GEOLOGY OF THE OX LAKE Cu - Mo PORPHYRY DEPOSIT

by

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Date May 16, 1974
ABSTRACT

The Ox Lake copper-molybdenum deposit is localized in the margin and contact zone of a Late Cretaceous granodiorite porphyry. Hazelton Group rocks, including a lower Felsic Tuff, a middle Andesitic Tuff and an upper Sandstone-Siltstone, are country rocks in the area.

The granodiorite porphyry is nearly circular in cross-section with a radius of 1500 feet and plunges fifty degrees west. Intrusive breccia occurs mainly along the southwestern contact of the porphyry.

Nine vein types are grouped into four stages of vein development based on relative ages determined from vein intersections. They are:

- **Stage I** Potassic and Biotite Veins
- **Stage II** Propylitic and Pyrite-Chalcopyrite Veins
- **Stage III** Quartz-Molybdenite and Quartz Veins
- **Stage IV** Calcite, Gypsum and Sphalerite Veins

Potassic, albitic, propylitic, sericitic and intermediate argillic alteration zones are related to host rock and position around the intrusion. In the east, an outer potassic alteration zone is separated from the intrusion by a zone of albitic-propylitic alteration. Three propylitic assemblages are distributed zonally about the intrusion. Sericitic and intermediate argillic alteration occur only in rocks of acidic composition. The intrusion is unaltered except within 100 feet of its western contact.
Brecciated and unbrecciated hornfels west of the intrusion contains the highest and most persistent grades of copper and molybdenum—about 0.5 per cent copper and 0.02 per cent molybdenum. Within this zone, feldspar porphyry contains two to five times the molybdenum content and about one-half the copper content of adjacent andesitic rocks.

The Ox Lake porphyry deposit is one of a group having similar geological features, that includes Len, Fab, Laura and Bergette deposits. All contain copper and molybdenum mineralization and have apparent K-Ar ages of 83 ± 3 my, except for the Bergette with an age of 76.7 ± 2.5 my [Carter and Harakal personal communication].
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Supervision of the thesis was provided by the late Dr. J. Gower, Dr. J. Chamberlain, and Dr. A.J. Sinclair. Their guidance and assistance throughout the study has been of great value.

Unpublished apparent K-Ar ages were generously provided by Mr. N. Carter of the British Columbia Department of Mines and Petroleum Resources and Mr. J. Harakal of the Geophysics Department, at the University of British Columbia.
Frontispiece

View looking northeast over Ox Lake towards Tahtsa Reach on the left and Ootsa Lake in the centre distance.
CHAPTER I

INTRODUCTION

The Ox Lake granodiorite porphyry, in west central British Columbia, is associated with low-grade copper-molybdenum mineralization. The purpose of this thesis is to describe the geology of the deposit and examine its genesis.

Chapter II describes the geology outlined above under the headings of Regional Geology, Local Geology, Metamorphism and Structure. Hazelton Group volcanics are divided into three units and their distributions, lithologies and certain primary structural features are discussed in some detail. Intrusive rocks include granodiorite, diorite and basic dykes. An intrusive breccia related to the granodiorite is also described separately. The section on metamorphism outlines textures related to hornfels development around the granodiorite and diorite. Large scale structures such as major lineaments and doming are discussed in the section on structure.

Chapters III, IV, and V describe veining, alteration and mineralization, respectively. As these features are closely related, an attempt to show the significance of each is made in a discussion following each chapter. Nine vein types are described and grouped into four stages of vein development. Five alteration types are described and related where possible to specific vein types. Mineral-
Figure 1  Location map of the Ox Lake copper-molybdenum deposit
ization is described and zoning of Cu and Mo is shown to be related to rock type, veining and alteration.

Chapter VI compares the Ox Lake deposit with other Cu-Mo deposits on a regional scale, and summarizes the work of others on K-Ar dating of mineralized intrusions.

Chapter VII synthesizes conclusions reached in previous chapters and presents a summary conclusion on the origin of the Ox Lake Cu-Mo deposit.

LOCATION: (53° 40.2'N; 127° 03'W)

Ox Lake is two miles south of Tahtsa Reach and four miles east of Huckleberry Mountain in the northern limit of Whitesail Range seventy miles southwest of Smithers, B.C. (Figure 1). The lake is approximately one-half mile long lies at an elevation of 3,080 feet and is drained by a small creek at its north end. Locally, hills rise to 3,500 feet compared with the 2,800 foot elevation of Tahtsa Reach, but peaks in Whitesail Range rise to elevations of over 6,500 feet. The hills are thickly timbered.
ACCESS

A three-mile-long "cat" road leads south from the south shore of Tahtsa Lake to the property at Ox Lake. This road can be reached by float-equipped aircraft from several bases such as those at Smithers and Burns Lake both seventy miles distant. The road is also accessible by boat via the Tahtsa Lake road from Houston to Tahtsa Reach, or via several other roads further east on Ootsa Lake.

HISTORY

Exploration in the general area began with Alexander Mackenzie's voyage to the Pacific in 1793. In the late nineteenth century, the area was visited by several members of the Geological Survey of Canada, notably G.M. Dawson in 1875, and James Richardson in 1879. The beginning of the twentieth century saw the arrival of settlers to the shores of Ootsa Lake. Even with the building of the railway and a paved highway to the east with gravel roads into the area, the settled area has not grown west from Ootsa Lake. The building of Kenny Dam on the Nechako River in 1951 to 1952 by the Aluminium Company of Canada Limited, as part of the Kemano power project, has flooded many of the lakes, thereby providing easy water transport through much of the area.

Geological mapping has been carried out by the Geological Survey of Canada and the B.C. Department of Mines over the past 100 years. Mineral exploration began soon after the turn of the century.
and continued intermittently to the present day. The main interest in
the area has been with gold, lead-zinc-silver, tungsten and high grade
copper deposits, but since the late 1950's interest has turned to the
search for low-grade, large-tonnage "porphyry" deposits of which the
Ox Lake Cu-Mo deposit is an example.

The Ox Lake deposit was found in 1968 as a result of geo-
chemical silt sampling by Silver Standard Mines and American Smelting
and Refining Co. Follow-up prospecting of a copper anomaly from silt
taken from the stream draining Ox Lake led to the discovery of disseminated
chalcopyrite and molybdenite in the Ox Lake intrusion and surrounding volcanic rocks. Eleven diamond drill holes, drilled in the fall
of 1968, outlined a mineralized zone around the western side of the Ox Lake intrusion. An additional twenty-three holes were drilled in 1969
to better outline this zone and to test other areas near Ox Lake. A prominent gossan associated with a Pb-Zn-Ag vein occurs on a bluff overlooking Ox Lake. The author spent ten days on the property in the
fall of 1969 to collect core and rock samples for material for this thesis.
CHAPTER II

GENERAL GEOLOGY

REGIONAL GEOLOGY

The following summary of the regional geology is taken from Souther and Armstrong [1966] except where otherwise noted. The Ox Lake granodiorite intrudes sedimentary and volcanic rocks of the Takla-Hazelton Assemblage which developed from submarine and subaerial volcanism in the Nechako Trough. (Figure 2). Much volcanoclastic material, derived from the erosion of volcanic islands, is interlayered with the volcanics. Takla Group rocks have an upper Triassic to Lower Jurassic age and Hazelton Group rocks a Middle Jurassic age.

In Whitesail Lake map area the Hazelton group comprises interbedded volcanic and sedimentary rocks over 11,000 feet thick. [Duffell, 1959]. The most common rock types are volcanic breccias and tuffs with sedimentary and intermediate to basic flow rocks less common than the fragmental volcanics. Duffell [1959] separated lower and upper volcanic units by a middle marine sedimentary unit.

The main Coast Range Batholithic Complex borders the Takla-Hazelton assemblage to its east. Many small intrusions believed related to the Coast Range intrusions intrude the Takla-Hazelton rocks as far east as the Pinchi Geanticline. These intrusions were emplaced from the end of Triassic time to at least Oligocene time.
Figure 2 Diagrammatic restored sections illustrating the accumulation and interrelations of the Takla-Hazelton assemblage. After Souther and Armstrong [1966]
Figure 3 Above: Oblique drawing of topography and general geology. Below: Detailed geology projected from drill holes onto plane of projection shown in top diagram.
Metamorphism of the Hazelton group is typically lowgrade with epidote, albite and chlorite, the most common alteration products. More intense alteration exists near contacts with Coast Range Intrusions.

Structures trend northwest. All rock units are folded to some degree, usually to broad open folds following the northwest trend. Faults more-or-less paralleling fold axes accentuate the northwest trend. The possible existence of more intense folding and major faults might be obscured by the lack of both marker beds and better exposures.

LOCAL GEOLOGY

Hazelton Group rocks at Ox Lake are intruded by a diorite and granodiorite stock and by basic dykes. The position of the Hazelton Group rocks within the general stratigraphic column is unknown. Figure 3 is an oblique drawing of the geology at Ox Lake based on field observations and diamond drill hole data. Appendix I is a more detailed geology and sample location map.

1. Hazelton Group

Hazelton Group at Ox Lake is subdivided by the writer into three units: (1) Felsic Tuff; (2) Andesitic Tuff; and (3) Sandstone-Siltstone unit. The contact between the lowermost Felsic Tuff and
Figure 4  Schematic stratigraphic column of Hazelton Group illustrating interpreted interrelations of units. Sandstone-Siltstone dips steeply SW
overlying Andesitic Tuff is gradational over several hundred feet. The uppermost Sandstone-Siltstone is distinctly different from the lower two units and might be separated from them by an unconformity. Figure 4 is a schematic stratigraphic column of the Hazelton Group at Ox Lake.

(a) Felsic Tuff

Outcrops of the Felsic Tuff extend at least three thousand feet east and northeast of Ox Lake. Of the approximately one thousand foot section, an estimated 50 per cent is feldspar porphyry, 40 per cent a pale-grey siliceous tuff, and 10 per cent mafic crystal tuff. The base is not exposed and the top is a gradational contact with the Andesitic Tuff. The top of the feldspar porphyry section in the "ore-zone" seems to mark the middle of a two or three hundred foot transition zone between Felsic Tuff and Andesitic Tuff and is therefore used to separate the two units. North and east of Ox Lake this contact is not as well known but appears to pass through drill holes 5 and 25 north of Ox Lake and just east of drill hole 8, east of Ox Lake. Bedding occurs in some sections of siliceous tuff and mafic crystal tuff. Six altitudes measured in outcrop indicate gentle dips of 20 to 30 degrees south. This regional dip is supported by consistent dips of about 20 degrees indicated from several sections of well-bedded cherts in vertical drill hole 27.

Feldspar porphyry at Ox Lake has been described previously as dykes and sills [Sutherland-Brown, 1968] but are considered by the writer to be largely extrusive in origin with possibly some dyke feeders.
Figure 5 Sample pairs of unaltered feldspar porphyry. Note variability of texture. Lower samples etched with hydrofluoric acid and stained with sodium cobalinitrite. Yellow indicates potash feldspar, white indicates plagioclase, clear indicates quartz and grey indicates other minerals.

