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Alkalic intrusion hosted copper-gold mineralization at the Lorraine deposit, north-central British Columbia

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ABSTRACT

The Lorraine property is located in the northern Intermontane Belt, north-central British Columbia. The property is underlain by intrusive rocks of the Duckling Creek Syenite Complex, an Early Jurassic, alkaline phase of the Late Triassic-Early Cretaceous Hogem Batholith. Two significant zones of copper-gold mineralization have been explored to date; the Main zone (historical Upper and Lower deposits) and the recently discovered Extension zone. A combined geological resource was estimated in 1975 for the Main zone deposits at 10 million tonnes averaging 0.7% Cu, and from 0.1 g/t Au to 0.34 g/t Au. The Extension zone, still at an exploration stage, is estimated to be considerably smaller than the Main zone.

Copper-gold mineralization at Lorraine Mountain exhibits characteristics suggestive of both magmatic and hydrothermal origins, and may be related to orthomagmatic-hydrothermal fluid flow contemporaneous with magmatism and development of migmatitic fabrics. A depth greater than the depth of formation of classical porphyries may explain many of the variations displayed by mineralization at Lorraine. These characteristics distinguish Lorraine from other members of the alkalic suite of porphyry Cu-Au deposits in the Canadian Cordillera.

Introduction

The Lorraine prospect is located in the Omineca Mountains, at the headwaters of Duckling Creek, 56 km northwest of Germansen Landing (Fig. 1). The property is centred at latitude 55°55′N, longitude 125°26′W on NTS mapsheet 93N/14W. The area is typified by mountains of moderate relief, with elevations ranging from 1150 m in the valleys to peaks of 2000 m. Valleys are U-shaped and blanketed by glacial till which give way to steep, talus covered slopes and sharp ridges. Outcrop is generally limited to elevations above 1600 m (Fig. 2).

History

The highly visible, malachite-stained bluffs at Lorraine Mountain were first brought to the attention of prospectors by local indigenous people during World War I. The following property history has been synthesized from Wilkinson et al. (1976). The earliest claims were reportedly staked in 1931 by F. Weber of Fort Graham. In 1947, D. Heavenor staked the initial Lorraine claims for Kennco Explorations (Western), Limited. Early exploration work in the area, completed between 1949 and 1974, utilized stream sediment and soil geochemical surveys, prospecting, geological mapping, geophysical surveys (magnetometer and I.P.), diamond drilling and percussion drilling. The first diamond drill was mobilized to the property by dogsled in 1949. Five AX holes, totalling 965 m, were completed to test the upper portion of the Main zone (Fig. 3). An additional 118 m of diamond drilling was completed by Kennco in 1961 to test for an extension of the zone. In 1970, Granby Mining Corporation optioned the property and, over a three year period, completed 3992 m of diamond drilling and 2470 m of percussion drilling which succeeded in intersecting and delineating the Main zone Lower deposit (Fig. 3).

A potential resource, calculated in 1975 from Granby's and Kennco's work, was reported as 4.5 million tonnes grading 0.75% Cu, 0.34 g/t Au in the Upper deposit and a total of 5.5 million tonnes grading 0.6% Cu, 0.1 g/t Au (Wilkinson et al., 1976) in several discontinuous segments in the Lower deposit. These figures were calculated employing a 0.4% Cu cutoff grade. Gold grades were estimated based on a limited number of analyses.

The property lay dormant from 1975 until 1990 when Kennecott Canada Inc. reinitiated exploration work at Lorraine to evaluate the tenor of gold mineralization associated with copper and to explore areas peripheral to the Main zone (Upper and Lower deposits) for additional mineralization. This paper focusses on the results of this work, completed between 1990 and 1993, which included soil geochemistry, geological mapping, I.P. and magnetometer surveys and 2392 m of diamond drilling in 15 holes. Exploration succeeded in discovering a new zone of mineralization, referred to as the Extension zone (Fig. 3; Archambault et al., 1991, Bishop and Fingler, 1992). Results from mapping and drilling indicate that mineralization in this zone is rod-shaped, plunging gently to the southeast. The Extension zone has been intersected over 300 m down-plunge to the southeast, but has not been fully delineated; a resource has, therefore, not been calculated for this zone.

Regional Geology

The Lorraine property is located in northern Quesnellia in the Intermontane Belt of British Columbia. Quesnellia comprises a northwest trending sequence of Mesozoic volcano-sedimentary strata (Takla and Nicola Groups) representative of an intraoceanic volcanic arc environment (Souther, 1992), which was intruded by a series of coeval, comagmatic stocks and batholiths (Woodsworth et al., 1992).

