MINERAGRAPHY OF THE CASSITERITE-SULPHIDE ORES

INTRODUCTION

The stratiform replacement and fissure replacement, cassiterite-sulphide deposits at Mt. Bischoff, Renison Bell and Cleveland have a generally simple mineralogy with a limited number of metal sulphide and oxide components. Macroscopically the ore consists predominantly of pyrrhotite with minor pyrite, arsenopyrite, chalcopyrite and sphalerite. Cassiterite is generally too fine-grained and indistinct to be visible macroscopically although clusters of cassiterite crystals are rarely visible. The sulphides and oxides recognised microscopically in this investigation and previous mineragraphic examinations by Stillwell (1945) at Mt. Bischoff and Stillwell and Edwards (1943) at Renison Bell are listed in Table 3, and their relative abundance in the respective ore deposits is shown.

The Sn content (as cassiterite) is relatively consistent between deposits. The ore at Mt. Bischoff has averaged 1 per cent Sn, the average for Cleveland is estimated at 1.02 per cent Sn (Cox and Glasson, 1967) and for Renison Bell is estimated at 0.85 per cent Sn (Gilfillan, 1965).
<table>
<thead>
<tr>
<th></th>
<th>Mt. Bischoff</th>
<th>Cleveland</th>
<th>Renison Bell</th>
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<tbody>
<tr>
<td>dep. veins</td>
<td></td>
<td>dep.</td>
<td>fiss. dep.</td>
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<td></td>
<td>dep.</td>
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<th>Mt. Bischoff</th>
<th>Cleveland</th>
<th>Renison Bell</th>
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<tr>
<td>Arsenopyrite</td>
<td>xx xx</td>
<td>xx xxx</td>
<td>xxx xxx</td>
</tr>
<tr>
<td>Bismuth</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Boulangerite</td>
<td>x x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Canfieldite</td>
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<td>x</td>
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<tr>
<td>Cassiterite</td>
<td>xx xx</td>
<td>xx xx</td>
<td>xx xx</td>
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<tr>
<td>Chalcopyrite</td>
<td>x x</td>
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<tr>
<td>Franckeite</td>
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<tr>
<td>Galena</td>
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<tr>
<td>Gold</td>
<td></td>
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<tr>
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</tr>
<tr>
<td>Jamesonite</td>
<td>x xx</td>
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<td>Pyrargyrite</td>
<td></td>
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<tr>
<td>Pyrite</td>
<td>xx xxxxxx</td>
<td>xx xx</td>
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</tr>
<tr>
<td>Pyrrhotite</td>
<td>xxxxxx xx</td>
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<td>xxxxxx xxxx</td>
</tr>
<tr>
<td>Sphalerite</td>
<td>x xx</td>
<td>x</td>
<td>x x</td>
</tr>
<tr>
<td>Stannite</td>
<td>x x</td>
<td>x x</td>
<td>x x</td>
</tr>
<tr>
<td>Tetrahedrite</td>
<td>x x</td>
<td>x x</td>
<td>x x</td>
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<tr>
<td>Valleriite (?)</td>
<td></td>
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</tr>
</tbody>
</table>

xxxx Predominant  xxx Abundant  xx Common  x Rare

Table 3. Sulphide and oxide composition of cassiterite-sulphide ores.
There are small differences in mineralogy between deposits (e.g. the higher percentage of chalcopyrite in the Cleveland ore) and some minerals have only been recorded from one deposit (e.g. canfieldite and franckeite at Renison Bell). A major difference between deposits is the proportion of sulphides present. Modal analyses (volume percentages) of the ores examined in polished section are given in Appendix D2, Table 45. The analyses of the replacement deposits at Mt. Bischoff, Cleveland and No. 2 Horizon, Renison Bell are significant as representative specimens were obtained from a relatively wide area of mineralization. The specimens from No. 1 Horizon and the Federal Lode are limited spatially and modal analyses of these ores are probably not significant. For example, Hall and Solomon (1962) suggested that the ratio of pyrite to pyrrhotite is higher in the Federal Lode than in the replacement deposits whereas the modal analyses show the reverse relationship. The analyses in Table 4 demonstrate the disseminated nature of the Cleveland deposit with a sulphide: non-sulphide ratio of 0.5 relative to the deposits at Mt. Bischoff and No. 2 Horizon, Renison Bell with ratios of 2.3 and 5.3 respectively. The Federal Lode also has a low ratio (1.4).
<table>
<thead>
<tr>
<th>Component</th>
<th>Mt. Bischoff</th>
<th>Cleveland</th>
<th>No. 2 Horizon, Renison Bell</th>
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</thead>
<tbody>
<tr>
<td>Pyrrhotite</td>
<td>57.7</td>
<td>22.7</td>
<td>74.4</td>
</tr>
<tr>
<td>Pyrite</td>
<td>5.5</td>
<td>6.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Arsenopyrite</td>
<td>1.5</td>
<td>1.9</td>
<td>6.5</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>0.8</td>
<td>1.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Sphalerite</td>
<td>0.3</td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Tetrahedrite</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Galena</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Stannite</td>
<td>0.3</td>
<td>0.3</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Bismuth</td>
<td>nil</td>
<td>nil</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Jamesonite</td>
<td>0.3</td>
<td>nil</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Supergene Pyrite</td>
<td>2.8</td>
<td>0.9</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Sulphide/
non sulphide       2.3        0.5       5.3

Table 4. Weight percentage of components in cassiterite - sulphide ores, calculated from modal analyses (Appendix D2, Table 45) assuming specific gravities of the non-sulphide phase of 2.9, 2.7 and 2.9 for Mt. Bischoff, Cleveland and No. 2 Horizon, Renison Bell respectively. Specific gravities are based on visual estimates of non-sulphide components in thin section.
The elemental composition of the sulphide phase for each deposit is shown in Table 5, and is compared with the composition from bulk analyses of "typical ore" from Cleveland. (Mason, 1965). The tin in the sulphide phase at Cleveland is calculated from copper : soluble-tin ratios given by H.K. Wellington (pers. comm.). It is evident that there is reasonably good agreement between the Cleveland analyses although the Zn content from modal analysis is significantly high and the Sn content is low. Iron and S are the major components and the Fe : S ratio varies slightly between deposits (Table 5) with the Cleveland ore having the lowest ratio (i.e. the most S-rich). Minor elements vary considerably from one deposit to another. The sulphides from Cleveland appear richer in minor elements (particularly Cu, Zn and Sn) than the other deposits while the No. 2 Horizon at Renison Bell is relatively enriched in As.

However, the textural relationships between minerals, and their paragenesis are similar for all the cassiterite-sulphide deposits. The criteria of paragenesis are discussed in Appendix D1.

