Morrison - Hearne Hill copper-gold deposits Babine region, west-central British Columbia

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ABSTRACT

Morrison and Hearne Hill are classic porphyry copper-gold deposits associated with a Tertiary continental magmatic arc in west-central British Columbia. The deposits are located within and around dikes and plugs of an Eocene high-potassium calc-alkaline suite, the Babine Igneous Suite. Despite the calc-alkaline major element geochemistry, rocks of the Babine Igneous Suite possess immobile trace element ratios typical of alkaline rocks and may have been derived from an alkaline precursor or parental magma. Sulphide mineralization in both deposits occurs as disseminations, fracture fillings and quartz stockwork veinlets. Hearne Hill also hosts a deposit of chalcopyrite-cemented breccia which has characteristics that are unique among the Babine deposits.

Stockwork mineralization on Hearne Hill formed at a minimum depth of 4 ± 1 km from highly saline hydrothermal brines. Temperatures of homogenization in complex fluid inclusions range from 164.5°C to >600°C, with salinities of 40% to 60%. The Hearne Hill breccia pipe formed at a minimum depth of <100 m from dilute epithermal fluids. Temperatures of homogenization average 172.5°C, with salinities of 2% to 10%.

The Morrison and Hearne Hill deposits are separated by a major regional structure, the Morrison Fault. Reconstruction of the Mesozoic-Eocene stratigraphic sequence suggests that Hearne Hill formed the root and that Morrison formed the upper slice of an originally contiguous deposit which was subsequently dismembered by extensional faulting and dextral shear. Faulting occurred before the cessation of magmatic and hydrothermal activity on the exposed root of the deposit. The circulation of highly corrosive hydrothermal brines resulted in solution, withdrawal of support and subsequent collapse to form the Hearne Hill breccia pipe.

Indicated and inferred resources for the Morrison deposit, using a 0.30% Cu cutoff grade, are estimated to total 190 million tonnes grading 0.40% Cu and 0.2 g/t Au to a depth of 300 m. Inferred resources for the Hearne Hill stockwork and breccia pipe mineralization, using a 0.10% Cu cutoff grade, are estimated at 60 million tonnes grading 0.16% Cu and 0.1 g/t Au to a depth of 100 m. Using a cutoff grade of 0.75% Cu, the Hearne Hill breccia pipe contains an indicated resource of 143 000 tonnes grading 1.73% Cu and 0.8 g/t Au to a depth of 100 m.

Introduction

Two porphyry copper-gold deposits, Morrison and Hearne Hill, have been delineated just east of Morrison Lake in central British Columbia. The deposits are some 2.2 km apart and are contained within the Babine porphyry copper district which comprises two past producers (the Bell and Granisle mines owned by Noranda Mining and Exploration Inc.) together with a number of subeconomic deposits. The deposits of this district are associated with a Tertiary (circa 50 Ma) continental magmatic arc with intrusive and extrusive members collectively known as the Babine Igneous Suite.

As the senior author's research (Ogryzlo, in prep.) on the Hearne and Morrison deposits has yet to be finalized and active exploration continues on the Hearne Hill deposit, the concepts and conclusions in this paper must be viewed as preliminary.

Location

The Morrison and Hearne Hill deposits are located in the Babine Lake region of the Intermontane Belt of central British Columbia (Fig. 1). They are situated at latitude 55°11′N and longitude 126°18′W. Vehicle access is by logging road from the Bell mine 25 km to the south. The village of Granisle, built to service the Granisle and Bell mines, is reached via a 4 km ferry crossing of Babine Lake from the Bell mine and an additional 14 km of gravel road.

The Granisle mine ceased production in 1982 and all surface facilities have been removed. Production ceased at the Bell mine in 1992 due to the exhaustion of ore reserves and the minesite is currently being decommissioned.

Physiographic Setting

The Babine Lake region forms part of the rolling uplands of the Nechako Plateau within the Intermontane Belt of central British Columbia (Fig. 1). Oligocene to Recent block faulting dissected the region into a basin and range morphology consisting of northwesterly trending ridges and valleys. The major trenches are filled with long, narrow and deep lakes, the largest of which is Babine Lake. Morrison Lake lies to the northwest of Hatchery Arm of Babine Lake and occupies the same valley. Elevations range from 733 m on the shore of Morrison Lake to 1380 m on Hearne Hill. The eroded scarp of the Morrison Fault forms the western flank of Hearne Hill.

History

The Morrison Lake area was first explored in the early 1960s during the initial rush of exploration to the Babine region. Regional stream sediment sampling in 1962 by the Norpex Group of Noranda Exploration Company, Limited led to the discovery of the Morrison deposit in 1963 with critical early work by I. Saunders, R. Woolverton and D. A. Lowrie (Woolverton, 1964). Delineation of the deposit took place during the period 1963 to 1973 and included soil

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geochemical, electromagnetic (JEM) and magnetic surveys together with trenching, geological mapping, alteration studies and 13 890 m of diamond drilling in 95 drill holes (Carson and Jambor, 1976).

The discovery of the Bell deposit in 1963 and the opening of the Granisle mine in 1965 further stimulated interest by others in the area. Acting on this interest, Tro-Buttle Exploration Limited undertook a large-scale soil sampling survey and magnetometer survey to the east of Morrison Lake on Hearne Hill (Dirom, 1967). While excavating a bulldozer trench on the most prominent anomaly on the western flank of Hearne Hill, Peter Bland and George Burdett unearthed a 1.5 m boulder of brecciated rock cemented with chalcopyrite (P. Bland, pers. commun., 1991). On the strength of this discovery, the property was optioned in 1967 to the Texas Gulf Sulphur Company, which undertook a systematic geological assessment of Hearne Hill (Newell, 1968). Their exploration culminated in the boring of 12 diamond drill holes for a total of 1942 m. Although drilling intersected only a small section of mineralized breccia, a large low-grade porphyry copper deposit was partly delineated. As the copper grades encountered were considered subeconomic and confronted with a major option payment, Texas Gulf returned the property to Tro-Buttle Exploration Limited in the spring of 1968. Shortly thereafter, Canadian Superior Exploration Limited acquired an option on the property and undertook magnetometer, induced polarization, geological and geochemical surveys (Kahlert, 1968) followed by a program of percussion drilling in 1969 (Sampson, 1993). After this work, the property became dormant and eventually reverted to the Crown.

In 1989, the Hearne Hill property was acquired by D. Chapman and P. Bland and was optioned the same year by Noranda Minerals Inc. to evaluate the possibility of developing high-grade feed for the Bell mill. Diamond drilling during 1989 and 1990 delineated a small, high-grade, breccia pipe (Ogryzlo, 1990, 1991), but the identified resource did not meet the Bell mine requirements and the property was returned to the vendors. Subsequent drilling of the breccia pipe was done in 1991 (Sampson, 1993) by the vendors and they were in the process of permitting the breccia deposit for production when the Bell mill closed in April, 1992. In late 1992, Booker Gold Exploration Ltd. acquired the property and in 1993 completed trenching, a magnetometer survey, geological mapping and follow-up percussion drilling (Sampson, 1993; Schroeter, 1993).

Applied Exploration Techniques

Geochemistry was the most cost-effective exploration technique used in the discovery of the Morrison and Hearne Hill deposits. The distribution of copper in soils is shown in Figure 2. Babine valley is notorious for its thick blanket of glaciolacustrine clays which can effectively mask residual anomalies (Okon, 1974; Levinson and Carter, 1979). In the case of the Morrison deposit, however, hornfelsing, silicification and hydrothermal activity has made the deposit more resistant than its enclosing rocks. Hence, although the deposit is located in a valley bottom where it normally would be blanketed with clay, there is enough positive relief that the deposit protrudes through the impervious cover. In the case of Hearne Hill, the deposit is exposed on the eroded scarp of an uplifted fault block. Although thick deposits of glacial outwash gravels are locally preserved in ravines, most of the deposit is covered with only a thin layer of glacial soils and is above the blanket of impervious clays. Soil sampling was effective in revealing the general outline of the stockwork mineralization and was also effective in locating the Hearne Hill breccia pipe (Newell, 1968; Ogryzlo, 1990).

Magnetic surveys were invaluable in defining the limits of the host intrusions, zones of secondary biotite alteration and associated mineralization on the Morrison property (Woolverton, 1964; Fountain, 1969; Carson and Jambor, 1976). Magnetics were also used to focus exploration on the Hearne Hill property with the Hearne Hill breccia pipe defined by a magnetic low, possibly because intense hydrothermal activity and consequent sulphidization had reduced magnetite to pyrite.

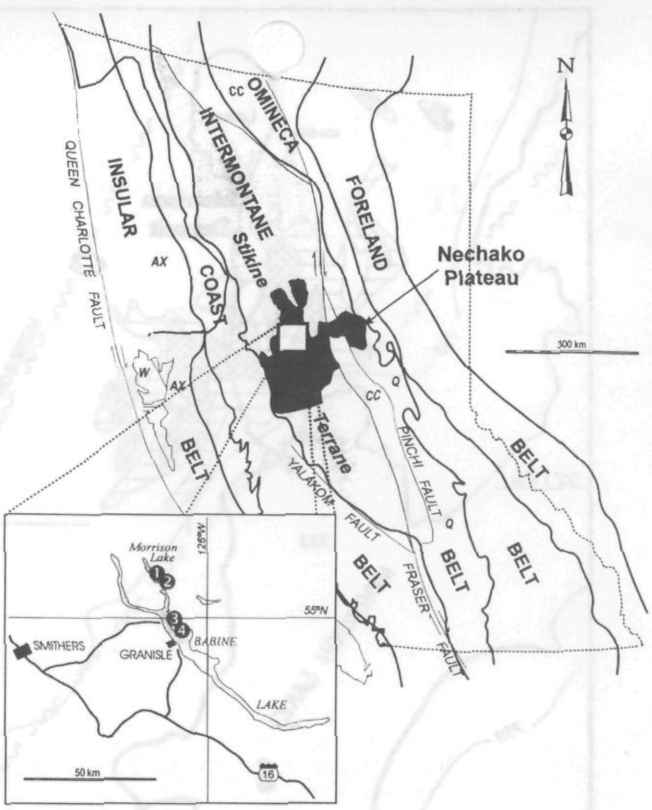

FIGURE 1. Location of the Babine porphyry copper district. Morphogeological belts, major faults, and terrane boundaries modified after Gabrielse and Yorath (1989). Only the major terranes are shown: AX (Alexander), W (Wrangellia), CC (Cache Creek), Q (Quesnellia) and Stikine. Stikine terrane is shaded. 1. Morrison deposit. 2. Hearne Hill deposit. 3. Bell mine. 4. Granisle mine.