The Lorraine claims lie entirely within the Hogem Batholith, a Late Triassic to Middle Jurassic multiphase intrusion of calc-alkaline to alkaline composition that is intruded by Early Cretaceous granitic bodies (Garnett, 1978; Woodsworth et al., 1992). The three principal phases of the batholith are defined by distinct petrographic, chemical and geochronological signatures, represented by: (1) Phase I Hogem basic suite rocks and Hogem granodiorite, with

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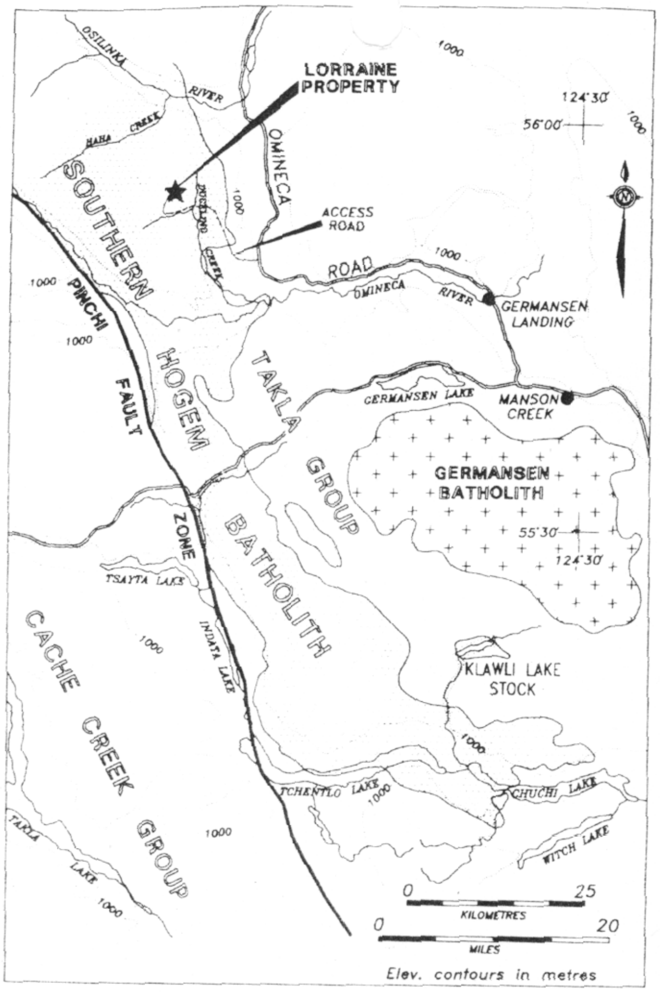

FIGURE 1. Location (after Garnett, 1978).

FIGURE 2. Lorraine Mountain, looking southeast over the Main zone (taken from Garnett, 1978).

K/Ar dates of 176 Ma to 212 Ma; (2) Phase 2 Duckling Creek and Chuchi syenite bodies, with K/Ar dates of 162 Ma to 182 Ma; and (3) Phase 3 granite/aplite dikes or plugs with considerably younger ages of 108 Ma to 206 Ma (Garnett, 1978). Constituent plutons are elongate northwesterly, suggesting long-lived structural control of plutonism (Woodsworth et al., 1992). The batholith intrudes volcanic rocks of the Takla Group to the east and is bounded to the west by the northerly trending Pinchi Fault (Fig. 1; Garnett, 1978).

The majority of known copper occurrences in the area, including mineralization at Lorraine, are hosted by the alkaline, Phase 2, Duckling Creek Syenite Complex of the Hogem Batholith.

Property Geology

Property rock types were grouped into six units for the purposes of this paper (Figs. 3 and 4), although compositional gradations exist between all units. Units 1 to 5 comprise a diverse alkaline suite ranging from pyroxenite through diorite to syenite. Unit 6 consists of late stage granite dikes. Intrusive paragenesis is complicated by: (1) repeated intrusion of Units 1 to 5 which display conflicting cross-cutting relationships; (2) obscuring of contacts by alteration or local development of migmatitic fabrics; (3) lack of observed sharp intrusive contacts; and (4) compositional gradations, resulting from both primary differentiation and secondary alteration, which occur between all phases. In general, field relationships indicate that Unit 1 is oldest and Unit 6 youngest.

Biotite pyroxenite (Unit 1) is typically dark green to black, medium- to coarse-grained, and composed predominantly of clinopyroxene, porphyroblastic biotite, variable amounts of potassium feldspar, abundant magnetite (±ilmenite) and apatite. This unit commonly weathers to distinctive piles of coarse greenish black sand. With increasing potassium feldspar content, biotite pyroxenite grades into alkali gabbro. Locally, either an oikocrystic or porphyroblastic variety of pyroxenite, with prominent pink-orange potassium feldspar oikocrysts or porphyroblasts occurs. Further study is required to determine the origin of this texture.

In the Main zone, pyroxenite occurs as irregular, lens-like bodies that generally crop out in areas of lower elevation. Previous mapping (Garnett, 1978) depicted these lenses as easterly trending and steeply dipping, parallel to the trend of the migmatitic foliation. Recent mapping in the Extension zone has determined that a large body of pyroxenite to alkali gabbro, interpreted to represent a cumulate layer within the syenite complex, occurs southeast of the mineralized zone.

