British Columbia Geological Survey
Geological Fieldwork 1990

GEOLOGY AND ALTERATION AT THE MOUNT MILLIGAN GOLD-COPPER PORPHYRY DEPOSIT, CENTRAL BRITISH COLUMBIA (93N/1E)

By R.C. DeLong and C.I. Godwin
The University of British Columbia
M.W. Harris and N.M. Caira
Continental Gold Corp.
C.M. Rebagliati
Rebagliati Geological Consulting Ltd.

KEYWORDS: Economic geology, Mount Milligan, alkaline porphyry, Quesnellia, Takla Group, gold, copper, potassic alteration, propylitic alteration.

INTRODUCTION

The Mount Milligan deposit, centred at latitude 55°08′ north and longitude 124°04′ west, is 100 kilometres west-southwest of Mackenzie and 160 kilometres northwest of Prince George in central British Columbia. The deposit occurs in gently rolling topography (Plate 2-6-1) 5 kilometres due south of Mount Milligan. Access to the property is by a 93-kilometre logging road that connects with the Hart Highway 30 kilometres south of Mackenzie.

Estimated geological reserves for the deposit, including the Southern Star deposit to the south, are 400 million tonnes grading about 0.20 per cent copper and 0.48 gram per tonne gold (Preto, 1990).

The property was originally held by a joint venture between Continental Gold Corp. and B.P. Resources Canada Ltd. (69.8 and 30.2 per cent, respectively). Placer Dome Inc. bought all of B.P. Canada Ltd.'s interest in the property in October 1990. On October 22 Placer Dome acted on a

Plate 2-6-1. Oblique view looking westerly across the main part of the Mount Milligan gold-copper porphyry deposit. The MBX stock (Figure 2-6-1) occurs in the north-central part of the photo. Coordinates (metres) for the borders of the grid used in Figures 2-6-3 to 2-6-8 are: north = 10 000, south = 8500, east = 18 750 and west = 11 750.

