WALLROCK ALTERATION AT PIONEER AND BRALORNE MINES
BRITISH COLUMBIA

by

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PREFACE

The writer was engaged as mine geologist at Pioneer Mine from May, 1946 until October, 1946. Unfortunately the underground workings during most of that period were inaccessible as the mine workers' strike started on the 3rd of July. However, the writer had the opportunity to become acquainted with the larger features of the geology of the southern Bridge River mining area and with some features of the detailed geology of many of the prospects in that area.

This thesis is based largely on the examination of specimens collected by the writer and by Mr. F. R. Joubin for the University of B. C.

The writer wishes to thank Dr. Howard James, the operating staff of Pioneer Mine, Mr. Allan Poole, geologist at Bralorne Mine and Mr. J. A. Donnan of the Dept. of Geology, University of B. C. for their help and cooperation in collecting and preparing specimens. Mr. F. R. Joubin, Dr. C. E. Cleveland, Dr. J. S. Stevenson and several of the graduate students were very helpful in contributing their ideas and discussion during the investigation.

The writer is particularly indebted to Dr. H. C. Gunning and Dr. K. DeP. Watson for giving much of their time toward guiding his efforts in the solution of many problems.
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**Figure 1.** Pioneer-Bralorne Gold Belt. 6

2. Vertical Section Through No. 2 Shaft, Pioneer Mine. 7
WALLROCK ALTERATION AT PIONEER AND BRALORNE MINES
BRITISH COLUMBIA

ABSTRACT

Hydrothermal wallrock alteration is an important feature of the gold quartz veins of the Pioneer and Bralorne Mines in the Bridge River district, British Columbia. In the principal host rocks, Bralorne soda diorite and Pioneer greenstone, the alteration is evidenced by bleaching and, to a limited extent, by the formation of a reddish-brown alteration material to a maximum distance of 2 or 3 feet from the vein walls. By microscopic means, the principal alteration minerals are determined to be chlorite, carbonate, sericite, pyrite, and arsenopyrite with some local biotite. In the minor host rocks, Bralorne soda granite and acid dykes, the hydrothermal alteration is not readily apparent to the naked eye. It consists essentially of sericitization although chlorite, biotite, carbonate and pyrite occur in minor quantities. The hydrothermal wallrock alteration in these four host rocks, has caused an increase in carbon dioxide, potash, sulphur and arsenic and a decrease in silica and soda.

The above changes in the wallrock, together with the observed mineralogical nature of the veins, is typical of Lindgren's mesothermal mineral deposits. The high temperature minerals, biotite and tourmaline, are formed
in minor amounts by mineralizing solutions introduced prior to the deposition of gold.

An important feature of the Pioneer-Bralorne Gold Belt is the uniformity of the nature of quartz veins and of hydrothermally altered wallrock over a vertical range of over 3,000 feet.

INTRODUCTION

Location

Pioneer and Bralorne Mines are located in the Bridge River mining area of British Columbia on the eastern flank of the Coast Range batholith. These mines are situated 100 miles due north of Vancouver and about 50 miles, by a circuitous road, westward from Shalalth on the Pacific Great Eastern Railway.

History

Placer mining first commenced in the Bridge River district in 1858 and the first lode claims were staked in 1896. Spasmodic production from the Pioneer-Bralorne Gold Belt by F. H. Kinder, A. F. Noel and others amounted to less than one half million dollars prior to 1924. In that year systematic development and steady production began at the Pioneer Mine under the late David Sloan who was largely responsible for the organization of the present company. Continuous
production began at Bralorne Mine with the organization of the present company in 1931. From 1930 to 1945 Pioneer Mine produced 777,588 ounces of gold and from 1932 to 1945 Bralorne Mine produced 996,383 ounces of gold. These two mines have distributed about 25 million dollars in dividends.

General Geology and Bibliography

The most comprehensive publications on the geology of the Bridge River area were written by W. S. McCann (1) and C. E. Cairnes (2) of the Geological Survey of Canada. Cairnes gives a complete annotated bibliography of the published writings prior to 1937, which will not be repeated here. A complete bibliography of the literature pertaining to the Pioneer-Bralorne Gold Belt written since 1936, is included below.

(1) 1922, McCann, W. S. Geol. Surv., Canada, Mem 130. "Geology and Mineral Deposits of the Bridge River Map-area, British Columbia".

(2) 1937. Cairnes, C. E. Geol. Surv., Canada, Mem 213. "Geology and Mineral Deposits of the Bridge River Mining Camp, British Columbia".


* The number in brackets have reference to bibliography found on Page 3
PLATE II
U-shaped Valley of Noel Creek, tributary of Cadwallader Creek.

PLATE II
Glaciers and Glacial Cirques at headwaters of Noel Creek.
PLATE III
Cadwallader Creek in Background and its Hanging Valley Tributary, Piebiter Creek in Right Foreground.

PLATE IV
Pioneer Mine, Cadwallader Creek Valley, No. 2 Shaft Headframe on Left.


The Bridge River area is one of early maturity having a very rugged topography of great relief. Extreme elevations range from 2100 feet in the Bridge River valley to 9450 at the summit of Mt. Truax. Cadwallader Creek valley lies between the Bendor Mountains to the north-east and the Cadwallader Mountains to the south-west. Cadwallader Creek and its tributaries are conspicuously modified by glacial features such as U-shaped valleys, hanging tributary valleys, truncated spurs and morainal drifts. Landslides on the over-steepened flanks of the glaciated valleys are also conspicuous. (See Plates I-IV).

Locally, Cadwallader Creek flows north-westerly, parallel to the structural trend of the underlying formations. The Pioneer-Bralorne Gold Belt lies close to Cadwallader
Creek on its north-east bank. Due to accumulated glacial debris on the lower slopes of the Cadwallader Creek valley, bedrock outcrops are rare so that the detailed lithology and structure of the Pioneer-Bralorne Gold Belt has been mapped largely on the basis of diamond drilling and underground development.

