Preliminary studies of hydrothermal alteration events at the Island Copper deposit, northern Vancouver Island, British Columbia

Craig H.B. Leitch, Katherina V. Ross, John A. Fleming[1], and K.M. Dawson

Mineral Resources Division, Vancouver

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Abstract: Core logging/pit mapping suggest three main stages of intrusion (early, intermediate, late), defined by differences in alteration intensity. Hydrothermal events comprise early biotite-magnetite "hornfels", followed by magnetite-actinolite-plagioclase veining, and then quartz-chalcopyrite veins and fractures with or without "hydrothermal" biotite envelopes. Chlorite-sericite ± clay are likely retrograde overprints as the system cooled and collapsed inwards; epidote may be prograde peripheral, retrograde, or both. Chalcopyrite was introduced in several stages: minor with magnetite-biotite, followed by main-stage disseminations/fracture fills accompanying quartz veins, some with biotite envelopes, and finally with epidote-chlorite and pyrite-chalcopyrite filled fractures. Fluid inclusions in quartz-magnetite veins are highly saline (multiple daughter products); in quartz-chalcopyrite veins saline (halite only); in late veins or reopenings associated with epidote less saline (liquid/vapour only).

Résumé : De nombreux indices géologiques ont été découverts d'un ou de plusieurs séismes d'importance qui ont secoué la zone de subduction de Cascadie il y a environ 300 ans. Les séismes ont provoqué de fortes secousses, une subsidence crustale et de gigantesques tsunamis le long de la côte du Pacifique, depuis l'île de Vancouver jusqu'au nord de la Californie. Ils ont dû affecter grandement les habitants de ces régions. Les traditions orales des Amérindiens de la côte du Nord-Ouest font état, quoiqu'avec des exagérations, de tsunamis provoqués par ces événements rares, se produisant à la frontière de plaques. Le plus ancien séisme connu de la période historique en Colombie-Britannique a eu lieu en février 1793 et a été consigné par des explorateurs espagnols passant l'hiver dans le détroit de Nootka, dans l'île de Vancouver. Il est possible que ce séisme se soit produit à une faible profondeur dans la croûte ou encore plus profondément, au sein de la plaque Juan de Fuca en subduction.

[1] BHP Minerals Canada Ltd., Island Copper Mine, P.O. Box 370, Port Hardy, British Columbia V0N 2P0

INTRODUCTION

Island Copper is an island-arc type porphyry Cu-Mo-Au deposit (Perelló et al., 1989; Arancibia and Clark, 1990) operated by BHP Minerals Ltd. on northern Vancouver Island near Port Hardy, British Columbia. It resulted from the intrusion of a series of dyke-like bodies of rhyodacitic quartz-feldspar porphyry of about 180 Ma age into possibly comagmatic high-alumina basalts, basaltic andesites, minor rhyolites and pyroclastic rocks of the Middle Jurassic Bonanza Group (Northcote and Robinson, 1973; Muller, 1977; Nixon et al., 1994). The size of the deposit was initially estimated at 257 million tons of ore at 0.52% Cu and 0.017% Mo (Cargill et al., 1976); the final mined plan envisages a total of 377 million tons at 0.41% Cu and 0.017% Mo at a 0.2% Cu cutoff (Perelló et al., in press). Gold has been produced at an annual rate of 1200-1500 kg (40-50 000 oz) from a head grade of 0.19 g/t. Only about 50% of the gold is recovered in the copper concentrate, which averages 24% Cu, 7 g/t Au and also contains 60 g/t Ag. The molybdenum concentrate contains up to 1400 ppm rhenium, making Island Copper Canada's only producer of this element (Perelló et al., in press).

A joint project with the Mineral Resources Division of the Geological Survey of Canada (GSC-MRD), the British Columbia Geological Survey Branch (BCGSB), BHP Minerals Ltd., and Auckland University (New Zealand) has been initiated to study the deeper levels of the deposit before mine closure and pit flooding, anticipated in 1995 or 1996. Project members involved include: Craig Leitch, Katherina Ross, Ken Dawson, Rod Kirkham, Colin Dunn, and Mel Best of the GSC; Graham Nixon, Jan Hammack, Andre Panteleyev, Victor Koyanagi, Steve Sibbick and Peter Bobrowsky of the BCGSB; John Fleming of BHP Minerals; and Stuart Simmons and Geraint Mathias of Auckland University. The objectives of the GSC-MRD team are to study the geology and alteration of the deep exposures and drill core, to better understand the sequence of intrusive, alteration, and mineralizing events at all levels in the deposit. Methods include U-Pb zircon geochronology, fluid inclusion and stable isotope studies, and lithogeochemistry. Other related studies include biogeochemistry over and around the deposit by Colin Dunn of GSC-MRD and depth of overburden using geophysical methods by Mel Best of GSC-Geophysics and Marine Geoscience Branch. The BCGSB team is updating knowledge of the regional geology, mineral deposits, geochronology, and geochemistry of the surrounding part of northern Vancouver Island. A detailed study of the high-level advanced argillic alteration is the focus of the Auckland University members.

