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Referee: WJ McMillan

ORE-FORMING PROCESSES ~~AT~~ IN THE HIGHLAND VALLEY PORPHYRY COPPER DEPOSITS, BRITISH COLUMBIA ~~– A REVIEW~~

BY

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PORPHYRY COPPER
HIGHLAND VALLEY
ORE-FORMING PROCESSES
(and model)

ABSTRACT

The Guichon Creek batholith located in south-central British Columbia is host to several producing and potentially ~~pre~~-producing porphyry copper deposits with an aggregate tonnage in excess of 2 billion tons ~~of material~~ grading approximately 0.4% Cu equivalent. ~~Most of~~ these deposits ~~are confined~~ within or close to the younger and more felsic units of the batholith in the Highland Valley district. Ore-forming processes are reviewed in light of known and newly-acquired geochemical and isotopic data. ~~Published results of~~ Radiometric and stable isotope studies indicate a close relationship between mineralization and emplacement of the Guichon Creek batholith. Relatively low K, Rb and Rb/Sr values, and high K/Rb ratios in batholithic rocks ~~are consistent with~~ as well as primitive Sr and stable isotope data and suggest derivation of the Guichon Creek magma and associated metals from a subcrustal source.

not clear - specify nearly simultaneous emplacement and mineralization or ?

Distribution of trace elements especially Cu in rocks and minerals of the batholith is however inconsistent with the prevalent hypothesis that ore metals were derived and concentrated by crystallization-fractionation ~~of a~~ from the Cu-rich magma. On the contrary, it is argued that the Guichon Creek magma became impoverished in Cu as a result of fractionation. Thus, the role of the Guichon Creek magma in ore-forming processes is envisaged as one of structural control in channeling ore metals to the surface and providing structural openings for localization, of ore deposition

(A)

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rather than a direct source of metals. The nature of epigenetic alteration-mineralization processes is also examined in light of bedrock and mineral geochemistry. Available evidence suggests that altered wall rocks are ~~may~~ not be the source of ore metals.

INTRODUCTION

In recent years, numerous genetic models have been proposed for porphyry copper deposits (Burnham, 1967; Meyer and Hemley, 1967, Fournier, 1967; Nielsen, 1968; Lowell and Guilbert, 1970; White, 1968; Philips, 1973). Most of these models ~~have not benefited from~~ were not supported by studies results of bedrock geochemistry, which in conjunction with experimental studies ~~are crucial to the~~ lead to a better understanding of chemical aspects of ore-forming processes in porphyry coppers. The purpose of this paper is to review ore-forming processes at Highland Valley, and on the basis of newly available geochemical data (Olade, 1974; Olade and Fletcher, 1975a, 1975b) to speculate further on the origin of the mineral deposits.

Most ~~of the~~ genetic models ~~presented for~~ of porphyry copper deposits recognize the importance of magmatism in hydrothermal processes; the main differences between models are in the depth of intrusion, the timing of hydrothermal processes and source of mineralizing fluids (Lowell and Guilbert, 1970). In the orthomagmatic models (Burnham, 1967; Nielsen, 1968), an aqueous-rich volatile phase is released from the magma when internal vapour pressure exceeds lithostatic pressure, or when the intrusive system is subjected to external stresses. At the other end of the ~~ore-genetic~~ 'spectrum' ~~to the~~ in orthomagmatic models, White (1968) ~~postulates~~ an almost completely external source of mineralizing fluids is postulated. The source ~~connate~~ hydrothermal solns which may be of connate and/or meteoric origin are ~~hydrothermal solutions~~ subject to convective movement as a result of ~~processes by~~ heat generated by subjacent intrusions. In ~~this~~ models of this type the pluton plays a passive role in mineralizing ~~processes~~ action.

GEOLOGIC SETTING OF GUICHON CREEK BATHOLITH

i.e.

