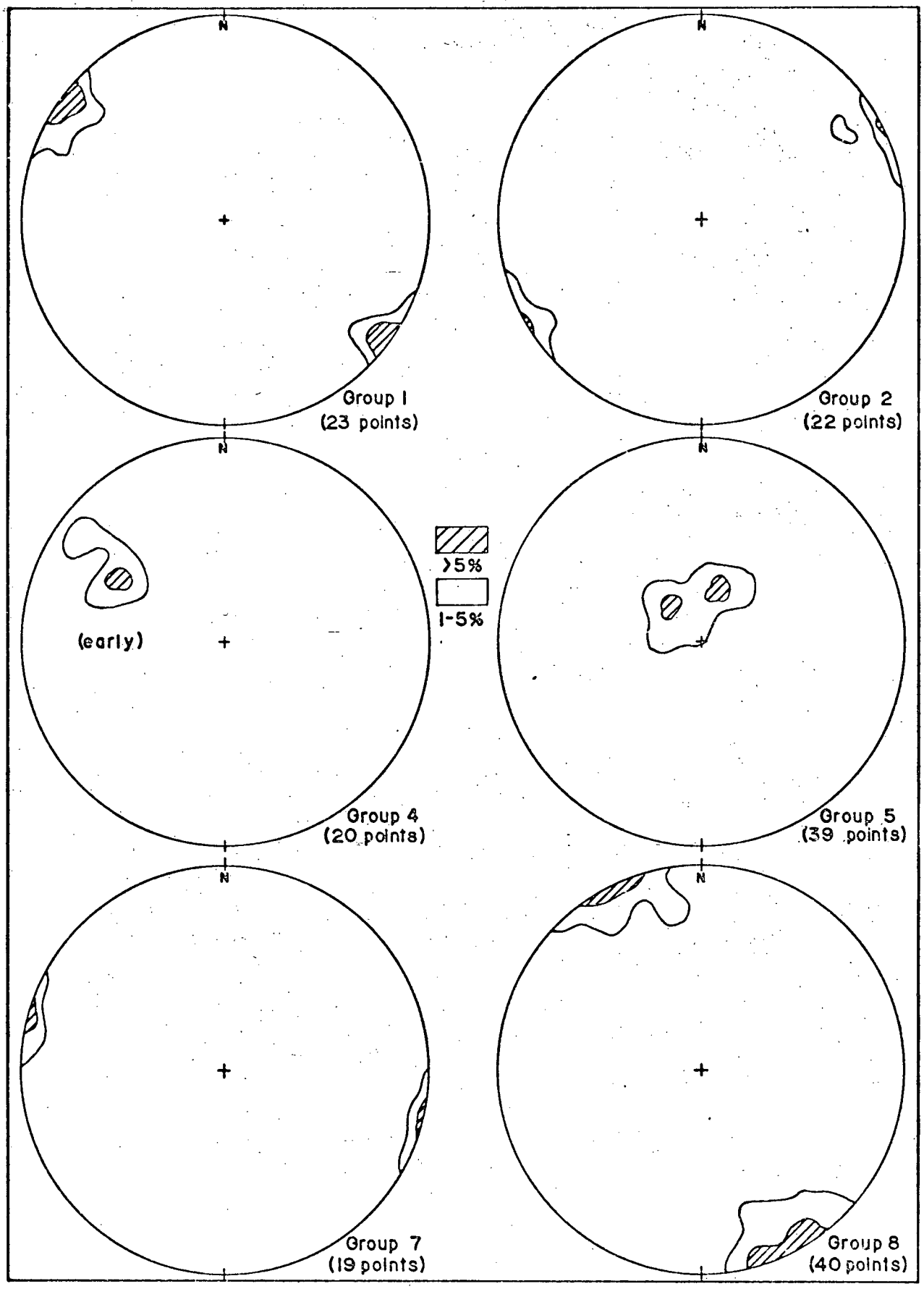


Figure I.5. Contoured equal-area projections (lower hemisphere) of poles to fractures in Area E; 5045 level.

