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GEOLOGY, MINERALOGY AND PETROGENESIS OF TIN-BEARING BRECCIA/VEINS
AT OLIVER CREEK, MCQUESTEN RIVER AREA, YUKON

by

Diane S. Emond

A thesis submitted to the Faculty of Graduate Studies
and Research in partial fulfillment of the requirements
for the degree of Master of Science.

Department of Geology

Carleton University

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April, 1985

The undersigned hereby recommend to
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ABSTRACT

The Oliver Creek stanniferous breccias occur in cataclastic rocks regionally mapped as the Hadrynian Grit Unit (quartzites and quartz-mica schists with minor intercalated amphibolite, calc-silicate rock and marble). The breccias are in several steeply-dipping, tabular zones of early rock flour breccia (fragments of quartzite in a matrix of finely comminuted rock) crosscut by late crystalline-matrix breccias identified by the following matrix materials, i.e., in paragenetic succession, quartz, tourmaline, chlorite, calcite, or kaolinite. Cassiterite occurs mainly in chlorite breccia, but also in some rock flour- and tourmaline-breccias; it is locally accompanied by native silver, pyrrhotite, pyrite, chalcopyrite and sphalerite.

Chemical composition of tourmaline and chlorite from breccia matrices and veins shows iron enrichment with time until the last stage of chlorite deposition, when there was slight iron depletion. In tourmaline, there is also sodium enrichment with time. Titanium is depleted in later phases of the silicates. Calcium- and fluorine-enrichment occurs in some late chlorite and tourmaline phases. Cassiterite is associated with iron-rich chlorite and with time becomes depleted in Ta, Nb, W, Zr and Fe, and enriched in Ti and Ag. Granite-hosted tourmaline is richer in sodium and titanium than breccia-hosted, and similarly both tourmaline and biotite are richer in iron.

An orthomagmatic model with late magmatic-meteoric water mixing and final meteoric water domination is proposed. Emplacement of a granitic intrusion during the Cretaceous caused contact metamorphism (andalusite porphyroblastesis and pervasive biotite alteration), fracturing of the overlying country rock (rock flour breccia), the

setting up of a thermal gradient, and the precipitation in, and alteration of permeable breccia zones (quartz breccia). Exsolved magmatic fluids and gases were released in fractures, precipitating tourmaline and chlorite. These magmatic fluids evolved toward sodium- and iron-enrichment, and titanium depletion with time. Subsequently they gradually mixed with the cooler meteoric waters rich in CO_2 and Ca, and late chlorite, calcite and fluorite were deposited.

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Chapter 1

INTRODUCTION

General Statement and Purpose

Tin mineralization at Oliver Creek occurs in several thin, steeply southward-dipping breccia bodies hosted in, and containing clasts of quartzite of the Hadrynian 'Grit Unit'. The breccia matrix is mostly chlorite with minor cassiterite both as disseminated grains and clasts.

The purpose of this study is to describe the geology, mineralogy and petrogenesis of these tin-bearing breccias, and also to compare the mineralogy and style of mineralization therein with those of other tin deposits in the world. From this, a possible model of genesis of the stanniferous breccias at Oliver Creek is to be formulated.

Location and Access

The Oliver Creek tin occurrence is located in central Yukon (Figure 1a), approximately 30 km northwest of Mayo, just south of the McQuesten River, at 63°45'N, 136°46'W. Oliver Creek traverses the EPD tin property, running northwestward into the McQuesten River (Figure 2). Mayo can be reached from Whitehorse by plane (regularly scheduled flights), or by a 370 kilometre all-weather gravel road. From Mayo, the property can be accessed by helicopter or by dirt roads and cat trails which are in poor condition.

Figure 1a.
Location and tectonic setting of the Oliver Creek area, Yukon Territory (Tempelman-Kluit 1981)

Figure 1b.
The main stratigraphic units of the tectonic elements of Yukon in Figure 1a (Tempelman-Kluit 1981).

Figure 2. Geology of the McQuesten River area (after Bostock 1964) and location of the EPD property at Oliver Creek.

History of the Area

There are no early records of mineral discoveries in the immediate vicinity of Oliver Creek; however, in the general region, placer gold has been mined since 1898. Placer gold is still mined in Hight and Johnson Creeks, and stibnite occurs in quartz veins at the head of Hight Creek (Figure 3). Silver-lead-zinc veins occur at Keno and Galena Hills, where mining has been taking place since 1913 (Boyle 1965). Also several nearby tin and/or tungsten occurrences have been found in the past 10-15 years, such as Scheelite Dome (W) (Kuran et al. 1982), Ray Gulch (W) (Lennan, C.I.M. Special Volume in prep.), Tin Dome (Sn) and Boulder Creek (Sn).

In 1977, a regional reconnaissance study of stream sediments directed by Mr. A. Woodsend of CCH Resources Limited revealed anomalous tin, silver, zinc and copper in Oliver Creek (i.e., heavy mineral concentrates with 2.5% Sn from the mouth, and 7.35% Sn 1 km upstream). In 1978, the 84 claim EPD property was staked, and preliminary soil geochemistry work gave encouraging results. In 1979, the property was taken over by Cortin Joint Venture, consisting of Billiton Canada Limited, INCO, and CCH Resources Limited. Billiton is currently in charge of the exploration project. From 1979-1981, detailed geochemical, magnetometer and VLF-EM surveys, geological mapping, trenching, and diamond drilling totalling over 3000 m were conducted.

Figure 3. Tin deposits of the McQuesten-Mayo District, Yukon Territory (Mulligan 1974) accompanied by biotite K/Ar age dates of some granitoid plutons (Stevens et al. 1982b).

Previous Work

The first geological report that covers the McQuesten River area was by Keele (1904). More recently, Bostock mapped the McQuesten area at 1:250 000 scale (1964). Mulligan's report (1974) on tin occurrences in Canada describes several of those in the Mayo-McQuesten area. Preliminary work on the tin mineralization of the EPD property was done by Noble (1980) in a B.Sc. thesis, and a preliminary report on the present study was done by Emond (1983).

Methods of Study

The project is based on detailed logging of over 2300 m of diamond drill core, recording the data using the "Geolog" system (Blanchet and Godwin 1972), and a minor amount of geological mapping. Drill logs are in a data file, hereafter referred to as EDATA in thesis, held at both Geology Departments of Carleton University, Ottawa and D.I.A.N.D., Whitehorse. Whole rock chemistry and detailed petrography were performed on selected samples. Chlorite, tourmaline, biotite, and cassiterite were analyzed on the electron microprobe.

Chapter 2

GEOLOGY

A. TECTONIC AND REGIONAL SETTING OF THE MCQUESTEN RIVER AREA

The McQuesten River area is located just northeast of the Tintina Trench, within the Omineca Belt (Figure 1a) and is covered by Hadrynian 'Grit Unit' rocks (Figure 1b). Following major arc-continent collision in the Late Triassic to Early Jurassic, many felsic intrusions of Cretaceous age were emplaced in the ancient North American continental margin. The high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of these granitoid rocks indicate their derivation from partial melting of continental crust (Tempelman-Kluit 1981). Tin and tungsten deposits are commonly associated with this type of granitic rock, especially in the northern Cordillera. Intrusions in the McQuesten-Mayo area are in the form of "small discordant plugs that have forcefully invaded and thermally metamorphosed the surrounding strata" (Tempelman-Kluit 1981 p. 13). These granitoid plutons intruded to high levels, locally reaching the surface to form acid to intermediate volcanic rocks, the "South Fork Volcanics" (Tempelman-Kluit 1981 p. 16):

B. GEOLOGY OF THE OLIVER CREEK AREA

(a) Metamorphic Rocks

Cataclastically deformed quartzite and quartz-mica schist with minor amphibolite, calc-silicate rock and marble similar to Hadrynian "Grit Unit" (Tempelman-Kluit 1981 p. 9)(Figure 2)

dominate the area. There is a continuum between quartzite and mica schist (i.e., quartzite, micaceous quartzite, and quartz-mica-, mica-quartz- and mica-schist). There are also gradational rock types within the schist group (i.e., chlorite-, chlorite-muscovite-, muscovite-, biotite-chlorite-, and biotite-schist), the amphibolite group (i.e., amphibolite, and chlorite-, chlorite-biotite-, biotite- and pyrrhotite-amphibolite), and the calc-silicate rock group (i.e., tremolite-, tremolite-phlogopite-, and tremolite-epidote-calc-silicate rock).

Most rock units exhibit pervasive deformational textures and structures, including medium grain size, mica layers outlining the foliation, schistosity, mylonitic banding, and gneissosity. Layer thickness is commonly less than 5 mm.

Amphibolite, calc-silicate rock and marble occur as thin lenses intercalated within the schist and quartzite (Figure 4) and are reported in more detail in data file EDATA. Metamorphogenic or 'sweat' quartz veins are common in the quartzite and schist units, and make up 1-5% of the rock, but locally attain 50%.

Quartzite

Quartzite is the most abundant rock type and is medium- to greenish-grey. In the continuous suite of quartzite, chlorite-muscovite quartzite is the most common type and consists of more than 80% quartz plus chlorite and/or muscovite. Quartz and/or relic feldspar eyes are common. With depth, biotite is the major mica. Locally, the quartzite contains small (less than

Figure 4. Plan view of the Oliver Creek drill area (with length of drill holes exaggerated) showing distribution of rock units in core. The "spotted zone" is a zone of andalusite porphyroblastesis. Histograms show the amount of chlorite veining (volume %).

2 mm) ilmenite crystals aligned with the foliation, and some mantled by biotite.

Mica Schist

Mica schist is greenish grey, dark grey, or green with quartz, chlorite, muscovite, and biotite. Biotite in the schist is most abundant with depth. Quartz lenses are more common in schist than in quartzite. Small (2 mm long), elongate, clay-altered porphyroblasts (original mineral unknown) which appear syn- to post- regional metamorphism occur in some of the more chloritic layers. Small chlorite porphyroblasts (2 mm diameter) also occur locally in the chlorite schist. At depth, the schist has round porphyroblasts of fine-grained biotite. They make up to 25% of the rock, are dark grey, approximately 1 cm in diameter, and some are concentrically zoned. Their equant shape and mineral association indicate they were probably originally andalusite porphyroblasts.

Marble

Several lenses of dolomitic marble and minor calcareous rocks occur in the Oliver Creek area (Figure 2). These are commonly parallel to the dominant S_2 foliation - an axial planar foliation; they have been plastically deformed and moved into the hinges of folds. Marble and siliceous dolomitic marble consist of 50-90% carbonate, 10-45% quartz and feldspar, and minor chlorite (5-15%). The siliceous dolostone consists of quartz and feldspar grains with interstitial dolomite and locally

minor phlogopite. The feldspar and quartz present in this rock may represent immobile mineral grains, whereas the dolomite was mobile and moved into the interstices between immobile feldspar and quartz grains in areas of less stress (i.e., along planes of weakness).

Calc-silicate Rock

Calc-silicate rock is minor. It is cream, green and brown, and consists of 30-50% quartz, 10-20% feldspar, 10-20% phlogopite, as much as 40% tremolite and locally up to 35% epidote, minor sphene, rutile, tourmaline and trace amounts of cassiterite. The texture is similar to the dolomitic marble with tremolite interstitial to quartz and feldspar grains. Drill intersections show that the amount of calc-silicate rock locally increases with depth, as does the amount of phlogopite within it.

Amphibolite

Amphibolite of minor, most of it occurring in the eastern part of the drill area, closest to Oliver Creek. It is dark green, and highly schistose to coarse-grained idiomorphic granular (of apparent igneous origin). Present are 45-90% hornblende, 5-40% andesine and minor orthoclase, as much as 15% quartz, and locally abundant epidote, chlorite and biotite, up to 50% pyrrhotite, and minor disseminated pyrite, scheelite, cassiterite, sphene, ilmenite and rutile. Pyrrhotite is strongly foliated and recrystallized, and is probably pre-metamorphic. Some cassiterite-bearing pyrrhotite amphibolite contains abundant

tourmaline and fluorite.

Four samples of amphibolite were analyzed for major elements, and six for trace elements (Appendix 1, part a). The amphibolite is similar to Hawaiian alkali olivine basalt (Hughes 1982 p. 92). Samples 14-28 and 20-32 contain anomalously high iron and sulfur due to pyrrhotite content, and thus lower silicon, aluminum and magnesium. According to CIPW normative mineralogy, they are hornblende gabbro. Copper and zinc are anomalously high in the samples of sulphide-rich amphibolite.

(b) Igneous Rocks

Porphyritic muscovite-biotite granite occurs within the study area (3 km northwest of the showing) and may be part of the larger Boulder Creek stock (Figure 2). The granite is one of many high level granitoid plutons in the Mayo-McQuesten area that range from 83-108 Ma (biotite - K/Ar, W.D. Sinclair in Stevens et al. 1982b, Figure 3). Remnants of the "South Fork Volcanic" rocks occur in the form of hypabyssal sills and dykes, and probable extrusive equivalents. An 89.0 ± 2.6 Ma (biotite - K/Ar, Stevens et al. 1982a) biotite-quartz porphyry dyke on nearby Mount Haldane has cassiterite-bearing greisen at its contact with quartzite. Near Minto Lake, 20 km east of Oliver Creek, columnar jointed hornblende-biotite latite is interpreted as an extrusive rock (Bostock 1964), and is dated at 85.3 ± 2.1 Ma (whole rock-K/Ar, W.D. Sinclair, personal communication).

subangular quartzite fragments, or rock flour breccia fragments, with minor subangular to subrounded chlorite breccia fragments. The matrix consists mainly of medium- to coarse-grained, commonly euhedral calcite crystals, and locally there are small amounts of fluorite, and/or galena and sphalerite. The calcite breccia crosscuts all other breccia types.

(g) Kaolinite Breccia

Kaolinite breccia is relatively rare, except very close to surface. Its texture is very similar to the rock flour breccia (Figure 10g) except there is a greater proportion of matrix (as much as 35%). The matrix is microcrystalline kaolinite stained with limonite.

(h) Veins

Veins are most abundant in areas surrounding breccia zones. Most vein attitudes vary, but there are some parallel vein sets; the tourmaline veins in particular, and some chlorite and quartz veins occur in parallel sets which dip steeply to the south-southwest. Vein minerals are generally the same as those in the crystalline-matrix breccias, and thus most textures are similar to the appropriate breccia matrices. Only features different from the breccias will be mentioned below.

Quartz Veins

Quartz veins are abundant in the schist and quartzite in varying thicknesses; however, more than two-thirds of these are

Figure 5. The Oliver Creek granite pluton, just south of the McQuesten River.

- a. Porphyritic granite cut by an aplite dyke in the contact region (with country rock).
- b. "Flow foliation" of granite at the contact.

5

COLOURED PICTURES
Images en couleur

of plutons occur in northeastern Selwyn Basin; the northeasternmost is hornblende-bearing granite to granodiorite and the southwesternmost hornblende-free biotite granite with associated tungsten skarn (Anderson 1983). The Oliver Creek pluton is similar to the hornblende-free biotite granite, and it contains accessory tourmaline and muscovite which are typical of this group where associated with tin and/or tungsten.

Aplite Dykes

There are a few fine-grained, creamy white aplite dykes cutting the granite, ranging from 1-30 cm wide and of greatest abundance close to the granite/country rock contact. The aplite consists mostly of fine-grained quartz, K-feldspar and plagioclase, and locally, 5-15% tourmaline, 0-5% sericite and minor sulphides (0-2%).

Hornblende-Biotite Latite Sills

Rare hornblende-biotite latite occurs in the eastern part of the study area as several thin sills up to 5 m wide. In this thesis, "latite" is used to indicate a felsic volcanic rock and is not a compositional term. A small outcrop of latite occurs on the eastern side of Oliver Creek. The rock is light grey to green, fine grained, and the groundmass consists of 30% quartz, 30% feldspar (K-feldspar and plagioclase), 15% muscovite (sericite), 10% biotite, 5% hornblende, 5% chlorite and 5% magnetite. There are 5-15% hornblende and/or biotite phenocrysts. Some biotite is pseudomorphous after hornblende.

Chemical Composition

Three samples of granite, one of aplite and two of latite were analyzed for major, minor and trace elements by x-ray fluorescence methods (Appendix 1, part b). Chemical composition of the Oliver Creek samples are similar to granites and latites from other areas (i.e., Hughes 1982, and Carmichael et al. 1974).

CIPW normative values calculated for these samples were plotted on a QAP diagram (Streckeisen 1973) (Figure 6a). The three granite samples project onto the granite field, monzogranite subfield. Other samples from the Mayo-McQuesten area plutons (analyses from W.D. Sinclair, personal communication, description of samples and age dates in Stevens et al. 1982b) also lie in the monzogranite field, but are somewhat closer to quartz monzonite and granodiorite. The aplite sample is of similar composition to tonalite. The latite samples are quartz monzonite, and are likely a less-differentiated phase of the same intrusive complex.

A triangular diagram of SiO_2 - K_2O - $\text{Na}_2\text{O} + \text{CaO}$ (Figure 6b) shows the six samples from Oliver Creek, those from the Mayo-McQuesten area, and a suite of granites from the Selwyn Basin (Garrett 1971). The Selwyn Basin granites have lower, the Mayo-McQuesten granites intermediate, and the Oliver Creek granite samples higher SiO_2 /alkali ratios. The Oliver Creek latite is lower than the granite in SiO_2 , similar to the Selwyn Basin granites, and the aplite has high SiO_2 and very low K_2O contents. Compared to other granitic rocks in Selwyn Basin and Mayo-McQuesten area, Oliver Creek granite is siliceous, and Na-

Figure 6. Triangular diagrams showing compositional variation in granite from Oliver Creek (Emond, this report), from the Mayo-McQuesten area (Sinclair, pers. comm.), and from the Selwyn Basin (Garrett 1971). 6a. Quartz - K feldspar - plagioclase (normative). 6b. SiO_2 - K_2O - $\text{Na}_2\text{O} + \text{CaO}$ (wt. %). 6c. CaO - Na_2O - K_2O (wt. %).

and Ca-poor. The aplite is even more siliceous and also K poor.

A $\text{CaO} - \text{Na}_2\text{O} - \text{K}_2\text{O}$ triangular diagram (Figure 6c) has Selwyn Basin granites central to the distribution, while most Mayo-McQuesten granites contain more CaO, and Oliver Creek latites contain still higher CaO while are lower in Na_2O . The Oliver Creek granites are very low in CaO and high in K_2O , and the aplite is very rich in Na_2O . A continuous suite of compositions ranging from Oliver Creek latite to Mayo-McQuesten granites, to Selwyn Basin granites, and to Oliver Creek granites may represent various differentiates of one main igneous suite, of which the Oliver Creek granite is the most differentiated.

The Oliver Creek aplite is not really a tonalite as its CIPW normative mineralogy suggests. Petrographic textures, such as albite rims on feldspar and chemical composition of the aplite, suggest it is an altered rock, and thus the normal classification scheme cannot be used. This aplite may be a sodium-metasomatized late phase of the granite which indicates that sodium-rich fluids were abundant in the late phases of magma at Oliver Creek. Sodium-metasomatized late magmatic phases are common near tin deposits and are believed closely related to their formation (Taylor 1979 pp. 182-200).

(c) Structural Geology

Folding and Foliation

The Oliver Creek area lies on the south limb of the 'McQuesten Anticline' (Boyle 1965; Figure 3). The prominent foliation strikes easterly to southeasterly and dips shallowly to

moderately to the south. Cataclastic deformation (probably during Mesozoic arc-continent collision) resulted in complicated folding, transposition foliation and mylonitic textures similar to the those of the Yukon Cataclastic Complex (Tempelman-Kluit 1981). These features make correlation difficult. Abundant marker horizons of marble, calc-silicate rock and amphibolite, especially in the closely spaced drill holes of the eastern drill area enable stratigraphic correlation of some lithologic units (Figure 4).

Faulting and Jointing

Abundant faults of varying attitudes occur in the Oliver Creek area and are characterized by gouge zones 1 cm to several metres in width. These faults commonly strike east-northeasterly and dip steeply to the south (Figure 7). The rocks are highly fractured and jointed in the central drill area; however in the general Oliver Creek area joints are well spaced at 10-50 cm and occur at two or three variable attitudes.

(d) Metamorphism

Regional Metamorphism

Grit Unit rocks of the McQuesten River area were regionally metamorphosed to the greenschist facies during the Late Jurassic to Early Cretaceous (Tempelman-Kluit 1981 p. 9).

Contact Metamorphism

A zone of porphyroblastesis and subsequent pervasive biotite

Figure 7. S-N cross-section of the tin-bearing breccia zone at Oliver Creek, DDH 13, 7, 8 (located at "C-S" on Figure 4).

alteration occur at depth in the country rocks and is related to intrusion of the nearby granite. The porphyroblasts are probably pseudomorphic after andalusite, and are completely altered to fine-grained biotite. Chlorite in some of the deeper quartzite, schist and calc-silicate rock is also locally altered to biotite. The intrusion is probably of Mid- to Late Cretaceous age and subjacent to the drill area (Figure 8). The minimum depth of the porphyroblastic zone decreases toward the west in the direction of the exposed pluton. A similar porphyroblastic zone surrounds the nearby Scheelite Dome intrusion (Kuran et al. 1982).

Figure 8. WSW-ENE cross-section of the zone of andalusite porphyroblastesis and pervasive biotite alteration, Oliver Creek drill area.

Chapter 3

MINERAL ASSEMBLAGES AND ALTERATION

A. BRECCIA AND VEINS

Breccia/veins are the most common host to tin and silver mineralization at Oliver Creek and crosscut mainly quartzite and schist. The breccias are tabular bodies which locally grade into veins and may be traced between some drill holes (Figure 4). The major breccia/vein bodies strike east-northeasterly with a steep southerly dip (approximately 70°), following the strike of major fracture zones with adjacent subparallel gouge zones (Figure 7). They commonly pinch in less competent schists and swell in quartzite irregularly along strike, ranging from less than 1 to 15 m wide and are more common in the eastern drill area. Breccia zones are commonly bordered by, or grade into zones of stockwork (mainly chloritic). This indicates that in situ brecciation (or shattering) took place in a brittle-deformation pressure regime, with localized zones of intense stockwork extending into the surrounding country rock.

ROCK FLOUR-MATRIX BRECCIA

Rock flour breccia is the main breccia type and consists of 70-95% angular to subrounded, quartzite and mica schist, multi-sized (less than 5 cm in diameter) fragments in a finely comminuted matrix of similar composition (Figure 9). The breccia has a closed framework and shattered appearance, with little relative movement or rotation of rock fragments. The rock flour

Figure 9 Rock flour breccia (quartzite fragments with ground-up quartzite matrix).

a. Rock sample, field of view 6.5 cm.

b. Thin section, field of view 0.45 cm.

Figure 10 Crystalline-matrix breccias (quartzite and vein material fragments in a matrix of vein material of variable composition).

a. Chlorite breccia (chlorite matrix)

i) rock sample, field of view 5.0 cm;

ii) rock sample, field of view 5.0 cm;

iii) thin section, field of view 0.50 cm.

b. Tourmaline breccia (tourmaline matrix)

i) rock sample, field of view 7.0 cm;

ii) thin section, field of view 0.50 cm;

iii) thin section, field of view 0.55 cm.

c. Quartz breccia (quartz matrix). Rock sample, field of view 7.5 cm.

d. Biotite breccia (biotite matrix). Thin section, field of view 0.50 cm.

e. Muscovite breccia (muscovite matrix). Rock sample, field of view 4 cm.

f. Calcite breccia (calcite matrix). Rock sample, field of view - 7.5 cm.

g. Kaolinite breccia (kaolinite matrix). Rock sample, field of view - 7.5 cm.

9

a

b

10a

ii

i

111

10b

i

ii

10c

iii

10d

10e

10f

10g

matrix contains a minor amount of chlorite, tourmaline or mica alteration, and locally, small crystals of cassiterite or rutile. Limonite stain is very common, and in some places (near the surface) kaolinite, manganese oxide, malachite and azurite also stain the matrix.

CRYSTALLINE-MATRIX BRECCIAS

Crystalline matrix-breccias crosscut rock flour breccia and other country rocks. They consist of 50-80% rock fragments (mainly quartzite and schist, and minor clasts of vein material) in a matrix of various minerals which distinguish the breccia phases (Figure 10). The fragments are poorly sorted, subangular to subrounded, moderately spherical, and have an open to closed framework. Main minerals in the matrix are chlorite, tourmaline, calcite and quartz with minor amounts of biotite, muscovite and kaolinite-limonite (Appendix 2).

(a) Chlorite Breccia

Chlorite breccia (Figure 10a), of greatest abundance is the major tin- and silver-bearing breccia type. The clasts range from 1 mm to 4 cm in diameter. Clasts of quartzite, vein quartz and vein tourmaline are angular to subangular; schist fragments are subangular to subrounded; chlorite vein clasts are sub- to well-rounded; clasts of cassiterite aggregates and crystal fragments are angular to subrounded; and rare cassiterite breccia fragments, consisting of subrounded to subangular, medium-grained cassiterite grains in a fine-grained matrix of cassiterite, are

subangular to subrounded.

The matrix consists of 80 to 100% dark green, fine- to coarse-grained, anhedral to subhedral chlorite which locally forms radiating aggregates. In thin section, the chlorite is medium- to dark-green and has dark- to medium-blue anomalous interference colours. Chlorite is locally associated with tourmaline, rutile, biotite and/or muscovite, and is commonly stained with limonite. Minor sphalerite, chalcopyrite, pyrite, pyrrhotite and native silver, and rare galena and arsenopyrite occur as pods within the chlorite. Cassiterite occurs as small crystals and crystal fragments within the chlorite matrix, and is commonly in contact with quartzite and vein quartz fragments.

(b) Tourmaline Breccia

Tourmaline breccia (Figure 10b) is of moderate abundance; a minor amount of this breccia is tin bearing and some is silver bearing. Clasts contained are 1 mm to 2 cm in diameter, angular to subangular, have corroded edges, and commonly consist of quartzite, schist, vein quartz and vein tourmaline (mostly coarse- to medium-grained). Locally, fragments of tourmaline breccia occur in the tourmaline matrix.

The matrix consists of 65 to 100%, fine- to medium-grained, subhedral to euhedral, and mostly microcrystalline tourmaline. The tourmaline is commonly dark brown, although there are light brown and dark blue varieties, and in thin section it ranges from bright orange to brown, to light blue, and to colourless in different vein samples. Tourmaline is commonly finely mixed with

biotite and is locally mixed with chlorite and/or muscovite. Abundant pyrrhotite and pyrite, as much as 5-10% rutile, minor chalcopyrite and zircon, and rare arsenopyrite (locally silver bearing), sphalerite and cassiterite also occur locally in the matrix.

(c) Quartz Breccia

Quartz breccia (Figure 10c) is uncommon. It consists of 1 mm to 3 cm (diameter), angular to subangular quartzite and schist fragments; minor subrounded clasts of white argillic material (kaolinite determined by x-ray diffraction); and minor subrounded to subangular chlorite- and rock flour-breccia clasts. The matrix consists of fine- microcrystalline to coarse-grained, mostly monomineralic and commonly euhedrally terminated quartz crystals with minor, local pyrite. In one place, quartz breccia grades into stockwork, and then into pervasively silicified rock (silicified rock flour breccia and quartzite).