The Geology of the Guichon Creek batholith has been described in detail by Northcote (1969) McMillan (1972) and Hylands (1972). It is of late Triassic age and ~~The Triassic batholith~~ intrudes sedimentary and volcanic rocks of the Permian Cache Creek ~~Group~~ and Upper Triassic Nicola Group. It is unconformably overlain ~~, and is overlain unconformably~~ by Middle Jurassic to Tertiary sedimentary and volcanic rocks. The batholith consists ~~pluton is composed~~ of several concentric intrusive phases that range in composition from ~~hybrid~~ diorite towards diorite at the outer margins to porphyritic quartz monzonite ~~at~~ in the ~~core~~ centre (Northcote, 1969). Most of the major porphyry copper deposits are associated with the younger ~~and~~ central phases of the batholith (Fig. 1).

CHARACTERISTICS OF MINERALIZATION IN THE BATHOLITH
~~REVIEW OF EVIDENCE~~

Various lines of evidence suggest close relationships between mineralization at Highland Valley and evolution of the Guichon Creek batholith (Northcote, 1969; Brabec and White 1971).

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Firstly, most of the major porphyry copper deposits are spatially associated with the younger and most felsic ~~[illegible]~~ components of the batholith, the Bethsaida and Bethlehem Phases. Secondly, isotopic age determinations indicate a close temporal relationship between magmatism and hydrothermal processes. Results of K-Ar age determinations on fresh biotites (Northcote, 1969) and hydrothermal sericites and biotites (Blanchflower, 1972; Jones et al., 1972; Dirom, 1965) indicate that, within limits of analytical error, ~~mineralization and~~ emplacement of the batholith and mineralization were contemporaneous.

Origin of Guichon Creek Magma

only two references better to say "Various"

Numerous workers have shown that K/Rb ratios set ~~important~~ constraints on the source materials of igneous masses (Hurley, 1968; Culbert, 1972). ~~Results of~~ Regional geochemistry (Olade, 1974) indicate that K/Rb ratios in rocks of the Guichon Creek batholith are relatively high (mean = 358) and largely outside the limit considered normal (reference) for continental plutonic rocks (Fig. 2). Furthermore, the Rb/Sr ratios plot in the region of basalts and andesites (Fig. 3) and the mean Rb/Sr ratio of 0.05 is one-fifth the value cited for sialic crust by Faure and Hurley (1963). Compared to other Mesozoic plutons in the Intermontane Structural Belt (Table 1), the Guichon Creek batholith is relatively impoverished in Rb and K, and characterized by higher K/Rb and lower Rb/Sr ratios. However, values obtained for the Guichon Creek batholith are similar

specify limit

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Why not add these data to Table 1?

to those reported by Culbert (1972) for the Coast Mountains batholith of the Coast Mountains Structural Belt.

The Relatively high K/Rb and low Rb/Sr ratios in rocks of the Guichon Creek batholith suggest derivation from a subcrustal source region which is depleted in alkalis and enriched in Sr, most likely from either ~~probably from~~ subducted oceanic crust or upper mantle. This interpretation is consistent with the primitive initial Sr isotopic ratio (Sr^{87}/Sr^{86} = 0.7037) reported by Chrismas et al., (1969). Furthermore, ~~results of~~ sulfur isotopes in hydrothermal sulfides and sulfates, as well as ~~and~~ deuterium and oxygen isotopes in hydrothermal sericites and kaolinites (Field et al., 1973; Jones et al., 1972; Sheppard et al., 1969) suggest a subcrustal source for mineralizing solutions and their associated metals.

Monger et al. (1972) and Dercourt (1972) have presented tectonic models for the evolution of the Canadian Cordillera. They ~~which~~ suggest that the Intermontane Belt, comprising extensive andesitic volcanic rocks and calc-alkaline plutons (including the Guichon Creek batholith), was the site of an ancient island arc which was generated by subduction of oceanic crust of the Pacific Plate beneath continental crust of the overriding North American Plate during the Mesozoic time. In accordance with this model and ~~studies by Hetherton and Dickinson (1969) on other island arc systems,~~ * replace with comment in referee note Ⓒ the ~~relatively~~ early Mesozoic age (200 m.y.) of the Guichon Creek batholith and its low K_2O content (mean = 1.85%) suggest derivation at relatively shallow depths (150 to 200 km) in from the subduction zone and close to the Triassic 'trench'. 350 to 400 km)