Induced polarization surveys on the Morrison property effectively outlined the extent of the hydrothermal system as defined by the pyrite halo. Induced polarization surveys were also effective on Hearne Hill by delineating sulphides in the stockwork deposit although the pyrite halo appears less well defined than at Morrison. The breccia pipe is defined by the induced polarization survey and appears as a >20 millisecond chargeability anomaly.

Implicit in all techniques used in the delineation of the Morrison deposit was the use of geological modelling. Alteration mineralogy, particularly the hydrothermal biotite-magnetite assemblage, was recognized early as a guide to mineralization (Woolverton, 1964). The pioneering concepts (for the Canadian Cordillera) of symmetrical concentric zoning of alteration and mineralization developed by Carson and Jambor (Carson and Jambor, 1974) were used to plan definition drilling and to define postmineral fault displacements.

The use of angle diamond drill holes was essential in providing information on the horizontal and vertical grade distributions at Morrison and Hearne Hill. Without detailed information on horizontal grade distribution, vertical assay-wall boundaries would only be poorly approximated by mathematical manipulation and interpolation of assay data between vertical drill holes.

Despite the success in using simple geochemical techniques to outline the Morrison and Hearne Hill deposits, their secondary geochemical dispersion halos developed because they were exposed to surficial processes and were not masked by the glaciolacustrine clay and till that blanket much of the Babine region. Future exploration in the area will need to consider more sophisticated geochemical techniques such as basal till sampling and biogeochemical and lithogeochemical methods, and geophysical methods that are able to detect and define "blind" deposits concealed beneath thick blankets of till and clay.

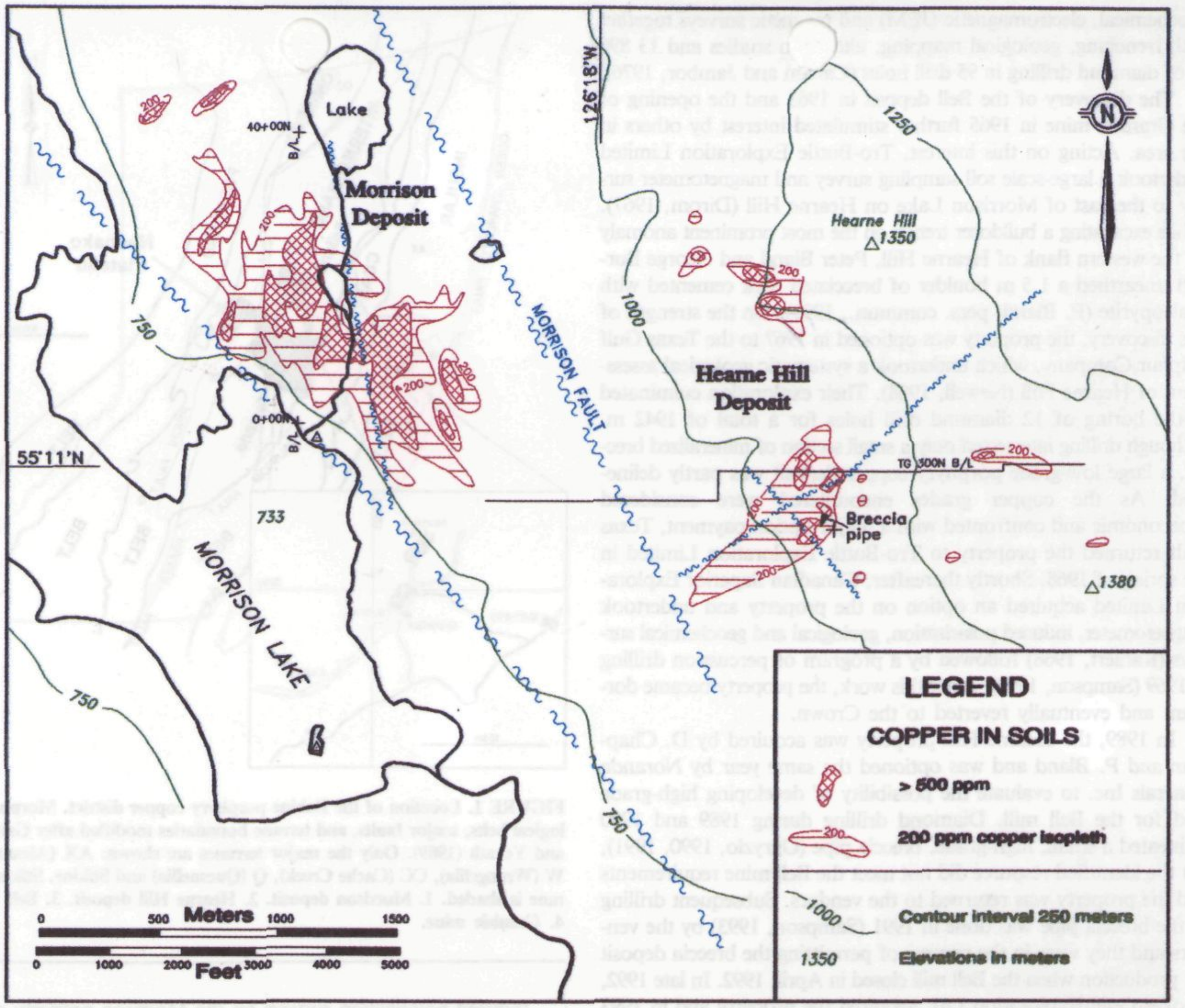

FIGURE 2. Soil geochemistry. Copper in soils for Morrison from Carson and Jambor, 1976. Copper in soils for Hearne Hill from Dirom, 1967 and Ogryzlo, 1990.

Regional Geology

The Intermontane Belt of central British Columbia comprises a collage of accreted island arc and oceanic terranes (Gabrielse and Yorath, 1989). The largest of these accreted terranes is the Stikine terrane (Fig. 1), which covers a surface area of 120 000 km^2 (Richards, 1988). The Stikine terrane is subdivided into four assemblages: a late Palaeozoic to Middle Jurassic island arc; a Middle Jurassic to early Late Cretaceous molasse assemblage; a Late Cretaceous to Eocene transtensional continental magmatic arc; and Eocene to Recent plateau basalts accompanied by uplift and erosion.

In the vicinity of Morrison Lake, the older island arc assemblage is exposed in the highlands surrounding the lake as marine volcanic rocks, tuffs and greywacke of the Lower Jurassic (Sinemurian to Bajocian) Telkwa Formation (Fig. 3; Tipper and Richards, 1976). Post-Eocene block faulting has dissected the area, with younger molasse-type sedimentary rocks of the Middle Jurassic Bowser Lake Group preserved in the down-faulted blocks which now occupy the lowlands. The Eocene continental magmatic arc comprises hornblende + biotite + plagioclase ± quartz phyric dikes and plugs, felsic plugs and associated volcanic and epiclastic rocks, all of which are collectively known as the 50 Ma (Carter, 1976) Babine Igneous Suite. The suite is bimodal, with compositions of andesite or rhyolite. Mafic end-members have not been identified. The hornblende-biotite-plagioclase phyric members of the suite are generally described as biotite feldspar porphyry (BFP).

Volcanic and epiclastic equivalents of the intrusions were deposited in discrete, structurally controlled down-dropped volcanic basins. The formation of the basins marks the end of the molasse stage of sedimentation in the Stikine terrane. The contractional tectonic regime that was marked by impingement of the Alexander and Wrangell terranes in Late Cretaceous time changed in the Eocene to one of extension east of the Insular Belt (Gabrielse and Yorath, 1989). Extension was accompanied or followed by a component of dextral shear, which continues at present along the Queen Charlotte Fault.

The Eocene volcanism has been attributed to magmatic activity over a subduction zone that lay to the west (Richards, 1988), with an axis that may have coincided with the axis of the present-day Coast Plutonic Complex, 250 km to the west of the Babine valley. If this is the case, the Eocene magmatism in the Babine region occurred a considerable distance above the subducted slab.

Locally, extensional and transtensional tectonic elements are represented by the major block faults that define the basin and range morphology of the region. The Morrison Fault and Graben are among the most prominent structural features of the area and have been traced for over 100 km. Intrusions hosting the major porphyry copper deposits in the region occur along or adjacent to the Morrison Fault and the closely related Newman Fault. These intrusive centres appear to be localized by intersecting major and subsidiary faults, or by dilatant zones that have developed between the major transforms.