PREVIOUS WORK

Since the beginning of production in 1971, the Island Copper deposit has been the subject of numerous geological studies. Brief summaries of the geology were published by Young and Rugg (1971) and Northcote and Robinson (1973). A more detailed description was published by Cargill et al. (1976), and an updated review of the geology was presented by Fleming (1983). Several theses, including those of Cargill (1975), Fahey (1979), and Perelló (1987), have been completed on the deposit; a PhD study by Arancibia, begun in 1977, remains unfinished. The most recent publications include a comprehensive review by Perelló et al. (in press) and partial results of the Arancibia thesis work (Arancibia and Clark, 1990 and in press).

TIMING OF EVENTS

Porphyry intrusions

All phases of the porphyry are texturally and mineralogically similar, and probably of rhyodacite composition (dacite to rhyolite: O.N. Arancibia, in Perelló, 1987). Unaltered porphyry (O.N. Arancibia, unpublished data; Leitch, unpublished data) consists of approximately 20-30% coarse (0.5-1 cm) bipyramidal quartz phenocrysts, 15-30% 2-5 mm plagioclase laths and <5% chloritized biotite books to 2 mm set in a fine (10 to 30 µm) matrix of quartz and K-feldspar or albite. The plagioclase phenocrysts are oscillatory zoned oligoclase-andesine (An_{30-40}) from rim to core (Leitch, unpublished data).

Distribution of the porphyry phases is shown for section 155 through the mine in Figure 1. Three main intrusive events of quartz-feldspar porphyry are recognized in the present study (cf. Perelló, 1987; Perelló et al., in press; Arancibia and Clark, in press), based on differences in alteration/veining intensity, crosscutting relations and included fragments:

Early phase, characterized by intense magnetite-quartz to quartz-magnetite stockwork and/or flooding by disseminated magnetite, frequently leading to total destruction of texture. Quartz-magnetite veins appear to form a continuum with quartz-pyrite±chalcopyrite-molybdenite-magnetite veins. Increasingly quartz-rich veins crosscut magnetite-quartz veins.

Intermediate phase, cut only by rare quartz-magnetite veins and magnetite fractures, and characterized by a general abundance of planar grey quartz-pyrite±chalcopyrite±molybdenite veins. This phase rarely contains clasts of intensely magnetite-quartz stockworked porphyry. It is generally less intensely altered by clay-sericite-chlorite than the early phase, but the contacts are not always clear, as the porphyries are texturally almost identical. Distinction between the phases is based on the abrupt disappearance of intense quartz-magnetite alteration (including the truncation of veins).

Late phase, completely lacking quartz-magnetite stockwork. This phase contains only minor amounts of disseminated magnetite, and clearly truncates quartz-magnetite veining in the early phase (Fig. 2a, b). It is also observed to cut marginal breccia (see below) developed around the early porphyry. Chalcopyrite is restricted to altered mafic mineral sites. Rare quartz±pyrite veins and crosscutting molybdenite on slips occur. Contacts are fresh, sharp and slightly chilled. Inclusions of earlier intrusive phases are common, but crosscutting relations with intermediate porphyry have not been observed.

Breccias

A "marginal breccia" unit mapped around the margins of the early intrusive at Island Copper by previous authors (e.g. Perelló, 1987) appears to be an inclusive term for several breccia types. These range from crackled and hydrothermally veined or stockworked porphyry (unrotated blocks) to heterolithic breccias including volcanic and porphyry clasts (transported blocks) to hydrothermal breccias composed of rounded, intensely altered clasts (highly milled blocks). Matrix to the breccia is difficult to resolve pending petrographic study, but may include some igneous material in addition to the dominant rock flour (cf. Sillitoe, 1989; Perelló et al., 1989). The milled breccia contains clasts of white quartz, dark magnetite-quartz±hematite, and clay-sericite-pyrite altered rock in a matrix of siderite-quartz-hematite-pyrite±chalcopyrite and rare bornite-chalcocite-covellite.

In exposures of marginal breccia, quartz-magnetite veins are cut off in some clasts but cut through other clasts (cf. Padilla-Garza, 1993), indicating several stages of brecciation that possibly overlap the transition from intrusive breccia to hydrothermal breccia associated with the early porphyry. The marginal breccia was not observed to be associated with the intermediate and late porphyries, although Perelló (1987) stated that some breccias post-date the main mineralizing stage.