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Emplacement of the Guichon Creek Batholith

Northcote (1969) has presented geologic evidence which suggests that ~~the~~ older intrusive units within the batholith were emplaced under mesozonal conditions, whereas ~~the~~ younger units that are spatially associated with mineralization were emplaced at shallower levels in the crust. Particularly towards the close of intrusive activity, volatile pressure did exceeded load pressure and tensile strength of the confining rocks. Consequently, ~~resulting in the development~~ of breccia pipes were developed as a result of subvolcanic explosions in an epizonal environment (White et al., 1957).

Carr, 1966
Breccias, Porphyries + Cu Mineralization in H.V.
Western Miner

Distribution of Trace Elements

Brabec 43 to 65

Within the batholith as a whole, Cu concentrations generally decrease from more than 300 ppm in the relatively older mafic units to less than 10 ppm in the younger felsic rocks at the core (Fig. 4). Similarly, ~~Similar trends are shown by~~ Zn, Mn, Ti, V, Ni and Co which are all relatively depleted in the youngest, most felsic phases of the batholith. However, unlike Cu, these elements are strongly correlated with Fe and Mg (r = 0.7). Apparently they substitute for Fe ~~which they are assumed to substitute for in~~ the lattices of femic minerals (Olade and Fletcher, 1975b). The weak ~~lower~~ correlation of Cu with Fe and Mg (r = 0.5) and its

very different → to Brabec's figure! yet the 10 ppm figure agrees with him.

r = 0.5 for both ?

...../6

relative ease of extraction with a sulphide selective leach (Olade and Fletcher, 1974) suggest~~s~~ that copper sulfides account for a significant proportion of the Cu in "unmineralized" samples.

Nature of Alteration - Mineralization Processes

Extensive wall-rock alteration~~, that is so characteristic of~~ in porphyry copper deposits constitutes the most visible evidence of interaction between host rocks and hydrothermal solutions. Meyer and Hemley (1967) among others, have demonstrated ~~the~~ that close temporal and genetic relationships exist between sulphide deposition and wall-rock alteration ~~at~~ in porphyry copper deposits.

~~Mineralogy of~~ alteration minerals in ~~assemblages at~~ Highland Valley deposits provides evidence ~~of the~~ about the composition of mineralizing fluids. All the ~~deposits of the~~ Highland Valley deposits contain sericite alteration either in association with kaolinite, or quartz or K-feldspar. Argillization and sericitization of wall rocks require conditions of slight to moderate acidity (pH < 6) whereas abundant K-feldspar ~~suggests pH exceeding 7~~ requires less acid conditions (pH>7) (Barnes and Czamanska, 1967). Cross-cutting vein relationships suggest that K-feldspar with or without quartz is generally early in the paragenetic sequence, and is followed by sericite and argillic veins or selvages. This sequence suggests ~~increasing acidity of~~ the hydrothermal fluids became more acid as the ~~with increasing evolution.~~ evolved. However, at Valley Copper, K-feldspar envelopes

Jones suggests initial pH ~1.5 changing to 2.5 to 3 during main stage mineralization then pH ~ 4 when Kspar deposited at Valley Copper

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occur around sericite veins and are in equilibrium with kaolinite. This relationship, which is contrary to the stability-field relationships established for these minerals by Hemley and Jones (1964), is attributed to ~~a resurgence of~~ an influx of ore-forming fluids with abnormally high silica activities that ~~in ore-forming fluids shifting~~ shifted the mineral stability field to higher pH levels.

~~Results of~~ Bedrock and mineral geochemistry (Olade, 1974) ~~suggest that~~ document that widespread chemical changes occurred in wall rocks ~~are~~ adjacent to ore deposits. ~~intimately associated with mineralization and hydrothermal alteration.~~ Each deposit is characterized by a central mineralized zone ~~s~~ in which metasomatic activity ~~is~~ was most intense.