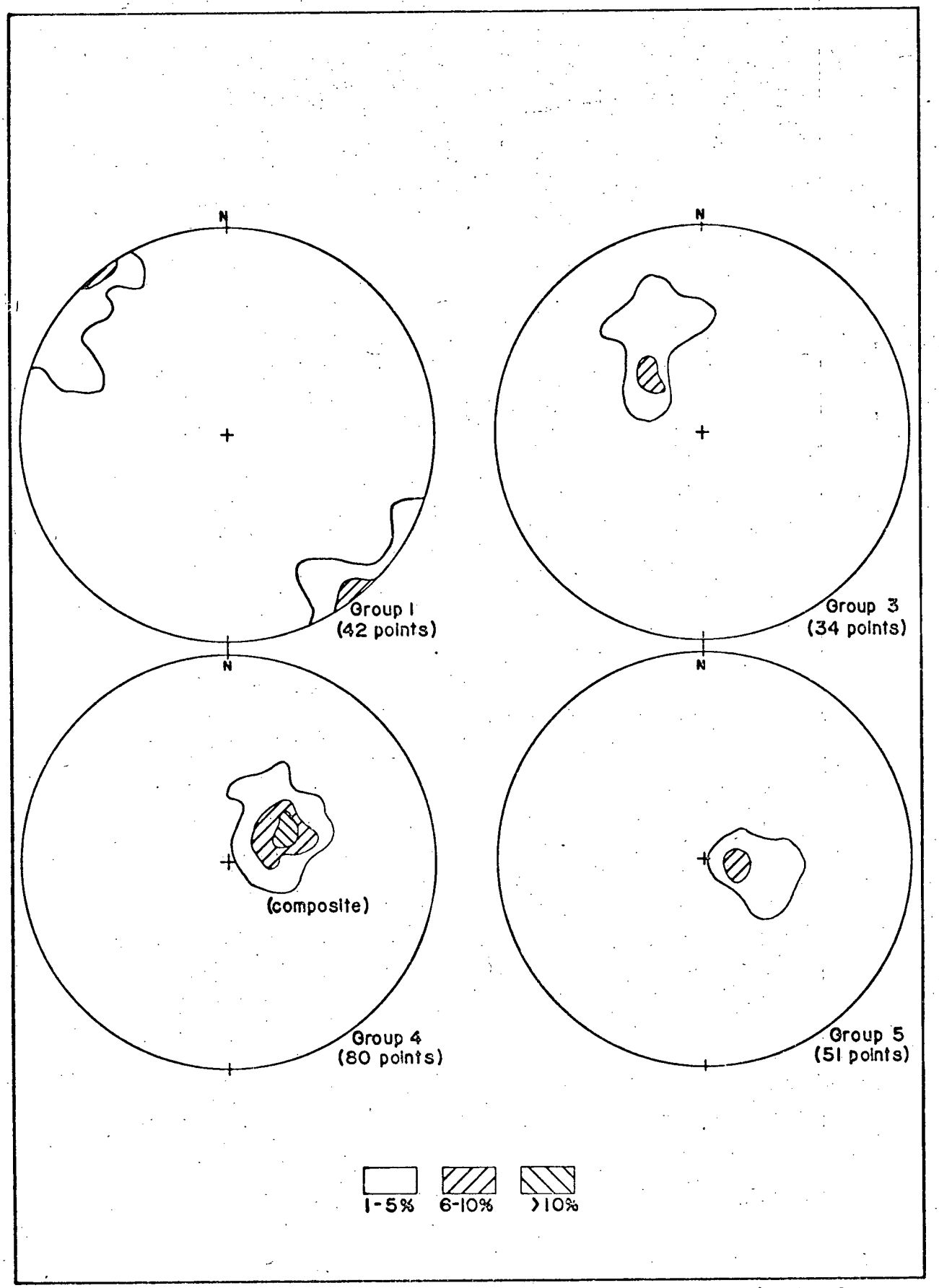


Figure I.6. Contoured equal-area projections (lower hemisphere) of poles to fractures in Area F; 5045 level.