Below is a table of the formations found in the vicinity of the Pioneer-Bralorne Gold Belt:

<table>
<thead>
<tr>
<th>Period</th>
<th>Formation</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Lower Cret.</td>
<td>President Intrusives</td>
<td>Lamprophyre dykes.</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Bralorne Intrusives</td>
<td>Serpentine Peridotites, Acid Dyke Soda Granite</td>
</tr>
<tr>
<td>Triassic and/or Jurasssic</td>
<td>Hurley-Noel Intrusives</td>
<td>Banded argillaceous and tuffaceous sediments with some conglomerate, limestone and flows.</td>
</tr>
<tr>
<td>Triassic and/or Jurasssic</td>
<td>Pioneer (Greenstone) Series</td>
<td>Andesitic tuffs, flows and fine-grained intrusives.</td>
</tr>
<tr>
<td>Permian</td>
<td>Fergusson Series</td>
<td>Lavas, interbedded chert and argillite.</td>
</tr>
</tbody>
</table>

The above table is largely based on Cairnes' report (2) but includes important modification by Joubin (8). Cairnes places the Pioneer formation in an intermediate position between the older Noel and the younger Hurley formations. However, Joubin, on the basis of extensive mapping of drill holes and underground development, concludes that the Hurley and Noel formations are one and the same formation, being
LEGEND

- Serpentinite
- Soda Granite
- Soda Diorite
- Hurley-Noel Sediments
- Pioneer Greenstone
- Ferguson Series
- Shaft
- Fault
- Quartz Vein
- Pioneer Main Vein
- Footwall Vein
- Hangingwall Vein
- 77-Countless Vein
- 51 Vein

PIONEER-BRALORNE GOLD BELT

Scale 1 in. = 2000 ft

After F. Joubin

Fig 1.
repeated by close folding (see fig. 2).

Joubin (8) has ably presented the detailed structure of the Pioneer-Bralorne area. The known ore occurrences lie between two major faults, the Fergusson Overthrust and the Cadwallader Break (see figs. 1 and 2), and are spatially and possibly genetically related to the Bralorne intrusives which consist in the main of soda granite and soda diorite *.

The host rocks to the commercial quartz veins are in order of importance: (a) Soda diorite; (b) Pioneer greenstone; (c) Soda granite; (d) Acid dykes. In the Pioneer Mine, the greenstone is the most important host rock to the productive veins whereas in the Bralorne Mine the soda diorite is most important. The soda granite is second in importance at each mine. It is held that the competency of the rocks to hold fissures is the dominant factor which produces localization of the ore deposits. Where the Bralorne 51 vein passes from soda diorite into greenstone it decreases in width, continuity and values, becoming non-commercial. On the other hand, the Pioneer Main vein is equally strong in size and values in greenstone as in soda diorite or soda granite. However, the greenstone in the Pioneer Mine is of a more massive, competent variety than that adjoining

* Commonly called augite diorite. Nomenclature is discussed under heading, "Soda Diorite and Its Alteration".
the Bralorne 51 vein. The acid dykes consist of aplite, albitite and quartz porphyry and commonly occur in intrusive relation to the above three host rock types, especially in horizons of commercial importance.

The Hurley-Noel sediments and the serpentine in particular have proved unfavorable for ore deposition due to their incompetency. The failure of the serpentine to maintain fissures has resulted in this formation producing a damming effect on the mineralizing solutions. This has resulted in unusually rich concentrations of ore in favorable formations close to the serpentine contact.

**Nature of the Veins**

Fig. 1 illustrates in plan the most important veins with the exception of the Pioneer 27 vein. The latter occurs as a short, north-easterly striking, hangingwall branch vein of the Main vein on 11 level. With increasing depth it surpasses the Main vein in size and values. In addition to the Main vein, the Hangingwall and the Footwall veins have produced appreciable commercial ore. In the Bralorne Mine the most productive veins at present are the 51 and the 77, although the King, Shaft, North and C veins in the western workings produced considerable ore in the past.

The large vein fissures and faults in the area form conjugate shear faults, while the "cross-over" veins form tension faults. Joubin (8) has shown the pattern of the faults and fissures conforming to the conventional strain
ellipsoid diagram with compressive forces from the north-east or south-west and the major folds plunging to the south-east at about 45 degrees.

The veins that have been mined average over 3 feet in width. There is evidence of considerable movement along the vein fissures: gouge on one or both walls, slickensides, ribboning of the quartz, and displacement of cross-cutting structures.

The gangue is predominantly quartz with some calcite, scheelite, sericite, mariposite, ankerite, chlorite and in rare instances, tourmaline. Calcite commonly occurs as bands on either wall or along ribbon faces where movement has taken place.

The metallic content of the vein is very low, averaging less than 3 percent. The most abundant minerals are arsenopyrite and pyrite, while gold, sphalerite, galena, pyrrhotite and chalcopyrite occur in minor quantities. Rarely, stibnite, tetrahedrite and molybdenite have been identified. Warren and Runkle (6) have noted the occurrence of millerite, a sulphide of nickel in Bralorne ore.

Arsenopyrite occurs in the quartz as needles and finely-divided grains along the ribbon faces and as coarsely-crystalline aggregates. The pyrite occurs similarly but less abundantly. Gold tends to be with the arsenopyrite in preference to pyrite and occurs as marginal coatings or veinlets in the former. Plate VI shows massive arsenopyrite veined by two generations of quartz, one of which contains
27 Vein
2500 Level

$Q_1 =$ Early quartz
$Q_2 =$ Late quartz
$Au =$ Gold
$G =$ Galena

PLATE V

E 3518

$Q_1 =$ Early quartz
$Q_2 =$ Late quartz
$Asp =$ Arsenopyrite
$G =$ Galena

PLATE VI
inclusions of gold. Gold also occurs along ribbon faces
with fine crystals of arsenopyrite and pyrite and as
disseminations in massive quartz.