In zones of intense argillic and phyllic alteration at Valley Copper, Lornex and Highmont, the base elements Ca, Na, Sr, Ba, Zn, Mn, Mg and Fe are depleted, whereas in potassic zones at JA, Lornex and Valley Copper K, Rb and Ba are relatively enriched. Calculations of chemical gain and loss of principal rock for major elements ~~constituents~~ through alteration and mineralization at Valley Copper (Fig 5), suggest that in quartz-sericite and potassic zones, Ca, Mg, Fe, Na and Al are removed ~~and~~ whereas K, Si and S are added (for method of calculation, see Gresens, 1967). The (obvious) depletion of base cations in mineralized and altered zones is attributed to the breakdown of ferromagnesian minerals and plagioclase to sericite and kaolinite. Incipient stages of the ~~above process~~ alteration are demonstrated by results of mineral analyses. Zn, Mn, and

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possibly Ni also?

Co levels in biotites and magnetites are consistently lower in mineralized and altered than in fresh samples (Table 2). Cu and S concentrations, though erratic, are highest in zones of intense alteration and metallization, and decrease ~~decreasing~~ outward~~s~~ to background levels in fresh unmineralized host rocks.

DISCUSSION

The following modes of origin have been proposed for porphyry copper deposits, hence are relevant to the interpretation ~~genesis~~ of ~~the~~ Highland Valley deposits.

(i) Derivation ~~Extraction~~ of ore metals by leaching of wall rocks by convecting meteoric waters ~~as proposed by~~ (White, (1968), or by deuteric alteration ~~as suggested by~~ (Putman, (1972).

(ii) Derivation of ore metals by assimilation of metal-rich country rocks (Schau, 1970).

(iii) Derivation of ore-forming fluids from magmas by a process of fractionation during crystallization ~~Derivation and concentration of aqueous-rich, metal-bearing fluids from magmas during their emplacement and crystallization-fractionation~~ (Nielsen, 1968; Brabec and White, 1971; Graybeal, 1973).

(iv) Generation of ore-forming fluids from similar source regions as the magmas; the role of magmas being one of structural control rather than acting as ~~source of~~ sources metal~~s~~ (Noble, 1970, Sillitoe, 1972; Mitchell and Garson, 1972; Wright and McCurry, 1973).

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On the basis of variations of Cu contents in the Guichon Creek batholith, Brabec and White (1971) postulated that the Highland Valley deposits were derived and concentrated during emplacement and crystallization of ~~a probably Cu-rich~~ t/a Guichon Creek magma. In contrast Schau (1970) suggested that Cu in the batholith was generated ~~from the~~ by assimilation of ~~a~~ ~~supposed~~ Cu-rich Nicola volcanic country rocks. On the basis of Sr and other stable isotope studies, Chrismas et al. (1969) ~~have~~ proposed an upper mantle source for the Guichon Creek batholith and associated mineral deposits. These alternatives are now considered in light of new regional and detailed bedrock, and mineral geochemi~~stry~~cal. analyses.

I thought they only worked in Craigmont ?

The first hypothesis concerning derivation of metals from wall rocks is considered least likely because, at the level of sampling, ~~results of~~ both regional and detailed bedrock geochemistry (Olade, 1974; Olade and Fletcher, 1975b) ~~around~~ adjacent to mineralized zones ~~indicate~~ showed that no zone ~~of~~ depleted in Cu and/or S depletion surrounds the orebodies. ~~at the level of sampling.~~ The possibility that ~~these elements could~~ Cu and S were derived from wall rocks ~~be extracted from~~ channelways ~~at~~ at greater depths is not ruled out. Moreover, ~~results of~~ mineral geochemistry provides no evidence of obvious leaching of Cu from biotites.