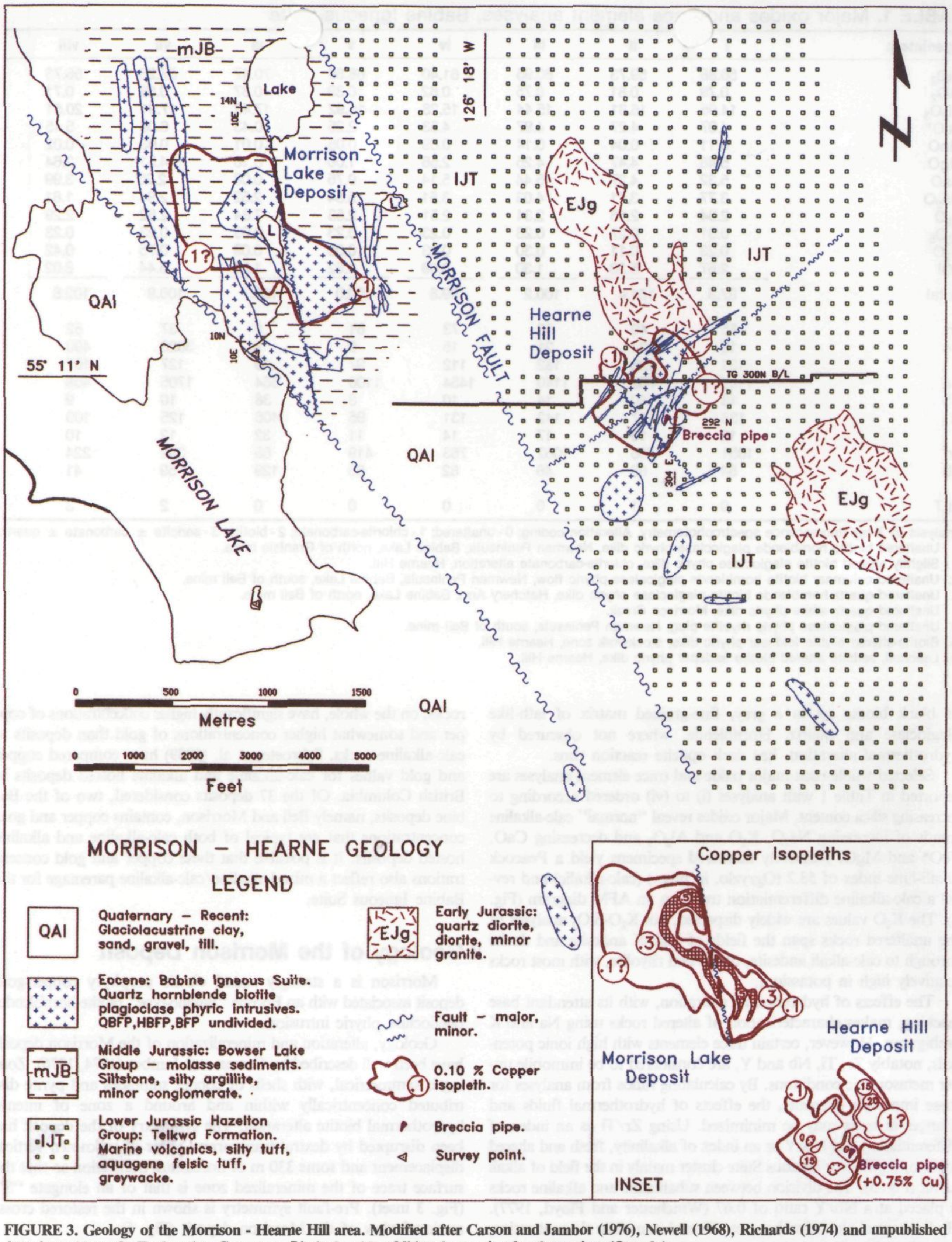

FIGURE 3. Geology of the Morrison - Hearne Hill area. Modified after Carson and Jambor (1976), Newell (1968), Richards (1974) and unpublished data from Noranda Exploration Company, Limited, with additional mapping by the author (Ogryzlo).

Whole-rock Geochemistry of the Babine Igneous Suite

The Babine Igneous Suite is a high-K calc-alkaline magmatic suite but has an alkaline trace element signature. Dikes, plugs and coarse vent-breccias of intermediate to acidic composition predominate. Extrusive and epiclastic equivalents consist of poorly consolidated hornblende crystal tuffs with tree roots and carbonized wood fragments, debris flows with green and red clasts, and columnar flows. The intrusive rocks have a distinctive "crowded" porphyritic texture, with zoned plagioclase phenocrysts and "books"

TABLE 1. Major oxides and trace element analyses, Babine Igneous Suite

Specimen:	i	ii	iii	iv	v	vi	vii	viii
SiO_2	56.88	59.73	60.95	61.40	68.68	70.47	57.28	56.73
TiO_2	0.79	0.81	0.75	0.62	0.39	0.37	0.88	0.71
Al_2O_3	14.95	16.31	15.44	15.28	16.92	17.46	17.91	20.51
FeO*	4.97	4.27	4.97	4.53	2.25	0.43	6.06	5.45
MnO	0.11	0.04	0.14	0.09	0.05	0.01	0.03	0.02
MgO	5.48	4.47	4.25	2.56	1.00	0.10	4.51	2.64
CaO	5.32	4.27	5.44	5.14	0.75	0.08	2.25	3.99
Na_2O	3.77	3.71	4.03	3.51	5.54	2.52	2.94	1.81
K_2O	2.34	2.16	2.34	2.51	2.53	7.84	2.62	2.29
P_2O_5	0.31	0.27	0.28	0.23	0.23	0.03	0.23	0.23
H_2O-	0.23	0.11	0.30	0.23	0.00	0.09	0.75	0.42
LOI	2.67	5.20	1.30	3.69	1.62	1.25	5.44	8.02
Total	97.8	101.4	100.2	99.8	100.0	100.7	100.9	102.8
Zn	65	40	63	73	61	6	37	62
Cu	13	234	21	15	9	tr	3023	400
V	131	128	132	112	97	10	127	107
Ba	1197	789	1140	1454	1100	654	1705	459
Nb	13	10	14	10	8	38	10	9
Zr	133	117	142	131	95	406	125	109
Y	16	10	17	14	11	32	12	10
Sr	1051	786	1062	763	419	65	392	224
Rb	54	68	46	62	65	129	59	41
ALT	0	1	0	0	0	0	2	3

Analysis by X-ray fluorescence spectrophotometry. Alteration coding: 0 - unaltered; 1 - chlorite-carbonate; 2 - biotite; 3 - sericite ± carbonate ± quartz.
i. Unaltered biotite hornblende plagioclase phyric dike, Newman Peninsula, Babine Lake, north of Granisle mine.
ii. Slightly altered biotite plagioclase phyric dike, chlorite-carbonate alteration, Hearne Hill.
iii. Unaltered columnar biotite hornblende plagioclase phyric flow, Newman Peninsula, Babine Lake, south of Bell mine.
iv. Unaltered quartz hornblende biotite plagioclase phyric dike, Hatchery Arm, Babine Lake, north of Bell mine.
v. Unaltered quartz albite phyric dike, Morrison Creek.
vi. Unaltered plagioclase phyric rhyolite plug, Newman Peninsula, south of Bell mine.
vii. Biotite-altered biotite feldspar phyric dike, stockwork zone, Hearne Hill.
viii. Leached, sericite altered biotite feldspar phyric dike, Hearne Hill.

of black biotite set in a grey, fine-grained matrix of lath-like plagioclase and quartz. Hornblende, where not obscured by hydrothermal alteration, has dark opacite reaction rims.

Selected whole-rock major oxide and trace element analyses are reported in Table 1 with analyses (i) to (vi) ordered according to increasing silica content. Major oxides reveal "normal" calc-alkaline trends of increasing Na_2O, K_2O and Al_2O_3 and decreasing CaO, FeO* and MgO. Relatively unaltered specimens yield a Peacock alkali-lime index of 58.2 (Ogryzlo, in prep.) (calc-alkalic) and reveal a calc-alkaline differentiation trend on an AFM diagram (Fig. 4). The K_2O values are widely dispersed, but K_2O-SiO_2 analyses of the unaltered rocks span the fields of high-K andesite and dacite through to calc-alkali andesite, dacite and rhyolite, with most rocks relatively high in potassium.

The effects of hydrothermal alteration, with its attendant base leaching, makes characterization of altered rocks using Na and K ambiguous. However, certain trace elements with high ionic potentials, notably Zr, Ti, Nb and Y, are considered to be immobile under metasomatic conditions. By calculating ratios from analyses for these immobile elements, the effects of hydrothermal fluids and changes in mass may be minimized. Using Zr/Ti as an index of differentiation and Nb/Y as an index of alkalinity, fresh and altered rocks of the Babine Igneous Suite cluster mainly in the field of alkali basalt (Fig. 5). The division between subalkaline and alkaline rocks is placed at a Nb/Y ratio of 0.67 (Winchester and Floyd, 1977). Hydrothermal alteration has not affected immobile element ratios, as indicated by the close clustering of data points in Figure 5.

The alkaline character revealed by the immobile element ratios is at odds with the calc-alkaline major element trends of the Babine Igneous Suite. The immobile element ratios may reflect ratios inherited from an alkaline precursor or parental magma which has acquired its calc-alkaline major oxide chemistry by contamination. Porphyry copper-gold deposits associated with alkaline rocks, although of minor importance worldwide, are very important in the Canadian Cordillera (McMillan, 1991). Deposits in alkaline rocks, on the whole, have significantly higher concentrations of copper and somewhat higher concentrations of gold than deposits in calc-alkaline rocks. Schroeter et al. (1989) have compared copper and gold values for calc-alkaline and alkaline hosted deposits in British Columbia. Of the 37 deposits considered, two of the Babine deposits, namely Bell and Morrison, contains copper and gold concentrations that are typical of both calc-alkaline and alkaline hosted deposits. It is possible that these copper and gold concentrations also reflect a mixed alkaline/calc-alkaline parentage for the Babine Igneous Suite.

