Porphyry copper-gold deposits, Babine Lake area, west-central British Columbia

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ABSTRACT

Although porphyry mineralization in the Babine Lake area is associated with four distinct ages of intrusive activity including Early to Mid-Jurassic (176 Ma), Early Cretaceous (136 Ma) and Late Cretaceous (77 Ma), the most significant deposits and occurrences are temporally and spatially related to Tertiary (50 Ma) Babine intrusions. These host more than a dozen deposits and occurrences in addition to the past producing Bell and Granisle open-pit mines which processed 130 million tonnes with average recovered grades of 0.40% Cu, 0.15 g/t Au and 0.75 g/t Ag between 1966 and 1992.

Babine intrusions occur as small stocks, plugs and dike swarms emplaced along northwest-trending regional faults developed in arc-derived Mesozoic volcanic and sedimentary assemblages. The intrusions are calc-alkaline in composition but recent trace element work suggests a possible alkaline parentage. The dominant hostrock for copper-gold mineralization is a distinctive, fine- to medium-grained, crowded biotite feldspar porphyry (BFP) of granodiorite composition. Pre-, inter- and postmineral intrusive phases are evident and extrusive equivalents of these high-level intrusions are locally preserved.

Copper-gold mineralization occurs as chalcopyrite and bornite within narrow quartz-filled fractures and stockworks and as disseminations within and marginal to BFP intrusions. Markedly higher copper grades are associated with irregular, intermineral intrusive breccias within several of the known deposits. Weakly developed supergene chalcocite enrichment was a feature of the near-surface part of the Bell orebody. Pyrite haloes may extend up to 300 m outward from internal copper zones.

Classic hydrothermal alteration zoning is well documented at several deposits and includes a central potassic zone, consisting principally of secondary biotite and crudely coincident with zones of higher grades of copper, grading outward to phyllic (quartz-sericite-pyrite) and propylitic zones.

Although most of the known porphyry deposits and occurrences were found by basic prospecting and stream sediment geochemistry, subsequent exploration in the Babine area has been hampered by extensive glacial overburden cover. Stream sediment and soil sampling has limited application throughout much of the area; airborne and surface geophysical surveys have proved to be more useful in detecting intrusive bodies and in defining drilling targets.

Introduction

The northern Babine Lake area is a well-mineralized district featuring several deposit types. These include porphyry Cu (±Au±Mo) deposits related to four distinct intrusive ages; those associated with the Tertiary (Eocene) Babine Igneous Suite have been the most productive to date. Production from two open-pit mines (Granisle and Bell, both now closed) totals 517 577 tonnes copper, 19 627 kg gold and 97 566 kg silver from 129.9 million tonnes of ore milled.

The area is highly prospective for the discovery of additional deposits. Mineral exploration in the past has been hampered by vegetation and locally thick overburden cover; refined geophysical and geochemical methods may prove useful in future work.

This paper is intended as an overview of the district as a whole; detailed descriptions of four of the better known deposits are contained in the following two papers (Dirom et al.; Ogryzlo et al., this volume).

Applicability of Exploration Techniques

Events leading to the discovery and/or the recognition of the potential of the principal Babine porphyry deposits (Fig.1) has been documented in this volume by Newell et al., Dirom et al., and Ogryzlo et al.

The malachite-stained rocky ridge in the central part of McDonald Island (Granisle) and the polymetallic veins, on the lakeshore peripheral to both the Granisle and Bell deposits, were initially prospected prior to 1913 (Emmens, 1914). Similarly, the polymetallic vein marginal to copper mineralization at Trail Peak was investigated a number of years prior to porphyry-directed exploration in the 1960s and 1970s when virtually all of the deposits and prospects shown in Figure 1 were discovered.

Basic prospecting resulted in the initial identification of copper mineralization at the Horetzky and Tachek Creek prospects. Regional soil and stream sediment geochemical surveys and subsequent prospecting were successful in locating the Morrison, Hearne Hill, Old Fort, Nak, Dorothy, Trail Peak, Lennac Lake and French Peak prospects.

The Morrison deposit (Ogryzlo et al., this volume), discovered by the follow-up of anomalous copper in stream sediment samples from a creek draining the central part of the copper zone, is reflected by greater than 500 ppm Cu in soils overlying the deposit. Values of more than 200 ppm Cu in soils extend downslope from the Hearne Hill stockwork copper zone (Ogryzlo et al., this volume) and greater than 500 ppm Cu values are coincident with the higher grade breccia zone.

Copper values in soils exceeding 100 ppm identified areas of copper mineralization at both the Old Fort and Trail Peak prospects (Carter, 1993), while anomalous copper in stream sediments (up to 320 ppm; Carter, 1994) led to the discovery of the Nak prospect. Subsequent soil sampling indicated a number of areas within and marginal to the southern half of the intrusive stock with values of between 150 and 300 ppm Cu.

Traditional geochemical methods were used to good effect in identifying the foregoing deposits and prospects, virtually all of which featured at least some bedrock ›sure and only a thin mantling of overburden.

Much of the Babine area is one of low to moderate relief and mineral exploration throughout the district has been hampered by a paucity of bedrock exposures due to extensive overburden cover. Thicknesses of more than 40 m are not uncommon and the overburden consists of impervious glaciolacustrine clay horizons which overlie or are intercalated with glacially transported tills. These glacial deposits present serious difficulties in interpreting the results of soil and stream sediment surveys (Levinson and Carter, 1979) throughout much of the Babine district.

Other geochemical methods, including biogeochemistry and basal till sampling, may prove to be useful in assessing overburden-covered areas. A good example of the applicability of other techniques is lake sediment sampling (values of up to 24 ppm Mo and 105 ppm Cu; Cope and Spence, this volume) which resulted in the discovery of the Mac molybdenum prospect east of Babine Lake.

Lithogeochemistry can be useful in determining areas for further exploration but is obviously limited to areas of reasonably good bedrock exposure. Areas of pyrite mineralization are obvious targets for follow-up exploration inasmuch as they may be parts of broad haloes surrounding undetected porphyry mineralization. Anomalous zinc in rocks, commonly developed in the outer parts of pyrite haloes, has proven to be one of the more useful trace elements in this area (Jambor, 1974). Current studies of the mineral chemistry of biotites and apatites (Sheets and Nesbitt, 1994) is being directed to the identification of possible differences between well-mineralized and weakly-mineralized or barren Babine porphyry intrusions.

Airborne and surface magnetic surveys have been useful in identifying prospective porphyry intrusions which commonly contain at least some magnetite. A re-interpretation of existing government airborne magnetic data preceded the discovery of copper mineralization on the Sat property. Previous work on most of the district deposits and occurrences has demonstrated the usefulness of induced polarization surveys in identifying targets for subsequent drilling by defining areas of higher chargeabilities which are usually coincident with pyrite haloes.