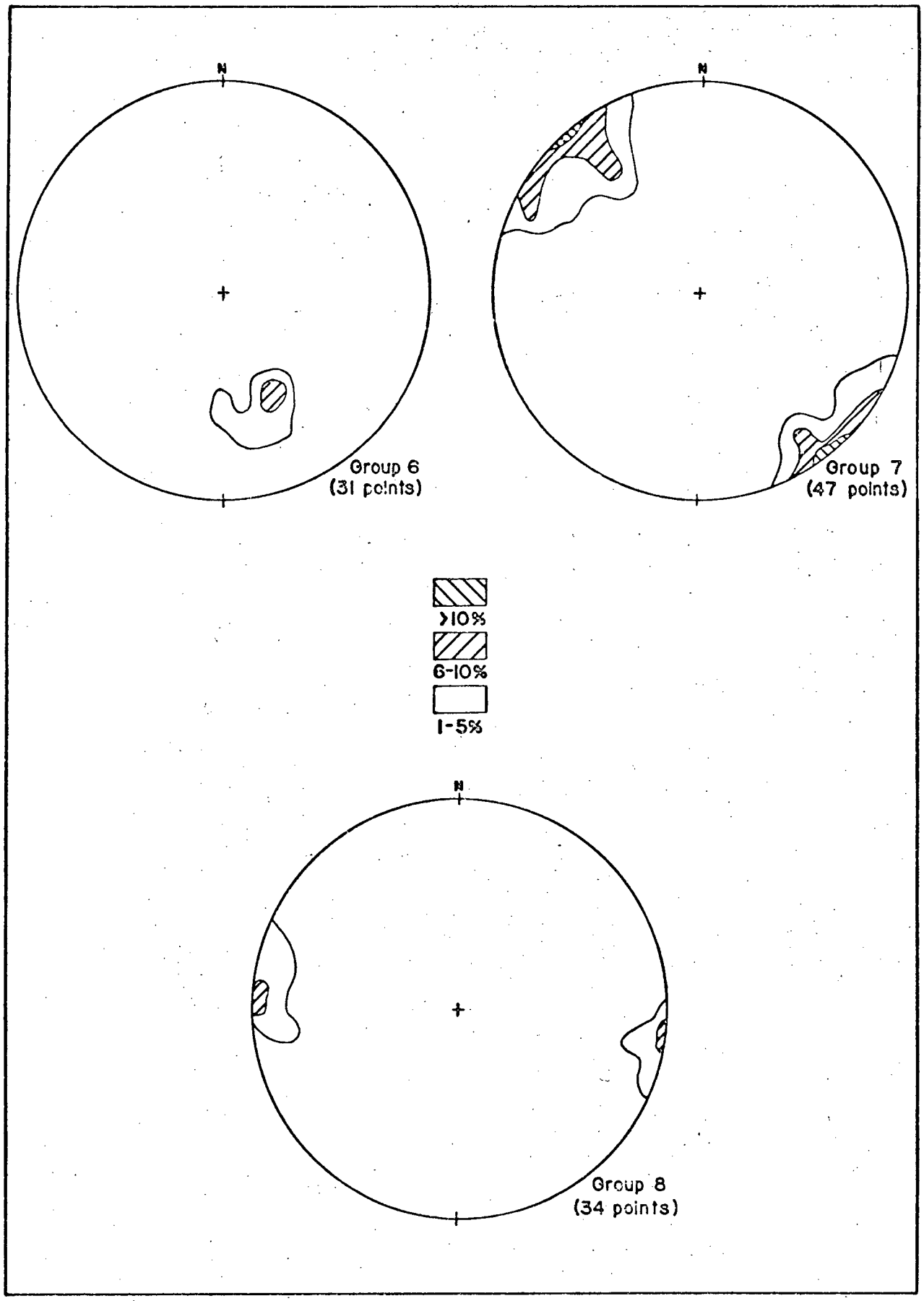


Figure I.7. Contoured equal-area projections (lower hemisphere) of poles to fractures in Area F; 5045 level (Continued from Figure I.6).

