

GEOLOGY AND MINERALIZATION  
IN THE LORRAINE PROPERTY AREA,  
OMINECA MINING DIVISION,  
BRITISH COLUMBIA

by

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B. Sc., Seoul National University, 1963

A THESIS SUBMITTED IN PARTIAL FULFILMENT  
OF THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF SCIENCE

in the Department  
of  
GEOLOGY

We accept this thesis as conforming to the  
required standard

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THE UNIVERSITY OF BRITISH COLUMBIA

April, 1968

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## ABSTRACT

The Lorraine property area occupies the north eastern part of the Duckling Creek syenite located within the central part of the Hogen batholith in British Columbia. The rocks of the Lorraine property area consist of "metasomatic syenites" or "fenites" formed by the metasomatism of the fractured Hogen diorite. They are believed to have been derived from a hypothetical alkaline magma formed beneath the diorite. The residual magma differentiated from the alkaline magma, produced late dykes and hydrothermal fluid.

A K-Ar date, 170±8 m. y. (Lower Jurassic) may correspond to both the minimum age of the fenites and the maximum age of the sulphide mineralization at the Lorraine property. Also, the age may mark the time point dividing the first division and the second division of the Hogen batholith. ✓

The characteristic minerals of the successive stages of alteration are 1. biotite, 2. albite, 3. orthoclase, 4. quartz, 5. sericite, 6. chlorite, and 7. epidote. The altering fluid contained concentrations of soda, potash, silica, hydrogen sulphide, water, and a minor amount of lime.

The primary sulphides are bornite, chalcopyrite, and pyrite. The Lorraine deposit possesses no noticeable gossan, but contains secondary copper minerals such as covellite, chalcocite, azurite and malachite. The deposit is divided in

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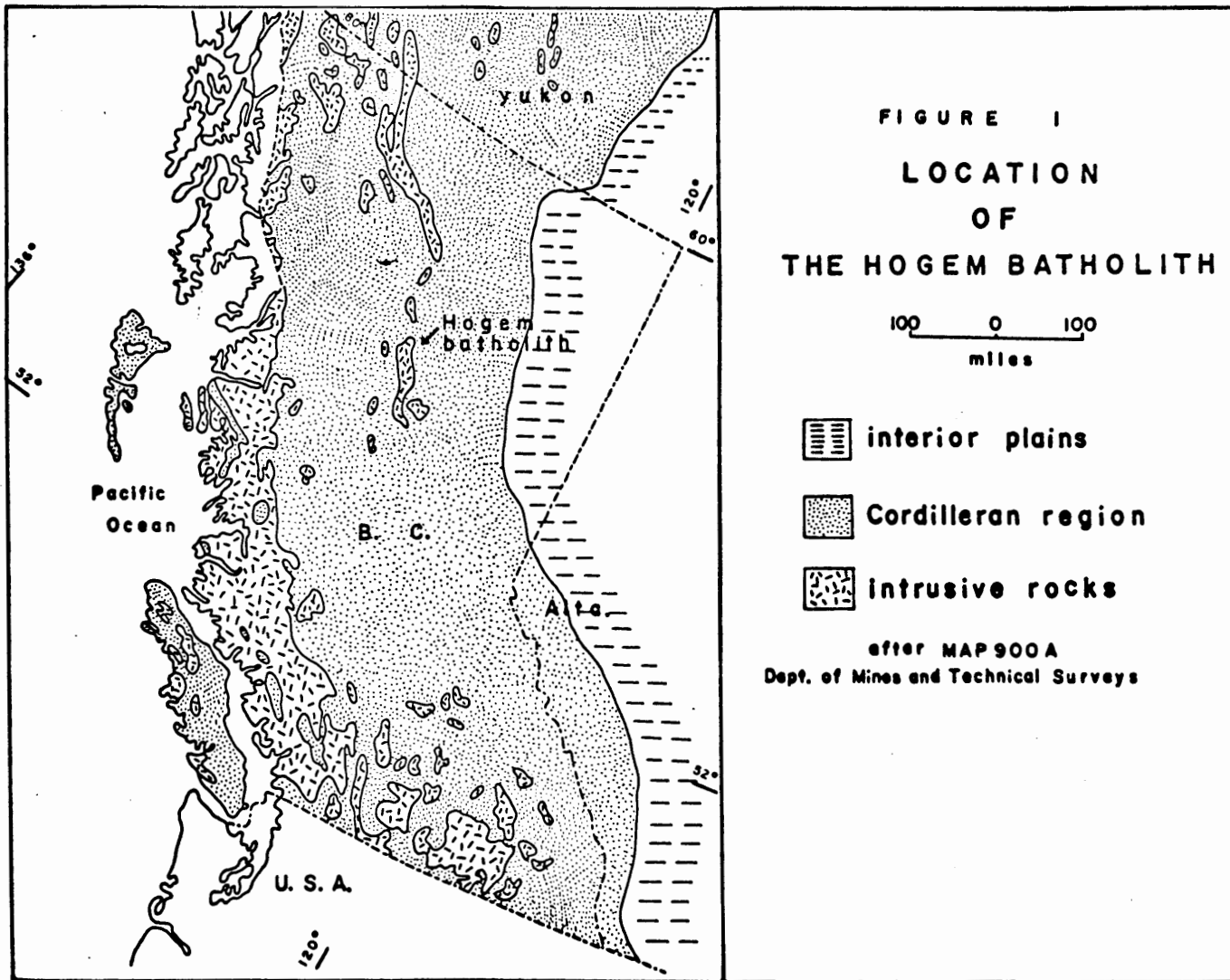
GEOLOGY AND MINERALIZATION  
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BRITISH COLUMBIA

INTRODUCTION

Scope of the Study

Early geological work indicated the existence of several low grade copper deposits in the vicinity of the Lorraine property in north central British Columbia (see Figure 1, p.27). It was suggested by some investigators that the deposits are of the "porphyry copper" type. Encouraged by the discovery of several deposits peripheral to the Lorraine property and by the type of mineralization, geologists of Kennco Explorations(Western) Limited carried out geological investigations over a period of several years. In the summer of 1966, Kennco Explorations(western) Limited maintained a camp several miles northeast of the property.

During that time, the writer of this paper took an opportunity to combine the previous geological study of the Lorraine property area with the results of his own field investigation, and he presents as a thesis an account of this work along with the results of his laboratory investigations.



The writer has coordinated mineralogic, petrologic, and structural evidence in an attempt to unravel the geological history of the thesis area (the Lorraine property area) and to shed some light on the origin of the mineral deposit. The petrologic and structural study deals with the geological setting of the Lorraine property in the Hogon batholith. The petrologic study describes the rock types and their alteration. The mineralogic investigation has been a qualitative study principally of the ore-forming minerals.

References used in this thesis study are indicated by numbers corresponding to those given on individual references in "Bibliography" (see pp. 78-81).

#### Methods of the Study

To survey the Lorraine property area of about 6 square miles, two methods of field mapping were chiefly used; tape and compass traversing, and photogeology (8, 23, 29). The geology was mapped at scales of 100 feet and 750 feet to 1 inch.

Laboratory research includes the study of a total of 289 hand specimens. Sixty five thin sections were made for examination under polarizing microscope (11, 12, 51, 55). From the point-counts, the modal compositions were calculated and averaged for the thin sections chosen as representative

of each rock variety found in the thesis area. The thin sections and rocks under examination were stained with concentrated nitric acid prior to investigation to avoid confusion in distinguishing between potash feldspar and unstrained plagioclase. The point-count was done with grids of various spacing. The point distance chosen was larger than the largest grain fraction that is to be included in the analysis, following the idea of Vander Plas and Tobi(50). Using the chart for judging the reliability of point counting results formulated by the same authors, the number of points counted allowed more than 95 percent confidence.

The composition of the potash feldspars(cryptoperthites) could be determined with X-ray diffractometer with a goniometer head(9 , 30), following Sellmer's(41) detailed outline of the original procedures. The angle between the peak of(101) reflection of potassium bromate( $KBrO_3$ ) and the peak of (201) reflection of alkali feldspar was measured to get the difference,  $2\theta$  which is directly proportional to orthoclase content. Parsons' graph(33) was used to determine the composition.

Forty five polished sections were made for the mineralographic examination. The ore minerals were identified by the examination of physical and optical properties, and etch test, using polished sections(7, 14, 39, 42, 49). The X-ray powder photograph method(9 , 30) was also used.

Potassium-Argon dating technique was used to obtain an absolute age from the Lorraine property area(13).

#### Previous work

The Lorraine property was originally owned by Consolidated Mining and Smelting Company. They did a small amount of surface work, but later dropped the property. In 1948, Kennex Limited carried out mapping and surface sampling. In 1949, they also carried out diamond drilling on the Lorraine deposit(19, 44). In the same year, this area had been mapped by Geological Survey of Canada(1). In 1961-2-3, Kennco Explorations(Western) Limited used geochemistry, geophysics and diamond drilling along the valley southwest of the main mineral body. They also did a small amount of surface sampling and trenching(44).

#### Location and General Character of the Thesis Area

The thesis area lies within the Omineca Mountains in north central British Columbia at latitude  $55^{\circ}56'N$  and longitude  $125^{\circ}26'W$ (see Figure 2, p. 8). Germansen Landing is 25 miles east of the thesis area. Final access to the thesis area is by packhorse trail from the mouth of Duckling Creek 30 miles northwest of Germansen Landing, a distance of 18 miles. The thesis area is also easily accessible by helicopter, with numerous alpine meadows providing landing places



(see Photograph 1a, p.82).

The thesis area consists of rugged, mountainous country and is mostly above a tree line which is at 5,000 foot elevation. A 6,700 foot mountain rises as the highest one from which a few major ridges branch away(see Photograph 1b, p.82). Accessible outcrop is almost continuous in the thesis area. The main mineral body occurs on a northwest-trending ridge of the 6,700 foot mountain. The southwest side of this ridge is steep, with a slope of about 35 degrees, that is close to the angle of repose. Much of it has an unstable covering of talus blocks(see Photograph 2, p.83). This slope is dissected by northeasterly-trending gullies, which act as funnels for rock slides and contain small streams during the spring thaw. At the base of the slope, there is a cliff which is apparently a fault scarp steepened by glacial action.

The general area is known to have been subjected to continental glaciation during the Pleistocene Epoch(1). The glaciers carved V-shaped valleys, and mantled valley floors with moraine. Local ridges in recent cirque floors mark resistant rock formations that now form topographic highs.

#### Acknowledgements

The writer wishes to thank Dr. K.C. McTaggart and Dr. V.H. White who suggested study of the area and also provided valuable advice and help during laboratory study and

encouragement in the preparation of the manuscript. Thanks are due also to Dr. W.H. Mathews who gave much needed help, and Mr. Montgomery who was very helpful in preparing thin sections.

The writer is deeply indebted to Dr. J.A. Gower and Mr. R.L. Stevenson for permission to use geological data from field work and Keneco reports, and for their advice in planning this study. I also acknowledge gratefully their financial aid for field mapping and laboratory study. Acknowledgements are due also to many geological investigators and authors from whom the writer obtained through their publications much information needed in this study.

## REGIONAL GEOLOGY

The Lorraine property area is situated within the roughly central part of the Hogen batholith which is the largest body of the outcropped Omineca batholithic complex in north central British Columbia(see Figure 2, p. 8 ). The Hogen batholith occupies a relatively small part of the Western Cordillera (see Figure 1, p. 2 ). The following description of the regional geology is based largely on the papers of the previous investigators(1, 17, 19, 20, 26, 28, 35, 36, 44, 53) and partly supplemented with the writer's own observations.





FIGURE 2

REGIONAL GEOLOGY

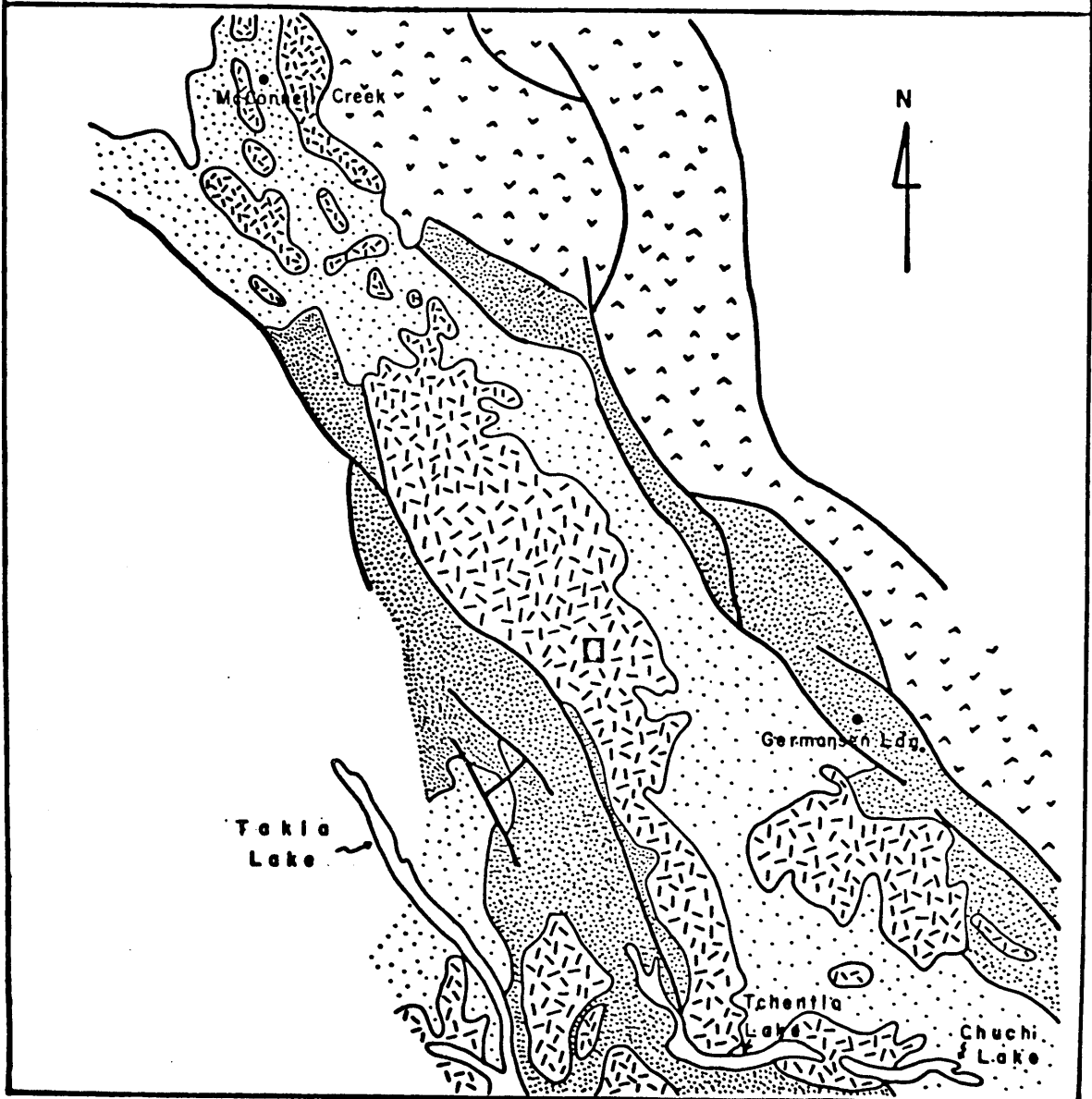
Hogem batholith area



after G. S. C. map 932A

-  Omineca intrusions
-  Takla group
-  Paleozoic rocks  
(Cache Creek group)
-  Wolverine complex

-  fault
-  thesis area



The eastern part of the Cordillera in British Columbia consists of miogeosynclinal sediments including mainly Paleozoic carbonates and Mesozoic clastic wedge deposits. The southern part of it involves an earlier, middle Precambrian geosynclinal sediments known as the Purcell Series. During late Cretaceous and early Tertiary time (Laramide or Rocky Mountain orogeny), all the previously described rocks were deformed. The orogeny created lengthy folds and thrusts with possible décollement over the basement(20).

West of the Rocky Mountains, eugeosynclinal sediments and volcanics, mainly of middle and late Paleozoic and early Mesozoic ages, constitute the supracrustal rocks of the belt. These were much deformed and invaded and metamorphosed by granitic plutons on a large scale during the Mesozoic time (Nevadan or Coast range orogeny).

The climactic evolution of the Cordillera was in the Mesozoic. Orogeny in Mesozoic time in the Western Cordillera might be termed continuous-intermittent throughout an age-range of probably 150 million years. It is generally agreed that the span of emplacement of granitic rocks is from the late Triassic to the Cretaceous.

In the previously eugeosynclinal areas toward the west, the largest plutons were formed in the Coast Crystalline Belt of the Western Cordillera in British Columbia. Deeply

down-folded, supra-crustal rocks of huge thickness suggest that the granitic material was derived from supra-crustal rocks remobilized by melting. Nevertheless, other smaller plutons occur to the east and found their way into the present loci through basement rocks.

Potassium-argon dates mainly from the southeastern part of the Western Cordillera in British Columbia, combined with stratigraphic and structural evidence from the northeastern part indicate "pulsatory" plutonism at intervals of crudely 30 million years since approximately 200 million years ago, culminating at the time of the late Cretaceous. In connection with isotopic dating, White(53) emphasized accurate and careful application of the isotopic dates to geological interpretation, particularly in the Western Cordillera as in the following quotation; "geochronological methods undoubtedly will prove to be powerful additions to the geologists' repertoire, but particularly in the Cordilleran region where metamorphic and plutonic events are closely spaced and superimposed they must be applied with great care and results interpreted with caution. However, the writer would agree that wholesale publication of lists of isotopic ages, with no indication of the probable amount of "younging" due to argon loss and no confirmation from co-magmatic minerals, may well lead to chaotic concepts of Cordilleran tectonism". It is also known that smaller granitic plutons were emplaced in various Tertiary ages as young as Miocene.

Most plutons are structurally conformable with surrounding rocks but some lie athwart and cut the structural grain. Still others were forcefully intruded with the appearance of deformed foliation in older rocks or protoclástico margins. The composition of the granitic rocks varied with time. In the north, quartz diorite in the early Mesozoic trends by differentiation toward leucogranite in the Tertiary. Likewise, hypersthene-monzonite in the late Paleozoic was succeeded through a quartz-diorite-leucogranite series in the Mesozoic by largely syenitic rocks, monzonite and quartz-monzonite in the Tertiary in the south(17, 20). Among the granitic rocks of the Coast Range Belt, diorite and quartz-diorite are more abundant in the western part and biotite-granodiorite and quartz-monzonite in the eastern part. Most of the rocks in the interior belt contain hornblende and much more potash-feldspar than the rocks found on the western side of the Coast Range Belt. The Omineca intrusion is considered to be a part of the interior belt but appears not to fit this generalization, being potash-poor. (not to my knowledge from Nadin takes to Oshinka) JH/7.

The Shuswap and Wolverine metamorphic complexes lie between the miogeosynclinal and eugeosynclinal areas in the Western Cordillera of British Columbia. They were interpreted by earlier geologists as an Archean protaxis separating the two prescribed geosynclines(17). Stratigraphic criteria prove that some of the complexes are older than less metamorphosed Mesozoic or Paleozoic rocks. However, many isotopic ages down

to 150 million years or less suggest a prolonged metamorphism.

The rocks in the vicinity of the thesis area range in age from late Precambrian(?) to Cretaceous. The oldest group of rocks in the region is known as the Wolverine complex which lies in the north eastern part of the region. The complex consists of granitic gneiss, granodiorite, pegmatite, quartzite, micaceous, chloritic, and garnetiferous schists, and crystalline limestone. These rocks probably lie unconformably below the Paleozoic rocks. (ref. Armstrong?)

Paleozoic rocks of Pennsylvanian(?) and Permian age, known as the Cache Creek group, consist essentially of a thick assemblage of limestone, chert, argillite, slate, greenstone and derived schists with minor amounts of greywacke and conglomerate.

Upper Triassic and Upper Jurassic(?) rocks known as the Takla group comprise a series of interbedded volcanic and sedimentary rocks, consisting of andesitic and basaltic flows, tuff, breccia and agglomerate, shale, limestone, greywacke, and conglomerate and coal.