The northeastern portion of the property is dominated by a mass of relatively homogeneous monzodiorite to diorite (Unit 2). This unit is characteristically grey in colour, medium-grained, equigranular and is composed of 30% to 80% plagioclase, up to 50% potassium feldspar and up to 30% mafic minerals (clinopyroxene and biotite, with lesser hornblende). In the southern part of the property, a gradation from pyroxenite to melanocratic and leucocratic diorite occurs. With increasing potassium feldspar content, diorite grades into monzonite, monzosyenite and grey syenite (Unit 3). Grey syenite, composed primarily of potassium feldspar and clinopyroxene with minor biotite, magnetite and apatite, is restricted to the southern half of the property. In the central part of the property, grey syenite is in contact with syenite migmatite (Unit 4) along a fault which truncates the Upper Lorraine deposit (Fig. 3).

Syenite migmatite (Unit 4) is distributed in a broad, northwest trending area through the Main and Extension zones. Its migmatitic texture is most pronounced in the Main zone, however, this unit grades into more texturally uniform leucocratic syenites in both the Main and Extension zone areas. Unit 4 is the predominant host of mineralization on the property. Syenite migmatite is fine- to medium-grained and is agmatitic, migmatitic or gneissic with alternating pink-orange and grey banding. Principal minerals are potassium feldspar, biotite and clinopyroxene, with variable magnetite. In the Main zone, foliated migmatitic syenite contains metasomatized xenoliths of pyroxenite, diorite, monzonite and metavolcanic "basement" rocks.

Cross-cutting, sub-vertical leucocratic syenite and plagiophyric syenite dikes (Unit 5) and granite dikes (Unit 6) post-date all rock types, alteration and mineralized zones. They vary from aplitic to pegmatitic in texture and range in width from 1 m to 25 m. The greatest density of dikes occurs at higher elevations in the Main zone and along adjoining ridges, with lesser syenite dikes in the lower part of the Main zone. Syenite and granite dikes commonly trend 000° to 020° whereas plagioclase porphyry dikes strike from 090° to 120°.

