REPORT OF METALLOGRAPHIC AND PETROGRAPHIC

STUDY OF GLACIER ZONE, COPELAND MOUNTAIN, B.C.

PART I

Prepared for

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CONCLUSIONS AND RECOMMENDATIONS

Mineralization in the Glacier Zone has taken place in part of a succession of metamorphosed sedimentary rocks.

The ore syenite which is the host rock is probably derived from the biotite-feldspar syenite or from a distinctive series of beds within the succession which included the biotite-feldspar syenite. It is extremely unlikely that the ore syenite is an intrusive, but if it is, it was intruded before Stage II folds.

Sulphide deposition is partly in open spaces (pyrite) and partly replacement (pyrrhotite). Sulphide replacement seems to have favoured a medium-grained rock with either grain margin replacement of microcline by plagioclase, or with fine equant plagioclase between larger orthoclase grains.

Mineralization occurred between Stage I and Stage II deformation and may have been concentrated in Stage I folds.

The complexities of the chemistry involved in rock genesis and sulphide deposition have not been worked out nor have the chemical effects been fully identified and assigned to their appropriate processes.

It is recommended that:

1) A detailed mapping program be carried out in the Glacier Zone and its vicinity to determine the position and importance of Stage I fold axes, especially antiform axes.

2) Oriented specimens be collected over short intervals from an underground working in the Glacier Zone to determine whether any systematic variation in plagioclase composition exists across the zone within a given rock type, and if one does whether it had any effect on sulphide mineralization as regards type or amount.

3) Analyse pulps of assay samples previously run as well as those collected in future to investigate relation between MoS_2 grade and amount of iron sulphides.

4) Prospect all areas with ore type syenite. Attractive areas should be recognizable by one or more of the following:

    a) Stage I fold axes.

    b) Bluish grey colour imparted to feldspar by alteration of iron sulphides.

    c) Geochemical field tests of both qualitative and quantitative type.

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d) Plagioclase along margins of orthoclase grains or else fine granular plagioclase interstitial to orthoclase. This can be determined by a field staining procedure outlined in appendix iii.

e) If the field staining method provides insufficient information, it will be necessary to have a petrographic microscope available. Such microscope should be equipped for the examination of covered and uncovered specimens so that staining may be combined with petrology.

f) Terminal moraine or talus slopes should be examined in the vicinity of biotite-amphibole gneiss, biotite-feldspar syenite and ore syenite for molybdenite mineralization.

OBJECT OF INVESTIGATION

This investigation was commenced with the object of determining:

a) the relationships between sulphide minerals and the silicates which comprise the host rock of the Glacier Zone;

b) the paragenisis of the sulphides;

c) relations between sulphides and tectonism and time of mineralization;

d) genesis of host rock and its enveloping strata;

e) the existence of alteration products in the host rock which could be used as indicators of mineralization.

METHOD

The Glacier Zone and related strata were reviewed briefly in the field in mid-September, 1967. Surface core was logged in October and underground core in late November of 1967. Core logging was done at a scale of 10 feet to 1 inch (Appendix ii, pp. 1-11). When it was decided to conduct a petrographic and metallographic study, the core was briefly re-examined and specimens were selected for thin and polished sections. Specimen selection was based on the principle that a representative suite would have to demonstrate mineralogical consistencies or the lack of them in the rocks without enough duplication to produce an excessively long program. Massive sulphide zones were generally avoided because, although they generally provide information on paragenisis of sulphides, they rarely assist in obtaining and understanding of the mechanism of the emplacement of the sulphides or of the genesis of the strata.

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Sampling of the biotite-feldspar syenite was done partly to investigate consistency in mineralogy but principally to determine whether significant variations occurred in the biotite-feldspar syenite in the vicinity of aplite syenites to be used as indicators for concealed ore bodies.

Specimen locations are shown on Figs. 2-17. Diamond drill hole locations are shown on Figs. 1-17.

LITHOLOGY

GENERAL COMMENTS

Several characteristics of the zone deserve special comment. One such characteristic is the absence of quartz except in the quartz-mica-amphibole feldspar gneiss which crops out some distance below the Glacier Zone and which occurs in drill holes GU-1 and GU-3 (Ap. ii, p. 8, 10). The quartz in the quartz-mica-amphibole gneiss occurs as lenticles to 3 cm wide composed of fairly large strained and fractured grains. It has replaced gneiss.

Another characteristic is the dominance of potash feldspar in certain parts of the biotite-feldspar syenite. In places it is really a monzonite. The plagioclases, too, have their peculiarities. On none of the thin sections examined was there a clearly zoned plagioclase. Progressive extinction through three or four degrees of stage rotation was common. Generally extinction shadow moved across the mineral in a way more consistent with strain than with compositional zoning.

Euhedrism except for the basal surfaces of mica is almost non-existent. A few potash feldspar grains have boundaries which resemble crystal faces, but only in contact with other potash feldspar grains. None of the plagioclase grains are even subhedral. The relationship between plagioclase and orthoclase is invariably one of replacement. The relative ages are indeterminate on some specimens, but wherever it is clear which mineral replaces the other, it is always plagioclase which is younger (Pl. II A,C; III A, V A). Mutual contacts between plagioclase grains are generally smooth, rounded and with a granular texture or serrated with a mosaic texture (Pl. I A; III C; VI A,B). In either case plagioclase grains should be considered to have grown together in a crystal mesh or to have recrystallized after stress.

Stress is apparent in most sections. It has two forms. One judged to be the earlier consists of microfractures in two directions forming a rhombic pattern of microperthite in orthoclase (Pl. I, II). The other consists of kink bands, microfaults, and bends in the plagioclase (Pl. III B,C; IV), and is judged to be later. The later type of stress probably exists in the orthoclase as well as in the plagioclase but is not recognized due to the absence of polysynthetic twinning.

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A final period of deformation is represented by a set of sub-parallel fractures which cut all sulphides and silicates apparently without displacement (Pl. XIX C).

Alteration products are not conspicuous. An exception to this is kaolinite which is ubiquitous except in some specimens which are dominantly plagioclase (Pl. II C; VII C; VIII C; X A). Chlorite, epidote, muscovite and ilmenite also occur and are discussed in appropriate sections. In general alteration is not severe.

Zircon is the only accessory mineral in any significant quantity. It is common in the biotite-feldspar syenite as well as in the aplite and pegmatite ore-bearing syenite. Generally it occurs as clusters composed of dozens of small, slightly rounded to rounded grains in contact with one another. In a few specimens, the zircon occurs as scattered larger tetragonal grains with cloudy centers and occasionally appearing to have developed by overgrowth around a smaller rounded grain.

Ore Syenite

Pegmatite Syenite

The pegmatite syenite is the coarser phase of the ore syenite of which it constitutes some 26 per cent in the total ore zone (Figs. 2, 3, 4, 5). Prior to this study it was expected that the pegmatite syenite would tend to occur more in the central part of the ore syenite but this is not the case. The distribution of the pegmatite follows no recognizable pattern, a condition which may be attributable to post ore syenite tectonics but which is probably due to the genesis of the ore syenite.