It is evident from textural relationships that cassiterite and wolframite have crystallized before the sulphides. The earliest formed sulphides are arsenopyrite and pyrite which are followed by pyrrhotite and further pyrite. Chalcopyrite, sphalerite and stannite were formed penecontemporaneously and exhibit extensive solid solution. They were followed by tetrahedrite, jamesonite and native bismuth. The final group of sulphides to crystallize were galena and associated canfieldite, franckeite, boulangerite and pyrargyrite. Some supergene alteration of pyrrhotite to pyrite and marcasite has occurred.
Element | Mt. Bischoff | Cleveland | No. 2 Horizon, Renison Bell.
--- | --- | --- | ---
Fe | 56.7 | 52.8 (53.6) | 57.2
As | 1.0 | 2.5 (2.4) | 3.6
Cu | 0.5 | 1.8 (1.5) | 0.2
Zn | 0.25 | 1.32 (0.56) | 0.03
Pb | 0.23 | 0.03 (0.0) | 0.11
Sn | 0.12 | 0.23 (0.35) | 0.00
Sb | 0.13 | 0.00 (0.0) | 0.00
Bi | 0.00 | 0.00 (0.04) | 0.02
S | 41.0 | 41.3 (41.9) | 38.8

Total | 99.93 | 99.98 | 100.06
Fe/S | 1.38 | 1.28 | 1.47

Table 5. Elemental composition (weight per cent) of sulphide phase of cassiterite - sulphide ores calculated from modal analyses. Figures in brackets represent bulk analyses of ore from Cleveland (Mason, 1965).
The deposits are described collectively and any differences in mineral occurrence, composition or structural state between deposits are discussed. Detailed descriptions of the minerals in their approximate sequence of formation are given below.

SYSTEMATIC MINERAL DESCRIPTIONS

Wolframite

Wolframite is present as rare bladed crystals, up to 0.5 mm in length, associated with quartz in all deposits. Stillwell and Edwards (1943) recorded that in rare cases it formed the central core of crystals of cassiterite in the Renison Bell ores. Its rare occurrence is shown by analyses of the Renison Bell tin concentrates which indicate 0.5 weight per cent wolframite (Stillwell and Edwards, 1943) which is approximately equivalent to a 0.007 weight per cent concentration in the ore.

Cassiterite

Cassiterite occurs throughout the ores as granular cracked crystals which average between 0.05 and 0.1 mm in diameter. The maximum diameter of cassiterite grains in the sections examined is approximately 1 mm although crystals up to 4 mm in diameter were recorded by Stillwell and Edwards (1943) from the Dalcoath Lode at Renison Bell. The larger cassiterite crystals are commonly zoned. The cassiterite grains generally occur in clusters in non-sulphide gangue, commonly quartz, carbonate or micaceous minerals (Plate 11). They are relatively rarely enclosed in sulphides, where they have been corroded and in one
Plate 11 - Clusters of cassiterite crystals in talc and sellaite matrix. Replacement deposit, Mt. Bischoff. Specimen No. 1517, x 86.

Plate 12 - Concentration of granular cassiterite in quartz from arsenopyrite-rich ore, from No. 2 Horizon, Renison Bell. Specimen No. 100,095, x 126.
section from Cleveland (62-415) cassiterite crystals have been invaded along irregular cracks by the enclosing sulphides. Partial rims of stannite, similar to those described by Novak et al. (1962) are rarely developed at cassiterite - pyrrhotite interfaces. In the No. 2 Horizon at Renison Bell extensive clusters of fine grained cassiterite crystals occur in quartz in association with abundant arsenopyrite (Plate 12).

**Haematite**

Small irregular patches of haematite are associated with quartz in the Cleveland ore (e.g. 66-28) and in the Federal Lode (e.g. 100,101). It has been partially replaced by sulphides. Haematite also occurs at Mt. Bischoff in association with secondary pyrite and marcasite.

**Arsenopyrite**

Arsenopyrite occurs generally as small euhedral crystals forming a minor component of the ore. However in places it is abundant and rarely the dominant sulphide at Cleveland and Renison Bell, where it occurs as euhedral crystals up to 5 mm in length (e.g. 100,095). It is apparently the first sulphide to form. It encloses small quartz and cassiterite grains and rarely contains inclusions of pyrrhotite whose relationship to the arsenopyrite is obscure. Etching with 1:1 HNO₃ reveals well developed growth zoning, particularly in the larger, discrete crystals (Plate 13). Euhedral crystals of arsenopyrite are commonly partially replaced by pyrrhotite with convex embayments of pyrrhotite against arsenopyrite producing caries texture (Plate 14).
Plate 13 - Zoned arsenopyrite crystals, etched with 1:1 HNO₃, with dilational veinlets of pyrrhotite, from No. 1 Horizon, Renison Bell. Specimen No. 100,120, x 95.

Plate 14 - Arsenopyrite crystals (white) replaced by pyrrhotite (grey), from No. 1 Horizon, Renison Bell. Specimen No. 100,120A, x 95.
Commonly the arsenopyrite is fractured by veinlets of pyrrhotite, chalcopyrite and stannite and more rarely by sphalerite (Plate 13). Matched irregularities in vein walls and offsets of zonal textures proportional to the width of the dyke and the angle of intersection demonstrate a dilational emplacement.

A second generation of arsenopyrite is recorded from galena-rich ore at Renison Bell by Stillwell and Edwards (1943). Minute euhedral crystals occur with galena which encloses tetrahedrite around partially replaced pyrrhotite grains.

Determination of the 13l spacing of arsenopyrites from Mt. Bischoff (100,039 and 100,040), No. 2 Horizon, Renison Bell (100,095) and Federal Lode (100,100) indicate similar values of 1.6295 and 1.6305, 1.6297 and 1.6295 ± 0.0003 Å respectively. These spacings are indicative of very S-rich arsenopyrites with S contents between 36.5 and 37.5 atomic per cent S. (Morimoto and Clark, 1961).

Pyrite

Pyrite is ubiquitous in the deposits. It typically occurs as discrete, coarse grained, euhedral to subhedral grains ranging from 1 to 2 mm in length. The pyrite contains only rare inclusions of arsenopyrite and cassiterite and encloses small grains of chalcopyrite in places. It has crystallized prior to the majority of sulphides which replace a vein in a similar manner to the arsenopyrite (Plate 15). Cox and Glasson (1967) recorded relic rim structures of pyrite as the penultimate stage of replacement by pyrrhotite.
Plate 15 - Euhedral pyrite (whitish) replaced by pyrrhotite (grey), from No. 1 Horizon, Renison Bell. Specimen No. 100,120, x 95.