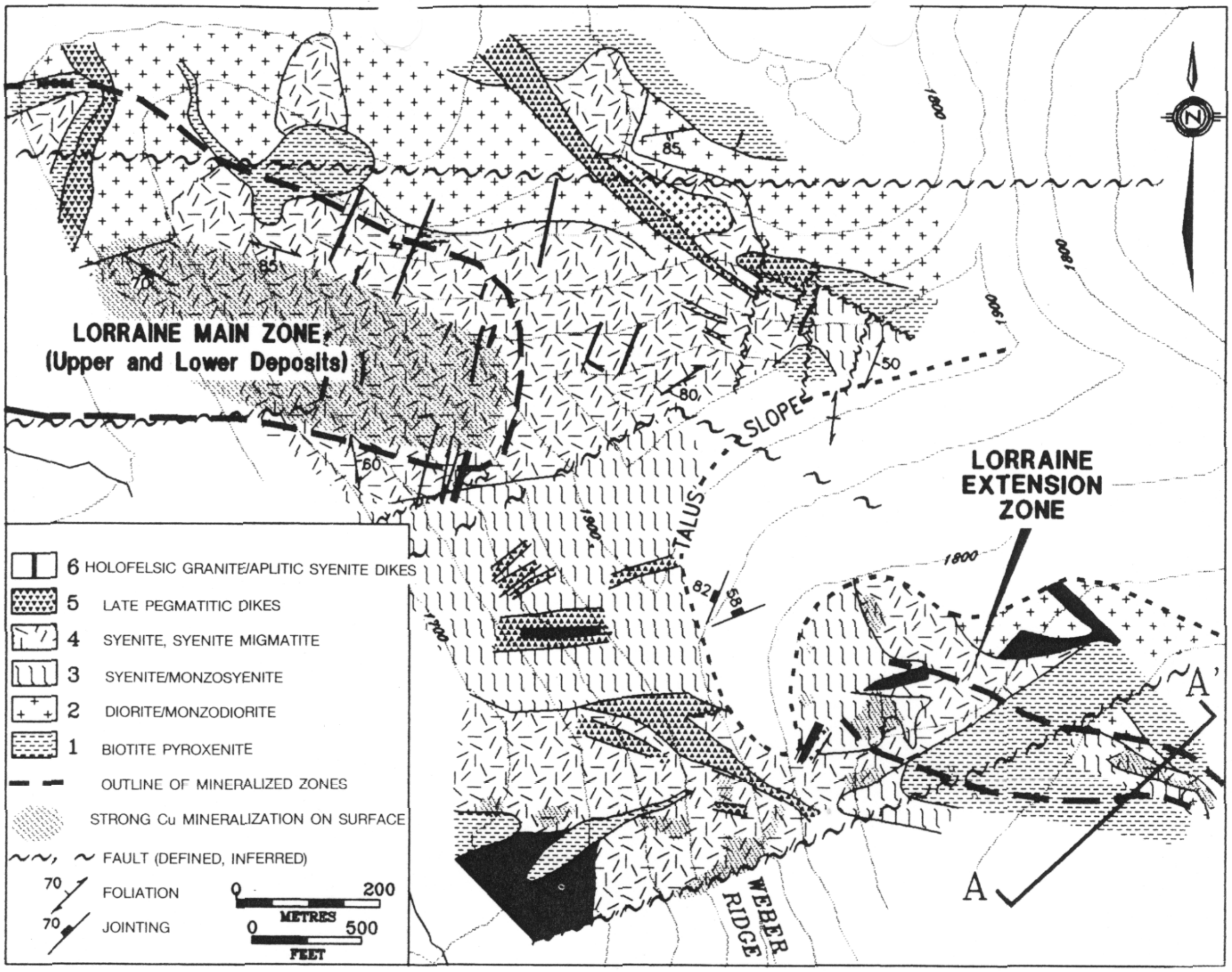

FIGURE 3. Lorraine Mountain: simplified geology.

Structure

Igneous contacts and all ductile and brittle structural fabrics exhibit prominent trends at 020°, 060° and 110° to 120°. The main foliation in syenite migmatite strikes west-northwest and dips gently to the south. The intensity of migmatite development, fracture density and frequency of pegmatite and granite dike intrusion is greatest in the Main zone.

Three significant east-west trending faults occur in the property area (Fig. 3). The first cuts the northern property area, and is indicated by sheared pyroxenite exposures and by a series of igneous contacts that mark a compositional change from syenite migmatite to diorite and monzodiorite. Minor late-stage copper mineralization is localized along this structure. The second fault, trending through the centre of the property, is steeply south-dipping and truncates mineralization in the Main zone to the southeast. A third east-west trending fault is interpreted to lie in the west-central property area and to truncate or displace Main zone mineralization to the south.

East-northeast trending structures are also prominent in the Lorraine property area. A major 060° trending fault was mapped across the middle of the Extension zone and through the ridges on either side of the zone (Fig. 3). Mineralization in the Extension zone is not offset across this fault and localized pockets of mineralization occur along this structure where it transects Weber Ridge.

North-northeasterly trending structures are also significant at Lorraine. A 020° trending fault, located immediately west of the map area (Fig. 3), parallels a tributary of Haha Creek (Fig. 1). Lower zone mineralization is interpreted to be bounded, or displaced to the west, by this fault.

Recent field work did not determine the relative ages nor the sense of motion of these structures. Outside the area of Figure 3, slickensides indicate oblique-slip (normal and left lateral) displacement on 060° trending faults.

Alteration

Three major alteration assemblages are represented at Lorraine: (1) early potassium metasomatism resulting in secondary biotite, (2) main-stage potassium feldspathization; and (3) late-stage, weak sericitization and propylitization (chlorite-epidote-carbonate). In addition, clay-sericite and quartz-sericite-carbonate alteration occur locally throughout the property. Minor quartz veins occur in the Main zone area. Melanite, a dark coloured, Ti-bearing, andraditic garnet that normally occurs in sodic igneous rocks, was observed in thin section in some samples (Leitch, 1992). The results of work completed to date have not indicated the presence of a systematic, property-scale, alteration zonation and evidence to define the temporal relationship of alteration assemblages is insufficient to propose a well defined paragenetic sequence of alteration.

Fine- to coarse-grained secondary biotite occurs as partial to near-complete replacement of pyroxenes in pyroxenite and melanocratic phases of the Duckling Creek Syenite Complex. Stringers and books of biotite are common in leucocratic phases. Potassium feldspathization, characterized by a pink-orange colour, is widespread and varies in intensity throughout the property. Potas-