Electromagnetic surveys have less application in the search for porphyry mineralization but it is noteworthy that this method was instrumental in the discovery of the Bell orebody which was obscured by between 4 m and 30 m of overburden including a significant clay component. Spotty copper values in soils were obtained from initial work but the initial targets for drilling were electromagnetic anomalies caused by the pyrite halo immediately east of the polymetallic veins exposed on the lakeshore (Dirom et al., this volume).

Most of the prospects in the area have been investigated by at least some diamond drilling. The two past-producing mines, Bell and Granisle, were tested by 78 000 m and 47 700 m of drilling respectively, principally at 30 m to 60 m spacings (Dirom et al., this volume). Vertical holes comprised 75% of the holes drilled at Granisle and 40% of the holes at Bell, notwithstanding the fact that virtually all of the mineralized quartz veinlets and fractures are steeply dipping to vertical as are most of the weakly mineralized or postmineral porphyry phases. By contrast, the resource estimate for the Morrison deposit is based on less than 14 000 m of diamond drilling in 95 inclined holes.

Regional Geological Setting

The Babine Lake area, 70 km east of Smithers in west-central British Columbia (Fig. 1), is within the Intermontane tectonic belt which comprises a number of accreted terranes, the largest of which, Stikine terrane, underlies much of this part of British Columbia.

The oldest rocks exposed in the Babine area, which is near the eastern margin of Stikine terrane, are island arc assemblage Late Triassic (Takla Group) and Early Jurassic (Hazelton Group) marine volcanic, volcaniclastic and sedimentary rocks. These older sequences are best exposed withi d adjacent to the northeast-trending Skeena Arch, a prominent transverse zone of uplift during Mesozoic time. Early Jurassic Topley granitic intrusions, in part comagmatic with Hazelton Group volcanic rocks, are distributed throughout the arch (Fig. 1).

Accretion of Stikine terrane with North America in Middle to Late Jurassic time resulted in uplift, the development of the Bowser and Nechako successor basins north and south of Skeena Arch, respectively, and the onset of a period of sedimentation represented in the Babine area by marine and nonmarine clastic sedimentary rocks of the Middle to Late Jurassic Bowser Lake and mid-Cretaceous Skeena groups which overlie the older, arc-related volcanic and sedimentary rocks. These younger sedimentary rocks are preserved in down-dropped basins bounded by north-northwest-trending regional faults (Fig. 1) and developed during a period of extension and transtensional faulting in Late Cretaceous and Early Tertiary time.

These same deep-seated faults and related dilatant zones provided conduits for calc-alkaline magmas. Products of these magmatic episodes include plutons of the Late Cretaceous Bulkley intrusions (Carter, 1976, 1981) and the Eocene Babine Igneous Suite with which most of the porphyry Cu-Au deposits and occurrences in the district are associated.

Babine Igneous Suite

Babine Igneous Suite intrusions are the easternmost of a broad belt of Late Cretaceous and Early Tertiary granitic plutons which cut older rocks of Stikine terrane east of the Coast Plutonic Complex (Carter, 1976, 1981). Originally referred to as the Babine intrusions (Carter, *ibid*), the term Babine Igneous Suite more accurately reflects the diversity of these rocks which appear to be restricted to a belt 40 km wide which extends more than 100 km northwesterly from the northern part of Babine Lake (Fig. 1).

These Eocene intrusions occur as irregular dikes, dike swarms and plugs generally not exceeding 1 km in surface area (Carter, 1973a). The suite consists of a variety of intrusive types, including, from oldest to youngest, equigranular, fine- to medium-grained quartz diorite and lesser quartz monzonite, sub-porphyritic rhyolites and dacites and distinctive (hornblende)-biotite-feldspar porphyries which are the principal hostrocks for porphyry copper-gold mineralization.

Intrusive Sequence

The apparent oldest phases of the Babine Igneous Suite include a small (500 m by 300 m), oval pluton of fine-grained quartz diorite microporphyry on the east side of the Granisle pit and a larger (900 m by 600 m), elliptical stock of similar composition and texture, but locally gradational to quartz monzonite, at the Old Fort prospect (Fig. 2). Contacts with these and country rocks range from well defined at Old Fort, where predominantly Bowser Lake Group sedimentary rocks are altered to biotite hornfels (Carter, 1967), to gradational at Granisle, where bordering Hazelton Group fragmental volcanic rocks are in part recrystallized and metasomatized (Carter, 1972).

Rhyolite and dacite plugs, dikes and sills are widespread throughout the Babine area. At Bell mine (Dirom et al., this volume) and on central Newman Peninsula a short distance south, these intrusions are porphyritic with small feldspar phenocrysts widely dispersed in an aphanitic, siliceous matrix. Similar intrusions, northwest of the Old Fort prospect and between the northwest arm of Babine Lake and Morrison Lake, are more coarsely porphyritic, with prominent quartz eyes and scattered biotite books. A small sill of aphanitic rhyolite is situated near the northwest margin of the Morrison deposit (Ogryzlo et al., this volume).

Youngest phases of the Babine Igneous Suite are comprosed of distinctive (hornblende)-biotite-feldspar porphyries (BFP) which are characterized by crowded phenocrysts of euhedral plagioclase, biotite and sometimes hornblende, set in a light to medium grey,