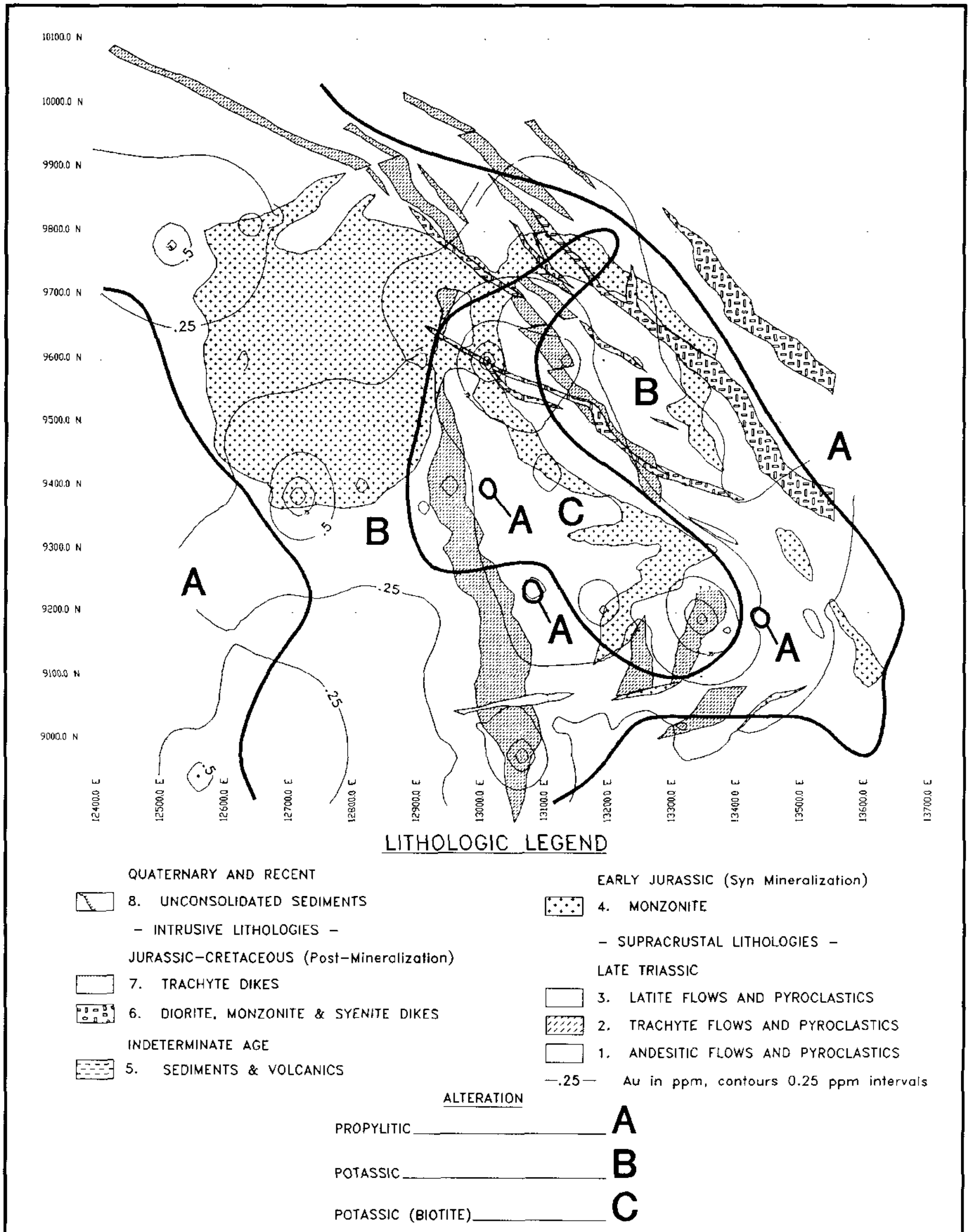

Figure 2-6-1. Geology and alteration of the Mount Milligan gold-copper porphyry deposit. Mineralization is concentrated around the stock, especially its east flank. Geological plan 995-metre level.

previous agreement with Continental Gold to purchase all its outstanding shares and now holds 97 per cent of all shares.

This report incorporates data from company reports with a compilation of drill-core data collected by DeLong and Godwin. The latter data are the basis of research by DeLong at The University of British Columbia.

METHODS

Figures 2-6-1, and 2-6-3 to 2-6-8 were prepared by collecting and examining samples from drill-hole intersections at the 1000-metre elevation in the Mount Milligan deposit. The area surveyed lies between coordinates 8500 and 10 000 metres north, and 11 750 and 13 750 metres east on the property grid (*see* Plate 2-6-1 and Figures 2-6-1 and 2-6-3 to 8).

Holes sampled are on east-west lines 200 metres apart. The vertical 10-metre interval, from 995 to 1005 metres around the piercing point for each hole, was described by examination of the core in the field, the samples in the laboratory and the existing geological logs. The values assigned to each 10-metre interval are averages of assay data. Assays of postmineral dikes have been excluded. About 100 piercing points on the 945-metre level plan were examined. All data were collated into a computer file for statistical examination and computer plotting. Figures 2-6-5 to 2-6-8 define the qualitative geometry of the distribution of alteration minerals. The 1000-metre level geological map (Figure 2-6-1) is constrained by geological interpretation of sections and adjacent levels.

REGIONAL GEOLOGY

The Mount Milligan property lies within the Quesnel Terrane in the Intermontane Belt of the Canadian Cordillera (Monger *et al.*, in press). The region is underlain mainly by Early Mesozoic Takla Group rocks (Armstrong, 1949; Garnett, 1978) of island-arc affinity (Mortimer, 1986; Nelson *et al.*, 1991, this volume). The Takla Group is equivalent to the Nicola Group in southern British Columbia.

The Takla Group in the area studied is Late Triassic to Early Jurassic in age. It is represented by volcanic, pyroclastic and epiclastic rocks overlying and, in part, interfingering with, an early Late Triassic sedimentary unit (Nelson *et al.*, 1991, this volume). The volcanic rocks are mainly augite phyric, although plagioclase and hornblende phenocrysts are present and occasionally abundant.