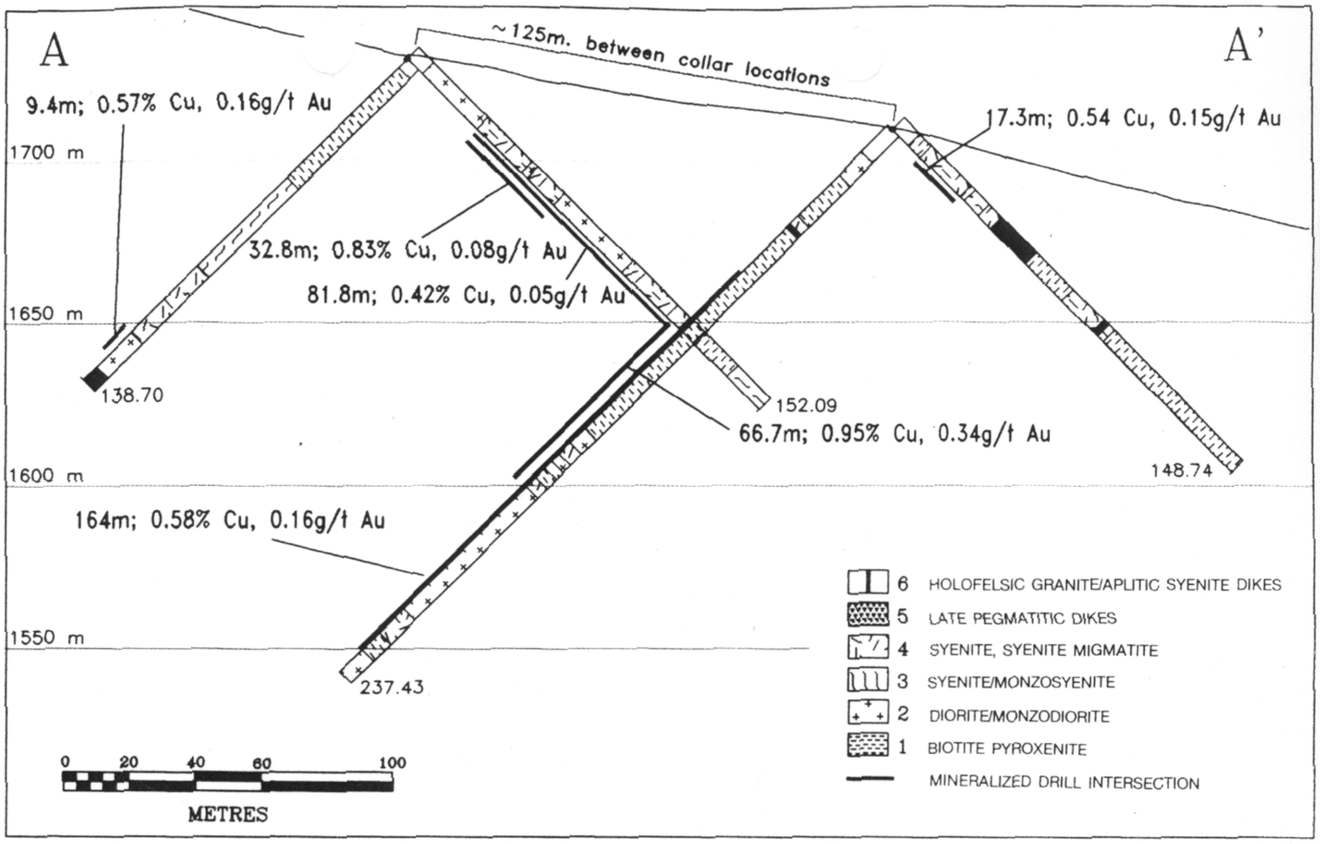

FIGURE 4. Cross-section A-A′, looking northwest, through the Lorraine Extension zone.

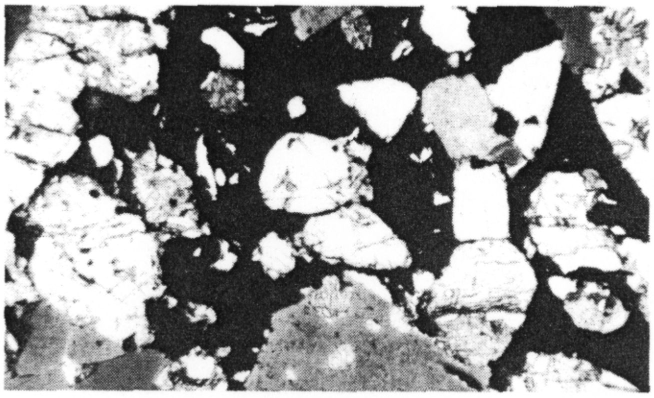

FIGURE 5. Polished section in reflected light, sulphides (magnetite, chalcopyrite, pyrite) exhibiting classic magmatic textures interstitial to silicates (clinopyroxene and biotite). Field of view approximately 2.5 mm.

sium feldspar occurs as incipient grains, in stringers or as patchy, pervasive flooding. Potassium metasomatism is associated with emplacement of syenitic intrusions. Late stage sericite, only noted in thin section, occurs as partial replacement of plagioclase. Epidote occurs locally as patches, ranging in intensity to complete replacement of the protolith. Spectacular, late hydrothermal magnetite occurs as pegmatoidal aggregates, veinlets and as matrix to breccias.

Mineralization

The greatest concentrations of mineralization occur in syenitic rocks and, locally, in biotite pyroxenite in the Main and Extension zones. Elsewhere on the property copper mineralization occurs as localized patches or zones, hosted by all rock types except late granite dikes. These small zones of copper mineralization are generally discontinuous. The Weber Ridge (Fig. 3) and Eckland Ridge (immediately southwest of map area, Fig. 3) occurrences contain the most significant concentrations of mineralization outside the Main and Extension zones.