(d) Biotite Breccia

Biotite breccia is minor (Figure 10d) and consists of clasts from 1 mm to 2.5 cm. The clasts are angular to subrounded and consist of quartzite, mica schist, vein quartz, tourmaline breccia or vein material, and vein muscovite. Quartz-rich fragments have corroded edges. The matrix consists mostly of fine-grained, anhedral to subhedral, medium-brown biotite. This breccia type commonly cuts tourmaline breccia, and is also finely mixed with it where the breccia/veins intersect. The tourmaline

and biotite are fine-grained, inextricable intergrowths, beyond resolution of the microprobe. Chlorite is also intergrown with biotite locally; limonite stain is very common, and ilmenite and rutile occur locally in the biotite matrix.

(e) Muscovite Breccia

Muscovite breccia is minor to rare (Figure 10e), and consists of 1 mm to 2 cm (in diameter), subangular to subrounded clasts of quartzite, mica schist, vein quartz, vein chlorite and chlorite breccia. The matrix consists most commonly of muscovite, chlorite and locally minor fluorite, and less commonly monomineralic muscovite. Locally cassiterite occurs with chlorite and muscovite, and some muscovite appears to be pseudomorphous after chlorite. Sulphides (mainly sphalerite and chalcopyrite) are present, but are mainly associated with the chlorite. In a few samples where cassiterite and chlorite are present, there is a bright green mineral, possibly willemite (Zn_2SiO_4) associated with native silver, and some brownish Mn- and Cu-bearing smithsonite (these minerals were identified by qualitative Energy Dispersive Spectroscopy (EDS)).

(f) Calcite Breccia

Calcite breccia (Figure 10f) is of moderate abundance, commonly occurs adjacent to rock flour breccia zones, and locally grades into rock flour breccia. Calcite- and rock flour-breccias have similar textures (i.e., calcite precipitated in the matrix of the rock flour breccia). The clasts are mostly angular to

subangular quartzite fragments, or rock flour breccia fragments, with minor subangular to subrounded chlorite breccia fragments. The matrix consists mainly of medium- to coarse-grained, commonly euhedral calcite crystals, and locally there are small amounts of fluorite, and/or galena and sphalerite. The calcite breccia crosscuts all other breccia types.

(g) Kaolinite Breccia

Kaolinite breccia is relatively rare, except very close to surface. Its texture is very similar to the rock flour breccia (Figure 10g) except there is a greater proportion of matrix (as much as 35%). The matrix is microcrystalline kaolinite stained with limonite.

(h) Veins

Veins are most abundant in areas surrounding breccia zones. Most vein attitudes vary, but there are some parallel vein sets; the tourmaline veins in particular, and some chlorite and quartz veins occur in parallel sets which dip steeply to the south-southwest. Vein minerals are generally the same as those in the crystalline-matrix breccias, and thus most textures are similar to the appropriate breccia matrices. Only features different from the breccias will be mentioned below.

Quartz Veins

Quartz veins are abundant in the schist and quartzite in varying thicknesses; however, more than two-thirds of these are

concordant, considered 'metamorphogenic' (quartz 'sweats'), and are probably unrelated to hydrothermal activity. Both concordant and discordant quartz veins are mostly barren. The discordant veins are similar to the quartz breccia in texture and mineralogy i.e., medium- to coarse-grained, euhedral crystals. Quartz breccias are mostly barren of mineralization; however, the chlorite which fills the centres of some quartz veins is locally associated with sulphides. These zoned veins (Figure 11) are common.

Chlorite Veins

Chlorite is a very common vein mineral, second in abundance to concordant quartz. The chlorite is medium- to coarse-grained, and has similar mineral associations and textures to the chlorite breccia matrix. Cassiterite occurs locally in small to medium, euhedral to subhedral crystals adjacent to the chlorite grains, in textural equilibrium. Near zones of chlorite breccia and veining, chlorite vein material is commonly developed in bands along the foliation and also along fractures. In places it is difficult to distinguish between hydrothermal and metamorphic chlorite because of their similar position within the quartzite. This veining is most intense close to the breccia zones.

Tourmaline Veins

Tourmaline veins are common and are more abundant in the deeper drill intersections. Parallel tourmaline vein sets are common, especially at depth.

Figure 11. Zoned vein cutting mica quartz schist. The vein consists of quartz with a chlorite-pyrite-pyrrhotite core which is traversed by subparallel calcite stringers. Rock sample, field of view 7.5 cm.

Figure 12. Chlorite envelopes.

- a. Mica quartz schist. Rock sample, pencil for scale.
- b. Marble. Rock sample, field of view 7.0 cm.

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12

Muscovite Veins

Muscovite veins are rare. The muscovite is beige and is commonly associated with chlorite. Locally the chlorite and muscovite are banded parallel to the vein (i.e., bands of green chlorite alternating with beige muscovite).

Calcite Veins

Calcite veins are common, and increase in abundance with depth, probably due to near-surface leaching by acidic groundwater percolating down from the surface. The mineral associations and textures are similar to the calcite breccia.

B. OTHER ALTERATION

(a) Selvedges and Envelopes

Selvedges on fractures are rare, except for muscovite (sericite) on some fracture surfaces in the granite. Locally, chlorite selvedges occur on the borders of discordant quartz veins.

Envelopes are common, especially chlorite-rich envelopes bordering fractures in the mica schist (Figure 12a), amphibolite and marble. In the marble, chlorite-rich envelopes are locally rich in sphalerite and galena (Figure 12b). Quartz-rich envelopes also border fractures in the quartzite. Most envelopes are less than 1 cm wide.

(b) Pervasive Alteration

The strongest pervasive alteration is biotite alteration of

the contact metamorphic porphyroblastic andalusite zone and other rock units at depth. Other forms of pervasive alteration are not prominent, although varying degrees of chlorite alteration occurs in hornblende-biotite latite, marble and amphibolite.

C. MINERAL PARAGENESIS

(a) Paragenesis and Mineral Associations

Crosscutting relationships of veins in drill core are abundant at the Oliver Creek tin occurrence (Appendix 3 and the "Breccia/Vein" section) and facilitate the deduction of mineral paragenesis (Figure 13). Mineral-deposition history is divided into six stages, (according to the major gangue or ore mineral present. In order of deposition, the following mineral assemblages were precipitated: (1) quartz; (2) tourmaline (+/- biotite, muscovite, pyrrhotite, pyrite and chalcopyrite); (3) chlorite (+/- cassiterite, sulphides, native silver and muscovite); (4) calcite (+/- fluorite); (5) limonite (+/- kaolinite, manganese-oxide, malachite and azurite). Common mineral associations are tourmaline with pyrrhotite and pyrite; tourmaline with biotite or muscovite; cassiterite with chlorite; and chlorite with sphalerite and chalcopyrite.

The most prominent hypogene breccia/vein types from oldest to youngest are quartz, tourmaline, chlorite, and calcite (Figure 14).

Figure 13. Paragenesis diagram for minerals of the Oliver Creek tin-bearing breccias, separated into five main stages of mineral deposition.

Figure 14. Cartoon of S-N cross-section of the major cross-cutting breccia types in paragenetic order.

(b) Metallic Minerals

Cassiterite

Cassiterite is the only tin mineral found in the Oliver Creek area, and is closely associated with the chlorite stage (Figure 13), as it occurs most commonly as crystals or crystal aggregate fragments in the chlorite breccia (Figure 15). Some cassiterite also occurs as crystals in chlorite veins, in textural equilibrium with the chlorite. Although cassiterite is commonly present in sulphide-rich chlorite breccia/veins, the two are not ubiquitously associated.

The cassiterite is light to dark brown, some crystals are colour zoned, and most are non-pleochroic; crystals are less than 3 mm in diameter (many are less than 1 mm) making them difficult to detect in hand specimen. The crystals are short prismatic dipyrramids, commonly contact twinned and in aggregates.

Silver

Silver occurs mainly as the native element in chlorite breccia. It also occurs in both sulphide-rich and sulphide-poor chlorite breccias/veins. Cassiterite and silver are not together in all the breccias, suggesting that the depositing solutions may have overlapped in time and composition. However other physico-chemical parameters may also have been involved, e.g., pH, fO_2 , temperature.

Rare silver-rich arsenopyrite (determined by EDS) occurs in sulphide-rich tourmaline breccias/veins.

Figure 15 Cassiterite in chlorite breccia. Thin sections, field of view 0.55 cm.

- a. Fragments and/or crystals of cassiterite in chlorite matrix of chlorite breccia.
- b. Fragments of cassiterite mineral aggregates in a chlorite clast within a chlorite breccia.
- c. Fragments of monomineralic cassiterite crystal aggregates in a chlorite matrix.
- d. Clast of cassiterite breccia (cassiterite matrix) within chlorite breccia.

a

b

c

d

Sulphide minerals

Most commonly pyrite, pyrrhotite, chalcopyrite and sphalerite, and minor galena and arsenopyrite occur locally in the matrix of tourmaline- and chlorite-breccias/veins. Pyrite, pyrrhotite and chalcopyrite are associated with tourmaline; and sphalerite and chalcopyrite, along with minor pyrite and pyrrhotite are associated with chlorite. Pyrrhotite and pyrite also occur as fine-grained disseminations within some mica schists.

Most sulphide minerals occur in anhedral, medium- to coarse-grained aggregates; however, pyrite commonly occurs in euhedral cubes. Common intergrowths of the sulphide minerals are pyrite, pyrrhotite, and chalcopyrite (+ arsenopyrite); sphalerite and chalcopyrite; and sphalerite and galena. Chalcopyrite is commonly exsolved in sphalerite as small blebs aligned along major cleavage traces, and as large, randomly oriented blebs (less than 5 mm in diameter); it also occurs rarely as exsolution blebs in pyrrhotite.

D. ALTERATION MINERAL VARIATION

Estimates were made of the amount of vein material in each rock unit during drill core logging. A graph of the proportion of rock occupied by vein chlorite (% chlorite per rock unit) (Figure 4), along with others for quartz and tourmaline, show a general increase in the amount of alteration, stockwork, and fracturing of the country rock toward the breccia zones.

Several parallel, east-northeast-striking zones of alteration

following the fault and breccia zones can be traced between drill holes (Figure 4), pinching and swelling along strike. In the Discovery Zone, several alteration zones are depicted, but most do not continue to the west. Locally, marble, calc-silicate rock and amphibolite are more susceptible to alteration than nearby quartzite, and consequently they contain more pervasive chlorite and biotite.

Drill hole 16 is used to compare the variation in abundance of chlorite, tourmaline, quartz and calcite veins, and tin and silver content with the rock units (Figure 16). Discordant and concordant quartz veins were also distinguished in core logging. One histogram in Figure 16 shows the amount of discordant vein quartz (hydrothermal quartz) as a percentage of the total vein quartz (hydrothermal + metamorphogenic).

These alteration parameters all increase in abundance with proximity to breccia (or fracture) zones. As the amount of total vein quartz increases (from the "background" values of approximately 1%), so does the percentage of discordant quartz veins. Two main anomalies occur in the central drill hole through two breccia zones, and deeper in the drill hole through another breccia body. Chlorite veins are not only abundant in the breccia zones, but also in the calc-silicate rock and marble units. Calcite veins are most abundant in the marble and calc-silicate rock. Tourmaline veins, although of minor abundance in this drill hole, occur in one of the deeper breccia zones. Tin is not only abundant in the breccia zones (as much as 1%), but also in the amphibolite and calc-silicate rock. Silver is

Figure 16. Alteration, metal variation and associated rock types through DDH 16 located at "D-S" on Figure 4. The histogram values are volume % veins, and arrows indicate greater than scale values.

abundant in fault gouge zones, breccias, and in the amphibolite unit adjacent to the breccia (as much as 30 ppm). Zinc, although not shown on this diagram, commonly closely follows tin distribution, and occurs in quantities greater than 2% locally. Metallic minerals are irregularly distributed through the breccias; some breccias contain tin, silver, copper, or zinc minerals, and some do not; and metal values are not constant through the metalliferous breccias.

Chapter 4

CHEMICAL COMPOSITION OF SILICATE MINERALS AND CASSITERITE

A. METHOD OF ANALYSIS

Polished thin sections were made by Vancouver Petrographics Limited and at Carleton University from selected samples, mainly of drill core, and also from a few outcrops and trenches on the property. Some thin sections, of which exact locations of samples are unknown, were also received from Billiton Canada Ltd. After petrography was completed, selected sections were carbon-coated for analysis on the electron microprobe at Carleton University, Ottawa. Details of the microprobe and its running conditions with a list of the standards used for each element, the detection limits for minor and trace elements, and an account of the accuracy of data are recorded in Appendix 3.

The semiquantitative EDS (Energy Dispersive Spectroscopy) was used in identification of some unknown mineral grains and the WDS (Wavelength Dispersive Spectrometer) was used for quantitative mineral analyses. The two most abundant vein/breccia silicate minerals, chlorite and tourmaline, and lesser abundant biotite were analyzed for eleven elements: Fe, Mg, Ca, Na, Mn, Al, Ti, Si, K, F and Cl. Cassiterite was analyzed for Sn, for the following seven trace elements which commonly substitute for Sn: Ti, Ta, Mn, W, Fe, Nb and Zr (Taylor 1979), and for Ag since it also occurs in the breccias. Several grains were analyzed on each polished thin section (from 1 to 12 grains of each mineral present). In all analyses, total

iron was determined and quoted as FeO since the microprobe cannot distinguish Fe_2O_3 and FeO. Zoned grains, where large enough, were analyzed on the core and on the rim. Only those analyses between 97 and 103 weight percent (once the water, calculated according to stoichiometry, was added) were regarded as reliable. In tourmaline, the amount of boron was assigned a constant value of 10.60 weight percent BO_3 (average of values from tourmalines of Deer et al. 1962a). Analyses for all minerals are recorded in weight percent abundances in Appendices 4 to 7.

Each grain analyzed is characterized according to different variables. For silicate minerals the variables are host rock, occurrence type, grain size, paragenetic position, metallic and gangue mineral association, and type of clast contained (if breccia), and for tourmaline, colour is also included. The variables for cassiterite are grain size, shape, occurrence type, zonation and metallic mineral association. These variables are coded, and the key for codes used in identifying each of the silicates and cassiterite are found in the front of each appendix (#'s 4-7). This is followed by a list of samples analyzed with their appropriate codes characterizing each grain, and then by a list of the oxide weight percents.

This chapter summarizes variations in mineral compositions and assumes that these are a direct reflection of fluid composition. However, the reader should keep in mind that some mineral compositions may have been more strongly affected by changes in temperature, pH or pressure than by changes in fluid

composition, other variables being constant.

B. ELEMENTAL VARIATION IN MINERAL COMPOSITIONS

(a) Chlorite

The ideal formula for trioctahedral chlorite is:

$(\text{Mg,Al,Fe})_{12}(\text{Si,Al})_8\text{O}_{20}(\text{OH})_{16}$ (Deer et al. 1962b). The principal substitutions which take place are Al^{+3} in four-fold coordination for Si in the tetrahedral sites, observed in the range of $(\text{Si}_7\text{Al})^{\text{IV}}$ to $(\text{Si}_5\text{Al}_3)^{\text{IV}}$; Al^{+3} in six-fold coordination for Mg in the octahedral sites, observed in the range Mg_{11}Al to Mg_8Al_4 ; and also Fe^{+2} for Mg in octahedral sites which may be complete ($\text{Fe}^{+2}/\text{Fe}^{+2}+\text{Mg} = 0-1.0$). Minor substitution of Mn (and Ti) for Mg is common. Only trace amounts of Ca, Na and K are possible in the chlorite structure because of their large radii. Trace amounts of F and Cl substitute for OH.

Compositional data on the 181 Oliver Creek chlorites representing 42 specimens are in Appendix 4. The chlorite formula used for these chlorites in the following interpretation (Figures 17-23 and Table 1) is based on 56 charges and all iron assumed divalent. Major element composition of the chlorite is shown by a diagram of the elemental Fe/Fe+Mg ratio versus Si+Al_{total} (Figure 17a). Within the general compositional range for chlorite, including 36 chlorite analyses (Deer et al. 1962b) from a wide range of locations, host rocks and occurrence types, Oliver Creek chlorite has moderate to high Fe/Fe+Mg ratios (Figure 17b). The Si+Al values are not strictly comparable since

Figure 17. Graph of major element composition of Oliver Creek chlorites.
(Fe/Fe+Mg versus Si+Al_{total}).

- 17 a. Chlorite from different host rocks: A = quartzite;
B = schist; C = granite; D = biotite latite; E = tourmaline
breccia; F = vein quartz; G = chlorite breccia; H = rock
flour breccia.

Figure 17b. Chlorite from Oliver Creek compared with that from various localities and occurrence types (from Déer et al. 1962b).

Table 1. Average compositions of Oliver Creek chlorite based on 36 negative charges and assuming all iron divalent.

Host Rock, or Occurrence Type	Atomic Formula (average)	FeO FeO+MgO (wt. % ratio)
vein or breccia matrix	(Fe _{7.28} Al _{2.95} Mg _{1.37} Mn _{0.26}) (Si _{5.23} Al _{2.77})O ₂₀ (OH _{15.94} F _{0.06})	0.85
granite (pod, or vein)	(Fe _{7.26} Al _{2.84} Mg _{1.39} Mn _{0.34} Na _{0.12}) (Si _{5.20} Al _{2.80})O ₂₀ (OH _{15.91} F _{0.09})	0.85
granite (pseu- domorph of biotite)	(Fe _{6.30} Al _{2.65} Mg _{2.76} Mn _{0.07} Ti _{0.02}) (Si _{5.6} Al _{2.4})O ₂₀ (OH _{15.94} F _{0.06})	0.70
latite	(Fe _{6.61} Al _{2.73} Mg _{2.47} Mn _{0.11}) (Si _{5.33} Al _{2.67})O ₂₀ (OH _{15.97} F _{0.03})	0.73
envelope in quartzite	(Fe _{5.8} Al _{2.43} Mg _{3.64} Mn _{0.2}) (Si _{5.31} Al _{2.69})O ₂₀ (OH _{15.93} F _{0.07})	0.62
selvedge on quartz vein	(Fe _{6.73} Al _{2.74} Mg _{2.38} Mn _{0.19}) (Si _{5.06} Al _{2.94})O ₂₀ (OH _{15.92} F _{0.08})	0.75
along the foliation in quartzite	(Fe _{6.92} Al _{2.9} Mg _{1.76} Mn _{0.28} K _{0.02}) (Si _{5.18} Al _{2.82})O ₂₀ (OH _{15.90} F _{0.1})	0.81

the formulae from Deer et al. (1962b) were calculated on the basis of number of ions, whereas Oliver Creek chlorite's formula are based on charge balance. Oliver Creek chlorite is similar in major element composition to two vein chlorite samples from Cornwall, England, and to a chlorite vein sample in granite from Northern Ireland.

Oliver Creek chlorite is iron rich, trioctahedral, classified as chamosite according to Bailey (1979), and is characterized according to host rock and occurrence type (Table 1). There are approximately five Si and three Al atoms in the tetrahedral sites. The amount of octahedral Al is nearly equal to tetrahedral Al. Fe is the dominant octahedral atom (5 - 8.6 atoms per unit cell); Mg is subordinate (0.3 - 4.3 atoms per unit cell).

Histograms show trace and minor element abundances in the Oliver Creek chlorite (Figure 18). The total range in weight percent abundances (with the main range in parentheses) are as follows: 0.21 to 4.19% (0.20-2.20%) MnO, 0.02 to 1.06% (0.02-0.14%) TiO₂, 0 to 0.22% (less than 0.14%) CaO, 0 to 0.22% (less than 0.04%) Na₂O, and 0 to 0.62% (less than 0.14%) K₂O in the octahedral sites; and 0 to 0.59% (less than 0.32%) F, and 0 to 0.13% (less than 0.05%) Cl in the hydroxyl site. Zero indicates below detection limit; Na, F and Cl are most commonly below detection limit. Anomalous K, Na and Ca in a few samples was likely due to spurious readings.

Figure 18. Histograms for trace and minor elements in Oliver Creek chlorite (weight percent). "f" stands for frequency, or number of samples. Samples with values below detection limit are omitted.

Compositional Variation in Oliver Creek Chlorite

The graph of major element composition in Figure 17a separates Oliver Creek chlorite into groups according to their host rock type. The bulk of samples plot in the high Fe/Fe+Mg portion of the total field of samples (Fe/Fe+Mg (atomic) = 0.8-0.93); Si+Al is commonly between 10.5 and 11.25 atoms per unit cell. One problem in the interpretation of data is the effect of ferric iron which is not accountable in microprobe analysis. If there is appreciable Fe₂O₃ in the chlorite, the total Si+Al will be significantly reduced due to the increase in charge. Other diagrams (for the same chlorite analyses), constructed using different groupings (i.e., grouping according to ore mineral association rather than host rock), are in data file EDATA. Schematic diagrams (e.g., Figure 19) will be used in the following sections to show the main compositional fields of different Oliver Creek chlorite groups.

(i) Host Rock and Occurrence Type

From rock flour breccia to chlorite- and tourmaline-breccia (crystalline-matrix breccias), there is an obvious increase in the amount of hydrothermal alteration (a greater amount of crystalline matrix occurs in the latter breccias). This suggests that the fluid/rock ratio increased with time during this transition and/or a change in physico-chemical conditions. There is also an increase in the average chlorite Fe/Fe+Mg from rock flour- to crystalline-matrix-breccias (Figure 19).

Figure 19. Chlorite from different host rocks and occurrence types from Oliver Creek (schematic diagram). Graph of Fe/Fe+Mg (atomic) versus Si+Al_{total} (atoms).

Tourmaline and Chlorite Breccias

Chlorites contained in these rocks have high Fe/Fe+Mg. Tourmaline-breccia chlorite commonly has a higher Fe/Fe+Mg ratio and lower Si+Al than that in chlorite breccia. This may reflect a different method of formation of the two chlorites (i.e., the former may be an alteration product of tourmaline while the latter may be a direct precipitate from solution); or a different time of formation, from solutions of varied composition. No chlorite is seen to be pseudomorphous after tourmaline, thus favoring the temporal, solution composition factor.

Granite

Chlorite occurs in the granite in two forms: 1) clots or veins; and 2) pseudomorphs after biotite. The clot or vein chlorite is similar in composition to that in chlorite breccia suggesting a similarity in fluids altering the country rock to those altering the contact zone of the granite. Chlorite pseudomorphs after biotite in the granite have a composition similar to the biotite-replaced and thus have a much lower Fe/Fe+Mg ratio (0.68 - 0.7) than the vein or clot chlorite, but similar to igneous biotite (0.68-0.79)(Chapter 4, section c(i)). This agrees with the conclusions of Dodge (1973) for chlorite of the central Sierra Nevada Batholith.

Veins and Alteration in Hornblende-Biotite Latite

Chlorite in latite has a low Fe/Fe+Mg ratio, similar to the biotite present(0.73)(Chapter 4, section c(i)), and thus may be either an alteration of that biotite, or it may have formed at a

time when solutions were depositing an iron-poor chlorite. The latter is preferred because of its vein-like appearance, and the lack of biotite relics.

Selvages and Envelopes in Country Rock

The low Fe/Fe+Mg ratio of this chlorite may be a function of low Fe activity of the depositing fluid, or original composition of the country rock. The envelope chlorite may also have replaced biotite of a lower Fe/Fe+Mg ratio; however, no relic biotite is present.

Chlorite in the Foliation of Country Rock

Some of this chlorite is part of the original metamorphic rock, while other is similar to chlorite in nearby veins and may have been precipitated along planes of high permeability during hydrothermal activity. This 'concordant' chlorite forms two compositional fields (although data is not abundant, Figure 19): one contains lower Fe/Fe+Mg chlorite, and the other is similar to chlorite from chlorite breccia. Perhaps the latter field represents the hydrothermally precipitated chlorite, while the former (lower Fe/Fe+Mg chlorite) is regional metamorphic chlorite.

(ii) Paragenetic Relations of Breccia/Vein Chlorite

Several crosscutting phases of chlorite are distinguishable: clasts of vein chlorite within a chlorite matrix are "early", the chlorite matrix is "intermediate", and a vein crosscutting the breccia is "late" phase chlorite (Figure 20). From early to intermediate phases, chlorite changed to higher Fe/Fe+Mg. From intermediate to late phases: a) those at high initial Fe/Fe+Mg

Figure 20. Paragenesis of chlorite compositions of Oliver Creek chlorite (schematic diagram). Graph of $\text{Fe}/\text{Fe} + \text{Mg}$ versus $\text{Si} + \text{Al}_{\text{total}}$.

all decrease in this ratio in the latest phases; and b) those at a lower initial Fe/Fe+Mg remain close to the same or increase in this ratio in the later phase. Other elemental graphs indicate a general decrease in the Si+Al and in Ti, and an increase in Ca and F content of chlorite from intermediate to later phases.

Summary

Overall, there is a trend of iron enrichment in later stages of chlorite, until near the end of chlorite deposition when it decreases slightly. An increase in Fe, Al, and locally, in Ca and F, and a decrease in Mg and Si points to a greater substitution of Al for Si, and Fe for Mg in later phases of chlorite. This probably reflects the changing abundances of these elements in the depositing solution with time (fluids evolved to a higher Fe and Al (also Ca and F) concentrations). The increase in Ca and F in later chlorite correlates with the deposition of calcite and fluorite late in the paragenesis. The relatively titanium-rich composition of early and intermediate hydrothermal chlorite may also have been affected by contact metamorphic fluids generated during formation of the contact aureole. Recently, Evans and Trommsdorff (1983) have found that Ti can be easily mobilized during contact metamorphism.

The changes in chlorite composition noted above shed some light on the varying composition of chlorite in different host rocks and occurrence types. For instance, chlorite in tourmaline breccia may be iron rich because it was deposited late in the fluid evolution when the solutions were enriched in iron, and subsequent to tourmaline deposition. Petrography indicates that

chlorite is not intergrown with tourmaline. Perhaps tourmaline breccias were only permeated during late chlorite deposition. Iron-poor chlorite in latite, envelopes and selvages may have formed early in the hydrothermal evolution, before precipitation of vein- and breccia-chlorite took place, when solutions depleted in iron pervasively altered and prepared the rock.

(iii) Clast Type

Chlorite from the matrix of chlorite breccias are grouped according to the different types of clasts contained (Figure 21). On the basis that paragenetically later chlorite breccias commonly contain a wider range of clast types, especially greater variety in vein material clasts, there is an increase in Fe/Fe+Mg of chlorite with time, similar to the 'early' to 'intermediate' change. Chlorite with cassiterite and all other types of vein material clasts are the most iron rich.

(iv) Metallic Mineral Association

Most metallic (non-silicate) minerals occur with high Fe/Fe+Mg chlorite (greater than 0.75, atomic)(Figure 22). Cassiterite's rare association with chlorite in tourmaline breccia (superposition of Figures 22 and 19) may be due to (1) the chlorite being an alteration product of tourmaline, or (2) its precipitation very late in the fluid evolution, after the tin had been precipitated.

Sulphide Minerals

Chlorite associated with sulphide minerals defines two

Figure 21. Chlorite (matrix in breccias) containing different clast types (schematic diagram). $\text{Fe}/\text{Fe} + \text{Mg}$ versus $\text{Si} + \text{Al}_{\text{total}}$.

Figure 22. Chlorite of different metallic mineral associations (schematic diagram). Graph of Fe/Fe+Mg versus Si+Al_{total}.

compositional fields (Figure 22): 1) low Fe/Fe+Mg chlorite associated with sphalerite only (as well as rutile), and 2) higher Fe/Fe+Mg chlorite associated with iron sulphides (pyrite, pyrrhotite and chalcopryrite) including sphalerite.