Geology of the Morrison Deposit

Morrison is a strongly zoned classic porphyry copper-gold deposit associated with an Eocene "Babine-type" biotite-hornblende-plagioclase phyric intrusion.

Geology, alteration and mineralization of the Morrison deposit have been well described by Carson and Jambor (1974, 1976). Zoning is symmetrical, with shells of copper sulphides and pyrite distributed concentrically within and around a zone of intense hydrothermal biotite alteration. The symmetry of the deposit has been disrupted by dextral transcurrent shear of unknown vertical displacement and some 330 m of horizontal translation so that the surface trace of the mineralized zone is that of an elongate "S" (Fig. 3 inset). Pre-fault symmetry is shown in the restored cross-sectional view of the Morrison deposit (Fig. 6).

Of note is the presence of marcasite, sphalerite and arsenopyrite in quartz-carbonate veinlets and vugs in the intensely clay-carbonate altered Morrison shear structure and in other minor post-stockwork faults on the Morrison property. This suggests late-stage hydrothermal activity followed stockwork copper mineralization at Morrison. Elevated arsenic values, as indicated by drill hole composite analyses, also clearly map the Morrison shear structure and other post-stockwork structures. Gold appears to be primarily associated with the stockwork copper mineralization and to a much lesser ex-

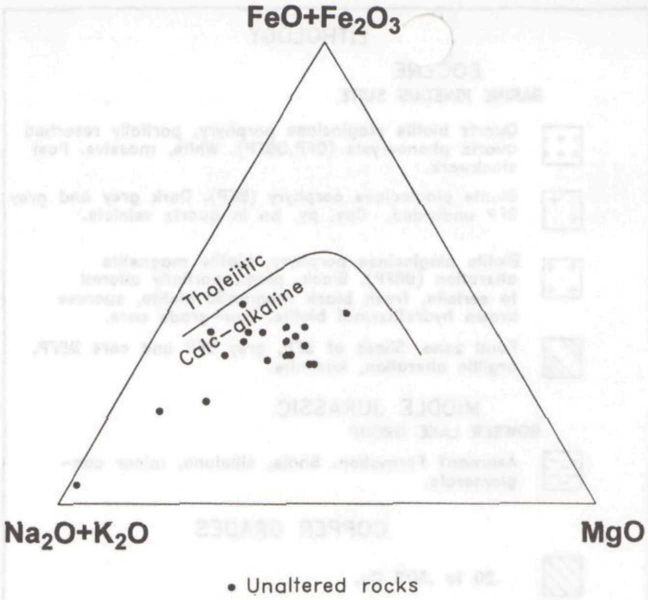

FIGURE 4. AFM diagram, Babine Igneous Suite. Only those rocks showing little or no alteration are plotted. Tholeiitic - calc-alkaline fields are from Irvine and Baragar, 1971.

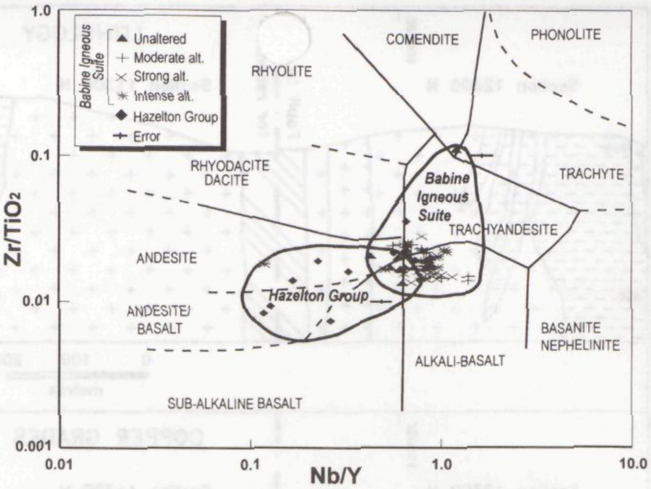

FIGURE 5. Zr/TiO$_2$ versus Nb/Y classification diagram for fresh and hydrothermally altered rocks of the Babine Igneous Suite. Classification fields and boundaries from Winchester and Floyd, 1977.

tent with arsenic and late stage sulphide quartz-carbonate mineralization along the Morrison shear.

Alteration zoning is simple, consisting of a central core of hydrothermal biotite, with a peripheral zone of chlorite-carbonate (propylitic) alteration. Hydrothermal biotite is particularly well developed at Morrison, with mafic minerals in the core zone being replaced by sugary brown masses of biotite.

The Morrison deposit differs from the two economic deposits of the region (Bell and Granisle) in that it lacks the extensive phyllic alteration overprinting of pre-existing biotite and propylitic alteration zones.

Magmatic waters appear to have been involved in the formation of hydrothermal biotite and chlorite, with the possible addition of an evolved meteoric water component. Fluids in equilibrium with hydrothermal biotite in the potassic zone at Morrison have calculated δD_{H_2O} values at 541°C of −75 and −70 and calculated $\delta^{18}O_{H_2O}$ of 8.1 (Zaluski, 1992), indicating a magmatic source. Fluids from the propylitic alteration zone at Morrison had similar δD_{H_2O} at 350°C, but had slightly lower $\delta^{18}O_{H_2O}$. Evolved meteoric waters were also involved in argillic alteration along one of the major shears.

Geology of the Hearne Hill Deposit

Marine volcanic rocks and volcaniclastics of the Lower Jurassic (Sinemurian) Telkwa Formation of the Hazelton Group are exposed on Hearne Hill (Richards, 1980). The volcanic rocks have been tentatively correlated with the submarine Kotsine Facies of the Telkwa Formation (Tipper and Richards, 1976). Fine-grained grey to maroon volcanic rocks (and possibly synvolcanic intrusions) of intermediate composition predominate. The volcanic rocks are characterized by grey crystal-lapilli tuffs and grey andesite. Buff to brownish silty tuffaceous rocks, green siltstone and greywacke are also present.

The Lower Jurassic rocks have been intruded by dike-like bodies of biotite-plagioclase porphyry (BFP) of the 50 Ma Eocene Babine Igneous Suite. The largest mass of BFP on Hearne Hill is approximately 750 m long and reaches a maximum width of 250 m with its long axis oriented to the northeast. A number of smaller bodies of BFP also are oriented with their long axes to the northeast. Where intersected by boreholes, contacts of the intrusive bodies appear to be vertical.

Both the BFP bodies and the country rocks adjacent to the intrusions have been intensely fractured. Fracturing appears in the intrusive bodies as widely spaced planar joints giving subcrops of BFP a blocky appearance. Fracturing is more intense in the volcanic wallrocks, occurring as closely spaced hairline fractures.

A younger phase of the Babine Igneous Suite intrudes both the BFP and the volcanic sequence. It is a buff to white plagioclase-biotite phyric massive rock with rare quartz phenocrysts. Plagioclase is invariably altered to sericite, and biotite occurs as pale brownish relics. Fracturing and fracture filling are virtually absent and there is no stockwork development. Where present, fracturing occurs primarily as shear zones enveloped with greenish swelling-clay minerals. This younger phase on Hearne Hill is nearly identical in appearance to the post-stockwork quartz biotite feldspar porphyry (QBFP) that intruded the southeastern quadrant of the Bell orebody. The QBFP at Bell, however, has more prominent quartz phenocrysts (Dirom et al., this volume).

Hypogene Sulphide Mineralization

Stockwork

Chalcopyrite, pyrite, bornite and minor molybdenite occur as disseminations, as fracture fillings and in quartz veinlets on Hearne Hill. The limit of copper mineralization (as defined by the 0.10% Cu isopleth) delineates a zone 600 m long by 400 m wide (Fig. 3). The long axis of the zone is oriented northeasterly and appears to parallel the trend of the intrusive bodies. Copper concentrations in the stockwork zone range up to a maximum of 0.5% Cu and average 0.16% Cu. They are highest in the volcanic and sedimentary rocks, with somewhat lesser concentrations in the BFP intrusions. The preferential deposition of copper sulphides in the country rocks appears to be related to the greater density of fractures in the volcanic rocks and volcaniclastics. Symmetrical zoning of copper values is not as apparent as at Morrison, but this may be a function of the lower density of sampling on Hearne Hill.