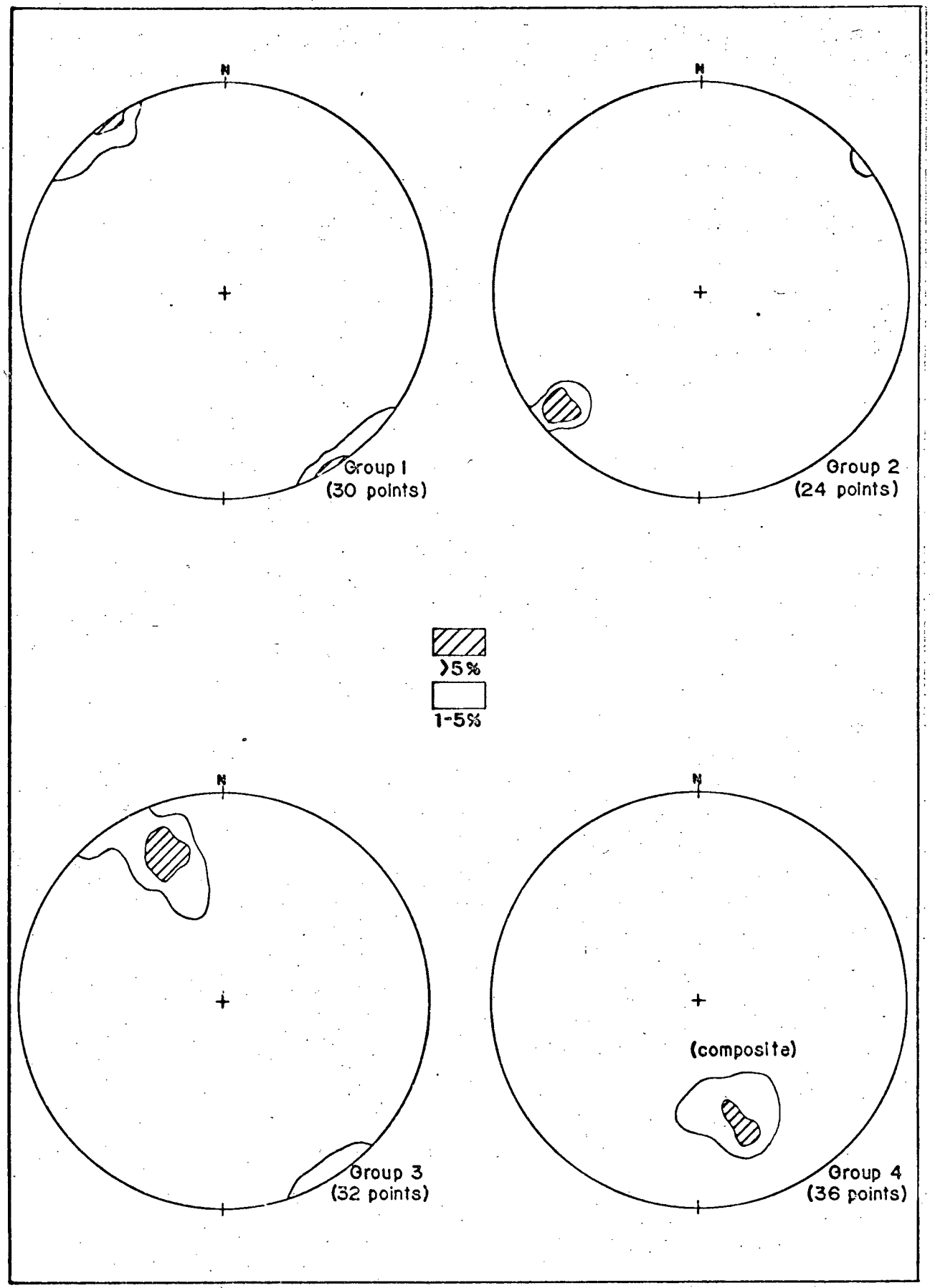


Figure I.8. Contoured equal-area diagrams (lower hemisphere) of poles to fractures in Area G; 5045 level (continued).