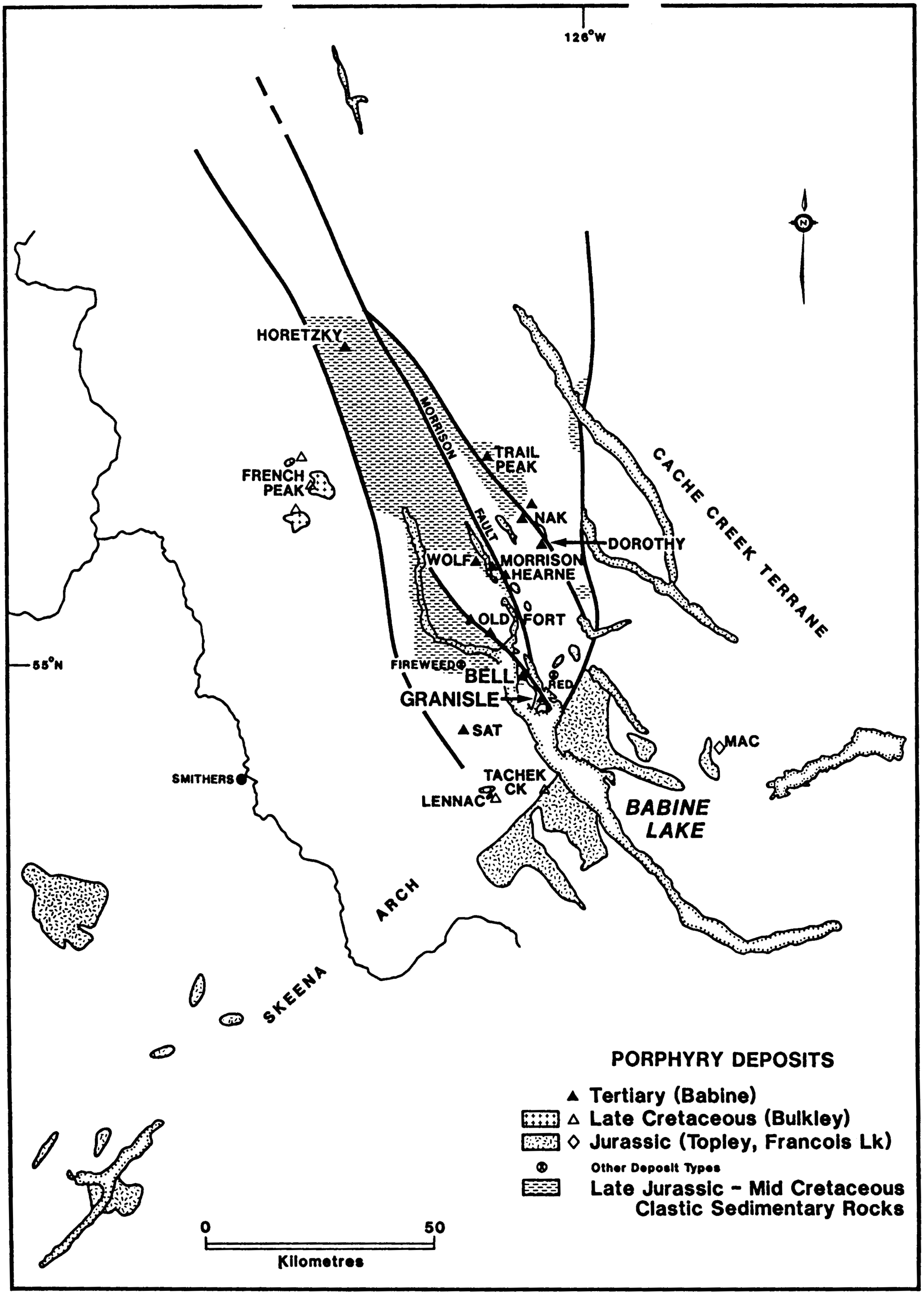

FIGURE 1. Babine Lake area — regional geological setting.

fine-grained matrix of plagioclase, q , biotite and minor K-feldspar. These porphyries are common to all Babine deposits and prospects and occur as dikes (Granisle), small plugs and stocks (Bell, Dorothy, Nak) or as dike swarms marginal to central plugs (Morrison, Trail Peak - Fig. 2). These intrusions, in addition to having sharp contacts with country rocks, clearly cross-cut the earlier quartz diorite intrusive phases although contact relationships with apparently earlier rhyolites are less clear. Repeated pulses of BFP intrusion are evident at many of the deposits and prospects in the district.

Biotite-feldspar porphyry compositions range from quartz diorite to granodiorite (Carter, 1976, 1981). Recent studies (Ogryzlo et al., this volume) indicate these intrusions are part of a high potassium, calc-alkline magmatic suite but have an alkaline immobile trace element signature.

Age of Intrusion

Fifteen radiometric (K-Ar) age determinations obtained from mineralized and unmineralized BFP and extrusive equivalents at ten different localities (Carter, 1981; Richards, 1990) yielded an average age of 50 Ma. Limits of error for most of these determinations are between ±1.9 and ±3.0 Ma (Carter, 1981).

Fewer radiometric ages are available for recognizably older phases of the Babine Igneous Suite. One sample from unmineralized, equigranular quartz monzonite southwest of the Old Fort prospect returned an age of 52 Ma or slightly older than the BFP phase. A rhyolite porphyry from the northwest arm of Babine Lake was dated at 47 Ma (Carson et al., 1976) which, while at odds with the geologically inferred older age for similar intrusions at Bell mine, is within the limits of error of the other age determinations cited.

In summary, it is evident that all intrusive phases of the Babine Igneous Suite were emplaced over a short time span in the Middle Eocene.

Structural Setting and Level of Emplacement

As noted previously, intrusions of the Babine Igneous Suite are spatially related to north-northwest trending regional faults, and splays off them, as illustrated on Figure 1. The most important of these is the Morrison Fault with a known extent of more than 100 km and along which are intrusions hosting the Morrison and Hearne Hill deposits. The Granisle and Bell deposits and the Old Fort prospect are associated with intrusions which heal a northwesterly splay off the southern end of the Morrison Fault. The Trail Peak, Nak and Dorothy intrusions are adjacent to a parallel fault east of the Morrison Fault (Fig. 1). Most of the foregoing intrusions and related mineral deposits and occurrences are within down-dropped blocks or grabens marginal to the regional faults.

The mineralized intrusions cut a variety of older volcanic and sedimentary rocks ranging in age from Early Jurassic (Granisle mine, eastern part of Bell mine, Hearne Hill, Nak, Dorothy, Sat) through Middle to Late Jurassic (Morrison, Old Fort, Trail Peak, Horetzky) to Middle Cretaceous (western part of Bell mine). Therefore, it would appear that neither the age or composition of the country rocks were factors in the emplacement of the intrusions or in the development of the associated mineral deposits. However, Late Jurassic to Middle Cretaceous sedimentary rocks are preserved in down-dropped blocks marginal to major faults and recognition of isolated remnants of these sedimentary rocks in relatively unexplored areas could be of use in identifying additional prospective areas.

The area immediately south of Granisle mine is part of an uplifted block of older rocks along the axis of the Skeena Arch (Fig. 1) and is underlain by Jurassic Topley granitic rocks which intrude volcanic and sedimentary rocks of the basal part of the Hazelton Group and older, Late Triassic Takla Group. Angular BFP float has been noted in at least one locality and it is possible that some rhyolite dikes and sills, which cut older plutonic and layered rocks in this area, may be part of the Babine Igneous Suite.

North and east of Granisle and Bell, some of the Eocene intrusions are close to, or cut, isolated granitic plutons of Jurassic age which may be evidence epeated intrusive activity along regenerated fault structures. Examples include the Hearne Hill, Dorothy and Trail Peak prospects (Fig. 2).

Evidence for the high-level emplacement of the epizonal Babine intrusions includes the incidence of intrusive breccias and the presence of compositionally and texturally similar extrusive equivalents consisting of crystal tuffs, debris flows and columnar jointed flow rocks which are preserved west of Babine Lake, on Newman Peninsula between the Bell and Granisle mines and at the Trail Peak prospect to the north.

Fluid inclusion studies (Wilson et al., 1980) indicate that the Granisle deposit formed at higher pressures and at slightly higher temperatures than Bell.

Styles of Porphyry Mineralization and Alteration — Babine Igneous Suite

Porphyry mineralization associated with the Babine Igneous Suite is a product of hydrothermal processes related to multiple episodes of BFP intrusion. The best documented examples of mineralizing styles and attendant alteration are the two formerly producing mines, Bell and Granisle (Dirom et al., this volume).