~~Schau (1970) suggested that ore metals were derived by assimilation of Nicola volcanic rocks. Subsequently~~ Brabec and White (1971) criticized ~~this~~ Schau's hypothesis by demonstrating that the border Hybrid Phase, the most contaminated unit within the batholith, ~~is not significantly higher in Cu than~~ has approximately the same Cu content as uncontaminated

less than Guichon, more than Chataway

........./10.

D

rocks of the Guichon and Chataway ~~Phases~~ Varieties. Drabec (1970) further suggest~~s~~ed that the relatively high Cu levels ~~in~~ of the batholith would require selective assimilation of ~~this metal from a~~ of a very large volume of country rocks. Field evidence does not support ~~a~~ large-scale contamination of the batholith. ~~beyond~~ Only its the outer margins show evidence of country rock assimilation (Northcote, 1969).

Available geochemical data are not consistent with the hypothesis of Brabec and White (1971), ~~since~~ because:

(i) Cu, together with Zn, Mn, Ti, V, Ni, Co, Fe and Mg generally decreases with increasing ~~fractionation or felsic composition~~ differentiation of intrusive units. This geochemical pattern simply reflects normal differentiation trends observed in unmineralized intrusions. Sheraton and Black (1973), who ~~investigating~~ investigated trace element geochemistry of zoned granitic intrusions ~~unmineralized with respect to Cu~~ with no associated Cu deposits? respect to Cu, found that Cu concentrations decreased from more than 40 ppm in granodiorite to less than 5 ppm in more differentiated granites. In contrast, studies on intrusions that are known to have generated immiscible sulphide phases such as the Skaergaard intrusion (Wager and Brown, 1967), and mineralized Laramide intrusions in Arizona (Graybeal, 1973), Cu content~~s~~ of bedrock and mineral constituents generally increase with fractionation until Cu separates from the melt as an immiscible sulphide phase, then decreases sharply. Graybeal (1973), investigating the partitioning of Cu between co-existing biotite and hornblende found that, under equilibrium conditions, higher concentration of Cu within the magma was reflected by higher Cu concentrations in the two mineral ~~phases~~. In the Guichon

E

confusing, was he measuring real rocks and comparing Cu in bi + hb to whole rock copper? or was he making the magma? ie doing "bomb" work?

......./11.

Creek batholith, results of Cu determinations in 18 biotite~~s~~ and 4 hornblende~~s~~ concentrates (Brabec, 1970) suggest no appreciable variations throughout the batholith. From the foregoing discussions it is ~~apparent~~ concluded that geochemical data ~~do~~ are not ~~support~~ consistent with the hypothesis that ore metals ~~at~~ in Highland Valley deposits were derived by differentiation of a Cu-rich Guichon Creek magma. On the contrary, it is argued that the Guichon Creek magma became increasingly impoverished in Cu as a result of differentiation.

An hypothesis, which regards mineralization as an independent by-product of magma generation rather than a direct result of differentiation processes, is consistent with geochemical data and contemporary ideas ~~of~~ about plate tectonics and ore genesis. Nevertheless, it must be emphasized that differentiation processes within a magma~~s~~ provide the right chemical setting and emplacement of the magma provides the right physical environment for ~~localization~~ formation of ore ~~metals~~ deposits.

High K/Rb ratios and Sr values, ~~and~~ low Rb, and K values and Rb/Sr ratios as well as low Sr^{87}/Sr^{86} ~~K,~~ ~~Rb/Sr and Sr~~ isotopic ratios are consistent with derivation of Guichon Creek magma from a deep-seated source, ~~(most)~~ probably either subducted oceanic crust or upper mantle.* Results of sulphur, oxygen and deuterium isotopes suggest a similar deep-seated source for mineralizing solutions and ore metals (Jones et al, 1972). Because of the temporal and spatial relationships between mineralization and magmatism, it is logical to presume that ore metals at the Highland Valley deposits were derived from a metal-rich portion of the subducted oceanic crust from which the Guichon Creek magma was generated.

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proof That The magma was not generated by partial melting of upper mantle?