The Omineca intrusions are the most important intrusive masses in the region and bears a direct relation to the rocks outcropping in the thesis area. These bodies vary in composition from ultrabasic to acidic.

The Hogen batholith is the largest known body of the Onineca intrusions (see Figure 2, p. 8). The Hogen batholith extends from Chuchi Lake into the McConnell Creek area. It is a composite body comprising a wide range of rock types, and contains many minor intrusive bodies within the main mass. It probably represents a prolonged period of igneous activity by a differentiating magma. Stocks, dykes, and sills, catellitic to the Hogen batholith are abundant in the surrounding Takla group and late Paleozoic rocks. All are relatively small.

The intrusive rocks composing the Onineca intrusions or the Hogen batholith have been classified into two divisions. The first division, oldest, comprises chiefly mafic rocks containing little or no quartz. This division consists of pyroxenite, biotite-pyroxenite, hornblendite, meladiorite, hornblende-or pyroxene-diorite, monzonite and syenite and syenite fenite. These rocks are believed to be older than those of the second division. In places, the rocks of early age are found to have been intruded by the rocks in the later age. The rocks in the first division comprise about one-sixth of the exposed area of the Hogen batholith and the related stocks. The second division, younger, consists of rocks that are light in color with less than 30 percent dark minerals and with a significant amount of quartz. Granodiorite, quartz-diorite and quartz-monzonite are the predominant rock types in this division. Included in this division are true granites. Numerous, small irregular bodies of leucogranite, alaskite, and quartz-microperthite pegmatite and aplite cut all the other

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rocks.

Two main syenitic bodies, belonging to the first division, occur in the Hogen batholith north of Chuchi Lake and northwest of Duckling Creek, respectively (see Figure 3, p. 15). The "Chuchi Lake syenite" approximately 30 square miles in area, intrudes early phases of the first division of the Hogen batholith. The syenite is a medium- to coarse-grained rock, in part porphyritic. Armstrong's study(1) of five thin sections revealed that some parts of the Chuchi body are found to be true granite in composition which might have been formed by further differentiation of the Chuchi syenite magma. The presence of quartz also indicates that the Chuchi Lake syenite magma was saturated or slightly oversaturated with silica, and similar conditions hold at the Duckling Creek syenitic complex. X

The predominant rock of the Chuchi syenite body is: quartz(5 %), potash-feldspar(14 %), oligoclase(16 %), microperthite(51 %), ferromagnesian minerals(12 %), and magnetite, apatite and sphene(2 %)(1).

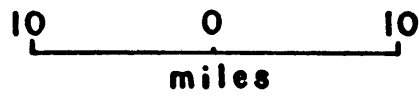
!!  
under saturated!

The Duckling Creek syenite about 15 square miles in area, is the direct concern of this thesis study. The part of the syenitic body underlying the present area is believed to be a complex of "metasomatic syenites" or "fenites". This fenite body has been called the "Lorraine syenite" by some previous investigators. The body shows a transitional contact with the adjacent diorite of the Hogen batholith. A swarm of dykes cut both the "Lorraine syenite" and the diorite. In the

!!  
interpretation before description

FIGURE 3

LOCATIONS OF TWO SYENITIC BODIES  
IN THE HOGEM BATHOLITH



Hogem batholith

after

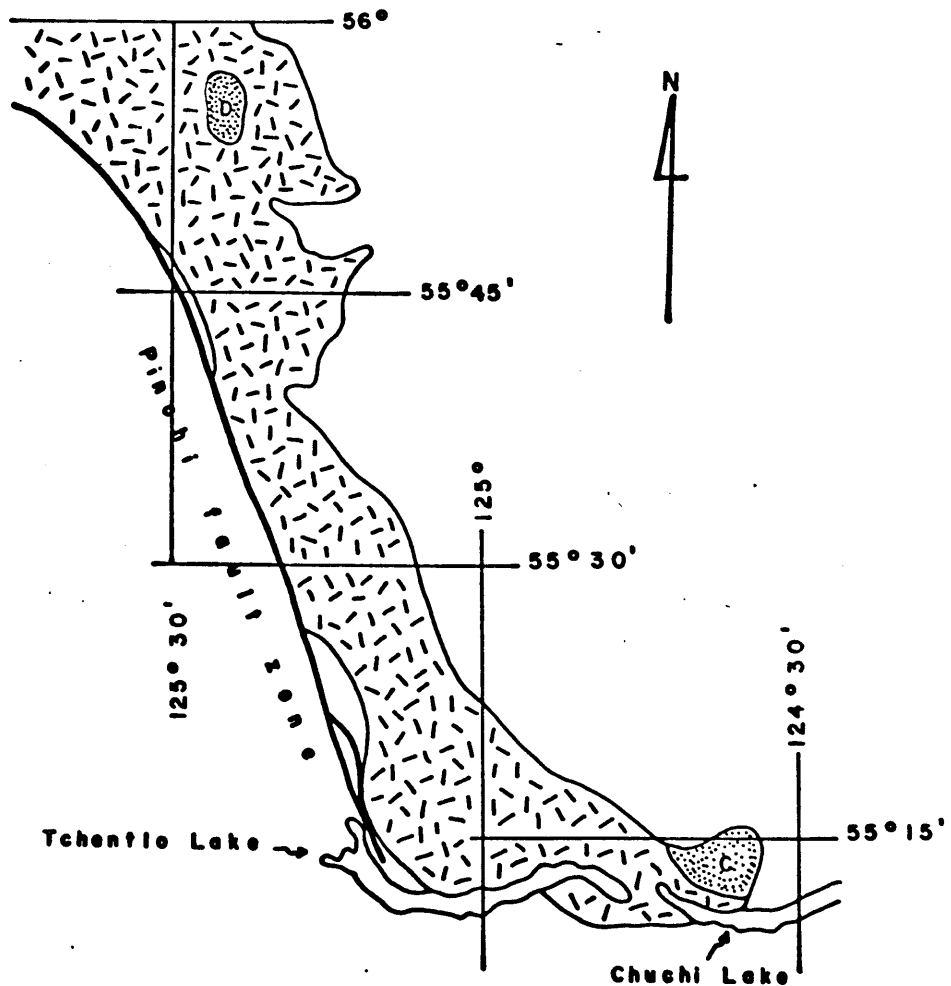


Duckling Creek syenite

ARMSTRONG  
(1949)



Chuchi Lake syenite



syenite cutting syenite 66 ✓

vicinity of the "Lorraine syenite", syenitic bodies of various shapes and sizes also intruded the rocks similar to the "Lorraine syenite". The bodies vary in composition from monzonite to true granite with predominant syenite. They are mostly pegmatitic or porphyritic. Such known syenitic rocks near the Duckling Creek, whether magmatic or metamorphic in petrogenesis, are included collectively in the "Duckling Creek syenite".

Call it DUCKLING CREEK SYENITE COMPLEX.

From the structural relations of the Omineca intrusions with the bedded formations and groups of the region, the age of the Omineca intrusions was placed probably between late Triassic and early Cretaceous time.

? TALLA ?

All the sedimentary and volcanic rocks intruded by the Omineca intrusions have been complexly folded and faulted to a varying degree. General orientation of the formations is in parallelism with the northwesterly-trending long axis of the Omineca intrusions. ✓ The major fault zones also trend northwest. ? The Pinchi fault zone is considered to be the most important one with an overall length of 150 miles. The Pinchi fault seems to mark the site of intense thrust faulting from the west, (ref.) where the Permian sediments in the west were thrust against the Mesozoic volcanics and intrusives. The Omineca intrusions might have been emplaced along the weak zone of the northwest-trending Pinchi fault. Along the Pinchi fault zone, the rocks are intensely sheared and crushed, and hydrothermally altered. Many steeply dipping faults are developed within and adjacent to this zone. These are presumed to join one thrust fault at

depth. The Cache Creek and Takla groups are generally schistose and somewhat altered, with the most intense alteration in the part adjacent to the Omineca intrusive masses.

*hornfels? would what type of alteration?*

Many places in the region are known to contain metalliferous deposits. All of these, excepting the cinnabar associated with the Pinchi fault zone, are believed to have originated from hydrothermal solutions genetically, directly or indirectly related to the relatively late phases of the Omineca intrusive masses.

*(the syenite (end of phase 1) or qtz rich phase 2?)*

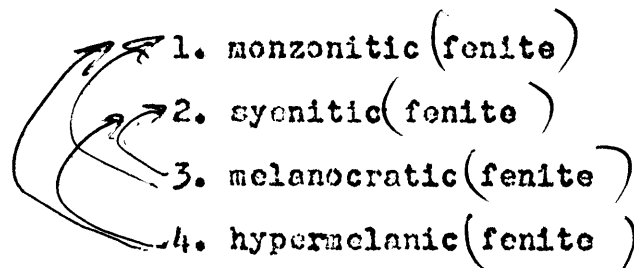
### LOCAL GEOLOGY

#### Petrology

The area mapped in detail lies roughly in the north eastern part of the Duckling Creek syenite. The rocks of the thesis area consist of "fenites" formed by the metasomatism of the Hogem diorite. There are no rocks of magmatic origin, except for the dykes cutting the fenites. The rocks are described here in detail. Four transitional types of fenite can be distinguished on the basis of mineralogy, texture and field criteria in the thesis area. Turner and Verhoogen(47) describe "fenite" as follows; "a kind of alkali metasomatism (fenitization) has commonly affected quartz-feldspathic country rocks (granites, gneisses, sandstones) around carbonate-alkaline

complexes..... The end product is what Brögger termed fenite - a syenitic rock composed of alkali feldspars, [pegmatite], and various introduced minor minerals (blue amphibole, apatite, sphene). It seems that fenitization, advancing ahead of the alkaline or carbonate magma, developed immediately prior to rather than following emplacement of the igneous-carbonate complex".

The different phases of fenite are completely transitional in composition and texture. However, arbitrary demarcation was made among them simply for the purpose of field mapping and description (see Figure 4, p. 19). The dykes cutting the fenites are also widely variable, but generally speaking, well gradational in composition from monzonitic through syenitic up to granitic. All types of rock distinguished in the thesis area are as follows;

- 
1. monzonitic (fenite)
  2. syenitic (fenite)
  3. melanocratic (fenite)
  4. hypermelanic (fenite)
  5. late dykes

1. syenitic pegmatite

2. granitic aplite

also for square of monzo-diorites.

#### Diorite

Diorite of the Hogen batholith forms the country rock which occurs around the thesis area. The description of the diorite is based on the data obtained largely from the

previous investigators(1, 19, 44) and supplemented partly by the writer's observation. The diorite is relatively fresh, greenish grey, medium-to coarse-grained rock composed of plagioclase and orthoclase with dark greenish pyroxene.

In thin section, the diorite consists of quartz(1%), potash feldspar(20%), plagioclase(55%), mafics, mainly augite(20%), and apatite, sphene and magnetite(4%). Flaty grains of plagioclase(oligoclase-andesine) and prismatic grains of augite are interlocking each other with interstitial potash feldspar. The rock exhibits, in places, porphyritic texture and obviously lined structure with a parallel arrangement of plagioclase and augite along a preferred orientation.

*monzo-diorite?*

*// direction?*

#### Monzonitic fenite

With a decreasing amount of plagioclase, the diorite country rock imperceptively grades into monzonitic fenite of the thesis area. The monzonitic fenite is found on almost all sides of the thesis area. The rock also occurs as relict bodies of various shapes and sizes in the other phases of fenite within the thesis area. The coarse- to medium-grained texture in the diorite changes transitionally to become medium- to fine-grained one in the monzonitic fenite. The porphyritic texture with the phenocrysts of the coarse-grained plagioclase obviously seen in the diorite is no longer easily recognized in the monzonitic fenite. The monzonitic fenite exhibits only a weakly lined structure with a subparallel arrangement of elongate feldspar crystals along a preferred orientation.

*been*

This structure is considered to have inherited from the diorite country rock and to have been obscuring gradually by alkali metasomatism. The rock is typically a grey to pinkish grey, medium-grained, massive rock composed mainly of potash feldspar and plagioclase with a subordinate amount of mafics.

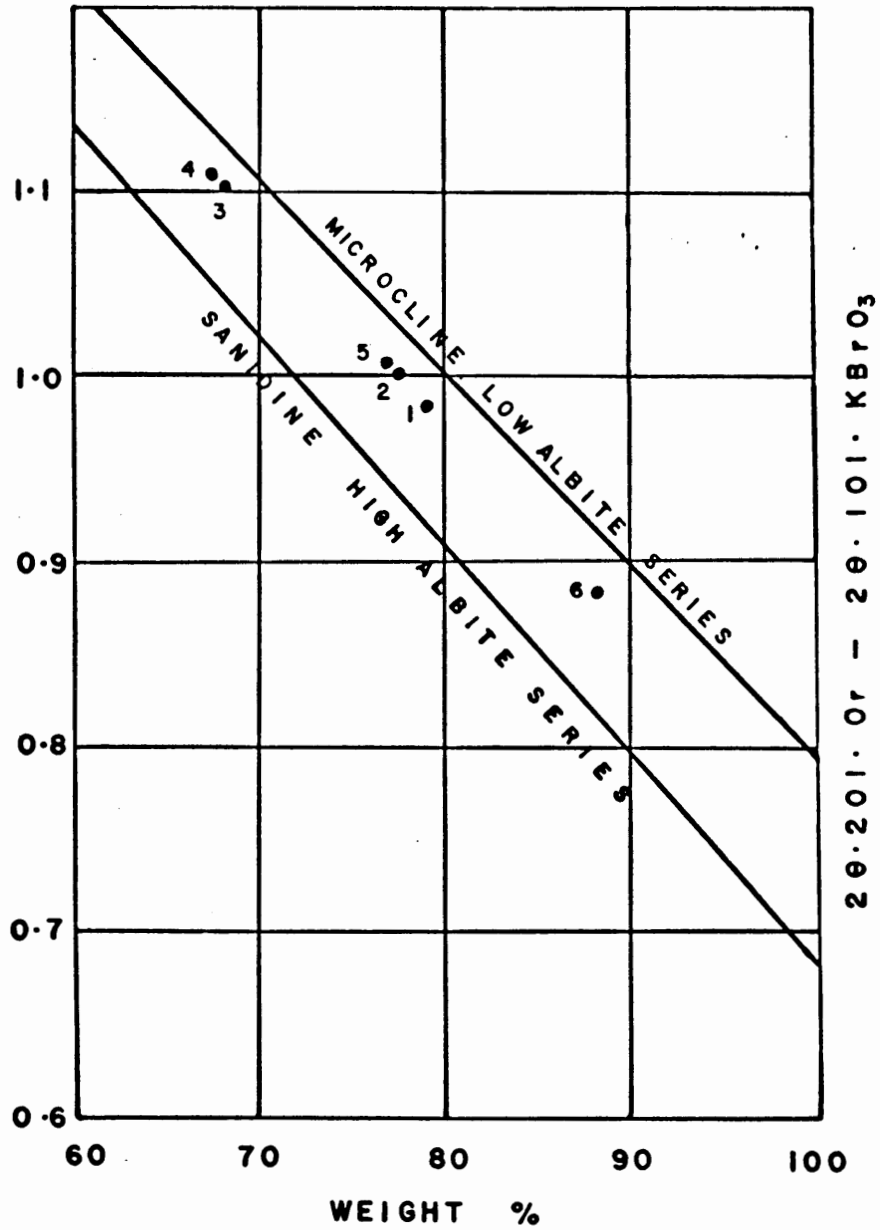
*diorite!*

In thin section, the monzonitic fenite consists of potash feldspar(13 %), plagioclase(73 %), mafics, mainly green soda pyroxene(9 %), and accessory apatite. The rock, as a whole, appears to be relatively consistent in composition and texture as compared to other phases of fenite. The rock reveals hypidiomorphic, medium-grained texture with a weakly subtrachytoidal arrangement chiefly of lathlike grains of plagioclase (see Photograph 5, p. 84). Uncommonly it shows weakly porphyritic texture with a few of plagioclase phenocrysts(see Photograph 6, p. 85).

Potash feldspar(mostly microcline) occurs mainly as anhedral, interstitial fine-grained crystals and uncommonly as subhedral lathlike grains. "Tartan" twinning is recognized in almost all the potash feldspar grains. The bulk composition of cryptoperthite extracted from this rock was found to be Or<sub>78</sub>Ab<sub>22</sub> by X-ray method(see Figure 5, p.22). Most of the potash feldspar grains exhibit microperthitic texture with rods, beads and rimming of albite. The average ratio between microcline and albite is approximately 10/1.

Plagioclase(An<sub>7-10</sub>) occurs as subhedral to anhedral

FIGURE 5  
 $\Delta 2\theta = 2\theta \cdot 201 \text{ FELDSPAR} - 2\theta \cdot 101 \text{ KBrO}_3$  PLOTTED  
 AGAINST % ORTHOCLASE (after PARSONS)



- |     |  |
|-----|--|
| 1 - | MONZONITIC FENITE                        |
| 2 - | SYENITIC FENITE                          |
| 3 - | CRYPTOPERTHITES from MELANOCRATIC FENITE |
| 4 - | HYPERMELANIC FENITE                      |
| 5 - | SYENITE PEGMATITE                        |
| 6 - | GRANITE APLITE                           |

ALL SAMPLES HEATED  $920 \pm 10$  DEGREES CENTIGRADE



medium grains, and is twinned or untwinned. The ratio in amount between albite and oligoclase is about 2/3. Faintly twinned or untwinned plagioclase appears to have pervaded a large portion of the plagioclase grains(see Photograph 7, p.85). Most of the untwinned plagioclase grains are albite. The pervasive replacement by sodic plagioclase or potash feldspar appears to have been facilitated along fractures, cleavages and grain borders(see Photograph 8, p. 86). Displacement along the fractures can be recognized easily by offset of zones in some grains of zoned plagioclase. Plagioclase was weakly granulated along grain borders producing numerous micrograins which were easily albitized.

Green soda pyroxene(aegirine) occurs as anhedral, fine-grained crystals mainly along borders of feldspar grains (see Photograph 9, p.86). A few of them are found to be included in feldspar grains, suggesting that probably they represent the aegirine pseudomorphous after the grains of augite inherited from the diorite. Color of the pyroxene grains grades from slightly greenish to yellowish green.

From the foregoing observations, the diorite country rock of the thesis area is inferred to have been fractured and shattered after complete solidification. Along the fractures, alkali content was introduced into the diorite country rock. As a result, the plagioclase grains mainly of andesine composition in the diorite were replaced by the relatively fresh oligoclase or albite prefer~~r~~ably along the fractures, cleavages

and crystal borders, with removal of the large part of lime content. The potash feldspar(microcline) was likely supplied with soda plagioclase to form the weakly micropertthitic texture. At the same time, augite was replaced by a more sodic variety of pyroxene and a little excess aegirine was formed in favorable places. Possibly the primary quartz has been replaced by alkali feldspar, although the amount of quartz in the original rock was negligible. Therefore, the characteristics of the diorite country rock were much obliterated, and the fenite of monzonitic composition was formed.

#### Syenitic fenite

The central part of the thesis area is composed mostly of syenitic fenite. The rock is also found as small bodies of irregular shape. The homogeneity of mineral distribution in the rock is interrupted commonly by local abrupt increases in the amount of green pyroxene. In some places, aggregates of green pyroxene are strewn along a particular direction so that weakly linear or planar structures are formed. Veinlets of green pyroxene range from a few millimeters to several centimeters in thickness. The veinlets of pyroxene appear to have formed preferably along earlier fractures in the country rock. Porphyritic texture and lineation(parallel arrangement of lathlike plagioclase) recognized relatively strongly in the diorite country rock and weakly in the monzonitic fenite, have disappeared almost completely in the syenitic fenite. The rock grades imperceptibly into the monzonitic fenite. The syenitic fenite is a fine-to medium-grained massive

rock composed mainly of alkali feldspar and green pyroxene. The dominant potash feldspar tends to give the rock characteristically a pink color. With an increasing amount of green pyroxene, the rock grades transitionally into the mafic fenites. ✓

In thin section, the syenitic fenite is seen to have potash feldspar(54-85 %), plagioclase(4 %), green soda pyroxene (3-41 %), and accessory minerals such as apatite and sphene(1 %). The rock shows typically allotriomorphic, fine-to medium-grained texture. However, in some places a few phenocrysts of potash feldspar much broken along borders are noticed to yield a very weakly porphyritic nature in limited parts of the rock(see Photograph 10, p.87). Potash feldspar occurs as highly anhedral, fine-to medium-grained crystals which are commonly intergrown with stringer-shaped albite to form microperthite(see Photograph 11, p.87). The average ratio between potash feldspar and albite is about 8/1. The bulk composition of cryptoperthite is determined to be  $Or_{77}Ab_{23}$  by X-ray method(see Figure 9, p.22). Most of the potash feldspar in the microperthite does not display the "tartan" twinning. Some microcline grains appear to have been transformed into the monoclinic(disordered) form, orthoclase by alkali(soda)-metasomatism. Likewise, the untwinned albite grains are deduced to have changed into orthoclase containing soda plagioclase in a solid solution by alkali(potash) metasomatism.