The Takla Group and Nicola Group are intruded by coeval plutons up to Early Jurassic in age (Mortimer, 1986). Most of these plutons are alkalic and closely related to alkaline copper porphyry deposits enriched in gold, such as the Copper Mountain, Ingerbelle, Afton and Ajax mines (Barr *et al.*, 1976). The Mount Milligan porphyry gold-copper deposit belongs to this clan.

LOCAL GEOLOGY

Outcrops and subcrops on the Mount Milligan property are Takla Group volcanic rocks intruded by small alkaline stocks and dikes. Three volcanic units, the MBX stock and associated dikes, and three types of postmineral dikes are described below.

VOLCANIC ROCKS

Volcanic rocks are divided into three units in Figure 2-6-1 (*cf.* Rebagliati *et al.*, 1990): Unit 1, andesitic flows and fragmentals; Unit 2, trachyte flows and tuffs; and Unit 3, latitic flows and fragmentals. The andesitic and latitic units are similar texturally. Rocks where more than one-third of the total feldspar is potassic (based on staining) are classified as latite.

Andesitic volcanic rocks (Unit 1), stratigraphically the lowest unit mapped, consist of flows, and commonly, monolithic fragmental rocks. Clasts are lapilli-sized and augite (altered to actinolite) phyric. Flow and fragmental units are often interbedded with ash to fine lapilli augite-crystal tuffs.

Trachyte flows and tuffs (Unit 2) are potassic. Rocks interpreted as flows commonly contain over 70 per cent potassium feldspar as fine-grained felted microlites in the groundmass (Harris, 1989). Flows are massive but locally exhibit curvilinear banded textures defined by partings of pyrite with chlorite. This texture may mimic primary flow banding. Potassium feldspar rich ash to fine lapilli tuffs are well bedded. Sometimes they show sedimentary structures such as crossbedding, grading and load casts. These units are lensoidal. Although thickness of the trachyte flows and spatially related tuffaceous units varies abruptly, they are the best stratigraphic markers on the property.

Latite flows and fragmental rocks (Unit 3) *are augite* (altered to actinolite) phyric. They host most of the copper and gold mineralization in the Mount Milligan deposit. These rocks may be potassically altered andesite. If so, the stratigraphic interpretation of a lower andesite and a higher latite is a result of the geometry of the intruding stock and corresponding alteration patterns. Fragmental rocks vary from augite and augite plagioclase crystal ash tuff to lapilli tuff. Lapilli tuffs are commonly monolithic. Clasts are *mainly augite-phyric fragments. Subordinate, discon*tinuous, heterolithic, coarse fragmental units are occasionally associated with a turbiditic cap. These are interpreted as submarine debris flows and contain clasts of latite, andesite, trachyte, and rarely, monzonite.

Most of the stratigraphy trends south-southeast and dips steeply (70°) east. Near the southeastern end of the Mount Milligan deposit (Figure 2-6-1) the strike swings east and dips shallow to 20° north. Based on textures within the *tuffaceous and turbidite units, the stratigraphy is upright and* faces east or north.

INTRUSIVE ROCKS

Intrusive rocks at the Mount Milligan deposit include the MBX stock and Rainbow dike (Figure 2-6-1). Postmineral dikes are common throughout the property.

The MBX stock and Rainbow dike (Unit 4) occur in the centre of the area covered by Figure 2-6-1. Unit 4 also includes a swarm of smaller cogenetic stocks and dikes. These rocks are monzonitic and are contemporaneous with the associated porphyry-style alteration and gold-copper mineralization (Rebagliati *et al.*, 1990). The MBX stock, about 400 metres in diameter at the 1000-metre level, is typically a crowded plagioclase porphyry with an aphanitic groundmass rich in potassium feldspar. Plagioclase phenocrysts, 1.0 to 4.0 millimetres long and locally trachytoid, make up 25 to 50 per cent of the rock. Hornblende and biotite are variable and, together, average 10 per cent. They occur as single grains and aggregates. Quartz usually forms less than 3 per cent of the matrix (Harris, 1989). Accessory magnetite is often present in the matrix.