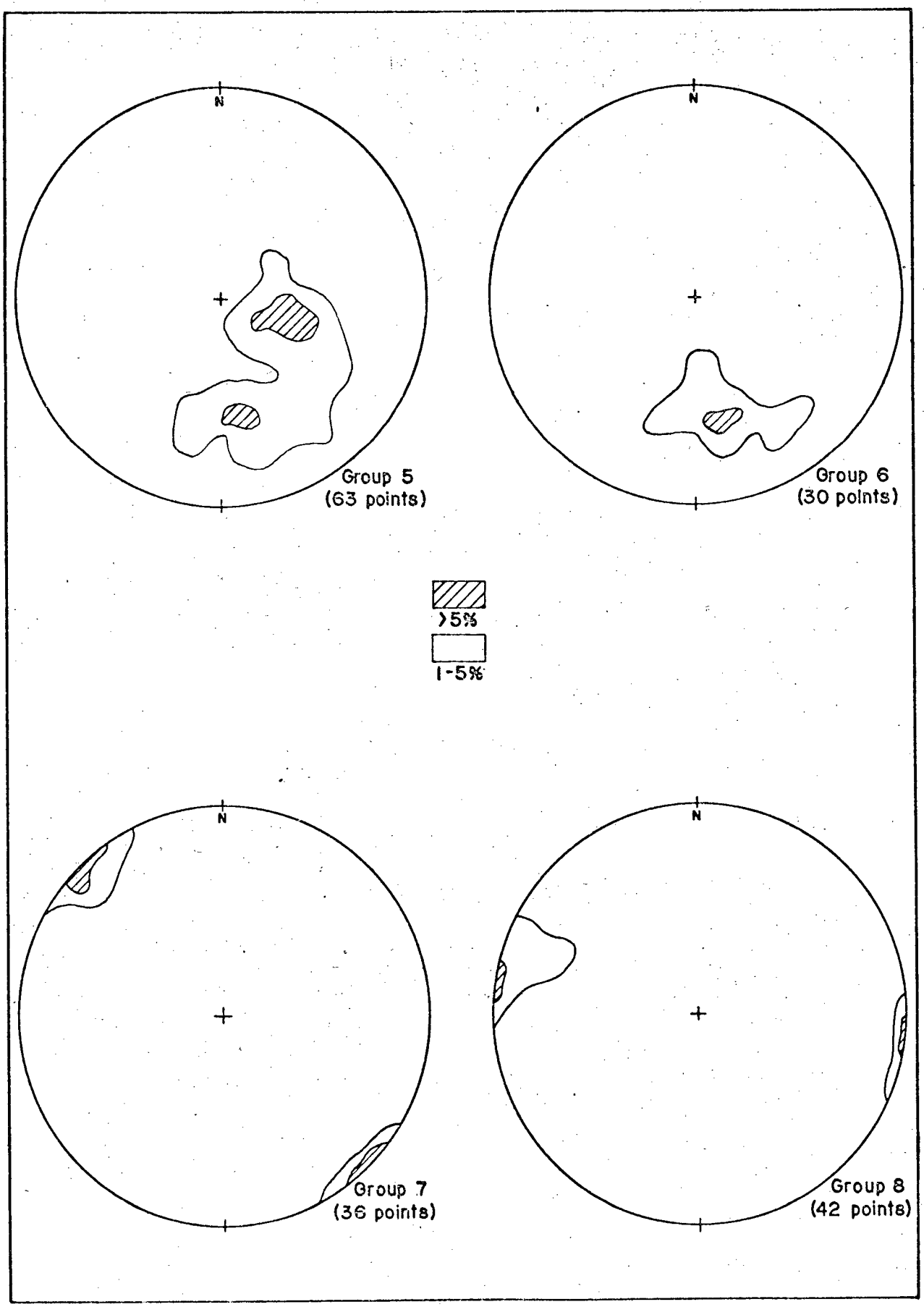


Figure I.9. Contoured equal-area projections (lower hemisphere) of poles to fractures in Area G; 5045 level (continued from Figure I.7).