The estimated mineral composition of 11 specimens of pegmatite is shown on Table I. The most consistent feature is the dominance of total feldspar although the proportion of plagioclase to orthoclase varies considerably. Plagioclase comprises approximately 28 per cent of the rock type. Biotite is a minor constituent except for three of the specimens. None with a high proportion of biotite contain much sulphide. Some specimens have an important amount of calcite which has the same relationship to the silicates as they have to one another and which has the appearance of an original rock constituent (Pl. XIV A). In GU-2, 13'2"-3", plagioclase occurs as very small grains along the margins of orthoclase and was not identified, hence the relationship between the occurrence of calcite and composition of plagioclase is unknown.

The coarsest grains in nearly all specimens are potash-feldspar. Both adularia and a microcline occur in varying proportions. In some places, microcline, with a very fine anorthoclase-like quadrille twinning may have been classed as adularia. The microcline appears to be younger and is slightly clearer where both adularia and microcline are present.

TABLE I

ESTIMATED PER CENT MINERAL COMPOSITION OF PEGMATITE SPECIMENS

Specimen	K Felds	Plagio	Total Felds	Bio	Sulphides	Other
G-101, 56'0"-1"	65	25	90		3	7
56'2"-3"	15	65	80		10	10
G-102;111'3"-4"	70	10	80	2	13	5
126'3"-4"	60	20	80	5	15	
132'8"-9"	60	15	75	15[1]	2	8
G-104;103'2"	75	< 5	80	13		7
G-107'150'8"	20	50	70	20	2	8
GU-1; 79'7"-8"	90	8	98	< 2		< 1
GU-2; 42'4"-5"	65	15	80		20	< 1
GU-3; 85'5"	40	35	75	20	1	4
135'	35	40	75	< 1		25

    Both adularia and microcline are perthitic (Pl. I, II) and have a milky appearance in hand specimen. Very little of the perthite can be regarded as a definite ex-solution type. Perthites which are clearly depositional and/or replacement are common. The depositional perthite consists of lenticular bands of plagioclase, probably albite or oligoclase in one or more directions (Pl. I A,B,C; II A,B,C). Replacement perthites have regular to subparallel lamellae of a varying width and occasionally fuzzy boundaries. The replacement perthites have developed from depositional perthites by broadening and extension of plagioclase lamellae producing an intermediate stage which is an antiperthite with residual unreplaced potash-feldspar lamellae and an end result which is a plagioclase crystal. Some grains grade from perthite at one end to antiperthite at the other through progressive increase in the proportion of plagioclase along the grain (Pl. I A). In other potash-feldspar grains, replacement by plagioclase seems to have started simultaneously at many places, perhaps along fractures. The plagioclase so deposited has a constant orientation and a nearly constant proportion over grains too large to be represented in a single

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[1]This is original proportion of biotite. It is replaced by muscovite.

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illustration (Pl. I C). Advance of the process produces plagioclase with residual patches of microcline. The end result would be a plagioclase pegmatite.

Most of the plagioclase occurs as small euhedral grains along the boundaries of orthoclase (Pl. V C). Much of it is equant but it is partly in long slender, slightly curved to nearly straight twinned grains which have grown at the expense of both orthoclase grains with which they are in contact. Plagioclase may be as much as 1 mm across but in such cases there is generally a later and less calcic finer-grained plagioclase. Plagioclase composition (Figs. 6, 7, 8 and 9) and appendix i varies from AN-45 to AN-0. Determinations of AN45$\frac{+}{}$ are from apparently reliable bisectrix figures but in the same thin sections refractive indices of some grains are only slightly higher than the mounting medium which presumably has a refractive index of 1.54. Most of the plagioclase is near AN-20 and thus is oligoclase.

Where plagioclase is the dominant feldspar, it invariably has replaced orthoclase. Mica tends to be oriented in two directions, one more distinct than the other. Where mica is absent, there are patches of inclusions in the feldspars approximating the size of biotite. These patches have an orientation of grade comparable to that of the biotite in other specimens (Pl. XI A,B; This is aplite but identical textures occur in pegmatite.)

Accessory minerals are confined to zircon, which is generally larger than in the other rocks in the suite and tends to have a tectragonal form. The center of the zircon crystals is normally quite cloudy. In a few specimens, there appeared to be shadowy remnants of small, rounded zircon grains within the larger crystals. Possibly the small grains represent centers about which the larger grains formed by grain growth.

Depositional minerals besides sulphides are calcite, in veinlets (Pl. IX C), chlorite, common in late fractures, and epidote also in late fractures which cut feldspars and sulphides.

Pyrite and pyrrhotite occur as irregular masses, rounded blebs, and as minute veins in cleavage and other fractures. Pyrite has rounded colloform banding in most of the specimens (Pl. XIV C; XV A; XVI A,B; XX B). In others, the banding consists of repeated cusps which are reminiscent of relict s-surfaces inherited from banded sediments by pyrite nodules which have replaced argillaceous strata (Pl. XV B). Most of the more irregularly shaped sulphide masses have spidery shapes and seemingly have replaced the finer plagioclase which occurs along orthoclase grain boundaries (Pl. XIII A,B). Sulphide with such form is generally in contact with the coarser potash-feldspar grains except where very narrow, barely recognizable plagioclase remnants occupy this border between sulphide and feldspar (Pl. XIII A). A thin rim of carbonate, probably siderite, surrounds some of the smaller sulphide blebs

(Pl. XI C. This illustration is aplite but the condition is the same in pegmatite.) It is not known whether this rim is a remnant from an almost completely replaced grain of syngenetic carbonate or whether it represents post-sulphide deposition, but it is thought to be the latter, because the rims seem to consist of many small grains.

Molybdenite occurs as plates and clusters of small plates; generally deformed, in iron sulphides, and silicates. The iron sulphides and molybdenite occur together in some places although both can, and do, occur separately. Molybdenite which occurs separately from iron sulphides has the form of isolated plates, generally deformed, in cleavage and other fractures, or rounded clusters of deformed plates interstitial to feldspars (Pl. VI A; XIII A; XIV B). The clusters of plates frequently have a doughnut shape with a feldspar fragment at the center (Pl. VII C; XX C). In one specimen, from hole GU-2, 42', 4"-5", molybdenite occurs as deformed plates in fractures which cross pyrite. For additional comments regarding relations between the various sulphides and between sulphides and silicates please refer to the section entitled Mineralization.

Alteration products consist of kaolinite, epidote, mostly in mica, chlorite, muscovite, sphene and rutile. Kaolinitic alteration is evident on almost all potash feldspar (Pl. II C; VII C; VIII C; X A). It occurs as irregular masses on cleavages in company with minute, rod-shaped inclusions. Most of the epidote occurs interlaminated with chlorite, with or without sphene and rutile in pseudomorphs after biotite. Otherwise, epidote occurs sparsely as vein filling or as isolated crystals, some fairly coarse, in the feldspars.

Chlorite is of two types. The most common is pale green and only slightly pleochroic. Its most common forms are as random grains with iron oxides or rutile crystals, or alternating with epidote and/or sphene crystals, in both cases pseudomorphous after biotite (Pl. VI B; VIII A). The other chlorite is a dark bluish-green to pale yellow, strongly pleochroic variety, probably peninite, with a dark bluish-violet interference colour. It is commonly associated with iron sulphide minerals where they are in contact with silicates. It separates iron sulphides from silicates as a thin film and occupies late fractures in both feldspars and sulphides. It is this mineral which imparts the characteristic bluish-green to grey-green tint to much of the ore syenite.