The Rainbow dike is an extension of the east side of the MBX stock (Figure 2-6-1). It is up to 50 metres wide and forms an elongate bowl or trough with gently dipping sides. The southwest part is subparallel to stratigraphy. The northeast part cross cuts stratigraphy to the bedrock surface. The southwest part also follows a segment of the Rainbow fault, one of several large structures on the property.

Postmineral dikes (Unit 6 and 7), volumetrically minor, occur throughout the deposit. Three distinct types are recognized: grey fine-grained trachyte, augite-plagioclase-porphyritic monzodiorite, and plagioclase porphyritic diorite.

ALTERATION AND MINERALIZATION

Alteration and mineralization assemblages at Mount Milligan are either potassic or propylitic – emphasized by correlation coefficients and the tree diagram shown in Figure 2-6-2. This is compatible with detailed geological observations, although detailed patterns are complex where alteration assemblages overlap. Locally, propylitic alteration overprints the potassic assemblage. The reverse is noted occasionally. The two-fold division of alteration is an important exploration guide because gold and copper are concentrated in the potassic assemblage.

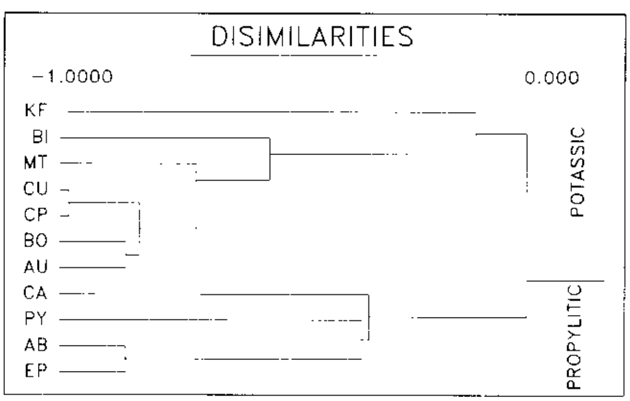

Figure 2-6-2. Tree diagram (Wilkinson, 1989) generated from Gutman mu^2 monotonicity coefficients (Shye, 1978). The potassic assemblage, in order of closest correlation, is copper [CU], chalcopyrite [CP], bornite [BO], gold [AU], magnetite [MT], biotite [BI] and potassium feldspar [KF]. The propylitic assemblage, in the same order, is albite [AB], epidote [EP], pyrite [PY] and calcite [CA]. Note that potassic alteration is independent of propylitic alteration.

POTASSIC ALTERATION

Potassic alteration is concentrated around the contacts of the monzonite intrusions. Alteration may extend several hundred metres outward from the contact, into fractured volcanic rocks, for example, along structures such as the Rainbow fault. Potassic alteration also occurs within the monzonite.

The potassic alteration assemblage (Figure 2-6-2) is characterized by widespread development of secondary potasssium feldspar. However, hydrothermal biotite, bornite, chalcopyrite and magnetite are better indicators of areas of intense potassic alteration.

The potassic alteration is crudely zoned. Biotite is most abundant close to the stock and around parts of the Rainbow dike (Figures 2-6-1 and 2-6-5). Figure 2-6-2 shows the close statistical correlation between gold and copper, bornite and chalcopyrite, and magnetite and biotite. The broader relationship to potassium feldspar is also shown. Figure 2-6-2 shows that potassic alteration is independent of the propylitic assemblage of epidote, albite and pyrite.

Figures 2-6-3 to 2-6-6 show the distribution of gold and copper with respect to minerals characteristic of the potassic assemblage. Gold abundance in Figure 2-6-3 is represented by a smoothed surface such that the influence of neighboring points decreases exponentially with distance. The other three-dimensional plots that represent abundances use surfaces that are more smoothed by a distance-weighted least-squares fit. The plots and methods are from the computer program SYGRAPH (Wilkinson, 1988).

Fine-grained secondary biotite commonly forms 30 per cent (up to 60 per cent in places) of the volcanic rocks near the intrusive contact. It is most abundant in intermediate to basic protoliths. Biotite is usually pervasive, but it also occurs as envelopes to potassium feldspar veinlets. Pervasive biotite alteration usually leaves relict porphyritic textures. Augite phenocrysts are not biotitized, but are always actinolitized. Locally, intense biotitization has destroyed primary textures.