Figure 6 Thin section of feldspar porphyry showing albite phenocrysts set in matrix containing spheres of intergrown potash feldspar and quartz with small albite crystals.
Evidence in support of an extrusive origin for the feldspar porphyries lies in their large areal extent northeast of Ox Lake, their inter-stratification with well-bedded cherts and mafic crystal tuffs, and the grossly conformable pattern of feldspar porphyry units to known bedding. Flow structures, crystallinity, and other textures can be interpreted as either extrusive or intrusive features.

In hand specimen the feldspar porphyries are pale-grey dense rocks with barely discernable plagioclase phenocrysts 1 to 5 mm long and with 1 to 3 per cent finely disseminated mafic minerals. Samples etched and stained with hydrofluoric acid and sodium cobaltinitrite enhance the variability of the texture (Figure 5). Mafic and felsic patches 3 to 10 mm in diameter constitute up to one per cent of total rock volume and are probably fragments. Phenocryst content varies from 5 or 10 per cent to 20 or 30 per cent of rock volume from outcrop to outcrop and occasionally within a single outcrop. Mafic content in places varies abruptly, from absent to 5 per cent of rock volume.

Microscopically the feldspar porphyry is a rhyodacite porphyry. The average modal composition based on four thin sections and about twenty stained rock samples is as follows:

<table>
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<th>Mineral</th>
<th>Phenocryst Volume Per cent</th>
<th>Total Volume Per cent</th>
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<tbody>
<tr>
<td>Plagioclase</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Quartz</td>
<td>1</td>
<td>35</td>
</tr>
<tr>
<td>Potash Feldspar</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Chlorite</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>100</td>
</tr>
</tbody>
</table>
Figure 7  Samples of felsic tuff. Dark layers and bedding are rare within this rock type*

Figure 8  Typical dark brown mafic crystal tuff containing few rock fragments and albite crystal fragments

*Refer to Figure 5 for explanation of stains.
A characteristic of the porphyry is the occurrence of spheres of 0.1 to 0.4 mm diameter. These spheres are composed of plagioclase laths set in myrmekitic intergrowths of potash feldspar in optically continuous quartz (Figure 6). The spheres constitute 10 to 50 per cent of the groundmass, sometimes border on each other and sometimes occur alone in the groundmass. Size of groundmass crystals is generally .05 mm or less. The plagioclase is everywhere albite and both feldspars are slightly clouded from alteration. Mafic minerals are restricted to clots of chlorite, quartz phenocrysts, epidote, carbonate, sericite and opaques and have probably been derived from an earlier mafic mineral.

The second most abundant rock type of the Felsic Tuff is pale-grey felsic tuff with a somewhat variable texture. Included with this rock unit are finely bedded cherts and rare argillite sections up to one or two feet thick (Figure 7). In general, the siliceous tuff is characterized by a pale-grey colour and dense nature. Siliceous and albitic fragments, .01 to .04 mm diameter, and set in a very fine-grained cloudy quartz-plagioclase-potash feldspar groundmass, make up as much as twenty per cent of the rock volume. With the exception of some siliceous tuffs which are lacking in potash feldspar, these rocks are compositionally similar to feldspar porphyry. In some sections they grade into one another repeatedly.

Mafic crystal tuff occurs throughout the Felsic Tuff and near the base of the Andesitic Tuff. Sections usually measure one to twenty feet thick but an unusually thick section occurs in drill
holes southwest of Ox Lake and apparently extends under the hill southeast of Ox Lake. This thick section occurs just above the Felsic Tuff.

In hand specimen the mafic crystal tuffs are characterized by abundant albite phenocrysts set in a dark brown matrix (Figure 8). The lath-like phenocrysts are .5 to 2 mm long, much narrower than phenocrysts of the felspar porphyry, and make up 5 to 15 per cent of the rock volume. Volcanic fragments, as large as lapilli size, constitute 1 to 10 per cent of rock volume. Bedding is not uncommon. Albite laths are somewhat aligned in bedded samples.

(b) Andesitic Tuff

The middle unit occurs in both drill holes and outcrop west and north of Ox Lake. Of the approximately 1,000 feet of exposed section, an estimated 30 per cent is lapilli tuff and the remaining 70 per cent is undivided fine-to coarse-grained tuffs. Some and possibly much of this unit could be volcanic sediments. This unit immediately overlies the Felsic Tuff unit and is overlain, probably unconformably by the Sandstone-Siltstone unit. Bedding is indicated within the unit by sections of lapilli tuff. Three such sections on the hillside northwest of Ox Lake indicate 5 to 10 degrees dips to the north or northwest. Bedding within the "ore-zone" near the intrusion is somewhat steeper as described below under structure.

The middle unit is described as andesitic although its composition is not known. Potash feldspar is rare, albite common, and silica content undetermined within rocks of this unit. In hand
Figure 9  Three samples of lapilli tuff and one sample of the more abundant fine-grained andesite. Felsic fragments are similar to feldspar porphyry and felsic tuff

Figure 10  From left to right; siltstone, sandstone, chert-pebble conglomerate
specimen, rocks of this unit are characteristically dark green to almost black with little colour variation. There is an apparent coarsening of fragment size toward the base of the unit. The bulk of the rocks forming outcrops on the ridge northwest of Ox Lake are very fine-grained tuffs and volcanic sediments (Figure 9). Lapilli tuff and mafic crystal tuff are common at the base of the unit. Feldspar porphyry occurs at the top of the exposed section on the hilltop northwest of Ox Lake and also halfway down the slope towards Ox Lake. Sections of lapilli tuff from five to fifty feet thick and several hundred feet long contain up to 70 per cent fragments of andesitic and more acidic composition. The andesitic fragments are commonly vesicular, indicating they were largely airfall tuffs. Porphyritic fragments are not uncommon. More acid fragments look similar to the feldspar porphyries and siliceous tuffs of the Felsic Tuff unit, and may be derived from them. The cloudy groundmass commonly contains a few per cent albite fragments.

(c) Sandstone-Siltstone

The most westerly outcrops examined by the writer at Ox Lake have been grouped into the Sandstone-Siltstone unit. Of the six hundred to eight hundred feet of section examined, approximately five per cent is chert-pebble conglomerate and the remaining 95 per cent undivided sandstone, siltstone and minor volcanic sediment (Figure 10).

This unit overlies the Andesitic Tuff apparently unconformably although the exact contact was not located and could be interpreted as a tight fold or a fault. No evidence for either of the last two possibilities was seen by the writer. The upper contact of the
Sandstone-Siltstone unit was not located. An air photograph interpretation, (Figure 14) suggests this unit extends at least 2 miles further west.

Bedding is well developed with dips of 50 degrees to 70 degrees west in marked contrast to the underlying, nearly flat-lying, Andesitic Tuff. Structures interpreted as current bedding were observed in a slumped block of sandstone. A sedimentary breccia with siltstone and sandstone clasts up to one foot long forms a conspicuous outcrop at the south end of the hill west of Ox Lake. Chert-pebble conglomerate sections one to fifty feet wide and up to several hundred feet long occur throughout the unit. There is an apparent increase in amount of coarse-grained sandstones and conglomerates towards the base of the section. The basal part of the unit, within two hundred feet of the supposed unconformity, contains dark green and grey volcanic sediments. The bulk of the unit consists of pale-grey and brown sandstones and siltstones.

Although the occurrence of volcanic sediment near the base of this unit suggests some gradation from the middle unit, the writer feels that the marked contrast in rock types and dips indicates the likelihood that an unconformity exists between the upper two units. The Sandstone-Siltstone unit is of pre-ore age as it contains fringe alteration from the Cu-Mo deposit.

2. Intrusive Rocks

The Hazelton Group at Ox Lake is intruded by two acid intrusions and many dykes. Centered about Ox Lake is a granodiorite
porphyry plug, intrusive into the Felsic Tuff unit. A diorite stock intrudes the Andesitic Tuff and Sandstone-Siltstone units on the west side of the ridge that lies northwest of Ox Lake. Basic dykes intrude all Hazelton Group rocks, the granodiorite porphyry and possibly the diorite. Hornfels surrounding the granodiorite is described in the section which follows on Metamorphism.

(a) Granodiorite

The granodiorite underlies the southern half of Ox Lake and adjacent land. It is oval in plan, measuring 2,400 feet long by 1,400 feet wide but plunges steeply west 45 to 60 degrees and is thus nearly circular in true cross-section. Dykes of granodiorite measuring up to twenty or thirty feet thick have been recognized in drill core near the contact with hornfels. These dykes occur less than two hundred feet from the main intrusive body and are most numerous along the western side. Intrusive breccia occurs along the southwest margin and is discussed in detail in the following section. Figure 11 shows elevation contours of the contact determined from drill hole intersections and surficial geology. Also shown on the figure is occurrence of intrusive breccia.

In hand specimen the granodiorite is a porphyry with phenocrysts of plagioclase, biotite, hornblende and quartz comprising 54 per cent of rock volume (Figure 12). The average modal composition based on three thin sections and seven stained rock samples is as follows:
Figure 11  Shape of plug and occurrence of breccia. Westward plunge of plug indicated from elevation contours of granodiorite-hornfels contact
Figure 12  Typical texture of granodiorite porphyry. Sample is hornblende rich variety *

Figure 13  Typical sample of medium-grained diorite with atypical alteration along fracture *

*Refer to Figure 5 for explanation of stains.
<table>
<thead>
<tr>
<th>Mineral</th>
<th>Phenocryst Volume Per cent</th>
<th>Total Volume Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td>Potash Feldspar</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Quartz</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Biotite</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Hornblende</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Apatite</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Opaque</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>54</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

A pink to grey fine-grained matrix makes up the remaining 46 per cent rock volume. The mafic content varies between samples that are biotite-rich to those that are hornblende-rich. The most noticeable change of texture occurs along the western contact where some of the dykes exhibit a finer grain size of phenocrysts and groundmass. In a few cases individual granodiorite dykes with a normal texture grade with decreasing width into this fine-grained variety and then ultimately into a mafic-free sugary-textured quartz-feldspar dyke one-half inch wide.

In thin section, complexly zoned plagioclase ranges from An20 to An40. The matrix is a fine-grained sugary-textured mixture of quartz and potash feldspar. Accessory minerals are apatite and magnetite.
The intrusion was probably emplaced in approximately the same attitude as it presently lies. Alteration and mineralization, which are shown below to be contemporaneous with intrusion, are most intense "over" the western contact of the intrusion. Similarly, sections of fault gouge and dykes of granodiorite porphyry are also more numerous along this contact. Evidence of forceful intrusion of the granodiorite porphyry is also shown below to occur "above" this western contact. The asymmetric nature of the above features all lend support to the idea that the westward rake of the intrusion is a primary feature.

(b) **Intrusive Breccia**

An intrusive breccia occurs along the southwestern contact of the granodiorite (Figure 11). Sections of breccia ninety to one hundred and sixty feet long are intersected in drill holes 14, 20, 21, 23, and 35. Sections of breccia less than thirty feet wide are intersected in drill holes 12, 16, and 17. The shape of the breccias is not clear, but they appear to be sheet-like bodies associated with granodiorite dykes. Breccia occurs along the sides of the main granodiorite, along sides of granodiorite dykes and as separate bodies containing small granodiorite dykes within hornfels near the intrusion. Thus a zone of brecciation can be outlined parallel and peripheral to the southwestern intrusion-hornfels contact.