Plate 16 - Granular mass of second generation pyrite (+ marcasite) from hypogene alteration of pyrrhotite. From replacement deposit, Mt. Bischoff, Specimen No. 100,140, x 95.
A second generation of pyrite, probably resulting from the hypogene alteration of pyrrhotite, occurs typically in the Mt. Bischoff ores and similar pyrite has been recorded at Renison Bell by Stillwell and Edwards (1943). At Mt. Bischoff the distribution of this pyrite is not controlled by the present land surface and in some sections it is apparently replaced by jamesonite (Plate 23). The early stage in alteration appears to be the formation of aggregates of granular pyrite containing minute patches and fine specks of marcasite with fine grained carbonate or quartz (Plate 16). These masses appear to have recrystallized in places to form areas of bladed or lamellar pyrite, containing marcasite, with interstitial carbonate or quartz (Plate 23). In places euhedral to subhedral pyrite crystals occur within the lamellar pyrite-marcasite zones. In many examples (e.g. Plate 17) the pyrite crystals are completely surrounded by quartz or carbonate and it appears probable that pyrite and quartz/carbonate have recrystallized and segregated from the lamellar pyrite-marcasite and quartz/carbonate areas. Fryklund (1964) observed similar alteration from the ore deposits of the Coeur d'Alene District, Idaho and also considered the alteration to be hypogene and in the direction suggested here. Rhoden (1959) has shown that similar alteration in the Silver-mines district, County Tipperary, Eire is also hypogene. It seems improbable that the pyrite-marcasite textures are unrelated or result from alteration in the opposite direction (i.e. from cubic pyrite to granular pyrite-marcasite). The experiments described by Stanton (1964) in which cubic pyrite was formed from solid pyrrhotite by passing H₂S over the pyrrhotite at 300°C are
Plate 17 - Recrystallization of second generation pyrite and segregation of pyrite (white) and carbonate (dark grey), from replacement deposit, Mt. Bischoff. Specimen No. 100,140, x 190.

Plate 18 - Micro-botryoidal supergene pyrite and marcasite forming around fracture in pyrrhotite, from replacement deposit, Mt. Bischoff. Specimen No. 100,147, x 95.
significant as they provide a possible mechanism for the formation of
the described textures. Kullerud (1966) has shown that pyrite and
marcasite are stable together up to $432 \pm 30^\circ\text{C}$, this temperature being
independent of confining pressure.

A further generation of pyrite is present in some specimens which
occur adjacent to the present surface at Mt. Bischoff and in one specimen
from Cleveland (62-411). The pyrite is finely granular or framboidal
and occurs in colloform masses, up to 5 mm in diameter, in pyrrhotite.
These masses commonly have a rim of uniformly oriented marcasite and
contain small irregular grains of haematite with rare chalcocite.
In places botryoidal forms have developed around small veins of quartz
and carbonate in the pyrrhotite (Plate 18). In these examples
rhythmically banded granular pyrite, commonly containing small specks
of marcasite, alternates with earthy layers of unknown composition.
The concentric forms commonly have cores of non-banded, framboidal
pyrite or are centred on coarsely crystalline irregular pyrite masses
(Plate 18). This generation of pyrite (and marcasite) is considered
to be supergene. Hill (1966) recorded rare supergene alteration
of pyrrhotite to pyrite and marcasite between undisturbed gossan
and pyrrhotite at Renison Bell. The alteration of pyrrhotite is to
boxworks of colloform, botryoidal pyrite containing minute patches
and decussate specks of marcasite.

Marcasite

Early reports on the outcropping cassiterite-sulphide ores
at Renison Bell (e.g. Ward, 1909; Conder, 1918) and Mt. Bischoff
Plate 19 - Colloform supergene pyrite replacing pyrrhotite, from replacement deposit, Brown Face, Mt. Bischoff. Specimen No. 100,060, x 95.

Plate 20 - Elongate lamellae of monoclinic pyrrhotite in an hexagonal pyrrhotite host, from replacement deposit, Mt. Bischoff. Specimen No. 100,073, x
(e.g. Reid, 1923) stressed the abundance of supergene marcasite. It was apparently comparatively rare at Cleveland (e.g. Reid, 1923). At present, with no gossans being stripped, it is extremely rare at Renison Bell (e.g. Hill, 1966) and Mt. Bischoff, where it is only present in association with hypogene and supergene pyrite as described above. It has not been observed in the Cleveland ore by the author, although Cox and Glasson (1967) recorded marcasite as occurring typically in replacement rims around pyrite and pyrrhotite. It is apparently hypogene as they recorded intensive replacement by carbonates and chalcopyrite, sphalerite and tetrahedrite.

**Pyrrhotite**

Pyrrhotite is the predominant sulphide in all the cassiterite-sulphide ores except the fissure lodes at Mt. Bischoff where it is subordinate to pyrite. It occurs as anhedral grains which form large irregular interlocking masses and small disseminations. The grain size varies considerably and is generally greater in larger areas of pyrrhotite. The pyrrhotite replaces and invades fractures in cassiterite, arsenopyrite and pyrite and is itself replaced and invaded by second generation pyrite and marcasite, chalcopyrite, sphalerite and non-sulphide gangue minerals. Growth twinning and/or transformation twinning is rarely present in the pyrrhotite. A minor second generation of pyrrhotite occurs as minute exsolution bodies in sphalerite.
The symmetry and composition of the pyrrhotite have been determined by X-ray diffraction (Appendix C2) and are summarised in Figure 20. Both hexagonal and monoclinic pyrrhotites occur at Mt. Bischoff and many specimens contain mixtures of the two types. The metal (predominantly Fe) content of hexagonal pyrrhotites ranges from 46.5 to 47.6 atomic per cent.

The pyrrhotites from the conformable replacement deposits at Renison Bell (No. 1 and No. 2 Horizons) have either hexagonal symmetry or are mixtures of hexagonal and monoclinic types. The metal content of the hexagonal pyrrhotites ranges from 46.6 to 47.5 atomic per cent (i.e. a similar range to the hexagonal pyrrhotites from Mt. Bischoff). The pyrrhotites examined from Cleveland and the Federal Lode at Renison Bell have exclusively monoclinic symmetry. Clark (1966) indicated that the maximum composition range for monoclinic pyrrhotite was from 46.4 to 46.8 atomic per cent metals. Hence the pyrrhotites from Cleveland and the Federal Lode have a lower symmetry and are generally more S-rich than the majority of pyrrhotites from Mt. Bischoff and the No. 1 and No. 2 Horizons, Renison Bell. The significance of these variations is discussed in a later section.

Etching with a saturated solution of chromic acid produces different etch reactions in the two structural types of pyrrhotite (e.g. Arnold, 1966). Mixtures of hexagonal and monoclinic pyrrhotite (determined from X-ray diffraction) from the replacement deposits at Mt. Bischoff and Renison Bell were etched and found to consist predominantly of hexagonal pyrrhotite. Elongate blebs of monoclinic pyrrhotite, recognised by its more intense etching, occur in the host of hexagonal
Figure 20

COMPOSITION AND STRUCTURAL TYPE OF PYRRHOTITE.
CASSITERITE—SULPHIDE DEPOSITS
WEST COAST, TASMANIA
pyrrhotite. The lamellae are apparently crystallographically oriented and have the appearance of an exsolved phase; the lamellae generally terminate at grain boundaries in the host. The monoclinic pyrrhotites from Cleveland and the Federal Lode, Renison Bell contain only minor blebs of hexagonal pyrrhotite.