Plagioclase( $An_9$ ) occurs as subhedral, fine-grained prisms interstitial to or interlocking with the fine-to medium-

grained, commonly microperthitic potash feldspar or included in them. Some of the fine-grained albite scattered in the potash feldspar are squarish in their general shape but mostly irregular in detail along their borders. They are thought to be relict grains left from an advanced replacement of the more calcic plagioclase by the untwinned albite and subsequently potash feldspar or aegirine. Alkali feldspar became only one feldspar identified in this rock, i. e. homogenization of the different compositions of the feldspar in the diorite was taken place to create the alkali feldspar.

Green pyroxene(aegirine) occurs as anhedral, fine-grains or as aggregation of the grains in clots mainly between the grains of the alkali feldspar(see Photograph 12, p.88). They appear to have replaced preferably the borders of the alkali feldspar grains. Color of the pyroxene ranges from greenish to light yellow-greenish. Contemporaneously with and later than the alkalization of feldspar, the country rock is (convinced) to have been fractured. The green pyroxene formed along the fracture planes and borders of the alkali feldspar grains(see Photograph 13, p.88). In places, an incipient replacement of the alkali feldspar by the very fine-grained green pyroxene renders a "spongy" texture and causes a cloudy appearance of the alkali feldspar grains(see Photograph 14, p.89). In the syenitic fenite, the replacement of the alkali feldspar by the green pyroxene seems not to have ~~been~~ progressed as much as in the mafic fenite described in the following, but *has been* more intense than in the monzonitic fenite. The original

features of the diorite country rock are hardly recognizable in the syenitic fenite because the fenitization of the country rock had been progressed considerably so that all minerals and their texture were formed anew.

Mafic fenites (Pyroxene - biotite - K-feldspar rock)

The distribution of mafic fenites is fairly random in the thesis area. However, the large bodies of the rocks occur mostly on the low valley floor. The rocks are found in plan as elongated masses with irregular projections or as rounded inclusions. On the relatively high areas, merely the small bodies of the mafic fenites can be found. This fact may suggest that in general, fenitization of the diorite country rock was more intense at depth rather than at higher levels, although the fenitizing front might have been controlled locally by the vertically developed fractures and therefore, in some places of the higher levels, the fenitization was intense as well. The mafic fenites have been classified into two types - melanocratic and hypermelanic phases of fenite, mainly on the basis of mineral composition and texture. The mafic fenites grade imperceptibly from one into the other. //

#### Melanocratic fenite

Melanocratic fenite is composed of pinkish grey alkali feldspar and green pyroxene in a subequal amount in places, but proportion of the minerals is seen to be much variable. The rock is commonly porphyroblastic with medium-grained porphyroblasts of dark green pyroxene set in a dense,

Pinkish grey matrix of feldspar.

In thin section, the melanocratic fenite contains potash feldspar(15-40 %), plagioclase(1-14 %), green soda pyroxene(54-66 %), and accessory minerals such as apatite and sphene(5 %).

Potash feldspar occurs as anhedral, fine-grained crystals chiefly interstitial to green pyroxene. "Tartan" twinning is encountered in some grains. Some display microperthitic texture with stringlets of the intergrown albite. The grains of potash feldspar <sup>are</sup> ~~is~~ thought to have been fractured and shattered so intensely that they provided a favorable environment for replacement by green soda pyroxene. The bulk composition of cryptoperthite is determined to be  $Or_{67}Ab_{33}$  by X-ray method(see Figure 5, p. 22).

Plagioclase( $An_5$ ) occurs as subhedral, fine-grained crystals associated with potash feldspar and therefore also interstitial to green pyroxene. The crystals are considered to be probably relict grains like those attained in the syenitic fenite. However, they might have formed probably by hydrothermal alteration.

Green soda pyroxene(aegirine) occurs as euhedral to anhedral, medium-to fine-grained crystals. Clots of anhedral, small grains of the green soda pyroxene are formed along the borders and fractures of alkali feldspar. Replace-

ment of alkali feldspar by the numerous fine-grained pyroxene renders a spongy texture in places. Some of the medium-grained pyroxene constitute porphyroblasts in this rock. Relict anhedral, very fine-grained feldspar is scattered in some of the porphyroblasts(see Photograph 15, p.89). Pyroxene shows very weak change in color from faint green to light yellowish green. It is revealed that replacement of feldspar by green pyroxene (aegirine) progressed so much as to form largely medium-grained, yet anhedral to subhedral grains of green pyroxene in this rock. However, considering the amount, crystallinity and size of most of the pyroxene grains, the rock seems to exhibit a high but still imperfect degree in progress of replacement as compared to the hypermelanic fenite.

#### Hypermelanic fenite

Hypermelanic fenite consists mainly of medium-to coarse-grained green pyroxene with a subordinate amount of streaks of pinkish grey, alkali feldspar. Proportion of mineral components in the rock seems fairly consistent through the thesis area.

In thin section, the hypermelanic fenite is made up of potash feldspar(10-30 %), green pyroxene(64-34 %), and accessory minerals such as apatite and sphene(6 %). It is a general tendency that among the accessory minerals, apatite increases gradually in amount and size from the monzonitic fenite to the hypermelanic fenite. The texture shows prismatic medium-grained green soda pyroxene(aegirine) in the matrix

of alkali feldspar.

Potash feldspar occurs as anhedral, medium-sized grains and shows commonly microperthitic texture with stringlets of intergrown albite. The average ratio between potash feldspar and albite is roughly 8/1. Potash feldspar is interstitial to or poikilitically includes the grains of green pyroxene. Strongly undulose extinction is characteristic of relatively fresh alkali feldspar in the rock. Some grains of potash feldspar are hazy with incipient replacement principally along the borders (see Photograph 16, p. 90). Cloudy appearance of potash feldspar has been more pronounced in part by later hydrothermal alteration (see Photograph 17, p. 90).

Pyroxene (aegirine) occurs mainly as medium-grained, cuboidal prisms and cross-sections, changing in color from green to yellowish green. The grain borders are usually greener than the core, suggesting that the border parts of the individual grains contain more of soda content, and metasomatism was easier there than in the middle of the grains. Schiller textures are displayed in some grains of pyroxene. In places, the prismatic grains of pyroxene are arranged in a subparallel orientation to form a very weakly linear structure in the rock (see Photograph 18, p. 91), probably indicating a direction of introduction of the fonnitizing fluid. The size of pyroxene grains is almost<sup>3</sup> uniform in the rock. It has replaced almost all pre-existing feldspar grains although a very small amount of clouded feldspar survives.



The rock contains in a few places small segregations up to 1 foot across mainly of green pyroxene. They are composed of coarse-grained pyroxene(99 %) with small grains of potash feldspar and sphene(1 %). Color of pyroxene changes from green to yellowish green. It includes anhedral, fine-grained potash feldspar and euhedral, fine-grained sphene. The contacts between the hypermelanic fomite and pyroxene segregations are also transitional.

In the previous description, it is disclosed that alkali metasomatism or fomitization had modified the original diorite to yield four kinds of fomite with a complete gradation in intensity from one to the other.

#### Dykes

Dykes cut all the different phases of fomite and the diorite(see Figure 4, p.18). They appear to be more abundant in the fomitized area than outside of it. The late dykes consist of syenitic pegmatite and granitic aplite. Both have almost the same structural attitude, striking about north 10 degrees east across the thesis area. The thickness of the dykes ranges from 30 centimeters to 2 meters. The dykes show chilled, sharp contacts. Some of them appear to be vein-like structures. On the whole, the pegmatite is somewhat commoner than the aplite. In many places, the pegmatite and aplite form separate and distinct bodies of dyke or vein, but in some, both the pegmatitic and aplitic materials occur together in the same body.

yes, at  
Lorraine ✓  
may be chilled borders?  
as at Tyef ✓

### Syenitic pegmatite

Syenitic pegmatite is characterized by pegmatitic texture, lack of quartz, and low percent of mafic constituents. The average size of minerals is over 2 centimeters across. Feldspar may be white, pink, or dark grey. The pink feldspars are microperthites, and the dark grey is plagioclase. The white may be plagioclase or microperthite. The proportion between alkali feldspar and plagioclase seems variable so that the composition of the rock ranges from syenite to monzonite. *-not very often* However, the syenitic composition is so predominant that the pegmatite is called the syenitic pegmatite. Mafic minerals at most places amount to less than 5 percent of the total rock.

In this section, the syenitic pegmatite is generally a coarse-grained rock consisting mainly of microcline-microperthite(55-70 %) and plagioclase(25-40 %). The remaining 5 percent consists of anhedral grains of pyroxene, biotite, calcite and magnetite and euhedral grains of sphene, garnet and apatite.

Microperthite occurs as anhedral coarse-grained crystals. The ratio of plagioclase to microcline in the microperthite is approximately from 1/2 to 1/9. The average ratio would be 1/6. Most of plagioclase intergrown with microcline are commonly altered, but microcline remains relatively fresh(see Photograph 19, p.91). The bulk composition of cryptoperthite is determined to be  $Or_{76}Ab_{24}$  by X-ray method(see Figure 5, p.22). Microperthite includes small irregular grains of plagioclase and is granulated along the crystal borders.

Plagioclase grains ( $An_{17}$ ) are anhedral to subhedral prisms. The borders of the grains are albitized to remain fresh, while the more calcic (oligoclase) cores are intensely altered and clouded (see Photograph 20, p. 92). It is also seen that all the small grains of feldspars produced by granulation of the crystal borders are completely albitized. The albite rim or albitized micrograins might have been formed by hydrothermal alteration.

Pyroxene (aegirine) in subhedral to anhedral, small grains is poikilitically included in the larger feldspars and commonly partly replaced by biotite. The ragged grains of pyroxene are considered to be xenocrysts acquired from the fenite during the dyke intrusion. The euhedral to subhedral grains of accessory minerals are included in feldspars.

#### Granitic aplite

Granitic aplite is characterized by fine-grained sugary texture, presence of quartz, small amounts of mafic constituents, and light grey or pink color. The feldspars may be white, pink, or light green. All the quartz grains are grey. The amount of quartz varies to give the rock a syenitic to granitic composition. The granitic composition dominates to allow the rock to be called the granitic aplite. The ones bearing relatively a small amount of quartz are pinkish and the others light grey. The aplite shows an even grain size that rarely exceeds 2 millimeters.

In thin section, the granitic aplite consists mainly

of quartz(25-29 %), microperthite(66-70 %), and plagioclase (1 %). The remaining 4 percent consists of biotite, calcite, magnetite, spheno, zircon and apatite. The texture of the rock is allotriomorphic and finely granular.

Quartz occurs as anhedral grains found between microperthite grains and replacing the grain borders and fractures of the microperthite. Quartz grains also replace the middle parts of some microperthite grains(see Photograph 21, p.92). Quartz associated with microperthite shows, in places, the graphic texture(see Photograph 22, p.92). The quartz grains show fractures and undulose extinction and include all the other minerals. The above observation gives criteria supporting that quartz is the latest mineral among the minerals described above in the Lorraine property area, and received a stress after crystallization, and indicating some stress applied to the thesis area after the complete solidification of the dykes.

not  
we

brittle  
only?

~~too speculative~~  
~~no real evidence~~

Microperthite occurs as anhedral, small grains that have more or less mutual boundaries with each other; with quartz grains, the boundaries are smooth and rounded. Microperthite of vein and film types, encloses all the other minerals excepting quartz. The ratio of the albite lamellae to the microcline host ranges approximately from 1/2 to 2/1. The bulk composition of cryptoperthite is determined to be  $Or_{87}Ab_{13}$  by X-ray method(see Figure 5, p.22). It is seen that some albite lamellae in the microperthite extend beyond the crystal

boundaries of the microcline host and commonly coalesce near the edge of the crystal, leaving microcline areas between them and forming partial rims (see Photograph 23, p.93). This fact suggests that microperthite was formed more possibly by exsolution, although replacement of potash feldspar by albite had gone on before the exsolution. Microperthite is granulated along the crystal borders. The micrograins along the borders were albitized. This observation supports partly the idea that alteration followed fracturing of the rocks. Plagioclase (An<sub>10</sub>) occurs as interstitial, subhedral, small grains commonly rimmed with fresh, more sodic albite.

Biotite occurs as small ragged grains and is included in quartz and feldspars. Magnetite, sphene, apatite and zircon are sporadically scattered through the quartz and feldspars.

Final analysis of average modes

Using the known average ratio between potash feldspar and soda feldspar in microperthite, the amount of soda feldspar in microperthite has been included in the amount of plagioclase (albite) in the final modal analysis of the rocks occurring in the Lorraine property area as follows;

|                 | diorite                     | monzonitic<br>? fenite   | syenitic<br>fenite                    |
|-----------------|-----------------------------|--|---------------------------------------|
| K-feldspar (%)  | 20                          | $\left. \begin{array}{l} 16(O_{78}Ab_{22}) \\ 33(albite) \\ 42(oligoclase) \end{array} \right\}$ | 62(O <sub>77</sub> Ab <sub>23</sub> ) |
| Plagioclase (%) | 55(oligoclase-<br>andesine) |  | 10(albite)                            |
| Pyroxene (%)    | 20(augite)                  |  | 9(aegirine)                           |
| Quartz (%)      | 1                           | -  | -                                     |
| Magnetite (%)   | 1.5                         | -  | -                                     |
| Sphene (%)      | 1.5                         | -  | 0.5                                   |
| Apatite (%)     | 1                           | tr   | 0.5                                   |
| Etc. (%)        | -                           | -  | -                                     |

|                 | syenite<br>melanocratic<br>fenite      | syenite<br>hypermelanic<br>fenite      | aggregation of<br>aegirine |
|-----------------|--|--|----------------------------|
| K-feldspar (%)  | 30(Or <sub>67</sub> Ab <sub>33</sub> ) | 13(Or <sub>67</sub> Ab <sub>33</sub> ) | 0.5                        |
| Plagioclase (%) | 5(albite)                              | 2(albite)                              | -                          |
| Pyroxene (%)    | 60(aegirino)                           | 74(aegirino)                           | 99(aegirino)               |
| Quartz (%)      | -                                      | -                                      | -                          |
| Magnetite (%)   | -                                      | 1                                      | -                          |
| Sphene (%)      | 2.5                                    | 2                                      | 0.5                        |
| Apatite (%)     | 2.5                                    | 3                                      | -                          |
| Etc. (%)        | -                                      | -                                      | -                          |
|                 | syenitic<br>pegmatite                  | granitic<br>pegmatite                  |                            |
| <i>monz</i>     |  |  |                            |
| K-feldspar (%)  | 56(Or <sub>76</sub> Ab <sub>24</sub> ) | 35(Or <sub>87</sub> Ab <sub>13</sub> ) | <i>9/2 monz</i>            |
| Plagioclase (%) | 36(oligoclase)                         | 35(albite)                             |                            |
| Pyroxene (%)    | 1                                      | -                                      |                            |
| Quartz (%)      | 1                                      | 25                                     |                            |
| Magnetite (%)   | 1                                      | 1                                      |                            |
| Sphene (%)      | 1                                      | 1                                      |                            |
| Apatite (%)     | 1                                      | 1                                      |                            |
| Etc. (%)        | -                                      | 1                                      |                            |

**Petrogenesis of the Lorraine Fenite Complex**

From the previous discussion of the regional geology, and of the different phases of rock found in the Lorraine property area, it can be suggested that an alkaline magmatic body existed beneath the pre-existing diorite of the thesis area. It possibly resulted from differentiation of the magma from which the diorite country rock (first division) formed. In the early solidified upper part of the diorite, fractures might have formed as a result of subsidence on crystallization and shrinkage during cooling, although an effect by regional tectonic stress might be considered in addition.

*is this  
chemically  
possible  
yes.*

Fluids enriched in fenitizing constituents appear to have escaped from the alkaline magma beneath the diorite. the fenitizing fluids are conceived to have travelled in the diorite country rock through the grain boundaries, cleavages and fractures. As a result, the diorite country rock was metamorphosed to various degrees, producing four different stages of fenitization. Intensity of the fenitization in the diorite appears to have been controlled mainly by the distance from the source magma of the fenitizing fluids and by the degree of fracturing. Essentially, all minerals in the diorite country rock were replaced gradually by green soda pyroxene (aegirine-augite or aegirine) and/or alkali feldspar with minor amounts of accessory minerals such as apatite and sphene. The most intense fenitization created the mafic fenites. }  $\frac{22}{00}$

The faults and joints found in the thesis area bear no obviously close relation to the fenitization, suggesting that any early formed megascopic structural features (faults or joints) in the diorite country rock were probably completely obscured by the fenitization, although it is disclosed on a microscopic scale that the rocks were fractured to facilitate the fenitization more effectively.

While the fenitizing process was going on, the alkaline magma below would probably have been differentiating to generate eventually a residual magma which might have been more aqueous than the original magma, although it could not approach the degree of attenuation of hydrothermal solutions.

Thus, a part of the residual magma could escape and form pegmatite and aplite either in the fenitized rocks or in the adjacent unfenitized country rock, following the prepared fractures. Since the dykes were intruded along the fractures which cut all the phases of fenite, the fenitization must have been complete before the dyke intrusion. In the field, no spatial relation between the dykes and the fenites was recognized at all, at least in detail on a local scale. (*X cutting at Lorraine?*)

Some of the dykes showing vein-like structures suggest that they might have been formed mainly by replacement along a favorable structure by solutions, but many must have been injected more or less bodily into the prepared or probably simultaneously opened fissures, resulting in their chilled zone.

In the formation of pegmatite, its content of volatiles appears to have retained, until crystallization was considerably progressed resulting in the coarse-grained texture. In the case of aplite, volatile materials seem to have been depleted or used up for the formation of the pegmatite forming the sugary-textured rock(10). The residual solution appears to have varied in composition trending toward the granitic phase oversaturated with increasing amount of quartz, probably as a result of the further differentiation in the magma reservoir or on the ascending way with the crystallization of the monzonitic to syenitic dykes(4, 43).



The aplites of quartz syenite and granite composition were, therefore, crystallized probably from such formed phase of the residual solution. They may otherwise be the same aplite dykes as the quartz-microperthite aplite cutting the rocks of the second division of the Hogem batholith.

The thin section study, however, verifies that in places, many of the quartz grains were formed by replacement. Quartz veins are found to be closely associated with and cut the aplite dykes in the field. The detail of this will be described in the chapter on the "Hydrothermal Alteration". Therefore, at least the large portion of quartz amount in the aplite might have metasomatically introduced from the further differentiated solution which may be referred to as a hydrothermal fluid, although the remaining small amount of quartz in the aplite could probably crystallize from a melt so differentiated as to produce excess quartz.

Thus, the composition of the aplite before the silica metasomatism was in a range between syenite and quartz-syenite (less than 10 % quartz in the rock). However, the composition of the aplite originating from the second division (mostly oversaturated) of the Hogem batholith magma seems unlikely to be in this composition range unless the environment of the magmatic crystallization changed under a certain circumstance. The dykes of the thesis area are thought to have originated from the magma of the diorite country rock.

Considering all the rocks of evidently magmatic origin found in the thesis area, the original magma of the Hopen diorite appears to have followed a reasonably continuous series of differentiation, i. e. (?) - diorite(country rock) - (?) - monzonite(dyke) - syenite(dyke) - quartz syenite(dyke) - granite(dyke)(?) - (hydrothermal solution discussed in the following chapter).