Fragments of hornfels and altered feldspar porphyry are cemented by two types of matrix. The most common matrix is a mixture of rock flour and granitic material probably consisting of ground up
hornfels and granodiorite porphyry. About five per cent of the breccia is cemented by the second type of matrix, viz. hydrothermal minerals filling open spaces. Most common minerals are coarse-grained biotite, gypsum-anhydrite, and calcite with lesser amounts of quartz, epidote, chalcopyrite, pyrite, chlorite, magnetite, hematite, potash feldspar, and molybdenite.

(c) Diorite

A medium-grained diorite intrusion is exposed on the ridge northwest of Ox Lake. Its dimensions although poorly known are approximately one mile long by one-half mile wide.

In hand specimen the rock is a mottled-grey, medium-grained diorite containing 30 per cent biotite plus hornblende and 70 per cent feldspars plus quartz (Figure 13).

The average modal composition based on three stained rock samples and one thin section is as follows:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Volume Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase</td>
<td>50</td>
</tr>
<tr>
<td>Potash Feldspar</td>
<td>15</td>
</tr>
<tr>
<td>Quartz</td>
<td>5</td>
</tr>
<tr>
<td>Hornblende</td>
<td>15</td>
</tr>
<tr>
<td>Biotite</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>
The contacts are relatively sharp with no dykes observed in outcrop. The diorite is in contact with rocks of Andesitic Tuff along its eastern contact and with rocks of Sandstone-Siltstone along its eastern contact.

In thin section, plagioclase, hornblende, and biotite poikilitically enclosed by potash feldspar, form 30 to 50 per cent of the rock. The remaining 50 to 70 per cent is made up of euhedral medium-grained plagioclase, biotite and hornblende set in fine-grained quartz and potash feldspar. Minor apatite occurs with mafic minerals. Plagioclase is weakly zoned with an average composition of An\textsuperscript{34}.

Alteration of the diorite is weak with some sausseritization of plagioclase and minor chloritic alteration of biotite and hornblende.

(d) **Dykes**

Basalt and andesite dykes occur in all rocks of the Hazelton Group, the granodiorite, and probably the diorite. These dykes are both pre- and post-mineralization. Most drill holes intersect one or more of these dykes.

The dykes are recognized by well-developed chill contacts, textures and by absence of mineralization in post-mineralization dykes occurring in the hornfels. Diabase textures are particularly abundant.

As noted above at least some of the feldspar porphyry might be dykes.
3. Metamorphism

Metamorphism of rocks near Ox Lake is consistent with the regional development of low-grade greenschist facies within Hazelton Rocks, and of higher grades of metamorphism occurring near intrusions.

(a) Regional

Rocks unaffected by the two intrusions have a well-developed alteration assemblage of albite, chlorite, calcite and epidote, with lesser amounts of actinolite and biotite. The limit of contact metamorphism is unknown and thus some, but not all, of the actinolite and biotite might be a product of regional metamorphism.

(b) Contact

Near the diorite, development of hornfels, if present, is not pronounced. Outcrops near the diorite are occasionally slightly crackled and minor amounts of pyrite occur along a few fractures in these rocks.

In contrast to the diorite, the granodiorite has a well-developed hornfels surrounding it. The outer limit of hornfels, which is roughly coincident with the outer limit of pyrite, varies from about 500 feet from the east contact to about 1,500 feet from the west contact.

It is difficult to distinguish overall thermal effects from hydrothermal vein activity. From the alteration study de-
scribed in Chapter IV it is suggested that the earliest alteration events are related to intense micro-fracturing and more closely approach contact metasomatism. Subsequent alteration events become more and more closely related to individual veins and thus more closely approach hydrothermal alteration. Potassic, albitic, propylitic, sericitic and intermediate argillic alteration assemblages are present and discussed in detail in Chapter IV.

4. **Structure**

Major structures at Ox Lake appear to be: a broad anticline or dome; two faults, intersecting at the north-west end of Ox Lake; and a vein stockwork related to intrusion of the granodiorite and discussed in detail in the following chapter.

A broad anticline possible related to doming over the granodiorite is indicated from dips of Hazelton Group rocks. Northwest, north and east of Ox Lake bedding has gentle dips as described previously. Within the Ore Zone immediately west of the granodiorite, bedding roughly parallels the granodiorite-hornfels contact at dips of 45 to 60 degrees. Figure 3 shows how the feldspar porphyry section within the Ore Zone wraps around the granodiorite. Drill data suggests that this feldspar porphyry section is slightly concave upward. Variations in bedding are interpreted to be the result of forceful intrusion of the granodiorite causing folding of Hazelton Group rocks. The result has been the formation of an anticline whose westward plunging axis lies over the westward plunge of the intrusion. Some of
Figure 14  Air photograph interpretation of lineaments
the apparent folding could be the result of structural adjustments along faults.

Steep bedding within Sandstone-Siltstone could be related to the above described doming effect of the granodiorite. However, this steep bedding is more of a regional feature of this unit and probably is the eastern limb of a syncline of unknown magnitude. As the upper unit dips 50 to 70 degrees west and the granodiorite rakes about 50 degrees west, folding involving this upper unit most likely occurred prior to emplacement of the granodiorite. Otherwise the plug would have been emplaced at a very shallow angle.

Figure 14 is an air photograph interpretation of the geology near Ox Lake. The northeast trending lineaments parallel glacial striations. The northerly trending bedding scarps in the middle of the figure indicate the strike of the Sandstone-Siltstone. This unit apparently outcrops one to two miles west as indicated there by similar north-south bedding scarps. Three major lineaments converge at Ox Lake and for two of these, there is some evidence of fault origin.

The two fault-controlled lineaments are the north-south and east-west trending features that intersect at the west side of Ox Lake. The feldspar porphyry section within the ore zone is apparently offset, possibly by the supposed east-west fault. A diabase dyke reportedly crops out along this fault on the ridge west of Ox Lake. (Sutherland-Brown, 1968). A fault zone, mapped by Mr. D.H. Olson of Asarco, strikes north, dips 70 degrees east and lies on the ridge north-
west of Ox Lake. The presence of Pb-Zn-Ag mineralization in the exposed fault, of magnetite in breccia near the fault, and of pyrite mineralization extending out along the fault in a broad pattern from the granodiorite, indicates a premineralization age of this fault.

Drill holes within hornfels contain numerous sections of fault gouge indicating that faulting is much more prevalent than recognized in outcrop. Drill holes outside the hornfels contain much fewer sections of fault gouge than drill holes within hornfels, which might indicate faulting is related to emplacement of the granodiorite. The vein stockwork described in the following chapter is good evidence of fracturing and faulting near the intrusion.
Figure 15  Position of the various zones about the granodiorite porphyry. Section line is for Figures 22, 25 and 26.
Figure 16 Above: Diagrammatic intersections of some vein types showing relative ages. Below: Data indicating relative ages of vein types.
CHAPTER III

VEINS

Veins are developed to some extent in all rocks adjacent to the granodiorite porphyry but are most abundant along its western contact, a zone that also contains the most intense alteration and highest grades of Cu and Mo. The first part of this chapter describes nine vein types. Four stages of vein development are presented at the end of the chapter. Alteration and mineralization, which are related to veining, are discussed in the following two chapters. Throughout these three chapters reference is made to several zones shown in Figure 15.

Veins are classified into nine types based on commonly occurring mineral assemblages. Propylitic veins are subdivided into three subtypes. One vein type is shown to occur only in rocks of acidic composition where it is analogous to propylitic veins elsewhere. Cross-cutting relationships between different vein types within the well-mineralized western hornfels and contact granodiorite are summarized in Figure 16.

At their most intense development veins are fracture fillings 0.1 to 5 mm wide, spaced 3 to 10 mm apart. Wider veins are uncommon and narrower veins are not easily recognized in hand specimen. Along the less intensely veined eastern contact of the intrusion, vein spacing is about 10 to 50 mm. The intensity of veining decreases
with distance from the intrusion in a general way, and the limit of veining is roughly coincident with the limit of pyrite.

VEIN TYPES

1. **Potash Feldspar Veins**

Potash feldspar occurs as thin smears along fractures, but more commonly as an envelope up to one-quarter inch wide. Biotite is present as a thin fracture filling with a few potash feldspar veins. Potash feldspar envelopes occur with some propylitic veins, particularly those that are nearer the intrusion, and with few quartz-molybdenum veins and quartz veins. The relative age of the development of potash feldspar is discussed below.

2. **Biotite Veins**

Biotite veins are composed entirely of biotite with one or two exceptions where traces of pyrite and chlorite occur. The biotite is fine-grained and generally dark brown and felty looking. Where it occurs less than 100 feet from the intrusion, it is black. Because vein widths are very narrow, always less than one millimeter, biotite veins are difficult to recognize and are probably more abundant than indicated by the number identified. A number of narrow biotite veins were observed only in thin section.
Of the twenty biotite veins observed, six were cut by quartz-molybdenite veins, seven were cut by propylitic veins and seven occurred by themselves, indicating an early age for these veins.

3. Propylitic Veins

Propylitic veins, by far the most abundant type, are subdivided into three subtypes: a chlorite-calcite-pyrite subtype; an epidote-hematite-chlorite-calcite-pyrite subtype; and an actinolite-pyrite-magnetite subtype. They are referred to as the chlorite, epidote and actinolite subtypes respectively. The subtypes are mutually exclusive within a single sample. Distinction between the three is based on hand specimen examination. Veins are characterized by the mineralogies listed above. They also contain the following: chlorite subtype—trace amounts of epidote, rare hematite and no magnetite or actinolite; epidote subtype—visible clots and smears of epidote, common magnetite; actinolite subtype—minor chlorite, calcite and hematite. Chalcopyrite and apatite are associated with all subtypes. Quartz is rare, and plagioclase or potash feldspar is commonly present as an envelope less than five mm wide. Hornblende was noted in three veins of epidote subtype near the intrusion. Propylitic veins contain a significant proportion of the total copper content of the deposit.

Propylitic veins are rarely more than three mm wide and generally occur as a stockwork of closely-spaced fracture-fillings less than 0.2 mm wide. Propylitic veins are pervasive throughout the hornfels and rare within the intrusion, intrusive breccia and feldspar porphyry.
Of 97 cross-cutting relationships observed between propylitic veins and quartz-molybdenum veins, 87 indicate the propylitic veins are earlier and ten later than the quartz-molybdenite veins. A significant feature of this analysis is that the 10 "anomalous" relationships all represent a single propylitic vein cross-cutting a quartz-molybdenite vein, whereas the other 87 relationships represent, in the majority of cases, a single quartz-molybdenite vein cross-cutting several propylitic veins. Thus the 10 "anomalous" relationships probably represent much less than 5 per cent of the total propylitic veining.

All 34 cross-cutting relationships between propylitic veins and quartz veins indicate the quartz veins are later.

The three subtypes are zoned about the intrusion (Figure 15). The actinolite zone lies peripheral but adjacent to the epidote zone. The chlorite zone occurs as a core adjacent to the intrusion and surrounded by the epidote zone. These zones are outlined in more detail in the following chapters.

4. Pyrite-Chalcopyrite Veins

These sulphide veins are characterized by narrow fracture-fillings of pyrite and/or chalcopyrite. Calcite is generally present and quartz is present in small amounts.