An extensive area at the west end of the pit is underlain by what has been termed "pyrophyllite-dumortierite breccia"; it has been reported to include fragments of intermediate porphyry and to be cut by late porphyry (Perelló, 1987). Examination of available drill core and pit exposures of this unit, however, suggest an origin by pyrophyllite-dumortierite alteration of a fragmental volcanic rock or intrusion breccia (or both). The location of this breccia adjacent to and transitional

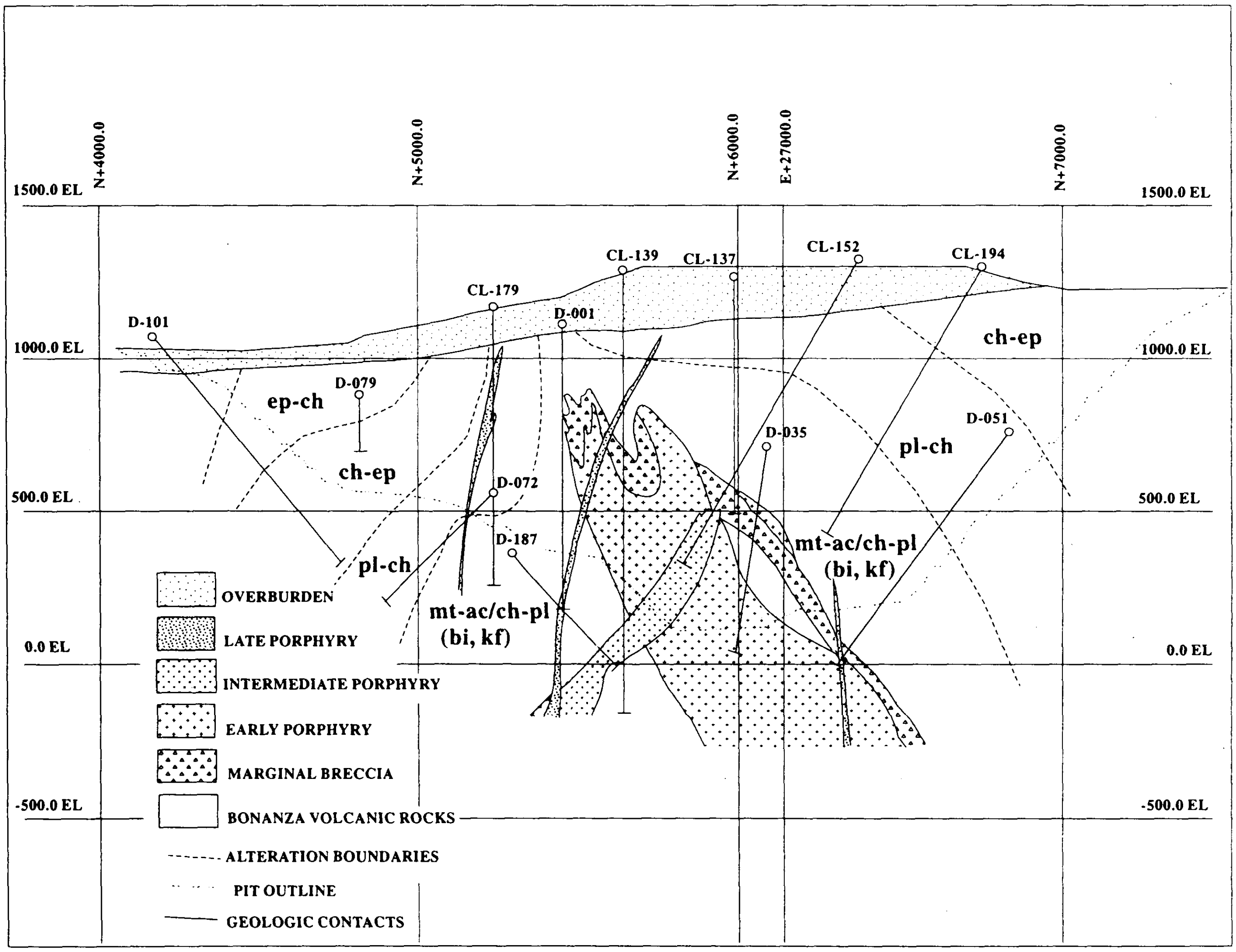


Figure 1. *Cross-section 155W at about 27000 E through the east-central part of the Island Copper deposit to illustrate interpreted geology and alteration zoning. All co-ordinates are in feet (vertical scale same as horizontal scale); mine elevations, used for pit bench designation, are relative to a zero at 1000' below sea level. Abbreviations: ac = actinolite, bi = biotite, ch = chlorite, ep = epidote, kf = K-feldspar, pl = plagioclase, mt = magnetite. Drill hole collars are shown by open circles and identified by number.*