Secondary potassium feldspar, present throughout and beyond the biotite zone, is the most abundant alteration mineral in the potassic assemblage. It occurs as veinlets and microveinlets, sometimes with accessory quartz. However, it is also present as patchy to pervasive, grey to occasionally pink, aphanitic alteration of the groundmass that obliterates primary textures. This type of alteration floods parts of the Rainbow dike. Some of the rocks mapped as trachyte could be pervasively altered units.

Chalcopyrite (Figure 2-6-6) occurs as fine-grained disseminations, often in biotitic envelopes around veinlets especially near the MBX stock. Less commonly, it forms veinlets and selvages of veins and veinlets. In veins and veinlets it is associated with either calcite, or quartz and potassium feldspar.

Bornite is not abundant but occurs exclusively with potassic alteration. It is correlated with higher gold assays. Chalcopyrite has a broader association with potassic alteration and gold (Figures 2-6-2 and 2-6-6).

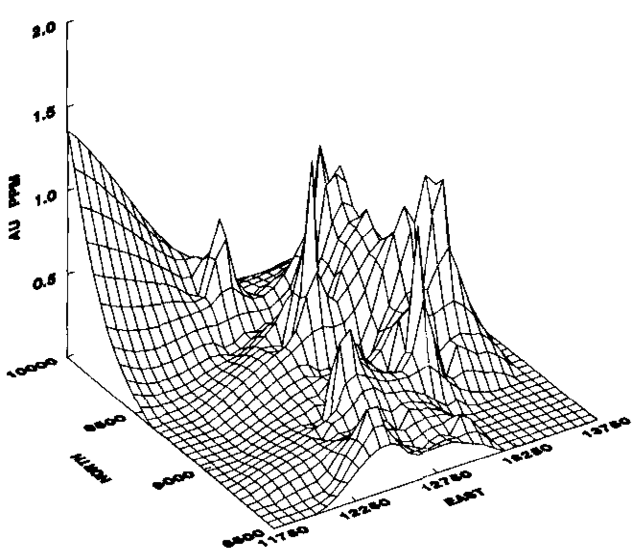

Figure 2-6-3. Gold [AU] surface in parts per million. Edge effects in the northwestern corner should be ignored.

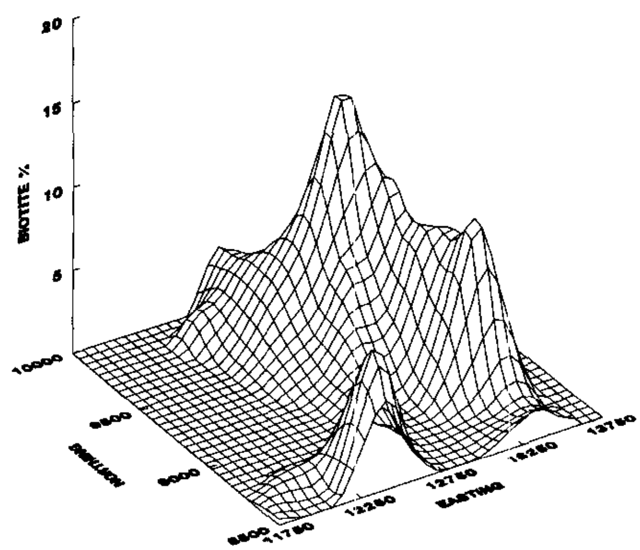

Figure 2-6-5. Biotite surface in visually estimated per cent. The potassic core to the deposit is well outlined.