Sphalerite and galena are useful as indicators of high
grade ore as they are invariably associated with the
coarser gold, and appear to be contemporaneous with it.
Plate V illustrates the association of gold with galena
and quartz. From the study of plates V and VI the relations
between the two generations of quartz are inconclusive, but
the appearance of embayed contacts indicates the quartz
containing inclusions of gold is the later. The latest
vein material to be deposited is therefore quartz with
contemporaneous gold and galena.

The mineralogy of the veins in the Pioneer-Bralorne
Gold Belt is remarkably uniform over the whole area and
through a vertical range of over 3,000 feet in the Pioneer
Mine. According to Lindgren's classification of ore
deposits the veins can be considered mesothermal because
of the following characteristics: (a) absence of high
temperature minerals such as magnetite, garnet, pyroxene
and tourmaline (with exception noted below); (b) fissures
are fairly regular in strike and dip without brecciated
structure of epithermal deposits or lenticular openings of
deep-seated deposits; (c) pyrite, arsenopyrite, galena,
chalcopyrite, sphalerite and gold are most abundant metallics;

* Lindgren, W., Mineral Deposits, P. 530
(d) the metallics occur in both vein filling and country rock but the gold is found "free"; (e) predominating gangue mineral is quartz with subsidiary carbonates; (f) extensive carbonatization and sericitization of the wallrocks.

In the deeper portions of the Pioneer Mine minor amounts of tourmaline occur in the 27 vein on 21 and 25 levels. Thin section 125 from near Station 2101A shows ribboned quartz which is minutely veined along the ribbon faces by carbonate, tourmaline, pyrite and arsenopyrite which appear contemporaneous.

**Nature and Significance of Chrome Mica**

Thin sections 127 and 127 (a) were prepared from an extremely highly-altered wallrock consisting of carbonate, quartz and green mica which occur contiguous to veins near the serpentine contact. Qualitative analyses of the mica and surrounding rock particles give positive tests for nickel and chromium, indicating the green mica is chromiferous.

The examination of thin sections supplemented by determination of refractive indices of the carbonate in oils indicate the rock to consist of dolomite, quartz, pyrite and arsenopyrite with minor chrome mica. The dolomite appears as clear to cloudy, anhedral crystal growths and the quartz as clusters of very fine-grained, anhedral crystals occasionally in a veining relationship with the dolomite. The sulphides appear as coarse-grained
euhedral crystals disseminated throughout the dolomitic rock.

The chrome mica in thin section varies from colorless to apple-green, resembling sericite in its mode of occurrence. It is in shreds, plates and veinlets cutting both carbonate and quartz, is biaxially negative with 2V less than 10° and has refractive indices: \( \alpha = 1.57, \gamma = 1.60 \). In veinlets it occurs with minute grains of a brownish-black, translucent to opaque mineral. From the nature and occurrence of the latter it is deduced to be chromite.

Knopf describes the original mariposite to be colorless to pale green in thin section, optically negative with an axial angle approaching zero and refractive indices, \( \alpha = 1.56 - 1.58, \gamma = 1.61 - 1.63 \). In the Motherlode of California it occurs as a minor constituent of an ankeritic rock resulting from the hydrothermal alteration of serpentine and Knopf states it to be a "green chromiferous sericite".

Whitmore, Berry, and Hawley found in their investigations that the chrome micas mariposite and fuchsite, identified on the basis of X-ray analyses, overlapped each other in their optical properties. However, most mariposite has 2V less than 25° whereas the fuchsite has 2V

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@ Whitmore, D.R.E., Berry, L. G., and Hawley, J. E. The American Mineralogist Vol. 31, 1945, "Chrome Micas".
greater than 25°. In addition the mariposite has lower indices of refraction than fuchsite. They concluded from quantitative chemical analyses that mariposite is a chromiferous phengite whereas fuchsite is a chromiferous muscovite. The mariposite has more silica and less chrome and alumina than the fuchsite.

From the optical properties and general occurrence of the green mica it may be concluded that it is mariposite very similar to that occurring in the Motherlode of California.

It has been held that mariposite is a good indicator of gold in the Bridge River veins. However, that contention has not been well-supported for much mariposite occurs contiguous to barren quartz. As mentioned previously; gold is often concentrated in quartz veins close to serpentine contacts due to the damming influence of the serpentinite which is incompetent in maintaining fissures. Mariposite is found only in or near highly-altered serpentinite rock adjoining vein quartz. It is natural, therefore, to find gold spatially related to mariposite but this relation has no genetic significance.

Soda Diorite And Its Alteration

The soda diorite has been referred to as augite diorite, diorite, hornblende diorite, meta diorite, and albitic syenite. The principal constituents of the unaltered rock have been described as albite or albite-oligoclase in more
or less equal proportion with hornblende or augite. In the Bralorne Mine where the soda diorite is most plentiful, Cleveland (5) recognized no augite in thin section although Poole (7) states there is "equally as much augite diorite as there is hornblende diorite". The hornblende occurs in rather stubby-shaped crystals with poorly-defined cleavage planes so it may have been mistaken for augite in hand specimens. Cairnes states (2), "Augite, though rarely abundant, is a characteristic mineral of much of the Bralorne diorite and generally is partly altered to amphibole, thus suggesting that it was originally more common. Most of the amphibole has, in part, the appearance of being secondary after augite or (and) some earlier amphibole." Cleveland, who examined soda diorite from the Empire section of the Bralorne Mine, could find no evidence of a secondary origin for the amphibole. Specimens of the soda diorite from the Bralorne Mine examined in thin section, show the amphibole to be common hornblende (see thin section 7, plate VII). This would support primary origin as secondary amphibole produced from pyroxene is usually in the form of tremolite or actinolite.