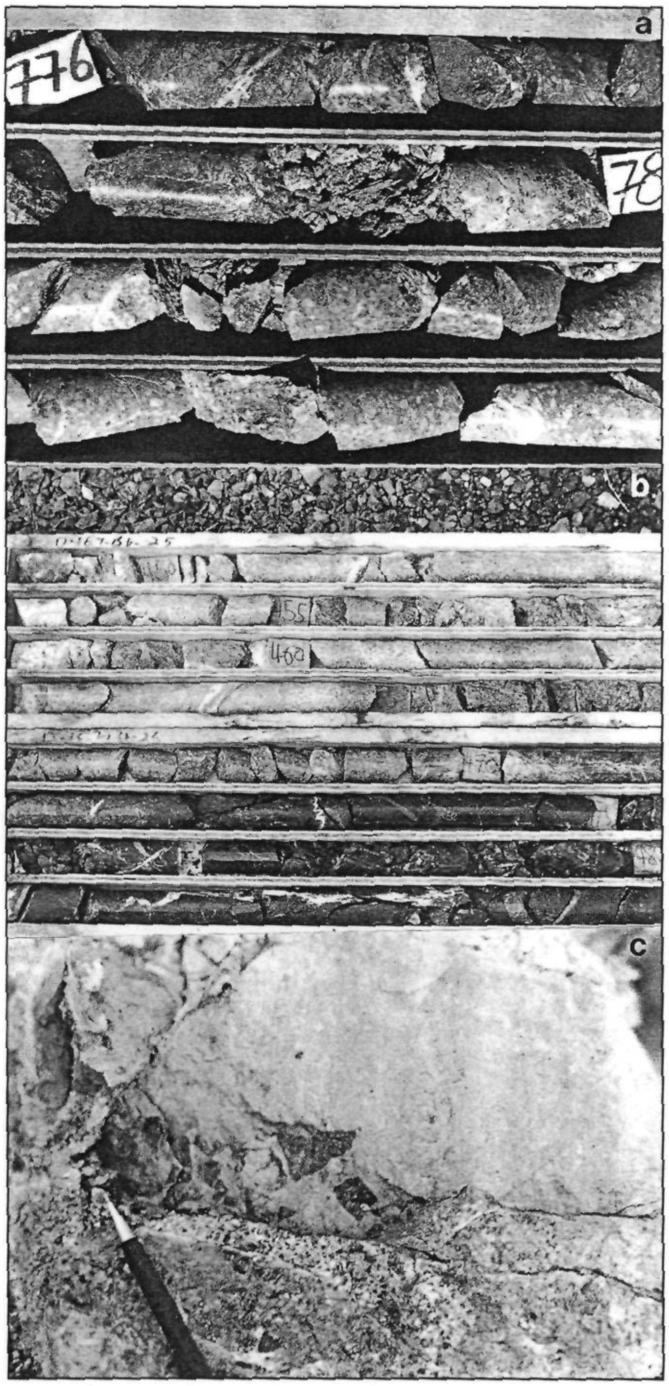
to marginal breccia indicates the possibility that it is an early breccia that has later undergone intense advanced argillic alteration.

Pebble dykes

Late pebble dykes, rarely observed in the pit, generally trend about 325° across the middle of the deposit. These dykes are up to 0.5 m thick and subvertical, and roughly parallel a minor porphyry dyke trend seen in the pit. They have sharp, commonly faulted or sheared contacts. Other examples are observed in drill core, with apparent widths (probably exaggerated in these steep holes) up to several metres. Pebble dykes are divisible into two types: a possibly slightly earlier type that is green, sericitic and strongly pyritic (up to 10% pyrite in the matrix), and a later pink, crumbly and unpyritic type that grades into calcite-zeolite rich fractured or crushed zones. The dykes contain clasts of highly altered and mineralized early porphyry, quartz-magnetite±chalcopyrite veins, and rare clasts of later porphyry in an aplitic-looking matrix (Fig. 2c). The age distinction between the two types is based on the greater degree of alteration, pyritization and lithification of the green type, plus the relation of the pink type to fractured zones. The green type is similar in appearance to some exposures of marginal breccia, implying it may not be much later. Variably pyritic, clay-rich gouge zones are abundant and may in places superficially resemble the pebble dykes, but generally are distinguished by the presence of a less "igneous-looking" matrix (petrography is required to resolve the pebble dyke matrix).

Alteration

A concentric pattern of alteration assemblages developed within the Bonanza volcanic rocks and centred on the porphyritic intrusions, has been recognized by previous authors (Cargill et al., 1976; Fleming, 1983; Perelló et al, in press; Arancibia and Clark, in press). However, the temporal relationships between porphyry intrusion, alteration and mineralization are not yet completely understood. The main alteration assemblages within the Bonanza volcanic rocks recognized in this study are, from innermost to outermost (Fig. 1): magnetite-actinolite/chlorite-plagioclase±biotite ±K-feldspar (Fig. 3a); plagioclase-chlorite (Fig. 3b); and chlorite-epidote. The distinction between actinolite and chlorite is almost impossible to make in hand specimen; in many places both may be present. Biotite appears to be partly relict in the inner two assemblages and partly late (see below). The alteration feldspar is generally albite but ranges from -



a) *Contact (sheared) of intensely magnetite stockworked and flooded early porphyry (dark grey, texture destroyed) with late, pink porphyry (grey, unveined except by calcite-zeolite). Hole E92 at 781 feet, from Bay Lake zone west of the pit.*