Cassiterite

Cassiterite occurs with chlorite of very high Fe/Fe+Mg (0.75 to 0.95, atomic) similar to iron sulphide-associated chlorite. It is contained in chlorite- and rock flour-breccia.

The fluid which deposited sphalerite and rutile (only) was in equilibrium with low Fe/Fe+Mg chlorite, possibly an early iron-poor hydrothermal solution. Later, when the fluid equilibrated with higher Fe/Fe+Mg chlorite, it precipitated iron-rich sulphide minerals (pyrite, pyrrhotite, chalcopryrite and sphalerite) as well as cassiterite. Although cassiterite locally occurs together with sulphides, no positive equilibrium textures have been observed, and sulphides locally crosscut cassiterite. Chlorite with no associated cassiterite has a much wider range of major element composition suggesting cassiterite deposition took place only late within the total deposition of chlorite (actually near the end of the early to intermediate stage transition), when the fluid was in equilibrium with iron-rich chlorite.

(v) Gangue Mineral Association

Very few conclusions can be made from the gangue mineral association graph (Figure 23). Chlorite with associated tourmaline has very high Fe/Fe+Mg (0.8 - 0.95, atomic). Chlorite with associated fluorite is of two main compositions: one of

Figure 23. Chlorite of different gangue mineral associations (schematic diagram). Graph of $Fe/Fe+Mg$ versus $Si+Al_{total}$.

slightly lower than average Fe/Fe+Mg (0.75 - 0.85), and one of very low Fe/Fe+Mg (0.55 - 0.65, one sample only). This suggests there may have been two periods of fluorite precipitation with chlorite from fluids of varied composition.

(vi) Other Variables

There is no correlation (nor zonation) of chlorite composition with depth from which the samples were taken. There was very little lateral variation in chlorite composition (i.e., across veins; semiquantitative (EDS) work) and most veins are so thin that variation is unlikely. Neither was there any correlation of chlorite composition with grain size.

(b) Tourmaline

The general formula for tourmaline is:

(Deer et al. 1962a). The main chemical substitution that occurs to varying extents is in octahedral sites, where Fe, Mn, Li, Al and minor Ti replace Mg. This site filling is the key to classification of the principal tourmalines: Mg tourmaline is dravite; Fe tourmaline is schorl; and Li, Al tourmaline is elbaite. Al does not commonly substitute for Si to any great extent; Ca and minor K may substitute for Na; Fe^{+3} , Cr^{+3} and V^{+3} may substitute for Al; and F and minor Cl may substitute for OH (Deer et al. 1962a, and Fleischer 1983).

Compositional data was obtained through microprobe analysis for 72 tourmalines representing 19 samples from the Oliver Creek

Figure 25. Histograms of trace and minor elements contained in tourmaline from Oliver Creek (weight percent). "f" stands for frequency, or number of samples. Samples with values below detection limit are omitted.

Figure 24. Graphs of major element composition of tourmaline from the Oliver Creek tin occurrence.

24 a. Tourmaline from different host rocks: A = quartzite;
B = schist; C = granite; D = tourmaline breccia.

i) $Fe/Fe+Mg$ versus $Si+Al$ total.

Figure 24a (cont.). 11) Na/Na+Ca+K versus Si+Al_{total}.

Figure 24a (cont.). iii) Tl versus Si+Al_{total}.

Figure 24 (cont.). J. Tourmaline from ~~Oliver Creek~~ compared with that from various localities and occurrence types (from Deer et al. 1962a).

1) Fe/Fe+Mg versus Si+Al_{total}.

Figure 24b (cont.). 11) Na/Na+Ca+K versus Si+Al_{total}.

(0.88, average atomic ratio) to vein tourmaline at Oliver Creek.

The Oliver Creek tourmaline is classified in the short-dravite series, and is characterized according to host rock and occurrence type in Table 2. Iron is the most abundant element in octahedral sites, ranging from 0.93 to 2.81 atoms, with magnesium next, from 0.03 to 1.82 atoms (from a fraction of, to almost equal the quantity of iron). Some lithium (not detected by the microprobe) may occur in these octahedral sites and may account for the apparent vacancies. Silicon is short of the six atom requirement in several samples; possibly some aluminum (0 to 0.32 atoms) substitutes for it. Aluminum is low in a few samples, and octahedral aluminum ranges mostly from 0 to 0.60 atoms. The apparent vacancy may be explained by Fe^{+3} which may substitute for Al. From 0.39 to 0.85 atoms of Na, and as much as 0.30 atoms (but most commonly trace amounts) of Ca, and 0 to 0.07 atoms K occur in tourmaline. Although two samples contain 0.14 atoms K, these may be due to spurious readings.

Histograms show trace and minor element abundances in the tourmaline (Figure 25). The range of weight percent abundances (with the main range in parentheses) are as follows: 0.03 to 1.70% (0.1-1.0%) TiO_2 , 0 to 0.44% (0-0.18%) MnO , 0 to 1.67% (0-1.0%) CaO , 0 to 0.66% (0-0.06%) K_2O , 0 to 1.49% (0-1.1%) F, 0 to 0.09% (0-0.05%) Cl. Zero indicates below detectability of the microprobe (detection limits in Appendix 3); Cl and Mn are below these limits in most samples.

Table 2. Average compositions of Oliver Creek tourmaline based on 31 negative charges with B_3O_9 assumed in formula and assuming all iron divalent.

Host Rock, or Occurrence Type	Atomic Formula (average)	FeO FeO+MgO (wt. % ratios)	Na ₂ O Na ₂ O+CaO +K ₂ O (wt. % ratios)
vein or breccia matrix	(Na _{0.61} Ca _{0.11} K _{0.05})(Fe _{1.5} Mg _{1.18} Al _{0.09} Ti _{0.07})Al ₆ (Si _{5.89} Al _{0.11}) O ₁₈ (BO ₃) ₃ ((OH) _{3.78} F _{0.22})	0.53	0.79
granite (all grains)	(Na _{0.7} Ca _{0.04})(Fe _{1.91} Mg _{0.62} Al _{0.15} Ti _{0.06})Al ₆ (Si _{5.78} Al _{0.22})O ₁₈ (BO ₃) ₃ ((OH) _{3.78} F _{0.22})	0.76	0.93
granite (core of grains)	(Na _{0.64} Ca _{0.05})(Fe _{1.98} Mg _{0.34} Al _{0.31} Ti _{0.09} Mn _{0.02})Al ₆ (Si _{5.68} Al _{0.32})O ₁₈ (BO ₃) ₃ ((OH) _{3.45} F _{0.55})	0.86	0.91
granite (rim of grains)	(Na _{0.61} Ca _{0.08})(Fe _{1.55} Mg _{1.04} Al _{0.22} Ti _{0.02})Al ₆ (Si _{5.87} Al _{0.13})O ₁₈ (BO ₃) ₃ ((OH) _{3.58} F _{0.42})	0.60	0.89
granite (unzoned grains)	(Na _{0.73} Ca _{0.03} K _{0.02})(Fe _{2.01} Mg _{0.56} Al _{0.09} Ti _{0.07})Al ₆ (Si _{5.79} Al _{0.21})O ₁₈ (BO ₃) ₃ ((OH) _{3.48} F _{0.52})	0.78	0.96
along the foliation in quartzite	(Na _{0.52} Ca _{0.11})(Fe _{0.94} Mg _{0.88} Al _{0.60} Ti _{0.03})Al ₆ (Si _{5.84} Al _{0.16})O ₁₈ (BO ₃) ₃ ((OH) _{3.75} F _{0.25})	0.56	0.81

Figure 25. Histograms of trace and minor elements contained in tourmaline from Oliver Creek (weight percent). "f" stands for frequency, or number of samples. Samples with values below detection limit are omitted.

Compositional Variation in Oliver Creek Tourmaline

The graphs of major element composition in Figure 24a separate the Oliver Creek tourmaline into groups according to their host rock type. Most samples have moderate to high $Fe/Fe+Mg$ and $Na/Na+Ca+K$. Other diagrams (for the same tourmaline analyses) characterizing different variables were also constructed (in data file EDATA), and schematic diagrams are used here to illustrate the main compositional fields of different groupings of tourmaline (e.g., Figure 26 for tourmaline of different host rock and occurrence types).

(i) Host Rock and Occurrence Type

Granite

Tourmaline contained in granite (with intergranular texture) has relatively high $Fe/Fe+Mg$ and $Na/Na+Ca+K$, and low Ti (0.0 - 0.12 atoms)(Figure 26 and Table 2), excluding Ti-rich cores of zoned grains.

Veins in Country Rock

Tourmaline contained in veins and breccias through the country rock has lower $Fe/Fe+Mg$, $Na/Na+Ca+K$ and Al, a wide range of Ti, and higher K and Ca than granite-hosted tourmaline. This indicates magmatic fluids were very iron- and sodium-rich. Vein tourmaline from the tungsten deposits of the Kaneuchi Mine, Japan are similarly higher in magnesium contents than tourmaline from granitic zones (Sibhue 1984).

Other Tourmaline Hosted in Country Rock

Tourmaline within the country rock, commonly along the

Figure 26. Tourmaline from different host rocks and occurrence types from Oliver Creek (schematic diagrams).

a. Graph of $\text{Fe}/\text{Fe} + \text{Mg}$ versus $\text{Si} + \text{Al}_{\text{total}}$.

Figure 26 (cont.). b. Graph of $\text{Na}/\text{Na}+\text{Ca}+\text{K}$ versus $\text{Si}+\text{Al}_{\text{total}}$

Figure 26 (cont.). c. Graph of Ti versus Si+Al_{total}.

foliation, has relatively low Fe/Fe+Mg and Ti content, with high Si+Al and may have been deposited by an early hydrothermal fluid rich Si and Al, and poor in Fe and Ti. The low amount of Ti compared to the even earlier Ti-rich tourmaline (discussed later) is due to the depletion of Ti in later depositing fluids which may be the result of early rutile and ilmenite precipitation. The chemical composition of this tourmaline may also have been affected by the original composition of country rock.

(ii) Paragenetic Relations of Tourmaline

Crosscutting relationships of vein tourmaline hosted in country rocks along with core-rim relations of zoned tourmaline indicate several phases of tourmaline. Early and intermediate phases are characterized in Figure 27 in the same manner as done for chlorite. Although one late-phase vein of tourmaline was also analyzed, biotite was finely intermixed with it giving a poor analysis.

From early to intermediate phases, the composition changed mainly toward higher Fe/Fe+Mg and Na/(Na+Ca+K), and mostly lower Ti and F content. This indicates less substitution of Fe by Mg, and Na by Ca and K in later tourmaline phases.

Core-rim analyses from zoned grains in two samples, one a vein in country rock and the other a granite, each have different results (Figure 27). The country rock-hosted vein tourmaline has an increase in Fe/Fe+Mg and F content (from 0.25 to 0.52

Figure 27. Paragenesis of tourmaline compositions from Oliver Creek tourmaline (schematic diagram).

27 a. Graph of $Fe/(Fe+Mg)$ versus $Si+Al_{total}$:

2

Figure 27 (cont.). b. Graph of $\text{Na}/\text{Na}+\text{Ca}+\text{K}$ versus $\text{Si}+\text{Al}_{\text{total}}$.

Figure 27 (cont.). c. Graph of Ti versus Si+Al_{total}.

weight percent F), and a decrease in $\text{Na}/(\text{Na}+\text{Ca}+\text{K})$ and Ti content from core to rim. The granite-hosted tourmaline has a marked decrease in $\text{Fe}/(\text{Fe}+\text{Mg})$ and Ti content, and a smaller decrease in $\text{Na}/(\text{Na}+\text{Ca}+\text{K})$ from core to rim. This rim is similar in composition to the intermediate-stage tourmaline (country rock-hosted vein material).

Summary

The earliest tourmaline phase at Oliver Creek is probably the iron-, sodium- and titanium-rich, orange-brown cores of intergranular granite-hosted grains, interpreted as 'magmatic'. The blue rims of these grains are interpreted as 'hydrothermal' tourmaline, similar to Power's conclusions (1968). However, the early hydrothermal solutions precipitating tourmaline vein material in the country rock evolved somewhat before they altered or precipitated the blue tourmaline rims. Early hydrothermal tourmaline became enriched in iron, and depleted in titanium and fluorine with time. The later, hydrothermally precipitated tourmaline occurring in veins in the country rock and as rims on magmatic tourmaline grains, is relatively iron-, sodium- and titanium-poor.

The 'magmatic' tourmaline from granite (i.e., the brown cores) will be referred to as I_G , and the 'hydrothermal' tourmaline in granite (i.e., the blue rims), I_H . The two stages of 'hydrothermal' tourmaline in veins in the country rock for which data are available are referred to as H_1 and H_2 , denoting early and intermediate phases. Paragenesis of these

tourmaline phases is illustrated below:

(refer to Figure 27). I_H is similar in composition to H_2 . Thus the blue rims on igneous tourmaline were probably deposited by 'hydrothermal' solutions, similar in composition to those precipitating the intermediate-stage hydrothermal tourmaline, at a similar time.

The evolution of tourmaline composition probably closely resembles the evolution of depositing fluids. The above paragenesis suggests that the magma-derived solutions which first deposited orange-brown tourmaline were very iron-, sodium- and titanium-rich, likely more iron- and sodium-rich than later 'hydrothermal' fluids circulating in the country rock and granite. The coincident magnesium- and calcium-enrichment suggests addition of meteoric water to the hydrothermal solutions since meteoric waters in dolomite-bearing country rocks are commonly calcium- and magnesium-rich. The 'hydrothermal' solutions were probably initially poorer in iron, and slightly poorer in sodium, evolving toward iron- and minor sodium-enrichment. Titanium depletion occurred during the $I_G \rightarrow I_H$ (or H_2) and mostly during the $H_1 \rightarrow H_2$ fluid stages. Magma-derived solutions were the most titanium rich; early hydrothermal solutions were also titanium rich (but somewhat less); and late hydrothermal solutions were titanium depleted. The early hydrothermal fluids may have been influenced by

titanium-rich magmatic solutions, and/or by titanium-rich contact metamorphic fluids (Evans et al. 1983). Early precipitation of rutile and ilmenite caused titanium depletion in late hydrothermal tourmaline.

(iii) Metallic Mineral Association

Oliver Creek tourmaline compositions are also grouped according to metallic (non-silicate) mineral association (Figure 28) including mainly cassiterite, rutile, pyrrhotite, pyrite and chalcopyrite. Rutile coexists with tourmaline in both granite ('magmatic'), and in veins through the country rock ('hydrothermal'), explaining the wide range of tourmaline compositions for rutile-associated grains. Sulphide minerals and cassiterite are strictly associated with 'hydrothermal' tourmaline, explaining its smaller compositional range.

Tourmaline associated with sulphide minerals (only) has higher Si+Al and lower Fe/Fe+Mg. The latter is possibly due to preferential partitioning of iron into sulphides i.e., high fS_2 in the fluid. Tourmaline associated with both cassiterite and sulphides has similar composition to tourmaline from the early and intermediate hydrothermal stages (H_1 and H_2), indicating that the small amount of cassiterite associated with tourmaline was precipitated at that time. During the iron enrichment of tourmaline from the early to intermediate stages, the fluid evolved from depositing sulphides only, to depositing sulphides with minor cassiterite late in this transition (Figure 28a).

Figure 28. Tourmaline of different metallic mineral associations (schematic diagrams).

a. Graph of $\text{Fe}/\text{Fe}+\text{Mg}$ versus $\text{Si}+\text{Al}_{\text{total}}$.

Figure 28 (cont.). b. Graph of $\text{Na}/\text{Na}+\text{Ca}+\text{K}$ versus $\text{Si}+\text{Al}_{\text{total}}$.

Figure 28 (cont.). c. Graph of Ti versus Si+Al_{total}.

(iv) Other Variables

Other variables used in classifying tourmaline, such as clast type, gangue mineral association, grain size and colour, were not useful in determining fluid evolution.

Most orange tourmaline has distinctly high Fe/Fe+Mg and Na/Na+Ca+K, is relatively Ti rich (Figure 29), and is precipitated from granitic magma. The blue and green tourmaline has significantly lower Fe/Fe+Mg, Na/Na+Ca+K and Ti content, and is 'hydrothermal'. Other tourmalines have wider compositional ranges.

(c) Biotite

The general formula for biotite is:

$K_2(Mg, Fe^{2+})_{6-4}(Fe^{3+}, Al, Ti)_{0-2}(Si_{6-5}Al_{2-3}O_{20})(OH, F)_4$
(Deer et al. 1966). Thus the main chemical substitutions are Fe^{2+} , Fe^{3+} , Al and Ti replacing Mg in octahedral sites, and Al replacing Si in tetrahedral sites, usually Al:Si greater than 2:6. Minor Ca and Na may also substitute for K, and F and Cl may replace OH.

Microprobe data of 13 biotites from 4 specimens from Oliver Creek are in Appendix 6 and their major element composition is shown by a Fe/Fe+Mg versus Si+Al graph (Figure 30a). The biotite formula used in the following interpretation and diagrams is based on 40 charges with all iron assumed divalent. Biotite, relatively rare in Oliver Creek breccias/veins, was analyzed from several different host rocks and occurrence types (i.e., grains

Figure 29. Tourmaline of different colours (schematic diagram).
a. Graph of Fe/Fe+Mg versus Si+Al_{total}.

Figure 29 (cont.). b. Graph of $\text{Na}/\text{Na} + \text{Ca} + \text{K}$ versus $\text{Si} + \text{Al}$ total.

Figure 29 (cont.). c. Graph of Ti versus Si+Al_{total}.

Figure 30. Graph of major element composition of Oliver Creek biotites (Fe/Fe+Mg versus Si+Al_{total}).

30 a. Biotite from different host rocks: A = quartzite; B = granite; C = biotite latite; E = biotite breccia.

Figure 30 (cont.). b. Biotite from Oliver Creek compared with that from various localities and occurrence types (from Deer et al. 1962b).

in granite, veins in the quartzite, along the foliation in quartzite, and envelopes in schist); however, fine grain size and mixtures with tourmaline led to few good analyses. Only analyses of biotite from biotite breccia, granite and latite were reasonable. Biotite from these rocks form two main compositional fields (Figure 30b) of similar Si+Al content (8.34 to 9.03 atoms), but varied Fe/Fe+Mg (ranging from 0.54 to 0.78, atomic). Again the unaccountability of oxidized iron (Fe^{+3}) may cause some error in the amount of Si+Al total.

Within the general compositional range for biotite, including 33 biotite analyses (Deer et al. 1962b) from a wide range of localities and occurrences, the Oliver Creek biotite is generally of moderately high Fe/Fe+Mg. The Si+Al total is not strictly comparable between the two sets of data, since Deer et al.'s values are calculated on the basis of 24 anions whereas Oliver Creek's are based on charge balance. The granite-hosted Oliver Creek biotite is similar in composition to that in other granites, although somewhat poorer in iron (Figure 30b). Biotite from the Oliver Creek hydrothermal breccia has a lower Fe/Fe+Mg ratio (Table 3), closer to biotite from metamorphic rocks and less felsic igneous rocks (Deer et al. 1962b).

There are commonly 4.96 to 5.47 Si and 2.53 to 3.04 Al atoms in the tetrahedral sites. The octahedral Al is less than half the amount of tetrahedral Al (and mostly less than one quarter), ranging from 0.34 to 1.03 atoms. In the octahedral sites, iron ranges from 2.47 to 3.74 atoms, and magnesium from 0.93 to 2.15 atoms. Potassium ranges from 1.44 to 1.76 atoms.

Table 3. Average compositions of Oliver Creek biotite based on 24 negative charges and assuming all iron divalent,

Host Rock, or Occurrence Type	Atomic Formula (average)	$\frac{\text{FeO}}{\text{FeO}+\text{MgO}}$ (wt. % ratio)
biotite breccia (clasts and matrix)	$\text{K}_{1.59}(\text{Fe}_{2.52}\text{Mg}_{2.07}\text{Al}_{0.99}\text{Ti}_{0.19}\text{Mn}_{0.04})(\text{Si}_{5.37}\text{Al}_{2.63})\text{O}_{20}$ $(\text{OH}_{3.95}\text{Cl}_{0.04})$	0.55
granite	$(\text{K}_{1.71}\text{Na}_{0.03})(\text{Fe}_{3.28}\text{Mg}_{1.26}\text{Al}_{0.56}\text{Ti}_{0.37}\text{Mn}_{0.05})(\text{Si}_{5.43}\text{Al}_{2.57})\text{O}_{20}$ $(\text{OH}_{3.5}\text{F}_{0.46}\text{Cl}_{0.04})$	0.73
latite	$(\text{K}_{1.5}\text{Ca}_{0.07})(\text{Fe}_{3.74}\text{Mg}_{1.44}\text{Al}_{0.86}\text{Ti}_{0.08}\text{Mn}_{0.03})(\text{Si}_{4.96}\text{Al}_{3.04})\text{O}_{20}$ $(\text{OH}_{3.93}\text{Cl}_{0.07})$	0.72

Histograms show abundances of minor and trace elements in biotite (Figure 31). Weight percent abundances vary as follows: 0 to 0.42% CaO, 0 to 0.13% Na₂O, 0.24 to 0.54% MnO, 0.67 to 3.6% TiO₂, 0 to 1.32% F, and 0.08 to 0.28% Cl.

Compositional Variation in Oliver Creek Biotite

Figure 30a characterizes biotite according to its host rock type. Other similar diagrams using different variables are in the data file EDATA.

(i) Host Rock and Occurrence Type

A schematic diagram of the biotite's major element composition shows the separate compositional fields for different host rocks and occurrence types (Figure 32). This, in conjunction with Table 3, shows variation between 'hydrothermal' and 'magmatic' biotite. 'Hydrothermal' biotite, occurring in veins, or breccia matrices hosted in country rock, is of fairly low Fe/Fe+Mg (0.55, average weight % ratio); granite- and latite-hosted 'magmatic' biotite has higher Fe/Fe+Mg (0.73), similar to biotite hosted in granites from other localities (Figure 30). The lower Fe/Fe+Mg of 'hydrothermal' biotite compared to granitic biotite is similar to those in porphyry copper deposits (Beane 1974).

Other compositional differences between biotites of the three host rocks - granite, latite and breccia in country rock are discussed below. Granite-hosted biotite is poorer in octahedral Al (0.56 compared to 0.86 and 0.99 atoms), and richer

Figure 31. Histograms of trace and minor element content of biotite from Oliver Creek (weight percent). "f" stands for frequency, or number of samples. Samples with values below detection limit are omitted.

Figure 32. Biotite from different host rocks and occurrence types (schematic diagram). Graph of $\text{Fe}/\text{Fe}+\text{Mg}$ versus $\text{Si}+\text{Al}_{\text{total}}$.

in Ti (0.37 compared to 0.08 and 0.19 atoms) and F (0.46 compared to 0 atoms) than both latite- and breccia-hosted biotite. The latite-hosted biotite is richer in Ca (0.07 compared to 0 atoms) and Cl (0.07 compared to 0.04 atoms) than granite- or breccia-hosted biotite, possibly due to its formation through the alteration of hornblende.

These biotite compositions suggest that 'magmatic' fluids precipitating biotite in granite were more iron-, titanium- and fluorine-, and slightly more sodium-rich than 'hydrothermal' fluids and 'magmatic' fluids precipitating biotite in latite.

(ii) Paragenetic Relations

Only one biotite sample (79-67) from hydrothermal biotite breccia has crosscutting biotite veins with early and intermediate phases of biotite (Figure 33) and composition of the two are similar.

(iii) Metallic Mineral Association

The only metallic mineral associated with biotite in the granite samples is rutile. The presence of rutile along with the presence of titanium-rich granitic biotite indicate 'magmatic' fluids were titanium rich.

(iv) Other Variables

It is difficult to draw conclusions from the small number of biotite samples available. The gangue mineral association, clast type and grain size variables do not give any conclusive

Figure 33. Paragenesis of biotite compositions of Oliver Creek biotite (schematic diagram). Graph of Fe, Mg, Ti, Mn, K, Ca, Na, Fe/Fe+Mg, F and Cl versus Si+Al_{total}.

results.

(d) Cassiterite

Sixty-nine cassiterite grains (Appendix 7) from fourteen rock samples (or polished thin sections; Table 4) were analyzed for trace and minor elements, as well as for tin. The greatest content of minor elements, 5.58 oxide weight percent, is contained in sample 79-154 where zoned cassiterite grains contain high amounts of iron. This particular sample contains as much as 4.63% FeO in solid solution with Sn in dark areas of the grains. The total amount of substituting elements is more commonly in the range 0.1-1.5 oxide weight percent.

Histograms show the minor and trace element abundance (weight percent) and frequency (i.e., number of spot analyses; Figure 34). Oliver Creek cassiterite is mostly free of manganese, niobium, tungsten and silver, but some of these occur in trace quantities: commonly less than 0.05% MnO (with two samples higher - 0.11 and 0.17%), less than 0.07% Nb₂O₅ (with two samples higher - 0.11 and 0.2%), less than 0.45% WO₃, and less than 0.14% Ag₂O.

Tantalum, zirconium, titanium and iron occur in trace to minor amounts, although almost half the cassiterite samples are below detection limit in the former two. There is commonly less than 0.4% TiO₂ and FeO_T, less than 0.3% ZrO₂, and less than 0.25% Ta₂O₅. However, these elements may be bimodally distributed (Figure 34), and thus are of higher abundance in some cassiterite i.e., 0.7-1.0% TiO₂; 0.4-0.5% Ta₂O₅; 1.0-1.5%

Table 4. Average minor and trace element content of cassiterite with all iron assumed divalent. LTD indicates an analysis below detection limit.

Sample Number	Weight %							
	TiO ₂	Ta ₂ O ₅	MnO	WO ₃	FeO	Nb ₂ O ₅	AgO	ZrO ₂
13-114	0.77	LTD ₁	LTD ₂	LTD ₃	0.24	LTD ₄	0.12	LTD ₆
13-127	0.26	LTD	LTD	LTD	0.43	LTD	LTD ₅	0.70
13-144	1.05	LTD	LTD	0.12	0.31	LTD	LTD	0.59
15-78	0.19	0.20	0.03	0.09	0.65	LTD	LTD	LTD
79-24	0.24	0.16	0.03	LTD	0.13	LTD	0.10	0.19
79-30	0.15	0.18	0.04	LTD	0.07	LTD	0.11	0.20
79-32	0.11	0.38	LTD	0.10	0.21	0.07	LTD	1.16
79-74	0.32	LTD	0.02	LTD	0.07	LTD	LTD	0.17
79-77	0.25	LTD	0.03	LTD	0.22	LTD	LTD	LTD
79-113	0.09	0.13	LTD	LTD	0.07	LTD	LTD	LTD
79-118	0.09	0.42	LTD	0.09	0.44	0.06	LTD	1.08
79-127	0.09	LTD	0.02	LTD	0.08	LTD	LTD	LTD
79-139	0.08	0.13	0.04	0.08	0.40	LTD	LTD	0.30
79-154	0.51	LTD	0.03	LTD	1.18	0.04	LTD	LTD

1. Detection limit for Ta₂O₅ is 0.12%.
2. Detection limit for MnO is 0.01%.
3. Detection limit for WO₃ is 0.08%.
4. Detection limit for Nb₂O₅ is 0.03%.
5. Detection limit for AgO is 0.06%.
6. Detection limit for ZrO₂ is 0.11%.