The veins are less than one mm wide and not as common as other vein types. They are most common in acidic rocks, particularly feldspar porphyry, felsic tuff overlying and underlying the feldspar porphyry and granodiorite near the contact.
Separate sections of feldspar porphyry occur in drill holes 5, 19, and 24 and near sample 63C. In each case adjacent andesite contains only propylitic veins although the feldspar porphyry contains only pyrite-chalcopyrite veins. Feldspar porphyry nearer the intrusion contains pyrite-chalcopyrite veins as well as all other types except propylitic veins. Thus the pyrite-chalcopyrite veins within feldspar porphyry are considered to be related genetically to propylitic veins outside feldspar porphyry. The granodiorite porphyry contains many pyrite-chalcopyrite veins which may also be the equivalent of propylitic veins as this latter type is rare within the intrusion.

There are, however, other pyrite-chalcopyrite veins occurring outside the feldspar porphyry which occur with propylitic veins. Less than ten such veins have been recognized and their relative age is unclear, but appears to be post-propylitic. Some of these contain appreciable quartz and thus may be related to quartz-molybdenum or quartz veins. They are relatively few compared with pyrite-chalcopyrite within feldspar porphyry and are not grouped together as a type, because of their few number and questionable association.

All ten cross-cutting relationships between pyrite-chalcopyrite veins and quartz-molybdenite veins indicate the pyrite-chalcopyrite veins are earlier -- a fact which further supports the contemporaneous developments of propylitic and pyrite-chalcopyrite veins.

5. Quartz-Molybdenite Veins

These veins are characterized by quartz and molybdenite but other minerals occur with these veins as described below. Quartz often
has a cockade structure with molybdenite concentrated along the vein walls and calcite filling a central parting. The molybdenite content of a single vein in some samples varies appreciably within a few centimeters. Chalcopyrite and pyrite are generally present in small amounts with pyrite predominating. Chlorite is rarely present and potash feldspar occurs as a narrow envelope less than two mm wide on some veins. These veins contain practically all the molybdenite in areas that have no brecciation.

Quartz-molybdenite veins are wider than the propylitic veins, ranging from one to ten mm, but change their widths appreciably from one area to another. They have not formed as extensively as the propylitic veins, being fewer and more localized near the intrusion. They are particularly common in feldspar porphyry but do occur in all rock types.

Quartz-molybdenite veins have already been shown to be generally later than the propylitic veins. Of 36 intersections of quartz-molybdenite veins with quartz veins, 35 indicate the quartz-molybdenite veins to be older and one younger than the quartz veins. The one "anomalous" intersection occurred within the granodiorite porphyry.

There were also 12 intersections noted between quartz-molybdenite veins of different molybdenite content. Eleven intersections indicated the molybdenite-rich vein to be older than the more molybdenite-poor vein.
6. Quartz Veins

Quartz veins are characterized by absence of molybdenite. Pyrite and chalcopyrite are normally present, forming up to ten or twenty per cent of vein volume. Calcite often fills a central parting of the vein. Narrow potash feldspar smears along vein walls and chlorite are rarely present.

Quartz veins are similar to quartz-molybdenite veins in size, number and distribution.

Biotite, propylitic and quartz-molybdenite veins are clearly earlier than the quartz veins.

7. Calcite Veins

Calcite veins are almost pure calcite with only a few veins containing trace amounts of pyrite. Some veins have a central parting. Vein widths vary from 1 to 20 mm but are generally about 3 mm. They are an abundant vein type occurring in all drill holes and outcrops within about six or seven hundred feet on the west side and two or three hundred feet on the east side of the intrusion. Intersections with other veins are numerous but were not counted as they are clearly later than all previously mentioned vein types.

8. Gypsum Veins

Gypsum also forms a late vein set. X-ray diffraction patterns indicate anhydrite is present with or without gypsum in
many veins but no zoning of these minerals was indicated from the few veins analyzed.

Vein width is generally less than 2 mm. These veins are most common within the contact granodiorite and adjacent hornfels, although as a vein type they are relatively few.

Intersections with other vein types are rare. Three intersections with quartz veins indicate a late age for gypsum veins. Occurrence of gypsum-anhydrite with calcite in vugs in the Breccia Zone also suggests a late age for gypsum veins.

9. Sphalerite Veins

Sphalerite veins typically contain 70 per cent carbonate and 30 per cent sulphides. Siderite is more abundant than calcite. Sulphides are pyrite and sphalerite with minor amounts of galena.

The ten or so veins found are generally one to four cm wide, occurring in hornfels and granodiorite more commonly on the west side than the east side of the intrusion. A lead-zinc-silver vein of larger dimensions occurs in a fault system on the ridge northwest of Ox Lake [D.H. Olsen, personal communication].

The relative age of this vein type is uncertain except that it is post-quartz veins.
DISCUSSION

A significant conclusion to be drawn from the veining study is that the rocks, both volcanic and intrusive, have been intensely fractured many times. This is indicated by the fact that veins of one type formed in a fracture stockwork prior to refracturing and development of another vein type. Cutting of one vein by several other veins of the same type indicates that fracturing occurred many times during even the formation of a single vein type. Thus the model for vein formation is the addition of hydrothermal solutions, chemically varying with time, into a fractured stock that is continually being healed by formation of one vein set and refractured prior to formation of a second set.

Sequence of vein formation and intrusion of granodiorite porphyry is not simple. Alteration of the contact portion of the intrusion indicates that at least this portion of the intrusion was brittle enough to fracture for vein formation. However, small dykes of unaltered granodiorite porphyry within the hornfels clearly intersect some veins.

Both replacement and open-space filling textures occur within the deposit. Open space filling textures are more common in late than in early formed veins. Vugs and cavities are common in calcite, gypsum and sphalerite veins, not uncommon in the centre of quartz-molybdenite and quartz veins, rare in propylitic veins and absent in biotite and potash feldspar veins. Comb quartz is present in some
quartz-bearing veins. Symmetrical banding is common in quartz-molybdenum, and sphalerite veins and to a lesser extent in quartz veins.

Replacement is a common feature of the early formed minerals potash feldspar and biotite. Propylitic mineralogies appear to have formed by both open-space filling and replacement. Still later quartz-molybdenite, quartz, calcite, gypsum and sphalerite veins display practically no replacement phenomena of vein material.

Although later veins are formed by open-space filling, much hydrothermal alteration is associated with some of these veins. This alteration is described in the following chapter.

Evolution from an early process involving much replacement and some open space filling to a later replacement-free fracture filling process is also reflected by variation of vein widths. Biotite and potash feldspar occur as envelopes on fractures with fracture filling, where present, less than 0.1 mm wide. Propylitic veins are in general 0.5 mm to 5 mm wide and quartz-molybdenite and quartz veins are 2 to 10 mm wide. Still later veins vary from 2 to 20 mm wide.

The evolution of vein types within the Ore Zone has been described. The other zones, outlined in Figure 15, are the East Zone, Intrusive Zone and Breccia Zone. All vein types described from within the Ore Zone occur in the other zones but to a much less extent. The number of intersections of different vein types is small in these other zones, but they all indicate similar age relations to those found in the Ore Zone.
VEIN STAGES

Four stages of vein development are proposed based on age relationships of the nine vein types. Formation of veins within each stage is presented below. The four stages were probably not discrete events. Stage I veins probably developed through Stage II and into Stage III. Similarly Stage II veins developed to some extent during the early part of Stage III. Stage IV veins, however, appear to have developed after all previous stages. Thus early stages overlap much, and late stages little of the other stages.

1. Stage I

Development of Stage I veins is the least distinct of the four stages. Development of potash feldspar and biotite veins began early and persisted throughout development of Stage II veins. Formation of biotite and potash feldspar is more closely related to hydrothermal alteration than to open-space filling and will be described more fully in the following chapter. However this chapter has shown that these minerals formed earlier than other vein minerals and continued to develop for some time.

2. Stage II

The three subtypes of propylitic veins and the pyrite-chalcopyrite veins are grouped in Stage II.

Within the Ore-Zone, pyrite-chalcopyrite veins in feldspar porphyry have been shown to be the equivalent of propylitic veins in
more mafic rocks. The same relationship has been suggested for pyrite-chalcopyrite veins within the Intrusive Zone. Feldspar porphyry and granodiorite are in marked chemical contrast to the andesite and probably reacted to mineralizing solutions differently, thereby yielding two different mineral assemblages. These two assemblages are further differentiated by associated alteration products as discussed in the following chapter.

Within the East Zone, both the epidote sub-type of propylitic veins and pyrite-chalcopyrite veins occur in feldspar porphyry. However mafic rocks in the East Zone contain only the epidote subtype of propylitic veins.

The three sub-types of propylitic veins have been grouped as subtypes for several reasons. Only one subtype occurs in a single hand specimen and the three zones of each subtype are adjacent to each other and roughly concentrically zoned. The epidote and chlorite subtypes have identical age relationships with other vein types. Similar age relationships can be shown indirectly. All three zones contain sections of feldspar porphyry that contains pyrite-chalcopyrite veins but not propylitic veins. Mineralogical similarities described previously also provide evidence for a genetic relationship between these subtypes.

The three zones of propylitic veins may have developed simultaneously or in some sequence. There is no evidence to indicate how these zones were developed.

Development of Stage II veins clearly began after Stage I veins began. Some overlap with Stage III vein development is indicated
from the ten "anomalous" intersections with quartz-molybdenum veins. No "anomalous" intersections were noted with quartz veins.

3. **Stage III**

Stage III includes development of quartz-molybdenite and quartz veins. Although the two vein types appear to have developed as consecutive stages themselves, they are grouped as one stage on the basis of similarities in mineralogy, size and distribution.

There is an apparent evolution from quartz-molybdenite veins with high molybdenite content to quartz-molybdenite veins with lower molybdenite content to quartz veins with no molybdenite content. Intersections of quartz-molybdenite veins of different molybdenite content indicate an earlier age for the vein with more molybdenite. Although the molybdenite content of a single vein can vary within a few cm, the above relationship is interpreted to indicate a general decrease with time of molybdenite content of these veins. This argument is strengthened by the fact that quartz veins, which are molybdenite free, are younger than the quartz-molybdenite veins. Occurrence of molybdenite as a coating on vein walls probably reflects its early age relative to quartz.

4. **Stage IV**

Calcite, gypsum and sphalerite veins are grouped together under Stage IV. Further subdivision of these veins might be possible with more detailed information. Calcite veins are far more common
than either gypsum or sphalerite veins. Calcite forms with Stage II and III veins in appreciable amounts particularly with Stage III veins where it occurs in the vein centre. This relationship provides further evidence of a continuous evolution of veins types.
Figure 17 Diagrammatic map illustrating alteration of plagioclase phenocrysts within feldspar porphyry and granodiorite porphyry.
Figure 18. Diagrammatic map illustrating occurrence of alteration minerals biotite, chlorite, epidote, and actinolite related to the granodiorite porphyry.
CHAPTER IV

ALTERATION

The preceeding chapter described nine vein types and arranged them into four stages. As alteration is intimately associated with vein development in space and time, this chapter will attempt to relate the two wherever possible.

The first section of this chapter describes alteration types within the four zones previously described; East Zone, Intrusive Zone, Ore Zone and Breccia Zone (Figure 15). Because alteration within the Ore Zone is complicated, it has been subdivided into four smaller zones. Alteration in each of these zones is described in detail. Alteration effects are strikingly different for felsic and mafic rocks. Figures 17 and 18 illustrate the distribution of several of the more abundant alteration minerals.