Mineral Distribution

Chalcopyrite, bornite, pyrite and lesser molybdenite are the principal sulphide minerals. These rarely exceed 5% by volume and most commonly occur in steeply dipping, narrow, quartz-filled fractures of preferred orientations, and, to a lesser degree, as disseminations in the hostrock. A notable exception is Bell where disseminated ore and randomly oriented, true quartz stockworks are present in roughly equal proportions. Millhead copper grades at both Granisle and Bell averaged 0.47%.

Sulphide zoning consists of an inner, central bornite zone, gradational outward to chalcopyrite and finally pyrite.

Higher copper grades are developed near the margins of BFP intrusions. At Granisle, an elliptical orebody was centred on the BFP-quartz diorite microporphyry contact; at Bell, the near-surface ore zone was crescent-shaped and was developed at the northwestern contact of the BFP plug with hornfelsed siltstones and earlier rhyolite intrusions. At depth, the Bell orebody is annular in plan but with higher copper grades localized near the western margin of the BFP intrusion (Dirom et al., this volume).

At Hearne Hill (Ogryzlo et al., this volume), chalcopyrite, pyrite, bornite and minor molybdenite occur as disseminations, fracture fillings and in quartz veinlets in a stockwork zone best developed in Hazelton Group volcanic and sedimentary rocks marginal to an east-northeast-trending elongate BFP dike-like body (Fig. 2). The nearby Morrison deposit consists of annular zones of chalcopyrite and bornite as fracture fillings and in quartz stockworks in BFP dike swarms cutting sedimentary rocks marginal to a central, fault-bisected BFP plug (Carson and Jambor, 1976).

Higher copper grades at both the Dorothy (Carson and Jambor, 1974) and Nak prospects (Carter, 1994) appear to be near the western margins of relatively large BFP intrusions (Fig. 2). At Trail Peak (Carter, 1970a, 1993), the highest copper grades encountered to date are restricted to a north-northwest trending BFP intrusion immediately southwest of a Jurassic-Cretaceous diorite plug (Fig. 2).

The Old Fort and Horetzky prospects (Figs. 1 and 2) are similar inasmuch as virtually all chalcopyrite mineralization is restricted to BFP dikes and irregular plutons which cut slightly older and essentially barren, fine- to medium-grained quartz diorite to quartz monzonite plugs and peripheral hornfelsed Bowser Lake Group sedimentary rocks (Carter, 1967a; Mackie, 1972; Campbell and Casselman, 1992).

Significant secondary or supergene ore was preserved only above the western part of the Bell orebody where it extended to depths of less than 100 m (Dirom et al., this volume). The supergene zone consisted of chalcocite coating chalcopyrite and pyrite and had the

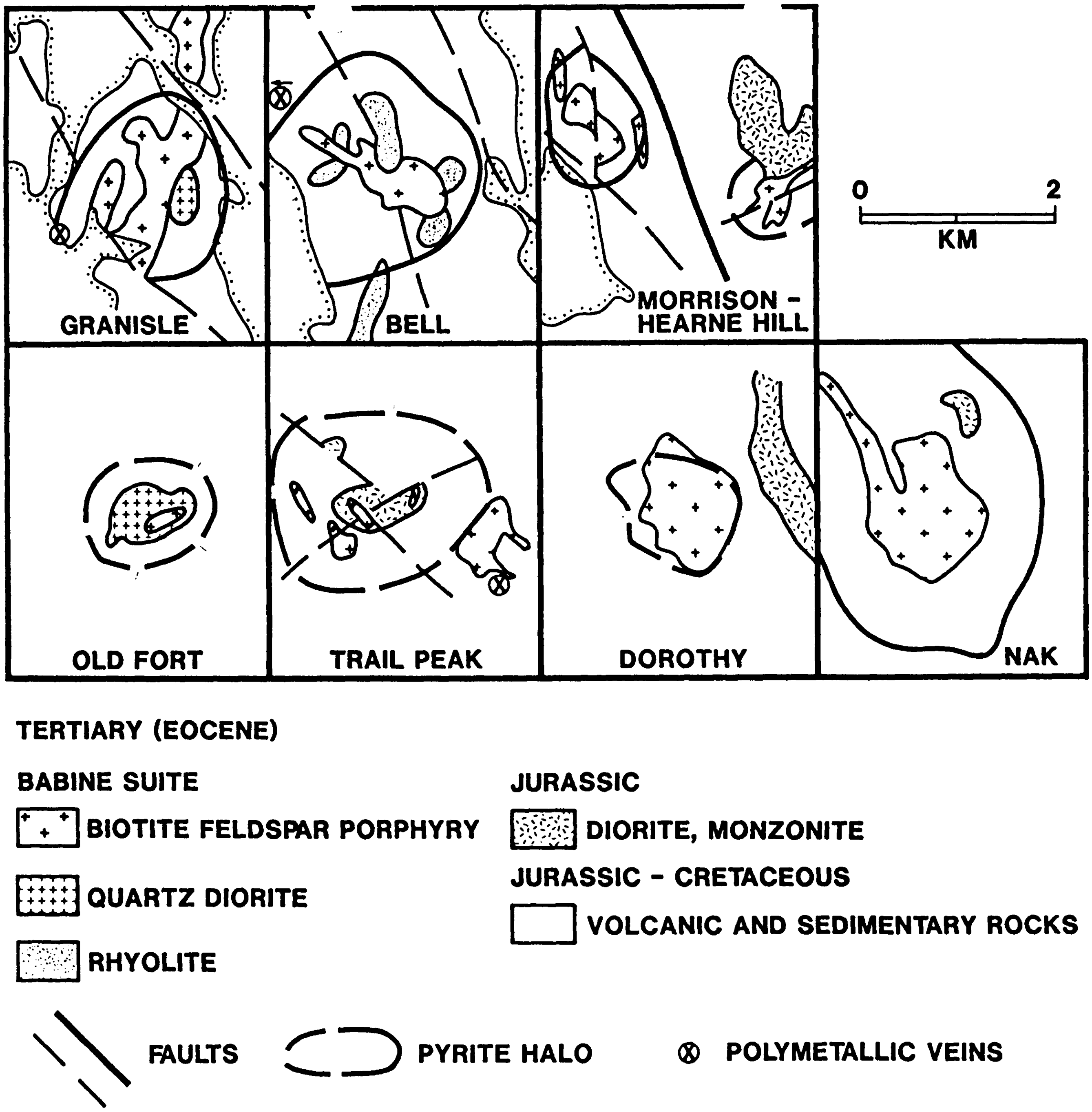

FIGURE 2. Generalized geology of some porphyry copper-gold deposits, Babine Lake area.

effect of increasing better grades of primary copper mineralization by as much as 10% to 15% (Carson et al., 1976). Similar supergene enrichment is also present in the upper 30 m of the Hearne Hill breccia pipe (Ogryzlo et al., this volume).

Pyrite haloes are variably developed around all known Babine deposits and prospects (Fig. 2). These annular zones, which may extend outward several hundred metres from the central copper zones, contain between 2% and 10% pyrite as fracture-fillings and disseminations in both the intrusions and adjacent country rocks.