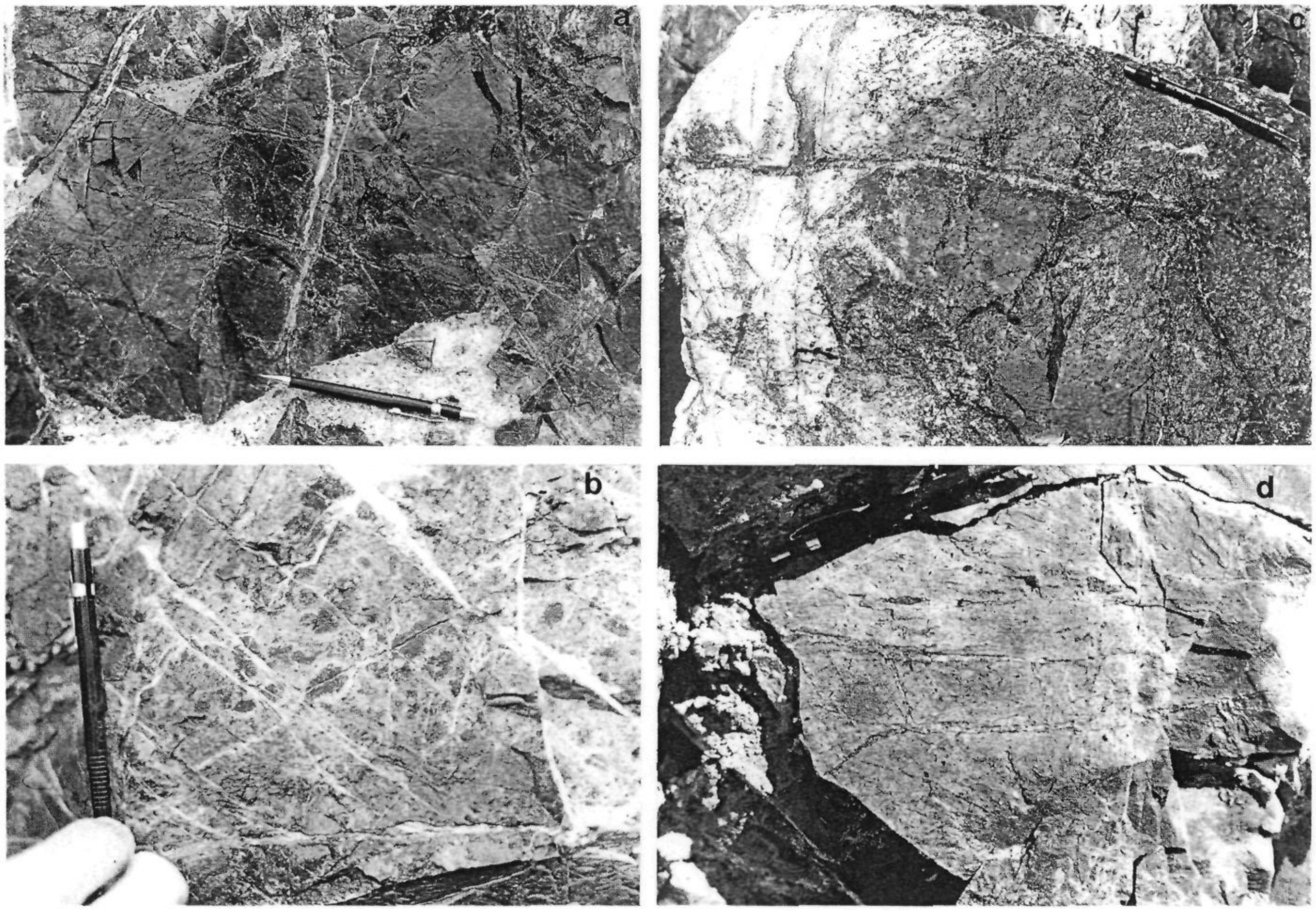
b) *Contact of late porphyry (grey, rare white calcite-zeolite veins) with early porphyry (darker grey, intensely magnetite stockworked) at 469.8' and then of early porphyry with intensely magnetite-actinolite-chlorite altered Bonanza volcanics (black, cut by white calcite-zeolite fractures and grey quartz-sericite-pyrite-clay envelopes). Hole D187, section 155W, centre of pit at 0 level (Fig. 1)*

c) *Pebble dyke (pink type) containing fragments of quartz vein, magnetite flooded early porphyry, and less altered intermediate or late porphyry in an aplitic matrix (southeast wall of pit, 120 level).*

Figure 2. *Contact relations of intrusive phases at Island Copper.*

oligoclase to locally andesine; K-feldspar, likely orthoclase, is also found with increasing alteration intensity closer to the centre of the system or inward in a single fracture envelope (Arancibia and Clark, 1990; Leitch, unpub. data; cf. Leitch, 1981). Pyrite is found throughout all zones. All these alteration types are cut by later, generally structurally controlled, quartz-sericite-clay- pyrite and pyrophyllite-dumortierite alteration assemblages. Plagioclase±chlorite and quartz-sericite-pyrite±clay alteration assemblages are intensely developed locally in both porphyritic intrusions and volcanic rocks. Silicification and magnetite alteration are also moderately to locally intensely developed in the porphyritic intrusive rocks and breccias (Fig. 3c). The distribution of altered intrusive rocks is too variable to show in Figure 1.