Fluids responsible for hypogene stockwork mineralization at Hearne Hill appear to have been highly saline chloride brines. Inclusions of fluids trapped in stockwork quartz veins commonly are multisolid (one or more solid phases) multiphase (one or more of liquid, vapour, or solid phases) inclusions which may contain halite, sylvite, an orange-coloured Fe-chloride phase, gypsum, and/or rare chalcopyrite tetrahedra. Temperatures of homogenization (Th) range between 164.5°C and 550°C (Fig. 7), with a mean Th of 346.5°C (Ogryzlo, in prep.). Homogenization was generally by vapour disappearance before halite dissolution. Salinities range from 40% to 60% NaCl equivalent (Fig. 8). Salinity was probably

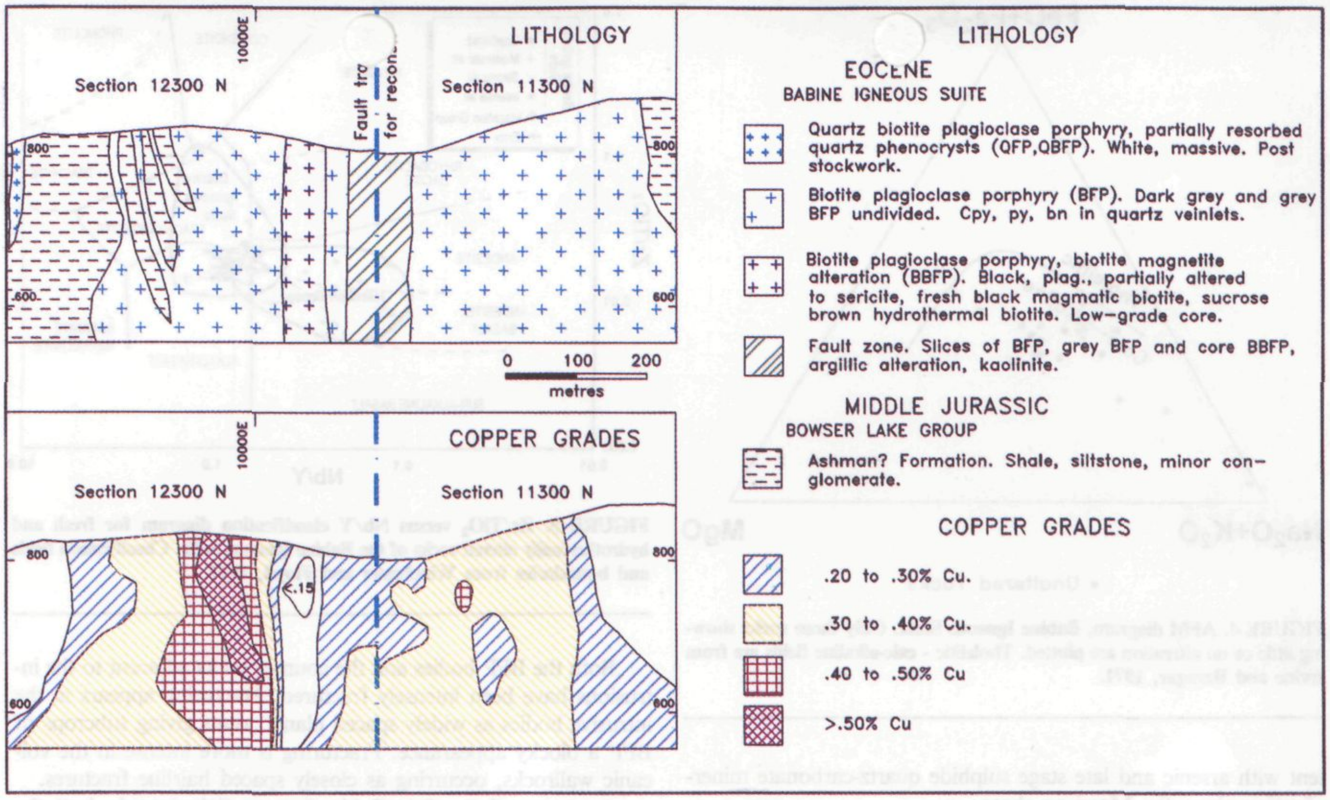

FIGURE 6. Restored cross-sectional view of the Morrison deposit.

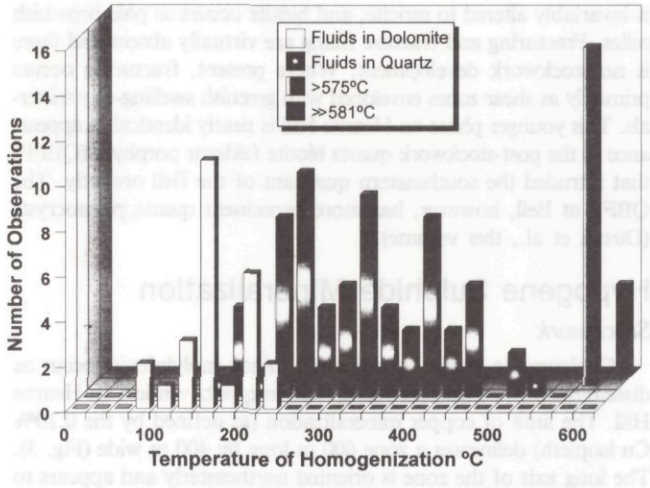

FIGURE 7. Fluid inclusion (FI) geothermometry, Hearne Hill. Temperatures of homogenization for quartz stockwork and for the breccia pipe. The upper temperature limit for the instrument used was 581°C, A number of inclusions in the quartz stockwork did not homogenize by 581°C, but appeared close to homogenization, and are displayed as the group of >575° inclusions. Inclusions not close to homogenization by 581°C represent a higher temperature population.

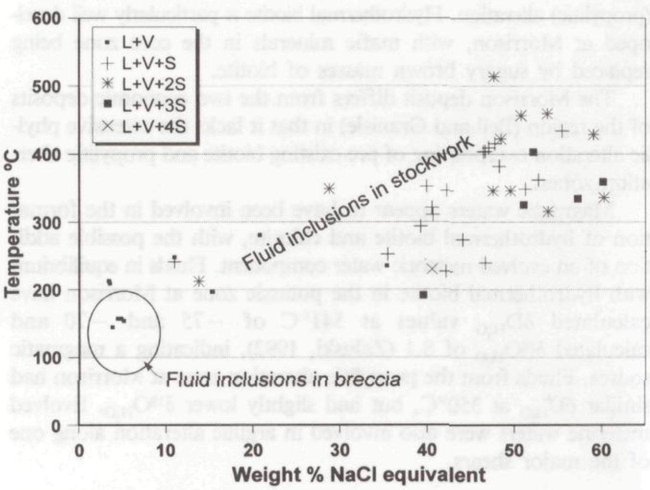

FIGURE 8. Salinity versus temperature of homogenization, Hearne Hill. Liquid (L), Liquid + Vapour (L+V), and Liquid + Vapour + nSolid (L+V+nS) inclusions. L+V inclusions mainly from breccia pipe. Multisolid inclusions all from stockwork.

increased by repeated boiling, with the evolution of a vapour phase. Several pulses or generations of fluids, with overlapping temperature ranges, may have generated the stockwork mineralization on Hearne Hill. Peaks occur at temperatures of 262.5°C, 337.5°C, and 412.5°C. A number of fluid inclusions failed to homogenize by 600°C and represent some higher temperature pulses.

A precise estimate of the pressure and depth at which fluids were trapped in the quartz stockwork is not possible because of the complex fluid chemistry. A rough estimate obtained from the curves of Gunter et al. (1983) using the system H_2O-NaCl indicates a minimum pressure of approximately 1000 bars for fluids trapped in the quartz stockwork on Hearne Hill. Assuming lithostatic load, this yields a minimum depth of emplacement of approximately 4 km ± 1 km.

Hearne Hill Breccia Pipe

Within the stockwork porphyry copper deposit on Hearne Hill, there is a pipe-like body of clast supported breccia. The breccia pipe is ovoid in plan, with a length of 68 m and a width of 26 m (Fig. 9), and it trends in a northerly direction with a steep east dip and a southeast plunge. Vertical extent of the breccia pipe is 130 m. Clasts are angular, with the brecciated rocks having the texture of cemented rubble or talus. Textures are best displayed in the discovery boulder which exhibits a crude stratification imparted by oriented slabs of rock and by crude sorting of clasts (Figs. 10 and