Significant pyrite concentrations (greater than 10%) are best developed around the Bell and Granisle deposits. It is noteworthy that the broadest distribution and highest concentration of pyrite marginal to the Bell deposit is within argillaceous sedimentary rocks west of the open pit, which may be in part a reflection of primary pyrite within this sequence. This may also explain the relatively well-developed pyrite halo developed in similar sedimentary rocks surrounding the the weakly mineralized Old Fort pluton and the broad distribution of pyrite around the Trail Peak prospect. A broad pyrite zone is well developed in volcanic and sedimentary rocks surrounding the relatively large BFP intrusion at the Nak property (Fig. 2; Carter, 1994).

Narrow, silver-bearing, polymetallic quartz-carbonate veins are known at or near the outer limits of pyrite haloes at several Babine prospects and deposits. Such veins at Granisle, Bell and Trail Peak (Fig. 2), which contain variable amounts of sphalerite, galena, chalcopyrite, pyrite and some tetrahedrite, were explored prior to the recognition of porphyry copper potential. At Morrison (Ogryzlo et al., this volume), late stage quartz-carbonate veinlets containing marcasite, sphalerite and arsenopyrite are developed within the fault which bisects the deposit (Fig. 2).

These peripheral veins, which reflect sulphide mineral zoning outward from a copper-rich core, are typical of a classic porphyry system. Trace element studies (Jambo 74; Carson and Jambor, 1974) indicate anomalous zinc (100 to >200 ppm) values in rock samples near the margins of pyrite haloes at several of the Babine porphyry systems.

Gold was an important by-product at the two former producing mines, particularly at Bell where it accounted for between 20% and 35% of mine revenue (Dirom et al., this volume). Average millhead grades were 0.26 g/t Au at Bell and 0.20 g/t Au at Granisle.

Gold is present as electrum at both deposits and occurs along bornite grain edges at Granisle and as fine inclusions in both pyrite and chalcopyrite at Bell which would explain the slightly better recoveries at Granisle (65%) as opposed to Bell (60%) (Cuddy and Kesler, 1982).

Gold grades at Granisle and Bell were directly proportional to copper grades (Dirom et al., this volume), a feature also noted at Morrison (Ogryzlo et al., this volume) and Trail Peak (Carter, 1993) where a 15 m section in one drill hole averaged 0.45% Cu and 0.21 g/t Au, roughly the same tenor as millhead grades at Granisle. Higher gold grades (0.8 g/t) are associated with demonstrably higher copper grades of 1.73% within the Hearne Hill breccia pipe (Ogryzlo et al., this volume).

There is little information concerning gold grade or distribution at other Babine prospects, as assaying for gold was not routine during exploration work in the late 1960s and early 1970s.

Low-grade molybdenite (0.005% Mo) at Bell occurs in the inner portion of the higher grade copper annulus; at Granisle, a zone of slightly higher grade molybdenite (0.010% Mo) flanks the copper zone on the west.

Distribution of silver within the copper deposits appears to be variable. Millhead grades of 2 g/t Ag at Granisle, double those of Bell (Dirom et al., this volume), were no doubt indicative of the greater concentration of bornite.

Inter- and Postmineral Intrusive Phases

A feature of all better documented Babine porphyry copper deposits is the multiplicity of BFP intrusive phases that overlap the period of mineralization. Best examples are at Granisle where several stages of BFP intrusion are recognized (Kirkham, 1971; Carter, 1972; Fahrni et al., 1976). Although these are lithologically and chemically similar, they can be identified by slight differences in colour and texture, by cross-cutting relationships and by inclusions of earlier porphyry phases within younger ones. Intermineral phases, as the name implies, are mineralized, and the fact that they contain fragments of earlier mineralized porphyry increases the overall copper grade.

Initial millhead grades at Granisle were also enhanced by narrow, discontinuous dikes and veins of intrusive breccia which were contained within a 60 m wide zone centred on the main BFP-quartz diorite microporphyry contact (Carter, 1972). In the upper part of the southern half of the orebody, coarse-grained, and locally euhedral, bornite, chalcopyrite, quartz, biotite and apatite occurred in 30 cm wide veins.

Significantly higher copper grades at Hearne Hill (Ogryzlo et al., this volume), are associated with an oval, breccia pipe (70 m by 25 m in plan) within a broad zone of lower grade stockwork mineralization. The open-space breccia consists of angular porphyry clasts cemented by chalcopyrite, pyrite and marcasite.

Weakly mineralized and/or postmineral porphyry phases are also present at most deposits and prospects and knowledge of their nature and distribution is critical in property evaluation. At Granisle, fine-grained, dark grey, post-mineral BFP dikes cut quartz diorite microporphyry in the eastern pit area and leucocratic, weakly mineralized BFP phases occur within the central part of the orebody (Carter, 1972). Two late-stage or postmineral intrusive events were evident in the upper pit benches at Bell (Dirom et al., this volume). These included a north-trending dike, 150 m wide, of late-stage BFP which separated the near-surface northeast limb of the orebody from the main zone and a funnel shaped (400 m diameter), leucocratic quartz-feldspar-(±biotite) fel porphyry (QBFP) and related breccia body which replaced the upper, southeastern part of the orebody.

The latter postmineral phase at Bell is considered to be a product of high-level, subvolcanic processes (Dirom et al., this volume). Grossly similar, leucocratic late-stage BFPs with and without quartz phenocrysts, are present at several other prospects, some in similar high-level structural settings. Examples include Granisle, referred to previously, Hearne Hill which is interpreted as being the root zone of the Morrison porphyry system (Ogryzlo et al., this volume) and Trail Peak where extrusive equivalents of the BFP are recognized. Similar late BFP phases have also been noted in drill core at the Nak and Dorothy prospects (Carter, 1994).

Postmineral basic dikes, common to most porphyry deposits and prospects in west-central British Columbia, are rare in the Babine Lake area with the exception of the Morrison deposit where a few andesite dikes were noted in drill core (Carson and Jambor, 1976).

Alteration

Babine deposits and prospects exhibit concentric zoning of alteration mineral assemblages, typical of classic porphyry copper deposits (McMillan, 1991). A central, potassic alteration zone, crudely coincident with better grades of copper mineralization, is gradational outward to a chlorite-carbonate or propylitic zone.

The potassic zones at Granisle and Bell, which extend beyond the orebodies, consist principally of abundant, fine-grained, dark brown hydrothermal biotite which occurs as replacements of primary amphibole and as disseminations in the groundmass of the host intrusive rocks. Some secondary K-feldspar, mainly as thin selvages enclosing quartz veinlets and fractures, was noted in the lower parts of the Granisle ore zone. Magnetite, an important constituent of the potassic zone, occurs in stringers in the outer parts of the Granisle orebody and as disseminations in the core (BBFP — Dirom et al., this volume) intrusive rock groundmass within the Bell deposit.

The outer or propylitic zone at Bell and Granisle consists of chlorite-epidote-carbonate alteration of volcanic and sedimentary country rocks. At Granisle, a quartz-sericite-carbonate-pyrite zone, which essentially rings the deposit, occurs between the potassic and propylitic zones, while at Bell (Dirom et al., this volume) a quartz-sericite-pyrite stockwork overprints the inner and outer parts of the propylitic and potassic zones, respectively.