The second section of this chapter is a discussion of alteration according to alteration type. Alteration described in the first section is summarized under the headings potassic, albitic, propylitic, sericitic and intermediate argillic alteration. Figures 25 and 26 summarize vein-alteration assemblages formed in the four stages.
Figure 19 Sample pairs showing alteration products within feldspar porphyry of the East Zone. Sample on right is unaltered feldspar porphyry. Dark coloured matrix in three altered samples on left is caused by hydrothermal biotite. Phenocrysts in left sample are albite. Phenocrysts in middle two samples are potash feldspar. Note albite envelope about an epidote subtype propylitic vein in second sample from left.*

*Refer to Figure 5 for explanation of stains.
Feldspar porphyry is abundant and mafic rocks rare within the East Zone. Alteration patterns are outlined from four cross-sections of the hornfels within drill-hole sections 8, 31, 10 and 9-32. The East Zone is characterized by a wide zone of feldspar constructive alteration with both albite and potash feldspar forming zones as indicated in Figures 17 and 19.

A potash feldspar zone extends outwards five hundred to one thousand feet from the granodiorite and is separated from the contact by a two to four hundred foot-wide albite zone. Potash feldspar has replaced original albite phenocrysts and some groundmass albite. In some phenocrysts at the outer limits of the zone, this replacement is not complete and a core of albite remains unaltered. In thin section the potash feldspar is slightly cloudy but generally freshlooking.

The transition from the above alteration assemblage to the more central albite alteration zone is transitional over several hundred feet. Going towards the intrusion from the potash feldspar zone the first noticeable change is the occurrence of propylitic fractures with an albite envelope up to two cm wide.

All potash feldspar has been hydrothermally altered to albite along these fractures (Figure 19). Albite has corroded the secondary potash feldspar phenocrysts along their margins and has replaced groundmass potash feldspar to some degree.

Nearer the intrusion, veining with associated albite alteration becomes more intense, until finally only minor amounts of potash
feldspar remain, leaving a zone two to four hundred feet wide, of nearly complete albite alteration. Less than half of the original groundmass potash feldspar remains in samples near the intrusive contact. In thin section the albite is characteristically a dark cloudy material with easily recognized polysynthetic twinning.

Intense albite alteration is also associated with a crackle-breccia zone intersected by drill-hole thirty-two. Disseminated molybdenum mineralization occurs in this zone which is twenty to thirty feet wide. Late potash feldspar envelopes are absent.

Pervasive potash feldspar alteration as described is not known to be directly related to any particular vein type. Biotite veins with trace pyrite, and epidote subtype propylitic veins occur as fracture fillings much less than one mm wide. Hydrothermal albite alteration envelopes are commonly related to epidote subtype propylitic veins one to three mm wide. Relationship of more pervasive albite alteration to vein type is ambiguous but possibly is similar to the above.

Disseminated mineralization associated with these alteration types is mainly biotite with lesser amounts of chlorite and pyrite. Biotite is usually altered to chlorite wherever biotite is in contact with pyrite.

A significant amount of potash feldspar alteration occurs as envelopes about veins that cross-cut veins with albite envelopes. Vein mineralogy is analogous to epidote subtype veins. This late potash feldspar alteration is not pervasive like the earlier events but is restricted to veins and vein envelopes.
Mafic rocks in the East Zone form about ten per cent of rock volume. They exhibit intense development of hydrothermal biotite and epidote subtype propylitic veins. Some actinolite subtype veins occur. Alteration effects associated with these veins are similar to those described below within the Ore Zone.

Later quartz-molybdenite, quartz, calcite, gypsum and sphalerite veins exhibit only minor alteration effects. Some quartz-bearing veins have alteration envelopes less than one cm wide. Feldspar phenocrysts have been slightly altered to sericite and clays within these envelopes.

**INTRUSIVE ZONE**

Alteration within the intrusion is restricted to its contact with hornfels and is extensively developed only where the intrusion is in contact with the Ore Zone. Destruction of plagioclase has resulted in the recognition by the writer of two different types — potash feldspar alteration which is rare, and intermediate argillic alteration which is extremely common. Detailed descriptions of each type are presented following a general description of alteration intensity.

Development of alteration is classed as intense, moderate or weak depending on the degree of destruction of plagioclase: Intense alteration is characterized by complete destruction of plagioclase
to sericite-clay minerals in sections of drill-core several feet long. Weak alteration is characterized by destruction of plagioclase occurring only near individual fractures, leaving over half the sample unaltered. Moderate alteration is intermediate between weak and intense alteration.

The intrusion is characterized by absence of alteration effects except near its contact. Alteration of granodiorite in contact with the East Zone is absent or extremely weak over a width up to ten feet. Granodiorite in contact with the Breccia Zone is weakly to moderately altered over widths of twenty or thirty feet. Granodiorite in contact with the Ore Zone is intensely altered over widths of thirty to seventy feet. In drill-hole 15 the section of intense alteration is separated from the hornfels by twenty feet of unaltered granodiorite.

Intense alteration is believed to have resulted from overlap of many alteration envelopes of the intermediate argillic type, and here identification of individual envelopes is difficult. The following descriptions are based on isolated envelopes from moderately or weakly altered granodiorite.

1. **Intermediate Argillic Alteration**

Intermediate argillic alteration was outlined by examination of seven alteration envelopes found in drill core samples. Altered feldspar phenocrysts were selected every cm or so outwards from the vein. The material collected from each of these areas was analyzed by use of X-ray diffraction techniques to determine the mineralogy. All seven samples showed alteration patterns similar to the one presented here.
Figure 20  Photograph of intermediate argillic alteration envelope and corresponding graph of mineral abundances away from vein. Note quartz vein with central calcite.
However the sharp boundaries between different zones as described below are developed in only three samples. The other four samples have somewhat gradational boundaries between adjacent zones. Potash feldspar content was determined by etching the sample with hydrofluoric acid and staining with sodium cobaltinitrite.

Veins are quartz and quartz-molybdenite types. Quartz is always abundant, pyrite is always present and calcite is usually present. Chalcopyrite, molybdenite, and hematite were present in three different samples. Vein width is one to three mm. The alteration envelopes vary from one cm to one meter wide. The best developed envelopes are about ten cm wide.

Figure 20 shows a photograph of intermediate argillic alteration envelope and a graph of mineral abundances away from the veins. The abundances are based on visual estimation and probably contain serious errors. Since all plagioclase is completely destroyed, it is assumed the sericite-clay abundances equal the plagioclase content of unaltered granodiorite. The amount of potash feldspar does not seem to vary much. Variation of quartz content could be appreciable. Calcite occurs throughout the altered zones but not in fresh granodiorite. Epidote is present but its variation unknown. Alteration of hornblende has not been determined. Biotite is stable up to the middle of the kaolinite zone. Veinward from here, the biotite has been altered to a golden brown mica. Magnetite has been altered to hematite at the outer limits of the alteration envelopes. Nearer the vein neither iron oxide is present. Pyrite and chalcopyrite occur disseminated in altered rock but not the unaltered rock.
Figure 21 Photograph of a potash feldspar envelope and corresponding graph of mineral abundances away from vein. Note pyrite-calcite vein.
2. **Potash Feldspar Alteration**

Potash feldspar alteration was outlined by use of thin sections and X-ray diffraction.

Only two of these envelopes were found, one in drill-hole twelve, and the other in drill-hole seventeen, both near the north end of the well-altered zone of the intrusion. Pyrite and calcite form veins one mm and five mm wide. Envelopes are four cm wide about the narrower vein and ten cm wide about the wider vein.

Figure 21 shows a photograph of the narrower envelope vein assemblage, and a graph of mineral abundances away from the wider vein. The narrower vein has a similar mineral assemblage although the minerals are not as well zoned. Near the vein, plagioclase phenocrysts have been albitized and about fifty percent replaced by potash feldspar. Coarse-grained sericite, epidote, and carbonate also occur within the plagioclase phenocrysts. Replacement is patchy but all minerals are easily recognized in thin section. Further out from the vein, plagioclase is altered to kaolinite and then montmorillonite. Near the vein, biotite and hornblende have been destroyed and chlorite, epidote and calcite are abundant in the groundmass. Magnetite is only partly destroyed as it occurs right up to within one cm of the vein.

**ORE ZONE**

Both feldspar constructive and feldspar destructive alteration assemblages are common within the Ore Zone. The occurrence of one or the other type is dependent on host rock. Alteration is described within
Figure 22 Variation of mineral abundances within the Ore Zone and adjacent Intrusive Zone. Line of section shown in Figure 15. Note control of host rock on alteration assemblages.
mafic and then felsic rocks within four different zones of the Ore Zone. These four zones are shown on Figures 15 and 22 and are: the Peripheral Zone; the Actinolite Zone; the Epidote Zone; and the Chlorite Zone. The latter three zones are defined by the distribution of actinolite, epidote, and chlorite subtypes of propylitic veins as described in the previous chapter.

1. **Peripheral Zone**

   Alteration most remote to the intrusion is the occurrence of actinolite along fractures and as disseminations in andesite one mile from the intrusion on the ridge northwest of Ox Lake. Magnetite commonly occurs with the actinolite and both are particularly abundant within brecciated andesite. There is an apparent zone of brecciation near the fault on the ridge. Within the breccia, actinolite and magnetite fill voids and replace wall-rock, forming up to twenty percent of total rock volume in hand specimen.

2. **Actinolite Zone**

   A zone of actinolite, biotite, magnetite and pyrite extends outwards five hundred feet from the Epidote Zone, and at least one-quarter of the way around the intrusion on its northwest side. Green acicular actinolite occurs associated with olive-brown and occasionally green biotite within veins and throughout the rock. Over half the magnetite occurs in disseminated form. Pyrite occurs in veins with magnetite and to a limited extent is disseminated within the rock.
Minor quartz is present in the narrow veins. Chlorite is a rare alteration product of biotite. Other alteration minerals, which occur nearer the intrusion are scarce or absent.

One known section of feldspar porphyry occurs within the Actinolite Zone. There is a striking contrast of vein and alteration minerals from within this feldspar porphyry and adjacent andesite. Within andesite, vein-alteration minerals are as described above. Within feldspar porphyry, pyrite-chalcopyrite veins have well-developed quartz-sericite alteration envelopes up to one cm wide. Away from the alteration envelopes the feldspar porphyry appears unaffected by alteration related to the granodiorite porphyry.

No other vein types or alteration assemblages have been observed in this zone.

3. **Epidote Zone**

This zone contains abundant epidote, biotite, chlorite, calcite, hematite, pyrite and magnetite but is characterized by epidote and hematite. Epidote occurs along veins and to a lesser extent as blebs and disseminations in andesite. Biotite is commonly brown and more euhedral, abundant and restricted to wall-rock than biotite in the Actinolite Zone. Chlorite is common in most veins and occurs as disseminations near sulphide grains. Calcite is commonly restricted to veins. Hematite, pyrite and magnetite are present in veins and as disseminations. Hematite and magnetite are more restricted to veins within about five hundred feet of the intrusion. Pyrite is more restricted to veins further out than this distance. Apatite and chal-
copyrite are generally present in varying amounts in veins and as disseminations.