Copper sulphides that occur at Lorraine include chalcopyrite, bornite and rare covellite. Chalcocite and digenite have also been reported in polished section (Leitch, 1992). Pyrite occurs in minor amounts (<1%), with an erratic distribution throughout the property. Malachite, azurite and chrysocolla also occur in oxidized portions of the mineralized zones. Sulphides are typically fine- to medium-grained and are disseminated throughout the host rock or concentrated along fractures and in narrow quartz veinlets. Rare net-textured sulphides were observed in pyroxenites in diamond drill core. Sulphide abundance ranges from trace amounts to greater than 7%.

A detailed petrographic examination of rocks in the Extension zone (Leitch, 1992) indicates that copper tenor, resulting from bornite-chalcocite-digenite ± chalcopyrite mineralization, shows a positive correlation with magnetite content (and possibly apatite content) but is not apparently related to alteration intensity or assemblage. Copper sulphides were noted to occur as anhedral grains interstitial to silicates (e.g. pyroxene, biotite; Fig. 5) suggesting that at least part of the mineralization is magmatic or late-magmatic. In samples where chalcopyrite and/or pyrite are the major sulphides, magnetite is oxidized to hematite and the sulphide tenor correlates with degree of secondary silicate alteration (biotite, sericite-epidote-carbonate).

Cu:Au ratios at Lorraine are unusually high in comparison to other alkaline Cu-Au prospects in Quesnellia (Stanley, 1993). A Cu:Au ratio of 45 000 was calculated for the Main zone and a ratio of 60 000 for the Extension zone, whereas other alkaline deposits such as Afton/Ajax, Copper Mountain (Similco) and Mount Polley have Cu:Au ratios that range from 10 000 to 25 000 (Stanley, 1993). In the mineralized zones at Lorraine, the tenor of copper mineralization ranges from 0.2% to 2.0% with gold values ranging from 0.1 g/t to 0.4 g/t. Work to date has not determined if gold has a particular association with any one copper sulphide.