Only limited quartz-sericite-(carbonate)-pyrite or phyllic alteration has been recognized at other Babine deposits and prospects, and in general, it is restricted to fault zones as at Morrison (Carson and Jambor, 1976).

Stable isotope data (Zaluski et al., 1994) indicate potassic alteration to be a product of magmatic fluids whereas propylitic and later quartz-sericite-carbonate-pyrite alteration involved a significant meteoric fluid component.

Intensity and "quality" (dark brown colour) of secondary or hydrothermal biotite within potassic alteration zones has been proposed as an indicator of the size and grade of the various Babine copper zones (Carson and Jambor, 1974). In this regard, it is noteworthy that the intensity of biotitization is probably greatest at Morrison where overall grade (0.40% Cu) is lower than the Bell and Granisle deposits. Furthermore, secondary biotite is abundant at Trail Peak (Carter, 1970a, 1993) and a recent petrographic study indicates that the intensity, colour and distribution of secondary biotite at the Nak prospect is similar to that at Morrison (Carter, 1994).

BFP phases which postdate the period of mineralization and alteration and are present within the potassic alteration zone at most deposits and occurrences contain little or no secondary biotite; this in part explains the leucocratic appearance of many of these late-stage intrusive phases. Identification of these is important in the interpretation of the styles of mineralization and alteration of any of the Babine porphyries.

Other Babine District Porphyries

Porphyry copper and molybdenum mineralization in the area is also associated with older, Jurassic and Cretaceous granitic intrusions east and west of the regional graben structures now occupied by Babine Lake. Examples include the Tachek Creek and Mac prospects, related to Early Jurassic and Early Cretaceous plutons respectively, and several prospects (Lennac Lake, French Peak area) associated with porphyry intrusions of Late Cretaceous age (Fig. 1).

The Mac property, 30 km east of Babine Lake (Cope and Spence, this volume) includes three known zones of molybdenum (+copper) mineralization developed within and marginal to plutons of late Jurassic to early Cretaceous (136 Ma, 141 Ma) age, similar to Francois Lake intrusions (Carter, 1981) which host the Endako molybdenum deposit 90 km to the south.

The principal or Camp zone is centred on a small, 500 m by 300 m stock of leucocratic, porphyritic granite satellitic to a slightly older, larger (2.5 km by 3 km) and apparently barren porphyritic granodiorite pluton. Both these and an intervening peridotite body intrude Late Paleozoic hornfelsed volcaniclastic rocks.

The leucocratic granite porphyry stock consists of several intrusive phases including fine-grained granite and quartz diorite and pegmatite dikes. Northeast trending basic dikes represent the youngest intrusive phase.

Molybdenite and lesser chalcopyrite occur as selvages in a stockwork of K-feldspar-rimmed, 1 mm to 5 mm, quartz veinlets within and marginal to the Camp zone granite porphyry stock with better grades are contained in a halo in hornfelsed volcanic rocks immediately adjacent to the stock. Quartz veinlets and lenses containing molybdenite have been identified in two areas a few hundred metres north and south of the Camp zone. These zones are underlain by hornfelsed volcaniclastic rocks and like the Camp zone, are characterized by anomalous concentrations of molybdenum, fluorine and copper in rock samples, suggesting the presence of intrusive bodies at shallow depths.

The Tachek Creek copper-molybdenum prospect, on the west side of Babine Lake and south of the Bell and Granisle deposits (Fig. 1), is developed in granitic rocks of the Topley intrusions near their contact with Late Triassic volcanic and lesser sedimentary rocks.

Bedrock exposures are limited and are mainly confined to two areas in Tachek Creek. The northernmost of these includes pale grey to pink, medium-grained granodiorites and quartz monzonites which are cut by slightly younger (176 Ma — Carter, 1970b, 1981) 2 m to 10 m wide quartz-hornblende-biotite-feldpsar porphyry dikes.

Chalcopyrite, pyrite and molybdenite occur in steeply-dipping quartz-magnetite stringers with K-feldspar selvages and as disseminations in the older granitic rocks, particularly in proximity to the porphyry dikes. North-northeast trending, 1 m wide, postmineral basic dikes were also noted in this area. Porphyry dikes were not noted in the second or southernmost area of bedrock exposure which features higher overall molybdenum values.

Diamond and percussion drilling in the late 1960s and early 1970s indicated average overburden depths marginal to Tachek Creek of between 30 m and 40 m. Drill holes in the vicinity of the creek showings encountered grades of 0.10% Cu, 0.02% Mo and between 0.02 and 0.17 g/t Au (Carter, 1992).

Chalcopyrite, pyrite and molybdenite, as selvages and as disseminations in narrow quartz veinlets rimmed by secondary K-feldspar in quartz-sericite-carbonate altered and finer-grained varieties of Topley intrusions, have been identified by limited drilling at the Red Top or Summit prospect 15 km southwest of the Tachek Creek property (Carter, 1973b). Similar styles of mineralization have been identified at several other nearby prospects.

Porphyry copper-molybdenum mineralization in the Babine area is also associated with Late Cretaceous intrusions at Lennac Lake (77 Ma — Carter, 1981) and in the French Peak area (71 Ma — Richards, 1990). These granodiorite porphyry plugs and dike swarms are part of the Bulkley intrusions (Carter, 1981) and are apparently restricted to the area west of Babine Lake (Fig. 1).

Characteristic of these intrusions is a quartz-hornblende-biotite-feldspar porphyry which has a similar chemical composition as the BFPs of the Babine Igneous Suite but differs by the presence of coarser-grained (4 mm - 6 mm) phenocrysts including anhedral quartz eyes.

Copper and molybdenum mineralization at Lennac Lake (Carter, 1973b) is centred on a 1200 m by 600 m porphyry plug which cuts Lower Jurassic volcanic rocks. Chalcopyrite, pyrite, magnetite, molybdenite and minor chalcocite occur in 2 mm to 4 mm wide quartz veinlets within the intrusion and as films on dry fractures in bordering hornfelsed volcanic rocks. Potassic alteration within the plug includes secondary K-feldspar selvages along mineralized quartz veinlets and incipient biotite alteration of primary hornblende. Northeast-trending porphyry dikes several hundred metres east of the plug contain disseminated pyrite and exhibit sericite-carbonate alteration of plagioclase and chlorite-epidote alteration of hornblende and biotite.

Similar porphyries in the French Peak area (Fig. 1) occur as border phases and as dike swarms within and marginal to larger quartz monzonite plutons which have converted bordering Upper Jurassic Bowser Lake Group sedimentary rocks to biotite hornfels. Chalcopyrite and molybdenite occur in steeply-dipping fractures and quartz veinlets and as disseminations within the porphyries and adjacent hornfelses north of Mt. Thoen (Carter, 1974) and on the southwest slope of French Peak where columnar jointed extrusive equivalents of the intrusive porphyry are widespread.