Albite is the only important light-colored mineral in the diorite. Typically, it is subhedral to anhedral in form and has only a very minor amount of Carlsbad or polysynthetic twinning.

In the unaltered portions of thin section No. 7 (see Plate VII) examined by the writer, pure albite and horn-
blende occur in equal amounts as subhedral, medium-grained crystals. Minor primary constituents are negligible.

It is desirable to classify this rock as accurately as possible because there has been such a confusion of terms in use in the past. Johannsen's system which gives a modal classification based on petrographic study, seems most appropriate and is therefore applied to this rock type. Assuming an average composition of 50% pure albite and 50% hornblende, the rock belongs to family 3112, melasodaclase-diorite. For convenience, the term soda diorite is used.

The following slides illustrate the alteration in the soda diorite:

<table>
<thead>
<tr>
<th>Thin Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>77 vein, 1600 level, altered wallrock contiguous to high grade ore.</td>
</tr>
<tr>
<td>3</td>
<td>Location as above, farther from the vein.</td>
</tr>
<tr>
<td>4, 5, 6</td>
<td>75 vein, 1600 level, altered wallrock contiguous to low-grade vein.</td>
</tr>
<tr>
<td>7</td>
<td>Location as above, farther from vein.</td>
</tr>
</tbody>
</table>

The approximate paragenesis of the alteration minerals is as follows: zoisite, chlorite, early calcite, sericite (and muscovite), quartz, late calcite, and the common sulphides, pyrite and arsenopyrite.

* Johannsen, A. "Essentials for the Microscopic Determination of Rock-Forming Minerals and Rocks".
T.S. 7  x30

H = Hornblende  Ab = Albite  Fe Z = Iron bearing zoisite  Z = Zoisite  C = Carbonate

PLATE VII

T.S. 4  x85

Q = Quartz  Chl = Chlorite  FeC = Iron bearing Carbonate  C = Carbonate

PLATE VIII
The earliest alteration noted is the formation of zoisite and chlorite of very low birefringence as fine-grained aggregates in albite. These minerals are occasionally found as filling veinlets cutting both albite and hornblende. It would seem that albite is more easily replaced by zoisite and chlorite. The zoisite alters to a rather opaque mineral appearing white under reflected light and brown under transmitted light. The opaque alteration appears to be more abundant in the albite close to the slightly altered borders of the hornblende (see thin section 7, Plate VII) and is often associated with carbonate. It seems probable that the hornblende on decomposing has supplied iron to alter zoisite to an iron-rich variety of the epidote group and that the calcium, magnesium and aluminum have been used up in the formation of carbonates and chlorite.

Zoisite varies somewhat in its mode of occurrence. Generally it occurs in small, anhedral crystals but one crystal was noted as a pseudomorph after euhedral albite. Some grains of zoisite resemble epidote in color and pleochroism but have other optical properties of zoisite.

Most of the chloritic material occurs in an almost isotropic form of extremely low birefringence and very pale green color. This would fit the description of serpophite, a serpentine end-member of the chlorite group. However, some of the chlorite has a bright green color, shows pleochroism, a radiating structure, and an anomalous blue or brown interference color, conforming to the mineral
penninite.

The carbonate, which is largely calcite, grows either in fine-grained aggregates or in rather coarse-grained crystals. Thin section No. 3 shows calcite as quite coarse-grained, acicular crystals. Some of the crystals penetrate variously-oriented crystals of albite, proving the calcite is not pseudomorphic.

Later alteration of the soda diorite consists of the introduction of sericite, quartz and late calcite veinlets. The sericite generally occurs in shreds but occasionally in plates (as muscovite) up to 1 mm. in diameter. The latter are found to be highly-altered and veined by quartz and carbonate in slide 6. The quartz also may occur as discontinuous veinlets or as scattered aggregates of fine crystals. The late calcite veinlets consist of quite coarse-grained, clear crystals at the centre but extremely fine-grained, cloudy aggregates at the walls. These cloudy aggregates are probably iron carbonate for they are more prolific where the veinlets cut the iron-bearing penninite (Plate VIII).

Pyrite and arsenopyrite occur in euhedral to subhedral crystals and pyrrhotite in anhedral grains. Opaque, yellow-brown material answering to the description of limonite is in association with these sulphides. The growth of the sulphides apparently commenced fairly early, but is more important in the later stage of hydrothermal alteration as pyrite and arsenopyrite appear in comparatively large
crystals in the more intensely-altered diorite.

To summarize, soda diorite is rapidly attacked by hydro-thermal solutions due to the large proportion of easily-altered hornblende and the lack of resistant quartz. Earliest alteration minerals formed are zoisite, chlorite, calcite and sericite. More intense alteration produces a rock composed essentially of sericite and carbonate with some quartz and sulphides. There is no biotitization.

**Pioneer Greenstone And Its Alteration**

Pioneer greenstone is a term used to designate a formation containing a number of rock types. Joubin (8) mentions four main types of greenstone: amygdaloidal flows, tuffs, flow-top breccias and a fine-grained intrusive phase. The latter is described as closely resembling the soda diorite. James * states the greenstones of the Pioneer Mine are of a general andesitic composition and Cairnes (2) describes the Pioneer greenstone formation to be essentially volcanic, composed mainly of amphibole and sodic plagioclase.

Of 25 thin sections of greenstone examined @ only one was so slightly altered that its original nature could be determined. The rock of that section is composed of

* James, H. T. The Miner, August, 1934. "Features of Pioneer Geology".