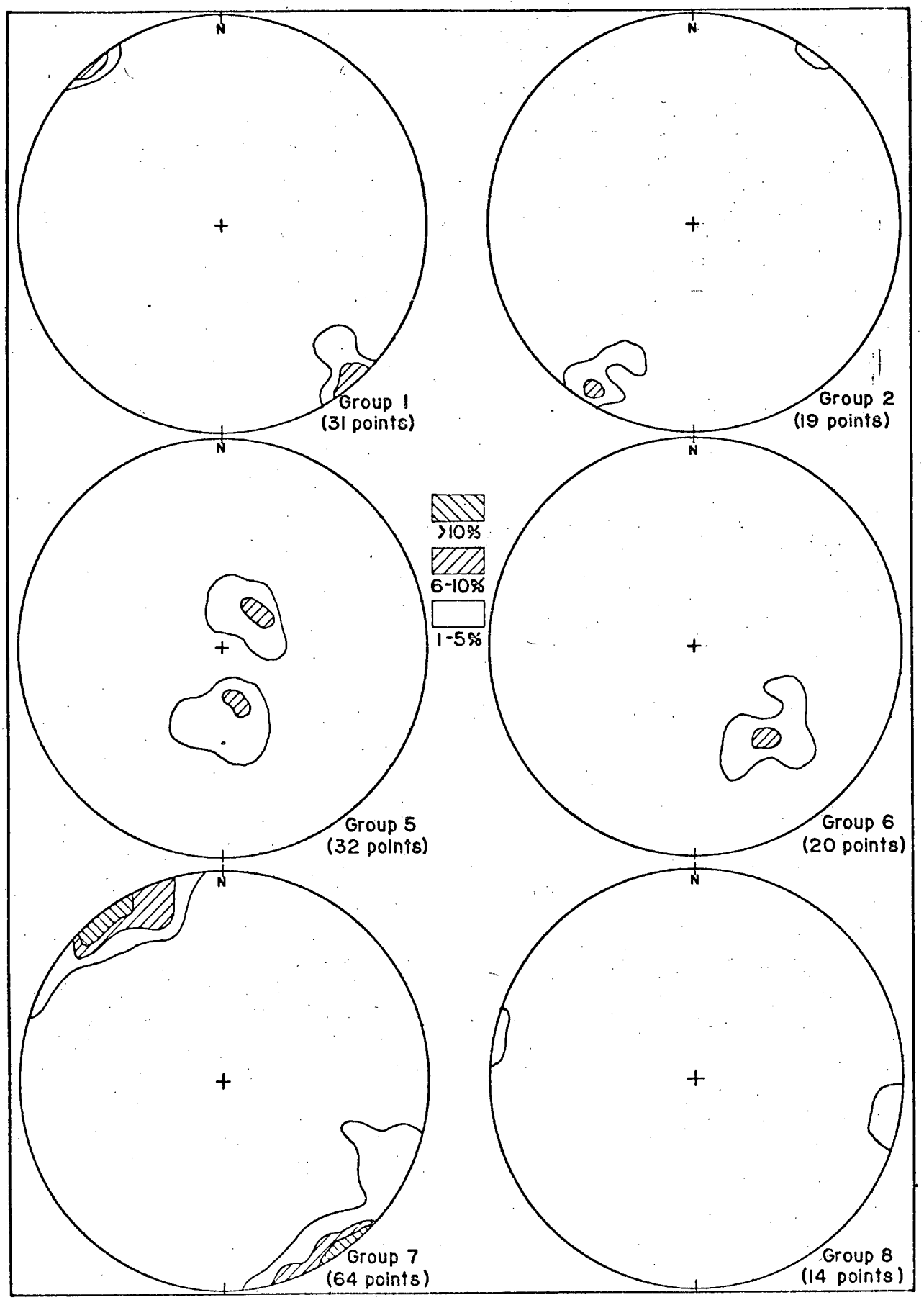
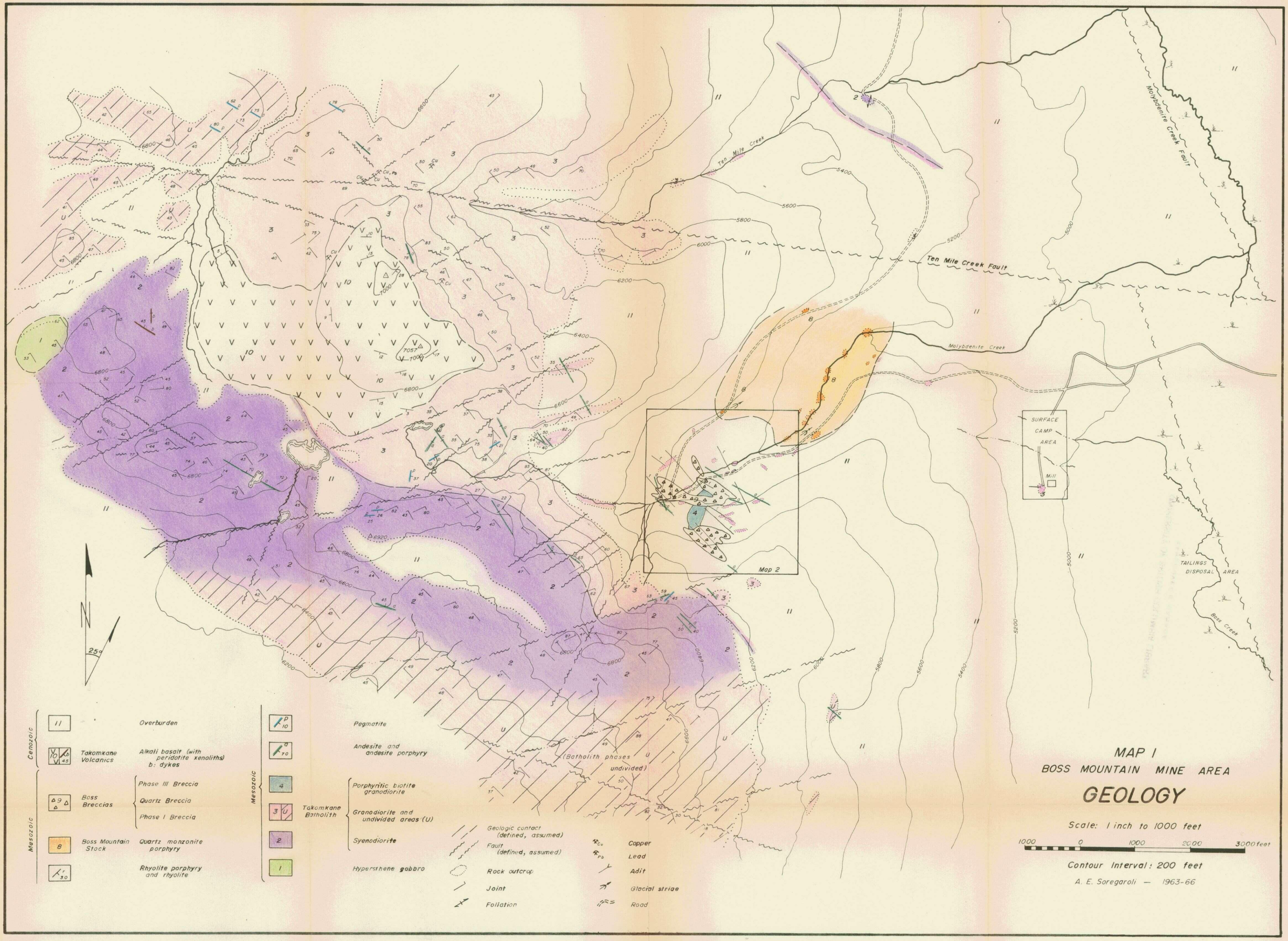