**Chalcopyrite**

Chalcopyrite is present as small disseminated anhedral grains in most ores although at Cleveland some large veinlets up to 20 mm in length occur. A common occurrence of the chalcopyrite is as small veinlets at the boundaries of pyrrhotite with non-sulphide gangue minerals or pyrite. The chalcopyrite also commonly occurs as veins in pyrrhotite and pyrite and is partially replaced by sphalerite, stannite, quartz and carbonate. Stillwell and Edwards (1943) recorded intimate intergrowths of chalcopyrite and pyrrhotite in chalcopyrite-rich specimens from Renison Bell but such textures have not been seen in this study.

The chalcopyrite contains ubiquitous exsolution bodies of sphalerite which are present as minute, star-shaped skeletal crystals, rarely greater than 0.01 mm in length. Larger blebs of sphalerite occur adjacent to the grain boundaries of the chalcopyrite and probably represent migration of the sphalerite towards the grain boundaries. Brett (1964) found that this was a common effect during exsolution in experimental studies in the Cu-Fe-S system. In several sections (e.g. 62-425, 100-135) small irregular included patches of sphalerite occur in chalcopyrite grain boundaries and contain minute exsolution lamellae of chalcopyrite. This appears to be an example of progressive
unmixing, with exsolved sphalerite subsequently exsolving a further
generation of chalcopyrite. It may be significant that Edwards (1954)
recorded a higher temperature for exsolution of sphalerite from chalcopyrite
than chalcopyrite from sphalerite as this would be in agreement with
the sequence described.

Microscopic blebs of pyrrhotite also occur within the chalcopyrite
and may represent exsolution bodies although they do not exhibit
crystallographic orientation within the chalcopyrite. In one section
from Cleveland (62-492) small aligned lamellae of stannite, which are
probably exsolution bodies, occur in the chalcopyrite.

At Cleveland secondary chalcocite and covellite are locally
developed from chalcopyrite (Cox and Glasson, 1967) and at Mt. Bischoff
rare native copper and cuprite have probably been derived from oxidation
of chalcopyrite.

Sphalerite

Sphalerite occurs sporadically throughout the ore and appears to
have formed penecontemporaneously with chalcopyrite. It occurs as
granular interlocking aggregates which generally form irregular areas
up to 15 mm in length and 1 to 2 mm in width. Large veins, in which
sphalerite is the dominant sulphide occur rarely in all ores. The
sphalerite replaces cassiterite, arsenopyrite, pyrite and pyrrhotite
and is replaced by galena, jamesonite and carbonates. Etching with
HI reveals coarsely crystalline aggregates which have well developed
growth and/or translational twinning. Further minor generations of
sphalerite are represented by exsolution bodies in chalcopyrite and stannite.
The sphalerite has a high FeS content (Appendix C1). Sphalerites from the conformable replacement deposits at Mt. Bischoff, Cleveland and Renison Bell contain 13.8 ± 1.6 to 25.0 ± 3.8 mole % FeS, 14.7 ± 1.6 to 19.7 ± 1.6 mole % FeS and 12.5 ± 1.6 to 21.5 ± 1.8 mole % FeS respectively. Sphalerites from the fissure lodes containing cassiterite contain 9.0 ± 1.6 to 17.3 ± 1.6 mole % FeS.

The sphalerite in most sections contains minute blebs of chalcopyrite, generally less than 0.01 mm in diameter, which form "emulsion" or "mottled" texture. The chalcopyrite bodies vary widely in size and are heterogeneously distributed throughout the sphalerite. Larger bodies of chalcopyrite, up to 0.1 mm in diameter, occur preferentially along grain boundaries in the sphalerite and are commonly surrounded by haloes of minute chalcopyrite blebs while more distant areas of sphalerite may be free of such accumulations. This is probably due to arrested diffusion of exsolution chalcopyrite into discrete bodies at sphalerite grain boundaries. The more common phenomenon of "drained" areas adjacent to coarse chalcopyrite bodies (e.g. Edwards, 1954) is rare in these ores.

More rarely small blebs of pyrrhotite and stannite occur within the sphalerite and are probably exsolution bodies. In some sections (e.g. 62-427 from Cleveland) the sphalerite contains spherical exsolution bodies of chalcopyrite and pyrrhotite and some compound bodies of both sulphides (Fig. 21A). Lawrence and Chand (1962) recorded similar exsolution textures in the Rockvale Mine, N.S.W. and termed the process of formation "exsolution pseudomorphism". They considered that the spheroids formed by pseudomorphism of exsolved chalcopyrite by
Plate 21 - Stannite (light grey) along a sphalerite (dark grey) grain boundary with other irregular blebs of stannite, from replacement deposit, Mt. Bischoff. Specimen No. 100, 133b, x 95.

Plate 22 - Sphalerite containing irregular blebs of stannite, replaced by fibrous jamesonite (whitish), from replacement deposit, Mt. Bischoff. Specimen No. 100, 133b, x 95.
penecontemporaneously exsolved pyrrhotite that was drawn out of solid solution in the wake of diffusing chalcopyrite.

Compound exsolution bodies of chalcopyrite and stannite also occur in sphalerite (e.g. 66-3A from Cleveland). The exsolution bodies are irregular in shape and some show marked discontinuity at the junction of chalcopyrite and stannite indicating accretion while some appear to have resulted from replacement of chalcopyrite by stannite (Fig. 21B).

Stannite

Stannite is present in small proportions in most specimens that contain sphalerite and/or chalcopyrite. It is more abundant at Cleveland and Mt. Bischoff than at Renison Bell. The stannite has been confirmed by X-ray diffraction and is generally olive green in colour and isotropic. This makes the optical distinction between stannite and tetrahedrite difficult and has probably resulted in misidentification of stannite as tetrahedrite at Cleveland. Cox and Glasson (1967) recorded that tetrahedrite occurred as rim replacement structures around sphalerite and also as rims around cassiterite but X-ray diffraction photographs of several discrete particles of the olive green mineral which occurred in this manner confirmed its identification as stannite by the author. Stillwell and Edwards (1943) recorded anisotropic stannite from Renison Bell and minor buff-coloured stannite from Mt. Bischoff (e.g. PS. 8-44) is also anisotropic.