@ Including a number kindly loaned by Dr. J. S. Stevenson of the B. C. Dep't. of Mines.
about 65% plagioclase, 15% hornblende, 15% chlorite and carbonate alteration, and a small amount of indeterminate, interstitial material. The plagioclase is untwinned and too fine-grained to give an interference figure but the index of refraction compared to balsam indicates it is oligoclase or andesine in composition. The plagioclase and hornblende both occur in small, lath-shaped crystals in a sub-parallel orientation, indicating the rock to have been a flow. Two other slides (138 and 147) have remnants of plagioclase laths at random orientation that were identified as albite. This indicates that the composition of the plagioclase varies in the greenstone from albite to oligoclase and possibly to andesine.

Taking the proportion of the mafics to total minerals to be about 25%, the quartz to be under 5% of the light constituents and the average composition of the plagioclase to be oligoclase, the greenstone may be placed in Johannsen's modal classification as an andesite.

In the past there has been confusion and difficulty in differentiating between the Bralorne soda diorite formation and the Pioneer greenstone formation as there often appears to be a gradational contact between the two, especially in the Bralorne Mine. The root of this difficulty is that highly-altered soda diorite resembles the Pioneer greenstone.

It is unfortunate that the term greenstone has been applied to the Pioneer formation which, in its normal environment, away from mineralizing solutions, is relatively
unaltered. Kemp suggests * that the name greenstone be applied to an old basaltic rock where there is a prevalence of green, chloritic alteration. He further states that it is difficult to distinguish greenstone from propylite derived from andesite. This would bear out the necessity to use means other than megascopic examination to differentiate between highly-altered Bralorne soda diorite and Pioneer greenstone.

The thin sections examined in detail were all prepared from specimens taken from the Pioneer mine within the boundaries of what has been mapped as the Pioneer greenstone.

<table>
<thead>
<tr>
<th>Thin Section Nos.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>126</td>
<td>Station 2101A on 2100 level, greenstone inclusions in the vein.</td>
</tr>
<tr>
<td>129, 130, 131, 147</td>
<td>Station 2101A, from hangingwall, with increasing distances from the vein.</td>
</tr>
<tr>
<td>138</td>
<td>27 vein, 2000 level, in hangingwall three feet from vein.</td>
</tr>
<tr>
<td>9, 10, 11</td>
<td>27 vein, 2500 level, in hangingwall adjoining vein of commercial grade.</td>
</tr>
<tr>
<td>12, 13</td>
<td>As above, two feet from the vein.</td>
</tr>
<tr>
<td>15</td>
<td>Footwall vein, 2500 level, in hanging-wall two feet from vein of non-commercial grade.</td>
</tr>
<tr>
<td>16</td>
<td>Drill core, 27 vein, 2500 level, inclusions of wallrock in vein near footwall.</td>
</tr>
<tr>
<td>17</td>
<td>As above, wallrock close to the vein.</td>
</tr>
</tbody>
</table>

* Kemp's Handbook of Rocks.
At the time the above specimens were collected it appeared that the limit of hydrothermal alteration as indicated by bleaching and brown alteration extended no more than two or three feet from the vein walls. However, from the study of thin sections, it is apparent that some alteration has extended for much greater distances from the vein. It is uncertain whether or not the alteration beyond the bleached zone in the Pioneer greenstone is due in part to hydrothermal processes. Samples of wallrock remote from veins were not collected. However, specimens of soda diorite * from locations 20 to 120 feet from known veins showed considerable chloritization and carbonatization. Such an occurrence indicates regional metamorphism.

The earlier alteration to take place in greenstone, some of which may be regional metamorphism, is that of biotization, chloritization and silicification as shown by slides 147 and 138 which have remnants of albitic feldspar laths. Biotite occurs in small plates and random orientation in small crystal aggregates. The chlorite comprises nearly 50% of these slides and occurs as a pale green, almost amorphous mineral of very low birefringence. From its appearance it is probably a magnesium-end member of the chlorite group - possibly serpophite. Quartz occurs in small scattered aggregates. It is probable that the alteration has taken place in a closed system for the quartz

* Collected by Dr. J. S. Stevenson of the B. C. Dep't. of Mines, thin sections of which were kindly loaned to the writer.
need not be introduced. Tyrrell states * that andesite may contain up to a maximum of about 10% excess silica which occurs latent in the cryptocrystalline or glassy parts of the groundmass.

The normal sequence of the reaction series on decreasing temperature from hornblende is through biotite to chlorite. Both chlorite and biotite occur in the comparatively mildly-altered greenstone. The appearance of biotite as small islands surrounded by chlorite in section 147 would suggest that there the biotite is altering to chlorite. However, in section 138 the biotite occurs as margins on the late carbonate veining indicating an alteration from chlorite to biotite (Plate IX).

It is evident that the alteration from biotite to chlorite is reversible. Butler states @ "As ore deposits are not formed in a closed system there is a possibility that conditions will be reversed and therefore that reactions will not always move in a direction normal to a closed system". Harker explains $ that a mineral in a reaction series will be altered to the paramorph which is stable at the existing temperature of metamorphism. At near-surface

@ Butler, B. S. "Influence of the Replaced Rock on Replacement Minerals Associated with Ore Deposits". Econ. Geol., Vol. 27, 1932, p. 6.
temperature, biotite may be considered to be in a metastable condition. A higher temperature maintained for considerable time may cause it to alter to chlorite and a still higher temperature may cause it to alter back to biotite.

From the above considerations one may deduce that the temperature maintained in the rock of slide 147 was suitable for the alteration of biotite to chlorite whereas the introduction of late, veining carbonate in slide 138 resulted in an alteration of chlorite to biotite due to the temperature of the vein solutions. In considering slide 16, one finds that there is both chlorite and biotite but the latter, where it occurs on the margins close to the vein quartz, has a fringe of chlorite. This would indicate that the temperature of the later vein-forming solutions were low enough to cause the biotite to revert to chlorite.