Propylitic veins commonly have either an albite or potash feldspar envelope which is generally noticeable in hand specimen. Some specimens contain both types of envelopes on different veins. Potash feldspar envelopes are much more abundant than albite envelopes and appear to have developed nearer the intrusion -- within about seven hundred feet. The number of albite envelopes observed is low and as some do exist near the intrusion this zoning of feldspar envelopes is not certain.

Alteration in mafic rocks near quartz-bearing veins is weak. Potash feldspar envelopes occur on many of these veins. Minor amounts of sericite-clay minerals occur along some vein walls.

Feldspar porphyry within drill-holes 5 and 24 contain pyrite-chalcopyrite veins with quartz-sericite envelopes as described above within the Actinolite Zone (Figure 23). A few samples from drill-hole 5 contain secondary biotite. Other samples from drill-hole 5 contain fractures with potash feldspar occurring along them and partly replacing adjacent plagioclase phenocrysts. These potash feldspar envelopes are cut by the pyrite-chalcopyrite veins.

Other alteration assemblages in feldspar porphyry occur near quartz-bearing veins like those described below within the Chlorite Zone.

4. Chlorite Zone

The Chlorite Zone contains abundant chlorite, biotite, calcite, and pyrite. Epidote, apatite and chalcopyrite are present
Figure 23 Samples of andesite and feldspar porphyry within the Epidote Zone of the Ore Zone six hundred feet from the intrusion. Middle feldspar porphyry sample contains a pyrite vein with quartz-sericite alteration. Andesite samples contain epidote subtype veins with albite and minor potash feldspar envelopes.

Figure 24 Samples of feldspar porphyry within the Chlorite and Epidote Zones of the Ore Zone within two hundred feet of the intrusion. Potash feldspar, sericite, kaolinite and montmorillonite are present as alteration products of albite but their relationship to the individual veins is obscure. Some of the potash feldspar clearly occurs along fractures.

*Refer to Figure 5 for explanation of stains.
in small amounts. Hematite and magnetite are scarce to absent. Biotite is pervasive except near sulphides where it is chloritized and near most veins where it is absent. Biotite is commonly brown and euhedral as in the Epidote Zone. Chlorite, calcite, apatite, epidote, pyrite and chalcopyrite occur in veins and disseminations in wall-rock.

The zone occurs in contact with the intrusion. The zones' surface area is about 800 feet by 1,500 feet and it extends downwards parallel to the intrusive contact to at least as deep as drilling -- over eight hundred feet.

As in the Epidote Zone, feldspar envelopes occur on propylitic veins. Potash feldspar envelopes are particularly abundant and albite envelopes scarce.

Alteration in mafic rocks near quartz-bearing veins is weak. As in the Epidote Zone, potash feldspar envelopes occur on many veins and minor amounts of sericite-clay minerals along some vein walls.

Sections of feldspar porphyry lying within the Chlorite Zone have complex alteration assemblages (Figure 24). Plagioclase has been almost completely altered to potash feldspar and sericite-clay minerals in all samples. Much primary potash feldspar has been destroyed. Secondary potash feldspar occurs as envelopes up to one cm wide on hairline fractures containing minor amounts of pyrite and on pyrite-chalcopyrite, quartz-molybdenite and quartz veins. Albitization within feldspar porphyry of the Ore Zone has not been recognized by the writer.
The mineralogy of altered plagioclase phenocrysts was examined in fifteen samples using X-ray diffraction techniques. Eight samples contained pyrite veins and also contained sericite in the altered phenocrysts. Six samples contained no pyrite veins and no sericite. One sample contained no pyrite but did contain appreciable sericite. Kaolinite and/or montmorillonite were also present in most samples. Quartz veins occurred in all samples.

Relating alteration assemblage to veins within feldspar porphyry is impossible without more detailed information. However, it appears that conditions fluctuated between feldspar constructive and feldspar destructive alteration since both types occur on similar vein types. Potash feldspar envelopes might have zones of sericite-clay minerals further removed from the vein. Quartz-bearing veins might be zoned sericite-kaolinite-montmorillonite as they are within the Intrusive Zone. Quartz-sericite alteration about pyrite-chalcopyrite veins is also possible as suggested by X-ray diffraction analysis and by the occurrence of similar alteration within the Epidote and Actinolite Zones.

BRECCIA ZONE

Intense albitionization and some potash feldspar alteration occurs in the few samples of breccia that are cemented by hydrothermal minerals described previously. Intense potash feldspar alteration is much more common, occurring in the many samples where fragments are
cemented with intrusive material. Sequence of development of these alteration types is obscured because the alteration minerals can not be related to veins of known relative ages as in other parts of the deposit.

Mafic rocks occurring adjacent to breccia contain veins of the epidote subtype of Propylitic Veins and quartz-bearing veins. They exhibit all the characteristic alteration effects described for similar rocks in the Ore Zone.

Alteration of feldspar porphyry is similar to alteration of this same rock type within the Chlorite Zone of the Ore Zone.

**DISCUSSION**

Hemley and Meyer [1967] review the problem of interpreting sequences of alteration and conclude that:

> The problem of interpreting the age relationships between different assemblages of wall rock alteration minerals is probably the most difficult and confusing of any in the entire study of the subject. As has been pointed out, unambiguous criteria are few.

In this study, alteration assemblages have been related to veins of pre-determined relative ages that were based on vein intersections. Even this criteria for determining relative ages of alteration assemblages is not decisive in all cases.

The relative age of potassic alteration is ambiguous since alteration of this type occurs as envelopes on several different vein
Figure 25  First three stages of vein development. Line of section indicated in Figure 15
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<th>ALTERATION</th>
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<td>pervasive biotite</td>
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<td>Pyrite-Chalcopyrite</td>
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Figure 26 Four stages of vein development and associated alteration assemblages. Refer to Figure 25. Question mark denotes mineral may not have developed with indicated vein type. Note control of host rock on vein-alteration assemblage.
types and as pervasive alteration in some areas. Albitic, propylitic, sericitic, and intermediate argillic alteration assemblages are restricted to one vein type everywhere in the deposit except within feldspar porphyry of the Chlorite Zone. Here alteration-vein relationships are poorly understood.

Supergene alteration effects are considered to be minimal. Oxides occur in outcrop and drill core to a maximum depth of ten feet. Gypsum and anhydrite occur together to a depth of at least one hundred feet.

The following is a discussion of the different alteration assemblages observed within the deposit arranged in the approximate order in which they began to develop. Names used for the various alteration types are taken from Hemley and Meyers [1967]. Figures 25 and 26 are helpful in reading the text.

1. **Potassic Alteration**

Potassic alteration occurs in all four zones and is indicated by development of potash feldspar and biotite.

In the East Zone, pervasive potash feldspar alteration is associated with micro-fracturing containing trace amounts of propylitic minerals. Biotite occurs in veins but more commonly as disseminations out to the limit of potash feldspar alteration. Later albitization and potash feldspar alteration are associated with individual epidote subtype propylitic veins.

Within feldspar porphyry of the Ore Zone-Breccia Zone, biotite and potash feldspar might have developed more extensively
than is now indicated. Minor biotite occurs in drill-hole 5 near the fringe of intense alteration within feldspar porphyry. If biotite developed more pervasively within now intensely altered feldspar porphyry, it has been subsequently destroyed. The weakly altered feldspar porphyry within drill-hole 5 indicates that if pervasive potash feldspar alteration did extend around the deposit within the Ore Zone, it developed nearer the intrusion than in the East Zone and was subsequently destroyed.

Within the Ore Zone, but outside feldspar porphyry, biotite is commonly pervasive but potash feldspar is restricted to envelopes. Both minerals began to form early as documented by intersections of veins of these minerals with later veins. However both minerals occur as envelopes on propylitic veins and potash feldspar occurs as envelopes on some quartz-bearing veins. Isolated propylitic veins have a feldspar envelope adjacent to the vein, a biotite envelope further from the vein and disseminated propylitic minerals within altered wall rock. The number of the above described veins is few, probably because overlap of adjacent veins has made vein-alteration relationships ambiguous. Thus it appears that potassic alteration began early and continued through Stage II and probably into Stage III.

Potash feldspar alteration is rare in the Intrusive Zone but might have formed prior to the extensive development of feldspar destructive alteration. Biotite does not occur as an alteration product within the Intrusive Zone.
2. **Albitic Alteration**

Albitization occurs in the Breccia Zone where its age is uncertain, and in the East and Ore Zones where its age is better known.

Within the east Zone, association of albite envelopes with propylitic veins establishes albitization as a Stage II event. The zone of overlap between pervasive potash feldspar alteration and pervasive albitization indicates albitization is later than pervasive potash feldspar alteration. Biotite occurs as disseminations within the zone of pervasive albitization. The crackle breccia zone has complete albitization of all previously existing feldspar.

Within mafic rocks of the Ore Zone, albitization occurs as envelopes on propylitic veins but is much less common than potash feldspar envelopes on similar veins. There is some suggestion that albite envelopes are generally further from the intrusion than potash feldspar envelopes. There is no evidence for albitization within feldspar porphyry of the Ore Zone.

3. **Propylitic Alteration**

Three propylitic zones occur about the intrusion. The Chlorite Zone occurs only in the Ore Zone and contains chlorite-calcite-pyrite with lesser amounts of chalcopryite, apatite, epidote, and quartz. Hematite is rarely present. The Epidote Zone is the most widespread, occurring peripheral to the Intrusive and Chlorite Zones. The Epidote Zone contains epidote-chlorite-calcite-pyrite-hematite with
lesser amounts of magnetite, chalcopyrite, apatite and quartz. The Actinolite Zone occurs outside the Epidote Zone and is well-developed only within the Ore Zone. The Actinolite Zone contains actinolite-magnetite-pyrite with lesser amounts of chalcopyrite, apatite, chlorite and calcite. The above minerals occur in veins and as disseminations in wall rock.

Propylitic alteration as described above is rare in the Intrusive Zone and absent in feldspar porphyry of the Ore Zone and Breccia Zone. In these areas, its age equivalent is represented by sericitic alteration about pyrite-chalcopyrite veins.

4. **Sericitic Alteration**

Sericitic alteration is well developed only within feldspar porphyry of the Ore and Breccia Zones and possibly within the Intrusive Zone. Sericite and quartz occur as envelopes on pyrite-chalcopyrite veins within feldspar porphyry that is well removed from the intrusion. Here no other vein or alteration types occur. In more intensely altered feldspar porphyry near the intrusion, there is indirect evidence for the occurrence of the same vein-alteration assemblage.

Sericitic alteration is not known in the Intrusive Zone, but might occur there. Sericite does occur within intermediate argillic alteration envelopes as described below.
5. Intermediate Argillic Alteration

Intermediate argillic alteration occurs in the Intrusive Zone and within feldspar porphyry of the Ore and Breccia Zones. Within the intrusion sericite-clay minerals are zoned sericite-kaolinite-montmorillonite outwards from a quartz-bearing vein. Within feldspar porphyry, the relation of clay minerals to veins is not known. In general, intermediate argillic alteration appears to be late because of its association with Stage III veins. However, some of this alteration within feldspar porphyry may have a different origin and relative age.