Muscovite alteration of biotite takes the form of random plates or as oriented grains, pseudomorphous after biotite. In both cases, iron oxides and probably also sphene are produced. There is no clear connection between the occurrence of alteration products and the extent of mineralization and some of the secondary minerals such as the dark green chlorite clearly are derived from the sulphides and adjacent silicates and must postdate the mineralization.

Aplite syenite

The aplite syenite is the finer grained component of the ore

syenite of which it constitutes 55 per cent. Its distribution is shown on Figures 2, 3, 4 and 5. No pattern of zoning is evident. In some cases thin section specimens from pegmatite zones may be entirely of finer material and so are classed as aplite syenite which appears to be the dominant component.

The estimated per cent mineral composition of the 21 specimens examined in thin section is shown on Table II. Mineral components are the same as in the pegmatite but proportions are different. Total feldspar content is higher and plagioclase seems to form a larger proportion of it, being approximately 40 per cent of the rock type. Biotite formed a significant proportion of only one specimen from GU-1, 48', 8"-9". The biotite has been entirely altered to muscovite-carbonate chlorite masses and thus this specimen probably should be named an altered biotite-feldspar syenite.

The character of the minerals, their mutual relations and degree of alteration are the same as in the pegmatite. A general feature of the aplite specimens is the occurrence of dusty zones with the shape and size of biotite and forming approximately the same proportion of the rock as biotite does in many of the biotite-feldspar syenites (Pl. IX A). Moreover, the dusty zones have a preferred orientation of about the same grade as the biotite has in the biotite-feldspar syenite. Nearly all of the dusty zones are remnants of potash-feldspar, and undoubtedly some are residual fragments of microperthite. Others have a form more reminiscent of biotite which has been replaced by potash-feldspar than of original potash-feldspar grains. The character is especially evident in G-106, 96', 6".

Plagioclase, much of it deformed, occupies, with replacement, a fracture in specimen GU-3, 16', 7"-8" (Pl. XII A,B). Plagioclase orientation in the vein ranges from parallel with the walls to perpendicular to them, the former being acicular or lath shaped and the latter being equant. Branching veinlets of plagioclase extend away from the vein along potash-feldspar boundaries. Deformation of the plagioclase in the form of reversed s-shapes is compatible with rotation by a clock-wise couple. Kaolinite alteration is intense adjacent to the vein and decreases away from it, over a distance of 2 mm to the normal level of kaolinization for orthoclase. No sulphides occur in the fracture. Evidently the introduction of plagioclase into the fracture was preceded by the circulation of solutions which kaolinized the orthoclase.

Alteration products and depositional minerals are the same as in the pegmatite, with minor exceptions. The lower proportion of biotite has resulted in fewer of the alteration products derived from it. Zircon and sphene grains are fewer in number but larger. Ilmenite occurs as scattered coarse grains to 1 inch in diameter (see appendix ii, pp. 1-11).

Fluorite, brown to colourless, small isolated grains or large irregular patches replacing other minerals, is a common but generally minor constituent (Pl. XIII C).

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TABLE II

ESTIMATED PER CENT MINERAL COMPOSITION OF APLITE SPECIMENS

Specimen	K Felds	Plagio	Total Felds	Bio	Sulphides	Other
G-101; 39'1"	10	80	90		< 5	< 10
40'8"-9"	< 5	85	90		7	3
73'3"	70	5	75			25[1]
G-103; 58'	80	20	100			
60'	40	55	95		< 5	< 5
G-104; 108'3"	60	30	90	5	2	3
131'4"	75	20	90	< 2		< 9
140'4"-5"	80	10	90	< 1	9	< 1
G-105; 46'3"	30	50	80	2	10	8
161'5"	15	75	90	Tr		10[1]
G-106; 92'6"		98	98			2
GU-1; 25'5"	15	75	90			10
GU-1; 49'8"-9"	50	35	85	15[2]		
GU-1; 55'0"-1"	89	9	98	2		
GU-2; 13'2"-3"	25	35	60			40[1,3]
27'8"-9"	20	80	100		Tr	Tr
GU-3; 16'7"-8" 17'9"	90	5	95	< 3	Tr	< 3
24'8"-9"	90	< 5	94+	2	1	3
GU-AD 1a	80	10	90		10	
GU-AD 1b	83	13	96		4	

[1]Mostly calcite, euhedral, irregular in shape, clear, twinned and forms an integral part of the rock except for a few carbonate veinlets in which there is wall rock replacement of microcline.

[2]Formerly biotite but entirely replaced by muscovite 1/2, carbonate 1/4 and chlorite 1/4.

[3]Composed as follows: 30% calcite, 5% fluorite, 5% other.

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Specimen GU-2, 27', 8"-9", contains clusters of inclusions which may represent entirely replaced orthoclase.

Stress effects are more noticeable in plagioclase than in potash-feldspar, probably because of the presence of twin planes which can be used as a reference in plagioclase. In some specimens, notably G-105, 46', 3", adjacent orthoclase feldspar grains separated by veinlets of pyrite and chlorite have orientations so similar that they probably represent a single orthoclase grain fractured and rotated.

Biotite-Feldspar Syenite

The biotite-feldspar is the host rock to the ore syenite. In outcrop its colour is green to dark green with lithologic variations which end abruptly in a direction perpendicular or nearly so to foliation and which persist for some tens or hundreds of feet parallel with foliation. The marble layers with diopside and amphibole are the most obvious sub-units within the biotite-feldspar syenite (G-108, 3 feet, Ap. i, p. 27). These layers are from a foot to several feet thick and of unknown length. Some layers of this type occur above the Glacier Zone. None were thoroughly examined and most exposures of them are terminated by snow or ice oover in both directions. The contacts of these zones are generally sharp but contorted.

Other zones which are indistinguishable from one another except by proportion and degree of preferred orientation of biotite are also recognizable. This unit grades into a dark-green calcareous biotite amphibole rock in a westerly direction.

Estimated per cent mineral composition of 21 specimens is shown on Table III. The variation in plagioclase composition is shown on Figures 6 to 9 and it appears to be erratic. In an attempt to determine whether plagioclase proportion and type are related to the intrusion or formation of the ore syenite, Figure 18 was drawn. On it, the ordinate is plagioclase proportion and/or composition and the abcissa is distance from the ore syenite. The points are randomly scattered and so it is concluded that variations in composition of the syenite are unrelated to the ore syenite. It should be noted here that narrow bands of ore type syenite occur at various places in the biotite-feldspar syenite, particularly in the axial planes of minor folds and so meaningful distance may be from the nearest layer of ore-type syenite or from the nearest massive perhaps hitherto unknown ore-type syenite.

Biotite, abundant in all specimens, varies from green to pale brown in hand specimen, and from dark green to red-brown in thin sections. The colour variation in thin section, Figures 10-13, is less spectacular than in the core because sampling of the unit was not done to demonstrate colour variation and most of the specimens are from altered layers near ore-type syenite. In core, the change in colour of biotite from dark green to brown in the vicinity of ore syenite is distinct.