Sericitization and carbonatization are important later phases of hydrothermal alteration as seen in slides 9, 10, and 11. Early sericitization is illustrated in slides 12 and 13 where scaly aggregates of sericite are arranged in lath-like form after the original albite. Sericitization also continues into the very late stage where it forms large parallel aggregates along shear planes as in slide 17. Here it forms a zone with late carbonate, pyrite and chlorite which cuts all earlier alteration. It would seem that slight shearing in the walls is a contributing factor towards the formation of sericite.

Carbonatization generally starts when alteration is
well-advanced and becomes most pronounced during the latest stage of wallrock alteration. Much of the early carbonate is in very small crystals near pyrite and is clouded by a pale, yellow-brown, opaque material. The latter is probably limonite formed from the alteration of iron carbonate and pyrite. The later carbonate is much more plentiful and has been determined by refractive indices in oils to be largely calcite.

Silicification is quite important also in the later stage of hydrothermal alteration. There is a tendency, especially where there is some movement, for the quartz to congregate in fine-grained, large aggregates.

The growth of the secondary sulphides, pyrite and arsenopyrite and, to a minor extent, pyrrhotite is most important during the latest stages of alteration. Intensely altered greenstone is composed of as much as 20% by volume of the sulphides.

An extremely fine-grained, opaque, black mineral altered to an opaque, white mineral occurs in both the relatively unaltered and the highly-altered greenstone (see slide 17). A sample of rock containing this mineral gave a positive test for titanium. It may therefore be assumed that this mineral is titaniferous magnetite or ilmenite altered to leucoxene. In most of the slides the ilmenite is completely altered to leucoxene.

A few crystals of tourmaline were noted in slide 9. It was not identified in other slides.
The earlier alteration in greenstone is the formation of biotite, chlorite and quartz. Highly-altered greenstone consists largely of sericite, carbonate and sulphides. Where there is lack of shearing and the rock remains massive, as in vein inclusions, the alteration may consist essentially of chlorite, biotite and the sulphides, pyrite and arsenopyrite.

Soda Granite And Its Alteration

Cairnes (2) gave the first complete description of the occurrence of soda granite or quartz diorite as it has been called, although Dolmage * and James @ had noted its occurrence earlier. Cairnes presents two almost identical chemical analyses of samples from the Bralorne and Pioneer Mines, one of which when recast in terms of mineral constituents gave the following:

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albite</td>
<td>42.4</td>
</tr>
<tr>
<td>Quartz</td>
<td>41.0</td>
</tr>
<tr>
<td>Chlorite (hornblende and (or) biotite)</td>
<td>6.5</td>
</tr>
<tr>
<td>Sericite</td>
<td>6.9</td>
</tr>
<tr>
<td>Calcite, apatite, leucoxene, pyrite, magnetite</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>100.1</td>
</tr>
</tbody>
</table>

* Dolmage, V. The Cariboo and Bridge River Goldfields, British Columbia; Trans C.I.M.M., 1934, pp. 405-430.

@ Op. cit.
In relatively fresh soda granite medium-grained quartz and albite occur in about equal amounts (slide 19). Minor sericite with secondary quartz is restricted to one small veinlet and the remainder of the minerals would constitute much less than 5% of the rock. The rock may be said to have only two essential minerals, quartz and albite. In Johannsen's modal classification it may be described as 118, a leuco-sodaclase-tonalite. However, the term soda granite is preferable for simplicity and because it is an accepted local designation.

The following thin sections were studied:

<table>
<thead>
<tr>
<th>Thin Section No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>136</td>
<td>27 vein, 2500 level, 6 feet from vein.</td>
</tr>
<tr>
<td>137</td>
<td>27 vein, 2500 level, footwall of vein.</td>
</tr>
<tr>
<td>18, 19</td>
<td>Main vein, 2500 level, 2 feet from vein.</td>
</tr>
</tbody>
</table>

In general the soda granite is very resistant to hydrothermal alteration which may be caused by the following: the relative coarseness of grain and the compactness of the quartz and albite prevent hydrothermal solutions from penetrating easily; the chemical nature of quartz and albite is so close to that of the vein solutions that the latter have little replacing power.

The more important alteration is sericitization and carbonatization. Sericite selectively alters albite and
occurs in veinlets cutting both albite and quartz. In slides 18 and 19 small plates of muscovite occur with dark inclusions in a herring-bone pattern. This occurs adjoining large crystals of pyrite. Carbonate also preferentially alters the albite but forms in much larger anhedral crystals than the sericite. However, it is quite apparent that it was introduced, for the grains of carbonate are often associated with pyrite and are interconnected by minute fractures. Much of the carbonate close to the grains of pyrite is coated with pale brown opaque material, probably iron carbonate.

Minor amounts of secondary quartz and peninnite and primary apatite occur. The quartz is in veinlets associated with sericite.

**Acid Dyke And Its Alteration**

Albitite, aplite, felsite and quartz porphyry dykes have been variously described by Cairnes and others as late differentiates of the Bralorne intrusives. They cut Pioneer greenstone, soda diorite and soda granite and are usually associated with the vein deposits.

Cairnes (2) describes these rocks as being composed largely of fine-grained quartz and albite with or without phenocrysts of either of these minerals. Secondary minerals include sericite, carbonate, chlorite, and pyrite.