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Sillitoe (1972) ~~has~~ demonstrated that there is enough Cu in oceanic basalts to generate metals in ore deposits. The ore metals derived from partial melting of subducted oceanic crust probably occur in a phase which is independent of the magma. Thus the ~~role of the magma is believed to be one of~~ magma has a structural role and opens access channels to enable the ~~structural control in channeling~~ ore metals to move up to crustal levels (Noble, 1970). Emplacement and ~~Nevertheless,~~ differentiation of the magma would provide~~d~~ volatiles and structural openings, such as fractures and breccia zones~~, dyke swarms that~~ to facilitate~~d~~ ~~the~~ extraction of metals from the system and concentration as ore deposits.

not necessarily permeable zones although the fractures they occupy were

Fig. 6 shows a ~~comprehensive~~ model for ~~the~~ evolution of ~~the~~ ore-forming fluids at the hydrothermal stage in Highland Valley. The close spatial relationship between porphyry dykes or dyke swarms and ore deposits ~~at Highland Valley~~ H.V., suggests that the fracture systems which controlled dyke emplacement also ~~porphyries~~ served as high-level structural 'outlets' for mineralizing solutions. The presence of saline fluid inclusions in quartz veins at Valley Copper Lornex and Highmont (R.D. Morton, pers. comm.) ~~and~~ as well as enhanced values of B, F, Cl and S in ore zones suggest that the mineralizing fluids contained HCl, H_3BO_3, HF, H_2S, H_2SO_4 and other volatile elements. Late stage differentiation products, such as K^+, SiO_2, Rb^+ and Na^+ were probably present. Extensive argillic and sericite alteration found around the deposits require that ore solutions be slightly to moderately acidic, and contain abundant H^+, probably derived from dissociated H_2O and H_2S ~~present~~ in ~~the~~ the

Ⓖ

juvenile fluids, or ~~by admixture with convecting~~ meteoric waters. ~~generated by heat from the porphyry dykes or stocks,~~

Helgeson (1970) ~~has~~ presented thermodynamic data which suggest ~~demonstrate~~ that all equilibria in hydrothermal systems can be represented in terms of the ratio of activities of cations in the aqueous phase to that of the hydrogen ion. Changes in base cation/H^+ activities in ~~as~~ ore-forming fluids as They pass through various ~~transgress the~~ alteration zones are portrayed in Fig. 6. The evolutionary

Which is which? → paths, designated 1, 2 and 3 in the diagram, represent (paths followed by fluids with) different states ~~degrees~~ of equilibration with the ~~between ore fluids and~~ wall rock. Formation of an early potassic zone containing (K-feldspar ± quartz ± sericite), that is commonly centred on porphyry dykes, requires a high base cation (K^+, Na^+)/H^+ activity ratio. This ~~which~~ could reflect ~~result~~ The ~~from~~ initial compositions of mineralizing fluids (inherited from the magma) or less likely could ~~probably~~ be derived ~~at depths~~ by H^+ consuming and base cation-releasing equilibrium reactions at depth

As the ore fluids rise and spread outwards they undergo adiabatic expansion, and as a result of ~~in conjunction with~~ reaction with wall rocks and/or mixing with meteoric waters, they cool, causing dissociation of the most acidic components. This dissociation provides most of the abundant H^+ required for hydrolitic base leaching within ~~the~~ quartz-sericitic and argillic alteration zones. ~~under acidic conditions.~~ The base cations (Mg^{++}, Ca^{++}, Fe^{++}, Na^+, Sr^{++}, Ba^+, Zn^{++}, Mn^{++}), released by leaching enter ~~are taken into~~ the fluid and are transferred to the outlying metasomatic front (Korzhinskii, 1968), as the solutions are cooled and neutralized, Changes in base cation/H^+ activity ratios are generally accompanied by changes in pH and sulfur fugacity (Meyer and Hemley, 1967) which ultimately control sulfide deposition and zoning patterns. ~~This accounts for the~~ Close association between sericite and argillic alteration which require H^+ consumption in their formation and sulphide mineralization, results, as is amply demonstrated at Valley Copper, Lornex, Highmont and in parts of Bethlehem-JA.