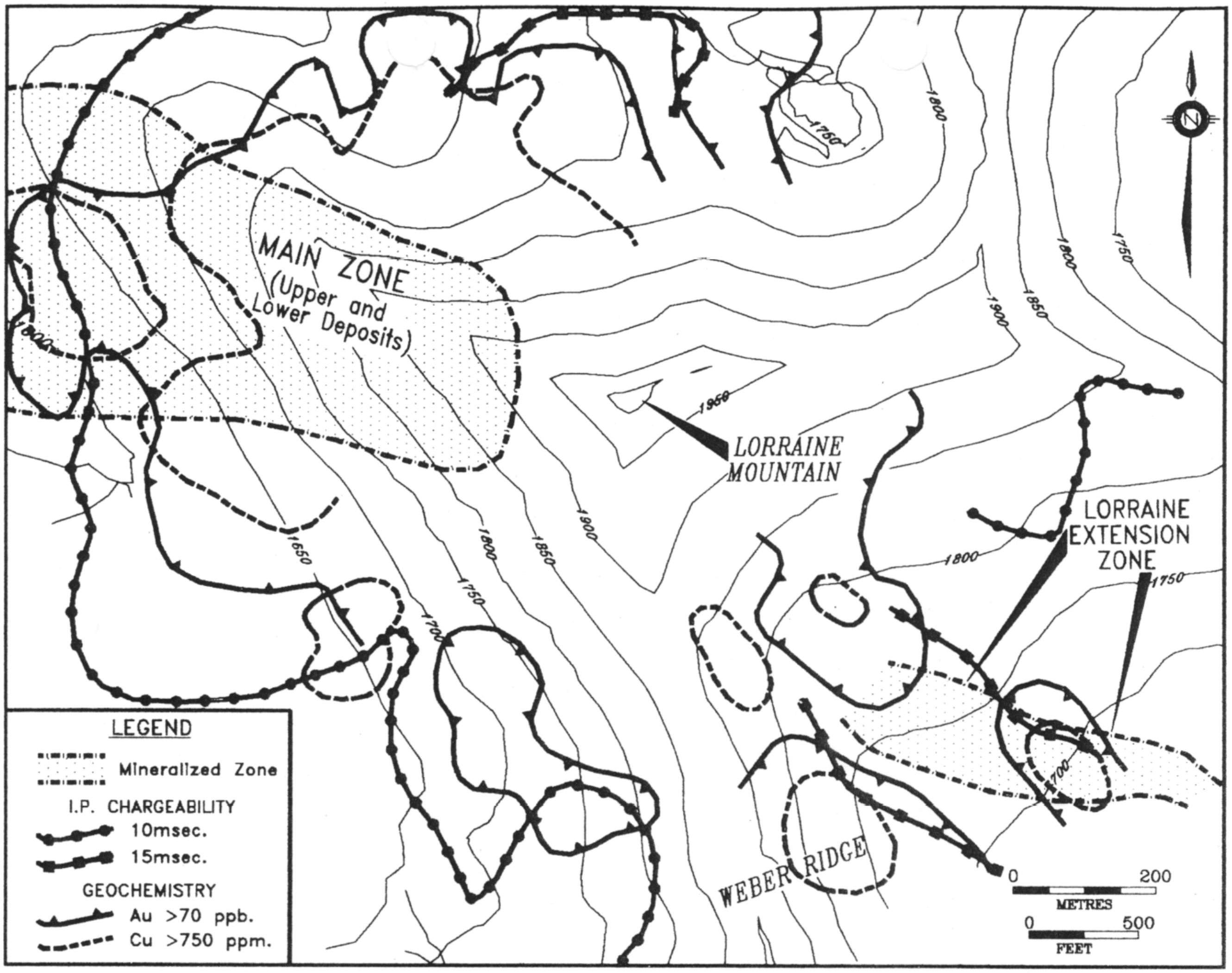

FIGURE 6. Geochemistry and I.P. chargeability compilation.

Trace element geochemistry of surface rock chip and diamond drill core samples from both the Main and Extension zones reveals significant inter-element correlations (>0.85) between Cu, Au, Ag, Pb, Sb, Bi and Te. This element suite is interpreted to reflect primary chalcocite, bornite and gold mineralization and subordinate Pb-Sb-Bi-Te sulphosalt mineral(s). Silver is probably associated with bornite mineralization and in the sulphosalt mineral(s). Anomalous lead concentrations (>50 ppm) also occur independent of these correlated samples, predominantly in the outlying Weber Ridge and Eckland Ridge occurrences. These are interpreted to reflect a possible camp-scale zoning of anomalous lead concentrations external to the copper-gold core mineralization in the Main and Extension zones. No obvious pattern of sulphide mineral zonation has been identified from the work completed to date in the Main and Extension zone areas.

Exploration Techniques

Since the initial investigation of malachite-stained bluffs at Lorraine Mountain, both prospecting and mapping have been effective tools for locating mineralization. These methods were responsible for the 1990 discovery of the Extension zone. Stream sediment and soil geochemistry also reflect the presence of significant copper-gold mineralization at Lorraine, the former at a regional scale and the latter at a property scale. Property-wide soil sampling completed in 1990 clearly outlines the Extension zone, the Main (Lorraine) zone and numerous smaller copper showings, each characterized by values exceeding 750 ppm Cu and 70 ppb Au (Archambault et al., 1991; Fig. 6).

An orientation time-domain I.P. survey, completed in 1990 over the Main zone Lower deposit, returned an anomalous signature over the area of known copper mineralization. Additional time-domain surveys, completed in 1991 and 1993, clearly identified the Main and Extension zones. The broad area of mineralization is signified by a 10 millisecond chargeability contour, while a 15 millisecond contour (with values ranging up to 26 milliseconds) defines higher grade zones (Fig. 6). Time-domain I.P. techniques have proven to be more effective than frequency-domain surveys, which were employed in the 1960s and 1970s, at identifying this low sulphide style (typically <2% sulphide) of mineralization.

Previous ground magnetometer surveys have identified several magnetite-rich migmatite and pyroxenite bodies (Wilkinson et al., 1976) in the Main zone. Recent magnetometer surveys over the Extension zone have, however, returned erratic and inconclusive total field magnetic data.

An airborne electromagnetic, magnetic and radiometric survey was flown over Lorraine in 1991 as part of a program commissioned by B.P. Resources Canada Ltd. to cover the Boot/Steele claims, which surround the Lorraine property claims. The results of this survey (Humphreys, 1991) indicated that (1) apparent resistivities show no correlation with mineralization at the deposit; instead, resistivity highs correspond with topographic ridges, and lows with valley bottoms near the deposit; (2) the entire Lorraine Mountain area has an anomalously high magnetic signature within which the Main zone and part of the Extension zone are denoted by moderate to high total field values (59 500 to 60 500 nT); and (3) calculated weight-per cent magnetite values exceeding 5% define an elongate, north-northwest trendin nomaly over the Main (Lorraine) zone and an anomaly adj . to the Extension zone.

A west-northwesterly trending VLF-EM conductor axis lies over the Main (Lorraine) zone. VLF-EM did not identify the major east-west fault which is interpreted to limit Main zone mineralization to the south. Finally, radiometric potassium highs and high K/U ratios distinguished potassium-rich syenites over parts of the deposit.