Figure 34. Histograms of trace and minor element content in Oliver Creek cassiterite (weight percent). "f" stands for frequency, or number of samples. Samples with values below detection limit are omitted.

ZrO₂; and 1.0% FeO (with a few samples at 2-5% FeO). These trace and minor elements are not all high in the same grains.

Compositional Variation in Oliver Creek Cassiterite

Five variables were used to classify the cassiterite: grain size, shape, occurrence type, zonation position, and metallic mineral association. Histograms were used to identify each cassiterite by these characteristics. No conclusions were drawn from the first two variables; however, the others were more useful.

(i) Occurrence Type

~~Two~~ occurrence types: crystals, and fragments were identified. Fragments have lower Ti and higher Ta than crystals (Figure 35). Assuming fragmented cassiterite was deposited earlier than unfragmented cassiterite, then the solution depositing cassiterite probably evolved towards titanium enrichment and tantalum depletion.

(ii) Zonation

This parameter separates zoned grains into core and rim analyses, however only one sample (79-154) had zoned cassiterite large enough to analyze both. The rim contains slightly higher Ta and Zr, and slightly lower Fe, Mn, and Nb than the cores (Figure 36). This zonal relationship suggests that the depositing solutions evolved towards iron-, manganese- and niobium-depletion, and tantalum- and zirconium-enrichment. A

Figure 35. Histograms of Ti and Ta content in Oliver Creek cassiterite for different occurrence types: A = crystal; B = fragment. "f" indicates frequency. Values below detection limit are omitted.

Figure 36. Histograms of Fe, Zr, Mn, Ta and Nb content in Oliver Creek cassiterite for different zonation positions: B = core; C = rim. "f" indicates frequency. Values below detection limit are omitted.

possible reason for the decrease in Fe in later cassiterite is that iron was used increasingly in sulphide precipitation. No inclusions were seen through the microscope, nor on a backscatter electron image, and thus the iron is most likely in solid solution.

(iii) Metallic Mineral Association

Cassiterite associated with rutile has relatively low Ti and Mn, and high Ta, W, Fe, Nb and Zr (Figure 37). Cassiterite associated with sulphide minerals has relatively low Ta, Nb and Fe, and trace amounts of Ag. Cassiterite associated with both rutile and sulphides has low Ti and Mn, and high Ta and W. During the cassiterite + rutile to cassiterite + rutile + sulphides to cassiterite + sulphides depositional sequence, solution evolution can be traced to some extent by the changing trace element content of cassiterite. The decrease in Fe of cassiterite during this period may be due to either iron depletion of the fluid, or to an increase in the amount of iron sulphide precipitation. Ta, Nb, W and Zr also decrease in abundance in cassiterite during this evolution, possibly due to precipitation of tantalum, niobium, tungsten and zirconium in the early rutile and cassiterite; the diminishing trend suggests no replenishment of these elements in the solutions, but rather their steady depletion. Cassiterite of magmatic origin is commonly richer in tantalum, niobium, and several other trace elements (Desborough et al. 1980). The low Ti in early cassiterite may have been due to its near complete removal from

Figure 37. Histograms of trace and minor elements in Oliver Creek cassiterite for different metallic mineral association: A = none; B = sulphides; C = rutile; D = sulphide + rutile. Values below detection limit are omitted.

the solution/by precipitation of rutile. The increase of Ti in later cassiterite may be because saturation was not reached in later solutions with respect to Ti, and consequently available Ti was accommodated by diadochic minerals such as cassiterite. The later sulphide-associated cassiterite contained trace amounts of Ag, compared to values below detection in rutile +/- sulphide-associated grains. Fluids circulating in the country rocks may have been richer in titanium and slightly richer in silver than those from the granite. Perhaps the late addition of these elements to cassiterite is due to mixing of the primary fluid (of magmatic origin) with a secondary fluid (of meteoric water and/or contact metamorphic origin) richer in these elements. Another possibility is that a later magmatic fluid enriched in these elements deposited the later cassiterite.

C. MINERAL COMPOSITION PARAMETERS THAT INDICATE FLUID EVOLUTION

Several parameters of vein mineral composition indicate the trend of fluid evolution at Oliver Creek.

(1) Minerals contained in granite:

(a) biotite has moderately high Fe/Fe+Mg (0.73, average atomic ratio), Ti and F, and slightly higher Na than vein- or latite-hosted biotite;

(b) tourmaline is schorl of moderate to high Fe/Fe+Mg (0.8, average). Zoning occurs, with two main types: orange-brown, very high Fe/Fe+Mg, Na/Na+Ca+K and Ti cores, and blue rims, lower in Fe/Fe+Mg and Ti and slightly lower in Na/Na+Ca+K. The blue rims are similar in composition to 'hydrothermal' tourmaline of

intermediate age (stage 2) in breccias/veins cutting country rock, but distinctly different from 'magmatic' orange-brown cores. The compositional variation suggests that during the interval of deposition from orange-brown to blue tourmaline in granite, there was iron-, sodium- and titanium-depletion in depositing solutions.

(c) Chlorite, a deuteric mineral in the granite, is pseudomorphic after biotite with similar Fe/Fe+Mg. Some vein chlorite also in the granite is similar in composition to chlorite from veins/breccias in the country rock.

(2) Minerals contained in hornblende-biotite latite:

(a) biotite is richer in Ca and Cl than both vein- or granite-hosted biotite, possibly due to its formation by alteration of hornblende;

(b) chlorite is of relatively low Fe/Fe+Mg, similar to that of contained biotite and may be either an alteration of biotite or an 'early hydrothermal' chlorite.

(3) Minerals contained in fractures, joints, envelopes and along foliation planes in the country rock (i.e., tourmaline and chlorite) are relatively iron poor. Regional metamorphic chlorite is poorer in iron than most vein chlorite (and some in the foliation). Envelope minerals commonly formed at the expense of earlier regional metamorphic minerals, with similar compositions. 'Early' deposition of these minerals when solutions were relatively iron poor may also explain their composition.

(4) Minerals contained in breccias/veins in country rock:

(a) tourmaline is schorl/dravite, but lower in Fe/Fe+Mg

(0.6, average atomic ratio) and Al, has a wider range of Ti, and is higher in K and Ca than granite-hosted tourmaline. From early to intermediate stages, there is an increase in Fe/Fe+Mg and Na/Na+Ca+K and a decrease in Ti and F; from core to rim, an increase in Fe/Fe+Mg and F, and a decrease in Na/Na+Ca+K and Ti.

(b) Biotite is lower in Fe/Fe+Mg (0.55) than granite-hosted biotite.

(c) From rock flour breccia to the crystalline-matrix breccias there is an increase in the percentage of crystalline matrix as well as in Fe/Fe+Mg of chlorite in the matrix.

(d) There are greater amounts and more varied types of clast material (especially more types of vein material clasts) in later, higher Fe/Fe+Mg chlorite matrices.

(e) Chlorite is high Fe/Fe+Mg (over 0.8, average atomic ratio) chamosite. From early to intermediate phases there is an increase in Fe/Fe+Mg and Al, and locally in Ca and F. Cassiterite and iron sulphides were mainly deposited in the latter (high Fe) part of this transition. From intermediate to late phases there is a slight decrease in Fe/Fe+Mg.

(f) Chlorite in tourmaline breccia is relatively very iron rich, possibly due to its precipitation late in chlorite deposition (post tourmaline deposition), after tin was depleted through cassiterite deposition.

(g) Minor fluorite is associated with chlorite of low to moderately low Fe/Fe+Mg, and may have been deposited early during chlorite deposition.

(h) Cassiterite crystals carry more Ti and less Ta than

fragments, indicating titanium enrichment and tantalum depletion of the solution with time.

(i) Metallic mineral association with cassiterites indicates that cassiterite became depleted in Fe, Ta, Nb, W and Zr and enriched in Ti and Ag with time.

Summary

During deposition of the main vein minerals chlorite and tourmaline, there was a general increase in the Fe/Fe+Mg ratio with time. A slight decrease in this ratio occurred in the later stages of deposition of both tourmaline and chlorite. Iron depletion of cassiterite occurs in later phases also. In later vein tourmaline phases there is sodium enrichment. There is also calcium- and fluorine-enrichment in late chlorite phases. In general, titanium became depleted in later phases of vein chlorite and tourmaline. Later phases of cassiterite were poorer in Ta, Nb, W, and Zr, as well as in Fe and richer in Ti, and the latest phases were also richer in Ag.

Chapter 5

COMPARISON OF THE OLIVER CREEK TIN OCCURRENCE WITH OTHER
TIN DEPOSITS IN THE WORLD

The Yukon Territory and contiguous Alaska are known for tin in four areas: 1) Eastern Brooks Range - Old Crow; 2) Klondike district; 3) Cassiar district; and 4) Mayo-McQuesten district (the latter three on Figure 38). The Eastern Brooks Range has cassiterite-bearing conglomerates overlying Devonian granite which may be a 'paleoplacer' (Mulligan 1974 p. 67). Lode occurrences exist in the upper Paleozoic Old Crow Batholith (Barker et al. 1977). Tin from the Klondike district is colloform cassiterite, or "wood tin" contained in placer deposits (Mulligan 1974 pp. 67-70). The Cassiar and Watson Lake areas have tin in skarn, greisen and some vein deposits in association with large concordant Cretaceous granitic batholiths (e.g., the Seagull and Cassiar Batholiths; Abbott 1981 p. 43). The Mayo-McQuesten area has cassiterite in veins, breccias, stockwork and some replacement deposits associated with small, discordant Cretaceous biotite granite plutons. These are higher level intrusions than those exposed in the Cassiar area (Tempelman-Kluit 1981 pp. 25-26).

The Cassiar and Mayo-McQuesten stanniferous districts complete a somewhat dispersed trend of tin-bearing areas which form a belt along the western part of North America from Mexico to the western tip of Alaska (Figure 39; Sainsbury 1969). This belt is part of the larger circum-Pacific tin belt (Mitchell et

Figure 38. Map of western Canada showing tin deposits (Sainsbury et al. 1969).

- NORTH AMERICA***
- 1 Seward Peninsula, Alaska
 - 2 Manley Hot Springs, Alaska
 - 3 McQuesten-Mayo area, Yukon
 - 4 Cassiar district, Yukon and British Columbia
 - 5 Kootenay district including Sullivan mine, British Columbia
 - 6 Black Hills area, South Dakota
 - 7 Franklin Mountains, Texas
 - 8 Black Range district, New Mexico
 - 9 Chisos Mts., Coahuila
 - 10 Gorman area, California
 - 11 Santa Eulalia district, Chihuahua
 - 12 Durango-Guanajuato belt
 - 13 Southern Appalachian belt
 - 14 New Brunswick area
- SOUTH AMERICA**
- 1 Rio Grande do Norte-Paraíba, Brazil
 - 2 Northeast Coast, Brazil
 - 3 Central Coast, Brazil
 - 4 Eastern Minas Gerais, Brazil
 - 5 Rondônia-Tapajós, Brazil
 - 6 Tin belt, Bolivia
 - 7 Itapemirim, Minas Gerais, Brazil
 - 8 Encarnación, Paraguay
 - 9 Amapá area, Brazil
- EUROPE**
- 1 Cornwall, England
 - 2 Portugal and Spain
- AFRICA**
- 1 El Kant area, Morocco
 - 2 Igila, Murabitah Abu, and Daboud el Mudiha areas, United Arab Republic (Egypt)
 - 3 Dinkak area, Algeria
 - 4 Tamanrasset area, Algeria
 - 5 Illi Oumgroun area, Mauritania
 - 6 Horas area, Mali
 - 7 An area, Niger
 - 8 Tawila area, Sierra Leone
 - 9 Jos Plateau, Nigeria
 - 10 Maniema area, in belt, Democratic Republic of the Congo
 - 11 Rwanda, Burundi, Uganda, and Tanganyika (Tanzania)
 - 12 Manono-Kiloile mines, Katanga, Democratic Republic of the Congo
 - 13 South-West Africa
 - 14 Southern Rhodesia and Nyasaland
 - 15 Rooiberg-Leeuport area, Republic of South Africa
 - 16 Warmbaai area, Republic of South Africa
- ASIA**
- 1-14 Siberia, U.S.S.R.
 - 1 Altai Mountains
 - 2 Khatanga-Khatanga area
 - 3 Khatanga, East Kazakhstan
 - 4 Transbaikalia (Zabaykalsky) area
 - 5 Yana-Adyche area
 - 6 Ege-Khatanga-Oymyakon region
 - 7 Ust'-Olenyok-Belugochag area
 - 8 Baidaryn area
 - 9 Khatanga area
 - 10 Gashun area
 - 11 Khatanga-Khatanga area
 - 12 Ust'-Olenyok area
 - 13 Khatanga area
 - 14 Ust'-Olenyok-Khatanga area
 - 15 Honshu Island, Japan
 - 16 Kwangsi, Kwangtung, Hunan, and Szechwan Provinces, China
 - 17 Kachin area, China
 - 18 Gobi-Altai, China
 - 19 Hainan Island, China
 - 20 Malay Peninsula
- AUSTRALIA**
- 1 Melbourne-Coolang area
 - 2 Crook area
 - 3 Stanthorpe-Bathurst district
 - 4 New England district
- OCEANIA**
- 1 Mount Tidenburg, Albany-Eldersburg belt
 - 2 Barrier Range
 - 3 Southwest Western Australia
 - 4 Northwest Western Australia
 - 5 Northwest Tasmania
 - 6 Northeast Tasmania

*The Klondike-Creston area (not shown) north-west of the Great Lakes is expected to become an important producer of by-product tin by 1974.

Figure 39. Major stanniferous regions of the world (Mulligan 1974, after Sainsbury 1969).

al. 1972) which includes deposits in North America, South America, Australia, Japan, China, and the eastern USSR.

Classification

Several methods of classification are applicable to the Oliver Creek occurrence. Taylor's (1979) environmental classification of granitoids associated with post Precambrian mobile zones and major orogenic periods includes post orogenic emplacement within fold belts which typifies the Oliver Creek occurrence. More specifically, the tin at Oliver Creek can be classed as a deposit associated with intrusive complexes of mixed character (i.e., deep volcanic to high plutonic environment) in the "Fold Belt Type" (Table 5, part 1c). - Some features of the occurrence are similar to deposits associated with subvolcanic intrusions (Table 5, part 1b).

Using the mineralogical classification after Smirnov (1977), from Magak'yan (1968), the Oliver Creek tin occurrence is of the sulphide-cassiterite assemblage type (Hottle 1980). This category is subdivided according to conditions of mineralization; Oliver Creek is a "hydrothermal deposit of cassiterite with tourmaline, chlorite, pyrrhotite, arsenopyrite of high and intermediate temperature range related to hypabyssal and near-surface granitoid intrusions". Two subtypes: 1) cassiterite-sulphide, and 2) cassiterite-silicate (i.e., chlorite, tourmaline) were identified. Oliver Creek tin is mainly associated with chlorite and some tourmaline, and is thus of the cassiterite-silicate subtype. Sulphides are a minor component of these veins. Oliver

Table 5. Environmental Classification of Tin Deposits (Richardson 1983, after Taylor 1979).

1. OLD DIRT TYPEA. Deposits associated with acid extrusives,
pyroclastics and fumaroles.

!Mexico
!Nevada

B. Deposits associated with subvolcanic
felsic intrusives, breccias, dikes, etc.

!S. Bolivia-Ilaligua, Potosí,
Oruro, Chorolque
!Ardlethan, Australia
!Japan
!Italy
!Hale Cheng, USSR

C. Deposits associated with intrusives
complexes of mixed character, i.e.
deep-volcanic-high plutonic.

!Mt. Pleasant, N.J., Canada
!Herberton, Australia
!Transbaikalia, USSR
!Chukotka, USSR
!Yabucia, USSR

D. Deposits associated with plutonic complexes.

-Gabbro dominated

-Endocontact area
!East Kempville, N.S., Canada
!Anchar Mine, Australia
!Ergebirge-Kruusabory Mts.
-Cinova, Nub, Altonberg
!Siedorf, Ehrenfriedersdorf
!S.E. China
-Tatushan, Chui Lung Mao
!E. Mongolia
-Barun Tsogto, Tumen Tsogto

-Quartz-calcite-wollomite veins.
-Endocontact or exocontact area
-May show minor gabbro alteration

!Bastoylo, Australia
!Panasqueira, Portugal
!Hammoth-Stony Creek, Australia
!Kazakhstan, USSR
!Clifford Wood, Cornwall, England
!Mt. Wellington, Cornwall, England
!Yugodary, E. Mongolia

E. Carbonate replacement

!Kensington Bell, Australia
!Cleveland, Australia
!Mt. Bleasford, Australia
!Molau, Australia
!J.C. Yukon, Canada
!Pinnacles, Australia

F. 'Scudabound'-Massive sulfide

!Kid Creek, Ont., Canada
!South Bay, Ont., Canada
!Geco, Ont., Canada
!Koleppa Kompli, Indonesia
!Sullivan, B.C., Canada

2. NOBOGENIC SETTING

A. Bushveld type

!S. Africa
-Laeuppoort, Roodberg
Zarplaza

B. Pegmatites

!Pibara, Australia
!Greenbushes, Australia
!Manono, Congo
!Kamativi, Rhodesia
!Kika, Rhodesia

C. 'Ring complexes'-disseminations

!Migatta
!Rondonia, Brazil

Creek tin mineralization, similar to other cassiterite-silicate occurrences, is "controlled by steeply-dipping shear joints of significant extent 'along strike and in depth', consisting of 'mineralized crush zones, ...' (Smirnov 1977).

Tectonics

Granitoid intrusion in the Cretaceous in northeastern central Yukon (including the Oliver Creek plug) was a post-orogenic event following Middle Jurassic to Early Cretaceous arc-continent collision (Tempelman-Kluit 1981). This is similar to the tectonic environment of the Cornwall area, southwest England (Figure 40, part d), where tin granites formed following collision of two continents (i.e., eastern North America with Europe) during the Variscan orogeny (Baumann and Tischendorf 1978).

Mineralization Styles

Many styles of mineralization in the Cornwall area (Figure 41) are also present in the Mayo-McQuesten and Cassiar tin districts of Yukon. The Oliver Creek occurrence is similar to "lodes proper" which may, or may not extend into the granite endocontact zone. Some "pyrometasomatic tin in greenstones" also occurs at Oliver Creek (Chapter 2, Pt. B.(a)). Greisen bordered veins in granite occur in the Seagull Batholith, and tin-bearing skarnified limestone is located adjacent to it (the J.C. property; Abbott 1981). Swarms of tungsten-molybdenum-tin quartz veins (stockwork) occur in thermally metamorphosed

Figure 40. "Suggested tectonic environments for various tin provinces" (Taylor 1979, selected from Mitchell et al. 1976)

Figure 41. Diagrammatic representation of primary tin deposits in the south-west of England, Cornwall (Taylor 1979, after Hosking 1969).

sediments in the Kalzas Lake area south of Mayo (Lynch 1984). Similar mineralization styles to those in Figure 41 are also found in southeast Asia (depicted by Hosking 1970).

Tin Deposits with Similar Characteristics to the Oliver Creek Occurrence

Noble (1980) describes several tin deposits which have similar characteristics to the Oliver Creek tin occurrence; the Ege-Khayd Deposit, Yakutian, USSR; Kellhuani, Bolivia; Mount Wellington Mine, Cornwall, England; and Dublin Gulch (more correctly Ray Gulch), Yukon, Canada. All these deposits occur in breccia composed of rigid (brittle) host rock and are genetically related to hypabyssal, or near-surface granitic intrusions. They are all in the exocontact zone of these intrusions, within 5 km of the exposed pluton.

The Oliver Creek tin occurrence and several other much larger tin deposits of the sulphide-cassiterite type are described in Table 6, including metals contained, geological setting, style of mineralization, ore and gangue minerals present, alteration and mineral or metal zonation and paragenesis (where identified).

Metals

The Oliver Creek breccias/veins contain Sn, Ag, Zn and Cu, but little associated W, similar to many Bolivian deposits. Many of the deposits outlined have associated base metals and are referred to as polymetallic tin ores. The paucity of W in the

Table 6. (Abbreviations for Table 6)

Rock Names			
QT	quartzite	MARB	marble
SH	schist	APH	amphibolite
CALC	calc-silicate rock	CRX	country rocks
GRAH	granite	APL	aplite
LAT	latite	INTR	intrusive rocks
HNFLS	hornfels	VN	vein
Mineral Names			
QZ	quartz	CT	cassiterite
CL	chlorite	RU	rutile
BI	biotite	ILM	ilmenite
TO	tourmaline	SX	sulphides
MJ	moscovite	GL	galena
MI	mica	SL	sphalerite
LI	limonite	CP	chalcocopyrite
SER	sericite	PY	pyrite
CB	carbonate	PR	pyrrhotite
CC	calcite	ASP	arsenopyrite
MAL	malachite	BIS	bismuthinite
AZ	azurite	BMSX	base metal sulphides
FL	fluorite	H,WOLF	wolframite
FS	feldspar	MARC	marcasite
KAOL	kaolinite	ST,STAN	stannite
TOP	topaz	MO,MOLY	molybdenite
MG,Marg	margarite	WIT	wittichenite
Andrad.	andradite	DICK	dickite
GT	garnet	IDO	idocrase
AB	albite	PHL	phlogopite
TREM	tremolite	EP	epidote
DOL	dolomite	ZINN	zinnwaldite
BE	beryl	APH	amphibole
STD,SD	siderite		
Other Abbreviations			
dissem.	disseminated	stkw	stockwork
phionit.	phionitization	sericit.	sericitization

Oliver Creek deposit may be due to zonation (possibly a W-rich zone is located deeper in the system).

Geological Setting

All of the deposits in Table 6 have similar geological settings; the country rock commonly consists of terrigenous, brittle sedimentary or carbonate rocks, and the intrusive is post-orogenic granite (Cretaceous or Variscan, and in one case, Upper Devonian age).

Style of Mineralization

The major style of mineralization is lode tin, with veins, stockwork, mineralized "crush zones", or hydrothermal breccias most common, and minor replacement, skarn and greisen in a few deposits. Breccias/veins and replacement type mineralization occurs at Oliver Creek.

Metallic Minerals

Cassiterite is most commonly the only potential ore mineral; silver occurs as the native element, freibergite, and Ag-rich galena; and arsenopyrite, sphalerite and chalcopyrite are common in many of these tin deposits. At Oliver Creek, cassiterite is the only tin mineral, native silver, sphalerite and chalcopyrite are common, and arsenopyrite is not overly abundant, but locally is associated with silver.

Gangue Minerals

Many of these deposits have abundant chlorite and tourmaline as the major gangue minerals present. Chlorite is the major gangue for the tin-bearing breccias at Oliver Creek. Several of the deposits have quartz accompanying, or intergrown with these minerals e.g., the Geevor Mine, Cornwall and the Renison Bell Mine, Western Tasmania. At Oliver Creek the quartz is earlier than the cassiterite stage, and is barren. Carbonate veins crosscut the ore veins of many deposits, similar to Oliver Creek.

Alteration and Zonation

Pervasive alteration and/or greisenization which may or may not be stanniferous are common in the cupola regions of granitic intrusions underlying tin lodes or stockwork. Sericitization, chloritization and kaolinization are most common. A granite below the Oliver Creek tin mineralization has not been intersected in drilling and its possible alteration is thus unknown. The granite exposed to the northwest is fairly fresh with minor sericitization of plagioclase and chloritization of biotite. Locally tourmaline, fluorite and muscovite are present in the interstices of the granite.

In several deposits there is a definite zonation of alteration types (Figure 42a). The only pervasive-type alteration zonation at Oliver Creek is the zone of pervasive biotite (or hornfels), also mentioned in the descriptions of some lode tin areas (i.e., Rudnoe and other deposits in the USSR, Smirnov 1977; and Renison Bell, Tasmania, Patterson et al.

Figure 42. Illustration of the vertical zoning in the Kapcherang tin deposit, Transbaikalia, U.S.S.R. (Taylor 1979, from Mel'nicov 1965).

Figure 43. Zonal and temporal distribution of the successive mineralization phases in Geevor Tin Mines, Cornwall (Garnett 1963a).

1981). At Oliver Creek, wall-rock alteration is common in the overlying country rock (i.e., chlorite and quartz envelopes), similar to many tin lode deposits (e.g., Cornwall).

Some zonation of vein types is evident at Oliver Creek: a deep zone of tourmaline veins and a shallower zone of chlorite veins. Although these vein types are zoned, there is a definite lack of zonation of mineral compositions of chlorite and tourmaline (i.e., Fe/Fe+Mg change with depth). A shallow zone of kaolinite filled fractures with limonite and manganese-oxide staining occurs at the surface with chlorite veins. Calcite veining is only present in deep zones, probably due to surface leaching. This zonation is similar to that in the Erzgebirge area, Czechoslovakia (Table 6 and Figure 42b) except at Oliver Creek, greisen below has not been intersected.

Metal zonation is also prominent, from an Fe(Cu) tourmaline zone to a Sn-Zn-Cu(Fe) chlorite zone. This is vaguely similar to the metal zones at Cornwall i.e., from the Cu to the Pb-Zn zone (Figure 42c). These metal and vein mineral type zones at Oliver Creek, however, are general, as telescoping of the vein types has altered the zone boundaries, causing overlap.

Metal zonation also occurs at the Kaperchang tin deposit in Transbaikalia, USSR (Mel'nikov, 1965), located in the exocontact region of a granite pluton (Figure 43) somewhat similar to that at Oliver Creek i.e., minor Sn with iron-sulphides in the tourmaline zone to tin, zinc and copper in the chlorite zone. However, the Kaperchang's main gangue mineral is quartz (Mel'nikov 1965), whereas at Oliver Creek it is chlorite.

Mel'nikov's opinion on formation of the zoned deposit is that "in individual cases the ore emanations ascended from the magmatic chamber towards the surface, uninterruptedly changing their composition in the course of the cooling of magma. In near-surface conditions polyascendent zoning was manifest as a result of periodical reopening of tectonic fissures and precipitation of ore components from solutions of changing composition."

Paragenesis

Several deposits have paragenetic mineral successions similar to the Oliver Creek deposit (i.e., from deposition of quartz to tourmaline, to chlorite, cassiterite and sulphides, to calcite and fluorite, and to limonite and other supergene minerals); an example is the Geevor Mine, Cornwall, England (Figure 44). This is comparable to the Oliver Creek mineral paragenesis (Figure 13), except that quartz and tourmaline phases are mostly barren of tin at Oliver Creek. Phases 1, 6, 7, 8, 10 and 12 of the Geevor Mine's paragenesis are present at Oliver Creek with slight variations and a few additions.

Many of the other deposits (described in Table 6) have similar paragenetic relations. Erzgebirge, Czechoslovakia, a famous tin province, has tourmaline-cassiterite to chlorite-cassiterite to sulphide-cassiterite vein phases (Baumann et al. 1978). This resembles the mineral paragenesis at Oliver Creek, except that the latter phase is also associated with chlorite.

Several deposits have early tin deposition with later sulphides and some overlap, such as the Rudnoe Deposit, USSR

Figure 44. Zonal and temporal distribution of the successive mineralization phases in Geevor Tin Mines, Cornwall, England (Garnett 1963a).