The stannite occurs as small areas which enclose or are enclosed by sphalerite and chalcopyrite with the development of "mutual boundaries" in places. These minerals appear to have formed penecontemporaneously.
The largest veinlets of stannite occur in chalcopyrite-rich ore from Cleveland where they have maximum dimensions of 1 mm. x 0.3 mm. (e.g. 66-2B). The grain size is generally much lower with an average diameter of 0.01 mm. Stannite which is associated with sphalerite generally occurs as small inclusions within the sphalerite, as elongate masses along sphalerite grain boundaries (Plate 21), and as narrow rims between sphalerite and non-sulphide gangue minerals. Small areas of stannite also rarely occur within pyrrhotite and as partial rims around cassiterite crystals enclosed by pyrrhotite, similar to those described by Novak et al (1962) from Kutna Hora. Further minor generations of stannite are represented by exsolution bodies in chalcopyrite and sphalerite.

The stannite almost universally contains minute exsolution bodies of chalcopyrite which are only observed under high magnification (x 1250). In some sections (e.g. 62-425 from Cleveland), star-shaped skeletal crystals of sphalerite, similar to those exsolved from chalcopyrite, occur in the stannite. In several instances small discrete granular bodies of chalcopyrite occur on the margins of the exsolved sphalerite, and in a few cases occur between the lobes of the star-shaped bodies (Fig. 21C). The textures suggest that sphalerite exsolution bodies formed initially, with subsequent accretion of chalcopyrite.

Tetrahedrite

It is not known whether the mineral belonging to the tetrahedrite group in these ores is tetrahedrite, tennantite or an intermediate type, as insufficient is present for an X-ray diffraction of micro-chemical analysis. It is generally olive to buff-grey in colour suggesting that it may be tennantite.
In the specimens examined it is found exclusively as small inclusions in arsenopyrite and is an almost insignificant component of the ores. Stillwell and Edwards (1943) recorded that it was restricted to patches of galena-rich ore at Renison Bell, where it occurred as blebs in galena crystals or as elongate particles dispersed along cleavage planes or grain boundaries in galena.

Jamesonite

Jamesonite occurs as a minor constituent of the ores at Mt. Bischoff and Renison Bell but has not been identified at Cleveland. Numerous specimens from Mt. Bischoff which have been referred to as berthierite and boulangerite by Petterd (1910) and Reid (1923) have been shown to be jamesonite by X-ray diffraction. The jamesonite is particularly abundant in the fissure lodes.

The jamesonite at Mt. Bischoff occurs as large curved fibrous masses replacing sphalerite (Plate 22) or as large acicular crystals, up to 10 mm in length, replacing pyrrhotite, arsenopyrite, sphalerite and second generation pyrite (Plate 24). At Renison Bell, Stillwell and Edwards (1943) recorded its occurrence as fine prisms and plates in galena and noted its association with tetrahedrite which it partially replaced.

Native Bismuth

Stillwell and Edwards (1943) recorded native bismuth from the replacement fissure deposits at Renison Bell. It occurs as fine grains with a maximum size of 0.09 mm x 0.06 mm along pyrrhotite grain boundaries adjacent to chalcopyrite, on cassiterite - pyrrhotite contacts and in
Plate 23 - Jamesonite (pale grey) replacing second generation pyrite (white) and carbonate (dark grey), from replacement deposit, Mt. Bischoff. Specimen No. 447 (Tasmanian Museum), x 95.

Plate 24 - Large acicular jamesonite crystal replacing second generation pyrite and carbonate, from replacement deposit, Mt. Bischoff. Specimen No. 100,940, x 95.
quartz. It has been identified from the No. 2 Horizon at Renison Bell (e.g. 10901, 100,095) where it typically occurs as small inclusions in galena.

Galena

Galena is generally a rare constituent of all the cassiterite-sulphide ores. It occurs as fine threads and anhedral grains replacing pyrrhotite and sphalerite (e.g. 62-425, 100, 133a). At Mt. Bischoff rare veins of coarsely crystalline galena occur (e.g. 2217 - Tasmanian Museum) and contain irregular patches and anastomosing veinlets of boulangerite. Stillwell and Edwards (1943) recorded that galena locally became the dominant sulphide at Renison Bell where it formed veins up to 3 feet wide. It typically occurs with sphalerite which it veins and corrodes leaving clusters of residual grains of sphalerite in a galena-rich host.

Boulangerite

Boulangerite occur at Mt. Bischoff as small, irregular inclusions and veinlets in massive galena (e.g. 2217 - Tasmanian Museum). At Cleveland it has been tentatively identified as occurring in small irregular patches at sphalerite grain boundaries (e.g. 64-2C).

Pyrargyrite

Pyrargyrite has only been identified from the replacement fissure deposits at Renison Bell where it occurs as irregular patches along grain boundaries in massive galena or as small grains in non-sulphide gangue which has been partially replaced by galena (Stillwell and Edwards, 1943).
Canfieldite

Stillwell and Edwards (1943) recorded the sulphostannate canfieldite from galena-rich portions of the replacement fissure deposits at Renison Bell. It occurs sporadically as spheroidal, discrete or compound inclusions in galena, commonly adjacent to areas of stannite. In the compound inclusions it is associated with tetrahedrite. It also occurs with non-sulphide gangue in thin, impersistent veinlets. Stillwell and Edwards (1943) suggested that the canfieldite formed by release of Sn from stannite during late Ag-Pb mineralization.

Franckeite

Stillwell and Edwards (1943) also recorded the sulphostannate franckeite from galena-rich portions of the replacement fissure deposits at Renison Bell. The franckeite occurs as discrete inclusions and compound inclusions with stannite in galena which contains abundant inclusions of stannite. Stillwell and Edwards (1943) suggested that the franckeite was formed by replacement of stannite during late Ag-Pb mineralization. The lack of these rare sulphostannates at Mt. Bischoff and Cleveland is probably due to the lack of massive galena in these deposits, in which galena and stannite were never seen in contact.

Valleriite

A small elongate bleb of a strongly bireflectant mineral with extreme anisotropism occurs in pyrrhotite from the No. 1 Horizon, at Renison Bell (100, 118B). It has been tentatively identified as valleriite.
Gold

Stillwell and Edwards (1943) recorded the occurrence of one particle of gold, 0.075 mm x 0.042 mm, at the contact of cassiterite and pyrite in arsenopyrite-rich ore from Renison Bell. Gold has not been found in mill products from Renison Bell, Mt. Bischoff or Cleveland.

Magnetite

Stillwell and Edwards (1943) recorded grains of magnetite showing incipient alteration to haematite along octahedral planes from mill products at Renison Bell.

Other minerals which occur only in the fissure lodes at Mt. Bischoff are native arsenic, molybdenite, bismuthinite and stibnite.