The fenitization is fitted in time relation convincingly into the monzonitic to syenitic stages between the dioritic and the quartz syenitic to granitic stages of differentiation of the intruded magma, so that the alkaline magma responsible for supply of the fenitizing solution was monzonitic to syenitic in composition.

As pointed out in the section on regional geology, monzonite or syenite pegmatitic in places and therefore probably abundant in volatiles, and granite intruded at various places. These bodies are found to be commonly associated with or intruding the same kinds of rock as the fenites of the thesis area. Many of them show roughly one preferred orientation of emplacement trending north 20 degrees east, parallel to that of the dykes of the thesis area. The dykes and the hypothetical monzonitic to syenitic magma at the Lorraine, and the monzonite, syenite or granite in the neighbouring region are probably the same phases of differentiate formed from the dioritic parent magma.

A potassium-argon date on the biotite extracted from the hy emelanitic fenite,  $170 \pm 8$  million years, corresponding to Lower Jurassic(22) indicates, in a somewhat broad sense, an age between the diorite country rock and the late dykes because the biotite was formed following or at the end of the fenitization. Therefore, the potassium-argon age of  $170 \pm 8$  million years may indicate the minimum age of the Lorraine fenites.

None of that time?

Few potassium-argon age determinations on the Hogem batholith are available. However, an age span from the late Triassic to the early Cretaceous has been generally accepted for the age range of the Omineca intrusions, i. e. The Hogem batholith. The potassium-argon age of  $170 \pm 8$  million years also lies within an age range as old as expected from the late position in age of diorite among the first division of all the phases of the Omineca intrusions or the Hogem batholith.

If it is accepted that the Lorraine fenites and the alkaline magmatic body responsible for the fenitization were formed as a result of differentiating evolution of a dioritic portion of the Hogem batholith magna, the Duckling Creek syenite including the "Lorraine syenite" can be considered to represent a phase of the Hogem batholith, i. e. the last phase of the first division, agreeing with the hypothesis of Roots(36). It is, however, improbable that the syenitic bodies are much younger than the main Hogem batholith, i. e. the rocks belonging to the second division, and occupying considerably large portion( $\frac{5}{6}$ ) of the Hogem batholith are believed to be younger than the potassium-argon age of  $170 \pm 8$  million years. The

evidence suggests that the diorite country rock was formed as a relatively early phase of the differentiating Hogen batholith magma, and the potassium-argon age indicates the time point separating when the first division (largely mafic rocks) of the Hogen batholith accomplished its formation and the second division (felsic rocks) started its formation, and probably the age marks the peak of fenitization in the surrounding region. ✓

### Structure

Faults and joints are of major structural importance in connection with petrogenesis and mineralization in the thesis area. Numerous faults are marked by slickensides, gouge and cataclastic rocks. The faults are divided on the basis of attitude and relative age into five groups and numbered from 1 to 5 (see Figure 4, p. 18) as follows;

The oldest fault, no. 1., strikes north 5 degrees east and is vertical. The fault is observed to be cut by faults of the other 3 groups named nos. 2, 3 and 4, and offset with displacement of up to 100 feet locally. No special relation is noticed between the locus of the fault and the distribution of fenites. The fault cut all phases of fenite, suggesting that the faulting is in age later than the fenitization. ✓

Fault no. 2, strikes east-west and dips 85 degrees north. It is cut by the faults nos. 3, 4 and 5 and offset with displacement up to 150 feet.

Fault no. 3, strikes north 50 degrees west and dips 75 degrees northeast. It is cut by faults nos. 4 and 5, and offset locally up to 450 feet.

Fault no. 4 strikes north 10 degrees west and dips 70 degrees toward northeast. The faults no. 5 are of relatively small scale, striking north 50 degrees east with almost vertical dip. No field evidence is available to establish the age relation between faults numbered 4 and 5. However, it is evident that they are all the youngest groups of fault in the thesis area. All the faults described above are seen to cut the late dykes.

Besides these five faults relatively easily defined in the field, there are faults developing in other directions along which the late dykes seem to have introduced. The faults are parallel to one another in a strike of north 20 degrees east with almost vertical dip. Since all the faults named 1 to 5 cut the late dykes, the fault striking north 20 degrees east is oldest among the faults so far known in the thesis area.

Most of joints were observed to strike and dip parallel to the faults and one set of horizontal joints is found in addition. In places, jointing in these directions is so intense that it is difficult to find a hand-sized specimen of un-fractured nature. Fracture spacing generally ranges from 5 inches to one foot in the mineralized zone, but locally

widths of as much as 30 feet are unfractured. Some of the oldest fractures striking north 20 degrees east bear the coarse-grained biotite or pyroxene veins, suggesting that this fracturing facilitated the fenitization.

## MINERAL DEPOSIT

### Hydrothermal Alteration

#### Alteration minerals

The term "hydrothermal alteration" used in this section and all through the paper specifically indicates the alteration which is considered to follow the alkali metasomatism, "fenitization" of the diorite country rock, and to precede immediately the mineralization of the thesis area. The hydrothermal alteration has been described under the main heading "MINERAL DEPOSIT" because the discussion of this subject is intimately interrelated with ore mineralization. All rocks of the thesis area, even the ones that megascopically appear to be fresh, had been affected to some extent by hydrothermal alteration. The alteration is so pervasive in some parts of the thesis area that it is difficult to find completely fresh rocks for the purpose of comparative study of the host rocks. Alteration minerals will be discussed from the earlier to the later in their paragenetic sequence.

#### Biotite

Biotite appears to have formed most abundantly among

the minerals described as alteration minerals in the thesis area. Particularly the hypermelanic fenite has been so intensely biotitized that the amount of biotite exceeds more than 30 percent of the rock in many places(see Photograph 24, p.94). In the rock, biotite occurs as anhedral, <sup>x</sup> potkilitic coarse grains, including the grains of green pyroxene and apatite. It replaces the included minerals along the crystal borders and fractures. It also replaces potash feldspar rather than green pyroxene.

In the melanocratic fenite, biotite is developed between grains of feldspar and green pyroxene, replacing partly or wholly the grains of those minerals(see Photograph 25, p.94). The amount of biotite in the rock attains up to 15 percent of the total rock volume. Feldspar grains appear to have been more favorable for replacement by biotite than green pyroxene, as in the hypermelanic fenite. Pyroxene grains reveal only incipient replacement by biotite along grain boundaries, cleavages and fractures. Commonly aggregation of more or less prismatic small grains of biotite<sup>?</sup> can be found along a direction probably indicating the pre-existing fractures which acted as channelway favorable for the introduction of fenitizing or hydrothermal solutions. // foliation planes?

In the syenitic and monzonitic fenites, biotite forms up to 5 percent of the total rock only in a few instances. The alteration mineral replaces, in general, only the parts of feldspar and green pyroxene mainly along grain borders or

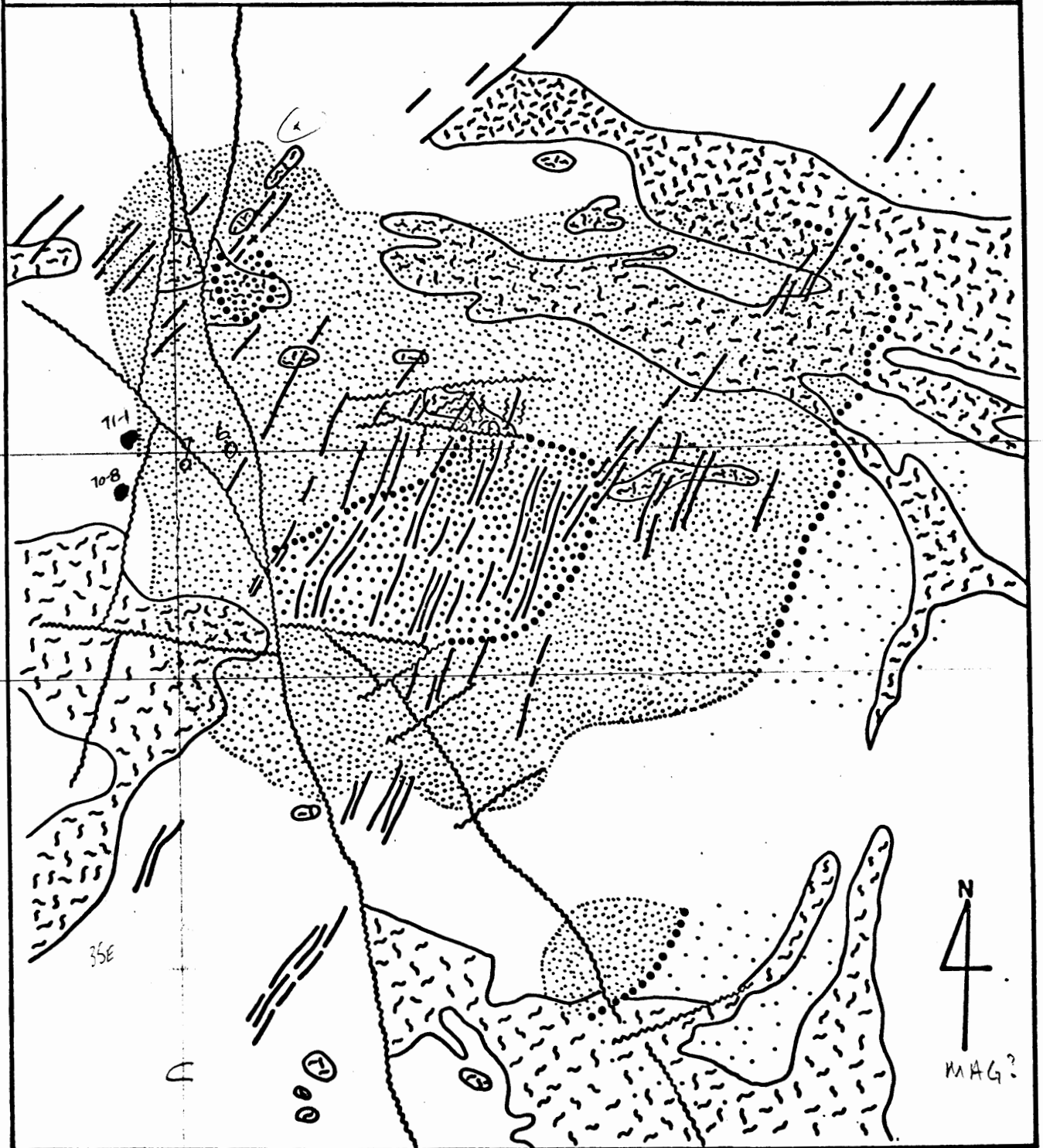
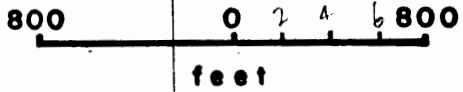
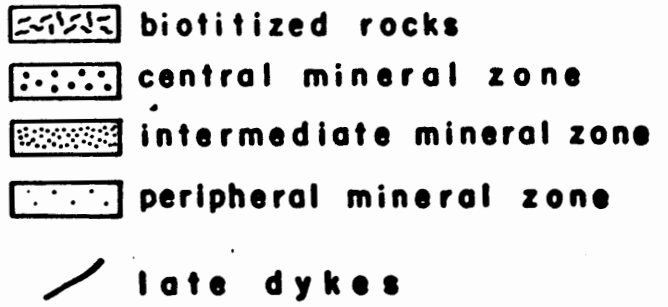
fractures, and occasionally a few poikilitic grains of the mineral are found(see Photograph 26, p.95). In general, the biotitization is not noticeable in the syenitic and monzonitic fenites as compared to the mafic fenites.

It seems necessary to establish exactly the time range of formation of the secondary biotite. Biotitized fenites are cut by the late dykes and quartz veins. Biotite grains are replaced by ore minerals and all of the other alteration minerals. In places, biotite has been introduced along fractures in the fenites to form veinlets of coarse-grained crystals of the mineral. From the above description, it is evident that biotite was formed after the main part of the fenitization.

The edges of biotite show highly irregular and mostly saw-tooth-like shapes. It is pleochroic from dark green to yellow or yellowish green. The amount of biotite varies with the type of fenite. As described already, the mafic fenites are more biotitized than the other fenites. The mafic fenites, although irregular in the detailed shapes of their outcrops, form a halo around the central mineral zone described later, and small bodies of the mafic fenites occur within the central and intermediate mineral zones. All these mafic fenites are equally, highly biotitized(see Figure 6, p.47). Based on the examination of a few thin sections, there appears to be no noticeable biotitization and change in the amount of biotite in all places within the monzonitic and syenitic fenites.



FIGURE 6  
BIOTITIZATION  
mineral zones  
late dykes



### Albite

Albitization is common in the thesis area. Alteration referred to as albitization here is confined only to that which occurred contemporaneously with or after intrusion of the late dykes, close in time to mineralization, since early albitization in the rocks of the thesis area was accomplished during the fenitization and obviously before intrusion of the dykes.

The alteration appears to be intense in the part of the thesis area where the late dykes are abundant. The late dykes themselves were albitized most intensely. This suggests that the late dykes were nearest to the channelway carrying albitizing fluid or probably the whole altering fluid. In the dykes, feldspar has been albitized along crystal borders and fractures to form microperthite or zoned grain (see Photograph 27, p.95).

In the different phases of fenite, albitization appears to have been facilitated mainly along the grain borders and fractures of feldspar (see Photograph 28, p.96). The relatively more intense albitization is seen in the syenitic fenite among the fenites.

### Orthoclase

Orthoclase forms pink veinlets commonly one centimeter or less thick, mainly in the central part of the thesis area. The mineral is found to cut the aplite dykes.

## Quartz

Quartz veins have been found in the thesis area, mainly in the central and western part. These usually average about 2 inches in width. Most of them are barren, but some contain coarse-grained ore minerals such as bornite, chalcopyrite and pyrite (see Photograph 3, p. 83). The country rock intruded by quartz veins has been silicified and mineralized. Some of the quartz veins are seen to cut the orthoclase veinlets and the granitic aplite, but most of them occur adjacent to the granitic aplite and lie parallel to the aplite, implying a close genetic relation.

at Dot  
claims  
also?

## Sericite

Sericite is relatively abundant in the altered rocks, being intimately associated with sulphides. This alteration mineral occurs mainly as very fine-grained scales pseudomorphous after feldspar, biotite, green pyroxene and even some quartz. Sericitization occurred most preferably along grain border and fracture, although in places it developed in the middle part of grains. Feldspar grains are seen to have survived the sericitization in the albitized rim, but to have been highly susceptible to sericitization in the unalbitized (more calcic) cores (see Photographs 29 and 30, p. 96 and 97), suggesting a close equilibrium state between the two alteration minerals, albite and sericite in the condition of formation. Anhedral, fine-grained muscovite is, in places, associated with scaly sericite (see Photograph 31, p. 97), particularly along grain borders of feldspar, biotite or pyroxene. Some of the sericitized minerals are again partly replaced by chlorite. Sericite grains show

weak pleochroism from very faint green to colorless. Development of scaly sericite causes turbid appearance in thin sections of the altered rocks.

#### Chlorite

Chlorite is widespread in the altered and mineralized rocks. Chloritization occurred preferably along grain boundaries and fractures of feldspar, green pyroxene and biotite (see Photographs 32 and 33, p. 98), although some of the chlorite grains replace the middle part of the rock-forming minerals. This green alteration mineral is intimately associated with sulphide minerals and commonly forms anhedral to subhedral, medium-sized grains.

#### Epidote

Epidote can be found in a very minor amount in the thesis area. Subhedral, small grains are found to replace along grain borders of feldspar and pyroxene. Microscopically thin films of epidote lie almost invariably between ore minerals and other alteration minerals, suggesting that in the thesis area, epidote is most closely related in timing to the ore minerals (see Photographs 33 and 34, p. 98 and 99).

#### Nature of alteration

The period of hydrothermal alteration must have followed formation of all the fenitized rocks in the Lorraine property area. The higher degree of biotitization in the mafic fenites than in the other fenites draws attention to the close genetic relationship between the biotitization and the fenitization. Probably this fact is simply because the mafic fenites

were overwhelmingly more favorable for the biotitization than the other fenites although all the rocks except for the dykes were exposed to the same amount of the biotitizing fluid.

It is not improbable, however, that the biotitizing fluid was derived as a product of the waning stage from the same source as the fenitizing fluid and dissipated preferably through the most highly fenitized rocks.

The alteration other than biotitization was contemporaneous with or immediately followed crystallization of the pegmatite and aplite dykes. The inference follows that since the dykes are the youngest rock of the Lorraine complex, the altering fluid, probably excluding the biotitizing phase, is considered to have been the last phase of magmatic crystallization of the unexposed alkaline magma. The source for the hydrothermal altering fluid is thought to have been close to the dykes. Intense albitization, orthoclase veinlets, and quartz veins are very closely related spatially to the dykes in their distribution. The dykes show, however, relatively smaller amounts of alteration minerals except for albite. Possibly they were closer to equilibrium with hydrothermal fluid than other members of the Lorraine complex. The aplite dyke, composed of alkali feldspar and quartz, formed probably by the further differentiation than the pegmatitic phase of the residual solution appears to have been more insusceptible to hydrothermal alteration than the pegmatite dyke.

The field relations and petrographic evidences make it

possible to fix the relative time of the periods of faulting and alteration. Most of faults cut the pegmatite and aplite dykes. They cut the altered rocks and are not genetically related to the alteration in the thesis area. However, faults or joints trending north 20 degrees east appear to have been rehealed and obliterated by alteration and have also controlled the development of some alteration zones. Thus, it may be concluded that the time of major alteration is later than the faults or joints trending north 20 degrees east and earlier than all of the other faults and joints.

Since the greatest development of relatively more altered rocks is in the central part of the thesis area, the main centre of alteration was probably in that zone. This suggests that the main alteration zone was limited to a particular area. In general, altered zone is much smaller than the fenitized zone.

The preservation of pseudomorphs with increasing alteration indicates that a major portion, if not all, of the alteration has taken place at constant volume. In general, ferromagnesian minerals and plagioclase were by far the most susceptible to alteration, and potash feldspar, quartz and apatite, relatively resistant.

A study of the products of alteration gives some indication as to the nature of the altering fluid. The hydrothermal alteration in the thesis area appears to have occurred

in a definite sequence. The dominant minerals characteristic of the successive stages of alteration are as follows:

1. biotite(?).
2. albite.
3. orthoclase.
4. quartz.
5. sericite.
6. chlorite.
7. epidote.

Later minerals overlap and replace the earlier ones, so it is very difficult to delimit individually the detailed distribution of them on maps of the scale employed. It is quite probable that they reflect the character of the altering fluid. Besides the alkali content governing the formation of alkali feldspars, albite and orthoclase in alteration zones, the fluids responsible for the other stages must have carried water, silica and lime.

The presence of hydrogen sulphide or some sulphur-bearing compound in the altering fluid would be the easiest way to account for the formation of pyrite in the altered rocks of the surrounding(marginal) part of the mineral body. The ferromagnesian minerals such as pyroxene, and biotite could thus be replaced by an iron-rich chlorite and by iron sulphide.

In summation from the foregoing description, the active fluid at the time of hydrothermal alteration probably contained concentrations of soda, potash, silica, hydrogen sulphide, water and a minor amount of lime. Alteration varies to some extent in intensity, but there is no significant change in the types of hydrothermal mineral from place to place. This fact signifies that the composition of the altering fluid

probably did not vary greatly from the highly altered rocks to the less altered rocks. The main variable seems to have been the degree of soaking, or the amount of altering solutions to which the rock was exposed. Again, the fractures and the other permeable routes in the rocks may have been the important conduits for the control of the amount of the altering fluids.