(Smirnov 1977 pp. 279-285) and the Bolivian deposits (Kelly et al. 1970). The order of sulphide deposition at the Rudnoe (from Fe(Cu) to Ag-Pb sulphides) and Renison Bell (from Sn-Fe-As-Cu to Pb-Zn-Cu-Fe) deposits are similar to that at Oliver Creek (from Fe(Cu) to Zn-Cu, to Zn-Pb sulphides). Silver is commonly paragenetically later than tin and is associated with zinc-lead mineralization (e.g., Cornwall) which may also be true at Oliver Creek. The silver at Cornwall is farther from the heat source than the tin mineralization, whereas at Oliver Creek it is possibly telescoped over the same place.

Late carbonate and fluorite is also common in the Rudnoe Deposit, USSR, at Renison Bell, Tasmania, and in the Bolivian deposits, as well as at Oliver Creek. Late clay mineral deposition occurs at Oliver Creek and also at the Rudnoe Deposit, USSR and the Lost River Mine, Alaska.

The cryptic variation of mineral compositions (i.e., the change in chlorite or tourmaline composition with time) at Oliver Creek is similar to that from other tin deposits. The general increase in Fe/Fe+Mg of later chlorite and tourmaline (the main vein minerals) also occurs in minerals from tin-bearing skarns. Einaudi et al. (1981) discussed the trend of increasing Ca and Fe with decreasing Mg in successive mineral phases present in tin-bearing, calcium-rich skarn rocks. This reinforces the hypothesis that the solutions forming the veins/breccias at Oliver Creek were magmatic late stage fluids which evolved similarly to fluids in other similar tin-rich systems.

Physico-chemical Parameters of Ore Deposition

No fluid inclusion or isotope data are available on vein minerals from Oliver Creek; however, through comparison with other similar, although much larger tin deposits which do have this type of data, an estimate is made on the range of temperature and depth of formation that one would expect this tin occurrence to have formed.

Pressure

Varlamoff's (1978) compilation of calculated depths of formation of various tin deposits from several authors' works is summarized in his table (Table 7). The Oliver Creek stanniferous breccias, with tourmaline and chlorite gangue, and associated with a hypabyssal to subvolcanic granite intrusion are compared with other similar deposits. According to Varlamoff's table, the possible range of depth of formation of the cassiterite-chlorite veins at Oliver Creek is between 500 m and 3000 m and the text of his report concludes that "cassiterite deposits associated with silicates (tourmaline, topaz, chlorite) are located between depths of 1000 m and 2500 m". Above 3000 m in depth, open fractures are common, and extend over long vertical and horizontal distances. They provide a rapid drop in pressure and narrow channels through which hydrothermal solutions can escape. The temperature of solutions in these narrow channels also very quickly reaches that of the enclosing country rock allowing rapid deposition of metals.

Tin deposits of central and southern Bolivia, according to

Table 7. (Legend)

- (1) rhyolites; (2) volcanic vents; (3) veins in general with various amounts of quartz and other gangue minerals; (4) albitized granites; (5) greisenized granites; (6) quartz cappings; (7) quartz veins; (8) albitized pegmatites with cassiterite, columbo tantalite and small, centimetric prisms of beryl; (9) poorly zoned pegmatites with quartz core, beryl in big prisms, important concentration of amblygonite and spodumene; (10) albitized pegmatites with small prisms of beryl; (11) zoned pegmatites; (12) metasomatic pegmatites

the stratigraphic record, were formed at depths of 350 to 2000 m and total pressures of 30 to 500 bars (Kelly et al. 1970). In Bolivia, the deeper, plutonic-associated deposits of the Cordillera Real are estimated to have formed at depths of 2000 to 4000 m and pressures of 190 to 1000 bars. The Oliver Creek occurrence is probably more similar to the deposits of central and southern Bolivia, although fewer coeval volcanic rocks are exposed than in Bolivia.

Temperature

Detailed fluid inclusion and isotope data are available for the Bolivian tin deposits (Kelly et al. 1970; and Grant et al. 1980), and for the Renison Bell deposit, Western Tasmania (Patterson et al. 1981). At Bolivia, the vein mineral paragenesis and environment of formation are similar to that at Oliver Creek (Table 6). An early tin-tungsten vein stage was followed by a sulphide stage, and later carbonate-fluorite. Tin-bearing fluids of the first stage were NaCl-rich (as much as 46 weight %) brines of low CO₂ content. The temperature of these presumed magmatic fluids ranged from 300° to 530°C during this stage (Kelly et al. 1970). Active boiling of these early vein fluids favoured quartz and cassiterite precipitation. Later ore fluids were more dilute, and gradually approached fresh water composition during closing stages of mineralization, with temperature declining to less than 70°C in the later stages. The main sulphide stage was formed at temperatures of 400° to 260°C; the later sulphide-siderite stage at 260° to 200°C;

late fluorite formed at 200° to 133°C; and late hydrous phosphate minerals formed below 70°C.

At Renison Bell (Table 6), the vein mineral paragenesis and environment of formation is also similar to Oliver Creek. Fluid inclusion, mineralogical and stable isotope data show that temperature inferred for cassiterite, silicate and sulphide stages 1 to 3 are about 350°C, for galena, sphalerite, silicates, carbonates and fluorite of stage 4 - 300°C, and for stage 5 carbonates, quartz, fluorite and sulphides - 250° to 150°C (Patterson et al. 1981). Stages 1 to 4 were deposited by Na-K-Cl brines (magmatic) and stage 5 by fluids even more saline. Cassiterite-bearing stages 1 to 3 and sphalerite-galena of stage 4 were formed at low fO_2 , fS_2 and pH. Oxygen and hydrogen isotopes indicate the stage 1 to 3 mineralizing fluids to be an exsolved magmatic aqueous phase. "Water from a different source, probably heated contemporary groundwater, is inferred for later stages" (Patterson et al. 1981), with some mixing of the two fluids possibly occurring in stage 3. From S isotopic evidence, the major source of sulphur for the fluids was the Pine Hill granite.

Physico-chemical data provided for these two deposits gives us an estimate of the conditions of formation of the Oliver Creek occurrence. This is only an approximation, as both deposits are much larger and no fluid inclusion data are available from Oliver Creek. Since there are no carbonate minerals early in the paragenesis, the CO_2 which was likely generated during contact metamorphism must have escaped. Early barren quartz was likely

deposited by hydrothermal solutions rich in silica, probably contact metamorphic and/or meteoric solutions. The first stages of mineralization, especially the tourmaline and cassiterite stages, were likely deposited by exsolved magmatic fluids of fairly high temperature (probably on the order of 300° to 400°C). These fluids may have been saline and acidic. The following stage of chlorite-cassiterite, with later sulphides associated, may have been deposited from slightly cooler solutions. These were either more evolved magmatic solutions, or a mixture of magmatic with some meteoric (lower temperature) hydrothermal solutions (temperature range of approximately 250° to 300°C). Stage 5 - calcite-fluorite was probably deposited by even cooler solutions (150° to 200°C) which were likely a meteoric-magmatic water mixture. These were likely less saline than the early magmatic fluids, and alkaline. The final supergene alteration was probably formed from low temperature (less than 100°C) acidic groundwater.

Chapter 6

MODEL OF FORMATION AND SUMMARY

Probable steps in formation of the tin-bearing breccias are summarized below (Figure 45).

(1) In the Mid Cretaceous, a granitic intrusion was emplaced into the regionally metamorphosed (greenschist facies), cataclastically deformed (Early Cretaceous) sedimentary rocks of the Hadrynian Grit Unit. The pluton was emplaced at a shallow depth (less than 3000 m), and may have been the source of coeval felsic lavas (exposed near Minto Lake). Sedimentary rocks were thermally metamorphosed and formed an andalusite porphyroblastic aureole; parts of the intercalated limestone and amphibolite were skarnified. Early CO_2 generated by this contact metamorphism escaped. Subsidence (on cooling) caused brittle fracturing and faulting of the overlying country rock. These fracture zones localized most of the rock flour breccias (quartzite fragments in a small amount of rock flour matrix). Refracturing, during later brecciation related to granite crystallization and fluid overpressures, probably used the existing fracture zones.

(2) Heat from the intrusion caused convection of groundwater contained in the overlying country rock, especially through the major conduits (fracture zones). Rock near the intrusion was pervasively altered (no relics of the original porphyroblasts) and formation of the biotite alteration zone probably resulted in release of silica. Hot, silica-rich, acidic groundwater was

Figure 45. Model of formation of the Oliver Creek tin-bearing breccias and veins
(see text for description).

transported to near-surface where it deposited quartz (mostly barren) in envelopes, veins and in the matrix of breccias, and sealed fractures - the first stage of hydrothermal alteration. It also caused the formation of calc-silicate rocks from dolomite, a transformation which made CO_2 and Mg available to meteoric waters.

While the granite solidified, more differentiated, residual magmas were formed, and fluids and volatiles exsolved from the rest magma, collecting in the upper part of the intrusion. Evidence that the late phases of magma contained abundant volatiles is in the presence of zoned tourmaline grains within some of the granite. Some of the residual magma intruded into fractures in the contact zone of the pluton and were quenched, forming tourmaline-bearing Na-rich aplite dykes. These further acted to seal off the intrusion.

(3) Once the fluid pressure within the intrusion exceeded the lithostatic pressure plus the tensile strength of the enclosing rock, the magmatic solutions hydraulically fractured the carapace of the intrusion and moved into the country rock. A tectonic overpressure (e.g., faulting) could also have caused escape of the solutions in the same manner. The solutions were localized by fracture zones already present in the country rock and subsidiary fractures and foliation planes causing alteration of favourable horizons, such as the marble, calc-silicate rock and amphibolite. Rebrecciation and fracturing of the fault breccia and country rock also occurred at this stage due to fluid overpressure. These breccias were likely formed between depths

of 1000 m and 2500 m. The great decrease in fluid pressure, from lithostatic to nearly hydrostatic, accompanied by the rapid temperature drop of the fluids, caused the precipitation of metals contained in the solution as crystalline matrices in breccias (fracture zones). The decrease in silica and increase in water associated with the influx of magmatic solutions rich in boron, tin and base metals resulted in the paragenetic change from quartz to tourmaline, to chlorite, sulphides, silver and cassiterite.

Many crosscutting phases of mineralization indicate that there were many episodes during the crystallization of the intrusion which supplied volatile-rich solutions to the fracture zones. These solutions evolved in composition with time and resulted in the deposition of tourmaline (of several compositions), pyrrhotite, pyrite, chalcopyrite, sphalerite, cassiterite, silver and early to intermediate stages of chlorite. The high temperature fluids (300° to 400°C) had fairly high B, Na, Fe, Cu, Zn, Ag, Sn and Ti contents, and minor amounts of Ta, Nb, W and Zr, according to the composition of granite-hosted biotite and tourmaline, and country rock-hosted tourmaline, chlorite and cassiterite. Tin was likely carried in solution in a fluoride complex such as SnF_4 , as proposed by Hosking (1972). The magmatic solutions probably evolved toward enrichment in water, causing minerals of higher water content to be precipitated, hence the change from tourmaline to chlorite. During tourmaline deposition, the fluids evolved toward iron- and sodium-enrichment, and titanium depletion, and during chlorite

deposition, they continued to be enriched in iron, and also became tin-, silver-, base metal- and sulphur-enriched.

During cassiterite deposition, fluorine content became enriched in the residual solutions because of the breakdown of SnF_4 . When fS_2 became high enough, sulphides were precipitated, causing a slight iron depletion in late fluids. Silver was also deposited in the later stages of chlorite deposition by late magmatic and/or meteoric solutions. Early deposition of rutile may have depleted late solutions in Ti, or the fluid's source may have been depleted by 'flushing out' of early Ti-rich fluids. These could both account for the slight Ti decrease in both later tourmaline and chlorite.

(4) The magmatic solutions eventually mixed with meteoric and/or contact metamorphic solutions which were probably rich in CO_2 and Ca (due to leaching of the country rock). Minerals deposited from this mixture were relatively richer in these elements e.g., late phase chlorite. These mixed solutions were cooler than the magmatic fluids (probably on the order of 250° to 300°C).

An increase in trace Ti, and a decrease in Ta, Nb, W and Zr from early to later cassiterite is due to the increasing influence with time of meteoric and/or contact metamorphic fluids. This is consistent with results of Desborough et al. (1980) which indicated that higher Ta and Nb were indicative of magmatic cassiterite.

(5) Ultimately, the convection system became sealed off from the intrusion (i.e., no further input of magmatic fluid) and solutions became increasingly more alkaline, and cooler (probably

about 150° to 200°C) because of country rock/solution interaction. The residual solutions enriched in Ca, CO₂ and F, possibly due to groundwater interaction with carbonates, deposited calcite-fluorite.

(6) Later supergene alteration by cool (less than 100°C), acidic groundwater caused formation of limonite, manganese oxide, kaolinite and malachite-azurite staining in the same main fracture zones of the country rock, mostly close to surface.

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APPENDIX 1

WHOLE ROCK ANALYSES

Part A. Amphibolite

Oxide	Sample Number (weight %)			
	14-28	19-95	20-14	20-32
SiO ₂	40.71	44.91	45.66	42.83
Al ₂ O ₃	11.59	15.13	14.34	10.79
Fe ₂ O ₃	27.62	14.07	11.36	14.26
MgO	2.32	6.22	8.33	16.96
CaO	13.54	11.31	10.99	9.25
Na ₂ O	0.87	2.27	2.48	0.36
K ₂ O	0.79	1.05	0.44	0.24
TiO ₂	0.50	1.64	1.26	1.17
P ₂ O ₅	0.00	0.90	0.47	0.56
MnO	0.43	0.20	0.25	0.25
S	0.01	0.05	0.01	0.00
(ppm)				
Ba	24	324	113	93
Cr	86	177	317	752
Zr	62	101	91	68
Sr	140	921	802	139
Rb	6	103	29	13
Y	19	22	21	24
Nb	11	24	13	23
Zn	309	160	179	272
Ni	53	17	64	548
(weight %)				
Total	98.46	97.97	95.78	97.13
K/Rb	1154.86	84.64	124.3	157.25
Rb/Sr	0.04	0.11	0.04	0.09
Ba/Sr	0.17	0.35	0.14	0.67

X-ray fluorescence, program IS30, University of Ottawa laboratory,
Ottawa, Ontario, analyses by R. Hartree (technician).

Part A (cont.)

Element	Trace Elements					
	Sample Number					
	(ppm)					
	14-28	19-95	20-14	20-32	13-60	13-60.4
Pb	41	13	10	6	21	58
Th	16	7	6	5	41	23
U	5	0	2	6	9	5
Rb	16	109	33	21	772	25
Sr	127	915	832	120	26	13
Y	30	27	23	25	11	23
Zr	88	92	88	85	69	134
Nb	21	35	25	28	14	15
Zn	330	168	180	259	250	343
Cu	0	192	0	1	1473	484
Ni	20	75	179	660	23	3
La	15	20	16	20	26	29
Ba	31	348	136	139	167	57
Ti	3900	13 500	10 900	10 900	3700	2600
V	70	252	230	211	52	31
Ce	31	39	32	36	31	40
Cr	58	152	320	778	37	33
Ga	8	11	18	13	58	34

X-ray fluorescence, program IS30, Memorial University of Newfoundland laboratory, St. John's, Newfoundland.

Part B. Granite, Aplite and Hornblende-biotite Latite

Oxide	Sample Number (weight %)					
	D-3-7 (granite)	D-3-8 (aplite)	D-3-10 (granite)	D-3-12 (granite)	6-34 (latite)	19-32 (latite)
SiO ₂	69.53	73.94	74.43	72.47	58.68	58.62
Al ₂ O ₃	14.18	14.39	13.09	13.18	13.85	13.83
Fe ₂ O ₃	3.72	1.81	1.86	1.45	7.08	6.67
MgO	0.64	0.29	0.12	0.18	5.59	5.56
CaO	1.85	0.39	1.23	1.13	4.32	6.24
Na ₂ O	2.62	5.52	3.08	2.48	1.54	1.88
K ₂ O	5.14	0.55	4.64	6.76	4.99	4.34
TiO ₂	0.64	0.04	0.20	0.12	0.75	0.69
P ₂ O ₅	0.44	0.06	0.11	0.05	0.74	0.57
MnO	0.05	0.04	0.04	0.04	0.29	0.14
S	0.00	0.00	0.00	0.01	0.00	0.00

(ppm)

Ba	1476	80	387	1679	2115	1763
Cr	220	161	163	134	337	349
Zr	212	27	91	37	149	152
Sr	293	100	118	182	457	541
Rb	334	78	379	450	261	223
Y	25	80	36	8	25	21
Nb	32	101	31	4	7	10
Zn	37	49	44	90	297	423
Ni	16	10	4	5	38	29

(weight %)

Total	99.12	97.12	98.95	98.16	98.26	98.96
K/Rb	127.72	59.23	101.44	124.75	158.77	161.67
Rb/Sr	1.14	0.78	3.22	2.47	0.57	0.41
Ba/Sr	5.03	0.80	3.28	9.22	4.63	3.26

Mineral (normative weight %)

or	30.64	3.34	27.29	40.10	29.52	25.62
ab	22.01	46.64	26.20	20.96	13.10	15.72
an	6.39	1.67	5.28	4.73	16.12	16.68
qz	30.59	38.28	35.88	29.45	13.82	12.26

X-ray fluorescence, program IS30, University of Ottawa laboratory,
Ottawa, Ontario, analyses by R. Hartree (technician).

Trace Elements

Element	Sample Number (ppm)					
	D-3-7 (granite)	D-3-8 (aplite)	D-3-10 (granite)	D-3-12 (granite)	6-54 (latite)	19-32 (latite)
Pb	20	13	37	28	261	25
Th	42	14	37	22	22	20
U	12	18	10	0	6	13
Rb	318	69	361	426	255	219
Sr	277	97	110	178	434	542
Y	34	87	51	11	31	27
Zr	243	28	103	35	179	186
Nb	45	119	41	10	15	15
Zn	30	37	30	75	271	410
Cu	7	0	5	7	40	37
Ni	2	4	0	3	52	64
La	45	0	17	16	20	24
Ba	1549	63	403	1654	2044	1631
Ti	6200	500	2000	1300	7000	7000
V	38	5	11	10	182	178
Ce	79	0	29	23	44	36
Cr	197	175	155	118	369	372
Ga	19	21	18	10	14	15

X-ray fluorescence, Program IS30, Memorial University of Newfoundland laboratory, St. John's, Newfoundland.

APPENDIX 2

PETROGRAPHY OF SELECTED BRECCIA/VEIN SAMPLES (abbreviations at end of appendix)

ROCK FLOUR BRECCIA

SAMPLE NO.	% of Rock	% Mineral	MATRIX Grain Size	Texture	Frame-work	Sor-ting	CLASTS Rounding	Type	REMARKS	PARAGENESIS
13-30-127.3	10-15	30 RKFL 30 CL 20 BI 10 PY 2 CT 3 MU 5 LI	fine to med.	shattered - little movement - thin BR zone - small PY cubes	closed	poor	moderate to well	100 OT	CT with as- soc. PY -PY along late frac's stained with LI & assoc. with MU	RKFL → BI+RU → CL+CT → CT+PY+MU → LI
13-32-135	20-30	30 RKFL 20 CL 30 MU 10 RU 10 TO	fine	shattered & ground-up	closed to open	poor	moderate	50 QT 40 VMU & BRMU 10 VCL	Some QT fragments are rimmed by CL -part of the rock is BRCL	BRK → CL+RU → TO → MU → BRK → LI
14-73.6	20	70 RKFL 20 CL 10 MU 1 ZR	fine (CL - minor medium)	shattered & ground-up	closed	poor	moderate	90 QT 10 VNCL	3 different breccia phases - 2 separate generations of CL (a green phase, and a brown green phase)	BRK → CL ₁ → CL ₂ → MU
18-19-84	5-10	65 RKFL 10 BI 2 CT 20 LI 5 Opaques (TLM)	fine to medium	shattered (not much movement) - anhedral opaques -small equant subhedral CT	closed	poor	moderate	95 QT 5 VN	some clots of chlorite on sides of fragments	OZ → RKFL → BI + CT → LI

79-36 5 100 RKFL fine CL pods with associated ilmenite closed poor poor 70 VQ 30 QT abundant CL pods with coarse grained Cl QZ → BRBK → CL → QZ (late veinlets)

QUARTZ BRECCIAS

SAMPLE NO.	% of Rock	% Mineral	MATRIX Grain Size	Texture	Frame-work	Sorting	CLASTS		REMARKS	PARAGENESIS
							Rounding	Type		
13-159.5	70	50 QZ 25 CC 10 FL 10 CL 5 SX (SL-GL-CP)	coarse	FL in centre of QZ vein cut by CC -euhedral to subhedral FL -SX assoc. with CL	open	poor	moderate	90 QT 10 VQ	BRCC cuts BRQZ with FL	QZ → CL+SX → MU → FL → CC
13-162	60-70	100 QZ	coarse	minor PY cubes in QT fragments -v. coarse eu- to subhedral QZ grains -minor CL in cracks of QZ crystals -also late CC in cracks -PY cubes in QZ veins	open	poor to mod.	moderate to well	70 NT 30 BRBI	Borders of some frag. are clay coated -some clasts of BRBI -minor BI in QT	BI → QZ+PY → CL → CC
14-23-101	60	100 QZ	coarse (and minor medium grained)	eu- to subhedral QZ grains	open	poor	moderate to well	20 NT 80 SHBM	some SHBI is altered to CL	RU → CL → QZ

TOURMALINE BRECCIAS

SAMPLE NO.	% of Rock	% Mineral	MATRIX Grain Size	Texture	Frame-work	Sor-ting	Rounding	Type	REMARKS	PARAGENESIS
5-12-69	40	70 TO 20 CL 10 MU	fine to medium	sub- to euhedral, elongated TO	open	poor	moderate to well	20 VT 60 QT 20 VQ	Clast of BRRK	OZ → BRRK → TO ₁ → TO ₂ +CL → MU → LI
14-93	20	85 TO 10 PY 3 access. (ZR, RU, IL, AP, PR, CP, SL) 2 CL	fine to medium	some tiny needles of TO -coarser grained veins of TO	closed	poor	moderate	90 OT 10 TO (coarse)	ANK veining replacing SX -2 gen. of IO	PY+TO ₁ → TO ₂ +CL → BI(+HE) → PY+CB → CB(ANK)
14-21-94	50	60 TO 20 CL 10 CP 5 RU 5 SL	fine to medium	CL is cutting TO of which there is more than one generation -CP is assoc. with late TO in veins	open	poor	sub-angular	40 VT 60 QT	crosscutting TO veinlets cutting TO clasts CL - large crystals which are bordered by SL (small)	OZ → TO+RU → TO ₂ → CL → SL
19-141	20	70 TO 7 CL 3 MU 7 SL 3 RU 1 ZR 10 BI	fine to coarse	coarse grained clasts & truncated TO veins -TO ₂ is mostly fine grained	closed	poor	moderate	80 QT 5 VQ 15 TO	2 gen. of TO QT → TO ₁ +ZR → & BI cuts TO TO ₂ +RU → BI → CL (+SL) → MU	

19-143.5	10	55 T0 30 CL 10 MU 5 CP, SL, RU	medium	tourmaline altered to chlorite -CP+SL with CL-MU	closed	poor	moderate to well rounded	95 QT 5 VQ	clasts are veined with T0 -CC veins cut every- thing	QZ → T0+RU → CL+SX → MU → CC
19-145	50	80 T0 10 CL 5 SL 5 MU	fine to medium	eu- to sub- hedral T0 when coarser grained -radiating coarse MU & CL -CL-MU veins cut T0	open	poor	sub to well- rounded	70 VQ 30 QT	corroded edges of V0 clasts -2 gen. of T0 -MU over- grows CL	QZ → T0 ₁ → T0 ₂ +CL (minor) → CL (+SL+CP) → MU (later alteration of T0)
19-147	40	85 T0 10 CL 1 SL 5 MU 1 RU	fine to coarse	eu- to subhedral T0	open	poor	subrounded	90 QT 10 T0 (coarse)	several gen. of T0 (at least 3)	Brown T0+RU → Blue T0 → T0+RU → CL+SL → MU
20-197.5	60	5 T0 15 PR 2 CP 2 SL 1 CT 5 CL	medium to coarse	coxcumb texture of T0 on sides of veins -pods of CL contain- ing SX	open	poor	moderate	60 QT (with dissem. PR+MU) 40 SHMU	veining BR -QT is very micaceous (MU) -PR is assoc. with MU in QT	(T0+PR+SX+CT) +CL → CL+MU

20-50-254	40-50	90 T0 10 FL	fine	clasts of VT are coarser grained aggregates (med.) -FL clasts (some is adj. to QZ, attached onto QZ grains) -some FL as clasts & some as cross-cutting veins	open	poor	sub- angular	30 VQ 50 QT 10 VT 10 VFL	some VQ clasts with VT also assoc. -similar texture to a BRRK with altered matrix (T0)	QZ → FL → T0 ₁ (coarse) → T0 ₂
79-45	30	75 T0 20 MU 5 CL	med. to fine	zoned T0 crystals	closed	poor	moderate	30 QT 30 VT 40 VQ	corroded edges of frags -cut by BI + HE	QZ → T0 ₁ (coarse) + RU → T0 ₂ (fine) -SER-RU → CL + MU → QZ-HE-BI
79-48	30	85 T0 5 CL 10 MU	fine (tiny needles of T0)	a few coarse crystals -coarse MU + CL -MU appears later than CL	closed	poor	moderate	50 VQ 50 QT	corroded frag. edges -some MU intergrown with T0, some cross- cuts it	QZ → T0 + MU → CL → MU

BIOTITE AND MUSCOVITE BRECCIAS

SAMPLE NO.	% of Rock	% Mineral	MATRIX Grain Size	Texture	Frame-work	Sor-ting	CLASTS Rounding	Type	REMARKS	PARAGENESIS
13-31-133	35	55 BI 25 CL 5 RU 15 LI + HE	fine (BI) to med. (CL)	-small sub-hedral CT intergrown with CL (not just fragments)	closed	poor	moderate to well	100 OT	several cross-cutting stages of brecciation	OZ → BI → OZ → CL+CT+RU → LI+HE
17-15-92	40	80 MU 17 CL 1 CT 2 Zincite	fine to med.	some CL pods	open	poor	moderate to well	20 VCL 10 VQ 30 QT 20 BRCL 20 SHMU	BRMU is cut by QZ+FS veins	QZ → CL ₁ → MU (+CL ₂) → FS → QZ → MN +LI
17-41.8	50	70 MU 30 CL	fine	some coarse grained clots of radiating CL crystals	open	poor	moderate to well rounded	10 VCL 40 VQ 10 QT 20 SHMU 20 SHCL (retrograde after BT)	MU schist is altered & cut by VCL, but VMU is later than VCL	QZ → CL+IL+RU → MU
18-82.9	30	70 MU 30 CL (two separate phases) 1 RU	fine	BRRK with CL & MU in matrix -MU after CL	closed	poor	moderate	40 QT 40 BRRK 20 VQ	cut by coarse CC veins -cut earlier by small QZ veins	OZ → BRRK → CL → MU → QZ → CC
79-46	20	Phase 1: 70 BI + IL 30 CL Phase 2: 80 QZ 20 PY	med. to coarse	PY euhedral along late fractures	closed to open	poor	moderate to well	100 QT	PY has SL assoc. -minor MU	BI → CL → MU → QZ+PY+SL