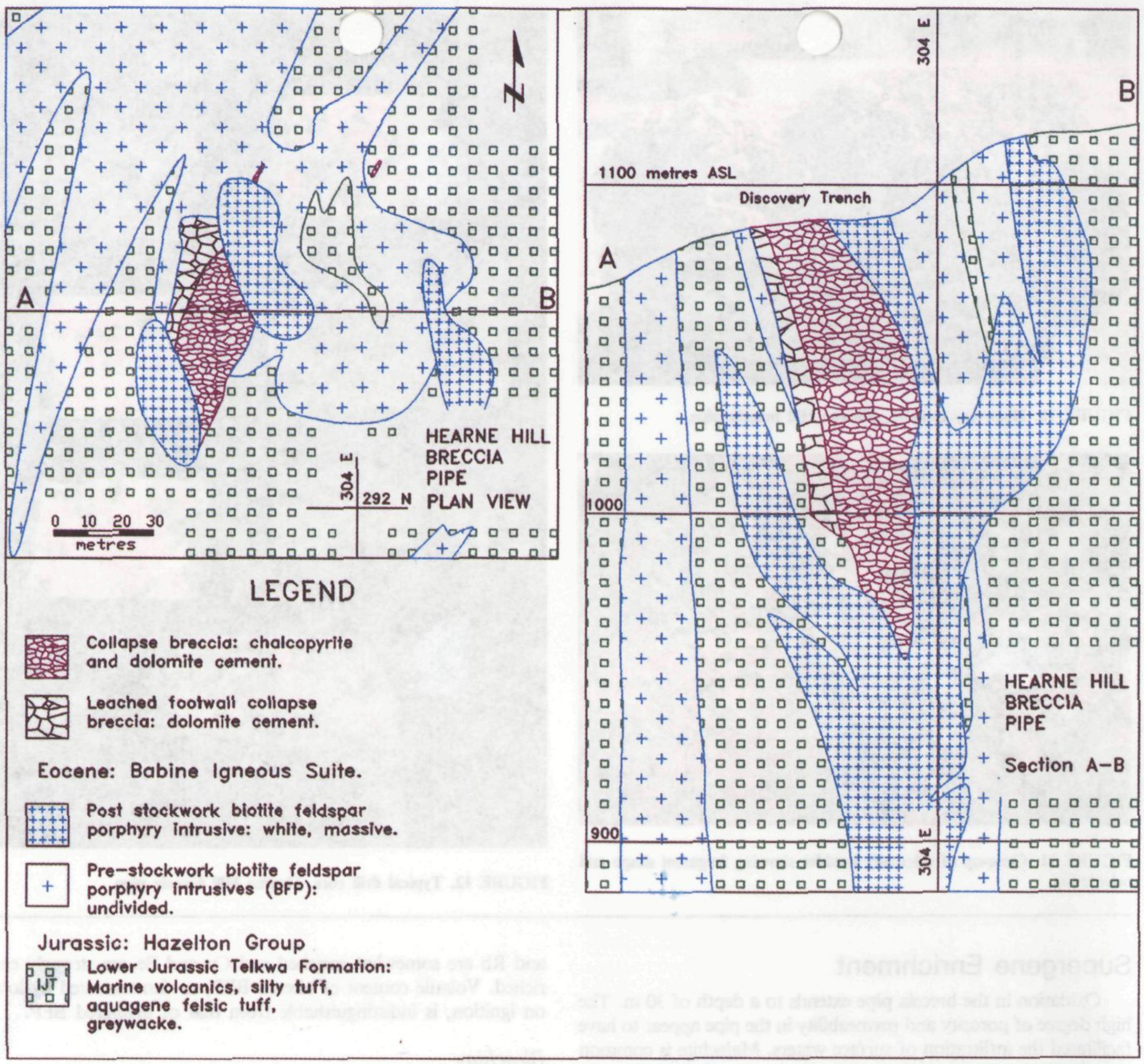

FIGURE 9. Plan and section of the Hearne Hill breccia pipe.

11). The porosity of the breccia before sulphide and carbonate cementation would have been close to the theoretical maximum of around 25%. Chalcopyrite, pyrite and marcasite fill angular interstices between the breccia clasts, with later cementation provided by calcite, dolomite and minor chalcedony (Fig. 12). Porosity remains between 5% and 8%. There is little evidence of milling or attrition of clasts. Rock flour is present between clasts but is a minor constituent.

Elemental concentrations display a distinctive zonation within the pipe. Virtually all metallic cations have been stripped from the footwall of the pipe and from the clasts lying against the footwall. More specifically, Na, Ca, Sr, Fe, Mg and Ba are depleted in the footwall breccia (Ogryzlo, in prep.). Elements such as Mo, Au, Ag and As exhibit low concentrations in the country rock and in the depleted footwall breccia, but are strongly enriched toward the hangingwall. The only elements enriched in the footwall breccia are Mn and K, although Mn enrichment is probably due to supergene processes. Concentrations of copper decrease from the average 1000 ppm to 2000 ppm in the footwall stockwork to below detection limits (by atomic absorption) in the footwall breccia, then increase significantly toward the hangingwall, reaching a maximum of 16% Cu and averaging approximately 1.7% Cu.

Fluids associated with the breccia mineralization were dilute epithermal chloride brines. In the breccia pipe, fluid inclusions trapped in the dolomite cement homogenize at a mean temperature of 172.5°C (in a range of between 83°C and 240°C) with salinities ranging from 2% to 10% NaCl equivalent (Orgyzlo, in prep.; Figs. 7 and 8). Inclusions in dolomite are simple two-phase liquid or liquid plus vapour types (L, L+V). No evidence of boiling is present; therefore an accurate determination of the depth of emplacement is not possible. However, estimates of the minimum depth of formation for the dolomite cement, using the curves of Haas (1971) and as outlined in Shepherd et al. (1985), average 66 m in a range from 50 m to 220 m.

Given the temperatures of homogenization and minimum depth of emplacement, the potential for epithermal precious metal deposits in a porphyry or transitional setting should be considered on Hearne Hill. Gold is enriched in the breccia pipe relative to the stockwork mineralization and averages 0.8 g/t. However, higher values (13.75 g/t over 3 m) have been obtained. Such values are rare in the stockwork deposits of the Babine region and indicate that suitable conditions for an epithermal precious metal deposit may be present.

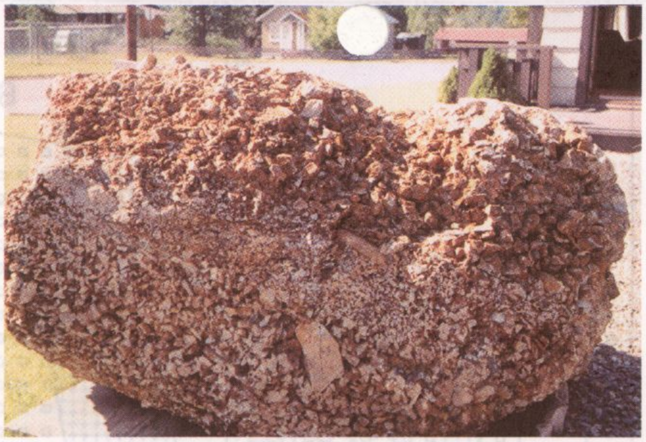

FIGURE 10. Discovery boulder, Hearne Hill breccia pipe.

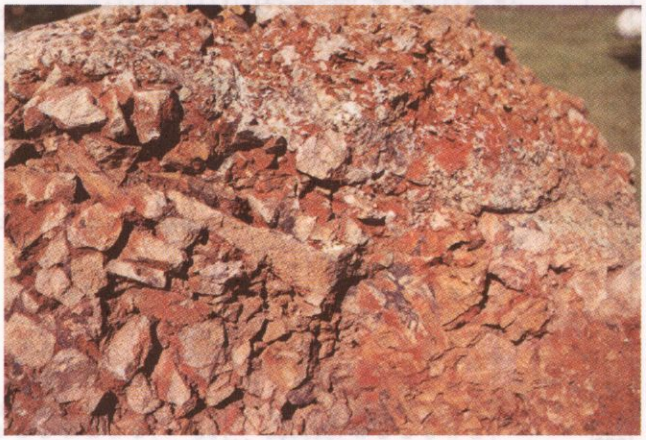

FIGURE 11. Close-up of discovery boulder showing fragment shape and orientation.

FIGURE 12. Typical drill core, Hearne Hill breccia pipe.

Supergene Enrichment

Oxidation in the breccia pipe extends to a depth of 30 m. The high degree of porosity and permeability in the pipe appear to have facilitated the infiltration of surface waters. Malachite is common in surface exposures and in the oxidized zone. Overlapping the zone of oxidation, a zone of supergene enrichment has enhanced the distribution of copper in the upper portions of the breccia pipe. To the unaided eye, chalcocite appears as a black, sooty coating on chalcopyrite and pyrite. Under magnification, chalcocite and covellite were observed as thin (1-3 μ) rinds on the grains of chalcopyrite and pyrite which fill the angular interstices between breccia clasts.

Alteration

Geochemical Considerations

The simplest geochemical index of alteration is Loss on Ignition (LOI, Table 1). As intensity of hydrolysis increases, so does the volatile content. Intense hydrolysis also yields an apparent increase in alumina: this increase results from depletion of other elements, with Al_2O_3 remaining relatively immobile during hydrothermal base leaching.

Hydrothermal Biotite Alteration

Analysis VII (Table 1) is of a biotite-altered BFP dike with stockwork mineralization from Hearne Hill. In general, balancing differences in mass between unaltered BFP protolith and BFP exhibiting hydrothermal biotite alteration indicates that Al, Si and Ti are immobile. Elements that are mildly depleted are Na, Nb, Y and Zr. Elements that are strongly depleted include Ca and Sr whereas K and Rb are somewhat enriched and Cu and Ba are strongly enriched. Volatile content of altered BFP, as demonstrated by loss on ignition, is indistinguishable from that of unaltered BFP.

Bleaching

Bleaching is volumetrically of minor importance on Hearne Hill. It is observed mainly in the clasts of the collapse breccia and in the late-stage post-stockwork dikes. Mineralogically, the bleached rocks are composed of pale ghosts of bleached biotite, sericite, clay minerals, quartz, carbonate and pyrite. Pervasive bleaching is accompanied by intense base leaching and hydrolysis. Elements strongly depleted are Na, K, Sr, Rb, Ba and Mg, occasionally to the point where Na is completely removed (Ogryzlo, in prep.). Elements such as Al, Zr and Nb are immobile and Si may show a gain or a loss. Additions occur principally in LOI and may occur in Ca. Copper may be strongly depleted in bleached rocks. Strongly acidic reducing conditions are inferred for this type of alteration.

Genesis of the Hearne Hill Breccia

Several observations must be reconciled in proposing a mechanism for the formation of the Hearne Hill breccia pipe. These include: the angular shape of the clasts, crude sorting and stratification of the clasts, clast support, abundant open space, depletion of elements in the footwall of the pipe and cementation by dilute (2% to 10% salinity) epithermal solutions at a minimum depth of less than 100 m.