Stage III veins in mafic rocks of the Ore Zone and all rocks of the East Zone contain one or more of the sericite-clay minerals within narrow envelopes. The minerals were observed in thin section but their amounts were insufficient to determine using X-ray diffraction techniques.
CHAPTER V

OPAQUE MINERALOGY

This chapter describes the distribution of the opaque minerals, particularly within the well-mineralized Ore Zone. Zoning of the more abundant minerals is shown in Figures 22 and 27. Distribution of these and other less abundant minerals is described below.

Zoning of copper and molybdenum is well known from assay data and is presented near the end of this chapter.

MINERALS

1. Pyrite

Probably more than 95 per cent of the pyrite is contained in Stage II veins and as disseminations in adjacent wall rock. Stage III veins contain most of the remaining five per cent of pyrite. Sphalerite and calcite veins contain only minor amounts of the total pyrite.

Disseminated pyrite grains are 0.02 to 0.5 mm in diameter. Pyrite within veins occurs as blebs and smears 0.1 to 3 mm wide.

Occurrence of pyrite is zoned in several ways. In mafic rocks near the intrusion, pyrite occurs in near equal amounts as vein material and as disseminations. Within similar rocks in the Actinolite Zone,
Figure 27  Diagrammatic distribution of the five most abundant opaque minerals within the deposit
over eighty per cent of the pyrite is restricted to veins. The change between these extremes is gradational. In feldspar porphyry near the intrusion over seventy per cent of the pyrite occurs in veins. Within similar rocks in the Actinolite Zone almost all the pyrite occurs in veins.

Within the intrusion about 70 per cent of the pyrite occurs in Stage II and III veins. The remaining 30 per cent occurs in altered wall rock.

2. **Chalcopyrite**

Probably more than 90 per cent of the chalcopyrite is contained in Stage II veins and as disseminations within adjacent wall-rock. All other chalcopyrite occurs in Stage III veins.

Chalcopyrite occurs as disseminated grains 0.05 to 0.3 mm in diameter and with bornite as inclusions less than 0.03 mm in diameter within some disseminated pyrite grains. Very little of the pyrite within veins contains inclusions of chalcopyrite.

There is a contrast of mode of occurrence of chalcopyrite from within mafic rocks and feldspar porphyry of the Ore Zone near the intrusion. Within mafic rocks chalcopyrite occurs in near equal amounts in veins and as disseminations in wall-rock, but within feldspar porphyry, more than about eighty per cent of the chalcopyrite occurs in veins.
Figure 28  One of the larger bornite-chalcopyrite inclusions and a smaller one within a disseminated pyrite grain
3. **Bornite**

Bornite occurs only as inclusions within disseminated pyrite grains within hornfels but not within the intrusion. Chalcopyrite is associated with bornite in some grains. Grain size varies from sub-microscopic to 0.03 mm in diameter.

Near the intrusion where the copper grade is high, one-half to two per cent of the total copper is accounted for by chalcopyrite and bornite inclusions within pyrite. More than three hundred feet perpendicular to the granodiorite contact, the amount of copper occurring within pyrite is as high as fifty per cent of the total copper in a single sample but probably averages about fifteen per cent. This value seems to increase to twenty or thirty per cent at the outer limits of propylitic veining. This zoning is probably due to the decrease in copper content outwards from the intrusion as the amount of included copper minerals is about the same throughout the Ore Zone. Thus copper minerals occurring as inclusions contribute more to the total copper content where the total content is low.

4. **Hematite**

More than 80 per cent of the hematite occurs within epidote subtype propylitic veins. A significant proportion of the remaining 20 per cent occurs as an alteration product of magnetite within the Actinolite Zone and the altered portion of the Intrusive Zone. Only trace amounts occur in a few Stage III veins.

Hematite occurs as blades 0.5 to 1 mm long and as rims on magnetite.
At the outer limits of the Epidote Zone hematite occurs within veins as described and to a less extent as disseminations within wall-rock. Within about five hundred feet of the intrusion, hematite is almost entirely restricted to veins.

5. Magnetite

Primary magnetite occurs within unaltered granodiorite forming about one per cent of rock volume. Magnetite is also associated with epidote subtype propylitic veins. However, most of the magnetite occurs with actinolite subtype propylitic veins.

Within the Epidote Zone, magnetite occurs as blades 0.5 to 1 mm wide and as equant grains 0.05 to 0.5 mm in diameter in veins and as disseminations in wall-rock. Magnetite is almost entirely restricted to veins within about five hundred feet of the intrusion.

Within the Actinolite Zone magnetite occurs as vein material and more commonly as disseminated grains 0.01 to 0.4 mm diameter.

6. Pyrrhotite

About ten samples contain minor amounts of pyrrhotite occurring as small disseminated grains and thin smears on fractures. All of these samples occur at the outer limits of veining except one which occurs within the East Zone.

7. Molybdenite

Molybdenite occurs with quartz-molybdenite veins as flakes 0.1 to 0.5 mm in diameter along vein walls. These veins are particularly
abundant within feldspar porphyry of the Ore Zone. Molybdenite also occurs in disseminated form within intrusive breccia and within the crackle breccia of the East Zone.

8. Others

Mineralogy of sphalerite veins has not been studied intensively. The known sulphides present, in order of decreasing abundance are pyrite, sphalerite and galena. Possibly some silver minerals are present as indicated from silver assays of the lead-zinc-silver vein-system on the ridge north of Ox Lake.

Arsenopyrite was observed in one quartz vein from within the Ore Zone.

ZONING OF COPPER AND MOLYBDENUM

Zoning of copper and molybdenum minerals is indicated from drill core assays (Figure 29). Sections of drill core averaging more than 0.1 per cent Cu and 0.05 per cent Mo occur up to a distance of four hundred feet from the granodiorite contact along its west side. Beyond this distance, assay grades decline gradually. Within the intrusion Cu and Mo occur in background amounts (e.g. 100 ppm). Cu and Mo grades along the eastern contact of the granodiorite rise abruptly from background values within the granodiorite to about .05 per cent Cu and .005 per cent Mo in hornfels adjacent to the
Figure 29  Zoning of copper and molybdenum assays within the deposit. Note strong control of host rock on grades. Plane of projection is indicated in Figure 3.
granodiorite. Grades decline gradually away from the contact.

Although veining is rare within the Breccia Zone, disseminated mineralization is abundant enough to result in Cu-Mo grades comparable to the Ore Zone. No paragenetic sequence of mineralization can easily be determined in this zone. Mineralization might have followed the sequence outlined from vein relationships in the Ore Zone.

Control of host rock on assay grades is clearly indicated in Figure 29. Molybdenum grades within feldspar porphyry of the Ore Zone-Breccia Zone average two to five times the value for adjacent hornfels. This is in strong contrast to the granodiorite which is similar in bulk composition to the feldspar porphyry, yet contains a molybdenum content less than a fifth the value of the feldspar porphyry. Feldspar porphyry also has somewhat lower copper grades than adjacent hornfels although the contrast is not as striking as with molybdenum. In general, feldspar porphyry contains average copper grades of one-half the average grade for surrounding more mafic hornfels. Granodiorite also has low copper grades but the average is much less than the average for feldspar porphyry.

SUMMARY

Distribution of opaque minerals outlines the propylitic, quartz-molybdenite and sphalerite vein types. The three propylitic subtypes are particularly distinguished by opaque minerals.
Zoning studies of molybdenum and copper assays from drill data indicate a general decrease in grades outward from the intrusive contact. There is also a correlation between grades and host rock with low Cu and Mo grades within mineralized intrusion and relatively high Mo and low Cu grades within feldspar porphyry.

Thus, distributions of opaque minerals, like distributions of non-opaque minerals, can be correlated with (1) vein type, (2) position around and within the intrusion, and (3) host-rock type.
CHAPTER VI

REGIONAL CHARACTERISTICS OF PORPHYRY DEPOSITS

SUMMARY

Studies of regional distributions of porphyry deposits in British Columbia have shown they are most prevalent in the Intermontane Belt where they preferentially occur in certain broad tectonic regions such as the Skeena Arch, the southern Intermontane area and the Stikine Arch. Furthermore, they occur within these regions in local clusters such as those at Babine Lake, Morice to Eutusk Lake, Alice Arm and Highland Valley. In general, the local clusters have similar petrology and metal ratios, but over the broad tectonic regions there are commonly major differences in these factors. For example, in the Skeena Arch, molybdenum-bearing porphyries occur in the southwestern half and copper without molybdenum in the northeastern half. [Sutherland Brown, et al., 1971].

The Ox Lake deposit belongs to the local cluster of molybdenum-bearing porphyry deposits that occur between Morice and Eutsuk Lakes in the southwestern half of the Skeena Arch.

Mineralized porphyry intrusions in the Canadian Cordillera are related to two magma series; the main calc-alkaline suite: and the barely saturated syenite suite. Mineralized intrusions of the main calc-alkaline suite are generally quartz monzonite, and less commonly granodiorite, quartz diorite or granite. Molybdenum is
almost always present in the copper deposits of the calc-alkaline suite, whereas mineralized intrusions of the syenite suite contain copper without significant molybdenum or tungsten. [Sutherland Brown, et al., 1971]. The mineralized Ox Lake granodiorite is a typical member of the calc-alkaline suite of intrusions.

Mineralized porphyry deposits of British Columbia have been divided into: Simple, Elaborate, Complex and Plutonic types on the basis of structural complexity [Sutherland Brown, 1969]. Sutherland Brown correlates more structurally complex deposits with greater depth of formation. The Ox Lake deposit is a Cu-Mo porphyry of the simple type. Simple porphyry deposits, as defined,

. . . are those associated with small cylindrical porphyry plugs. (Ox Lake, Red Bird) These show the mineralogical zoning of ore, alteration and metamorphic minerals most clearly. The wall rocks are thermally metamorphosed in an annular zone of variable radius in which growth of very fine brown felted biotite is characteristic. Roughly coincident with this hornfelsic aureole is a pyritic annulus which commonly grades inward through a chalcopyrite-rich zone that is normally external to the plug to a molybdenite zone either straddling or immediately internal to the contact. The core is commonly barren or very sparsely mineralized. Alteration is zoned in a parallel manner with intense potash feldspar alteration, if developed, coincident with the barren core. Alteration varies greatly in intensity, and in some deposits may only rise above argillic in envelopes to veins or intense stockwork areas. [Sutherland Brown, et al., 1971].

Exceptions to the above description for the Ox Lake deposit are: the occurrence of intrusive breccia which complicates the structure; the molybdenum zone occurring immediately external to the intrusive and not straddling or internal to the intrusive contact; and the potash
feldspar alteration occurring in hornfels and not the barren core. Otherwise, the definition above very aptly describes the deposit.

Mineralized porphyry deposits of British Columbia have been further subdivided into Phallic, Volcanic and Plutonic porphyry deposits on the basis of: shape and size of the intrusion; age of intrusion relative to an orogenic cycle; and genetic relationship of the intrusion to host rocks. Under this classification the Ox Lake deposit is a typical Phallic type.

Phallic porphyry deposits are ones centred on cylindrical plutons or related pluton groups intruded into an unrelated host rock at a high crustal level during late orogenic or platform tectonics. Metamorphic (1) alteration, (2) and ore (3) zones are characteristically annular and normally consist of (1) biotite hornfels, (2) an internal potassic zone, variably developed, a contact phyllic zone, and an external propylitic zone, (3) variably developed outward grading sequence, molybdenum, copper, iron, which at maximum development consists of barren core, molybdenum contact zone, copper external zone, and iron outermost zone. Examples within the group range from simple to elaborate, and are: Ajax, Red Bird, Berg, Alice (British Columbia Molybdenum), Lucky Ship. [Sutherland Brown, 1972].