79-67	40	95 BI 5 CL	fine	some coarser grained clots -some SL in QZ vein	open	poor	moderate to well rounded	30 QT 30 SHMU 30 VQ 5 IL 5 VBI	some retro- grade MU CL of clasts -small frag. of IL	OZ+SL → BI →
79-112	40	80 BI 20 LI (diff. phases)	fine to medium	botryoidal texture of LI along vein walls	open	poor	moderate to well rounded	55 VQ 40 QT 5 VCT	LI stained fractures post-date BR	QZ → CT → BI →

CALCITE BRECCIAS

SAMPLE NO.	% of Rock	% Mineral	MATRIX Grain Size	Texture	Frame- work	Sor- ting	CLASTS Rounding	Type	REMARKS	PARAGENESIS
13-133	30	100 CC	coarse	BRBK texture with some interstitial CL	closed	poor	moderate to well rounded	30 BRCL 10 VQ 60 QT	BRCC cross- cutting BRCL+PY+RU	OZ → CL+SL+PY → CC
18-84.25	30	100 CC	coarse	BRBK which contains some CL+MU in matrix is re-brecciated by CC -other BR's are finer grained than CC	closed to open	poor	moderate to well rounded	60 BRBK 20 BRCL 15 BRMU 5 VQ	breccia clasts are dominant	QZ → BRBK → CL → MU → CC

CHLORITE BRECCIAS

SAMPLE NO.	% of Rock	% Mineral	MATRIX Grain Size	Texture	Frame-Work	Sor-ting	CLASTS Rounding	Type	REMARKS	PARAGENESIS
8-10-61.3	20-30	80 CL 10 PY 10 IL + RU	fine to medium	sub to anhedral pyrite is fractured & altered to LI or HE in cracks -sub- to anhedral IL	open	poor	moderate to well	100 QT	v. thin BRCL zone -the rest is QT with CL alteration along foliation	CL+PY+IL → LI
14-15-70	40-50	60 CL 5 MU 5 CT 20 BI 10 CP, SL	fine	matrix has a foliated texture	open	poor	moderate to well	80 QT 20 VQ	flow texture	QZ → CL+SX+CT +BI+MU → CL ₂ LI
15-16-78	35	80 CL 5-10 CT 5 RU+IL 10 mica	coarse to med.	twinned, sub- to anhedral CT	open	poor	moderate	30 VCL 50 QT 10 VQ 10 VCT	CT in CL matrix (equigran.) -sometimes v. little, or no CL in between fragments	QZ → CL ₁ +CT → CL ₂ mica → QZ (late) → LI
18-38.5	20	75 CL 10 LI 5 SL + CP 10 FL	medium	vein breccia	open	mod. to poor	moderate	100 QT	FL pods within CL -a small Al-Si mineral assoc. with LI	CL+FL → CL+SL +CP → LI

18-81	25	33 TO 2 AP, ZR, RU w/TO coarse 55 CL (+SL) 10 PR, SL, PY, CP, AS, MAR	medium (some coarse TO)	CL contains relict grains of TO -subhedral TO crystals -coarse TO subhedral grains inside fine grained CL -CP exsolved blebs in PY, PR, SL	closed	poor	moderate	QT	corroded, embayed QT frag. edges	TO+RU → CL+SX
19-34-159	30-40	50 CL 20 MU 30 TO	fine	BRRK texture -altered to TO+CL & MU	open	poor	moderate to well	10 VMU 30 QT 40 SHMU 10 VCL 10 VQ	Vugs filled with coarse CC crystals	QZ → BRRK → MU+CL ₁ → MU → TO → CL ₂ → OZ → CC
19-34-168	25-30	95 CL 5 IL + RU 1 CT	medium to coarse	some radia- ting CL aggregates -subhedral CL grains -BRRK text.	open to closed	poor	moderate (sub- angular to sub rounded)	95 QT 5 VCL	some MU veining in QT clasts -cut by BRCL	OZ → MU → CL ₁ → CL ₂ +CL+IL → CC
20-139.05	60	30 CL 60 MU 9 SL 1 RU	medium to fine	MU aggre- gates cross- thatched texture -coarse calcite in open vein	open	poor	moderate to well rounded	100 QT	BRCL is pervasively altered to MU -late CC veins cut everything -some brown material in matrix (CY?)	CL+SL+RU → MU → CC

TR-23	25-30	90 CL 5 mica 1 ZR 5 IL	medium	fragments are rotated -subhedral laths of CL	open	poor	angular to sub- angular	70 QT 30 VQ	OZ → CL+IL+ mica+ZR → LI
79-24	40	96 CL 1 CT 1 PY 2 SL	fine to medium	subhedral CT -shreddy CL -euhedral PY	closed	poor	moderate to well	85 QT 10 VQ 5 CT	clasts only partially rotated -minor CL intergrown with CT OZ → CT → CL+ SL+CT → QZ (later) → LI
79-30	60	80 CL 2 RU 2 CT 16 FL	fine to medium	high relief, open shreddy CL -resembles BRK with CL alteration -minor CT adheres to VQ clasts	open	poor	moderate to well	40 VQ 50 QT 10 VCT	aggregates of CT cryst- als & single sub- to euhedral crystal frag- ments -late FL cutting BRCL OZ → CT → CL →
79-32	30	80 CL 10 CT 5 RU 10 TO	medium	subhedral CT crystals	closed	poor	moderate to well	45 QT 20 VCT 35 BRCL	some yellow green willemite LI (EDS) OZ → CT → CL (+CT) → CL →

79-56	35	Phase 1: 30 PY 20 CL 10 BI 40 QZ (+RU) Phase 2: 70 CL 30 SER + SL	coarse fine	2 matrix type 1: QZ-PY- VMS 2: CL-SER euh. PY xtals -some SL inclusions in PY	closed	poor	moderate	30 QT 30 VQ 20 BRSE 20 VCL	SER contains clasts of VCL PY+QZ → CL+BI (a BRRK) → ASP	QZ → BI → CL → CL+SER+SL → PY+QZ → CL+BI (a BRRK) → ASP
79-74	40	100 CL	medium	cut by HE-BI	open	mod. to poor	moderate to well	40 QT 20 VCL 10 VCT 30 VQ	CL-CT clots	QZ → CT+CL → CL → BI
79-77	50	100 CL	fine	aggregates of large sub- to euhedral grains (twinned) of CT (equant shapes) -pyramid termination	open	poor	moderate to well	30 QT 10 VCL 40 VCT 20 VQZ	VCL clasts are coarser grained -brecciation broke up CT aggregates	QZ → CT → CL ₁ → CL ₂ → BI •
79-113	35	90 CL 1 ZR 10 CT 1 SL	fine to medium	radiating CL aggregates	closed	poor	moderate to well	20 QT 30 VQ 30 VCL 20 CT	VCL clasts	QZ → CT → CL- SL-CT → QZ
79-114	35	100 CL	fine (to medium)	subhedral CT aggregates -some euhed- dral QZ crys- tal fragments	closed	poor	well- rounded	25 BRCL 45 VQ 10 QT 20 VCT	some CT adhering to vein QZ (+)	QZ+CT → CT → CL ₁ +CT → CL ₂ → BI

79-118	50	80 CL 17 CT 3 RU	medium	v. interesting zonal structure of CT	open	poor	moderate to well rounded	65 OT 30 VCT 5 VQ	difficult to tell whether all CT is frag- ments, or whether some is crystals	QZ → CT → CT- CL-IL-RU → CL → LI
79-127	35	95 CL 5 PY	fine to medium	little movement of clasts from original position -aggregates of equant cassiterite grains	open	poor	moderate	40 OT 30 VCT 10 VQ 10 VCL 10 VCL, VCT	some VCT fragments have a brec- cia texture with frag- ments of QT +VQ	QZ → CT → CT +CL → CL+PY
79-139	50	90 CL 10 BI 5 SX + CT 1 Blet Ag, As, S compound	fine to medium	VCL clasts have cross- hatch textured aggregates	open	poor	moderate to well	30 VCL 40 VQ 30 QT	late BI veins cutting BRCL -minor LI stain	QZ → CL ₁ → CL ₂ +SX (+SL) +CT → CL+BI+ LI
79-140	60	100 CL	fine	some ragged edges on QZ grains -rounded CT frag- ments	open	poor	well- rounded	30 QT 10 SHCL 40 VCL + CT 20 VQ 10 VCT	SHCL formerly BI schist but retro- grade CL -some VQZ with CT -late VBI	QZ+CT → CT+ CL ₁ → CL ₂ → BI → LI

S79-154	30	95 CL 5 CT	medium grained	CT impreg- nated in BRRK + in VN with some CL -RFLK texture	closed	mod. to well	well- rounded	50 VQ 20 VCL 10 VCT 20 QT	zoned and twinned CT crystals -large CL VN -CT almost in BRRK with QZ	QZ → RK → CT → CL + CT → CL
S79-926	40	80 CL 20 HE	fine	some zoned cassiterite subhedral rounded fragments	open	poor	moderate to well	60 QT 1 VCT 10 VCL 30 VQ		QZ → CT → CL ₁ → CL ₂ → HEM
S79-928	70	90 CL 10 IL 1 CT 1 RU	small to medium	radiating shreddy aggregates IL contains tiny inclu- sions of CT (EDS)	open	poor	well to moderate	80 VQ 20 QT	not a true breccia (only in parts), more like vein material	QZ → CL + CT + IL
S79-930	70	80 CL 20 IL + RU	coarse to med. grained	some radiating aggregates of CL (shreddy) -clots of opaques in CL VN material	open	poor	moderate to well	50 VQ 50 QT	parts of breccia VN contain no fragments while other veins have many fragments	QZ → CL + IL + RU

Appendix 2 (cont.)

VEINS AND STOCKWORK

Sample No.	% of Rock	% Minerals	Texture	Remarks	Paragenesis
8-6-40	20 (SHMU)	60 CL 5 IL 5 RU 20 TO 10 LI	coarse to med. grained CL -from a folia- ted texture with TO to a mass of ran- domly oriented CL aggregates (radiating)	TO-rich pods occur within CL -some of CL matrix con- tains clasts of high relief, green material -some IL in clasts of SHMU -some IL in matrix	TO → CL+IL+RU → LI
8-16-100	10-15 (QTMU)	55 QZ 25 CL 5 CP 15 BI	fine to med. grained -pods of SX within CL pods of the QZ vein & within CB pod	randomly oriented CL aggregates -some CL is altered to BI -QZ part of vein has coxcomb forms	QZ → CL → BI → CB → CP
13-16-69.4	50 (QTMU)	40 QZ 15 CL 20 FL 15 CB 5 SX (CP, SL, GL, PY)	pods of FL in CB -QZ is coarse, CL med., FL coarse, CB. med.-coarse -all are sep- arate cross- cutting phases	coarse FL veins are cut by thin micro- veins of CL -at the border of QZ vein, the QT is brecciated with a MU matrix	QZ → CL → FL → QZ (minor) → CL → CB
13-114.5	30 (SHBI)	40 QZ 20 CL 7 CC 20 PR 10 PY 3 CT	zoning of coarse grained material	wallrock alteration in schist -contains abundant CL and RU -QZ is coxcomb -several phases (shows poly- phase deposit- ion occurred) -CT assoc. with CL	QZ → CL+PR+PY+ CT → CC

13-134	5 (QTCL)	85 CL 5 RU 10 TO	coarse to med. gr. -some CL is in bands along foliation and some is in random aggregates in pinch and swell veins	some of rock has slight breccia text. with clasts of OZ crystals, or CL has an interstitial position to VO crystals	OZ → CL + RU → TO → LI
13-34-144	20 (QTMI)	60 CL 25 SL 2 CP 1 PY 1 IL + RU 10 CC 1 CT	coarse gr. radiating aggregates of CL -minor clasts of VO in CL matrix of vein -CP is exolved along cleavage traces of SL -CT crystals (euhedral)	CC found adjacent to SL (may be contemporaneous, later) -thin silica rich envelope	OZ → CL + CT + SL + IL + PY → CC + SL
14-35-170	20 (QT)	60 TO 15 PR 15 CL 10 MU	coarse and fine gr. parts -PR seems to be interstitial to TO grains (euhedral) -also some TO parallel, traversing PR veins	most of TO is randomly oriented	TO → PR → MU + CL
TR 35	20 (QT)	30 OZ 65 CL 5 RU	CL borders the OZ vein which is coarse gr. -CL is med. to fine grained -CL is a selvage, or later vein material	CL in QT may be a pseudomorph of BI CL in QT contains small ZR	→ CL → LI

APPENDIX 2 (cont.) ABBREVIATIONS

Rock Names

QT, OZIT	quartzite	BR	breccia
OTCL	chlorite OT	BRMU	muscovite BR
OTMU	muscovite OT	BRSER	sericite BR
OTMI	micaceous OT	BRPI	biotite BR
SHCL	chlorite schist	BRRK	rock flour BR
SHBI	biotite schist	VT	vein tourmaline
SHMU	muscovite schist	VO	vein quartz
SHBM	biotite-muscovite schist	VCL, VUCL	vein chlorite
VN	vein	VMU	vein muscovite
VB	vein biotite	VCT	vein cassiterite

Mineral Names

OZ	quartz	CT	cassiterite
CL	chlorite	RU	rutile
BI	biotite	ILM, IL	ilmenite
TO	tourmaline	ZR	zircon
MU	muscovite	AP	apatite
CB	carbonate	SX	sulphides
FS	feldspar	GL	galena
CY	clay mineral	SL	sphalerite
LI	limonite	CP	chalcopyrite
HE, HEI	hematite	PY	pyrite
ANK	ankerite	PP	pyrrhotite
CC	calcite	AS	arsenopyrite
SER	sericite	MAR	marcasite
RKFL	rock flour		
FL	fluorite		
MN	manganese-oxide		

APPENDIX 3

INFORMATION ON THE ELECTRON MICROPROBE

CARLETON UNIVERSITY

Part a. Microprobe Running Conditions

Microprobe:

Cambridge MK V electron microprobe, Carleton University, Ottawa.

Silicates:

voltage of 15 kV; specimen current of 0.5×10^{-7} amperes, or 50 nanoamperes on pure iron; counting time of 30 seconds for Fe, Mg, Ca, Na, Mn, Al, Ti & Si; counting time of 100 seconds for F & Cl.

Cassiterite:

voltage of 25 kV; specimen current of 0.4×10^{-7} amperes, or 40 nanoamperes on SnO_2 ; counting time of 50 seconds for all minor and trace elements analyzed; counting time of 30 seconds for Sn.

The data, collected in counts per second, was reduced to weight percent using the data reduction program of Rucklidge and Gasparrini (1969).

For all elements analyzed in the silicates and cassiterites $K_{\alpha 1}$ and L_{α} rays were used: L_{α} rays were used on Ag, Zr, Nb, Sn, Ta and W, and $K_{\alpha 1}$ on all other elements.

Bivariate scatter plots were done on the computer, using BMDP (Biomedical Data Package)(Dixon et al. 1979). BMDP allows grouping of cases according to different variables and plots them together on the same graph.

Part b. Microprobe Standards

Silicates

Elements	Standards' Name	Source of Standard
Fe,Mg,Ca,Na, Al,Ti,Si,K	KAKH	Kakanui Hornblende, U.S. National Museum, Microprobe standard 143965
Al	ANOR	Anorthite (synthetic)
Mn	R1596	Natural Mn-tremolite, Minnesota Rock Analysis Laboratory
F,K	R2088	Natural riebeckite, Minnesota Rock Analysis Laboratory
Cl	TUGT	Natural tugtupite, University of Toronto, Ontario

Cassiterite

Elements	Standard Name	Source of Standard
Ti,Mn,Fe,Nb	ILM	Ilmenite, U.S. National Museum, Microprobe standard 96189
Ta	Ta	Pure Ta metal
W	CaWO ₄	Scheelite, CANMET, Ottawa
Zr	ZrO ₂	Zirconia (synthetic)
Ag	Ag	Pure Ag metal
Sn	SnO ₂	Natural cassiterite

Part c. Detection Limits for Microprobe Analyses

<u>Silicates</u>		<u>Cassiterite</u>	
Oxide/ Element	Detection Limit (weight %)	Oxide	Detection Limit (weight %)
MgO	0.02	TiO ₂	0.01
CaO	0.02	Ta ₂ O ₅	0.12
Na ₂ O	0.03	MnO	0.01
MnO	0.03	WO ₃	0.08
TiO ₂	0.02	FeO _T	0.02
K ₂ O	0.01	Nb ₂ O ₅	0.03
F	0.19	AgO	0.06
Cl	0.03	ZrO ₂	0.11

Part d. Relative Error Due to Counting Statistics

<u>Silicates</u>		<u>Cassiterite</u>	
Element/ Oxide	Relative Error (weight %)	Oxide	Relative Error (weight %)
FeO _T	0.39	TiO ₂	0.02
MgO	0.10	Ta ₂ O ₅	0.11
CaO	0.03	MnO	0.02
Na ₂ O	0.05	WO ₃	0.02
MnO	0.06	FeO _T	0.03
Al ₂ O ₃	0.26	Nb ₂ O ₅	0.01
TiO ₂	0.01	AgO	0.09
SiO ₂	0.17	ZrO ₂	0.21
K ₂ O	0.01	SnO ₂	0.51
F	0.19		
Cl	0.26		

APPENDIX 4

MICROPROBE DATA OF CHLORITE
FROM THE OLIVER CREEK TIN OCCURRENCE

Part a. Key to Codes used to Identify Chlorite

- I. Sample number (including numbers 1-182).
- II. Drill hole number (#'s 5-20), or original sample number (first part)(#'s 222 and 333 - traverse number, 999 - trench sample, 79 - sample from Billiton of unknown location).
- III. Depth (in metres), or original sample number (second part).
- IV. Host rock type:

(1) quartzite (+ veins)	A	(8) tourmaline breccia	E
(2) schist (+ veins)	B	(9) vein quartz	F
(6) granite	C	(10) chlorite breccia	G
(7) biotite latite	D	(11) rock flour breccia	H
- V. Occurrence Type

(1) breccia matrix	(6) granular, clot, or porphyroblastic
(2) vein material	(7) pseudomorph, or alteration of biotite
(3) selvedge	
(4) envelope	
(5) along the foliation of country rock	
- VI. Paragenesis

(1) unknown	(4) late (vein cutting breccia)
(2) early (clast)	(5) earlier than tourmaline
(3) intermediate (matrix)	
- VII. Grain Size
 - (1) fine
 - (2) medium
 - (3) coarse
- VIII. Metallic Mineral Association

(1) none	(5) cassiterite+sulphides
(2) cassiterite	(6) cassiterite+rutile
(3) rutile	(7) sulphides+rutile
(4) sulphides	(8) sulphides+rutile+cassiterite

IX. Gangue Mineral Association

(1) none	(9) carbonate(+quartz)
(2) tourmaline	(10) fluorite(+quartz, carbonate)
(3) biotite	(11) biotite+muscovite
(4) muscovite	(13) fluorite+muscovite+biotite
(5) tourmaline+biotite	(14) fluorite+muscovite+tourm.
(6) tourmaline+muscovite	(15) fluorite+muscovite
(7) tourmaline+biotite+muscovite	
(8) quartz	

X. Clast Type

(1) not applicable	(8) vein chlorite+quartz + CRX
(2) country rocks (CRX)	(9) vein quartz+tourmaline + CRX
(3) vein quartz + CRX	(10) vein chlorite+tourm. + CRX
(4) vein tourmaline + CRX	(11) vein chlorite+cassit. + CRX
(5) vein chlorite + CRX	(12) vein cassit.+chlor.+qz.+CRX
(6) vein cassiterite + CRX	(13) vein muscovite+chlor. + CRX
(7) vein quartz+cassiterite + CRX	

Part b.

CHARACTERISTICS OF ANALYSED CHLORITE GRAINS (IN CODE) *

SAMPLE No.	DRILL HOLE	DEPTH	HOST ROCK	OCCUR TYPE	PARA- GEN.	GRAIN SIZE	ORE MIN.	GANGUE MIN.	CLAST TYPE
1	19	141	8	2	1	3	7	1	9
2	19	145	8	2	1	3	4	4	3
3	14	93	8	1	1	3	7	2	4
4	18	38	1	1	3	2	4	10	2
5	18	38	1	1	3	3	4	10	2
6	18	38	10	2	4	2	1	10	1
7	18	38	1	1	3	2	4	10	2
8	13	114	2	2	1	3	5	9	1
9	13	114	2	4	1	2	3	1	1
10	18	81	1	1	1	2	4	2	2
11	18	81	1	1	1	2	4	2	2
12	79	77	1	1	3	1	2	1	12
13	79	77	10	2	4	2	1	1	1
14	79	77	1	1	3	1	1	1	12
15	79	127	1	1	1	2	5	1	12
16	79	56	1	1	1	1	4	4	9
17	79	56	1	1	1	1	4	4	9
18	79	56	1	1	1	2	4	4	9
19	18	83	11	1	3	2	3	4	3
20	18	83	11	1	3	1	3	4	3
21	18	83	10	2	4	1	1	4	3
22	18	83	11	1	3	1	3	4	3
23	18	83	11	1	3	1	3	4	3
24	18	83	11	1	3	1	3	4	3
25	18	83	11	1	3	1	3	4	3
26	19	144	8	1	1	2	7	6	2
27	19	144	8	1	1	2	7	6	2
28	19	144	8	1	1	2	7	6	2
29	19	144	8	1	1	2	7	6	2
30	79	154	10	2	2	2	2	8	12
31	79	154	10	2	2	2	2	1	12
32	79	154	1	1	3	2	2	1	12
33	79	154	1	1	3	3	2	1	12
34	79	154	1	1	3	2	2	1	12
35	79	154	1	1	3	1	2	1	12
36	79	154	1	1	3	2	2	1	12
37	79	154	1	1	3	2	2	1	12
38	20	139	1	1	1	3	7	4	2
39	20	139	1	1	1	3	7	4	2
40	20	139	1	1	1	3	7	4	2
41	20	139	1	1	1	2	7	4	2
42	20	139	1	1	1	3	7	4	2
43	79	139	10	2	4	3	1	1	1
44	79	139	10	2	2	2	1	1	1
45	79	139	1	1	3	1	5	3	9
46	79	139	1	1	3	1	5	3	9
47	79	139	1	1	3	2	5	3	9
48	79	139	10	2	2	2	1	1	1
49	79	139	10	2	2	2	1	1	1
50	79	139	1	1	3	1	5	3	9

Part b (cont.)

CHARACTERISTICS OF ANALYZED CHLORITE GRAINS (CD CODE)*

SAMPLE No.	DRILL HOLE	DEPTH	HOST ROCK	OCCUR TYPE	PARA-SEP.	GRAIN SIZE	ORE MID.	GANGUE MID.	CLAST TYPES
51	79	139	1	1	3	1	5	3	8
52	79	137	10	2	2	2	1	1	1
53	79	139	10	2	2	2	1	1	1
54	79	118	1	1	3	2	6	1	7
55	79	118	1	1	3	2	6	1	7
56	79	118	1	1	3	2	6	1	7
57	79	118	1	1	3	2	6	1	7
58	79	118	1	1	3	2	6	1	7
59	79	119	1	1	3	2	6	1	7
60	79	118	10	2	2	2	6	1	7
61	79	118	1	1	3	2	6	1	7
62	799	23	1	1	1	2	3	1	3
63	799	23	1	1	1	2	3	1	3
64	799	23	1	1	1	2	3	1	3
65	799	23	1	1	1	2	3	1	3
66	799	23	1	1	1	2	3	1	3
67	799	23	1	1	1	2	3	1	3
68	799	23	1	1	1	2	3	1	3
69	799	23	1	1	1	2	3	1	3
70	19	168	1	1	1	3	6	1	5
71	19	168	1	1	1	2	6	1	5
72	19	168	1	1	1	3	6	1	5
73	19	168	1	1	1	3	6	1	5
74	19	168	1	1	1	2	6	1	5
75	19	168	1	1	1	2	6	1	5
76	19	168	1	1	1	2	6	1	5
77	19	168	1	1	1	2	6	1	5
78	14	70	10	2	1	1	1	1	1
79	14	70	10	2	4	1	1	1	1
80	14	70	1	1	3	1	5	11	8
81	14	70	1	1	3	1	5	11	8
82	14	70	1	1	3	3	5	11	8
83	14	70	1	1	3	1	5	11	8
84	14	70	1	1	3	1	5	11	8
85	15	78	1	1	3	3	6	1	12
86	15	78	1	1	3	3	6	1	12
87	15	78	1	1	3	3	6	1	12
88	15	78	1	1	3	3	6	1	12
89	15	78	1	1	3	3	6	1	12
90	15	78	1	1	3	3	6	1	12
91	15	78	10	2	4	2	1	1	1
92	15	78	1	1	3	3	6	1	12
93	15	78	1	1	3	3	6	1	12
94	79	113	1	1	1	3	5	1	12
95	79	113	1	1	1	3	5	1	12
96	79	113	1	1	1	3	5	1	12
97	79	113	1	1	1	3	5	1	12
98	79	113	1	1	1	3	5	1	12
99	79	113	1	1	1	3	5	1	12
100	79	113	1	1	1	3	5	1	12
101	79	74	1	1	1	2	8	1	12
102	79	74	1	1	1	2	8	1	12
103	79	74	1	1	1	2	8	1	12
104	79	74	1	1	1	2	8	1	12
105	79	74	1	1	1	2	8	1	12

Part b (cont.)

CHARACTERISTICS OF ANALYSED CHLORITE BRAINS (IN CODE)*

SAMPLE No.	DRILL HOLE	DEPTH	HOST ROCK	OCCUR TYPE	PARA-GEN.	GRAIN SIZE	ORE MIN.	GANGUE MIN.	CLAST TYPES
106	79	74	1	1	1	1	8	1	12
107	79	74	1	1	1	2	8	1	12
108	14	94	8	2	1	3	4	2	1
109	14	94	8	2	1	3	4	2	1
110	79	30	10	2	2	3	1	1	1
111	79	30	1	1	3	2	6	1	7
112	79	30	1	1	3	2	6	1	7
113	79	30	1	1	3	3	6	1	7
114	79	30	1	1	3	1	6	1	7
115	79	24	1	1	1	1	5	1	7
116	79	24	1	1	1	2	5	1	7
117	79	24	1	1	1	2	5	1	7
118	79	32	1	1	1	2	6	2	11
119	79	32	1	1	1	2	6	2	11
120	79	32	1	1	1	3	6	2	11
121	14	170	1	2	1	2	4	6	1
122	13	144	1	1	1	2	8	12	2
123	13	144	1	2	1	3	8	12	1
124	13	144	1	2	1	2	8	12	1
125	13	144	1	2	1	3	8	12	1
126	13	144	1	2	1	3	8	12	1
127	13	144	1	2	1	2	8	12	1
128	13	144	1	2	1	2	8	12	1
129	8	40	2	5	1	2	4	1	1
130	8	40	2	2	1	3	3	2	1
131	8	40	2	2	1	3	3	2	1
132	8	40	2	2	1	2	3	2	1
133	8	40	2	2	1	3	3	2	1
134	8	40	2	1	1	1	3	2	2
135	13	134	1	2	1	2	1	1	1
136	13	134	1	5	1	2	3	3	1
137	13	134	1	1	1	3	3	1	2
138	999	35	1	1	1	2	3	9	2
139	999	35	1	5	1	2	1	1	1
140	999	35	1	1	1	2	3	8	2
141	999	35	1	1	1	2	3	8	2
142	999	35	1	1	1	2	3	8	2
143	999	35	1	5	1	2	1	1	1
144	999	35	1	3	1	3	1	9	1
145	999	35	1	3	1	3	1	8	1
146	333	121	6	6	1	3	1	2	1
147	333	121	6	6	1	3	1	2	1
148	333	122	6	7	1	2	1	3	1
149	333	124	6	6	1	3	1	11	1

Part b (cont.)