**Potassium-Argon Age Determination of Biotite**

A sample was collected from outcrop of the hypermelanic fenite in the north central part of the Lorraine property area after removal of the weathered surface. Biotite is the most abundant, secondary mineral in the mafic phases of the Lorraine fenite. It is considered as a mineral formed in the earliest stage of the hydrothermal alteration or the latest stage of the fenitization. Constants, data and calculation of K-Ar dating of the extracted biotite are as follows, and the significant meanings suggested by the result are discussed respectively in the pertinent places of the thesis(18, 22).

$$K = 1.181 \times 10^4 K$$

$$\lambda_0 = 0.585 \times 10^{-4} / \text{yr.}$$

$$\lambda_1 = 4.72 \times 10^{-4} / \text{yr.}$$

Potassium % = 6.37 ± 0.04

$$\frac{\text{Ar}^{40*}}{\text{Total Ar}^{40*}} = 0.91$$

Ar<sup>40\*</sup> = 4.497 × 10<sup>-5</sup> cm<sup>3</sup> / gm S.T.P.

$$\frac{\text{Ar}^{40*}}{K^{40*}} = 0.010434$$

" A g o " =  $\frac{1}{\lambda_0 + \lambda_1} \left[ \frac{\text{Ar}^{40*} (\lambda_0 + \lambda_1)}{K^{40*} \lambda_0} + 1 \right] = 170 \pm 8$  million years  
(Lower Jurassic)



## Deposition of Ore Minerals

Deposits of various ore minerals occur in the region northeast of the Omineca River in the Omineca Mining Division, British Columbia where there had been magmatic intrusion and differentiation, faulting and shearing. The mineralization in the Lorraine property area is one example of such known, disseminated copper deposits within the Hogem batholith. The Lorraine deposit appears to represent a relatively large body of copper-bearing deposits now found in the region and particularly to have been one of the main foci for the development of several mineral deposits in the region. The best mineralization is believed to occur in the Lorraine property area. Very sparsely mineralized bodies are found in several places peripheral to the Lorraine property. The Lorraine deposit, while low grade, is possibly of large tonnage. A relatively simple assemblage of ore minerals has been found at the Lorraine deposit.

### Primary minerals

The important primary sulfides recognized at the deposit are chalcopyrite, bornite and pyrite. These sulfide ore minerals are widely disseminated throughout almost all of the hydrothermally altered phases of rock in the thesis area. When examined, the grains of ore minerals are not always in contact with alteration minerals (see Photograph 35, p. 99), but the alteration minerals are invariably found in other parts of specimens. It is, however, more common that the ore minerals

are, with only a few exceptions, immediately associated with the alteration minerals, suggesting both alteration and ore minerals originated from the same source. \*

The ore minerals replace in places the alteration minerals(see Photograph 36, p.101). The alteration minerals also form halos or rims around the ore minerals(see Photograph 34, p.99). It is therefore known that the time range of the alteration was longer than that of the primary ore mineralization. Also, the front of altering fluids was always ahead and more widespread. The last stages of alteration were contemporaneous with the primary ore mineralization or ended shortly before the primary ore mineralization, because some grains of the primary ore minerals are found alone without any alteration minerals immediately associated. Chlorite, and more commonly epidote rim the ore minerals. The ore minerals are disseminated mainly along the grain borders of the rock-forming minerals(see Photograph 37, p.100). However, it is noticeable that in some of those cases, the primary ore minerals corrode or replace the contact part of the rock-forming minerals(see Photograph 38, p.101). Furthermore, some of them penetrate the middle parts of crystals of the rock-forming minerals(see Photograph 39, p.101). This evidence verifies the idea that the minerals are metasomatid or epigenetic in origin.

#### Chalcopyrite

Chalcopyrite occurs as anhedral grains widely dissemi-

nated throughout almost all of the hydrothermally altered phases of rock. The grains may occur as clusters of a few or several disseminated grains, being associated commonly with a variable amount of bornite(see Photograph 40, p.102), or less commonly with a minor amount of pyrite(see Photograph 45, p.104). Chalcopyrite occurs as very thin, small flakes encrusting the fracture planes of the host rocks. Narrow massive stringers with or without bornite occur along the fractures(see Photograph 41, p.102). Also, clusters of small grains implanted in quartz veins are associated with bornite or pyrite. The grains of different occurrences range in size from a few tenths to a few millimeters. The fine-grained nature of chalcopyrite requires high power magnification in microscopic examination. It is seen that the contacts between the grains of chalcopyrite and bornite are smooth with a few irregularities. This mutual boundary relation in contact displays the contemporaneous growth.

### Bornite

Bornite occurs in the almost same amount as, or a little less than, chalcopyrite at the Lorraine deposit. It is found commonly as anhedral, disseminated grains in the highly hydrothermally altered rocks, ranging in size from a few tenths to a few millimeters across. The mineral is closely associated with the disseminated grains of chalcopyrite and in places, intergrown with the exsolved grains of chalcopyrite(see Photograph 40, p.102). Oriented exsolution intergrowths with chalcopyrite lamellae along the octahedral planes of bornite have been recognized at high magnification in some grains of bornite

(see Photograph 42, p.103), indicating a minimum temperature of deposition of 475°C because an extensive solid solution between the two minerals is attained above this temperature(40).

Bornite formed also as massive stringers along the fractures (see Photographs 4 and 43, p.84 and 103). It is usually associated with a minor amount of chalcopyrite. The stringers vary in width from a few millimeters to about two centimeters. Such bornite is closely associated with the abundant veins of quartz and aplite. This type of mineralization occurs in close association with high grade disseminated ore minerals.

#### Pyrite

Pyrite occurs except where bornite is abundant. It forms a lean or barren zone as a part of the overall mineralized area. The mineral occurs mainly as disseminated cubic grains 0.1 to 3 millimeters across in size, and also as subhedral to anhedral grains due to fracturing(see Photograph 44, p.104) or replacement by chalcopyrite(see Photograph 45, p.104) and therefore decreased in size, particularly when it is associated with relatively abundant chalcopyrite. Disseminated pyrite forming up to 9 percent of the total rock in volume occurs commonly as euhedral cubes without associated bornite and chalcopyrite. Veinlets of pyrite a few millimeters thick are found in the high grade pyrite zone.

#### Magnetite

Magnetite occurs as anhedral, fine-to medium-grained crystals mostly along the grain borders of the rock-forming

minerals and is in rare instances associated with fine-grained pyrite. The mineral also forms veins averaging about 2 inches in width. The veins are associated with veins or clots of pyroxene (see Photographs 46 and 47, p.105). Pyroxene was considered in the description of petrology to be a segregation of the fenitizing fluid. Association of euhedral, coarse-grained magnetite with the pyroxene-vein suggests the contemporaneous segregation of the two minerals. This further suggests that magnetite should be placed in the earliest position of paragenetic sequence of the primary minerals since the mineralization of all the primary sulphides at the Lorraine was later than the fenitization. The amount of the mineral is negligible in the area.

*magnetite  
cores  
in green  
mafic  
(hb, pyx?)  
Common  
in area.*

#### Lead, zinc, gold and silver

No crystalline grains of ore minerals of these metals have been found in the thesis area. Lead and zinc analyses have been made on some samples from the central part of the thesis area. Average assays are 20 ppm for lead and 90 ppm for zinc. Low but persistent gold and silver values occur throughout the central part of the thesis area. Average gold content is 0.05 ounces per ton, and the average silver content 0.35 ounces(19). It has been also reported that the samples contained only a trace of molybdenum(19).

#### Secondary minerals

The mineral deposit possesses no noticeable gossan. However, since fair amounts of limonite, malachite and to a

lesser extent azurite occur at the deposit, it is apparent that the sulphides have leached out to a certain extent at the surface. Locally, limonite and malachite are abundant particularly around the base of slope of the 6,700 foot mountain. Secondary minerals will be described in their approximate order of abundance.

#### Covellite

Covellite is seen to be the first stage of the alteration of chalcopyrite, bornite and pyrite to azurite or malachite, and usually occupies an intermediate position between the two minerals. Fractures and grain borders of the primary copper minerals appear to have been favorable for the initiation of replacement by covellite (see Photograph 48, p.106). It forms most commonly thin films coating the primary copper minerals, and appears to have replaced easily the whole bodies of fine-grained crystals of the primary copper sulphides.

#### Chalcocite

Chalcocite replaces bornite, chalcopyrite and covellite along fractures and grain borders. Exsolution lamellae of chalcopyrite in bornite survive in places the replacement by covellite, but not by chalcocite (see Photograph 49, p.106), indicating that a condition with the formation of the secondary chalcocite was more favorable for advanced supergene mineralization. Chalcocite occurs, however, in a very minor amount comparable with the other secondary copper minerals and suggests that supergene enrichment is unimportant at the Lorraine property.

diss.  
Chalcocite  
(primary?)  
noted  
further  
west.

#### Azurite

Azurite occurs as microcrystalline films on fractures

with malachite and limonite. In fractures, malachite usually lines the walls, while azurite forms a second layer coating the malachite. Azurite is much less abundant than malachite in the thesis area.

#### Malachite

Malachite occurs as thin films and as earthy coatings on fracture planes with azurite but seldom with limonite. It also pervades the adjoining massive rock. It is seen to encrust the grains of bornite and chalcopyrite, <sup>+ chalcocite</sup> forming a rim texture.

#### Limonite(goethite)

In places, the upper part of the host rock contains a considerable amount of earthy mass of limonite with minor amounts of secondary copper minerals. Most grains of the primary sulphides in the rocks examined are found to be surrounded by limonite showing a rim texture(see Photograph 50, p.107). Some of the hand specimens studied disclose that about 30 percent of chalcopyrite and bornite is estimated to have been replaced by secondary limonite. It is unknown how deep this extends.

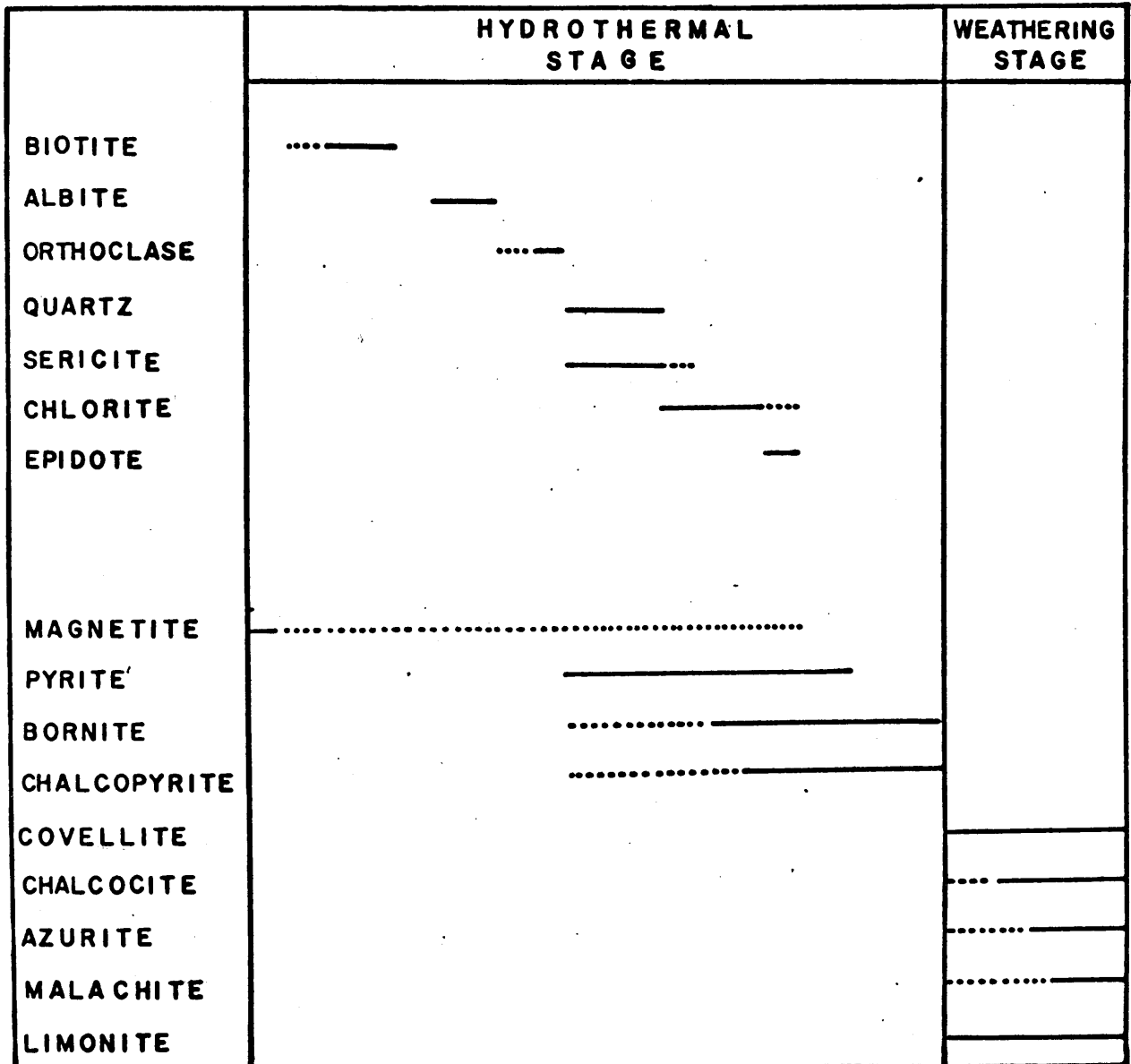
#### Paragenesis

The paragenetic relations of both alteration and ore minerals are summarized and represented in a graph on the basis of the already mentioned results of petrographic and mineralographic investigation(see Figure 7, p.62).

#### Mineral Zoning

FIGURE 7

PARAGENETIC RELATIONS  
OF  
ALTERATION AND ORE MINERALS



— OBSERVED      ..... PROBABLE

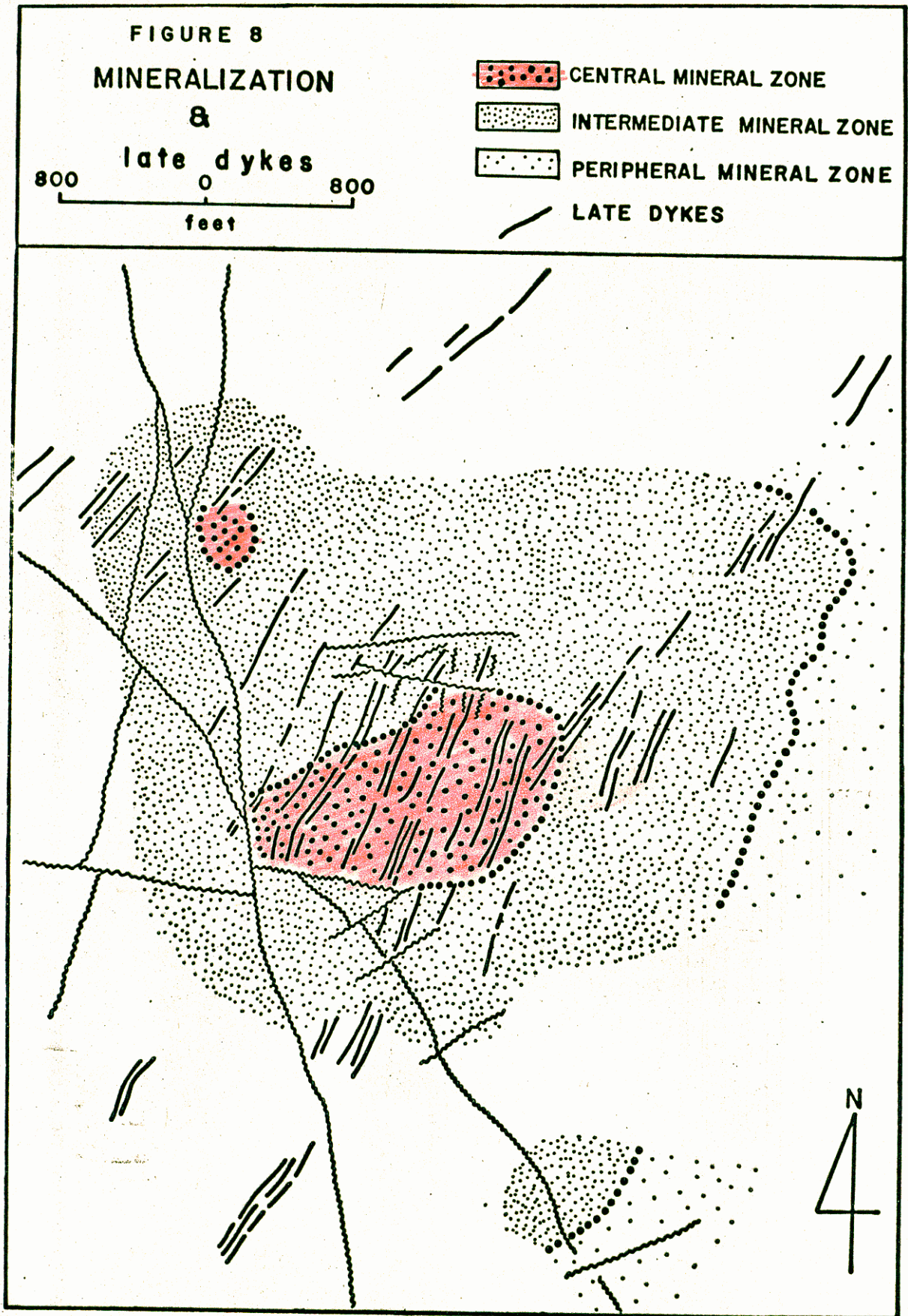


The boundaries of the mineral zones have been determined at the Lorraine deposit (see Figure 3, p.64). On a large scale, the deposit demonstrates a zoned pattern according to the primary sulphide mineral assemblage as follows;

In the central zone, the sulphide consists mainly of chalcopyrite and bornite in sub-equal amount. Very little pyrite can be found in this zone. The mineralization in this zone is relatively uniform. In plan, the central zone has roughly the shape of a circle or ellipse. The dimensions of the largest zone in a horizontal plane are estimated to be 1,200 by 1,000 feet. The mineralization in that particular zone occurs over a maximum vertical range of 950 feet as exposed in outcrop. A smaller one is located about 1,000 feet northwest of the large one. It is about 300 by 250 feet in horizontal area. In places, the central zone has been proved to be the most promising ore zone for more intensive prospecting at the Lorraine deposit. This zone is surrounded by the intermediate zone.

In the intermediate zone, the sulphide consists mainly of chalcopyrite with subordinate amount of pyrite. Pyrite occurs mainly as partly corroded crystals. The mineralization is not homogeneous and of too low grade to be ore at present. This zone grades into barren rock via the peripheral zone.

In the peripheral zone, pyrite is the only sulphide



disseminations of well defined cubic grains. This zone is developed either in continuity with the intermediate zone or in most cases alone in the barren zone far out from the intermediate zone.

### Controls of Mineralization

The grade of mineralization has been observed to vary rapidly within the space of a few feet. The rocks in the central zone are most intensely fractured; the fractures striking north 20 degrees east in the central mineral zone, many of them being better mineralized with bornite and chalcopyrite than fractures with other attitudes. Commonly, the fomite on either side of the fracture zones has been highly altered and mineralized with sulphides, so where the fractures are closely spaced the rock appears to have been highly mineralized. Massive stringer ore has been controlled clearly by fracturing, the disseminated ore found on both sides of it fading gradually on either side. This implies its introduction from the fracture channelways. It is known that the activated invading particles of an ore solution are deposited in the direction of minimum stress(45). Evidently the permeable, fractured zones offering unusually easy access of the ore fluid are the most important controls for replacement by ore in the thesis area.