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TABLE III

ESTIMATED PER CENT MINERAL COMPOSITION OF BIOTITE-FELDSPAR SYENITE

Specimen	K Felds	Plagio	Total Felds	Bio	Sulphides	Other
G-102; 60'8"	25	40	65	30	T	5
G-102;132'8"-9"	60	15	75	10	5	10
G-102;133'1"-2"	60	15	75	10	2	13
G-103; 32'3"	25	10	35	50[1]	10	5
58'	70	10	80	20		
67'	70	5	75	22		3
G-104;108'3"	30	40	70	20		10
131'9"	75	10	85	15		< 2
156'	40	20	60	35		5
G-105; 46'3"	10±5	60±5	75	25		
60'4"	40	20	60	20		20
81'7"	50	30	80	20		
G-106; 59'3"	15	60	75	20	5	
G-107;140'1"	40	35	75	25		
150'8"	20	50	70	20		5
158'	30	35	65	30		5
GU-1; 2'4"-5"	20	40	60	30	5	5
25'5"	20	40	60	35	4	1
49'8"-9"	50	35	85	15		
65'4"-5"	10	50	60	40		
GU-2; 13'-13'1"	30	35	65	25		10

[1]Original biotite proportion 20% of the biotite is altered to muscovite and chlorite.
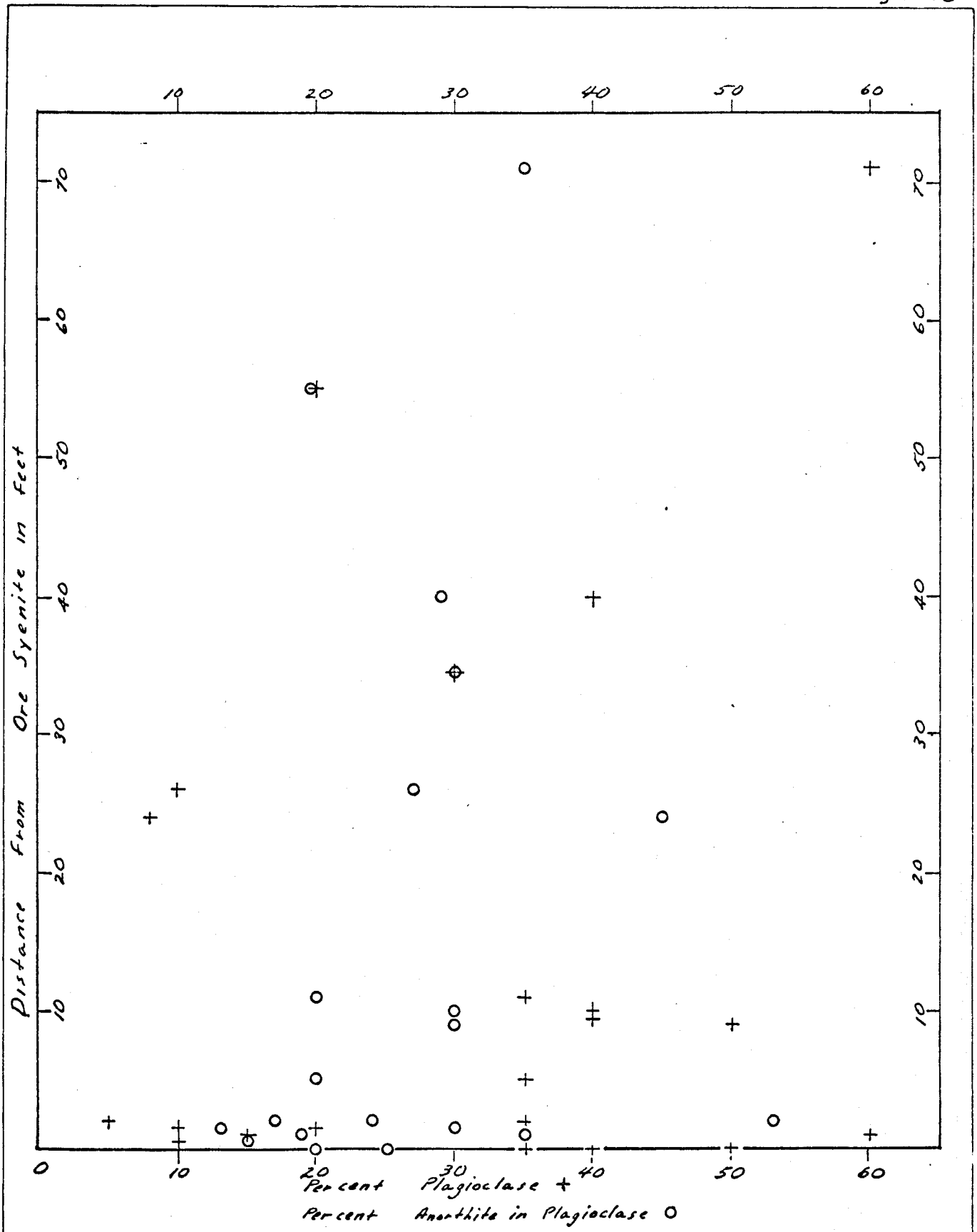
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FIGURE 18

Variation in % plagioclase and % anorthite in plagioclase
in biotite-feldspar syenite with distance from ore syenite

Replacement textures are as characteristic of this rock type as of the others (Pl. III C; V A; VI C; VII B; VIII A,B; IX A,B; XII C). The rock from which it was derived must have been high in potash, fairly high in alumina and very deficient in silica. Small lenticular structures 2 mm thick and up to 5 cm long consist of a mosaic of fine-grained equant orthoclase (Pl. X A,B).

Quartz-biotite-amphibole Gneiss

Only two specimens, GU-1, 128', 6"-8", and GU-3, 157', of this rock type were examined. Quartz, feldspar and biotite are dominant constituents. Amphibole is irregularly distributed in 1 cm clusters of grains. The amphibole specimen examined lacked biotite. Quartz occurs as lenticles of fractured quartz which contain oriented inclusions of biotite. Plagioclase is the dominant feldspar. The amphibole is probably actinolite or tremolite. For more complete information on this rock type, see Appendix i, pp. 38 and 48.

SULPHIDE MINERALIZATION

GENERAL STATEMENT

The sulphides in the ore syenite are pyrite, pyrrhotite, and molybdenite. The most significant features of the sulphides are the extensive deformation of all of them, the absence in most specimens of distinct age relations, and the absence of evidence of alteration effects on the host rock.

Two types of post-iron sulphide deformation are evident. One, the earlier, consists of what may have been rotation involving milling of grain boundaries and the later consists of sub-parallel fractures which cross all but the least competent minerals.

Iron-bearing sulphides are described first because they appear to be at least partly older than molybdenite which is the only mineral of economic importance.

Pyrite

Pyrite occurs in at least four forms and the fourth type is probably very much later than the others.

Colloform pyrite

This is the most common form of pyrite in the Glacier Zone. It consists of small nodules up to 3 mm long with fine regular to

crenulated bands. The nodules are rarely complete, none are unfrac-
tured, and the relation to the sulphides is obscured by fractures.
Some of the nodules appear to have been fractured and the fragments
rotated relative to one another. In some cases most of the fragments
seem to be present, in others much of the nodule is missing (Pl. XIV C;
XV A,B; XVI A,B; XVII B,C; XX B). The fractures along which movement
has taken place don't extend into the silicates.