CHARACTERISTICS OF ANALYSED CHLORITE GRAINS (IN CODE) *

SAMPLE No.	DRILL HOLE	DEPTH	HOST ROCK	OCCUR TYPE	PARA-GEN.	GRAIN SIZE	ORE MIN.	GANGUE MIN.	CLAST TYPES
151	333	124	6	6	1	2	1	14	1
152	333	11	6	6	1	3	3	15	1
153	333	11	6	6	1	3	3	15	1
154	333	11	6	6	1	3	3	15	1
155	333	11	6	6	1	3	3	15	1
156	333	11	6	6	1	3	3	15	1
157	222	1	7	2	1	2	1	1	1
158	222	1	7	2	1	2	1	1	1
159	222	1	7	2	1	2	1	1	1
160	333	7	6	7	1	2	1	1	1
161	333	7	6	7	1	2	1	1	1
162	13	135	11	2	5	3	3	6	13
163	13	135	11	2	3	3	3	6	13
164	13	135	11	2	2	3	3	6	13
165	333	123	6	2	1	3	1	15	1
166	333	123	6	2	1	3	1	15	1
167	333	123	6	2	1	3	1	15	1
168	13	69	1	2	1	3	4	10	1
169	13	69	1	2	1	3	4	10	1
170	13	69	1	2	1	3	4	10	1
171	13	69	1	2	1	3	4	10	1
172	8	100	1	5	1	2	3	1	1
173	8	100	1	5	1	2	3	1	1
174	8	100	1	5	1	2	4	3	1
175	8	100	1	2	1	2	4	9	1
176	18	84	11	2	3	3	5	3	1
177	18	84	11	2	3	2	6	3	1
178	18	84	11	5	2	2	1	1	1
179	8	61	1	1	3	2	7	1	2
180	8	61	1	1	3	3	7	1	2
181	8	61	1	5	2	2	1	1	1
182	8	61	1	1	3	2	7	1	2

* Codes are in part a.

Part c. Microprobe analyses of Oliver Creek chlorite (weight percent).

Sample No.	Depth	FeO _T	MgO	CaO	Na ₂ O	MnO	Al ₂ O ₃	SiO ₂	K ₂ O	F	Cl	H ₂ O (calc)	-O-F+Cl	Total	FeO _T - FeO _{calc}
1	19	141	36.34	5.34	.05	1.54	22.12	.07	22.50			10.56		98.59	.87
2	19	145	40.83	2.54	.06	1.53	21.62	.11	22.06			10.37		99.19	.94
3	14	93	40.35	3.70	.06	.28	20.14	1.06	23.55	.03		10.54		100.13	.92
4	18	38	36.50	4.02	.14	.32	20.54	.03	26.49	.11		10.77		98.99	.90
5	18	38	39.57	1.72	.09	.37	19.52	.05	23.25	.03		10.35		98.04	.89
6	18	38	33.10	3.48	.09	.21	25.01	.03	26.64	.08		11.11		99.86	.90
7	18	38	37.25	6.18	.07	.53	20.87	.05	23.71	.02		10.72	.08	99.41	.86
8	13	114	34.58	9.30	.03	.45	17.97	.04	24.74	.02	.19	10.56		97.82	.79
9	13	114	31.54	11.07	.03	1.08	19.67	.04	24.06	.01		10.80		98.26	.74
10	18	81	42.03	2.07	.04	.74	20.78	.06	21.64	.02	.24	10.07	.10	97.59	.95
11	18	81	44.15	2.75	.02	.73	18.37	.03	23.59	.01	.20	10.25	.09	99.53	.94
12	79	77	39.83	2.76	.02	1.50	21.68	.04	22.93	.10		10.46		99.41	.94
13	79	77	40.55	3.24	.05	1.28	21.80	.02	21.86	.10	.53	10.21	.23	99.44	.93
14	79	77	39.46	2.53	.05	1.32	21.26	.06	23.38	.01	.22	10.39	.09	98.79	.94
15	79	127	40.17	2.98	.04	1.01	20.59	.03	22.14	.03		10.26		97.43	.93
16	79	56	40.96	2.14	.10	1.04	22.18	.04	21.57	.62		10.31		99.08	.95
17	79	56	42.72	2.15	.07	1.08	21.71	.05	22.53	.03		10.57		100.94	.95
18	79	56	39.51	2.43	.11	1.54	22.14	.03	22.37	.26		10.46		98.90	.94
19	18	83	38.08	5.40	.04	1.54	19.55	.09	23.82	.02	.03	10.57	.01	99.18	.88
20	18	83	37.69	5.22	.03	1.53	19.51	.08	23.74			10.49		98.31	.88
21	18	83	38.53	5.11	.02	1.20	19.19	.05	23.58			10.42		98.15	.88
22	18	83	35.13	6.88	.04	2.11	20.19	.06	23.89	.01	.22	10.59	.10	99.05	.84
23	18	83	38.40	4.84	.03	1.59	20.95	.04	23.52	.03	.05	10.67	.01	100.11	.89
24	18	83	39.05	4.42	.02	1.40	20.16	.06	23.30	.02	.04	10.48	.03	98.97	.90
25	18	83	39.27	3.45	.05	1.40	20.20	.06	23.52		.05	10.39	.05	98.43	.92
26	19	144	42.49	2.10		1.14	21.34	.05	22.33		.03	10.46	.01	100.13	.95
27	19	144	42.08	2.42	.03	1.24	21.31	.09	21.95	.03		10.40		99.57	.95
28	19	144	42.31	2.27	.02	1.12	20.70	.11	22.37			10.37		99.28	.93
29	19	144	42.52	2.07	.04	1.40	20.91	.11	22.27			10.40		99.72	.95
30	79	154	39.52	3.08	.05	1.33	21.63	.07	22.30	.04	.04	10.41	.01	98.47	.93
31	79	154	40.62	2.91	.06	1.83	22.42	.06	22.18	.02	.05	10.59	.01	100.94	.93
32	79	154	39.89	2.80	.06	1.13	22.65	.08	22.50	.06	.05	10.59	.01	100.00	.93
33	79	154	41.46	1.93	.08	1.22	22.25	.06	21.99	.04		10.43		99.49	.96
34	79	154	40.42	2.57	.12	1.27	21.01	.07	22.49	.03	.01	10.33	.03	98.37	.94
35	79	154	40.93	2.83	.07	1.12	22.27	.07	22.02	.06	.03	10.52	.01	99.92	.94
36	79	154	40.31	2.37	.06	1.59	22.14	.05	21.99	.11	.03	10.43	.01	99.07	.94
37	79	154	40.41	2.52	.08	1.60	22.73	.08	22.53	.18	.03	10.65	.01	100.80	.94
38	20	139	41.14	10.31	.04	1.17	22.24	.04	24.49	.03	.24	11.08	.11	100.70	.75
39	20	139	40.71	10.33	.05	1.96	22.24	.03	24.14	.03		11.09		100.68	.75
40	20	139	41.28	10.08	.05	.73	21.66	.04	24.65	.05		11.01		99.89	.76
41	20	139	41.14	9.98	.07	1.13	21.52	.05	25.06	.04	.25	11.03	.11	100.40	.76
42	20	139	41.19	12.09	.07	1.11	21.57	.02	25.14	.04	.03	11.13	.10	99.83	.80
43	79	139	35.33	6.50	.14	1.75	21.92	.15	23.84	.03	.21	10.44	.11	97.76	.91
44	79	139	36.00	4.33	.08	1.18	21.56	.08	23.26	.06	.78	10.51	.11	97.56	.90
45	79	139	39.23	3.15	.04	1.17	22.26	.10	23.26			10.54		99.15	.82
46	79	139	39.23	3.15	.04	1.46	22.11	.18	23.23			10.60	.10	99.59	.89
47	79	139	40.45	3.24	.05	1.50	23.12	.09	22.74	.01		10.50	.08	100.68	.93
48	79	139	40.45	3.24	.05	1.55	23.12	.07	23.42		.01	10.50	.08	100.62	.91
49	79	139	40.45	3.24	.05	1.55	23.12	.07	23.42		.01	10.50	.08	100.62	.91
50	79	139	40.45	3.24	.05	1.55	23.12	.07	23.42		.01	10.50	.08	100.62	.91

3 3
OF / DE

Part c (cont.)

Sample Number	Drill Depth*	FeO _T	MgO	CaO	Na ₂ O	MnO	Al ₂ O ₃	TiO ₂	SiO ₂	K ₂ O	F	Cl	H ₂ O (calc)	-O-F+Cl	Total FeO _T	FeO _T /H ₂ O
51	79	139	40.40	2.97	.06	1.72	21.07	.09	23.43	.01	.24		10.50	.10	100.39	.93
52	79	139	39.28	3.48	.07	1.19	22.02	.04	24.05	.10	.25		10.73	.11	101.50	.91
53	79	139	36.59	4.68	.05	1.32	22.12	.04	22.43	.01			10.46		97.78	.89
54	79	118	39.52	3.36	.10	1.71	21.36	.07	23.47	.04	.28		10.52	.12	100.33	.92
55	79	118	38.83	3.08	.10	1.68	21.39	.07	23.06	.05	.29		10.36	.12	98.77	.93
56	79	118	38.34	3.79	.05	1.52	22.39	.09	23.29	.04			10.66		100.27	.91
57	79	118	38.54	4.25	.08	2.88	22.14	.06	22.99	.04	.29		10.47	.13	101.83	.90
58	79	118	38.73	3.65	.10	1.61	21.98	.07	23.12	.02			10.60		100.17	.91
59	79	118	37.44	3.18	.15	1.52	22.14	.07	24.40	.04	.30		10.61	.13	99.72	.92
60	79	118	39.81	3.47	.07	1.16	21.91	.06	23.29	.01			10.44		100.70	.92
61	79	118	38.67	3.65	.07	1.60	22.35	.06	23.37				10.68		100.53	.91
62	99	23	38.24	4.52	.05	.93	22.85	.05	22.10	.12			10.64		99.50	.89
63	99	23	40.86	2.15	.05	1.13	22.80	.07	22.40	.09			10.58		100.14	.95
64	99	23	49.13	3.29	.04	1.47	23.01	.03	23.30	.05			10.81		101.13	.92
65	99	23	42.15	2.12	.04	1.45	23.35	.04	22.42	.02		.04	10.76	.01	102.38	.95
66	99	23	40.62	2.53	.05	1.52	22.30	.09	23.42	.03			10.74		101.34	.94
67	99	23	40.99	2.33	.06	1.66	21.54	.07	22.55	.02			10.83		100.87	.95
68	99	23	41.63	2.24	.01	1.41	22.90	.11	21.94	.14			10.61		101.02	.95
69	99	23	42.04	2.08	.03	1.15	22.17	.06	21.93	.08			10.43		100.03	.95
70	19	168	37.00	3.54	.05	1.06	22.82	.13	22.65	.02			10.59		100.23	.87
71	19	168	38.16	5.47	.22	1.59	23.40	.06	22.15	.02			10.78		100.75	.87
72	19	168	38.16	4.96	.06	1.16	21.52	.08	22.73	.01			10.62		99.51	.89
73	19	168	40.61	4.66	.04	.98	21.57	.05	22.52				10.70		101.14	.90
74	19	168	36.55	5.46	.07	1.51	21.06	.06	22.88	.03			10.60		99.19	.87
75	19	168	38.64	5.64	.04	1.11	22.38	.04	22.84	.01			10.87		101.57	.87
76	19	168	38.69	5.52		1.71	22.33	.06	23.13	.02			10.94		101.47	.88
77	19	168	36.39	6.34	.08	1.62	22.61	.06	23.31	.06		.08	10.94	.01	101.47	.85
78	14	70	39.67	3.20	.06	1.90	20.64	.03	23.44	.04			10.51		99.51	.93
79	14	70	38.85	3.62	.04	2.45	21.33	.10	22.50	.02			10.51		99.43	.91
80	14	70	38.25	3.13	.04	1.27	21.13	.05	24.29	.02			10.51		98.80	.92
81	14	70	39.00	3.89	.02	2.34	21.81	.04	22.49				10.50		99.44	.93
82	14	70	39.45	3.16	.04	2.23	19.72	.04	23.96	.02			10.48		99.10	.93
83	14	70	39.73	3.10	.03	2.02	21.92	.05	22.83	.02			10.63		100.35	.91
84	14	70	40.06	2.89	.04	1.50	21.14	.06	23.33	.01			10.53		99.58	.93
85	15	78	37.18	3.59	.05	1.46	22.75	.06	22.80	.01			10.75		100.95	.92
86	15	78	37.73	3.63		1.40	22.40	.06	23.03	.01			10.67		100.76	.92
87	15	78	40.62	3.71	.04	1.72	21.03	.09	23.29	.02			10.65		100.47	.93
88	15	78	41.93	2.57	.03	1.23	22.03	.04	22.51	.01			10.59		100.74	.95
89	15	78	41.85	3.15	.04	1.13	22.61	.28	21.95	.01			10.87		101.46	.93
90	15	78	42.23	2.49	.06	2.07	21.62	.07	22.80	.02			10.68		102.05	.94
91	15	78	41.13	3.15	.04	1.61	21.11	.10	23.89	.01			10.76		103.14	.93
92	15	78	41.00	3.02	.03	1.22	20.80	.09	23.35	.02			10.69		102.15	.91
93	15	78	40.03	3.29	.03	1.08	21.74	.07	23.18	.02			10.67		100.95	.92
94	79	113	40.58	3.10	.03	1.34	21.69	.06	22.64	.02			10.51		100.01	.94
95	79	113	38.25	3.68	.06	1.25	21.28	.04	23.34	.01			10.53		99.66	.91
96	79	113	38.05	3.99	.06	1.27	21.71	.04	23.41	.01			10.60		100.17	.91
97	79	113	37.80	3.36	.09	1.13	20.36	.05	23.58	.08			10.47	.11	99.75	.90
98	79	113	42.53	3.45		1.44	21.69	.03	22.96	.02			10.17		100.13	.90
99	79	113	37.05	5.07	.05	1.08	21.80	.02	23.84	.01		.01	10.14	.05	98.36	.91
100	79	113	37.05	6.21	.04	1.07	21.66	.04	23.43				10.14		99.51	.91

Part c (cont.)

Sample Drill Number Hole	Depth*	FeO _T	MgO	CaO	Na ₂ O	MnO	Al ₂ O ₃	TiO ₂	SiO ₂	K ₂ O	F	Cl	H ₂ O ⁺ (calc)	-O-F+Cl	Total	FeO _T FeO _T +H ₂ O
101	79	39.21	3.16	.05		1.83	22.18	.03	22.48		.40		10.34	.1	99.55	.93
102	79	39.39	3.19	.06		1.53	22.33	.18	22.30				10.61		100.00	.93
103	79	40.41	2.57	.02		1.62	22.35	.06	22.36				10.52		99.98	.91
104	79	39.74	2.77	.03		1.55	22.97	.04	22.00	.01			10.38		99.00	.93
105	79	40.01	2.71	.03		1.44	22.40	.05	22.56				10.58		99.85	.91
106	79	39.73	2.64	.07		1.65	21.55	.05	22.33				10.37		98.90	.91
107	79	39.74	2.90	.03		1.42	22.80	.03	22.13	.01			10.45	.07	99.76	.93
108	14	39.39	1.68	.02	.06	1.01	22.93	.06	22.70	.01			10.59		102.03	.94
109	14	43.78	2.66	.02	.04	.91	20.31	.09	22.35				10.13		100.64	.94
110	79	38.95	3.08	.11		1.41	21.16	.08	22.32	.04			10.57	.01	99.56	.91
111	79	30	10.20	2.86	.11	1.53	21.50	.08	21.62	.01			10.18	.00	97.66	.91
112	79	30	38.38	3.93	.13	1.47	21.59	.08	21.62	.01			10.35	.01	97.69	.91
113	79	30	37.43	4.25	.18	1.47	21.60	.12	22.13				10.42	.01	97.71	.90
114	79	30	38.12	2.85	.14	1.51	21.78	.12	21.97	.18			10.32	.01	97.68	.93
115	79	24	38.17	3.21	.12	1.01	21.22	.07	21.14	.06			10.41	.01	98.25	.91
116	79	24	37.15	3.46	.14	1.40	20.72	.07	22.89	.05			10.27	.01	96.19	.91
117	79	24	37.03	2.87	.12	1.88	21.21	.10	22.71	.04			10.25	.02	96.29	.93
118	79	32	30.15	3.54	.07	2.19	21.33	.03	22.66	.03			10.45	.06	98.53	.92
119	79	32	37.96	2.83	.07	2.12	22.14	.03	22.61	.03			10.46	.07	98.26	.93
120	79	32	38.87	2.92	.03	1.69	22.19	.03	22.62	.02			10.50	.07	99.09	.93
121	14	33.42	8.78	.03		1.05	21.87	.16	24.84	.03			11.18		101.46	.99
122	14	40.51	2.59	.05	.04	1.57	21.82	.04	23.21				10.50		100.11	.91
123	13	37.14	3.51	.02	.04	2.18	21.23	.05	23.52				10.17	.03	98.27	.96
124	13	37.01	1.52	.01		1.30	21.78	.04	23.20	.01			10.50	.03	98.11	.90
125	13	37.63	4.20		.04	1.40	22.07	.03	23.42	.01			10.50		97.57	.94
126	13	38.01	2.61		.04	1.26	21.89	.03	23.25	.02			10.41		98.24	.96
127	13	40.45	1.50	.01	.09	1.25	22.00	.04	23.40	.09			10.40		100.21	.88
128	13	39.35	5.41	.06	.07	1.57	22.65	.03	23.08				10.57		98.95	.92
129	8	40	37.92	3.44	.06	1.68	21.82	.03	23.32	.05			10.81		101.92	.93
130	8	40	40.11	3.07	.03	1.78	21.99	.05	21.03	.01			10.40		101.59	.92
131	8	40	38.26	4.51	.05	1.63	21.71	.07	24.78	.13			11.42		101.06	.90
132	8	40	34.45	3.70	.05	1.31	21.11	.04	26.14	.06			11.42		97.93	.91
133	8	40	35.92	3.62	.02	1.40	22.75	.10	23.10	.11			10.78		99.80	.90
134	8	40	37.10	3.96	.04	1.79	21.80	.06	24.08	.12			10.71		99.80	.90
135	13	39.94	2.94			1.31	22.02	.04	21.34	.07			10.33		97.92	.9
136	13	38.33	3.38			2.11	21.77	.05	21.68	.09			10.43		97.79	.92
137	13	39.67	3.20			1.75	21.53	.06	21.81				10.43		98.18	.93
138	999	35	30.34	3.84		1.87	21.80	.04	21.29	.06			10.4		97.30	.92
139	999	35	30.53	2.82	.06	1.33	21.70	.03	22.53	.01			10.59		97.59	.93
140	999	35	39.41	3.54		1.66	20.73	.09	22.42	.06			10.7		98.31	.92
141	999	35	10.00	3.16		2.51	21.55	.03	21.25	.09			10.30		97.19	.93
142	999	35	30.04	4.40		1.63	21.13	.05	21.90	.05			10.7		97.62	.90
143	999	35	32.69	3.52		1.79	21.32	.10	21.52	.19			10.3		97.81	.92
144	999	35	30.87	7.54		1.04	21.1	.05	22.70	.03			10.3		96.81	.93
145	999	35	74.81	6.87		1.15	21.65	.01	22.60	.03			10	.98	100.43	.91
146	333	121	77.39	5.64	.03	1.80	1.19	.10	23.53	.04	.59		10.3		117.00	.87
147	333	121	77.51	5.92	.05	1.59	96.00	.13	24.18	.03			10.3		117.00	.87
148	333	120	77.08	7.79	.02	.59	1.91	.22	26.03	.03	.29		11.3		117.00	.87
149	333	121	77.06	6.40		1.15	90.45	.07	23.58	.04	.5		10.71		99.52	.88

Part c (cont.)

Sample Drill Hole*	Depth*	Fe _T	MgO	CaO	Na ₂ O	MnO	Al ₂ O ₃	TiO ₂	SiO ₂	K ₂ O	F	Cl	H ₂ O (calc)	-O-F+Cl Total	Fe _T / Fe _T +MgO
151 333	124	36.15	5.36	.04		.91	21.19	.13	23.01	.01			10.74	.03	97.55 .87
152 333	11	37.76	4.26	.03		3.49	21.52	.05	22.43	.03		.11	10.57	.03	100.24 .90
153 333	11	39.37	2.24	.03		1.85	21.52	.06	22.43	.01			10.14	.05	97.84 .85
154 333	11	44.00	.89			1.14	21.71	.07	22.05	.02		.03	10.11	.01	100.31 .98
155 333	11	38.86	3.17	.05		4.19	21.60	.05	22.25	.03			10.75	.01	101.95 .92
156 333	11	43.42	1.32			.96	21.71	.04	22.32	.17			10.45		100.66 .97
157 222	1	36.03	7.68	.08		.59	20.47	.08	24.51	.03		.08	10.90	.02	100.45 .82
158 222	1	35.90	7.65	.03		.65	20.70	.03	24.54	.04		.07	10.90	.02	100.39 .82
159 222	1	36.23	7.37	.03		.60	21.53	.05	24.14	.02		.1	10.90	.03	100.66 .83
160 333	7	34.02	8.73	.17	.03	.25	17.77	.06	25.62	.09			10.70		97.64 .80
161 333	7	34.44	8.95		.03	.26	19.35	.13	25.46	.07			10.53		99.72 .79
162 13	135	40.72	2.78			1.16	23.15	.03	22.07	.01		.01	10.63	.01	100.57 .94
163 13	135	40.32	2.94	.03		1.03	23.72	.05	21.81	.01		.05	10.53	.01	99.68 .93
164 13	135	37.50	4.44	.03		2.38	21.69	.04	23.30	.02		.04	10.67	.01	100.12 .89
165 333	123	36.10	6.36	.02		.99	21.64	.07	23.54	.11		.0	10.70		98.99 .85
166 333	123	37.14	5.57	.02		.95	21.39	.03	23.36	.12		.03	10.69	.01	99.60 .87
167 333	123	38.31	4.98	.04		1.06	21.71	.05	23.56	.03		.03	10.75	.01	100.33 .88
168 13	69	31.43	11.16	.04		.43	20.05	.03	26.10	.02	.40		11.03	.17	100.52 .71
169 13	69	29.13	13.64			.52	19.57	.03	25.82	.03	.27		11.1	.11	100.03 .68
170 13	69	30.41	11.90	.04		.50	20.25	.03	25.99	.05	.33		11.10	.14	100.16 .72
171 13	69	28.27	12.93	.06		.38	20.14	.06	26.27	.03	.34		11.10	.14	99.44 .69
172 8	100	33.52	8.88	.05		1.06	21.54	.14	24.37	.04	.41	.03	10.86	.18	100.72 .79
173 8	100	32.54	9.41	.05		1.04	20.32	.19	25.00	.09	.45		10.76	.19	99.60 .78
174 8	100	37.56	6.58	.02		1.07	21.52	.05	24.50	.06	.59		10.71	.25	102.03 .85
175 8	100	34.87	8.43	.05		.88	21.51	.07	25.16	.04	.4		10.71	.18	99.97 .81
176 18	84	37.54	5.54	.02		1.16	21.60	.08	23.83	.02		.01	10.83	.01	100.65 .87
177 18	84	41.78	3.01	.03		1.09	21.88	.05	22.40	.02			10.41	.01	100.87 .93
178 18	84	34.10	8.01	.03		1.15	21.70	.04	24.08	.06		.03	10.96	.01	100.17 .81
179 8	61	40.76	3.41	.02		1.20	22.84	.04	22.18	.04		.04	10.67	.03	101.23 .92
180 8	61	40.87	3.37	.02		1.61	22.36	.07	22.53	.06		.04	10.72	.01	101.64 .90
181 8	61	40.41	3.22	.02		1.57	22.08	.06	22.77	.14		.03	10.65	.01	100.97 .93
182 8	61	41.25	3.54			1.56	22.16	.06	22.26	.00		.04	10.35	.01	101.70 .92

* Note Drill Hole and Depth may be replaced by original sample number, as per Part a.

Note also that a blank space indicates below detection limit, and a dashed line indicates that no analysis is available.*

Note Depth is in metres from surface.

Note all iron is assumed divalent and is noted as Fe_T.

APPENDIX 5

MICROPROBE DATA OF TOURMALINE
FROM THE OLIVER CREEK TIN OCCURRENCE

Part a. Key to Codes used to Identify Tourmaline

I. Sample number (including numbers 1-77).

II. Drill hole number (#'s 5-20), or original sample number (first part)(333 - traverse number, 79 - sample from Billiton of unknown location.

III. Depth (in metres), or original sample number (second part).

IV. Host rock type:

(1) quartzite (+ veins)	A	(6) granite	C
(2) schist (+ veins)	B	(8) tourmaline breccia	D

V. Occurrence Type

(1) breccia matrix	(6) granular (between grains in granite)
(2) vein material, pod, or clast	
(5) along the foliation of country rock (or porphyroblasts)	

VI. Paragenesis

(1) unknown	(5) core of zoned grain
(2) early (clast)	(6) rim
(3) intermediate (matrix)	(7) later than chlorite
(4) late (vein cutting breccia)	

VII. Grain Size

- (1) fine
- (2) medium
- (3) coarse

VIII. Metallic Mineral Association

(1) none	(5) cassiterite+sulphides
(3) rutile	(7) sulphides+rutile
(4) sulphides	

IX. Gangue Mineral Association

(1) none	(6) chlorite+muscovite
(2) chlorite	(7) chlorite+biotite+muscovite
(4) muscovite	(12) fluorite+chlorite+muscovite
(5) chlorite+biotite	

X. Clast Type

- (1) not applicable
- (2) country rocks (CRX)
- (3) vein quartz + CRX

- (4) vein tourmaline + CRX
- (9) vein quartz+tourmaline + CRX

XI. Colour

- (1) dark brown
- (2) brown
- (3) light brown
- (4) orange-brown
- (5) orange

- (6) green & green brown
- (7) light blue
- (8) dark blue
- (9) colourless
- (10) blue green

Part b.