Solid Solution

An interesting feature of the ores is the range of solid solution shown by sphalerite, chalcopyrite, stannite and pyrrhotite. The resultant exsolution pairs are summarised below:

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Solute</th>
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<tbody>
<tr>
<td>Sphalerite</td>
<td>Pyrrhotite</td>
</tr>
<tr>
<td>&quot;</td>
<td>Pyrrhotite + Chalcopyrite (pseudomorphism)</td>
</tr>
<tr>
<td>&quot;</td>
<td>Chalcopyrite</td>
</tr>
<tr>
<td>&quot;</td>
<td>Chalcopyrite + Stannite (accretion)</td>
</tr>
<tr>
<td>&quot;</td>
<td>Stannite</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>Sphalerite (sphalerite 2nd generation chalcopyrite)</td>
</tr>
<tr>
<td>&quot;</td>
<td>Pyrrhotite</td>
</tr>
<tr>
<td>Solvent</td>
<td>Solute</td>
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<td>--------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>Stannite</td>
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<tr>
<td>Stannite</td>
<td>Sphalerite</td>
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<tr>
<td>&quot;</td>
<td>Sphalerite + Chalcopyrite</td>
</tr>
<tr>
<td>&quot;</td>
<td>Chalcopyrite</td>
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The formation of the compound exsolution bodies has not been satisfactorily explained by Lawrence and Chand (1962). Guy (1960), Brett (1964) and others have suggested that nucleation of atoms of the exsolved phase begins when they collect in sufficient concentrations to form nuclei at points throughout the lattice of the solvent, the particles growing spontaneously when they have achieved a certain critical size. The nucleations are facilitated by imperfections in the lattice of the solvent. A concentration gradient is produced due to removal of the exsolved phase in the vicinity of the growing bodies with acceleration of diffusion and subsequent growth of the exsolution bodies. As the exsolution bodies grow they cause an increase in strain energy due to volume differences with the host and a series of dislocations form around each body. Finally, when the elastic strain energy of the exsolution body becomes greater than the surface energy, the lamellae will break down with subsequent recrystallization of the matrix. If a further phase exsolves from the same solvent it will again nucleate at points of high strain energy in the lattice. The previously formed exsolution body interfaces probably represent the areas of highest strain energy excepting grain boundaries in the matrix and thus will be favourable loci for nucleation of the second exsolved phase. The
EXSOLUTION TEXTURES: CLEVELAND

Figure 21
driving force for the replacement of chalcopyrite by pyrrhotite ("exsolution pseudomorphism") is probably the disequilibrium of chalcopyrite in a host saturated with FeS.

Most of the exsolution bodies tend towards a spheroidal shape which results in a minimum surface area with a reduction of the surface free energy of the exsolved body. An exception is the star-like forms of sphalerite in chalcopyrite. These forms are generally elongated in the (111) plane of the chalcopyrite as there is a mutual S-plane parallel to this crystallographic direction (Gruner, 1929). It is interesting that the relative shapes involved in the sphalerite-chalcopyrite exsolution pair are the reverse of those indicated from measurements of interfacial free energy ratios from dihedral angles at two phase triple junctions by Stanton (1964). Stanton (1964) interpreted the occurrence of sphalerite as spheroids in galena and galena as cuspate forms in sphalerite in terms of a higher surface free energy of the sphalerite determined by the interfacial free energy ratio, galena : galena/sphalerite : sphalerite = 0.61. The determined free energy ratio chalcopyrite : chalcopyrite/sphalerite : sphalerite is 0.75 suggesting that the sphalerite should occur as spheroids in chalcopyrite and chalcopyrite as cuspate forms in sphalerite, whereas the reverse geometric relationship is observed.
NON-SULPHIDE COMPONENTS OF CASSITERITE-SULPHIDE ORES

Although the sulphide components of the cassiterite-sulphide replacement deposits are similar, the non-sulphide components vary between deposits because of differences in the chemical compositions of the host rocks and probable differences in the chemical compositions of mineralizing fluids. The replacement fissure deposits also have a different, mineralogically more simple non-sulphide component than the replacement deposits. The alteration of the dolomite horizon at Mt. Bischoff has been described in detail because of the availability of samples and the interesting mineral assemblages identified. The alteration of host rocks at Cleveland and Renison Bell is described briefly.

MT. BISCHOFF

Replacement Deposit

A wide variety of silicates, oxides, fluorides and carbonates have replaced the dolomite horizon at Mt. Bischoff. Pre-sulphide minerals occur rarely and include cassiterite, tourmaline, quartz, wollastonite and chondrodite. Garnet and corundum are also probably pre-sulphide formation. These minerals are extensively replaced by hydrous and fluorine-bearing minerals including fluorphlogopite, talc, chlorite, muscovite, serpentine, fluorite and sellaite and by several generations of carbonates and quartz. Minor amounts of sphene, apatite, topaz and zeolite are also present.
Plate 25 - Zoned tourmaline crystals in large fluorite crystal, from contact of quartz-feldspar porphyry and dolomite, Mt. Bischoff. Specimen No. 30634d, x 86.

Plate 26 - Zoned tourmaline crystals included in sphalerite, carbonate and sellaite, from replacement deposit, Mt. Bischoff. Specimen No. 1502b, x 32.
A macroscopic banding is evident in the majority of specimens examined. Adjacent bands are rich in sulphides, tourmaline, carbonates, fluorite, sellylite or micaceous minerals. The micaceous bands are commonly separated into talc- and phlogopite-rich layers. Cassiterite also occurs in clusters in distinct, generally sulphide-deficient layers.

In thin section tourmaline occurs as small, idioblastic, zoned crystals which are commonly included in fluorite, sulphides and carbonate (Plates 25-26). The crystals are commonly 0.05 mm in diameter in cross-section and 0.5 mm along their long axis. The tourmaline has refractive indices \( \omega = 1.6580, \epsilon = 1.6325, \delta = 0.0255 \) and chemical analyses (Appendix A4) indicate a variable composition between schorlite and dravite, in agreement with the optical properties. It is essentially a magnesian schorlite.

Quartz occurs as rare idioblastic crystals which are enclosed by later sulphides and micaceous minerals.

Garnet has only been identified in one section from the Greisen Face (1532) where it occurs as idioblastic crystals, approximately 1 mm in diameter, which have been replaced by talc and quartz (Plate 28). Insufficient garnet is present for identification of its composition.

Corundum has also been recognized in one section from Greisen Face (1535) where it occurs as short, rectangular, prismatic, weakly birefringent crystals, generally 0.06 mm x 0.04 mm, which are included in pyrrhotite, carbonates and serpentine (Plate 27). The occurrence of corundum is unusual as the assemblage is generally Al-deficient, although topaz is also present in minor proportions.
Plate 27 - Small idioblastic corundum crystals included in serpentine and carbonate, from replacement deposit, Mt. Bischoff. Specimen No. 1533, x 85.