Coarse Cubic Pyrite

This type of pyrite is at least partly derived from the collo-
form pyrite by recrystallization. It may all be derived from the
colloform pyrite. It is recognizable in most specimens (Pl. XV B). Its
presence in others may be obscured by post-recrystallization fracturing
and rotation. Size is up to 20 mm.

Fine Cubic Pyrite

This form of pyrite occurs in secondary silicates generally
peripheral to massive sulphides, either pyrite or pyrrhotite. The cubes
are generally less than .1 mm across and many are as small as 0.01 mm
(Pl. XVIII A,B). They are invariably imbedded in a secondary silicate,
generally chlorite.

Massive Pyrite

Some of the most massive pyrite may be coarse cubic pyrite
derived from colloform pyrite but so deformed by late fracturing that its
cubic character is not recognizable. Some of the massive pyrite clearly
replaces feldspar and seems to have no relationship to colloform pyrite
(Pl. XXII C).

Vein Pyrite

Veins of pyrite from 0.02 mm to 0.2 mm wide occur in cleavage
and other fractures in feldspar and in the pyrrhotite (Pl. XV C). This
is clearly a late stage of pyrite mineralization.

Pyrrhotite

The pyrrhotite is almost universally in spidery-shaped masses
which have replaced finer grained plagioclase (Pl. XII A,B). Each mass
of pyrrhotite is composed of individual grains with rounded outlines
(Pl. XVI A; XVII A; XXI A). The relation between pyrite and pyrrhotite
is clear on very few specimens. Most places grain margins are plucked
during the grinding and polishing process and are marked by a narrow moat
on the polished section, but wherever the mutual relations are clear
pyrrhotite has replaced pyrite (Pl. XVI C; XVII A). In one polished

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section, there are pyrite veinlets which are displaced along micro-
faults which are not present in the surrounding pyrrhotite (Pl. XXII
A). A curious type of pyrite-pyrrhotite intergrowth occurs in several
specimens typified by G-105, 109', 10". Here a large cube of pyrite
more than 2 cm across has a fringe of intergrown pyrite-pyrrhotite (Pl.
XVII B,C). The intergrowth consists of curved to straight, questionably
colloform pyrite with intervening pyrrhotite grains. In some places,
the webs of colloform pyrite divide a grain of pyrrhotite. The origin
of these structures is unknown but it is suggested that pyrite was
deposited in open spaces in some host which is now absent. Deposition
of pyrite evidently alternated with some other material which has now
been leached out and is represented by the very small open spaces with
lenticular shape in the pyrite. Subsequently, pyrrhotite replaced the
host mineral entirely. Finally, late fractures of two types occurred.
One type is tight, not linear and follows the pyrite. The other type
is open, linear and crosses other minerals. It is filled with a sili-
cate, probably chlorite.

Chalcopyrite

Chalcopyrite occurs in almost all specimens which contain
pyrrhotite, as blebs rounded to lenticular in shape and generally less
than 0.1 mm in width. It occupies fractures in cubic pyrite and so was
introduced after the recrystallization of the colloform pyrite. It is
generally associated with chlorite in fractures in or adjacent to pyrite
and pyrrhotite. It is crossed by the youngest fractures (Pl. XVIII C;
XIX A,B).

Molybdenite

The molybdenite occurs alone or with the iron sulphides. It
occurs as blebs, irregular masses from 1 mm to 2 or 3 cm across and as
isolated flakes in cleavages or fractures in the feldspar. The blebs
are almost invariably composed of flakes which tend to have two sizes,
one 0.02-0.03 mm in width and from 0.1 to 0.2 mm long, and the other
size as large as 0.1 mm by 2 mm. Few intermediate sizes occur. The
clusters of plates vary from lenticles to doughnut shapes to elliptical
masses. Its most frequent appearance is in feldspar, generally fine
plagioclase. Its occurrence in the biotite-feldspar syenite is confined
to zones near ore syenite.

Some of the clusters have U-shapes with one limb longer than
the other. Three such occurrences are in specimen G-102, 111', 3"-4".
Two sizes of molybdenite occur as usual. The smaller grains are sub-
perpendicular to the walls of the "U," and the larger grains extended
across it and are more or less at random. The mutual relations of the
three structures are not clear but they could be parts of a vein folded
tightly and dismembered.

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The relation of molybdenite to iron sulphides and ilmenite is unknown. Although it occurs within them it is generally on fracture planes and so distorted that its presence in them could be analogous to allochthonous blocks carried along fault planes during deformation.

Deformation of molybdenite is present to some degree in all specimens (Pl. XIII A; XX B,C; XXI; XXII A,B). It takes the form of twinning, kinking, and bending. In some cases, bending is through as much as 150° and is accompanied by rupturing of the plates. In no instances were fractures along which the deforming movements took place in evidence in the adjacent feldspar. Evidence of crushing is in the sulphides as well but in general does not extend into the silicates where the molybdenite is associated with sulphides.

Pyrite frequently occupies ruptured parts of molybdenite plates, but pyrrhotite rarely does (Pl. XXI B).

Late fractures with chlorite filling cross all sulphides and silicates but generally have reduced width in molybdenite (Pl. XIX C).

Oxides

Magnetite occurs in amounts ranging from traces to several per cent in the biotite-feldspar syenite. It constitutes irregular blebs to 1 mm long which are interstitial to biotite and feldspar. Incomplete replacement to pyrrhotite is common. Magnetite also occurs sparsely in the ore syenites as unreplaced remnants in pyrrhotite.

Ilmenite occurs as large twinned zoned crystals to 1 1/2 inches long in the ore syenite and sparsely in the biotite-feldspar syenite adjacent to the ore syenite. Polished sections show that what appears to be single crystals in hand specimens are really aggregates of crystals with ex-solution lamellae or strings of blebs (Plate XX A). These lamellae were not studied in great detail but they are thought to be an iron oxide probably specularite, possibly magnetite. Deformed molybdenite as well as iron sulphides occurs within the ilmenite but generally on fracture planes. Silicates, mostly feldspars in the form of very small equant grains, occur abundantly in the ilmenite. The origin of the ilmenite has been obscured by deformation. It is likely that the ilmenite grains are porphyroblastic and originally were solitary poikiloblastic crystals but have been shattered during later folding. Differential rotation of the fragments even if minor would create the illusion that the ilmenite occurs as clusters of grains. The large amount of titanium available but tied up in sphene and rutile in much of the suite supports the contention that the ilmenite is porphoroblastic. This should be verified by thin or polished sections of ilmenite and by comparison of chemical analyses of the various rock types.

PARAGENISIS

Paragenisis of the sulphides is clear in part, vague in part, and undecipherable with present information in other parts.

Obviously pyrite was first as a colloform deposit in open spaces. The colloform pyrite recrystallized at least partly to cubic pyrite, perhaps in late Stage I deformation. Pyrrhotite then replaced pyrite (Pl. XIV C; XVI A,B, etc.), and feldspar. Chalcopyrite probably accompanied pyrrhotite but is present in such small amounts that it could have been inherited from argillaceous beds in the original host sediments, if the ore syenite is not an intrusive.