CHARACTERISTICS OF ANALYSED TOURMALINE GRAINS (IN CODE) *

SAMPLE No.	DRILL HOLE	DEPTH	HOST ROCK	OCCUR TYPE	PARA-GEN.	GRAIN SIZE	ORE MIN.	GANGUE MIN.	CLAST TYPES	COLOUR
1	19	147	8	2	3	2	1	1	1	7
2	17	147	8	2	2	3	3	1	1	2
5	19	141	8	2	2	3	1	1	1	1
6	19	141	1	1	3	2	3	7	2	1
7	19	141	8	2	2	3	1	1	1	2
8	19	145	1	1	1	3	1	6	3	2
9	19	145	1	1	1	3	1	6	3	10
10	14	93	1	1	1	1	7	5	4	6
11	18	81	1	1	1	3	3	2	2	6
13	18	81	1	2	1	3	3	2	1	6
14	19	141	1	1	1	2	3	6	3	2
15	19	144	1	1	1	2	3	6	3	2
16	19	144	1	1	1	2	3	6	3	2
17	19	144	1	1	1	3	3	6	3	2
18	19	144	1	1	1	2	3	6	3	2
19	79	48	1	1	1	1	1	6	3	2
20	79	48	1	1	1	1	1	6	3	6
21	79	48	1	1	1	3	1	6	3	6
22	79	48	1	1	1	2	1	6	3	2
23	79	48	1	1	1	2	1	6	3	2
24	79	48	1	1	1	1	1	6	3	2
25	20	198	1	2	1	3	5	6	1	3
26	20	198	1	2	1	3	5	6	1	3
27	20	198	1	1	1	2	5	6	2	3
28	20	198	1	1	1	2	5	6	2	3
29	20	198	1	2	1	3	5	6	1	3
30	20	198	1	2	1	1	5	6	1	3
31	20	198	1	2	5	3	5	6	1	3
32	20	198	1	2	6	3	5	6	1	3
33	20	198	1	2	1	3	5	6	1	3
34	20	198	1	1	1	1	5	6	2	3
35	79	45	1	2	1	3	5	6	1	3
36	79	45	1	2	1	1	5	6	1	6
37	79	45	1	2	1	3	5	6	1	2
38	79	45	1	2	1	3	5	6	1	3

CHARACTERISTICS OF ANALYSED TOURMALINE GRAINS (IN CODE)*

SAMPLE No.	DRILL HOLE	DEPTH	HOST ROCK	OCCUR TYPE	PARA-GEN.	GRAIN SIZE	ORE MIN.	GANGUE MIN.	CLAST TYPES	COLOUR
39	79	45	1	2	1	3	5	6	1	2
40	79	45	1	2	1	1	5	6	1	2
41	79	45	1	2	1	2	5	6	1	2
42	14	94	1	1	1	2	3	2	4	1
44	14	94	1	1	1	3	3	2	4	9
45	14	94	1	1	1	3	3	2	4	9
46	14	94	1	1	1	1	3	2	4	2
47	5	69	8	2	2	3	1	1	1	9
48	5	69	1	1	3	1	1	6	9	1
49	5	69	8	2	2	3	1	1	1	9
50	5	69	8	2	2	3	1	1	1	9
51	20	254	8	2	2	2	1	1	1	3
52	20	254	8	2	2	2	1	1	1	3
53	20	254	8	2	2	3	1	1	1	3
54	14	170	1	5	1	2	1	1	1	3
55	14	170	1	5	1	2	4	1	1	3
56	14	170	1	2	1	2	4	6	1	3
47	14	170	1	2	1	3	4	6	1	3
58	14	170	1	2	1	3	4	6	1	3
59	8	40	2	2	1	3	3	2	1	6
60	8	40	2	2	1	3	3	2	1	6
61	8	40	2	2	1	2	3	2	1	6
62	13	134	10	2	7	2	3	2	1	3
63	333	8	6	6	5	3	1	4	1	5
64	333	8	6	6	6	3	1	4	1	8
65	333	8	6	6	5	3	1	4	1	5
66	333	8	6	6	6	3	1	4	1	8
67	333	8	6	6	5	3	1	4	1	5
68	333	8	6	6	6	3	1	4	1	8
69	333	121	6	6	1	3	3	12	1	5
70	333	121	6	6	1	3	3	12	1	8
71	333	121	6	6	1	3	3	12	1	5
72	333	121	6	6	1	3	3	12	1	8
73	333	122	6	6	1	2	3	12	1	4
74	333	122	6	6	1	3	3	12	1	5
75	333	124	6	6	1	3	3	12	1	3
76	333	124	6	6	1	2	3	12	1	3
77	333	124	6	6	1	2	3	12	1	9

* Codes are in Part a.

Part c. Microprobe analyses of Oliver Creek tourmaline (weight percent).

Sample Number	Drill Hole	Depth*	FeO _T	MgO	CaO	Na ₂ O	MnO	Al ₂ O ₃	TiO ₂	SiO ₂	K ₂ O	F	Cl	H ₂ O (calc)	-O=F+Cl Total	FeO _T - FeO _T /MgO
1	19	147	11.84	3.53	.25	1.98	.18	31.16	.11	36.26	.10	.31		3.1	.02 89.08	.77
2	19	147	11.93	4.44	.60	2.01	.17	29.22	.46	31.46	.04	.45		3.26	.19 86.85	.77
5	19	141	12.22	5.42	1.17	2.05	.05	27.87	1.58	36.75	.30	.26		3.34	.32 90.82	.67
6	19	141	19.32	6.06	.58	1.56	.33	27.61	.40	32.12	.01	.39		3.29	.21 91.42	.76
7	19	141	13.24	5.23	1.23	2.13	.04	27.74	1.70	35.39	.01	.39		3.20	.25 90.43	.73
8	19	145	13.05	3.20	.18	2.63	.09	31.26	.17	35.46	.04	.48		3.33	.20 89.69	.80
9	19	145	13.33	3.33	.18	2.15	.31	31.08	.25	34.94	.02	.40		3.33	.17 88.88	.80
10	14	93	12.17	6.12	.91	1.58	.12	30.33	.31	34.73	.03	.58		3.41	.09 89.89	.6
11	18	81	9.60	4.88	.51	2.31	.52	29.0	.35	34.32		.58		3.30	.24 88.50	.66
13	18	81	9.57	4.37	.34	2.17	.33	27.07	.35	35.97	.03	.42		3.43	.18 89.54	.60
14	19	144	9.20	4.79	.67	1.82	.34	27.77	.32	35.35	.03	.42		3.43	.16 89.62	.66
15	19	144	10.64	4.54	.44	2.01	.04	32.17	.43	35.41	.02	.53		3.34	.13 89.59	.70
16	19	144	10.25	6.77	1.53	1.99	.29	29.10	.70	35.52	.02	.31		3.39	.12 90.03	.51
17	19	144	10.37	3.04	.38	1.93	.03	32.67	.45	35.22	.02	.62		3.38	.22 89.13	.73
18	19	144	10.14	3.03	.50	2.01	.32	28.86	.49	35.40	.02	.57		3.36	.24 90.15	.67
19	79	48	12.22	4.28	.61	2.65	.05	28.71	1.32	35.12	.06	.43		3.33	.35 88.43	.71
20	79	48	10.86	4.38	.20	2.13	.03	32.63	.28	35.83	.04	.35		3.43	.15 90.01	.71
21	79	48	8.71	5.55	.61	2.06	.33	28.18	.37	35.72	.03	.30		3.42	.09 89.92	.61
22	79	48	17.12	6.95	.56	1.41	.14	25.38	.79	31.95	.19	.59		3.12	.25 87.05	.71
23	79	48	9.36	5.15	.33	1.99	.33	31.51	.66	36.30	.04	.47		3.17	.20 81.50	.67
24	79	48	10.02	5.07	1.01	2.24	.27	27.21	1.18	36.66	.12	.60		3.33	.25 82.09	.65
25	20	198	8.45	5.80	1.10	1.82	.12	32.59	.43	35.46	.04	.44		3.42	.19 89.48	.56
26	20	198	8.98	5.29	.93	1.73	.11	32.36	.56	35.06	.14	.50		3.36	.21 88.81	.53
27	20	198	9.07	5.86	.94	1.94	.11	32.21	.62	34.99	.04	.49		3.38	.21 89.44	.51
28	20	198	9.64	4.02	.62	1.57	.12	33.94	.54	35.16	.05	.67		3.30	.28 89.35	.71
29	20	198	7.61	6.22	.94	1.94	.12	32.46	.47	35.45	.04	.25		3.50	.11 80.92	.55
30	20	198	9.70	5.92	.68	1.88	.16	32.43	.34	34.80	.06	.27		3.48	.11 89.67	.53
31	20	198	7.31	5.72	.69	1.90	.11	31.81	.70	35.44	.05	.25		3.46	.11 87.31	.56
32	20	198	8.98	4.06	.68	1.40	.15	32.84	.66	33.80	.05	.51		3.27	.21 86.19	.67
33	20	198	9.23	6.06	.97	1.82	.09	32.15	.66	35.45	.03	.29		3.53	.12 90.12	.50
34	20	198	9.35	6.11	.83	1.97	.12	33.59	.43	35.25	.05	.26		3.38	.32 90.52	.61
35	79	45	11.33	3.50	.36	1.93	.14	31.07	.54	35.08	.02	.56		3.24	.25 87.59	.76
36	79	45	10.1	4.71	.26	2.15	.13	31.32	.46	35.23	.33	.53		3.42	.32 88.90	.60
37	79	45	10.34	6.00	1.31	2.02	.18	30.02	1.02	35.09	.07	.91		3.19	.18 89.72	.63
38	79	45	9.36	5.13	.64	2.08	.11	32.66	.32	34.85	.06	.30		3.30	.13 88.82	.65
39	79	45	10.38	5.56	.45	1.91	.12	31.39	.92	35.73	.16	.46		3.36	.15 90.10	.67
40	79	45	13.37	3.87	.50	2.56	.17	29.55	.94	35.00	.06	.91		3.13	.38 90.27	.79
41	79	45	6.95	6.3	.81	2.07	.11	33.73	.14	32.99	.05	.50		3.48	.21 90.31	.51
42	14	94	13.18	2.14	.17	2.00	.31	31.54	.54	34.97	.66	.74		3.20	.31 89.81	.87
44	14	94	13.50	6.67	1.67	2.15	.26	26.59	1.26	34.72		.50		3.39	.21 90.14	.67
45	14	94	15.01	3.49	.48	2.55	.29	27.57	.31	34.71	.01	.51		3.22	.23 89.31	.81
46	14	94	9.70	5.64	.59	1.96	.31	42	.82	35.72		.53		3.57	.03 89.31	.53
47	5	69	3.2	4.02	.30	1.88	.42	20	.38	36.07		.6		3.53	.03 89.64	.6
48	5	69	10.3	1.33	.46	1.91	.31	63	.15	34.74		.21		4.20	.03 87.41	.6
49	5	69	10.33	3.59	.57	1.96	.32	35.21	.37	35.21		.25		3.51	.09 90.01	.60
50	5	69	11.3	5.37	.56	1.86	.32	24	.43	35.30		.25		3.6	.11 88.62	.67

Part c (cont.)

Sample Number	Drill Hole*	Depth*	FeO _T	MgO	CaO	Na ₂ O	MnO	Al ₂ O ₃	SiO ₂	K ₂ O	F	Cl	H ₂ O (calc)	-O-F+Cl-Total	FeO FeO _T 100
51	20	254	19.06	4.89	.19	1.28	.14	28.62	.20	30.58	.02		3.59	.89.68	.80
52	20	254	13.27	2.19	.04	1.86	.08	33.90	.33	35.86	.02		3.47	.19 91.34	.86
53	20	254	13.84	2.53	.08	2.20	.08	32.04	.74	35.59	.66		3.30	.27 91.45	.85
54	14	170	7.06	5.96	.60	1.61	.35	31.31	.37	36.48	.06		3.65	.91.19	.54
55	14	170	6.93	5.52	.65	1.71	.36	30.09	.21	36.07	.03		3.72	.90.93	.53
56	14	170	8.64	5.02	.44	1.25	.50	30.02	.35	35.81			3.60	.90.22	.43
57	14	170	8.15	5.71	.63	1.82	.33	31.75	.64	35.78	.01		3.64	.90.14	.59
58	14	170	7.67	4.53	.43	1.82	.44	35.88	.44	35.88	.07		3.62	.88.51	.63
59	8	40	12.70	2.59	.71	2.27	.04	31.94	.45	35.02			3.56	.89.28	.83
60	8	40	11.39	3.68	.23	2.43	.06	33.74	.22	36.14	.03		3.63	.91.59	.76
61	8	40	12.60	3.39	.79	2.16	.04	31.54	.61	35.00			3.45	.10 89.72	.79
63	333	8	14.62	1.52	.27	1.90	.16	31.42	.49	34.15	.03		3.04	.50 91.29	.92
64	333	8	13.07	3.39	.48	2.12	.09	32.99	.21	35.63	.01		3.14	.45 91.74	.79
65	333	8	14.72	1.40	.30	2.14	.14	33.80	.82	34.35	.03		3.14	.41 91.40	.91
66	333	8	11.63	4.54	.60	2.27	.09	32.28	.16	34.21	.02		3.16	.44 91.56	.72
67	333	8	13.81	1.41	.23	1.94	.15	34.17	.70	34.88	.05		3.14	.42 91.06	.91
68	333	8	9.44	4.95	.42	2.02	.05	34.00	.03	36.24	.00	.05	3.52	.13 90.86	.66
69	333	121	15.41	2.52	.13	2.34	.10	31.30	.71	35.29	.03		3.92	.60 91.57	.83
70	333	121	12.67	2.64	.09	2.00	.08	34.00	.23	35.42	.09		3.29	.30 90.92	.83
71	333	121	15.07	2.68	.09	2.48	.10	31.12	.82	35.18	.03		2.88	.63 91.32	.85
72	333	121	13.33	2.69	.05	2.30	.10	32.75	.19	35.35	.04		3.20	.35 90.48	.83
73	333	122	13.67	2.77	.08	2.50	.10	30.73	.95	33.45	.03		2.95	.47 87.79	.83
74	333	122	14.30	2.79	.72	2.41	.31	31.38	.60	34.49	.05		3.73	.29 90.37	.84
75	333	124	15.02	2.34	.17	2.31	.07	31.65	.62	34.22	.03		3.07	.43 90.08	.87
76	333	124	14.56	2.11	.07	2.29	.04	33.27	.42	34.70	.03		3.18	.34 90.16	.87
77	333	124	15.50	.12	.06	1.74	.30	32.64	.28	34.06	.48		3.15	.31 88.50	.99

*Note: Drill Hole and Depth may be replaced by original sample number, as per Part a.

Note also that a blank space indicates below detection limit, and a dashed line indicates that no analysis is available.

Note Depth is in metres from surface.

Note all iron is assumed divalent and is noted as FeO_T.

APPENDIX 6

MICROPROBE DATA OF BIOTITE
FROM THE OLIVER CREEK TIN OCCURRENCE

Part a. Key to Codes used to Identify Biotite

- I. Sample number (including numbers 1-16).
- II. Original sample number (first part)(222 and 333 - traverse number, 79 - Sample from Billiton of unknown location).
- III. Original sample number (second part).
- IV. Host rock type:

(1) quartzite (+ veins)	A	(7) biotite latite	C
(6) granite	B	(12) biotite breccia	E
- V. Occurrence Type

(1) breccia matrix	(6) granular, clot, or
(2) vein material	porphyroblastic
- VI. Paragenesis

(1) unknown	(3) intermediate (matrix)
(2) early (clast)	
- VII. Grain Size

(1) fine
(2) medium
(3) coarse
- VIII. Metallic Mineral Association

(1) none
(3) rutile
- IX. Gangue Mineral Association

(1) none
(3) chlorite
- X. Clast Type

(1) not applicable
(13) vein muscovite+chlor. + CRX

Part b.

CHARACTERISTICS OF ANALYSED BIOTITE GRAINS (IN CODE ★)

SAMPLE No.	DRILL HOLE	DEPTH	HOST ROCK	OCCUR TYPE	PARA- GEN.	GRAIN SIZE	ORE MIN.	GANGUE MIN.	CLAST TYPES
3	79	67	1	1	3	1	1	3	13
4	79	67	1	1	3	1	1	3	13
5	79	67	12	2	2	2	1	1	1
6	79	67	1	1	3	1	1	3	13
7	79	67	12	2	2	1	1	1	1
9	333	1	6	6	1	2	1	1	1
10	333	7	6	6	1	3	3	3	1
11	333	7	6	6	1	3	3	3	1
12	333	7	6	6	1	3	3	3	1
13	333	7	6	6	1	3	3	3	1
14	333	10	6	6	1	3	3	3	1
15	333	10	6	6	1	3	3	3	1
16	333	10	6	6	1	3	3	3	1

*Codes are in Part a.

Part c. Microprobe analyses of Oliver Creek biotite (weight percent).

Sample Number	Drill Hole*	Depth*	FeO _T	MgO	CaO	Na ₂ O	MnO	Al ₂ O ₃	TiO ₂	SiO ₂	K ₂ O	F	Cl	H ₂ O (calc)	-O=F+Cl	Total	FeO _T - FeO _T +MgO
3	79	67	19.78	9.09	.15	.13	.28	19.60	1.65	36.17	8.38		.12	3.21	.05	99.26	.69
4	79	67	19.75	9.62	.11		.27	20.49	1.72	35.62	8.47		.08	3.97	.02	100.09	.67
5	79	67	20.51	9.08	.02		.33	20.70	1.30	35.16	8.18		.22	3.89	.02	99.97	.69
6	79	67	19.31	9.21	.05	.03	.26	20.55	1.80	35.15	7.39		.14	3.89	.04	97.54	.68
7	79	67	20.17	8.96	.04		.27	20.44	1.65	35.35	8.69		.16	3.92	.01	99.61	.69
9	222	1	29.20	6.33	.42		.24	21.61	.67	32.39	7.68		.28	3.84	.06	102.62	.82
10	333	7	25.77	6.48		.11	.27	15.93	3.40	35.12	8.64	.83	.26	3.37	.41	99.78	.80
11	333	7	26.43	6.37	.17	.10	.24	16.49	3.60	35.66	9.03	.88	.19	3.45	.41	102.20	.81
12	333	7	25.43	6.54		.10	.29	16.13	3.46	35.38	8.98	.64	.17	3.51	.31	100.32	.80
13	333	7	25.27	6.76		.05	.30	16.36	3.37	35.81	9.03	.66	.14	3.50	.31	100.99	.79
14	333	10	25.71	4.27		.10	.48	15.51	2.89	35.58	9.16	1.18	.12	3.25	.52	101.82	.86
15	333	10	25.40	4.17		.09	.50	18.66	3.10	35.83	8.99	1.12	.15	3.24	.59	100.86	.86
16	333	10	25.37	4.04		.05	.54	18.64	2.88	35.49	7.78	1.11	.11	3.28	.50	98.81	.86

*Note: Drill Hole and Depth may be replaced by original sample number, as per Part a.

Note also that a blank space indicates below detection limit.

Note Depth is in metres from surface.

Note all iron is assumed divalent and is noted as FeO_T.

APPENDIX 7

MICROPROBE DATA OF CASSITERITE
FROM THE OLIVER CREEK TIN OCCURRENCE

Part a. Key to Codes used to Identify Cassiterite

- I. Sample number (including numbers 1-77).
- II. Drill hole number (#'s 5-20), or original sample number (first part)(79 - sample from Billiton of unknown location).
- III. Depth (in metres), or original sample number (second part).
- IV. Grain Size
 - (1) fine
 - (2) medium
 - (3) coarse
- V. Shape

(1) not applicable, or broken grain aggregate	(4) anhedral
(2) euhedral	(5) rounded (grain aggregate, or grain) clast
(3) subhedral	
- VI. Occurrence Type
 - (1) crystal in chlorite vein, or breccia matrix
 - (2) clast, or fragment of mineral aggregate contained in chlorite matrix
 - (3) indistinguishable
- VII. Zonation
 - (1) none
 - (2) core of grain
 - (3) rim of grain
- VIII. Metallic Mineral Association

(1) none	(3) rutile + ilmenite
(2) sulphides	(4) sulphides+rutile

Part b.

CHARACTERISTICS OF ANALYSED CASSITERITE GRAINS (IN CODE) *

SAMPLE No.	DRILL HOLE	DEPTH	GRAIN SIZE	SHAPE	OCCUR TYPE	ZONATION	MIN. ASSOC.
1	79	77	1	2	3	1	1
2	79	77	3	4	1	1	1
3	79	77	1	5	2	1	1
4	79	77	3	1	2	1	1
5	79	77	1	1	2	1	1
6	79	77	2	1	2	1	1
7	79	127	3	3	3	1	2
8	79	127	3	3	3	1	2
9	79	127	3	1	2	1	2
10	79	113	3	3	3	1	2
11	79	113	1	3	3	1	2
12	79	113	3	5	2	1	2
13	79	113	2	5	2	1	2
14	79	113	3	4	3	1	2
15	79	113	2	1	2	1	2
16	79	113	3	1	3	1	2
17	79	113	3	1	2	1	2
18	79	154	2	3	1	2	1
19	79	154	2	3	1	3	1
20	79	154	2	3	1	2	1
21	79	154	2	3	1	3	1
22	79	154	2	3	1	3	1
23	79	154	3	4	3	1	1
24	79	74	1	3	3	1	1
25	79	74	2	3	3	1	1
26	79	74	2	3	3	1	1
27	13	114	3	2	1	1	2
28	13	114	3	3	1	1	2
29	13	114	2	4	1	1	2
30	79	118	3	2	3	1	3
31	79	118	2	5	2	1	3
32	79	118	2	5	2	1	3
33	79	118	3	1	2	1	3
34	79	118	2	1	2	1	3
35	79	118	3	3	3	1	3

Part b (cont.)

CHARACTERISTICS OF ANALYSED CASSITERITE GRAINS (IN CODE) *

SAMPLE No.	DRILL HOLE	DEPTH	GRAIN SIZE	SHAPE	OCCUR TYPE	ZONATION	MIN. ASSOC.
36	79	118	3	5	2	1	3
37	79	118	1	3	3	1	3
38	79	32	3	1	2	1	3
39	79	32	3	1	2	1	3
40	79	32	3	3	3	1	3
41	79	32	3	3	3	1	3
42	79	32	2	5	2	1	3
43	79	32	1	4	3	1	3
44	79	24	3	5	2	1	2
45	79	24	3	5	2	1	2
46	79	24	3	4	3	1	2
47	79	24	1	3	3	1	2
48	79	24	1	2	3	1	2
49	79	30	2	5	2	1	3
50	79	30	3	5	2	1	3
51	15	78	3	1	2	1	3
52	15	78	2	5	2	1	3
53	15	78	3	3	3	1	3
54	15	78	2	2	3	1	3
55	15	78	3	5	2	1	3
56	13	144	3	2	1	1	4
57	13	144	3	3	1	1	4
58	13	144	3	3	1	1	4
59	79	139	1	3	2	1	2
60	79	139	2	3	2	1	2
61	79	139	1	3	2	1	2
62	79	139	3	5	2	2	2
63	79	139	2	3	2	1	2
64	79	139	2	5	2	1	2
65	79	139	3	1	2	1	2
66	79	139	2	5	2	1	2
67	13	127	3	4	1	1	2
68	13	127	1	3	1	1	3
69	13	127	2	1	2	1	3

* Codes are in Part a.

Part c. Microprobe analyses of Oliver Creek cassiterite (weight percent).

Sample Number	Drill Hole*	Depth*	TiO ₂	Ta ₂ O ₅	MnO	WO ₃	FeO	Nb ₂ O ₅	AgO	ZrO ₂	SnO ₂	Total
1	79	77	.21	.15	.03		.23				100.85	101.50
2	79	77	.76		.02		.22				99.52	100.80
3	79	77	.09				.36				100.41	100.90
4	79	77	.11		.03		.30		.06		100.37	100.90
5	79	77	.24		.04		.19				99.44	99.98
6	79	77	.10		.04		.03				99.41	99.65
7	79	127	.10		.01						101.05	101.20
8	79	127	.10		.02		.10				99.87	100.10
9	79	127	.06		.02		.15				99.72	99.96
10	79	113	.14	.16			.25	.03		.18	100.25	101.00
11	79	113	.02	.18			.05			.37	100.53	101.20
12	79	113	.03								100.63	100.80
13	79	113	.05	.13			.06				99.90	100.20
14	79	113	.09			.20					100.44	100.90
15	79	113	.25	.21			.13				99.69	100.30
16	79	113	.06				.04	.03			100.39	100.60
17	79	113	.09	.12			.03	.03			99.00	99.26
18	79	154	.58		.17		4.63	.20			93.42	99.00
19	79	154	.70				2.27	.11			97.95	101.10
20	79	154	1.00				.09				98.15	100.83
21	79	154	.15	.12							100.22	100.60
22	79	154	.39	.16			.06				98.03	98.78
23	79	154	.21							.14	98.66	99.13
24	79	74	.05		.02		.10			.28	100.84	101.30
25	79	74	.09		.02		.02		.07	.12	99.22	99.58
26	79	74	.81		.02		.09				99.76	100.80
27	13	114	.67		.01		.16		.13		100.45	101.50
28	13	114	.73				.20		.08		98.80	99.87
29	13	114	.91				.35		.14		97.74	99.15
30	79	118	.08	.34		.10	.59	.07		1.28	97.53	100.00
31	79	118		.41			.18	.05	.07	1.48	96.75	98.95
32	79	118		.46			.39	.06		.96	98.57	100.40
33	79	118		.39			.31	.06		1.04	97.98	99.82
34	79	118	.34	.41		.11	.87	.06		1.22	97.38	100.40
35	79	118	.26	.49			.21	.06		1.18	97.33	99.56
36	79	118		.43		.42	.77	.07			99.43	101.20
37	79	118		.42			.21	.06		1.34	99.23	101.30
38	79	32	.16	.37			.20	.06		.99	98.15	99.73
39	79	32	.07	.40			.28	.07		1.18	97.37	99.38
40	79	32	.38	.41			.17	.07		1.41	97.27	99.71
41	79	32		.37		.18	.17	.06		1.01	97.43	99.25
42	79	32	.06	.37		.15	.13	.06		1.14	97.97	99.89
43	79	32		.34		.29	.33	.07		1.23	96.72	98.99
44	79	24	.20	.25	.04					.35	100.41	101.30
45	79	24	.08	.16	.02		.14		.07	.11	99.90	100.50
46	79	24	.66	.14	.03		.10		.14	.21	98.10	99.40
47	79	24	.13		.02		.15	.03	.11	.17	98.08	98.77
48	79	24	.14	.12	.02		.26	.03	.14		98.55	99.34
49	79	30	.21	.16	.03		.06		.12	.16	100.62	101.40
50	79	30	.09	.19	.04		.08		.09	.23	100.80	101.50

Part c (cont.)

Sample Number	Drill Hole*	Depth*	TiO ₂	Ta ₂ O ₅	MnO	WO ₃	FeO	Nb ₂ O ₅	AgO	ZrO ₂	SnO ₂	Total
51	15	78	.77	.25	.02		1.44	.07			98.61	101.20
52	15	78	.01		.03		.33				99.15	99.63
53	15	78	.07	.28	.03	.45	1.08	.04			98.41	100.40
54	15	78	.08	.23	.03		.18			.24	98.99	99.74
55	15	78		.21	.02		.23				99.91	100.40
56	13	144	1.02	.15	.02		.35				99.19	100.70
57	13	144	1.18	.16		.35	.41			.63	98.40	101.10
58	13	144	.94				.16			1.14	99.11	101.30
59	79	139		.17	.03		.44		.08		99.69	100.40
60	79	139	.16	.24	.05		.62		.06		100.03	101.20
61	79	139	.09	.18	.04		.65	.03			98.30	99.36
62	79	139	.14	.15	.11		.19			.26	100.01	100.90
63	79	139			.01		.27		.06	.83	99.07	100.30
64	79	139			.02	.28	.66		.06	.73	97.68	99.55
65	79	139		.12	.03		.18				100.23	100.60
66	79	139	.25			.39	.19			.53	99.85	101.20
67	13	127	.62				.23			1.13	98.01	100.00
68	13	127	.16		.01		.65		.07	.97	98.72	98.80
69	13	127					.42				98.65	99.10

* Note: Drill Hole and Depth may be replaced by original sample number, as per Part a. Depth is in metres from surface.

Note also that a blank space indicates below detection limit.

Note all iron is assumed divalent.

END

2	5	0	2	8	6
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FIN