Other Mineral Deposit Types

Several copper occurrences hosted by Upper Triassic - Lower Jurassic volcanic rocks are known in the Babine area. These consist of small amounts of chalcopyrite, bornite and chalcocite in epidote-filled fractures and are similar to a large number of copper-silver prospects and occurrences in basal units of the Hazelton Group between Smithers and Terrace.

Other deposit types in the area include the Fireweed Ag-Pb-Zn-Au prospect west of the Bell mine (Fig. 1). Initial prospecting in the mid-1980s resulted in the discovery of two mineralized exposures in a small drainage within an area of extensive (up to 40 m thick) overburden cover. Subsequent drilling of VLF-EM and induced polarization anomalies showed the property to be underlain principally by Cretaceous Skeena Group clastic sedimentary rocks which are cut by felsic sills and dikes related to the rhyodacite unit of the Babine Igneous Suite.

Several styles of mineralization are evident (Malott, 1989) including breccia zones in mudstones containing massive pyrite-pyrrhotite and lesser sphalerite, chalcopyrite and galena; disseminated pyrite, sphalerite and galena and minor tetrahedrite in coarser-grained sandstones and banded, fine-grained massive pyrite-pyrrhotite and galena-sphalerite in locally graphitic mudstones. Felsic dikes and sills are spatially related to the breccia and massive sulphide mineralization.

The Red prospect, east of the Bell mine (Fig. 1), also features extensive overburden cover and the geological setting is mainly interpreted from diamond drilling of induced polarization, electromagnetic and magnetic anomalies (Carter, 1991). An argillaceous siltstone, mudstone and greywacke sequence, in part intercalated with felsic and intermediate volcanic rocks, is considered to be part of a Lower Jurassic marine sequence at the base of the Hazelton Group (Richards, 1990). The layered rocks are intruded by a Jurassic diorite pluton and by felsic and basic dikes of Tertiary age.

Mineralization encountered by past drilling consists of multiple, 1 m to 3 m sections of massive and stringer pyrite-pyrrhotite which are best developed in a 30 m wide greywacke unit between graphitic mudstone horizons. Only low copper, zinc and silver values have been obtained from drilling to date.

Past Production and Resources

Production from the Bell and Granisle mines between 1966 and 1992 totalled 129.9 million tonnes yielding 517 577 tonnes Cu, 19 627 kg Au and 97 566 kg Ag (Dirom et al., this volume) as follows:

Deposit	Period	Tonnes milled	Average Head/Recovered Grades Cu (%)	Au (g/t)	Ag (g/t)
Granisle	1966-1982	52 700 000	0.47/0.41	0.20/0.13	2.0/1.32
Bell	1972-1992	77 200 000	0.47/0.39	0.26/0.17	1.0/0.36

Remaining in situ resources, as modelled in 1992 using a 0.30% Cu cutoff, are estimated to be 119 million tonnes grading 0.41% Cu and 0.15 g/t Au at Granisle and 296 million tonnes grading 0.46% Cu and 0.20 g/t Au at Bell. Inferred in situ resources for the Morrison deposit in 1992, using a 0.30% Cu cutoff, are an estimated 190 million tonnes grading 0.40% Cu and 0.21 g/t Au.

The Hearne Hill stockwork copper zone (at 0.10% Cu cutoff grade) contains an estimated 60 million tonnes of 0.16% Cu and 0.10 g/t Au; the higher grade breccia pipe includes 143 000 tonnes grading 1.73% Cu and 0.80 g/t Au (Ogryzlo et al., this volume).

Insufficient drilling of other prospects in the area precludes any definitive estimates of resource potential. An oval, 500 m by 300 m zone at Dorothy, developed near the western margin of the BFP intrusion (Fig. 2), includes copper grades of 0.20% while a large zone of 0.05% to 0.10% Cu forms a crude annulus about the southern half of the 1.5 km by 1.25 km stock at the Nak prospect (Carson and Jambor, 1974). Several shallow drill holes within an 800 m by 400 m area in the western part of this poorly-defined annular zone intersected average copper grades of between 0.20% and 0.57% (Carter, 1994).

At Trail Peak, four inclined holes within a 250 m by 150 m area returned copper and gold values and included two holes with average grades of 0.36% Cu and 0.18 g/t Au over hole lengths of 30 m (Carter, 1993).

Conclusions

The Babine Lake area is host to a variety of mineral deposit types of which the most significant to date are porphyry copper-gold deposits which are products of repetitive and episodic hydrothermal processes related with Eocene intrusions.

Combined production and indicated resources for the three defined deposits in the Babine area (Bell, Granisle, Morrison) total just under three-quarters of a billion tonnes grading 0.45% Cu and 0.23 g/t Au, assuming a 0.30% Cu cutoff for the in situ resources.

Porphyry mineralization in the area is also related to older, Jurassic and Cretaceous intrusions which occur east and west of the regional faults and graben structures which localized the Eocene intrusions. The significance of other recognized deposit types in the area remains to be determined.

The prospects for additional mineral discoveries, particularly porphyry copper-gold deposits, in this highly mineralized area is considered to be excellent. Future exploration will need to involve innovative exploration techniques and an appreciation and understanding of the complex intrusive relationships associated with these porphyries is critical in assessing their potential.

Acknowledgments

The authors are indebted to a great number of explorationists, past and present, for sharing their knowledge of the Babine area over the past thirty years. Foremost among these are have been the staffs of the Noranda group of companies and the former Granby Mining Corporation. Of particular assistance to the senior author was the advice and support provided by J.C. Stephen and R.W. Woolverton.

The authors would particularly like to thank the Geological Survey Branch of the British Columbia Ministry of Energy, Mines and Petroleum Resources, Noranda Exploration Company, Limited and Noranda Minerals Inc. for the opportunity to work in this most interesting area.

REFERENCES

CAMPBELL, E.A. and CASSELMAN, S.G., 1992. Kit Property: Geology and geochemistry. British Columbia Ministry of Energy, Mines and Petroleum Resources, Assessment Report 22647.

CARSON, D.J.T. and JAMBOR, J.L., 1974. Mineralogy, zonal relationships, and economic significance of hydrothermal alteration at porphyry copper deposits, Babine Lake Area, British Columbia. Canadian Institute of Mining and Metallurgy, 67 (No. 742), p. 110-133.

CARSON, D.J.T. and JAMBOR, J.L., 1976. Morrison: Geology and evolution of a bisected annular porphyry copper deposit. *In* Porphyry Copper Deposits of the Canadian Cordillera. *Edited by* A. Sutherland Brown. Canadian Institute of Mining and Metallurgy, Special Volume 15, p. 264-273.

CARSON, D.J.T., JAMBOR, J.L., OGRYZLO, P. and RICHARDS, T.A., 1976. Bell Copper: Geology, geochemistry, and genesis of a supergene-enriched, biotitized porphyry copper deposit with a superimposed phyllic zone. *In* Porphyry Deposits of the Canadian Cordillera. *Edited by* A. Sutherland Brown. Canadian Institute of Mining and Metallurgy, Special Volume 15, p. 245-263.