Molybdenite is something of an enigma. The lack of distinct age relations where it occurs with pyrite and pyrrhotite, coupled with the tendency of iron sulphides and molybdenite to occur separately from each other, makes the establishment of its position in a sulphide mineralization sequence difficult. Molybdenite was probably deposited in the ore syenite after pyrite and before pyrrhotite; but it antedated some pyrite and may have postdated some pyrrhotite. The deposition of ilmenite or its growth from materials in the host rock probably accompanied molybdenite. The next stage involved recrystallization of some molybdenite together with solution and redeposition of pyrite in fractures which may be contemporary with Phase II folds.

ALTERATION PRODUCTS

One of the objects in this investigation was to identify some of the alteration products which must have formed in the host rocks at the time the sulphides were deposited. None have been identified with certainty. The coarse ilmenite might be an exception to this although it is not certain whether it accompanied rock forming processes. Epidote which occurs in some thin sections could not be related to deposition of sulphides. Biotite alteration to chlorite-sphene pseudomorphs in a great many specimens of the biotite-feldspar syenite is probably related to pre-ore rock genesis and is not connected to sulphide forming processes. The pervasive kaolinization and abundant sericitization of some plagioclase as well as the replacement of biotite by muscovite may be related to ore deposition but this could not be established either. At least some kaolinization is earlier than plagioclase and so antedates sulphide deposition (Pl. XII B).

The prominent bluish-green to grey-green tint in much of the ore syenite is due to the deposition of a chlorite, pleochroic from dark green to bluish-green to a pale yellowish-green, which has formed by later alterations of sulphides. Its principle occurrence besides in fractures aforementioned is as a rim around sulphides where they are in

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contact with silicates. The fact that this chlorite is of secondary post ore genesis does not reduce its value as an indicator of areas where sulphides have been deposited.

RELATION BETWEEN GRAIN SIZE AND MINERALIZATION

Much of the host rock close to zones with massive sulphide mineralization consists of orthoclase feldspar with varying amounts of very fine grained plagioclase along grain contacts or as wedge to ribbon like strips between orthoclase grains (Pl. I A, V C). These small grains are absent wherever massive sulphide deposition has occurred (Pl. XIII B). The massive sulphides are almost invariably in contact with potash-feldspar, except where remnants of plagioclase exist along the sulphide feldspar contact (Pl. XIII A). The massive sulphides are spidery in shape with curved to wedge shapes. Generally, these sharply tapering wedges end against narrow clusters of fine plagioclase which occur between the coarse feldspar grains (Pl. XIII B). The absence of fine feldspar where sulphides are massive and the similarity of shape between the sulphides and zones of fine plagioclase are so wide-spread that it must be concluded that the sulphides replaced fine plagioclase.

Deposition of the sulphides may well have been a function of feldspar composition and grain size which would control permeability. The replacement could take place more easily with fine material in which surface area is more important than unit mass. Extremely fine material would probably be less permeable than the coarser material due to friction caused by excess of surface area. Fluids percolating through a rock consisting of a mixture of coarse and fine material would be relatively concentrated in the finer grained zones and if the composition of the finer material is appropriate it is likely that a replacement by sulphides would occur in such places.

RELATION BETWEEN THE COMPOSITION OF THE

FELDSPAR AND MINERALIZATION

Most of the plagioclase of the type postulated to have been replaced is too fine grained to be identified with precision on a single axis stage. Application of the Fedorov technique on a universal stage or the use of an electron probe might permit precise identification of the fine plagioclase. Grains large enough for interference figures have a composition between AN-10 and AN-20. Comparison of plagioclase composition and assay values (Figs. 6 and 14, 7 and 15, 8 and 16) shows that there is a tendency for higher values to occur in rocks with a low plagioclase to orthoclase ratio, and in which plagioclase is more sodic, as in hole 106. Contradictions to this generalization occur as at G-101 and 104. The range of plagioclase is sufficiently narrow that

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generalizations on the basis of plagioclase composition are unwarranted. It is a line of investigation which should be pursued preferably by a detailed study of an underground exposure where rocks are fresh. This would permit detailed sampling over the short intervals of the ore syenite where structures can be observed and where specimens can be selected from a particular rock type even though the zone be mixed.

It is quite possible that some of the anomalies in the relation between sulphide replacement and composition of the plagioclase result in the existence of two plagioclase types, one of which is coarse and identifiable and the other very fine and not identifiable. In places where there were clearly two plagioclase types, attempts were made to identify both, but were not always successful.

A general concordance between higher grades of molybdenite and medium grain ore syenite is shown by the core logs. See Appendix ii, pp. 1-11. The very coarse rocks contain a higher proportion of potash feldspar and also frequently a higher proportion of calcite. They would be high in potash, moderately high in calcium and very low in soda. On the other hand, the intermediate size rocks contain less potash feldspar, some calcium and much more soda and it is these which have the higher assay values.

<div align="center">ROCK GENESIS</div>

BIOTITE-FELDSPAR SYENITE

There is little in the mineralogy of the biotite-feldspar syenite except for a frequent abundance of calcite which is as much a part of the rock as the feldspar and biotite, to give a reliable clue to its origin. The lack of zoning in the plagioclase, the anhedrism of all minerals, and the replacement textures do not preclude the possibility of an igneous origin. If the rock is a very old one, that is earlier than Stage I folding, its mineralogy would be a function of its composition and history, neither of which is a guide to origin. Clusters of sub-rounded zircon grains, so abundant in many specimens of the biotite-feldspar syenite, are in a different category. The sub-rounded character of the grains could be attributed to re-solution in a melt during a temporary temperature increase in the environment of a cooling magma. The physical distribution of the zircon in clusters of fifty to several hundred grains is another matter. It is difficult to imagine how such assemblages could be formed during the intrusion of the melt. On the other hand, it is easy to understand how zircon grains would be deposited in certain strata and relatively concentrated in certain parts of the strata during sedimentation. Moreover, sedimentary processes offer a better explanation for the sub-rounded to rounded character of the zircon grains.

The abundance of calcite which appears to be primary is equally difficult to explain in an intrusive rock. Any reasonable explanation

must account for the calc-silicate layers up to several feet thick which commonly occur in the biotite-feldspar syenite (App. i, p. 27, G-108, 3 feet). These layers are not only parallel with foliation, they are also parallel with minor changes in composition within the biotite-feldspar syenite. Finally, there is also the manner in which the biotite-feldspar syenite grades to a biotite-amphibole gneiss or schist south of station No. 5 (see Wilson, G. A., 1965, Geology Report, Copeland Mountain Property, Fig. 5). All of these features are consistent with the theory that a pile of sedimentary rocks was subjected to regional metamorphism.

Nearly all of the specimens from the biotite-feldspar syenite include 2 "S" planes displayed by orientation of biotite (Pl. VII B; VIII A,B; X A,B). One is always more perfect than the other. It is likely that the less perfectly defined plane is related to the first period of folding and the more perfect "S" plane the second folding. Whatever the origin of the rock unit which is now the biotite-feldspar syenite, it must be older than Stage I folds.

ORE SYENITE

Problems of genesis of ore syenite are similar to those of the biotite-feldspar syenite. The mineralogy of the ore syenite is similar to that of the biotite-feldspar syenite (Tables I, II and III) except for the biotite which is sparse to absent. Zircon tends to be in fewer larger tectragonal euhedral crystals instead of as aggregates of small grains though both types occur. The euhedral tectragonal grains of zircon with shadowy rounded zircon grains within them are probably porphyroblastic grains produced by enlargement of single grains during metamorphism.