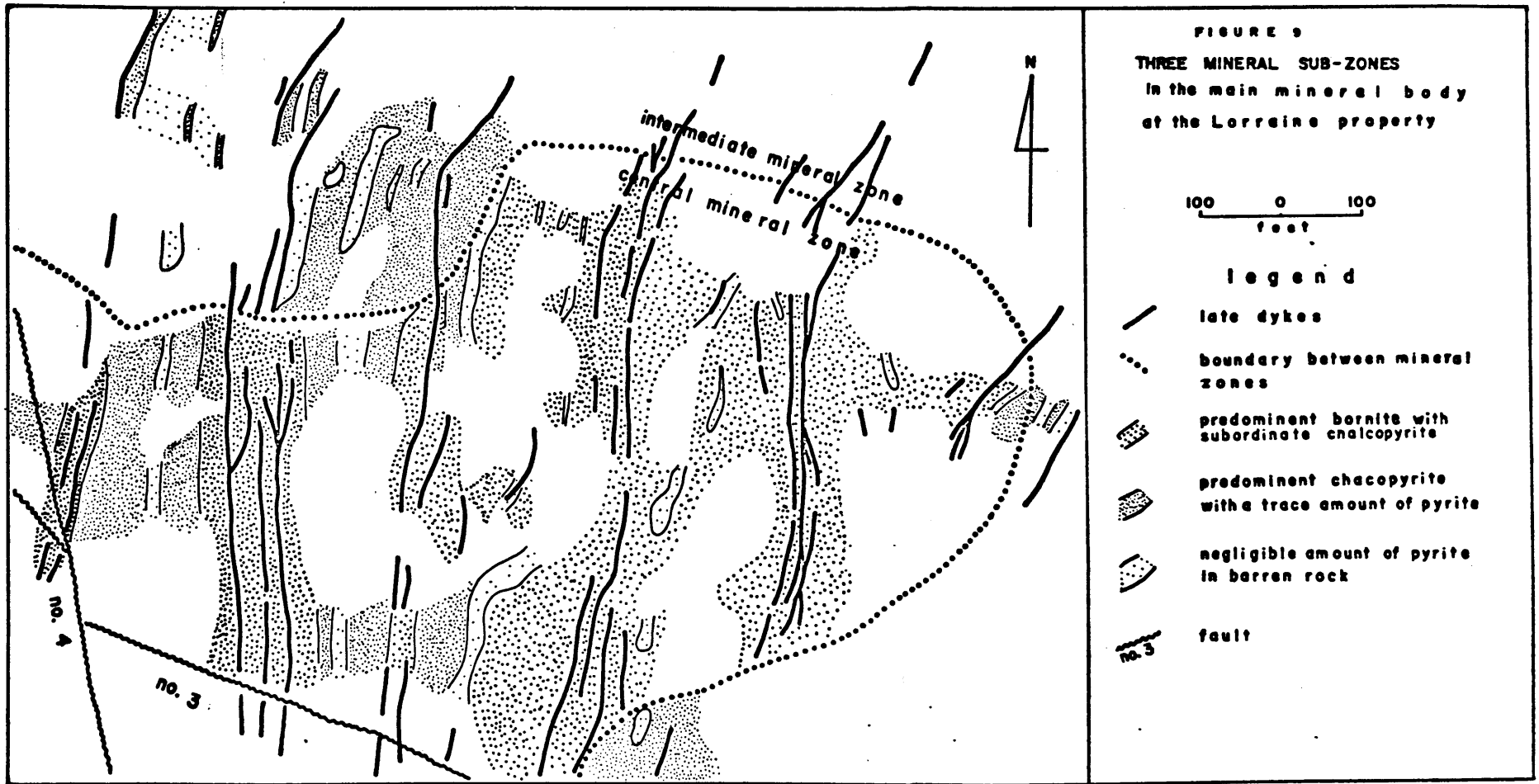
Pegmatite and aplite dykes have the general trend parallel to the attitude of the fractures striking in north 20 degrees east in the central mineral zone. Pegmatite and aplite

dykes are only sparsely mineralized with disseminated replacement of bornite and chalcopyrite. As mentioned before, however, pegmatite and aplite dykes appear to have been relatively unresponsive to copper mineralization. The phases of fenite immediately adjacent to the late dykes, are in general, more intensely fractured and better mineralized. The mineralized fractures are considered to have been formed as feather joints of the major joints and faults, most of which were filled with the late dykes. Some of them were formed probably simultaneously with intrusion of the dykes.

It is seen that copper-grade and assemblage of the primary sulphides varies as a function of the distance from the pegmatite and aplite dykes. The grade of the primary copper sulphides is increasing near the dykes. Three different assemblages of the primary sulphides could be recognized in order in the fenite host rock from contacts with the dykes outwards; *revised.*

1. predominant bornite with a subordinate amount of chalcopyrite.
2. predominant chalcopyrite with a trace amount of pyrite.
3. a negligible amount of pyrite in a barren rock (see Figure 9, p.67). It is suggested that the main channelway of the introduced ore fluid was closest to the dykes. The secondary copper oxides may have been modified by many other factors which are of later origin. However, the secondary minerals usually show the same relationship to the dykes as the primary mineralization.

This may further indicate that the dykes acted as a dam against ore fluids which escaped from the dykes and deposited



the ore minerals in the fractured fenites. In other words, the major part of the ore fluids found channelways other than through the dykes. It is also understood that the feather joints were developed in positions close to the major faults or joints better than away from them. Since mineralization is controlled partly by fracturing, better fractured rocks must have been introduced more ore fluids and better mineralized. However, except for the dyke-filling faults and their feather joints, all the faults and their related joints are known to have formed later than the mineralization, since fractured or pulverized ore minerals and no alteration minerals are developed on their planes. Therefore no control on the primary sulphide mineralization has been offered by them.

The mineralogical composition of rocks appear to have controlled partly the sulphide mineralization in combination with the fractures. The high grade disseminated sulphides occur uniformly throughout the small (commonly several feet across) disconnected lenses of the biotitized mafic fenites in the central mineral zone. Also the mineralization commonly occurs following the planar or linear structures which are usually defined by the alignment of the mafic minerals in the fenites. Even in hand specimen, the ore minerals are favorably concentrated in the mafic-rich part of the heterogeneous fenites. It is also observed under the microscope that the ore minerals are closely associated with the mafic minerals. As stated already, this is perhaps because the mafic-rich rocks are more loosely bonded, easily crushed and altered, making the rocks

more permeable or favorable for replacement. In contact with copper ore minerals, mafic, particularly biotite, grains are bent, crushed, and altered to be relatively loose aggregates of small grains of chlorite in many places. The ferromagnesian minerals in the fenites appear to have acted as numerous local "replacement centers"(3) which were permeable to admit the altering and mineralizing fluids.

### Genesis of Deposition of the Ore Minerals

In the Western Cordilleran region in British Columbia, metalliferous deposits are genetically associated with plutonic activity, and the intrusions directly responsible for the formation of ore minerals are always separated from the very large plutonic complexes(54). The mineralization at the Lorraine deposit would be considered as such a case; the mineralization occurred as a last phase of differentiation of the dioritic portion of the Hogem batholith magma which was a part of the Omineca plutonic activity.

It has been postulated in the previous sections that an alkaline magma body, possibly monzonitic to syenitic in composition existed beneath the early solidified diorite of the Hogem batholith. While the metasome from the alkaline magma diffused into the fractured diorite, fenitization was brought about to form four different phases of fenite. The magma in a closed system must have remained fluid as solidifying parts of it migrated down(38). Then, through the processes of differen-

tiation there must have been developed what has been referred to as an aqueous magmatic residue. The end of fenitization is placed at the time when the residual magma had been formed, and therefore the metasomatic fluids since then were solely from the residue. For this reason, the minerals created by the metasomatism of the fluids were considered as the hydrothermal minerals. The residual magma and the hydrothermal fluids are believed to be collinear descendants of the already described alkaline magma(2).

From the nature of the Lorraine altering fluids, it is known that as long as alkali feldspars were crystallizing out in the early stages of alteration - the stages of albitization and potassic(orthoclase) alteration, the magmatic residue was undoubtedly alkalic in character and reaction.

In later stages with the feldspars crystallized out, the residue became the ore solutions consisting mainly of water, silica, sulphur, and the metals of the ores. It seems reasonable to assume that in a closed system with a decreasing ratio of alkaline to acid constituents, the residue may have eventually become neutral or possibly acid in character(43). Quartz was crystallized following alkali feldspars from the cooling phase of the residual magma. Consequently the hydrothermal solution became more concentrated with the other constituents of metallic minerals by producing large amounts of biotite(?), alkali feldspar, and quartz.



It has been already noted that the ore solutions found their way into fractures in the host rocks. Therefore, the concentrated ore fluid is known to have followed fissures in the solid hood, then ascended to near surface zones where they deposited their mineral load(15, 24). When the volatilized constituents reached a zone in which pressure was suddenly reduced, stabilization of minerals may have been likely to ensue(13, 16, 21, 34). At the Lorraine property, faults, joints, and crystal boundaries, fractures and cleavage planes of minerals provided conduits through which mobilized or volatilized constituents might readily travel.

The early sulphur emanations of the ore fluid could react with the host rocks to give pyrite, which reacted with the later ore fluid to precipitate the other sulphides(27). At the Lorraine, pyrite was the first sulphide to be deposited. Decomposition of ferromagnesian minerals in the mafic-rich fenites may have supplied iron that combined with sulphur from the mineralizing(or altering) fluids of the early stage to form pyrite. The further alteration of the wall rock may also have reduced the sulphur ratio. Therefore, the ore fluid may have been trending toward the composition favoring deposition of the combined copper-iron sulphides, chalcopyrite and bornite(37, 38). The exsolution texture of chalcopyrite in bornite indicates that the sulphide fluid was cooling relatively slowly. The absence of pyrite in the bornite-chalcopyrite rich zones and the replaced disseminated grains of pyrite suggest the depletion or replacement of at least, some amount of pyrite by other

sulphide minerals. Such an origin may at least in part, account for the zoned pattern of the Lorraine deposit. However, the zoning may have been controlled in other way by the intensity of fracturing(5) in harmony with the effect of being close to the reservoir of the magmatic residue or the ore solution. At the Lorraine property, the zoning and paragenesis appear to be cogenetic, because they are only two different aspects of the same phenomenon(31, 32). At the Lorraine, the hydrothermal solution also removed the light silicates and oxides(slag) early and the progressively heavier sulphides later(15, 16, 25).

The age span of emplacement of the isolated intrusions in the Western Cordillera are known to be from 200 to perhaps 50 million years ago(53). The compilation of ages of the enclosing country rocks and member of deposits using the available data related, indicates that all of the major deposits in British Columbia are included in the group of Lower Jurassic and older, and many numbers(up to 20) of ore deposits occur in intrusive rocks ranging in probable age from late Upper Triassic through Lower Jurassic(28). The K-Ar age of  $170 \pm 8$  million years indicates that the possible age of the mineralization at the Lorraine property should be a little younger than or approximately same as  $170 \pm 8$  million years. Since the similar phases of alkaline intrusive masses occur in places throughout the region and are commonly related to copper minerals, perhaps this range of age indicates one "Copper-Metallogenetic Epoch" of the "Omineca Metallogenetic Province".

## Classification

The Lorraine deposit is characterized by the following aspects. It is of moderately large size and low copper grade. Mineralization was facilitated in fractured and hydrothermally altered host rocks. The late dykes or veins are spatially and genetically related to the mineralization. The intrusion of the late dykes marked the end of the igneous activity of the diorite magma. The metallization process took place during the last phase of hydrothermal activity. The grade of ore is dependent upon the degree of fracturing and the susceptibility to alteration of the host rocks, which in turn were functions of the physical and chemical properties of the host rocks. The ores are distributed zonally. All these features are common to most of the porphyry copper deposits in the western part of North America(46).

The majority of porphyry copper deposits have extensive leaching underlain by chalcocite-enriched zones(52), whereas at the Lorraine deposit there is neither deep surface leaching nor supergene enrichment possibly because the location of the deposit on a ridge has allowed mechanical weathering rather than chemical weathering. However, this may be an effect of climate as well as mineralogy, the ore being low in both pyrite and calcite. Nevertheless, there is considerable near-surface oxidation.

Lindgren(24) classified the disseminated copper deposits

into the mesothermal deposits, which he thought formed at intermediate temperatures from hydrothermal solutions genetically related to intrusive rocks. Lindgren believed the depth of cover overlying mesothermal deposits at the time of mineralization ranged from 4,000 to 12,000 feet and that temperatures of formation ranged from 175°C to 300°C. No typically hypothermal or epithermal minerals are found at the Lorraine. Ore and alteration minerals are fitted to those characteristic of the mesothermal deposit or probably the outer fringe of it.

However, it has been pointed out that the Western Cordilleran mineral deposits of porphyry type are closely associated with and commonly in granitic bodies intruded at relatively high level(54). In the thesis area, the Hogom diorite, older than 170±8 million years in age, is seen to have intruded the Upper Triassic and Upper Jurassic(?) Takla group, indicating that the diorite was a high level intrusion. Exsolution intergrowth of chalcopyrite with bornite was found to suggest a minimum temperature of deposition of 475°C in the previous section. Therefore, the best classification for the Lorraine deposit is perhaps xenothermal(6).

#### SUMMARY AND CONCLUSIONS

The writer has coordinated mineralogic, petrologic and structural features attempting to study the geological history of the Lorraine property area and particularly to shed

some light on the genesis of the mineral deposit.

The rocks in the vicinity of the Lorraine property area range in age from late Precambrian(?) to Cretaceous, consisting of the Wolverine complex, the Cache Creek group, the Takla group, and the Omineca intrusions.

The Lorraine property area is located within roughly the central part of the Hogem batholith which is the largest body of the Omineca batholithic complex. The Hogem batholith has been classified into two divisions. The first division, older, comprises chiefly mafic rocks containing little or no quartz. The second division, younger, consists of rocks with less than 30 percent dark minerals and with a significant amount of quartz. Two main syenitic bodies, called the Chuchi Lake syenite and the Duckling Creek syenite belonging to the first division, occur in the Hogem batholith.

The thesis area lies roughly in the north eastern part of the Duckling Creek syenite comprising both magmatic and metasomatic syenites. The rocks of the thesis area consist of "metasomatic syenites" or "fenites" formed by the metasomatism of the fractured Hogem diorite. Metasome is believed to have been derived from a hypothetical alkaline magma formed beneath the diorite.

While the fenitization was going on, the alkaline magma probably could have been differentiating to generate

eventually a residual magma, a part of which could escape and form pegmatite and aplite either in the fenitized rocks or in adjacent unfenitized country rock, following the prepared fractures.

A potassium-argon date on the biotite,  $170 \pm 8$  million years corresponding to Lower Jurassic may indicate the minimum age of the fenites and the maximum age of the sulphide mineralization at the Lorraine property. The Duckling Creek syenite including the Lorraine "metasomatic syenite" can be considered to represent a phase of the Hogem batholith, and it is improbable that the syenitic bodies are much younger than the main Hogem batholith. The age may indicate the time point separating the first division and the second division of the Hogem batholith.

Faults and joints found in the thesis area have been divided on the basis of attitude and relative age into five groups.

The major period of rock alteration was contemporaneous with or immediately followed crystallization of the dykes. The altering fluid is considered to have been the last phase of magmatic crystallization of the unexposed alkaline magma. The dominant minerals characteristic of the successive stages of alteration are as follows: 1. biotite, 2. albite, 3. orthoclase, 4. quartz, 5. sericit, 6. chlorite, and 7. epidote. The active fluid at the time of hydrothermal alteration contained concentrations of soda, potash, silica, hydrogen sulphide, water and

a minor amount of lime.

The primary sulphides recognized at the Lorraine deposit are chalcopyrite, bornite and pyrite. The mineral deposit possesses no noticeable gossan, but the secondary copper minerals such as covellite, chalcocite, azurite and malachite occur at the deposit.

The deposit demonstrates a zoned pattern according to the primary sulphide mineral assemblage.

The dykes, mafic rich rocks and fractures were the main control factors of mineralization. /

The hydrothermal solution concentrated with the constituents of ore minerals by removing large parts of biotite, alkali feldspar, and quartz, followed fractures in the host rock, then ascended to near-surface zones. The sulphur emanations of the mineralizing fluid could react with the iron generated by decomposition of the mafic minerals in the host rock to form pyrite. The reduced sulphur ratio may have provoked the composition of the mineralizing fluid favoring deposition of bornite and chalcopyrite which replaced some of the early formed pyrite. The paragenesis and zoning appear to be cogenetic.

The best classification for the Lorraine deposit is perhaps xenothermal(6).

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**PHOTOGRAPHS**



Photograph 1. a. A helicopter used in the investigation of the Lorraine property area(thesis area)



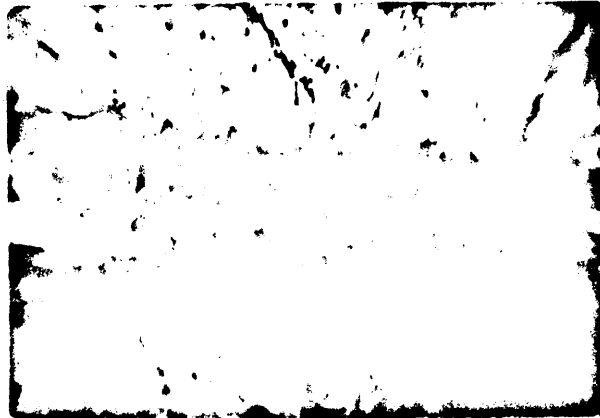
Photograph 1. b. Aerial view of the Lorraine property area.



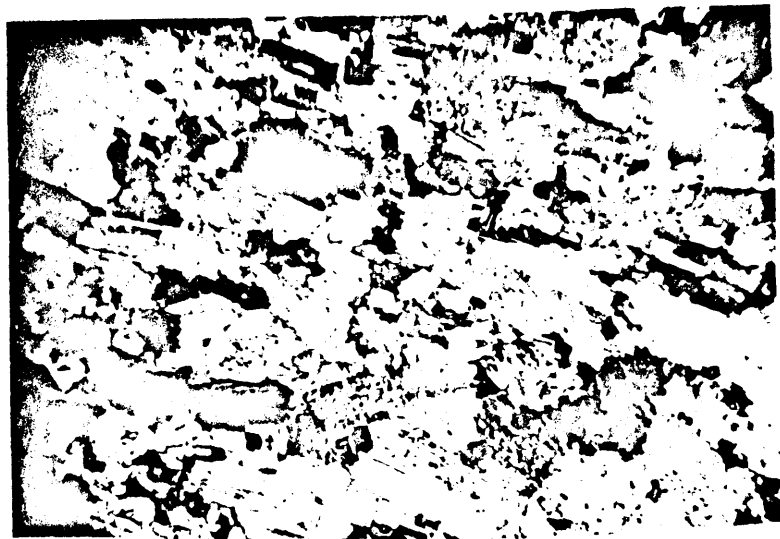
Photograph 2. Talus blocks covering the main mineral body.



Photograph 3. Quartz vein containing ore minerals.



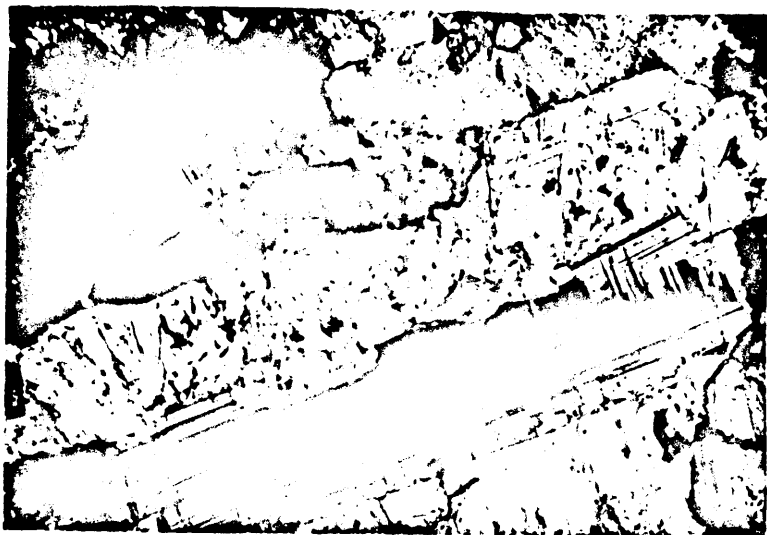
Photograph 4. Bornite associated with a minor amount of chalcopyrite forms veinlets along fractures in the main mineral body. x 1.



Photograph 5. Weakly subtrachytoidal arrangement chiefly of elongate feldspar grains along a preferred orientation in the monzonitic fenite. Thin section, crossed nicols, x 4.



**Photograph 6.** Weakly porphyritic texture with a few of feldspar phenocrysts broken along margin in the monzonitic fenite. Thin Section, crossed nicols, x10.



**Photograph 7.** Faintly twinned or untwinned albite replacing approximately half portion of an oligoclase grain in the monzonitic fenite. Thin section, crossed nicols, x 40.