More recently mineralized porphyries in the general area of the Skeena Arch have been classified on the basis of apparent K-Ar ages, into three separate belts transverse to the trend of the Arch.

K-Ar dating of copper and molybdenum-bearing porphyries in the central part of the Intermontane tectonic belt indicates two major periods of intrusion and associated mineralization. Results of the K-Ar dating indicate three north to northwest trending belts of porphyry intrusions, each being distinctive in rock composition and contained metallic mineralization. These are, from east to west: (1) Babine Lake area--50 my copper bearing dykes, plugs and dykes swarms of quartz diorite composition; (2) Hazelton to Whitesail Lake area--70-80 my. granodiorite and quartz
monzonite porphyries, containing copper-molybdenum mineralization; (3) an area marginal to the Coast Plutonic Complex--50 my molybdenum bearing stocks of quartz monzonite composition. [Carter, 19].

DISCUSSION

Figure 30 shows the distribution of known mineralized porphyries and prospects in the vicinity of Ox Lake. Figure 31 lists several features of these deposits and the Laura deposit near Hazelton. The first five deposits, which include the Ox Lake deposit, belong to the second group of porphyry deposits described by Carter that lie between Hazelton and Whitesail Lake. The other two deposits belong within the third group of porphyries that lie marginal to the Coast Plutonic Complex.

The Ox, Len, and Fab porphyries show remarkable similarity in age, petrology, size, and associated mineralization. These similarities and their proximity to each other probably indicate a similar genesis for these plugs and possibly the same source at depth.

The Bergette porphyry is slightly younger than the other deposits. The Laura porphyry is of similar age, but has a higher molybdenum and lower copper content than the other deposits and is one hundred thirty miles distant. These discrepancies probably indicate that intrusion of this group of mineralized porphyries was not local and possibly extended through several millions of years.
Figure 30  Apparent K-Ar ages of porphyry deposits within the general area of Ox Lake from Carter and Harakal (personnal communication). Geology taken from Geological Survey of Canada map 1064A
<table>
<thead>
<tr>
<th>DEPOSIT</th>
<th>INTRUSION</th>
<th>K-Ar AGE</th>
<th>SIZE</th>
<th>METALS</th>
<th>HOST ROCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>OX</td>
<td>Granodiorite Porphyry</td>
<td>83.4 ±3.2</td>
<td>2400 X 1400</td>
<td>Cu (Mo)</td>
<td>Hornfels &amp; Breccia</td>
</tr>
<tr>
<td>LEN</td>
<td>Granodiorite Porphyry</td>
<td>82 ±3</td>
<td>2200 X 1400</td>
<td>Cu (Mo)</td>
<td>Hornfels</td>
</tr>
<tr>
<td>FAB</td>
<td>Granodiorite Porphyry</td>
<td>838 ±28</td>
<td>2500 X 2000</td>
<td>Cu (Mo)</td>
<td>Contact of Intrusion</td>
</tr>
<tr>
<td>LAURA</td>
<td>Granodiorite Porphyry</td>
<td>82.4 ±31</td>
<td>2000 X 2000</td>
<td>Mo (Cu)</td>
<td>Intrusion</td>
</tr>
<tr>
<td>BERGETTE</td>
<td>Quartz Monzonite Porphyry</td>
<td>76.7 ±2.5</td>
<td>3500 X 3000</td>
<td>Cu (Mo)</td>
<td>Breccia (&amp; Hornfels)</td>
</tr>
<tr>
<td>BERG</td>
<td>Quartz Monzonite Porphyry</td>
<td>48 ±2</td>
<td>2400 X 2400</td>
<td>Cu (Mo)</td>
<td>Hornfels</td>
</tr>
<tr>
<td>CAFB</td>
<td>Quartz Monzonite Porphyry</td>
<td>50</td>
<td>3500 X 2500</td>
<td>Mo</td>
<td>Contact of Intrusion</td>
</tr>
</tbody>
</table>

Figure 31 Comparison of the Ox Lake porphyry deposit with several other porphyry deposits. After White et al. (1968), Carter and Harakal personal communication. B.C. Minister of Mines and Petroleum Resources Annual Reports -- 1964, 1966, 1968, 1969, 1970, 1971
Similar interpretations have been presented for several groups of porphyry deposits in British Columbia including this group. [White et al., 1968], [Christoper, 1973].

Relative ages of mineralization and intrusion of porphyry deposits have been suggested from potassium-argon age dating deposits in the Babine Lake area.

Age determinations of petrologically similar post-mineral porphyritic phases have yielded ages 2 to 3 million years younger than the mineralized phase and while such a difference is within the limits of error, these results do indicate that the age of mineralization is approximately contemporaneous with the age of intrusion. [Carter, 1970]

A similar age relationship for the Ox Lake deposit has been suggested above from intersections of veins with porphyry dykes.
CHAPTER VII

SUMMARY

Volcanic-sedimentary rocks of unknown stratigraphic position are assigned to the Hazelton Group on the basis of the work of others, mainly Duffell [1959]. They are subdivided into three units; a lower Felsic Tuff, a middle Andesitic Tuff and an upper Sandstone-Siltstone. Felsic Tuff over one thousand feet thick is characterized by abundant feldspar porphyry and felsic tuff. Both are rhyodacitic in composition and both are considered to be mainly extrusive in origin. The two grade into each other through a zone several hundred feet thick in which they are intercalated. Andesitic Tuff is about one thousand feet thick and contains numerous layers of lapilli tuff and a few layers or dykes of feldspar porphyry. Much of this unit could be of sedimentary origin. The upper Sandstone-Siltstone unit is possibly separated from the middle unit by an unconformity. Chert-pebble conglomerate occurs as lenses within the unit as does some volcanic sedimentary material.

The lower two units have flat to gentle dips where they are not near mineralized granodiorite porphyry. The upper unit has dips of fifty to seventy degrees westerly which probably represents the eastern limb of a syncline.

All units have undergone regional greenschist metamorphism prior to emplacement of a granodiorite porphyry plug, a diorite stock
and many basic dykes. Emplacement of the diorite appears to be controlled locally by an unconformity between the upper two units.

The granodiorite porphyry intruded the lower two units and was emplaced after regional metamorphism and probably after the folding indicated by the steep attitude of the upper unit. The plug is 1,400 by 2,400 feet in plan, but rakes west about fifty degrees and is thus nearly circular in true cross-section. It was intruded forcefully, approximately in its present attitude so that Hazelton Group rocks in contact with the west side of the intrusion form an anticline whose fold axis overlies and is approximately parallel with the westward rake of the intrusion. Intrusive breccia occurs in contact with the plug, mainly along its southwest contact. Many dykes of granodiorite porphyry occur along the western contact within hornfels and intrusive breccia. Some but not all of these dykes are unaltered and intersect earlier formed veins. The plug is unaltered except within one hundred feet of its western contact.

Two main lineaments intersect at the northwest edge of the intrusion and probably represent faults. Much fault gouge occurs in drill holes within the western margin of the intrusion and adjacent hornfels, less so within the eastern hornfels and even less within drill holes in unaltered Hazelton Group rocks.

Nine vein types and five alteration types have developed within four recognized stages of vein development. The stages are based on relative ages of veins determined from crosscutting relationships. Alteration is largely primary; surface oxidation occurs to a maximum recognized depth of ten feet.
Stage I is primarily an early potassic alteration event involving development of biotite and potash feldspar within veins and as alteration products of previously existing minerals. Potassic alteration began early but continued throughout Stage II and into Stage III.

Stage II is characterized by propylitic assemblages everywhere except within the intrusion and within feldspar porphyry on the west side of the deposit. Propylitic minerals show a zonal pattern as follows: a core zone of chlorite-calcite-pyrite lies adjacent to the west side of the intrusion; a zone of epidote-hematite-chlorite-calcite-pyrite surrounds the intrusion and the above zone; and an actinolite-magnetite-pyrite zone lies peripheral to the second zone.

In the west half of the deposit, weakly altered feldspar porphyry contains Stage II pyrite-chalcopyrite veins with quartz-sericite envelopes. In more intensely altered feldspar porphyry the same alteration assemblage possibly exists but alteration patterns are obscured by intense overlapping of several alteration types. Granodiorite porphyry contains only minor amounts of Stage II alteration. Potash feldspar, sericite, kaolinite and montmorillonite occur outwards from Stage II veins replacing plagioclase phenocrysts.

West of the intrusion, potash feldspar is common and albite rare as an alteration envelope on propylitic veins with some indication that the albite envelopes occur further from the intrusion than potash feldspar envelopes. East of the intrusion, Stage II veins have much albite and minor potash feldspar occurring as envelopes.
Quartz and quartz-molybdenite veins represent Stage III, with those containing only quartz being late paragenetically. Alteration occurring with these veins within the intrusion is sericite-kaolinite-montmorillonite as a replacement of plagioclase outwards from vein walls. Biotite is stable to the centre of the kaolinite zone. Veinward from here, the biotite is replaced by a golden brown mica. Magnetite is destroyed at the outer edge of alteration where it is first replaced by hematite. Within well-altered feldspar porphyry west of the intrusion quartz veins might have a similar alteration envelope. Within other rocks, some Stage III veins have potash feldspar envelopes and others have minor amounts of what is probably sericitic alteration.

Stage IV veins are calcite, gypsum and sphalerite type and have no noticeable alteration envelopes.

Economic minerals in order of decreasing importance are chalcopyrite, molybdenite and bornite. Stage II veins and associated disseminated mineralization represents the bulk of the introduced copper. Bornite occurs only as inclusions, commonly with chalcopyrite, within disseminated pyrite grains. Stage III veins contain all molybdenite except a small portion occurring as disseminations in breccia. Breccia, although containing very few veins, does contain Cu and Mo grades comparable to adjacent unbrecciated hornfels.

Unaltered granodiorite porphyry contains no visible sulphides. Altered granodiorite porphyry contains less than 0.05 per cent Cu and less than 0.005 per cent Mo. Grades of both elements
are highest in hornfels along the western contact of the intrusion and decline gradually outwards from the contact where grades average about 0.5 per cent Cu and 0.02 per cent Mo. The zone of Mo mineralization does not extend as far from the intrusion as does the zone of Cu mineralization. Feldspar porphyry seems to exert a strong control on Cu and Mo. Mo is 2 to 5 times higher and Cu about one-half as high in feldspar porphyry relative to adjacent andesitic hornfels.

The Ox Lake deposit is one of a group of deposits all associated with similar intrusions and having comparable mineralization products. This group includes Ox Lake, Len, Fab, Laura and Bergette deposits in the southwestern half of the Skeena Arch from Hazelton to Whitesail Lake. The intrusion (and probably the mineralization) have apparent K-Ar ages of 70-80 my [Carter, 1973]. They have been described by others and classified as Simple type based on structural complexity [Sutherland Brown, 1969], and as Phallic type based on; shape and size of the intrusion, age of intrusion relative to orogenic cycle, and genetic relationship of the host rocks [Sutherland Brown, 1972].
REFERENCES


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