In drill core on a macro scale, much of the biotite-feldspar syenite includes layers of ore type syenite either pegmatite or aplite. These layers range from less than 1 inch to 2 or 3 feet thick and they tend to occur in the hinges of folds. Contacts between ore type syenite and biotite-feldspar syenite are sharp to gradational. The contacts generally conform to foliation but in some places they cross it at a flat angle and in such places there is commonly a relict foliation in the ore type syenite. In some instances, the ore type syenite consists of aplitic alteration of biotite-feldspar syenite in 1/8" to 1/4" bands which have a rectangular pattern. Another variation involved the development of coarse feldspar probably microcline, in the biotite-feldspar syenite near the ore syenite, perhaps from recrystallization of orthoclase lenticles. One of the most obvious changes in the transition zone occurs in biotite which changes in colour from green in the biotite-feldspar syenite to brown in the transition zone and is absent in the ore type syenite.

One such contact zone was sampled in hole GU-1 in the interval 25'5"-26'1", a, b, c (see ap. ii, pp. 30-33). Orthoclase proportion decreases slightly from the biotite-feldspar syenite to the aplite syenite,

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plagioclase feldspar content increases significantly and gets progressively more sodic from AN20 $\pm$5 in the biotite-feldspar syenite through AN16 $\pm$5 in the transition zone to AN12 $\pm$5 in the aplite syenite. The most significant change occurs in biotite which is dark brownish-green and only slightly altered in biotite-feldspar syenite (Pl. VIII A,B). Five-sixths of the biotite in the transition zone is altered to muscovite-chlorite-sphene-epidote-iron oxide pseudomorphs, which have a brown colour. Biotite is absent in the aplite syenite although masses of secondary minerals pseudomorphic after biotite comprise a small proportion of the rock. In addition, there are masses of feldspar with abundant inclusions with an obscure origin. They seem to be oriented to about the same degree as the biotite and to comprise a slightly smaller proportion of the rock than biotite in the biotite-feldspar syenite. Moreover, they are only slightly smaller than most of the biotite. These factors taken together seem to warrant the inference that the masses of inclusions are the end result of an alteration process which has eliminated biotite from the biotite-feldspar syenite and produced an aplite syenite. Similar transitions occur in specimens in G-103, at 58' and G-105 at 46'3". All of this establishes that at least the outer parts of the ore syenite and the narrower bands of aplite and pegmatite syenite are derived from biotite-feldspar syenite. It does not establish that the main mass of ore syenite is derived from the biotite-feldspar syenite or from a common parent. The intimate mixture of the biotite-feldspar syenite in the ore syenite zones does help to establish the origin of the ore syenite. Each rock type, in marginal zones, contains much of the other in a way which is unlikely to have been caused by folding of contact surfaces during intense deformation. This mixing must be attributed to the action of hydrothermal solutions on the biotite-feldspar syenite, or to recrystallization of the biotite-feldspar syenite in an appropriate environment. Finally, any hypothesis for the genesis of the ore syenite must account for the existence and form of the high proportion of carbonate, generally calcite, in many ore syenite specimens. Intrusive mechanisms don't explain its presence. It is unlikely that the ore syenite originated through processes other than by alteration of sedimentary strata forming a part of the same series as the biotite-feldspar syenite and other metasediments.

The time of formation of the ore syenite is less in doubt than the origin. Two kinds of deformation are visible in the feldspars. The earliest, known here as dilational, is common to the orthoclase and absent in plagioclase. It occurs as a depositional and replacement perthite in which the plagioclase first appeared in fractures with one to three directions in adularia and microcline (Pl. I, II). Strain of a similar age may exist as twinning in plagioclase but is unlikely because this stress is essentially a dilational one which produced an increase in volume. A strain expressed by twinning could not be a response to a dilational stress. It is concluded, therefore, that this stress is later than the ore syenite and earlier than the plagioclase in it.

A second type of stress occurs but is rarely identifiable in the plagioclase, although its presence is suspected in many of the

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specimens. Plagioclase is rotated and deformed probably at high temperature and pressure. The strain is expressed as shadowy swirls or arcuate streaks of rod-shaped inclusions. There is an altered zone around many grains which may have been ground plagioclase along boundaries. Grains are broken and displaced in other places (Pl. III B). Distinct fractures along which such microfaults have occurred are never found. The only explanation is that the component mineral grains of the rock moved relative to one another and that larger tabular grains having been unable to rotate fractured thus forming equant grains which could rotate. This type of deformation is recognizable in plagioclase because it is twinned. It probably occurs in potash-feldspar as well but is not recognized due to the absence of reference planes such as twin planes. Slight differences in orientation of adjacent grains of potash-feldspar occur and are probably due to the same process (Pl. I A,B).

A third type of deformation is represented by minor kinking of plagioclase, microfaults, some of which cross more than one grain, and by bending of mica in the biotite-feldspar syenite. At least some of this last deformation seems to be of a brittle type and is less intense than the two mentioned above. It is not known whether it represents a late stage of deformation contemporary with the rotational type of folding but is in samples situated near the inflection points rather than near hinge lines of Stage II folds.

In any case two periods of deformation exist in the ore syenite. The earlier is probably associated with Stage I folds and the later with Stage II folds. Hence, a part of the ore syenite as it is now constituted must be older than Stage I folds. Hydrothermal activity which produced the plagioclase in the microcline and adularia perthite probably occurred late in Stage I folding or soon after it was over. Much of the plagioclase probably was introduced at this time. Deformation of plagioclase attributed to Stage II folds establishes the age of the ore syenite as pre Stage II.

If further proof that the ore syenite is earlier than Stage II folds is required, it can be obtained from a brief perusal of Figures 2, 3, 6, 7, 10, 11, 14, and 15. Two alternate philosophies have been used to explain the shape of the ore syenite. One is that it was emplaced prior to Stage II deformation and was involved in Stage II folding. The other is that it was intruded late after Stage II folds and was faulted to its present shape. It may be faulted but late faults did not determine its present configuration. The second theory is contradicted by mineralogy and by obvious metamorphic history of silicates and sulphides in the ore syenite. Whatever the genesis of the ore syenite may have been, it must have preceded Stage II folding.

The argument, that all the strain illustrated in feldspars and sulphides is of a brittle nature and therefore can't be related to the known stages of deformation, because they were of a plastic nature, lacks validity. There is no doubt that rock deformation was at least partly plastic. This is what may be expected of a rock composed of several

minerals each of which has its own peculiar response to stress. The minerals themselves are not amorphous and can't be expected to behave as though they are. The individual silicate minerals must express strain as the brittle materials. If they didn't, cataclastic textures, mylonites, and flaser rocks would not exist.

The carbonate in the rocks of the suite being soluble and soft and having a tendency to recrystallize or twin easily would behave differently from the brittle silicates and sulphides. Moreover, the ease with which the carbonate adjusts itself to pressure differential or otherwise would almost certainly affect the behaviour of the rock of which it comprises a part. Changes in shape could be accomplished without fractures or severe milling and therefore without the subsequent plagioclase replacement which seems to have been necessary for sulphide deposition. This may account for the generally low but in places erratic distribution of sulphides in rocks with a high proportion of carbonate.