Interpretation and Discussion

Many characteristics of the mineralization at Lorraine are similar to those of deposits of the alkalic porphyry copper-gold suite (Barr et al., 1976; Lang et al., in preparation). Similarities include: (1) the relationship of alteration and mineralization to magnetite-apatite rich intrusions with an alkalic chemical composition; (2) a probable Early Jurassic age; (3) the presence of propylitic alteration, pervasive and fracture-controlled potassic alteration assemblages and the absence of argillic and phyllic assemblages; (4) the presence of hydrothermal, andraditic (melanitic) garnet; (5) the presence of minor quartz in late, dilatant veins; (6) a high concentration of hydrothermal magnetite; (7) a metal assemblage of Cu-Au-Ag with very low Mo concentration; (8) low pyrite concentrations and a high ratio of chalcopyrite + bornite to pyrite in the mineralized zones; and (9) a strong correlation between copper and gold grades. These characteristics are most consistent with the silica-saturated subtype of alkalic porphyry deposits (Lang et al., 1992). The intrusions at Lorraine also share many petrographic similarities with a suite of silica-undersaturated, alkalic igneous complexes comprising pyroxenite and syenite that have been recognized in the Cordillera by Lueck and Russell (1994), but differ from this group in their silica-saturated chemistry. The local development of net textures in copper sulphide minerals is, however, a hitherto undescribed style of copper-gold mineralization within the alkalic suite.

Ambiguous igneous contact relationships, compositional diversity within each intrusive unit and overprinting by hydrothermal alteration severely complicate interpretation of the magmatic history of the deposit. Overall, the igneous rock types at Lorraine cannot be related to a simple fractional crystallization sequence in a single, homogenous magma chamber. Mutually cross-cutting relationships among igneous units 1 to 5 document contemporaneity among rock types as diverse as pyroxenite, diorite and syenite and suggest derivation from either a single, compositionally heterogenous magma chamber, or tapping of multiple reservoirs. In the Main zone and, to a lesser degree, the Extension zone, magmatism appears to have been coeval with development of penetrative fabrics in the migmatitic syenite. These complexities severely restrict efforts to ascribe mineralization to a specific stage in the intrusive assemblage.

The history of sulphide precipitation is also complex. Mineralization occurs in two principal styles. In both the Main and Extension zones, net-textured copper sulphides are most prominently developed in biotite pyroxenite, but may also be present, along with disseminated sulphides, in other intrusive types. The second style of copper mineralization is represented by chalcopyrite and bornite in fractures and quartz veins. Alteration, mineralization, magmatism and development of migmatitic fabric appear to be closely related in time. Two models which may account for this intimate relationship are: (1) formation of an alkalic porphyry Cu-Au deposit which was subsequently or concurrently metamorphosed; and (2) early magmatic sulphide precipitation in biotite pyroxenite intrusions followed and overprinted by a orthomagmatic-hydrothermal system. These models are not necessarily mutually exclusive and the evidence is currently insufficient to favour either or both models.

Redistribution of the components of an original alkalic Cu-Au deposit by a subsequent or concurrent metamorphic event is not inconsistent with field and petrographic observations which suggest close timing between intrusion, mineralization and development of migmatitic textures in syenite. The migmatites demonstrate that sufficient metamorphic grade was reached to effect remobilization of pre-existing sulphides and at least a portion of the current sulphide mineralization, alter n and igneous mineral assemblages may have been modified by r. norphism. The apparent absence of net textures in the abundant sulphide present in migmatitic syenite itself is not explained by this model.

The alternative model proposes that the net-textured sulphides precipitated as primary igneous mineral phases in the biotite pyroxenite. The net textures of the sulphides are more similar to those found in cumulate rocks with primary sulphide minerals than to metamorphically recrystallized intrusions. Furthermore, a similar style of sulphide mineralization which is definitely not related to high-grade metamorphism has been noted in the Averill alkalic complex, which also has an association between biotite pyroxenite and syenite (Lueck and Russell, 1994). In this model, the early sulphide immiscibility may have been followed by fluid immiscibility which resulted in the later, fracture-controlled sulphide mineralization and the weak to moderate hydrothermal alteration which occurs with sulphides of both net-textured and fracture-controlled morphologies. Alternatively, the fracture-controlled mineralization and alteration may have formed from an orthomagmatic-hydrothermal system which was initiated in response to later intrusive events in the district.

Each model is consistent with formation of the Lorraine system at substantially greater depth than is implied for most alkalic porphyry deposits (Lang et al., in preparation). The evidence for deep formation includes: (1) the mineralized zones are hosted within the main batholith itself rather than in genetically related volcanic sequences; (2) the development of the migmatites required pressure and temperature conditions which were substantially greater than those typical of shallow, subvolcanic environments; (3) growth of large potassium feldspar oikocrysts in some pyroxenite intrusions probably required high pressures over extended periods; and (4) the existence of the net-textured sulphides themselves. The net-textured sulphides may reflect the inability of the magmas to release significant volumes of sulphide-bearing hydrothermal fluids due to high confining pressure, forcing the contained sulphide to precipitate directly from the magma. A greater depth of formation may explain many of the variations displayed by the Lorraine deposit from the alkalic porphyry theme. In this light, the Lorraine system may provide an important example of the influence exerted by depth on the styles of mineralization developed in porphyry systems.

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			Don Mustard 'thinks' some consideration of a carbonatite setting i.e. fenitization / carbonate-rich tuffs		

Type: O = Outgoing Call I = Incoming Call M = Meeting C = Correspondence F = Facsimile