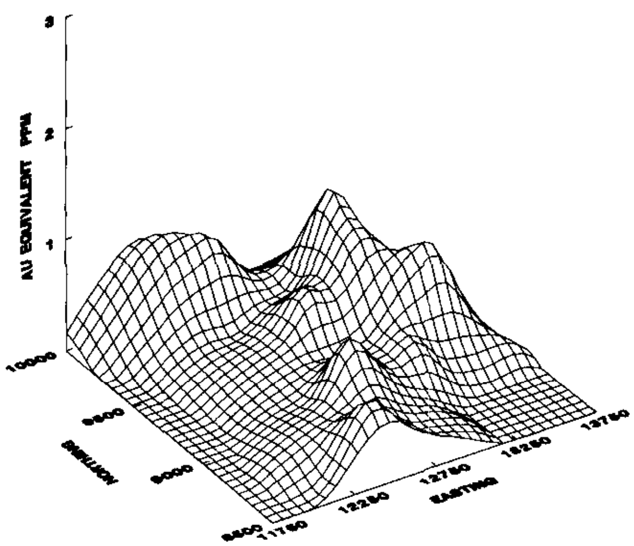

Figure 2-6-4. Gold [AU] equivalent (gold in parts per million plus copper in per cent) surface in parts per million. This surface is more smoothed, but is clearly similar to Figure 2-6-3.

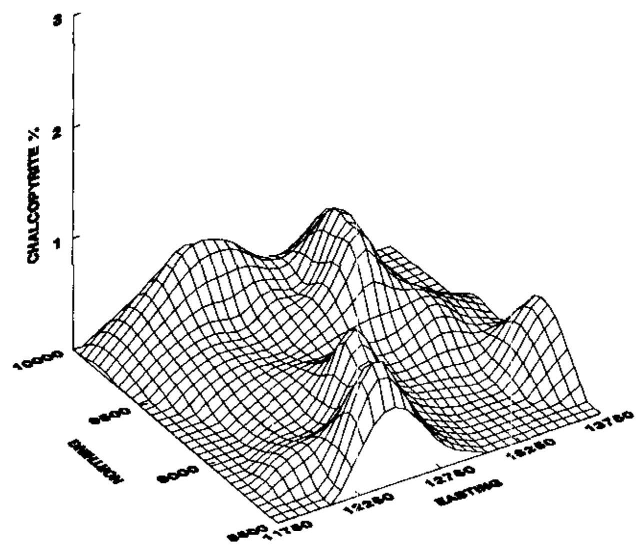

Figure 2-6-6. Chalcopyrite surface in visually estimated per cent. Note that abundant chalcopyrite coincides with concentrations of gold and biotite.

Secondary magnetite occurs throughout the potassic assemblage, and only locally in the propylitic assemblage. Most commonly it occurs as disseminations in biotite-rich areas. Within the MBX stock some of the magnetite may be primary. Magnetite also occurs locally as flooding, as veins and microveins, and as matrix to small breccia bodies around the eastern contact of the MBX stock. It also forms partings in trachyte flows and is concentrated along bedding planes in some tuffs. Abundant magnetite is associated with high copper and gold contents, and low pyrite estimates (Figure 2-6-2).

Propylitic Alteration

Propylitic alteration (Figures 2-6-7 and 2-6-8) is widespread and characterized by epidote with varying amounts of calcite, chlorite, albite and pyrite. The greatest volume of propylitic alteration is peripheral to the potassic alteration zone. Except for postmineral dikes, the rocks are never fresh; where they are not potassically altered, they are propylitized.

Potassic and propylitic zones locally overlap. Propylitic alteration, in part, is contemporaneous with potassic altera-

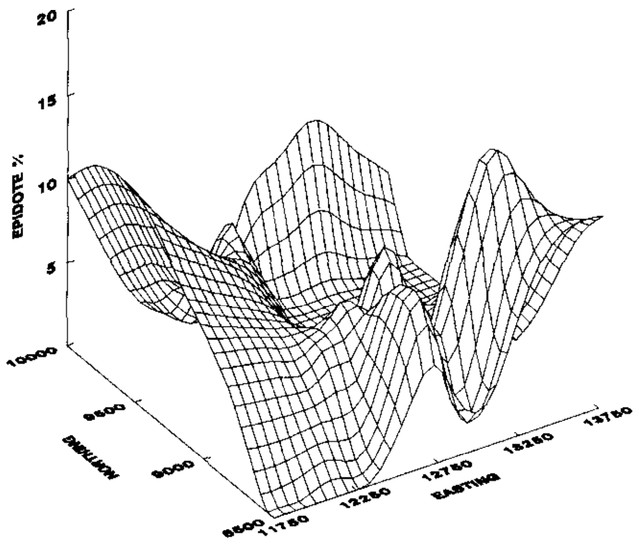

Figure 2-6-7. Epidote surface in visually estimated per cent. Epidote concentration is marginal to mineral concentrations in the potassic core (Figures 2-6-5 and 2-6-6). It is the inverse of the gold and gold-equivalent surfaces (Figures 2-6-3 and 2-6-4) except for the anomaly mentioned in the text around 9100 north and 12 800 east.