The timing of biotite alteration is both significant and contentious. Biotite altered volcanic rock is the most abundant host to copper-gold mineralization. Our observations from pit mapping and drill core logging indicate that a



a) *Biotite alteration as remnant "cores" (dark) in Bonanza volcanics cut by dark magnetite-actinolite ±pyrite veinlets with narrow white plagioclase envelopes, encroached on by albitic alteration (pale grey, on left) and chloritic alteration (grey, on right). Late white calcite-zeolite fractures cut all alteration types (east end of pit, 280 level).*

b) *"Mottled" albite (light grey)-chlorite (dark grey) alteration replacing biotite±magnetite altered Bonanza volcanics, cut by late white calcite-zeolite fractures (east end of pit, 320 level).*

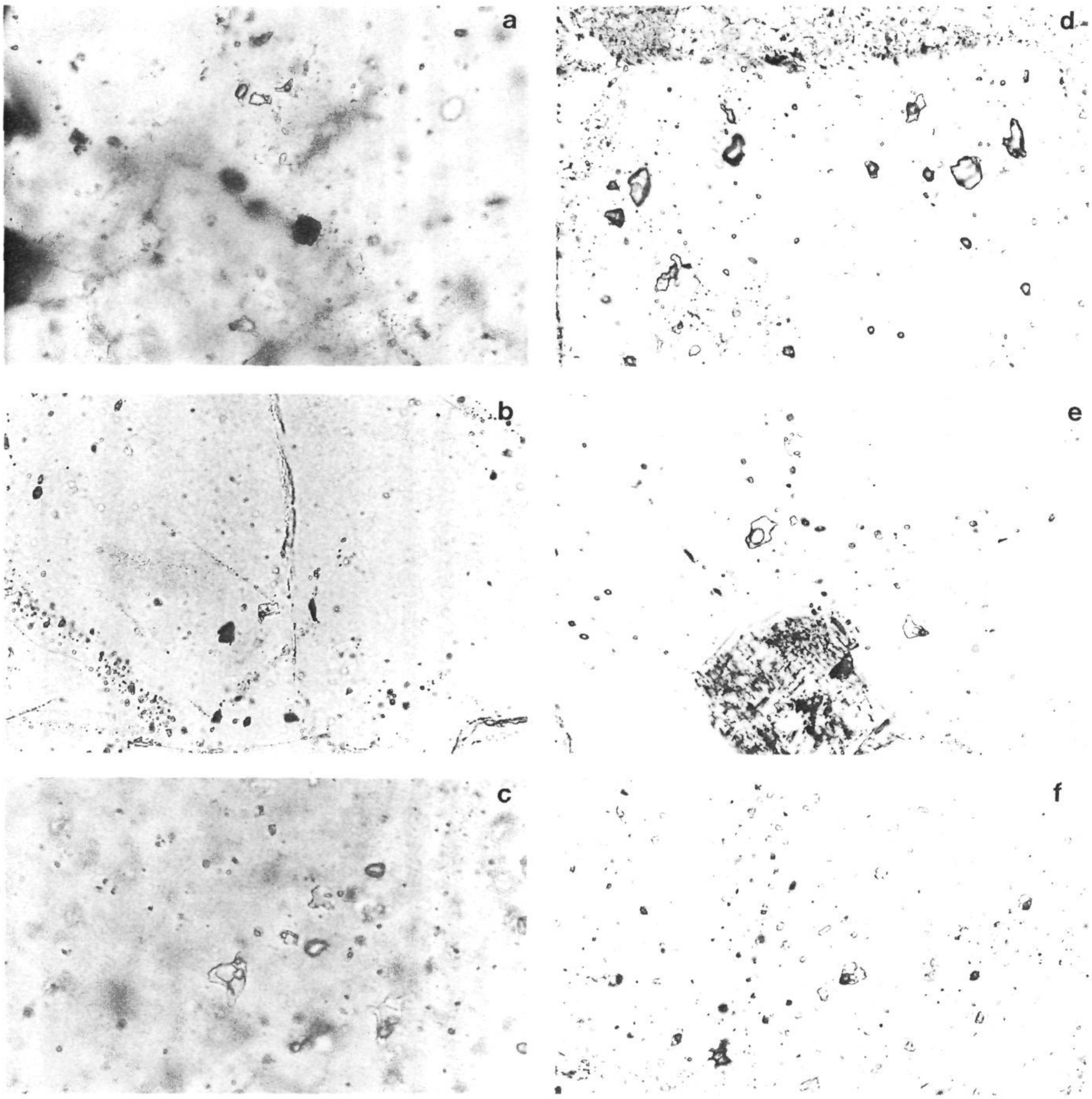
c) *Magnetite-quartz stockwork (dark) in porphyry (east end of pit, 160 level). Bleached area is due to later quartz-sericite-pyrite±clay alteration.*

d) *Late pyrite-chalcopyrite fractures with sericitic envelopes cutting variably biotite-albite altered Bonanza volcanics (north wall of pit, 280 level).*