TIME OF MINERALIZATION

The known pattern of deformation in the area together with the character and deformed condition of the sulphides enable us to establish, to a reasonable degree, the time of mineralization. The colloform nature of most of the pyrite has been well illustrated (Pl. XIV B; XV A,B; XVI A,B; XVII B,C; XX B). This pyrite can have had one of only two origins. Either it was inherited from an earlier sedimentary rock or it was deposited from a colloidal solution, in spaces created in the rock by stresses, or by solution of an earlier material, perhaps carbonate. Inheritance from an earlier sediment is unlikely but possible. Deposition from solutions in rock spaces is probable. Whether the spaces were created during stress or by solution could be determined if the original shape of the colloform masses were known. A stress condition should produce a space with a fairly regular shape. On the other hand, solution of a mineral such as carbonate should produce a cavity shaped like the parent mineral. The colloform pyrite is nearly all of irregular shape but much of it has been so deformed that their original shape can't be determined directly.

The shape of the banding does provide a clue to the shape of the cavity that was filled. Both regular (Pl. XIV C, XV A) and irregular (Pl. XV B) nodules appear to have existed. Plate XVI A,B probably represents a regular nodule deposited in a solution cavity. Whichever process is responsible or dominant, the carbonate in the ore syenite undoubtedly neutralized the sulphide bearing solutions and thereby established a chemical environment in which colloidal precipitation was likely.

The contribution of stresses to mineralization and the replacement of plagioclase by the sulphides places an older limit on mineralization. It must be younger than the first stage of folding. The extensive crushing, bending and kinking of the sulphides places a younger limit on mineralization. It must have preceded the Stage II folds.

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The fractures which cross all sulphides and silicates and which are frequently sub-parallel are probably related to late deformation, perhaps Stage III folds which some workers (Fyles, J. T., among them) consider to be the result of a milder phase of deformation than the Stage I and Stage II folds.

The time of mineralization between the Stage I and Stage II folds explains the absence of veins and host rock alteration related to sulphide deposition. Veins or breccia zones which may have been sites of deposition of sulphides were obliterated during Stage II folding by grain rotation and/or recrystallization. It is likely that the U shapes which occur in molybdenite G-102, 111', 3"-4", are deformed parts of veinlets. Much of the original character is now eliminated.

It is inconceivable that sulphides can have been deposited in amounts found in the Glacier Zone without some host rock alteration. Its absence must be due to post mineralization metamorphism and recrystallization and the only known agents which could have done it are the stresses involved in Stage II folding.

CHEMICAL SYSTEM

Several important questions regarding the chemistry of the genesis of the rocks in the system and of the deposition of the molybdenite remain unanswered. One enigma is the high proportion of potash in all the members of the series except some of the aplite in the ore syenite where potash minerals have been replaced. Was the sedimentary series abnormally rich in potash or was there a stage of potash metasomatism prior to Stage I folding?

Another puzzling feature is the absence of calcic andesine, labradorite and bytownite in rocks in which there is much available calcium in calcite. This must be due principally to a deficiency of silica and a surplus of potash. High confining pressures which prevented the escape of CO_2 may have kept some Ca tied up chemically so that it was not available for plagioclase feldspars. The general surplus of potash is indicated by the lenticles of potash feldspar in the biotite-feldspar syenite and in the biotite which may also have contained considerable Ti.

The metasomatic solutions which produced the sodic plagioclases must have been rich in soda and also somewhat deficient in silica. This prompts the question whether the nepheline in part of the syenite in the core of Copeland Ridge is the same age as the plagioclase in the Glacier Zone.

The fact that plagioclase forming solutions replaced parts of the coarse orthoclase indicates that potash metasomatism or recrystallization preceded the soda metasomatism.

Replacement of feldspars by sulphides, either iron or molybdenum, should have released silica into the system. Where did it go? Did it combine with calcium released by the attack of the same solutions on calcite to form more calcic plagioclase? If it did, it could explain the apparent reverse zoning seen on some plagioclase (Figs. 6-9).

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The anomalies in the chemical system have to be explained by silica deficiency and potash surplus under high pressure. A surplus of alumina without a silica deficiency would surely have resulted in the development of distinctive minerals which are absent. An alumina surplus with a silica deficiency would have resulted in the development of certain other equally distinctive minerals which are absent.

The absence of alteration of the host rocks by the mineralizing solutions has been explained by post deposition metamorphism of the Stage II folding.

GUIDES TO MINERALIZATION

The most important item in a search for mineralization in this suite of rocks is the occurrence of ore syenite.

The occurrence of medium grained rock either pegmatite with a high proportion of granular interstitial plagioclase or of aplite with a granular texture is important within the ore syenite.

None of the consistently high grade material contains either the high proportion of coarse mica or calcite. Perhaps the presence of such minerals permits the stress to be relieved without producing fractures. The age of the mineralization between Stage I and Stage II folds means that Stage I folds may have been important structural controls and that mineralization may be concentrated in particular zones such as hinge lines. The relative importance of antiform and synform axes can't be assessed fully. Both should have been equally satisfactory locii for the grinding which was a prelude to plagioclase replacement. The antiforms being enveloped in a biotite-feldspar syenite or its ancestor which would fracture less easily may well have been the most likely habitat of mineralization in this area. The importance of the Stage II folds lies principally in the shape they have given the ore bodies and the consequent effect on mining methods.

Few indicators of ore seem to exist. Post ore alteration of sulphides which has imparted the characteristic blue-grey to green-grey tint to the ore syenite should occur in the vicinity of ore. It is not known how far from mineralized zones this character will extend but it should be far enough to indicate the presence of ore not exposed on the surface. The particular variety of chlorite which is responsible for the colour should also occur in fractures in adjacent strata.

Structure of the syenite and hence locations of fold axes can be recognized by field mapping or laboratory studies on oriented specimens.
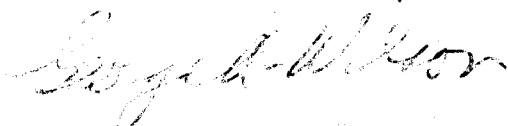
Appropriately fractured zones in the ore syenite can be recognized visually but the composition can't be. This can be determined in

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the field by staining methods. It is recommended that one of the two feldspar staining methods outlined in Appendix iii be adopted as a field procedure. Because some of the textures seen in hand specimens are somewhat deceptive, it would be desirable to have a microscope in the field and to cut thin sections for immediate examination if it is warranted. The microscope should be equipped with an objective lens suitable for viewing uncovered specimens so the staining may be combined with petrology.

As a phase of future study, oriented specimens should be selected at short intervals across not less than two intersections of mineralized ore syenite. If adequate structural data can be determined on a macroscopic scale the oriented sections should then be treated as ordinary petrographic specimens. If adequate structural data can't be obtained on a macroscopic scale then it would be desirable to do petro-fabric work on the thin sections.

Qualitative field geochemical methods followed by quantitative methods should be applied as field procedure.

Finally terminal moraine, particularly if it is iron stained, should be carefully searched in areas where sub-crop of ore type syenite beneath glaciers or moraine is suspected.

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