The significant depletion of metallic cations including Na and Ca from the breccia clasts lying against the footwall suggests the circulation of strongly corrosive hydrothermal fluids. No estimate

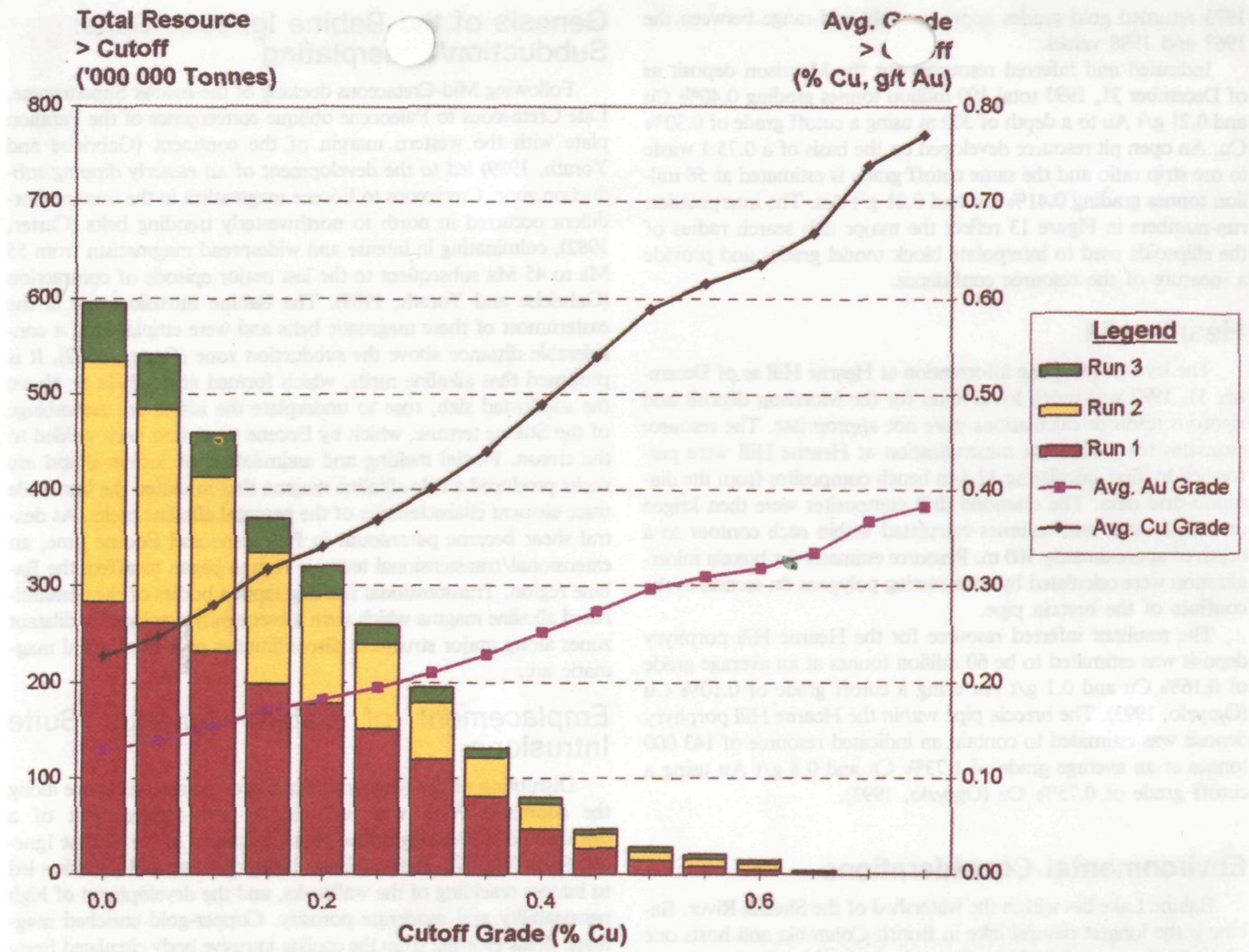

FIGURE 13. Distribution of grade and tonnage, Morrison deposit. Search radii used for grade interpolation: Run 1, 91 m; Run 2, 183 m; Run 3, 274 m.

of pH has been made for the hydrothermal solutions at Hearne Hill but waters in equilibrium with the phyllic alteration assemblage at the Bell mine had a calculated maximum pH of 3.8 (Zaluski, 1992). It is possible that the circulation of corrosive hydrothermal fluids led to the loss of volume and to the depletion of elements in the footwall. Loss of volume was accomplished by dissolution of the rocks along the BFP/volcanic contact, with the resultant formation of a void. Removal of support led to brittle failure of the roof and wallrocks, with the broken fragments collecting in the void as subterranean talus or rubble. Clasts were crudely sorted as they tumbled down the footwall in much the same way that talus is sorted on an open slope. The solution void may possibly have broken through to surface: a single, well rounded cobble is visible, cemented in the breccia of the discovery boulder. Continued circulation of corrosive fluids led to bleaching, leaching of clasts and depletion of metallic elements. Copper was transported and deposited as chalcopyrite, together with pyrite and marcasite, against the hangingwall. Neutralization of the fluids, possibly by carbonate/bicarbonate-rich alkaline groundwaters, resulted in deposition of calcite and dolomite.

Resource Estimations

Morrison

During the period 1963 to 1973, 13 893 m of drilling was completed in 95 diamond drill holes on the Morrison property. Most of these holes were BQ angle holes and were directed east or west on section lines approximately 60 m (200 ft) apart. The holes test the Morrison deposit to a maximum depth of 250 m.

Since 1968, several reserve estimates have been generated for the Morrison deposit, with the most recent published geological reserve being 86 million tonnes averaging 0.42% Cu calculated at a cutoff grade of 0.3% Cu (Carson and Jambor, 1976).

In 1992, a new inverse distance block model for copper was generated for the Morrison deposit using methods and experiences developed at the Bell mine (Dirom et al., this volume). These methods require evaluation of geological controls and grade distribution to establish appropriate constraints and search radii to interpolate individual block values within a block model. In the case of Morrison, four interpolation zones designated core, northwest, southeast and fault zone were used to screen assay data and to orient ellipsoid search directions to minimize adverse effects across geological and grade boundaries. Using the resultant Morrison block model file, grade and tonnage curves were generated to predict mineral resource parameters for copper at various cutoff grades and confidence levels (Fig. 13). The new Morrison model is preliminary and requires further work to bring confidence levels to those achieved for the Bell deposit.

Gold grades were estimated using a gold-copper regression equation developed on the basis of 477 composite gold samples assayed in 1988. The 1988 composite gold grades were significantly lower than composite gold grades obtained in 1967 (0.21 g/t gold versus 0.35 g/t Au at the 0.40% Cu level). Variances of this magnitude, which can be attributed to factors such as laboratory bias, sample size, sample bias, nugget effect and analytical sensitivity at or near detection limits are not uncommon in the Babine porphyry copper-gold camp. This emphasizes the need for careful and sufficient sampling and assaying for gold. Three metallurgical tests completed in

1973 returned gold grades approximately mid-range between the 1967 and 1988 values.

Indicated and inferred resources for the Morrison deposit as of December 31, 1993 total 190 million tonnes grading 0.40% Cu and 0.21 g/t Au to a depth of 300 m using a cutoff grade of 0.30% Cu. An open pit resource developed on the basis of a 0.75:1 waste to ore strip ratio and the same cutoff grade is estimated at 58 million tonnes grading 0.41% Cu and 0.21 g/t Au. The interpolation run-numbers in Figure 13 reflect the major axis search radius of the ellipsoids used to interpolate block model grades and provide a measure of the resource confidence.

Hearne Hill

The level of sampling information at Hearne Hill as of December 31, 1992 was much lower than for the Morrison deposit and rigorous resource calculations were not appropriate. The resource estimates for stockwork mineralization at Hearne Hill were performed by first calculating 12.5 m bench composites from the diamond drill data. The diamond drill composites were then kriged and contoured, and volumes calculated within each contour to a depth of approximately 100 m. Resource estimates for breccia mineralization were calculated by constructing polygons on-section to the confines of the breccia pipe.

The resultant inferred resource for the Hearne Hill porphyry deposit was estimated to be 60 million tonnes at an average grade of 0.16% Cu and 0.1 g/t Au using a cutoff grade of 0.10% Cu (Ogryzlo, 1993). The breccia pipe within the Hearne Hill porphyry deposit was estimated to contain an indicated resource of 143 000 tonnes at an average grade of 1.73% Cu and 0.8 g/t Au using a cutoff grade of 0.75% Cu (Ogryzlo, 1993).

Environmental Considerations

Babine Lake lies within the watershed of the Skeena River. Babine is the longest natural lake in British Columbia and hosts one of the largest runs of Sockeye salmon in the world. Morrison Creek, which drains Morrison Lake, also hosts a major salmon run. Forestry, recreational and wildlife values in the region are high and provide sustained employment for many residents of the district. Mining operations in the region must protect these resources.

Revegetation and restoration of disturbed sites in the region is relatively simple due to good soils and a humid climate. The impervious glaciolacustrine clays which so effectively mask residual geochemical anomalies are an asset in site rehabilitation. Acid generation potential of the stockwork mineralization at Morrison and Hearne Hill deposits is not known and would require rigorous sampling and evaluation before mining operations could be contemplated. Rocks from the breccia pipe are acid consuming with a net neutralization potential (NP) of 119 (L'Orsa, 1991), which represents 119 tonnes $CaCO_3$ per 1000 tonnes rock. The acid consumption potential is due to the dolomite and calcite breccia cement.

On Hearne Hill, antimony and uranium values in soils are near the lower limits of detection. Arsenic values in soils are close to background values of 20 ppm to 30 ppm, although a single sample reported at 313 ppm (Ogryzlo, 1990). Within the breccia pipe, arsenic and lead have mean concentrations of 88 ppm and 40 ppm, respectively. Arsenic values obtained on 477 selected Morrison drill core composite samples range to 2000 ppm and average 89 ppm.

Postulated Synthesis of the Morrison - Hearne Hill Deposits

The Morrison and Hearne Hill deposits may be dismembered portions of an originally contiguous classic porphyry copper-gold deposit. In this interpretation, the Morrison deposit would represent the upper slice and Hearne Hill would represent the root of the system. The following sequence of events is proposed for the formation of the two deposits.