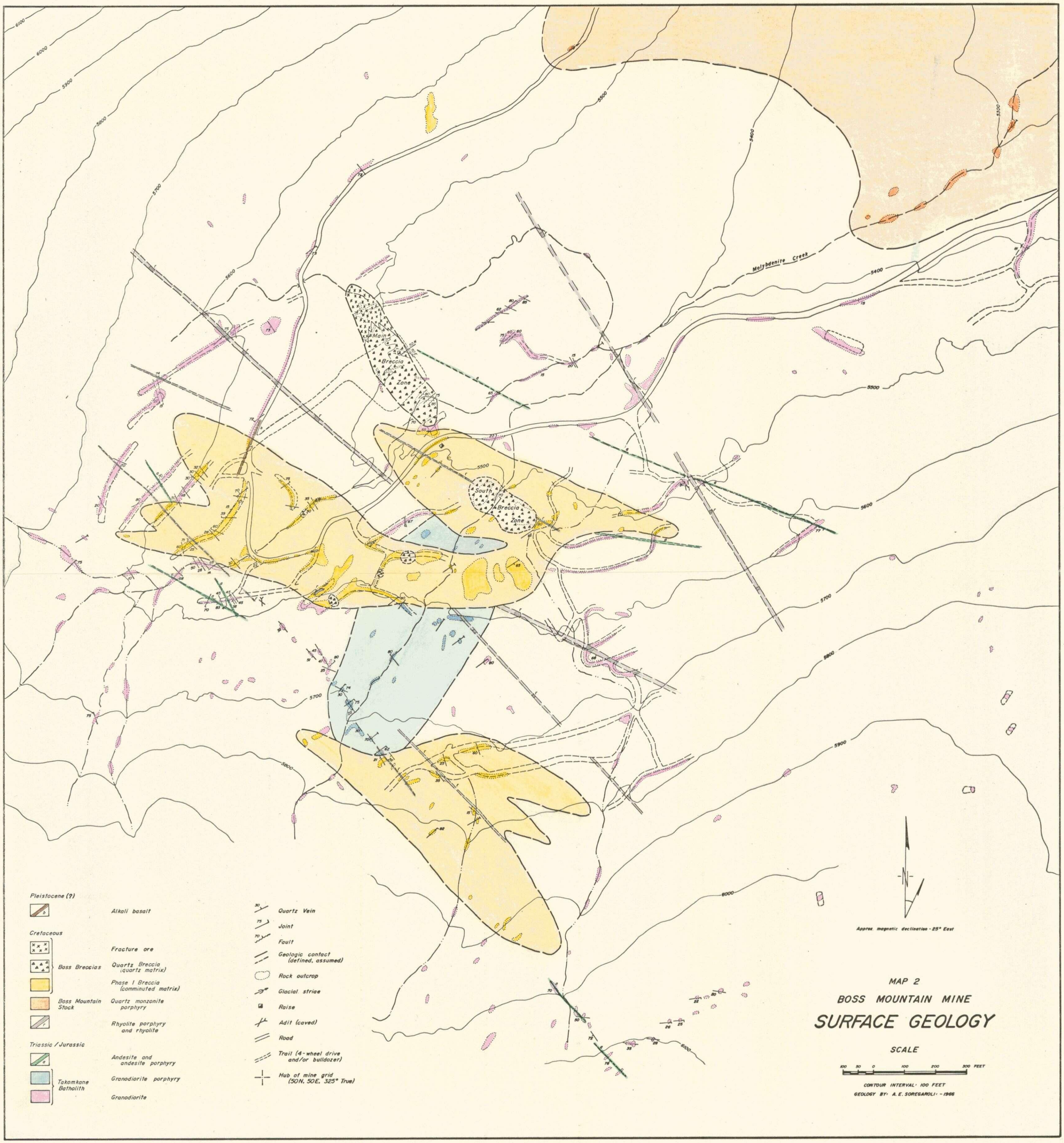
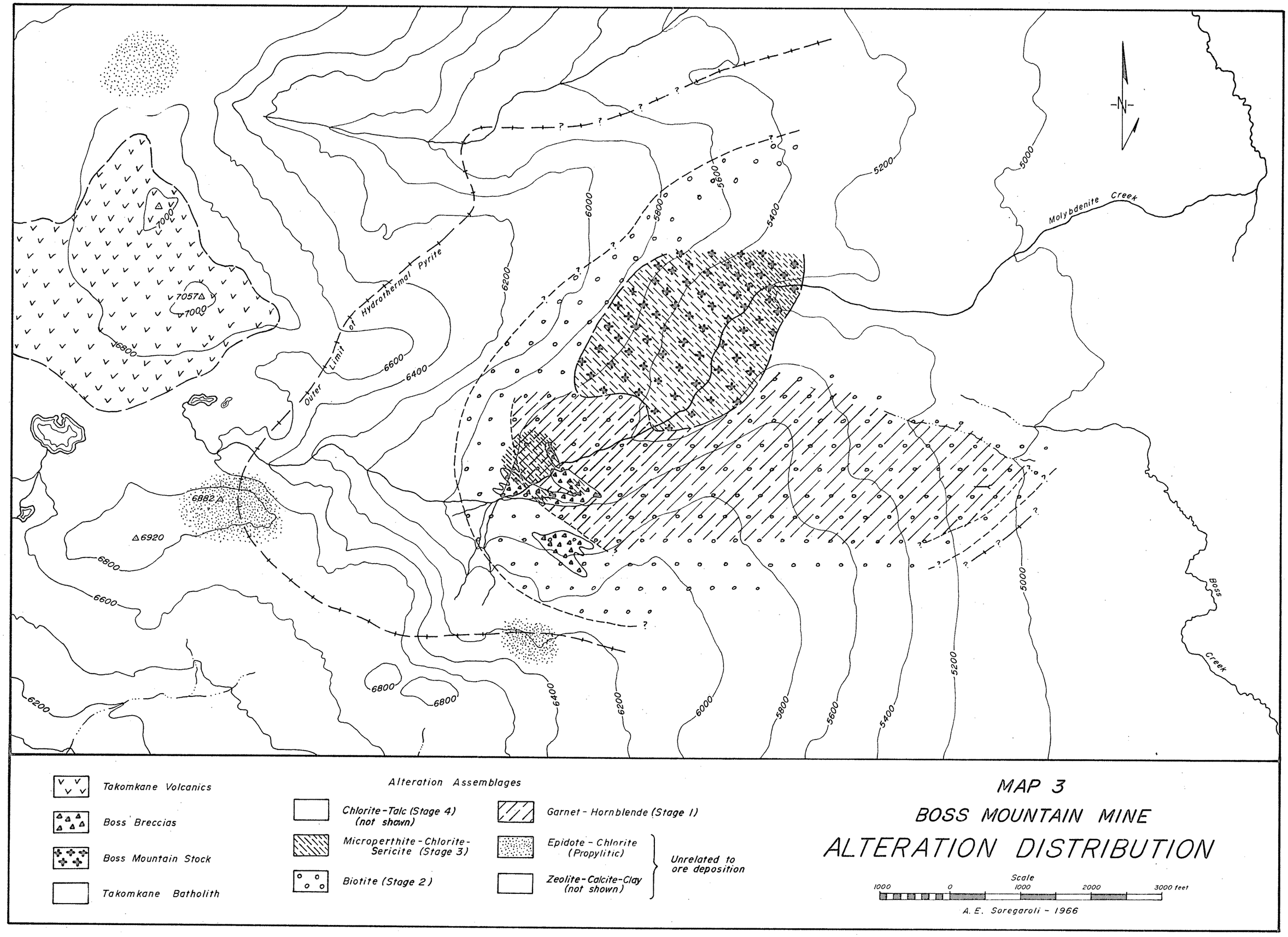