Plate 28 - Idioblastic garnet crystals replaced by talc and quartz, from replacement deposit, Mt. Bischoff. Specimen No. 1532. Crossed nicols, x 32.
Chondrodite is abundant in specimens from the eastern end of Brown Face (e.g. 33453) and occurs rarely in other sections from Greisen Face (e.g. 1517). In section 33453 it has been extensively replaced by serpentine (Plate 29) and to a lesser extent by pyrrhotite. It is colourless and non-pleochroic, has $2V = 72^\circ - 82^\circ$ (+)ve (6 determinations), $\alpha = 1.615$ and $\beta = 1.635$ and $\alpha : z = 30^\circ - 32^\circ$ (5 determinations). It has complex twinning (Plate 30): it is twinned on (001) and other composition planes which have not been determined. The identification has been confirmed by X-ray diffraction. Its typical occurrence is with grossular and wollastonite in metasomatized limestones (Deer et al, 1964 Vol. 1, p. 48).

Wollastonite occurs in some sections from the Greisen Face (e.g. 1502b, 1535) as columnar aggregates with a maximum diameter of 2mm, which have been replaced by sulphides, micaceous minerals and carbonates (Plates 31-32). The presence of wollastonite could not be confirmed by X-ray diffraction because of its rare occurrence. It is colourless and weakly birefringent, $2V = 50^\circ$ (-ve) with the optic axis almost normal to the length of the crystal. Longitudinal sections have a maximum extinction of $12^\circ$ and the refractive index is within the range for wollastonite as it lies between $\mu c$ and $\mu w$ for the carbonate. The presence of wollastonite has thermometric significance as Harker and Tuttle (1956) have determined the univariant $P_{CO_2} \cdot T$ curve for the reaction $CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$. The curve indicates that the minimum temperature of formation is approximately $400^\circ C$ at atmospheric pressure. The formation temperature should have
Plate 29 - Chondrodite replaced by serpentine, from replacement deposit, Brown Face, Mt. Bischoff. Specimen No. 33453B, x 70.

Plate 30 - Complex twinning in chondrodite crystals surrounded by serpentine, from replacement deposit, Brown Face, Mt. Bischoff. Specimen No. 33453. Crossed nicols, x 120.
Plate 31 - Columnar wollastonite rimmed by carbonate with inclusions of tourmaline, from replacement deposit, Mt. Bischoff. Specimen No. 1502b. Crossed nicols, x 32.

Plate 32 - Columnar wollastonite replaced by pyrrhotite and talc, from replacement deposit, Mt. Bischoff. Specimen No. 1535, x 32.
been considerably higher than 400°C at Mt. Bischoff as the Pco₂ should be high under the confining pressures involved (see section on geobarometry). However Buseck (1966) has shown that wollastonite at Concepcion del Oro, Mexico probably formed at temperatures below the temperature predicted from the Pco₂ - T curve. Buseck (1966) has interpreted this in terms of lower CO₂ pressure than predicted and has suggested that CO₂ was dissolved in streaming fluids, thus removing it rapidly as it formed. Therefore only a minimum temperature of formation of 400°C can be definitely established from the occurrence of wollastonite at Mt. Bischoff.

Fluorite, which varies from pink, purple and green in colour to colourless, is generally post-sulphide although some large pods which occur in the Slaughteryard and Greisen Faces appear to be penecontemporaneous with pyrrhotite. In thin section it contains inclusions of quartz and zoned tourmaline (Plate 25) and is partly replaced by micaceous minerals. It also occurs as a late stage mineral in vughs in carbonate. The cell size of the fluorites (5.4622 to 5.4630 ± 0.0005 Å) is independent of their colour and is probably due to trace impurities rather than high strontium contents (Steyn, 1954).

Sellaite occurs abundantly in some sections from Greisen Face. It is weakly birefringent, uniaxial + ve and has an extremely low refractive index (n = 1.378). Its identification has been confirmed by X-ray diffraction. It appears to have formed penecontemporaneously with fluorite (e.g. 1514) and is typically replaced by fluo phlogopite and talc (Plate 33). Sahama (1945) recorded that sellaite was extremely
Plate 33 - Sellaite replaced by fluorphlogopite, from replacement deposit, Mt. Bischoff. Specimen No. 1496, x 32.

Plate 34 - Rosettes of muscovite, quartz and carbonate against coarse sellaite with inclusions of zoned tourmaline, from replacement deposit, Mt. Bischoff. Specimen No. 1502b. Crossed nicols, x 32.
rare relative to fluorite in natural occurrences but that sellaite had been recorded from metasomatized dolomites. It occurs much more commonly in evaporite sequences (e.g. Kuhn, 1952; Hermann and Hoffman, 1961). At Mt. Bischoff it has probably formed from the reaction of excess F with MgCO$_3$ when available CaCO$_3$ has been replaced. The almost complete removal of CaCO$_3$ is indicated by compositions of carbonates in the replacement deposit (Fig. 22). Sellaite is not a stable phase during experimental formation of fluorite from dolomite by alkaline fluoride-bearing solutions in the kinetic system dolomite - NaF, and magnesite is the stable form in the magnesite - NaF system (Ames, 1961). However the maximum temperature and pressure of the experiments was only 60°C and 1 atmosphere respectively.

Carbonates occur abundantly and are commonly replaced by fluorphlogopite and talc. They vary considerably in composition (Appendix D3) and contain varying proportions of MgCO$_3$, FeCO$_3$ and MnCO$_3$ with only minor CaCO$_3$ (Fig. 22). They are manganiferous siderites, manganiferous pistomesites and ferriferous-manganiferous magnesites. They have apparently formed by replacement of dolomite, with initial almost complete replacement of CaCO$_3$ by FeCO$_3$ + MnCO$_3$ and replacement of MgCO$_3$ by excess FeCO$_3$ + MnCO$_3$, as with only one exception their MgCO$_3$ content is approximately equal to or less than the MgCO$_3$ content of the dolomite (Fig. 22). It is interesting that Sr shows a sympathetic decrease with Ca, although some Sr remains in carbonates deficient in Ca (e.g. 100, 210).
Figure 22

COMPOSITION OF DOLOMITE AND CARBONATE
MT. BISCHOFF - RENISON BELL.
Talc is extremely abundant in the Greisen Face ore where it replaces tourmaline, quartz, sulphides, sellaite and carbonates. Its identification has been confirmed in numerous sections by X-ray diffraction. It occurs as semi-continuous layers, probably shear zones, across Fig Flat and White Face (Fig. 10) where it is present as radiating fibres in large concretions up to 20 cm in diameter. It is possibly pseudomorphing tremolite. The formation of talc from dolomite and quartz is temperature dependant but is also a function of the concentration of CO$_2$ relative to H$_2$O in the fluid phase (e.g. Metz and Winkler, 1963). The temperature of the reaction ranges from 425°C at a mole fraction $X_{CO_2} = 0.3$ to 480°C at $X_{CO_2} = 0.7$, at a constant fluid pressure of 2000 atmospheres. A drop in fluid pressure to 1000 atmospheres reduces these temperatures by about 20°C. The presence of talc thus indicates a temperature probably slightly in excess of 400°C.