Genesis of the Babine Igneous Suite: Subduction/Underplating

Following Mid-Cretaceous docking of the Insular Superterrane, Late Cretaceous to Paleocene oblique convergence of the Farallon plate with the western margin of the continent (Gabrielse and Yorath, 1989) led to the development of an easterly dipping subduction zone. Cretaceous to Eocene magmatism in the western Cordillera occurred in north to northwesterly trending belts (Carter, 1982), culminating in intense and widespread magmatism from 55 Ma to 45 Ma subsequent to the last major episode of contraction (Gabrielse and Yorath, 1989). The Babine Intrusions are in the easternmost of these magmatic belts and were emplaced at a considerable distance above the subduction zone (Carter, 1982). It is proposed that alkaline melts, which formed at depth in or above the subducted slab, rose to underplate the island arc assemblage of the Stikine terrane, which by Eocene time, had been welded to the craton. Partial melting and assimilation of former island arc rocks produced a calc-alkaline magma that inherited the immobile trace element characteristics of the parental alkaline melts. As dextral shear became paramount in Paleocene and Eocene time, an extensional/transtensional tectonic regime began to affect the Babine region. Transtensional faulting tapped bodies of the contaminated alkaline magma which were subsequently emplaced in dilatant zones along major structural discontinuities as a continental magmatic arc.

Emplacement of Babine Igneous Suite Intrusions

Disruption of the Mesozoic island arc/molasse sequence along the Morrison Fault was followed by the emplacement of a hornblende-biotite-plagioclase phyric intrusion of the Babine Igneous Suite (Fig. 14). Brittle failure during faulting and intrusion led to intense crackling of the wallrocks, and the development of high permeability and moderate porosity. Copper-gold enriched magmatic fluids evolving from the cooling intrusive body circulated freely throughout the crackled wallrocks and to a lesser extent throughout the less fractured intrusion. The circulating fluids led to the development of hydrothermal convection cells and the formation of a symmetrically zoned porphyry copper deposit. Copper and iron ions in the highly saline magmatic waters were deposited as sulphides. Deposition of copper was associated with intense secondary biotite and magnetite which formed at the expense of hornblende, and rarely, magmatic biotite.

Dismemberment by Extensional Faulting

Before the cessation of magmatic and hydrothermal activity, the deposit may have been truncated by further movement along the Morrison Fault (Fig. 14). Extensional movement may have been accompanied or followed by several hundred metres of dextral shear. It is proposed that the younger molasse sedimentary sequence (accompanied by the contained BFP intrusions) was down-faulted into the Morrison Graben, with the Hearne Hill portion being exposed along the scarp of the Morrison Fault, effectively dismembering the originally continuous porphyry copper-gold system. Dextral shear along a subsidiary fault caused displacement of the western half of the Morrison deposit 330 m to the north.

Formation of the Hearne Hill Breccia Pipe: Leaching, Collapse and Cementation with Chalcopyrite

It is further proposed that a renewed magmatic pulse in the exposed root of the deposit on Hearne Hill led to the emplacement of white, massive, unjointed biotite-plagioclase phyric dikes containing sparse phenocrysts of partially resorbed quartz (QBFP?). The magmatic activity preceded or accompanied phyllic alteration and a pulse of strongly corrosive hydrothermal fluids. Solution of rocks along the BFP/volcanic contact led to collapse brecciation

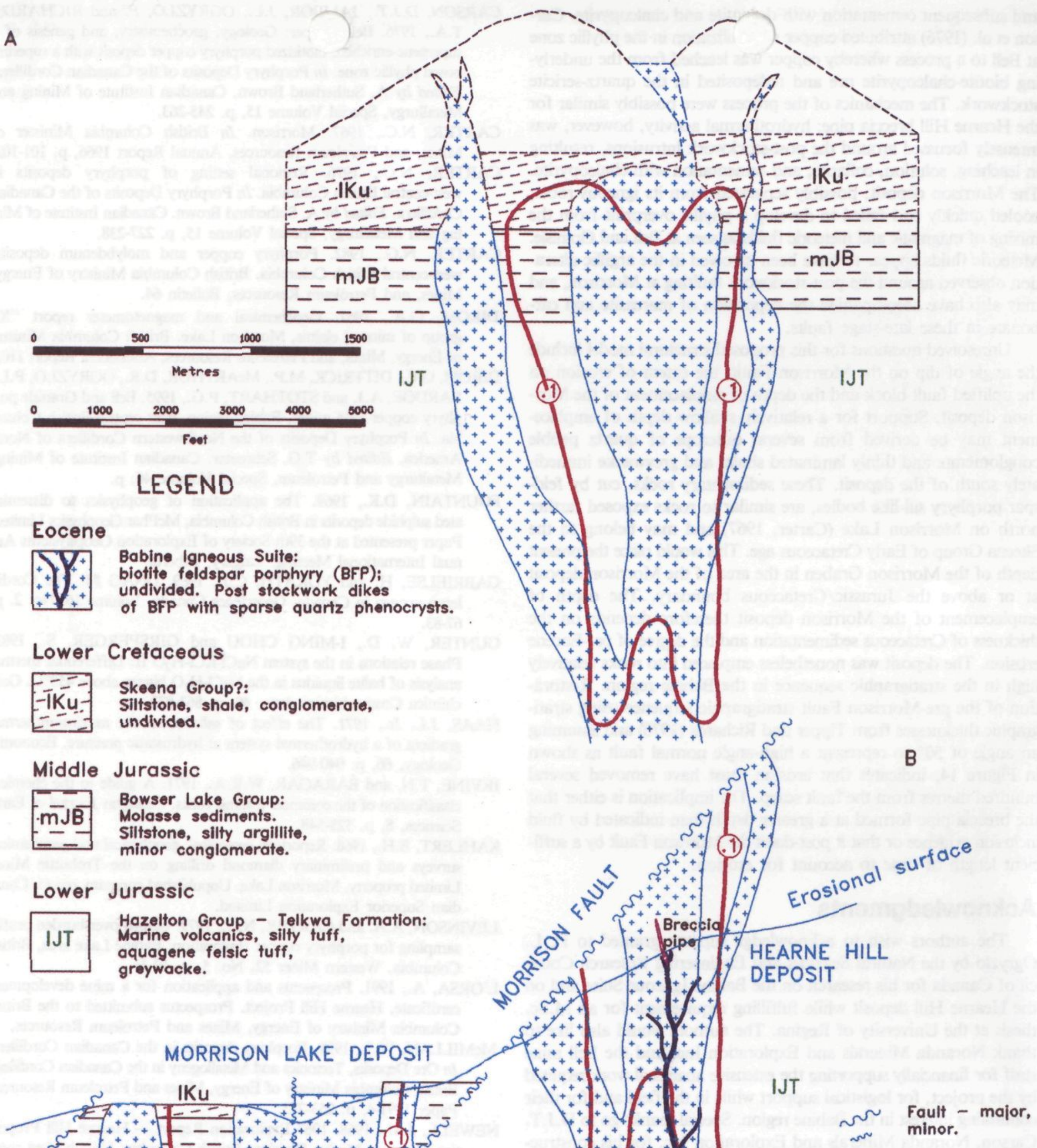

FIGURE 14. Reconstruction of the Morrison - Hearne Hill system. Fig. 14A: Morrison-Hearne classic porphyry copper system before dismemberment by the Morrison Fault. The Eocene volcanic pile is speculative: the nearest preserved volcanic equivalents are 20 km to the south. Fig. 14B: Post Morrison Fault configuration. The extent of the Lower Cretaceous sedimentary rocks in the westernmost fault block is moderately exaggerated: these occur as an isolated outlier of pebble conglomerate tentatively attributed to the Sustut Group. The projections of the deposits are relatively to scale.

and subsequent cementation with dolomite and chalcopyrite. Carson et al. (1976) attributed copper mineralization in the phyllic zone at Bell to a process whereby copper was leached from the underlying biotite-chalcopyrite ore and redeposited in the quartz-sericite stockwork. The mechanics of the process were possibly similar for the Hearne Hill breccia pipe; hydrothermal activity, however, was intensely focussed around the post-stockwork intrusions, resulting in leaching, solution, collapse, and cementation with chalcopyrite. The Morrison deposit, possibly separated from its igneous roots, cooled quickly and failed to develop a phyllic overprint from the mixing of magmatic and meteoric fluids as seen at Bell and Granisle. Meteoric fluids appear to have been involved in the argillic alteration observed around the post-stockwork faulting at Morrison, and may also have accompanied the deposition of marcasite and carbonate in these late-stage faults.

Unresolved questions for this proposed structural model include the angle of dip on the Morrison Fault, the extent of erosion on the uplifted fault block and the depth of emplacement of the Morrison deposit. Support for a relatively shallow depth of emplacement may be derived from several outcrops of quartz pebble conglomerate and thinly laminated shales and greywacke immediately south of the deposit. These sedimentary rocks, cut by feldspar porphyry sill-like bodies, are similar to rocks exposed farther north on Morrison Lake (Carter, 1967) and may belong to the Skeena Group of Early Cretaceous age. This would place the present depth of the Morrison Graben in the area of the Morrison deposit at or above the Jurassic/Cretaceous boundary. The depth of emplacement of the Morrison deposit therefore depends on the thickness of Cretaceous sedimentation and the degree of pre-Eocene erosion. The deposit was nonetheless emplaced into rocks relatively high in the stratigraphic sequence in the Babine region. Restoration of the pre-Morrison Fault stratigraphic sequence using stratigraphic thicknesses from Tipper and Richards (1976) and assuming an angle of 50° to represent a high-angle normal fault as shown in Figure 14, indicates that erosion must have removed several hundred metres from the fault scarp. The implication is either that the breccia pipe formed at a greater depth than indicated by fluid inclusion evidence or that it post-dates the Morrison Fault by a sufficient length of time to account for erosion.

Acknowledgments

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