Figure 3. *Photographs illustrating mesoscopic features bearing on the timing of alteration and mineralization in the Island Copper deposit.*

pervasive biotite alteration is everywhere cut by magnetite-actinolite/chlorite-plagioclase-pyrite-chalcopyrite veinlets. However, in places (rare in the pit; not uncommon in drill core) the magnetite-bearing veinlets are themselves cut by brown biotite-filled fractures and biotite envelopes to quartz-chalcopyrite veins. The biotitic envelopes appear in many places to be retrograded to later sericite. The principal occurrence of the earlier biotite is as widespread remnant "cores" in relatively less fractured areas of the veinlet controlled magnetite-actinolite-plagioclase alteration assemblage (Fig. 3a). Therefore we interpret two biotite episodes: an earlier hornfelsic biotite that predated the magnetite-actinolite/chlorite-plagioclase±chalcopyrite± pyrite alteration, and a later hydrothermal biotite localized along fractures that cut magnetite-bearing alteration assemblages. Biotite-magnetite along with the copper mineralization partly overprints the quartz-amphibole-magnetite "core" assemblage according to Perelló et al. (1989); and biotite-chalcopyrite assemblages that crosscut magnetite have been described by Arancibia and Clark (in press).

Epidote-chlorite hydrothermal alteration assemblages form a peripheral shell that grades outwards to a regional metamorphic assemblage of the same minerals. Quartz-sericite-pyrite±clay alteration assemblages are best developed in the quartz-feldspar porphyry intrusions. It overprints quartz-magnetite stockwork, resulting in a quartz-pyrite stockwork. Locally porphyritic intrusions are reduced to a



mass of clay with rounded quartz crystals and pyrite. The pyrophyllite-dumortierite alteration assemblages that occur in the upper levels of the western end of the pit, apparently overprinting fragmental volcanic rocks and/or breccias (see below), will be the focus of a MSc. thesis by Geraint Mathias at Auckland University.

Mineralization and veining

At the Island Copper deposit, multiple episodes of copper introduction are interpreted from crosscutting relations observed in drill core and pit exposures, but require refining by detailed petrography.

1. The first introduction was near the end of the period of quartz-magnetite veining (e.g. minor chalcopyrite is found with pyrite in magnetite veins in the Bonanza volcanic rocks, particularly in the east end of the pit, north side.
2. The "main-stage" copper introduction involved abundant fine hairline fracture fills and disseminations either accompanying or cutting pervasively biotitized rock – it is not clear which. In places this style of mineralization is accompanied by quartz-pyrite-chalcopyrite veins (±biotite envelopes where they cut volcanics, but not porphyritic intrusive rocks; many of these veins now have sericitic envelopes). This is comparable to the main Cu introduction of Arancibia and Clark (in press).
3. Minor epidote-chlorite±pyrite±chalcopyrite veining may represent either minor introduction or possibly remobilization of copper.
4. Pyrite-chalcopyrite fractures that cut all other veins (Fig. 3d) also possibly represent minor introduction or remobilization of copper.
5. Finally, the minor chalcopyrite present in late calcite-zeolite-gilsonite veins in the north wall of the pit, probably is remobilized copper.

There may have also been several episodes of molybdenum mineralization:

1. The earliest introduction occurs as disseminations, ribbons and parallel fractures in planar, frequently laminated grey-pink quartz veins. These veins are up to 0.3 m in width and occur in sets trending northwest with steep to vertical dips; they can be traced over 30 m.
2. The coarsest molybdenite occurs locally in high grade copper-molybdenum breccias developed in the intermediate porphyry.
3. The most economically significant molybdenite occurs on widespread slips that cut the late pyrite-chalcopyrite fractures.

Sphalerite was observed in rare quartz-?calcite veins peripheral to the main mineralization. It has also been noted in thin sphalerite-rich veins cutting intermediate and late porphyries, giving rise to local zones of over 1% Zn (Perelló, 1987).

Fluid inclusion petrography

A preliminary investigation of fluid inclusions was conducted on 40 thin and polished sections from previous petrographic work done on the Island Copper property. There are at least four types of inclusions present:

- Type 1: One phase or vapour-dominant (no liquid phase visible).
- Type 2: Two-phase aqueous inclusions containing liquid and vapour.
- Type 3: Moderately saline three-phase inclusions containing liquid, vapour and a salt crystal, likely halite.
- Type 4: Highly saline inclusions with multiple daughter products.

Type 1-4 inclusions occur dominantly in vein quartz and in quartz phenocrysts in the porphyries, either isolated or along fracture planes indicating pseudosecondary and secondary origin. No inclusions were observed in recognizable growth zones. Two phase inclusions occur in vein quartz, calcite, K-feldspar and ?zeolite. No temperature or salinity data are available yet for any inclusions.