Specimens of rock mapped as aplite-albitite and porphyry were collected at the Pioneer Mine and thin sections prepared
as detailed below:

<table>
<thead>
<tr>
<th>Thin Section No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.</td>
<td>27 vein, 2500 level, Station 2521A, aplitite-albitite adjoining vein.</td>
</tr>
<tr>
<td>21.</td>
<td>As above, two feet from the vein.</td>
</tr>
<tr>
<td>128.</td>
<td>27 vein, 2100 level, station 2101A, porphyry from footwall adjoining vein.</td>
</tr>
<tr>
<td>140.</td>
<td>20 level, Station 2013 plus 60 feet, porphyry from footwall adjoining vein.</td>
</tr>
<tr>
<td>141, 142.</td>
<td>As above, two feet from vein.</td>
</tr>
</tbody>
</table>

In hand specimen these rocks vary in color from dark grey to white. Especially in the porphyry, illustrated by Sections 140, 141, and 142, there is a color change from dark grey to a bleached white in the rock adjoining the vein. In thin section the rock consists of from 60% to 80% quartz. Some areas in the slides show rounded grains of quartz from 0.05 mm. to 0.2 mm. in diameter. In the other areas the quartz has an interlocking texture and appears clearer than the rounded grains. In all slides, sericite and chlorite are the chief secondary minerals with subordinate carbonate and biotite. The secondary minerals are largely interstitial to the quartz.

In thin section 141 there are some very interesting features which will be described in detail (Plate XI). Well-rounded grains of quartz, 0.1 mm. to 0.3 mm. in diameter occur in a very fine-grained groundmass of sericite and chlo-
**PLATE IX**

T.S. 138 x85

Chl = Chlorite  C = Carbonate
F = Sodic feldspar  Q = Quartz
B = Biotite

**PLATE X**

T.S. 141 x85

Q = Quartz  Chl = Chlorite
B = Biotite  Ser = Sericite
rite with some biotite. The quartz grains are not in close contact with each other. Some of the quartz grains have a radiating structure vaguely suggesting spherulites, being divided up into segments which have extinction angles parallel to radial lines in the segments. Other grains show ragged cores partially sericitized with rims much less altered. Most grains show quartz occurring in one crystal orientation only, although other grains are composed of two or more crystals of quartz at random orientation.

Outlines of platy crystals of the order of 1.0 mm. in length showing Carlsbad twinning occur as widely-scattered "phenocrysts" throughout the rock. These crystals are so highly sericitized that it is impossible to make optical determination of the feldspar. One of these "phenocrysts" was observed cutting through a rounded quartz grain (Plate XI).

As illustrated by Plate X, a minor amount of biotite occurs as minute crystals in the circumference of more or less circular areas which are superimposed on quartz crystals irrespective of boundaries. Outside the circular areas the alteration is largely fine sericite, whereas within the circular areas the alteration is relatively coarse particles of chlorite with minor sericite. The quartz appears to be clearer and in some cases has undergone recrystallization to finer particles within these areas. It is quite apparent from the appearance of a
large number of such areas that the biotite occurs in a zone representing the transition stage between a rock composed largely of quartz with fine-grained chlorite, sericite and small, dark inclusions and a similar quartz rock with coarser grained chlorite, little sericite and a lack of small, dark inclusions. The equilibrium between chlorite and biotite does not seem to be a straight function of temperature but is complicated by the presence of sericite and small, dark inclusions in the quartz. It is not possible to give a complete explanation.

Clear, euhedral crystals of quartz with a diameter of about 1.0 mm. are found in thin sections 141 and 142 (Plate XII). They are often rimmed by quartz with the same optical orientation but clouded by alteration to sericite. Parts of the rims may show quartz at a random orientation. Many of these clear crystals are cut by veinlets or wedges of replacing sericite. Quartz, filling tiny fractures cutting these crystals, assumes the orientation of the host quartz.

There are three possible explanations for the occurrence of the clear, euhedral crystals of quartz: that they are secondary due to recrystallization; that they have been transported as euhedral crystals and deposited as part of a sedimentary rock; that they are primary in an igneous rock. Recrystallized quartz in clear, euhedral crystals has not been noted in any of the other slides. Furthermore, if the euhedral crystals were secondary, the presumably
later rims should also be clear and unaltered. If they had been transported, one would expect a slight amount of rounding of crystal angles. The most logical explanation is that the euhedral crystals are primary in an igneous rock and that later changes of conditions have caused a recrystallization of neighboring quartz with inclusions of sericite.

The greater portions of slides 12g, 140, 142, 20 and 21 are composed largely of quartz grains in interlocking texture. The main mass of the material is cut by veins of sericite which in turn is cut by veins of calcite accompanied by another carbonate with cloudy appearing alteration, possibly an iron-bearing carbonate.

Pyrite with some arsenopyrite occur in euhedral to subhedral grains. A pale, yellow-brown, opaque mineral, probably limonite, occurs as pseudomorphs after pyrite (see slide 20).

The occurrence in the porphyry of well-rounded quartz grains suggests a sedimentary origin. It would be well to consider the facts supporting the sedimentary origin on the one hand and the igneous origin on the other. It is unfortunate that the evidence here is confined to the study of 6 thin sections.

As mentioned previously, these rocks have been mapped in the Pioneer Mine as porphyry and aplite–albitite dykes. Observations which bear out the igneous origin are as follows:
1. The occurrence of feldspar "phenocrysts" showing Carlsbad twinning. In most cases these have been completely altered by sericitization.

2. The occurrence of euhedral crystals of quartz which are considered of primary origin.

3. The prevalent interlocking relation of quartz crystals. This could be due to recrystallization however.

4. The occurrence of "spherulitic" structure in the rounded grains of quartz.

Observations bearing out the sedimentary origin are as follows:

1. Occurrence of well-rounded grains of quartz, most of which are composed of one or more crystals of quartz at random orientation.

2. The quartz content is 60 to 80%. An igneous rock of this composition is very rare.

One cannot draw any definite conclusion as to the origin of this rock on such a limited study. However, it should be borne in mind that there is a possibility that some of the rocks mapped as "acid dykes" may be of sedimentary origin.