Figure I.10. Contoured equal-area projections (lower hemisphere) of poles to fractures in Area H; 5045 level.


Ten Mile Creek
Ten Mile Creek Fault
Molybdenite Creek Fault
Molybdenite Creek
SURFACE CAMP AREA
Mill
TAILINGS DISPOSAL AREA
Boss Creek
Map 2
(Batholith phases undivided)
Cenozoic
Mesozoic
Overburden
Takomkane Volcanics
Alkali basalt (with peridotite xenoliths) b: dykes
Boss Breccias
Phase III Breccia
Quartz Breccia
Phase I Breccia
Boss Mountain Stock
Quartz monzonite porphyry
Rhyolite porphyry and rhyolite
Pegmatite
Andesite and andesite porphyry
Takomkane Batholith
Porphyritic biotite granodiorite
Granodiorite and undivided areas (U)
Syenodiorite
Hypersthene gabbro
Geologic contact (defined, assumed)
Fault (defined, assumed)
Rock outcrop
Joint
Foliation
Copper
Lead
Adit
Glacial striae
Road
MAP I
BOSS MOUNTAIN MINE AREA
GEOLOGY
Scale: 1 inch to 1000 feet
1000 0 1000 2000 3000 feet
Contour Interval: 200 feet
A. E. Soregaroli — 1963-66


Molybdenite Creek
Main Breccia Zone
South Breccia Zone
6100
6000
5900
5800
5700
5600
5500
5400
5300
Pleistocene (?)
Alkali basalt
Cretaceous
Fracture ore
Boss Breccias
Quartz Breccia (quartz matrix)
Phase I Breccia (comminuted matrix)
Boss Mountain Stock
Quartz monzonite porphyry
Rhyolite porphyry and rhyolite
Triassic / Jurassic
Andesite and andesite porphyry
Takomkane Batholith
Granodiorite porphyry
Granodiorite
Quartz Vein
Joint
Fault
Geologic contact (defined, assumed)
Rock outcrop
Glacial striae
Raise
Adit (caved)
Road
Trail (4-wheel drive and/or bulldozer)
Hub of mine grid (50N, 50E, 325° True)
Approx. magnetic declination - 25° East
MAP 2
BOSS MOUNTAIN MINE
SURFACE GEOLOGY
SCALE
100 50 0 100 200 300 FEET
CONTOUR INTERVAL: 100 FEET
GEOLOGY BY: A. E. SOREGAROLI - 1966



MAP 3

BOSS MOUNTAIN MINE

ALTERATION DISTRIBUTION