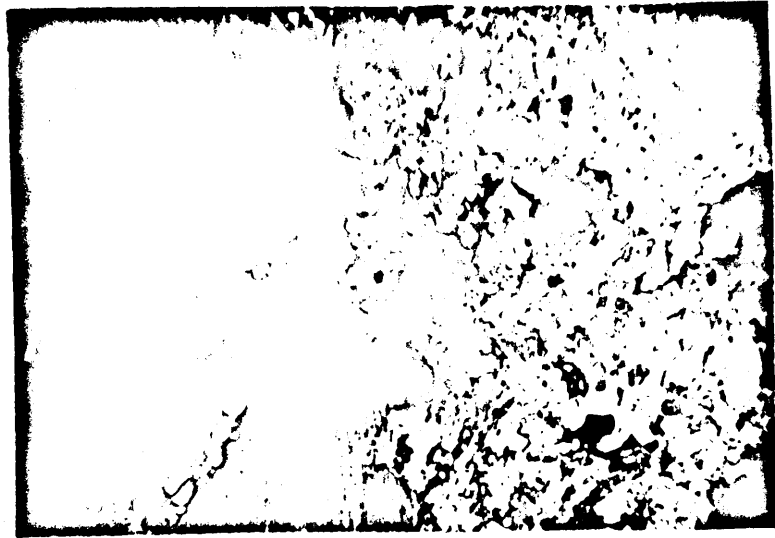




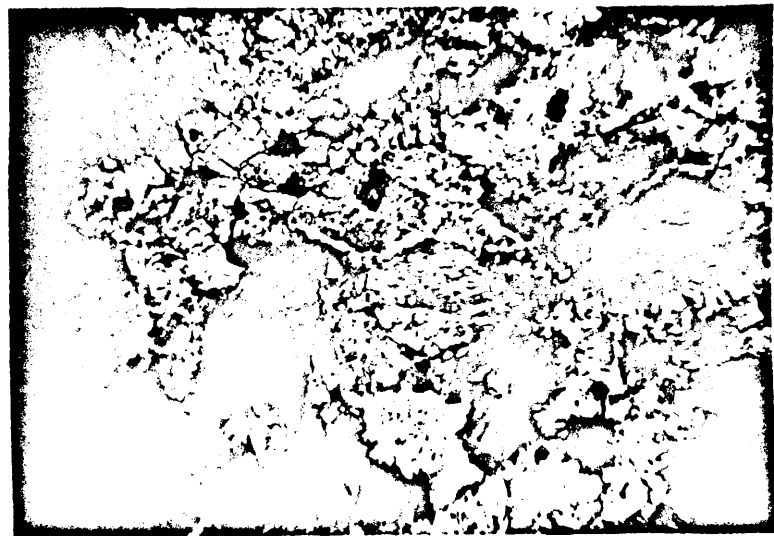
**Photograph 8.** Grains of albite-twinned oligoclase(o), untrinned albite(a) and microcline(m) in the monzonitic fenite pseudomorphous after probably a fractured grain of andesine which was in the diorite. Thin section, crossed nicols, x46.



**Photograph 9.** Anhedral, small grains of aegirine(px) mainly along the borders or fractures of feldspar grains in the monzonitic fenite. Thin section, crossed nicols, x10.



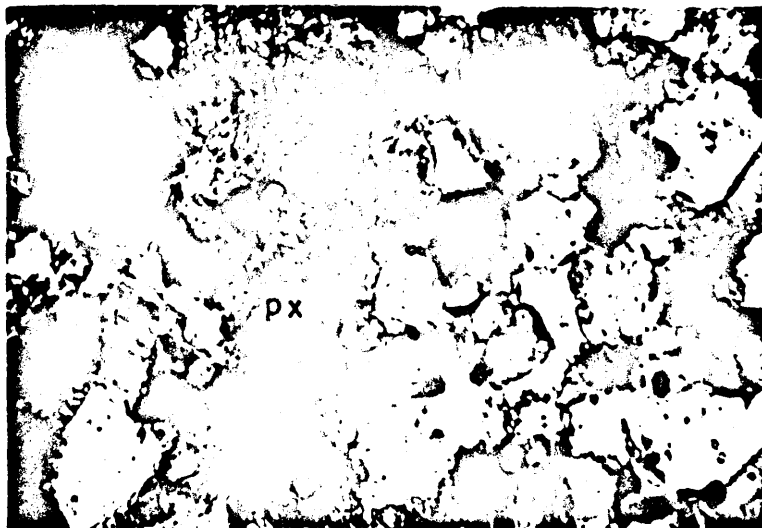
**Photograph 10.** Weakly porphyritic texture with a few of medium-grained microcline grains much broken along borders in a limited part of the syenitic fenite. Thin section, crossed nicols, x10.



**Photograph 11.** Highly anhedral, fine-to medium-grained potash feldspar commonly intergrown with stringer-shaped albite in the syenitic fenite. Thin Section, crossed nicols, x10.



Photograph 12. Aegirine(px) occurring as anhedral, small grains or as aggregation of the grains in clots mainly between the grains of alkali feldspar in the syenitic fenite. Thin section, crossed nicols, x10.



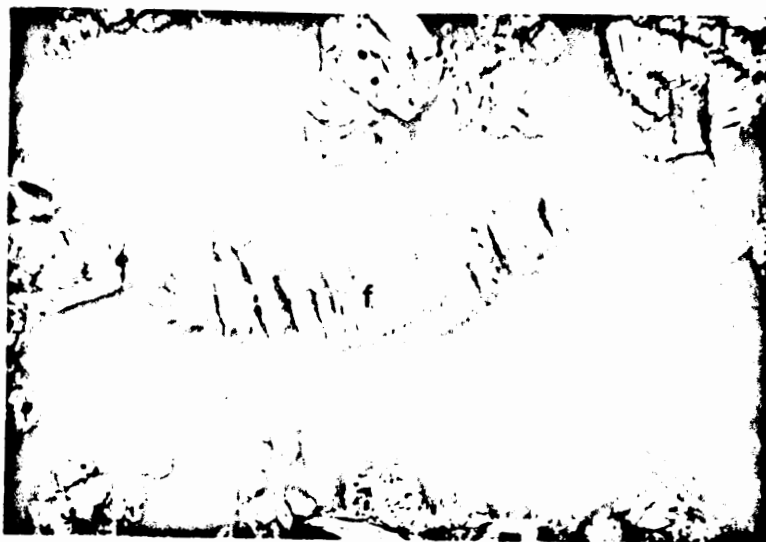
Photograph 13. Aggregation of fine-grained aegirine(px) forming a veinlet along a fracture plane in the syenitic fenite. Thin section, crossed nicols, x10.



**Photograph 14.** Replacement of alkali feldspar(f) by numerous fine-grained aegirine(px) showing a spongy texture and causing a cloudy appearance of alkali feldspar in the syenitic fenite. Thin section, open nicols, x10.



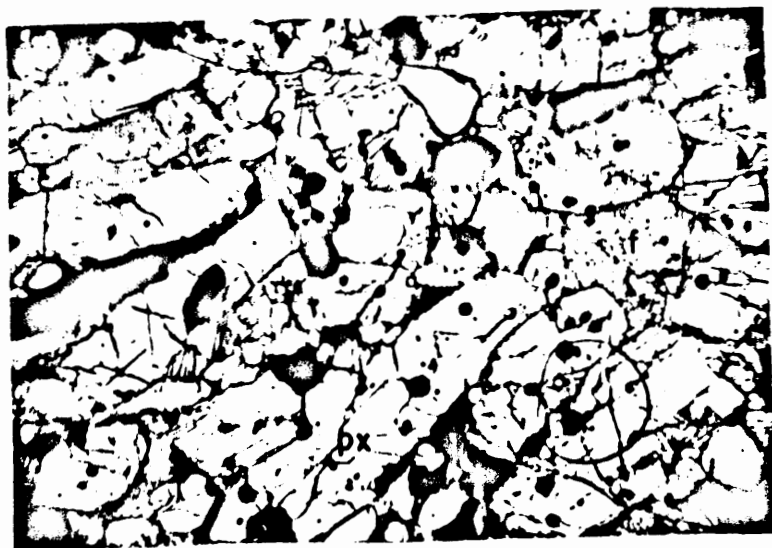
**Photograph 15.** Anhedral to subhedral, medium-grained aegirine(px) forming porphyroblasts in the melanocratic fenite. Small relict grains of feldspar(f) scattered in them. Thin section, crossed nicols, x10.



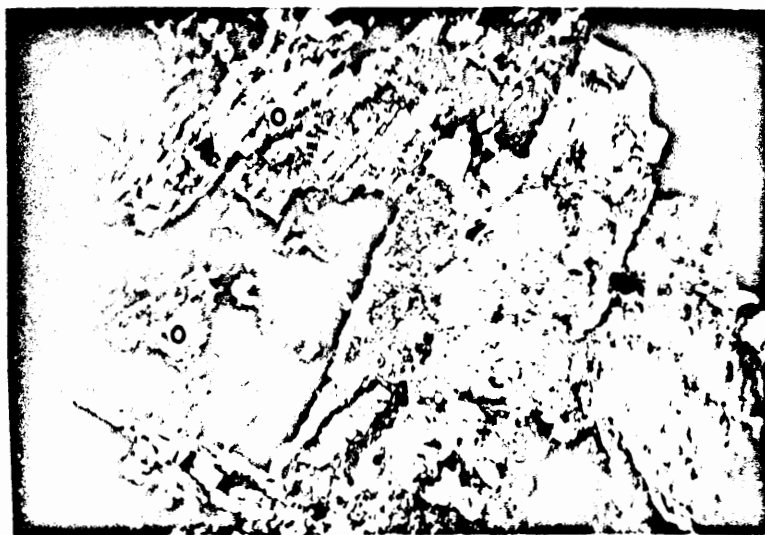
Photograph 16. The core and albitized rim of a potash feldspar grain(f) remain relatively fresh in the hypermelanic fenite. Thin section, crossed nicols, x 10.



Photograph 17. Cloudy potash feldspar(f) later hydrothermally altered to sericite(s) in association with copper minerals(or) in the hypermelanic fenite. Thin section, crossed nicols, x 10.



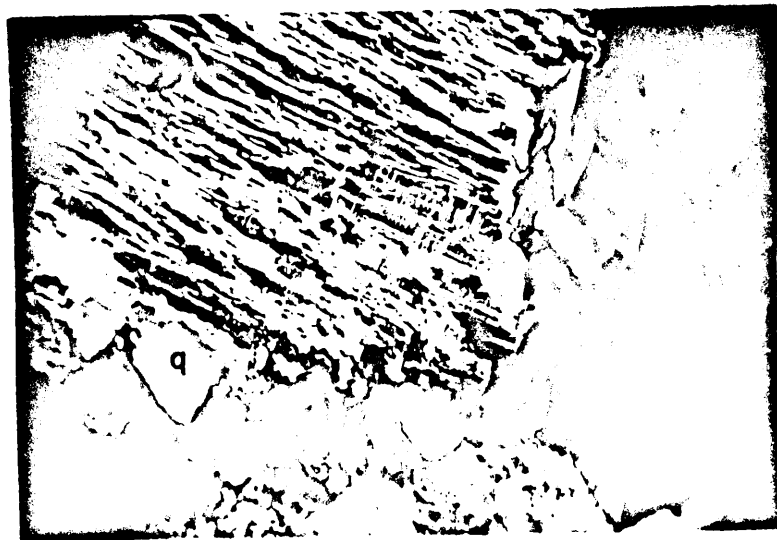
Photograph 18. Prismatic grains of aegirine(px) arranged in a subparallel orientation in the hypermelanic fenite. A very small amount of clouded potash feldspar(f) composes the interstitial parts of the rock. Thin section, open nicols, x4.



Photograph 19. Altered oligoclase(o) replacing microcline(m) in the fractured or shattered syenitic pegmatite. Thin section, crossed nicols, x4.



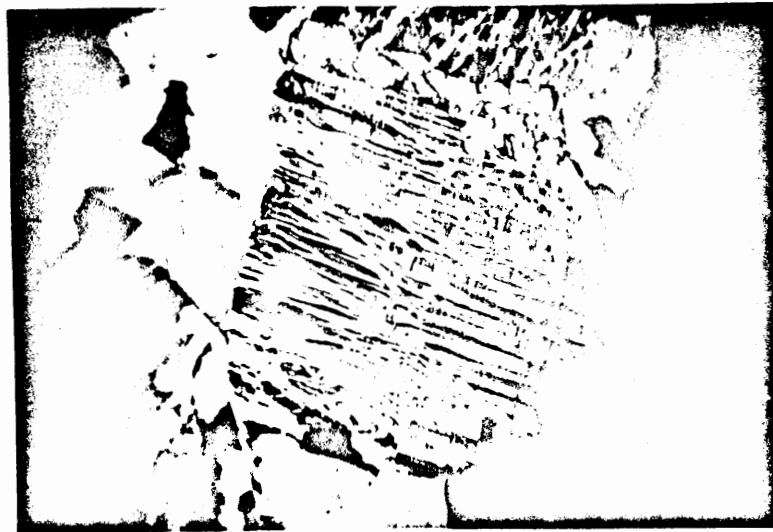
Photograph 20. Albite(a) replacing the border of oligoclase(o) remains fresh in the syenitic pegmatite. Thin section, crossed nicols, x 4.



Photograph 21. Anhedral grains of quartz(q) replacing the middle parts of or along the grain borders and fractures of microperthite in the aplite. Thin section, crossed nicols, x 10.

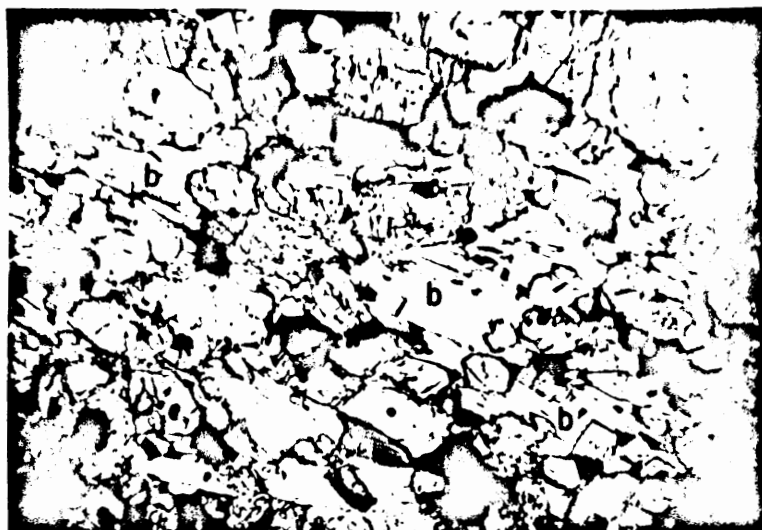


Photograph 22. Anhedral grains of quartz(q) mainly along the grain borders of the fractured microperthite forming graphic texture in part in the aplite. Thin section, crossed nicols, x10.



Photograph 23. Albite extending beyond the crystal boundary of microcline in microperthite of the granitic aplite. Thin section, crossed nicols, x10.





Photograph 24. Biotitization(b) in the hypermelanic fenite. Thin section, crossed nicols, x10.



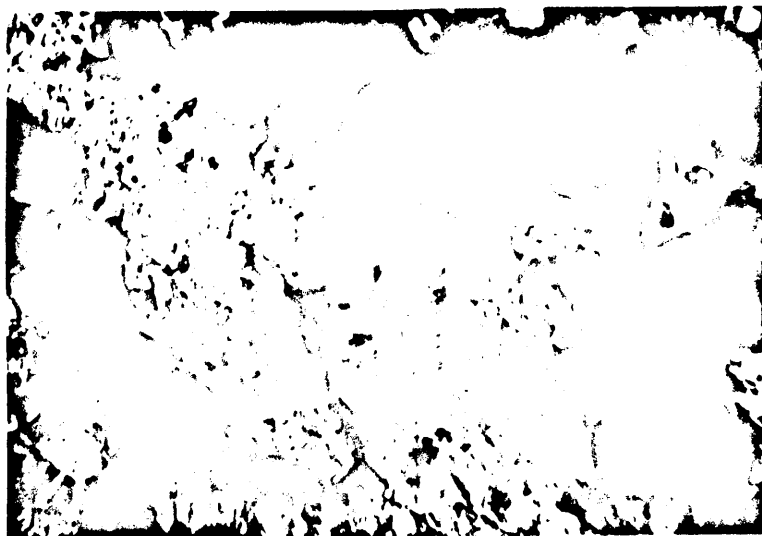
Photograph 25. Biotite(b) replacing fine-grained feldspar matrix and a phenocryst of aegirine mainly along the grain border and fracture, in the melanocratic fenite. Thin section, open nicols, x 4.



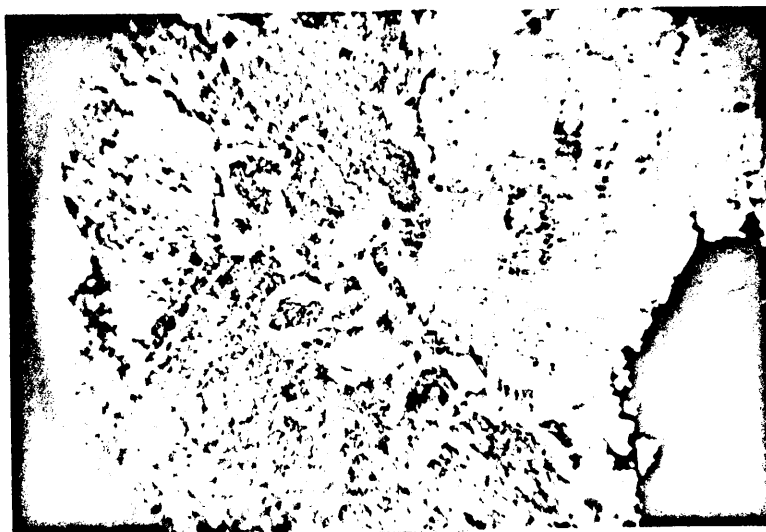
Photograph 26. A pokilitic grain of biotite(b) replacing feldspar(f) and aegirine(px) mainly along grain borders or fractures in the monzonitic fenite. Thin section, crossed nicols, x10.



Photograph 27. Small lathlike grains of albite(a) replacing microcline(m) are as fresh as the albite(a) rimming the altered oligoclase(o) in the syenite-pegmatite. Thin section, crossed nicols, x4.



Photograph 28. Albitization facilitated along grain borders and fractures of the feldspar grains in the syenitic fenite. Thin section, crossed nicols, x 10.



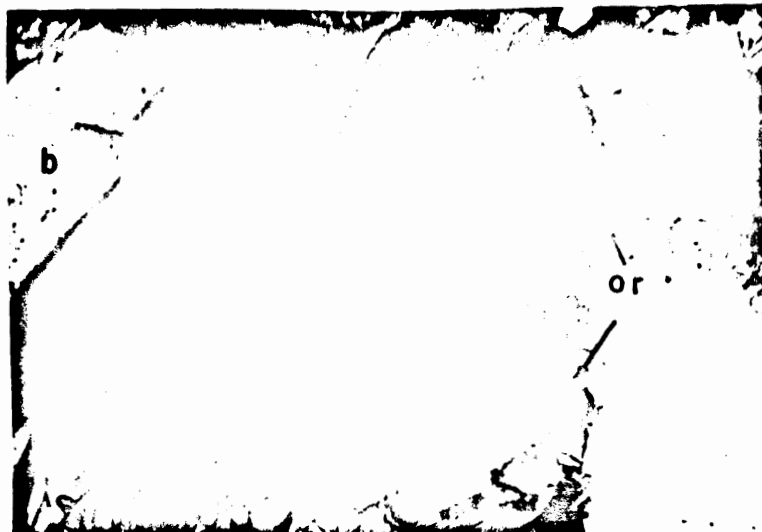
Photograph 29. Feldspar grains surviving the turbid sericitization in the albitized rim in the syenitic fenite. Thin section, open nicols, x 10.



Photograph 30. Close-up of an albite rim surviving the sericitization in a feldspar grain. Very fine-grained scales of sericite pseudomorphous after a grain of feldspar. Thin section, crossed nicols, x 40.