a) *Type 2 (2-phase) in quartz vein, showing highly variable vapour/liquid ratios from 10 to 70 per cent in a single cluster (hole E96-711').*

b) *Type 3 (3-phase) in quartz-pyrite-chalcopyrite vein, showing vapour bubble, halite crystal, and saline brine (hole E95-387').*

c) *Type 4 (multi-phase) in quartz-magnetite vein, showing vapour bubble, transparent and opaque daughter products, and saline brine (sample 88PPit 010, intensely potassic (biotite-K-feldspar-magnetite-chalcopyrite ±pyrite-molybdenite) altered Bonanza volcanic, from unknown location in pit; note several adjacent vapour-rich inclusions).*

d) *Type 2 (2-phase) in quartz phenocryst from strongly albite-quartz-chlorite-magnetite±pyrite-chalcopyrite altered early porphyry (hole E111-367.5'). Note abundant Type 1 (dark, vapour-rich) examples in the field of view.*

e) *Type 3 (3-phase with halite cube, to right of altered feldspar crystal) and larger Type 2, in quartz phenocryst from clay-sericite-pyrite altered intermediate porphyry cut by calcite-zeolite veins (hole E138-507').*

f. *Abundant Type 4 (multi-phase) inclusions in quartz phenocryst from intensely magnetite-chlorite altered early porphyry cut by calcite-zeolite veins (hole E140-168').*

Figure 4. *Photomicrographs of typical fluid inclusions in quartz from the Island Copper deposit (all in plane polarized light; width of field of view 130 µm except 50 µm in c).*

The vapour-rich inclusions (Fig. 4) are difficult to interpret because of their superficial similarity to decrepitated inclusions that are filled with air. They are variable in size, but tend to be large (over 15 µm) and have rounded, smooth outlines with vapour to liquid ratios 90% or over. There are no visible daughter minerals. These inclusions could contain variable amounts of carbonic (CO_2+CH_4) vapour. Crushing and freezing tests will be necessary to further identify the materials present in these inclusions.

The two phase liquid-vapor inclusions are mainly associated with late quartz, quartz-epidote or chlorite reopenings of main stage quartz veins (Fig. 4a). They are also found in late quartz±calcite±zeolite±K-feldspar veins, or in fractures in quartz phenocrysts in porphyritic intrusive rocks (Fig. 4d). Vapour to liquid ratios are highly variable, from 10 to 90 per cent. These inclusions tend to be small, less than 10 µm in maximum dimension, and are rounded to irregular in shape. No consistent variation in degree of filling with location in the deposit has so far been observed.

The three phase inclusions are associated with the intermediate stage quartz±pyrite±chalcopyrite±magnetite veins, locally with potassic (biotite and/or K-feldspar) alteration envelopes. They contain a liquid phase, a vapour bubble, and a halite cube. These inclusions are the most important from the point of view of the mineralization, but are the least abundant in the veins (Fig. 4b). They also occur in quartz phenocrysts in altered quartz-feldspar porphyry (Fig. 4e). They range in size from 3-12 µm, and are rounded to irregular in shape; liquid to vapour ratios range from 10-40 per cent.

The highly saline, multiphase inclusions are associated with the early stage quartz-magnetite±actinolite/chlorite ±pyrite±chalcopyrite veins. The inclusions are generally in the 5-15 µm size range, with a few up to 30 µm. They have smooth to rounded or irregular shapes (Fig. 4c). The inclusions consist of a liquid phase, a vapor phase, a halite cube, and a variable number of other daughter products. Two colourless, platelet-shaped (one hexagonal), highly birefringent minerals are most common. A red, translucent, hexagonal phase (hematite?) and an opaque phase (magnetite or chalcopyrite?) are less frequently seen. Liquid to vapour ratios range from 10 to 30 per cent. Inclusions of this type were also commonly observed in quartz phenocrysts in intensely quartz-magnetite±actinolite altered quartz-feldspar porphyry (Fig. 4f).

The inclusion populations thus far outlined fit well with the commonly observed progression in porphyry deposits from early high-salinity fluids trapped in veins and phenocrysts to late low-salinity fluids trapped in veins with phyllic alteration envelopes (e.g. Reynolds and Beane, 1985). So-called "blue" quartz veins at Island Copper that contain scattered low-salinity fluid inclusions have been attributed to early quartz that has been recrystallized by later fluids but without affecting the vein envelope mineralogy (J.T. Reynolds, pers. comm., 1994).

Outline of work plan

Geochronology: Three samples of the quartz-feldspar porphyry, representing the early, intermediate and late phases, have been collected for zircon U-Pb dating. These data will complement the zircon U-Pb dating of rhyolitic and andesitic phases of the Bonanza volcanic rocks currently underway on rocks collected by the BCGSB.

Geochemistry: Approximately 50 samples of the main alteration types in volcanic and porphyry and representative, least-altered samples of the three porphyry phases have been submitted for whole-rock and trace element analysis.

Isotope geochemistry: Samples of vein and phenocryst quartz and feldspar, plus vein calcite, magnetite, and hydrous minerals (chlorite, actinolite, biotite) will be analyzed for oxygen, deuterium, and carbon isotopes. Analyses of feldspar lead and sulphide sulphur are also planned.

Petrography: A comprehensive suite of samples from the lower levels of the pit and from drill core was collected this year to examine alteration changes in detail. Data will be presented as five cross sections and two long sections.

Fluid inclusion studies: At the time of the preliminary investigation, the hand sample equivalents of the thin sections were not available, therefore the overall relationships of veins and alteration were somewhat ambiguous. However, a well constrained set of samples was collected during this year's fieldwork to continue the fluid inclusion study. Following detailed petrography of these samples, microthermometry will be completed.

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