(H)

From the foregoing discussion, it is apparent that regional and detailed bedrock and mineral geochemistry, ~~and~~ isotopic and tectonic evidence are consistent with the mode of origin proposed for the Guichon Creek batholith. Assuming the genetic model is correct, it has ~~far reaching~~ implications in reconnaissance exploration for Cu deposits in calc-alkaline intrusions of the Intermontane Belt. First, the apparent negative correlation between Cu contents and ore potential of the Guichon Creek batholith suggests that ore-bearing intrusions need not be enriched in Cu. Thus the suggestion by Warren and Delavault, (1960) that high Cu contents of intrusions reflect ore potential might not be generally applicable. Second~~ly~~, if ore metals in the Guichon Creek batholith were derived from copper-rich subducted oceanic crust as an independent by-product of magma generation, it is ~~most plausible~~ probable that other calc-alkaline plutonic and volcanic rocks in the Nicola belt which are of similar age as the Guichon Creek batholith might originate from ~~the same~~ similar

The batholith as a whole is copper positive - only the phases associated with the deposits are copper deficient

(I)

metal-rich ~~portion of~~ subducted oceanic crust. Such calc-alkaline intrusive and extrusive rocks within the Intermontane Belt ~~can~~ could be identified by: (1) ~~their ages (Late Triassic - Early Jurassic);~~ late Triassic to early Jurassic ages ; (2) ~~their~~ low Rb, Rb/Sr and high K/Rb ratios; and (3) ~~their~~ low K_2O content which should reflect the relatively shallow depth of magma generation. Using the Guichon Creek batholith as a 'reference index', calc-alkaline intrusive and extrusive rocks which meet the above criteria might have ~~considerable~~ potential for further discoveries of porphyry Cu and/or massive sulfide deposits.

CONCLUSIONS

Regional and detailed bedrock and mineral geochemistry of the Guichon Creek batholith and associated mineralization is consistent with the hypothesis that ore metals did not arise as a direct result of differentiation processes within a Cu-rich magma, but rather as an independent by-product of magma generation from subducted oceanic crust of probably amphibolite composition. Nevertheless, emplacement as well as chemical and mineral fractionation within the Guichon Creek magma led to the ~~development of~~ increased volatile contents and pressures that provided suitable chemical and structural environments

OMIT
never previously mentioned

for localization of ore deposits. ~~Consequently not all ore-bearing plutons need be enriched in Cu.~~ omit

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(? not seen in the text)

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......./20

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WJM Comments

(A) Abstract bottom 4 lines ..... I think you are suggesting that the mineralizing solutions were <u>either</u> (1) emplaced with the magma as an immiscible phase <u>or</u> (2) that they followed behind the magma but used the same channelways. It is not clear to me which possibility you mean. If it is (1) it is difficult to envisage a magma structurally controlling channelways. It should also be made clear that the structural openings for localizing ores were in the crystallized carapace of the magma.

(B) It would be better to be more specific.

(C) You might be able to improve the depths and distances from trenches which I got from Hatherton and Dickson's curves by calculating K55 and K60 for Guichon data. There should also be a qualifying statement to the effect: "assuming conditions at the time the Guichon was emplaced were similar to

(D) I strongly criticize your decision to change what has become standard usage (Northcote, 1969) regarding the Highland Valley <u>PHASE</u> and the Guichon and Chataway <u>VARIETIES</u>. I suggest you stick to standard usage even though it would necessitate changing the Legend of Figure 1.

(E) Graybeal concluded that copper content was low in productive plutons <u>because</u> copper separated out into the volatile phase. At Skaergaard, copper in the rock and minerals was low after the sulphide phase separated. In the Guichon, Brabec shows copper increasing from Hybrid (57) to Guichon (65) then dropping (Chataway 43, Bethlehem 32 and Bethsaida 10). All figures are geometric means.