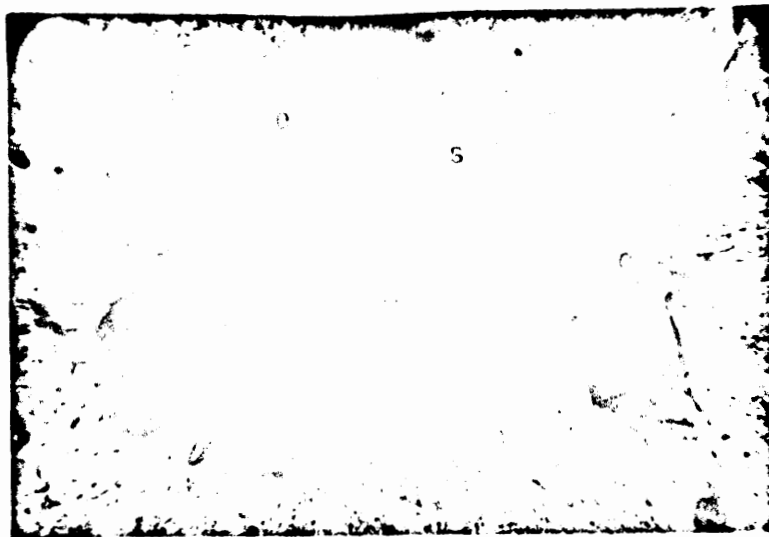
Photograph 31. Anhedrous, fine-grained muscovite(mu) associated with scaly sericite. Thin section, crossed nicols, x 10.



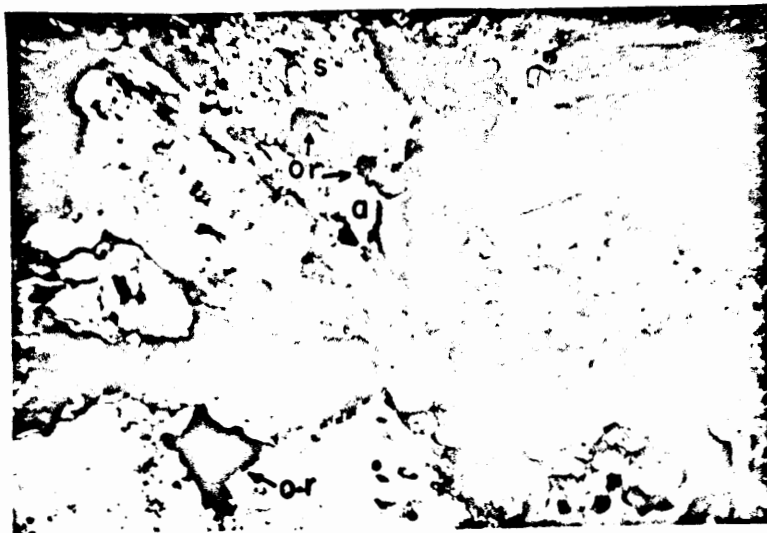
Photograph 32. Chlorite(c) replacing mainly biotite(b) and being associated with ore mineral(or). Thin section, crossed nicols, x 10.



Photograph 33. Chlorite(c) replacing feldspar(f) and being associated with a thin film of epidote(e) and a grain of ore mineral(or). Thin section, crossed nicols, x 40.



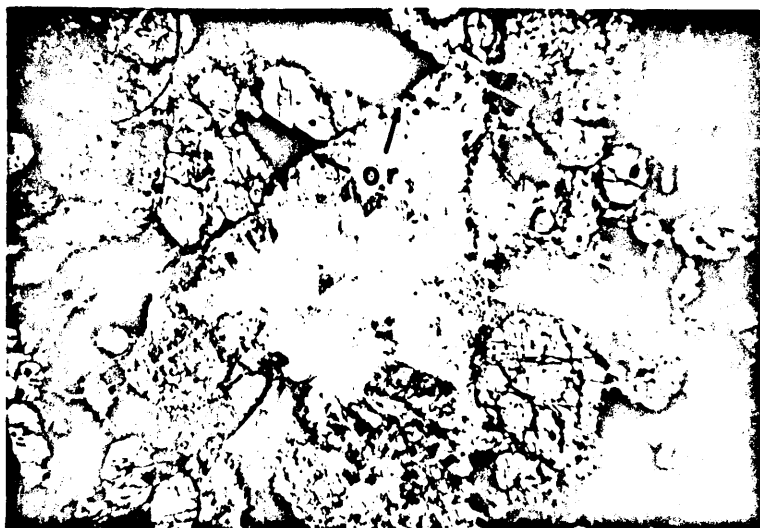
**Photograph 34.** Epidote(e) and sericite(s) surrounding two grains of ore mineral(or) and associated chlorite(c) pseudomorphous after biotite(b). Thin section, crossed nicols, x40.



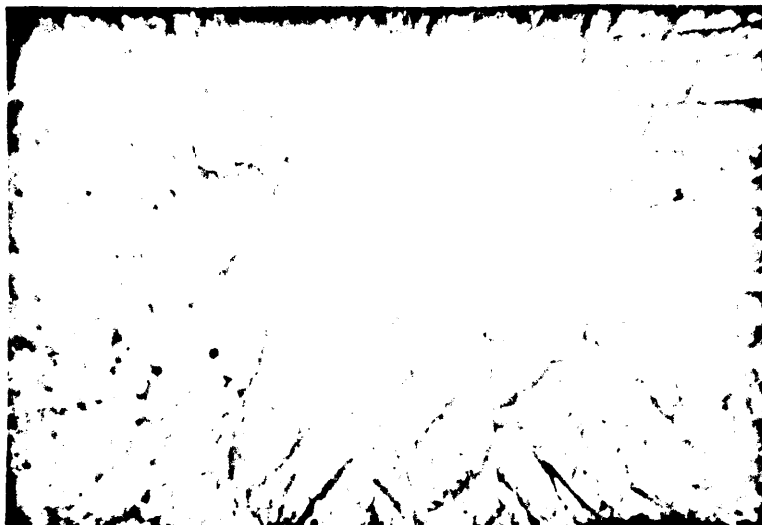
**Photograph 35.** Two grains of ore mineral(or) not in contact with alteration mineral, and two smaller grains of ore mineral(or) penetrating sericite(s) and albite(a) respectively. Thin section, crossed nicols, x10.



Photograph 36. Ore mineral(or) replacing biotite(b) which replaced aegirine(px). Thin section, crossed nicols, x40.



Photograph 37. Ore mineral(or) disseminated along the grain borders of rock-forming minerals. Thin section, crossed nicols, x10.

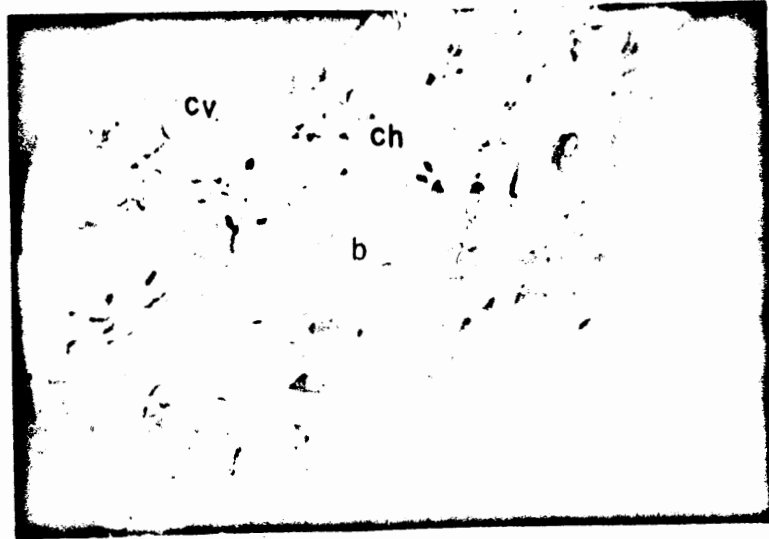


Photograph 38. Ore minerals disseminated along the grain borders of the rock-forming minerals corrode the contact part. Thin section, crossed nicols, x 40.

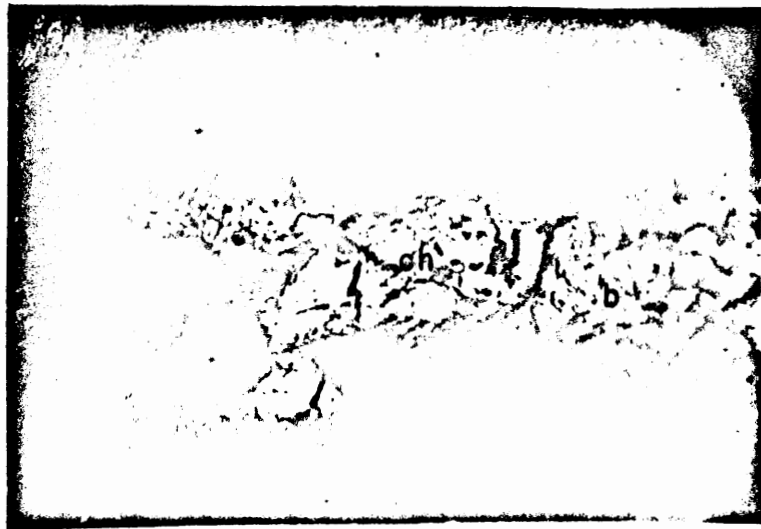


Photograph 39. Ore mineral penetrating the middle part of rock-forming minerals, feldspar(f) and aegirine(px) Thin section, crossed nicols, x 40.

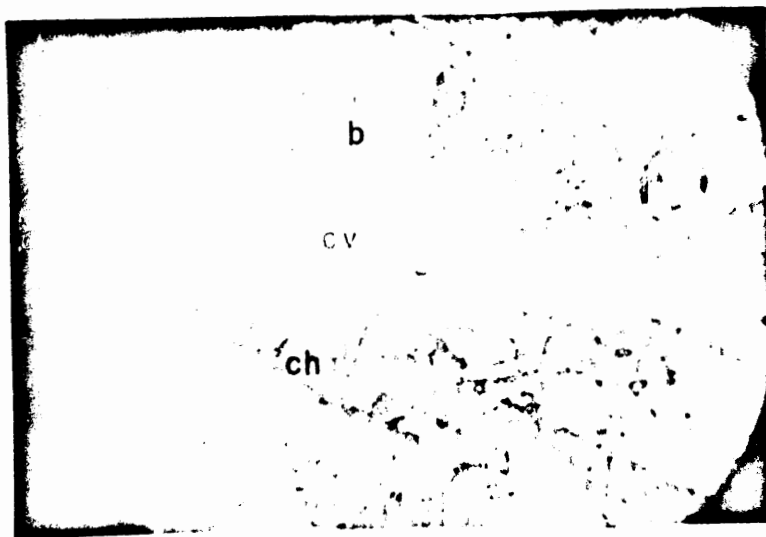




**Photograph 40.** Chalcopyrite(ch) intergrown with bornite(b).  
Covellite(cv) replacing the grain border.  
Polished section, reflective light, x 320.



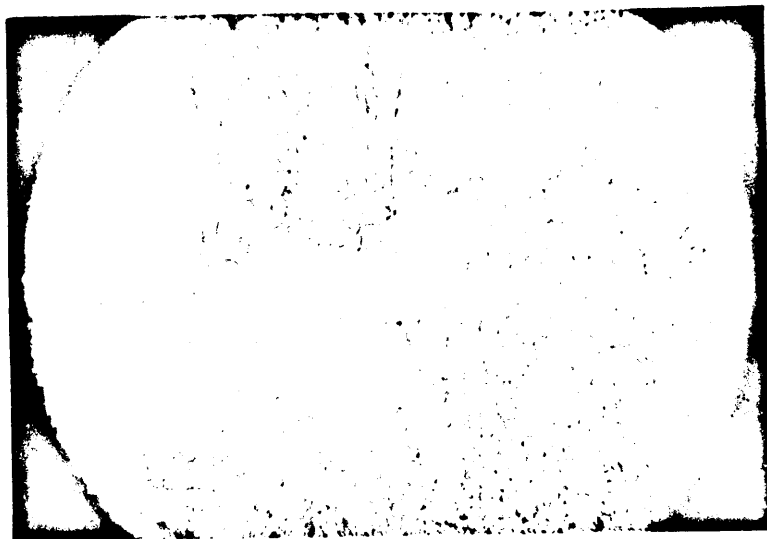
**Photograph 41.** Massive stringer of chalcopyrite(ch) including  
a grain of bornite(b) along a fracture.  
Polished section, reflective light, x 25.



Photograph 42. Exsolution lamellae of chalcopyrite(ch) in bornite(b). Covellite(cv) replacing bornite but not some of the chalcopyrite lamellae. Polished section, reflective light, x 320.



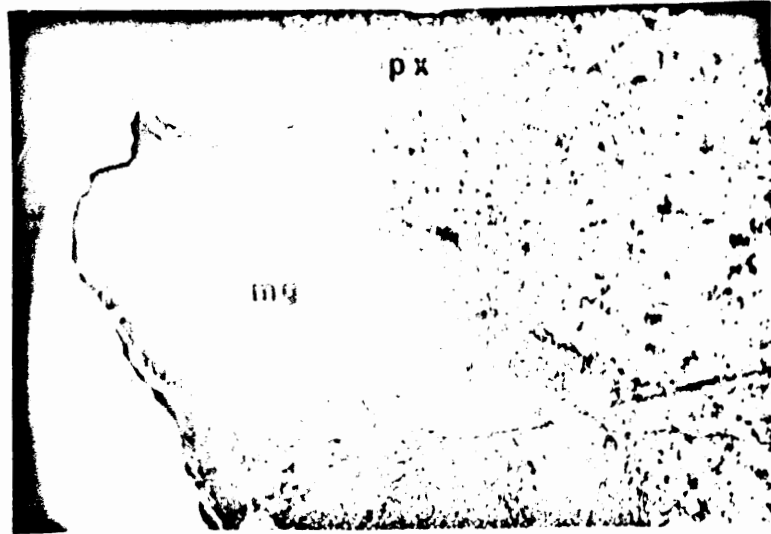
Photograph 43. Massive stringer of bornite(b) including a grain of chalcopyrite(ch) along a fracture. Polished section, reflective light, x 25.



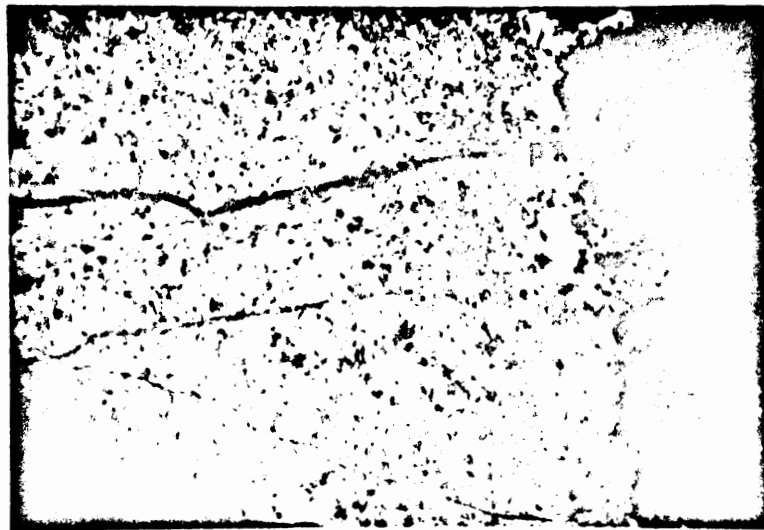
Photograph 44. Fractured grains of pyrite in a sheared rock (cut by a quartz vein) Polished section, reflective light, x 40.



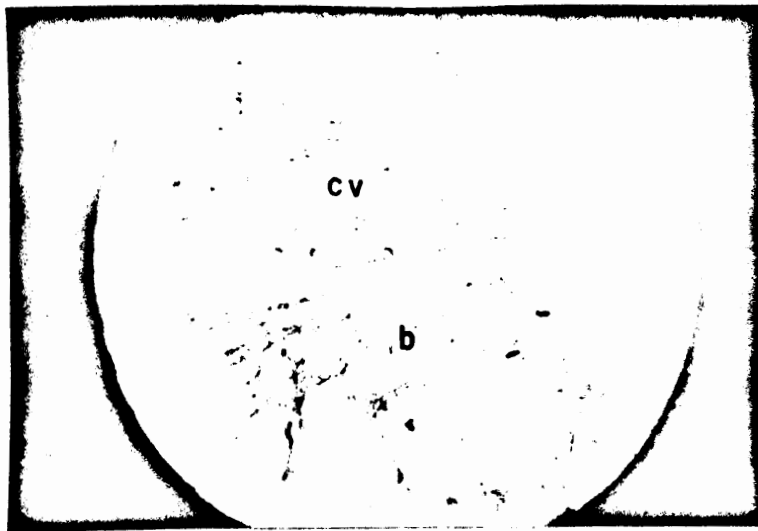
Photograph 45. A subhedral grain of pyrite(p) partly replaced by chalcopyrite(ch). Polished section, reflective light, x 400.



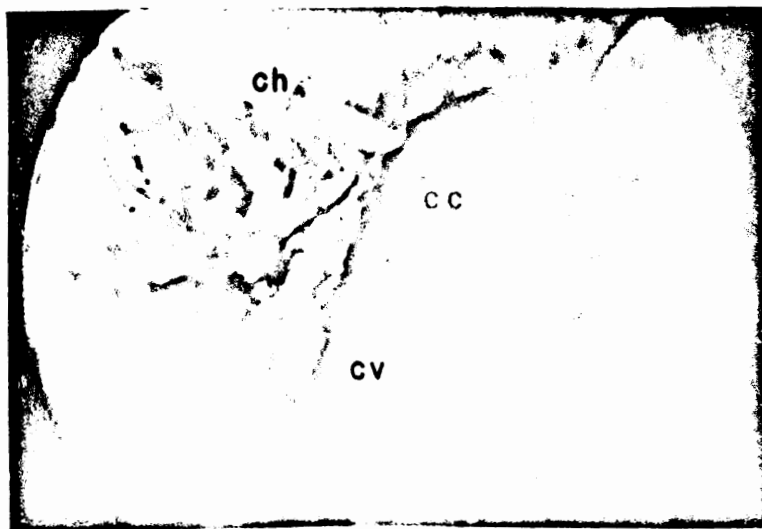
Photograph 46. Magnetite(mg) forming a vein and rimmed by and including segregated aegirine(px). Plain light, x 25.



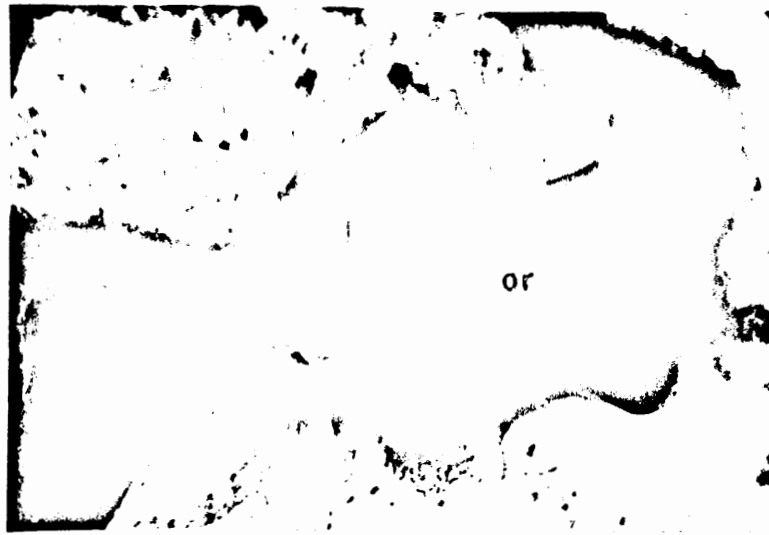
Photograph 47. Veinlets of aegirine(px) along fractures, branching from the segregated aegirine between the magnetite(mg) and the host rock. Plain light, x 25.



Photograph 48. Covellite(cv) replacing bornite(b) along fractures. Polished section, reflective light, x 80.



Photograph 49. Chalcocite(cc) replacing covellite(cv) and chalcopyrite lamellae(ch) which probably survived replacement by covellite. Polished section, reflective light, x 320.



Photograph 50. Limonite(1) forming a rim texture around cu-mineral(or). Thin section, open nicols, x40.

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G.S.K. report on Coal Fields, 1964(no. 5), p.21-44.

Geology and Coal Resources of Samchok Coal Field,  
G.S.K. report on Coal Fields, 1964(no. 5), p.45-68.

Report on the geology of the Sanan Coal mine area,  
G.S.K. report on Coal Fields, 1964(no. 5), p.69-77.

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