Phlogopite is also abundant and occurs in alternating bands with talc in some specimens (e.g. 1532). The phlogopite occurs as sheaves of varying size, a maximum of 1 mm in length, which replace carbonates and sellaite. It is faintly pleochroic from pale brown to colourless. X-ray diffraction of several specimens indicates a consistent pattern which is most similar to synthetic fluorphlogopite (e.g. Kohn and Hatch, 1955). A semi-quantitative, X-ray spectrographic analysis confirms the presence of at least 5 per cent F in the phlogopite. It is probable that it is a fluorphlogopite; Deer et al. (1964 vol. 3) also recorded naturally occurring phlogopites with up to 6.74 per cent F. Deer et al. (1964 vol. 3) recorded that phlogopite typically occurred in metamorphosed...
dolomites and that the K may have been derived from reaction of dolomite with muscovite and/or K-feldspar. In this instance the K may be derived from the ore-bearing fluids which have an abnormally high K/Na ratio (see section on geothermometry).

Other micaceous minerals include chlorite which occurs rarely as rims around pyrrhotite in serpentine-rich specimens (Plate 35). The serpentine occurs as fibro-lamellar aggregates replacing chondrodite (Plate 29). X-ray diffraction indicates that it is an extremely poorly crystallized serpentine with only four distinguishable reflections. The occurrence of serpentine indicates the presence of an aqueous fluid phase containing less than 5 per cent CO$_2$, as at greater concentrations the serpentine will react to form magnesite + quartz or talc + magnetite (Winkler, 1967, p. 29). Muscovite occurs rarely as rosettes associated with carbonates and quartz (Plate 34).

The pre-sulphide minerals have probably formed during metasomatism associated with intrusion of the porphyry dykes, with introduction of F, B, SiO$_2$ and minor H$_2$O at temperatures in excess of 400° C. These minerals have become unstable during later hydrothermal activity involving sulphide deposition and have been generally replaced by hydrous micaceous minerals. Introduction of Fe, Mn, K, SiO$_2$ and base metals with S, F and H$_2$O and removal of Ca, CO$_2$ and to a lesser extent Mg, has been widespread. The Ca and CO$_2$ may have been redistributed in the rocks above the replacement horizons as the greywackes and mudstones of the Waratah River sequence in particular contain abundant calcite veins.
Plate 35 - Chlorite rims around pyrrhotite and serpentine (centre of photograph), from replacement deposit, Mt. Bischoff. Specimen No. 1533, x 32.

Plate 36 - Sheaves of dolomite surrounding a dolomite-quartz nucleus from replacement deposit, Mt. Bischoff. Specimen No. 1490. Crossed nicols, x 65.
Fissure Veins

The fissure veins commonly consist essentially of quartz (e.g. Giblin Lode, North Valley Lode), carbonate (Thompson's Lode and most Pb-Zn-Ag lodes) or fluorite (Fooks Lode). They are commonly banded. Minor components include tourmaline, topaz, muscovite, biotite and apatite. The quartz occurs at all stages throughout deposition. The fluorite and carbonate are penecontemporaneous with, or later than the sulphide. Analyses of typical carbonates from Thompson's Lode and Silver Cliffs Lode (Appendix D3) indicate that they are manganiferous siderites or manganosiderites containing small amounts of MgCO$_3$ and very minor CaCO$_3$. They contain no detectable Sr in contrast with the carbonates from the replacement deposit.

Small quartz-cassiterite veins exhibit well developed "toothcomb" structure with marginal crystals of cassiterite growing towards the centre of the veins. Small veins containing beryl as euhedral hexagonal crystals up to 5 cm in length, in association with quartz, muscovite and minor cassiterite occur to the east of Brown Face.

RENIISON BELL

At Renison Bell the main non-sulphide components of the ores are quartz and carbonates, the quartz being more abundant in the replacement fissure lodes.
Quartz occurs abundantly as small idioblastic crystals which vary considerably in size. These crystals form large anastomosing masses with sulphides filling the interstices. Tourmaline and topaz almost invariably occur with the quartz as fine prismatic idioblastic crystals.

Carbonates are abundant and are generally later than the quartz, tourmaline and topaz. Analyses of the carbonates (Appendix D3) indicate that they are predominantly manganiferous pistomesites with manganosiderites and ferriferous rhodochrosites. As at Mt. Bischoff they contain approximately equal or less MgCO₃ than the host dolomites and very small amounts of CaCO₃ (Fig. 22). Minor amounts of fluorite are associated with the carbonates.

In general the chemical changes in the hydrothermal alteration are similar to those at Mt. Bischoff, but the early pre-sulphide phase is only represented by quartz, tourmaline and topaz. Wollastonite, chondrodite and garnet have not been recorded although minor axinite, epidote and phlogopite occur in some specimens from the Federal Lode hanging-wall (Appendix A3).

CLEVELAND

The most abundant non-sulphide component of the Cleveland ore is quartz which occurs in largely un replaced chert bands, as clastic, sub-rounded undulose grains in partially replaced rocks and as large idioblastic, non-undulose crystals associated with sulphides. The cherts, which are cut by quartzchlorite and carbonate-chlorite veins (Plate 37), have been considered to be primary sedimentary rocks (Ferrand, 1963).
Plate 37 - Fine grained chert cut by veinlets of quartz and chlorite and patches of pyrrhotite, from Cleveland. Specimen 62-42A, x 120.

Plate 38 - Quartz-chlorite aggregates with massive sulphides, from Cleveland. Specimen No. 62-406, x 120.
Carbonates occur abundantly as small interstitial, cloudy grains
which may be primary, and coarsely crystalline less cloudy crystals
which occur as small subidioblastic crystals and irregular aggregates and
veinlets which replace quartz, tourmaline, sulphides and the finer
gained carbonate. Cox and Glasson (1967) suggested that the carbonate
is predominantly dolomite.

Chlorite (possibly penninite) occurs as discrete flakes and
sheaf-like forms up to 0.5 mm in length which replace carbonate, quartz
and sulphides. Cox and Glasson (1967) recorded preferred orientation
parallel to compositional layering in some chlorite-rich laminae.

Tourmaline is present in most section as a minor component. It
occurs as small idioblastic crystals up to 1 mm in length which are
included in quartz, carbonate and fluorite. It is green or brown
in colour, commonly zoned and strongly pleochroic from pale green (e)
to green brown (ω) or pale brown (ε) to dark brown (ω). It is probably
schorlrite.

Small idioblastic topaz and apatite crystals and xenoblastic fluorite
and sericite occur rarely. The occurrence of wollastonite and cordierite
recorded by Everard (1963) has not been confirmed in this investigation,
and Cox and Glasson (1967) have also not recorded their occurrence.

The disseminated nature of the sulphides and the lack of calc-
silicates and fluorine-bearing silicates suggests that the host rocks
were less reactive than at Mt. Bischoff. Cox and Glasson (1967) suggested
that the ore horizon was originally a calcareous shale and this is
substantiated by the occurrence of probable primary carbonate.