In conclusion, hydrothermal alteration in a rock with such a high proportion of quartz is very minor. Sericitization is of primary importance. Chlorite, biotite, carbonate and pyrite occur in minor quantities. The change in color of the porphyry from dark grey to white is
apparently due to alteration of biotite to chlorite and some recrystallization of quartz with many minute inclusions to quartz that is relatively clear.

**Summary And Conclusions**

Wallrock alteration, unlike crystallization of igneous rocks and subsequent deuteric processes, is not a closed system. There is introduction of new material and leaching or withdrawal of old. Butler, in comparing crystallization in a magma with ore deposition, states, "A fundamental difference is that the magma as discussed by Bowen is essentially a closed system, and its crystallization results from loss of heat, whereas ore deposition is an open system, with the solutions moving in and out, giving renewal of solution and possibly additions and subtractions of heat".

Let us first consider the actual change in composition during the alteration of soda diorite and greenstone (which is very similar). Both rock types originally contained albitic feldspar and hornblende as the essential constituents. The final products of alteration are chlorite (or biotite), carbonate (largely calcite), sericite, pyrite and arsenopyrite. It is quite evident there must have been an introduction of carbon dioxide, potash, sulphur and

arsenic. One would not expect the original sodic plagioclase to contain sufficient potash for the formation of the large amount of sericite. There is most likely a decrease in silica and soda. In the original rock, albite is a polysilicate and hornblende an orthosilicate. In the altered rock, sericite is an orthosilicate, chlorite is a subsilicate and carbonate, pyrite and arsenopyrite contain no silica. The excess quartz is a very minor constituent.

One may conclude that there has been a very definite decrease in silica. The sodium of the albite is absent in the alteration minerals. Quantitative estimates of minerals in the altered rock were not sufficiently accurate to determine whether or not there is an increase or decrease of lime.

Likewise, the change in composition of the soda granite and acid dyke on alteration may be considered together, as the original rock types are quite similar in mineral content. Both consist essentially of quartz and albite. The altered rock is composed of quartz and sericite with minor amounts of carbonate, chlorite, biotite and the sulphides. For the same reasons as above, there has evidently been an increase in carbon dioxide, potash, sulphur and arsenic and a decrease in soda and silica. In addition there is an increase in lime and iron.

For the alteration of the four most important host rocks to fissure veins in the Pioneer and Bralorne Mines
one may show in tabular form the increase or decrease of mineral content. It is not possible to make a generalization as to the change in content of iron, magnesia and lime.

<table>
<thead>
<tr>
<th>Increase</th>
<th>Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>Silica</td>
</tr>
<tr>
<td>Potash</td>
<td>Soda</td>
</tr>
<tr>
<td>Sulphur</td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td></td>
</tr>
</tbody>
</table>

Lindgren states that typical metasomatism in wall-rock of mesothermal deposits result in a decrease of silica, magnesia and soda and an increase of lime, potash and carbon dioxide. With the exception of magnesia and lime, the change of which was indeterminate, the findings here conform to those of Lindgren's mesothermal type of mineral deposits.

Butler's statement concerning possible additions and subtractions of heat in the open system of ore deposition is of interest in connection with the occurrence of the paramorphs biotite and chlorite in the lower levels of the Pioneer Mine. There, biotite has altered to chlorite or chlorite to biotite, presumably depending on temperature

Lindgren, W: Mineral Deposits.

conditions. Lindgren states that brown mica is generally absent in mesothermal or epithermal deposits, i.e. those which have formed at a temperature of 300°C or less. It may be concluded that the higher temperature of the vein forming solutions producing biotite probably exceeded 300°C. In the Bralorne Mine which is developed down to an elevation of about 2300 feet, there is no report of the occurrence of biotite alteration. James has observed a minor occurrence of reddish-brown alteration (presumably biotite) on 10 level (elevation 2900 feet) in the Pioneer Mine but it is not known if it occurs above that horizon.

The occurrence of tourmaline as both vein filling and wallrock alteration in the deeper levels at Pioneer Mine would support this conclusion for it is diagnostic of higher temperatures. However, tourmaline has not been identified in the Bralorne Mine nor in the Pioneer Mine above 21 level (elevation 1500 feet).

The occurrence of tourmaline and biotite in wallrock of the lower horizons of the Pioneer-Bralorne Gold Belt indicates that vein-forming solutions probably existed at temperatures above those of the mesothermal range. However, a study of thin section 125 and polished sections illustrated by Plates V and VI indicate there are at least 4

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*Lindgren, W.; Mineral Deposits.*

*James, H. T.; Personal communication.*
generations of vein forming solutions, tourmaline having been introduced with carbonate, pyrite and arsenopyrite which veins most of the quartz. Two subsequent generations of quartz cut arsenopyrite, gold and galena being in the later generation. The deposition of tourmaline with the carbonate and sulphides may be indicative of temperatures higher than the mesothermal range, but apparently later precipitation of gold and galena may be well within that range. It is significant that there has been no other important changes in the mineralization in the Pioneer Mine in a vertical range of over 3000 feet. According to Lindgren, a great vertical range of up to 5,000 feet, or even more, is characteristic of many types described under mesothermal deposits, e.g. Motherlode and Kirkland Lake deposits.

In conclusion:

1. Wallrock alteration is generally of the type attributable to mesothermal deposits. The exceptional occurrence of minerals more typical of hypothermal deposits would indicate that at the lower horizons some vein deposition took place above the upper limit of the mesothermal temperature range.

2. Other attributes of mesothermal deposits, including structure of veins, proportion of metallics to gangue minerals and identity of vein minerals present, are characteristically uniform over a great vertical range.