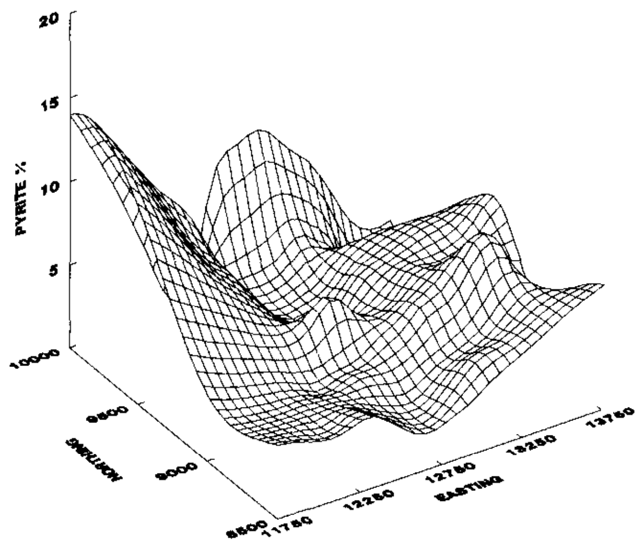

Figure 2-6-8. Pyrite surface in visually estimated per cent. Pyrite distribution is similar to epidote (Figure 2-6-7).

tion. It represents the peripheral part of the same hydrothermal system that generated the potassic alteration. However, some of the propylitic alteration is later. Retrograde alteration formed during the collapse of the hydrothermal system may account for some overprinting relationships.

Epidote (Figure 2-6-7) is the most common propylitic mineral. It is almost always associated with pyrite blebs and disseminations. Epidote forms in alteration envelopes up to 1.5 centimetres thick around pyrite-calcite veinlets, as medium-grained clots nucleated on mafic grains, as irregular aggregates in the groundmass of volcanics, and as cores to circular porphyroblastic aggregates with albite and calcite that are up to 5 centimetres across. Epidote envelopes may crosscut potassium feldspar and biotite alteration. Thin-section observations show that epidote replaces actinolite. Late, minor epidote occurs along fractures in postmineral dikes.

Albite forms irregular, creamy fine-grained patches of groundmass alteration. Mafic grains and phenocrysts are not albitized. Albite sometimes forms very fine grained pale yellow-green aggregates when intergrown with epidote. It has a negative correlation with gold and copper (Figure 2-6-2). However, this relationship is locally inconsistent, because high-grade mineralization occurs around rare, intensely albitized pipe-like zones in the order of 50 metres in diameter (Rebagliati *et al.*, 1990).

Calcite is present as groundmass alteration, replacement of actinolite, and in at least two generations of veins and veinlets. Both sparry and pink calcite veins crosscut most textures.

Pyrite (Figure 2-6-8) is widespread. Although present in the potassic zone, it is more abundantly developed in the propylitic zone. It forms veins, microveins, disseminations in wallrock, and pseudomorphs mafic grains. Several generations of pyrite veining are indicated by crosscutting relationships. Figure 2-6-8 shows an irregular pyrite halo around the potassic core of the deposit.

Carbonate, chlorite and clays occur in fault and fracture zones that locally show elevated gold and copper values. Most of the carbonate is calcite. Dolomite and iron carbonate form late crosscutting veins and the matrix of tectonic breccias.

SUMMARY

The Mount Milligan gold-copper alkaline porphyry deposit is large compared to Afton, Copper Mountain and other similar deposits. It formed by hydrothermal activity related to emplacement of the MBX stock into the Takla Group. On a property scale the alteration and mineral zoning are consistent with previously described models for alkaline porphyry deposits (*cf.*: diorite model of Lowell and Guilbert, 1970; Barr *et al.*, 1976; Fox, 1989). As in most porphyry deposits detailed patterns of alteration and metal zoning are complex where alteration assemblages overprint each other. The overprinting probably represents either separate pulses of alteration, or changes of the physical and chemical properties of the hydrothermal solutions with time and distance.