CARTER, N.C., 1966. Northern Babine Lake area. *In* Annual Report 1965. British Columbia Ministry of Energy, Mines and Petroleum Resources, p. 90-93.

CARTER, N.C., 1967. Old Fort Mountain area. *In* Annual Report 1966. British Columbia Ministry of Energy, Mines and Petroleum Resources, p. 92-95.

CARTER, N.C., 1970a. CAVZ. *In* Geology, Exploration and Mining 1969. British Columbia Department of Mines and Petroleum Resources, p. 110-112.

CARTER, N.C., 1970b. Tachi. *In* Geology, Exploration and Mining 1969. British Columbia Department of Mines and Petroleum Resources, p. 115-117.

CARTER, N.C., 1972. Granisle Mine. *In* Geology, Exploration and Mining 1971. British Columbia Department of Mines and Petroleum Resources, p. 178-183.

CARTER, N.C., 1973a. Geology of the northern Babine Lake area. British Columbia Department of Mines and Petroleum Resources, Preliminary Map No. 12.

CARTER, N.C., 1973b. Lennac Lake - Redtop Creek area. *In* Geology Exploration and Mining 1972. British Columbia Department of Mines and Petroleum Resources, p. 393-398.

CARTER, N.C., 1974. Hot. *In* Geology Exploration and Mining 1973. British Columbia Department of Mines and Petroleum Resources, p. 358.

CARTER, N.C., 1976. Regional setting of porphyry deposits in west-central British Columbia. *In* Porphyry Deposits of the Canadian Cordillera. *Edited by* A. Sutherland Brown. Canadian Institute of Mining and Metallurgy, Special Volume 15, p. 227-238.

CARTER, N.C., 1981. Porphyry copper and molybdenum deposits, west-central British Columbia. British Columbia Ministry of Energy Mines and Petroleum Resources, Bulletin 64, 150 p.

CARTER, N.C., 1991. RED property, Babine Lake area, British Columbia. Unpublished report.

CARTER, N.C., 1992. Geological and geochemical report on sampling of diamond drill cores and percussion hole cuttings, Gold Dust II mineral claim, Babine Lake Area. British Columbia Ministry of Energy, Mines and Petroleum Resources, Assessment Report 22025.

CARTER, N.C., 1993. Geological and geochemical report; sampling of diamond drill cores and soil sampling on the Trail mineral claim, Babine Lake area. British Columbia Ministry of Energy, Mines and Petroleum Resources, Assessment Report 22719.

CARTER, N.C., 1994. Geological, geochemical and geophysical report on the NAK 1-5 mineral claims, Babine Lake area. British Columbia Ministry of Energy, Mines and Petroleum Resources, Assessment Report 23358.

COPE, G.R. and SPENCE, C.D., 1995. Mac porphyry molybdenum prospect, north-central British Columbia. *In* Porphyry Deposits of the Northwestern Cordillera of North America. *Edited by* T.G. Schroeter. Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46.

CUDDY, A.S. and KESLER, S.E., 198ˆ ıld in the Granisle and Bell Copper porphyry copper deposits, Bri‿ Columbia. *In* Precious Metals in the Northern Cordillera. *Edited by* A.A. Levinson. Special Publication number 10 of the Association of Exploration Geochemists, p. 139-155.

DIROM, G.E., DITTRICK, M.P., McARTHUR, D.R., OGRYZLO, P.L., PARDOE, A.J. and STOTHART, P.G., 1995. Bell and Granisle porphyry copper-gold mines, Babine region, west-central British Columbia. *In* Porphyry Deposits of the Northwestern Cordillera of North America. *Edited by* T.G. Schroeter. Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46.

EMMENS, N.W., 1914, Babine Lake. *In* British Columbia Department of Mines, Annual Report, p. K112-K114.

FAHRNI, K.C., KIM, H., KLEIN, G.H. and CARTER, N.C., 1976. Granisle. *In* Porphyry Deposits of the Canadian Cordillera. *Edited by* A. Sutherland Brown. Canadian Institute of Mining and Metallurgy, Special Volume 15, p. 239-244.

JAMBOR, J.L., 1974. Trace element variations in porphyry copper deposits, Babine Lake area. B.C. Geological Survey of Canada, Paper 74-9.

KIRKHAM, R.V., 1971. Intermineral intrusions and their bearing on the origin of porphyry copper and molybdenum deposits. Economic Geology, 66, p. 1244-1249.

LEVINSON, A.A. and CARTER, N.C., 1979. Glacial overburden profile sampling for porphyry copper exploration, Babine Lake area, British Columbia. Western Miner, 52, Number 5, p. 19-31.

MACKIE, J., 1972. Report of geology, magnetometer and IP surveys, Add, Brian, Val Mineral claims, Mt. Horetzky. British Columbia Ministry of Energy, Mines and Petroleum Resources, Assessment Report 3870.

MALOTT, M.J., 1989. Fireweed (093M151). *In* Exploration in British Columbia 1988. British Columbia Ministry of Energy, Mines and Petroleum Resources, p. B127-131.

McMILLAN, W.J., 19ˀ ʼorphyry deposits in the Canadian Cordillera. *In* Ore Deposits, Te‿.ics and Metallogeny in the Canadian Cordillera. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1991-4.

NEWELL, J.M., CARTER, N.C. and SUTHERLAND BROWN, A., 1995. Porphyry Deposits of the Northwestern Cordillera: A Retrospective. *In* Porphyry Deposits of the Northwestern Cordillera of North America. *Edited by* T.G. Schroeter. Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46.

OGRYZLO, P.L., DIROM, G.E. and STOTHART, P.G., 1995. Morrison - Hearne Hill copper-gold deposits, Babine region, west-central British Columbia. *In* Porphyry Deposits of the Northwestern Cordillera of North America. *Edited by* T.G. Schroeter. Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46.

RICHARDS, T.A., 1990. Geology and mineral deposits of the Hazelton Map area (93M), British Columbia. Geological Survey of Canada, Open File 2322.

SHEETS, R.W. and NESBITT, B., 1994. Differences in biotite and apatite mineral chemistry from barren and mineralized porphyritic intrusions of the Babine Lake area, west-central B.C. *In* Final Program with Abstracts. Geological Association of Canada - Mineralogical Association of Canada Annual Meeting, Waterloo, p. A102.

WILSON, J.W.J., KESLER, S.E., CLOKE, P.L. and KELLY, W.C., 1980. Fluid inclusion geochemistry of the Granisle and Bell Porphyry Copper Deposits, British Columbia. Economic Geology, 75, p. 45-61.

ZALUSKI, G., NESBITT, B. and MUEHLENBACHS, K., 1994. Hydrothermal alteration and stable isotope systematics of the Babine porphyry Cu deposits, British Columbia: implications for fluid evolution of porphyry systems. Economic Geology, 89, p. 1518-1541.