The highest gold assays and chalcopyrite estimates correlate directly with potassic alteration. This is particularly clear from the close correlation (Figure 2-6-2) between the distribution of gold and copper (Figures 2-6-3, 4 and 6) and the biotite-rich zones (Figure 2-6-5). Gold distribution in the southeastern part of the deposit (Figure 2-6-1) is unusual. A gold zone, centred at 9250 north and 13 300 east (Figures 2-6-1 and 2-6-3) is anomalous. Copper concentrations are low and gold values are high. Both potassic and propylitic alteration are associated with this mineralization.

This might be explained by overprinting of earlier potassic alteration by later propylitic alteration. This anomaly, gold associated with epidote, is being investigated.

ACKNOWLEDGMENTS

Continental Gold Corp. has provided research funding, employment to DeLong and open access to company information. Fellow employees at Continental Gold Corp. have been helpful in many ways. Research funding has been given to Godwin by grants from the National Science and Engineering Research Council and the British Columbia Ministry of Energy, Mines and Petroleum Resources. DeLong is partly supported by a Science Council of British Columbia GREAT Award.

REFERENCES

Armstrong, J.E. (1949): Fort St. James Map-area; *Geological Survey of Canada*, Memoir 252.

Barr, D.A., Fox, P.E., Northcote, K.E. and Preto, V.A. (1976): The Alkaline Suite Porphyry Copper Deposits – A Summary; *in* Porphyry Deposits of the Canadian Cordillera, A. Sutherland Brown, Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 359-367.

Fox, P.E. (1989): Alkaline Cu-Au Porphyries – Schizophrenic Cousins of Real Porphyry Coppers; *in* Cu-Au Porphyry Workshop, April 5, 1989, Vancouver, *Geological Association of Canada, Mineral Deposits Division*, reprinted in *The Gangue*, No. 28.

Garnett, J. (1978): Geology and Mineral Occurrences of the Southern Hogem Batholith; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 70.

Harris, J.F. (1989): A Petrographic Study of Rocks from the Mount Milligan Gold Deposit; unpublished report for Continental Gold Corp.; *Harris Exploration Services Ltd.*

Lowell, J.D. and Guilbert, J.M. (1970): Lateral and Vertical Alteration-Mineralization Zoning in Porphyry Ore Deposits; *Economic Geology*, Volume 65, pages 373-408.

Monger, J.W.H., Wheeler, J.O., Tipper, H.W., Gabrielse, H., Struik, L.T., Campbell, R.B., Dodds, C., Garrels, R., and O'Brien, J. (in press): Cordilleran Terranes; *in* The Cordilleran Orogen: Canada, H. Gabrielse and C.J. Yorath, Editors, Chapter 8, Upper Devonian to Middle Jurassic Assemblages; *Geological Survey of Canada*, Geology of Canada, No. 4. (also *Geological Society of America*, The Geology of North America, No. G-2).

Mortimer, N. (1986): Late Triassic, Arc Related, Potassic Igneous Rocks in the North American Cordillera; *Geology*, Volume 14, pages 1035-1038.

Nelson, J., Bellefontaine, K., Green, K. and MacLean, M. (1991): Regional Geological Mapping Near the Mount Milligan Deposit (93N/1, 93K/16); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1990, Paper 1991-1, this volume.

Preto, V.A. (1990): British Columbia Exploration and Development Highlights for 1990: Gold and Porphyry Deposits Continue to Excite Investors; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Information Circular 1990-25, page 7.

Rebagliati, C.M., Harris, M.W. and Caira, N.M. (1990): Interim Geological Report, Mount Milligan Project: *Continental Gold Corp.*, unpublished report.

Shye, S. (1978): Theory, Construction and Data Analysis in the Behavioral Sciences; *Jossey-Bass*, San Francisco.

Wilkinson, L. (1989): Systat: The System for Statistics: *Systat Inc.*, Evanston, Il.

NOTES