(F) This statement must be preceeded by some logical reason for rejecting derivation from a metal-rich upper mantle source. I would add a sentence in at the "*" (p.11) saying:-

"In the Coast Mountains batholith Culbert (1972) has argued that similar Rb/K ratios indicate probable derivation of alkalis in the batholith at least in part from destruction of oceanic crust."

(G) Your chemical gain calculations (p.7) are good evidence that K, Si, and S were added and enrichment shows Rb and Ba addition <u>BUT</u> Na is supposedly depleted (p.7).

(H) At Valley in particular, argillic alteration is not closely associated with ore grade material. Argillic alteration at Valley is taken to be pervasive sericite and kaolinite development. Reference "Osatenko, M.J. and Jones, M.B., 1975 (?), Valley Copper Deposit : C.I.M. Special Volume 15, in preparation.

(I) Does it really matter whether the sulphide phase was independent? So long as the magma and sulphides have the same general source area the rest of your argument follows logically.

FIGURE 1

(a) HIGHMONT not HIGHMOUNT.

(b) Add a 6 to the area of Bethsaida south of Highmont and east of Lornex Fault.

(c) Are the two unnumbered areas near Ashcroft Barnes Lake and Willard Lake - if yes, remove them.

(d) JA deposit not shown (label it J.A. when you add it so people unfamiliar with the region will know which of the Bethleham deposits it is).

(e) Suggest you follow standard usage and use:-

Highland Valley phase
Guichon Variety
Chataway Variety

FIGURE 2

(a) Label the limits of normal continental plutonic rocks on the diagram itself.

(b) Show the average, specify the standard deviation for Guichon rocks.

(c) What is the significance of the r = 0.78. It is not mentioned in the text.

FIGURE 3

(a) Significance of r =-0.52?

(b) If Rb/Sr = 0.01 is typical for sialic crust, label it to that effect on the figure.

(c) Dacite not Docite

FIGURE 6

The "model" is a representation of Highmont and possibly J.A. It is not representative of Bethlehem, Lornex or Valley Copper. I suggest you entitle the Figure:

Schematic model for chemical and mineral zoning of the Highmont deposits, Highland Valley area. Possible evolution of ore forming fluids is shown schematically."

NOTE: It would be better if the pH, ore fluid diagram, were separated from the other. I expected the "path" to reflect the underlying data but in fact it seems to be showing a change from the beginning to the end of the mineralization process.

TABLE 2

Terms "Fresh", "weakly mineralized" and "strongly mineralized" are confusing. Are the samples from porphyry deposits ..... if so specify this in the title, and perhaps use terms:-

Unmineralized rock
Weakly mineralized zone
Strongly mineralized zone

CAPTIONS TO TABLES

TABLE 1: Means and ranges of Rb, Sr, Rb/Sr, K/Rb and Sr^{87}/Sr^{86} ratios in some Mesozoic intrusions of the Cordilleran Intermontane Belt (After Peto, 1974).

TABLE 2: Means and ranges of some *trace elements in biotites and magnetites from the Highland Valley (Values in ppm).

arithmetic ?

TABLE 1: Means and ranges of Rb, Sr, Rb/Sr, K/Rb and Sr^{87}/Sr^{86} ratios in some Mesozoic intrusions of the Cordilleran Intermontane Belt (After Peto, 1974)

Intrusions	Rb (ppm)	Sr (ppm)	Rb/Sr	K/Rb	Sr^{87}/Sr^{86}	Age (m.y)
Guichon Creek batholith	35 (3-132)	686 (249-1000)	0.05 (0.004-0.321)	358 (132-1030)	0.7037	200 ± 5
Similkameen batholith	95 (52-152)	390 (147-639)	0.151 (0.081-1.01)	250 (172-309)	0.7060	183
Nelson batholith	- -	- -	0.175 (0.056-0.483)	- -	0.7069	171
Hogem batholith	80 (55-118)	730 (468-1520)	0.100 (0.041-0.125)	430 (322-502)	-	170
White Creek batholith	265 (196-357)	804 (435-1118)	0.412 (0.108-1.655)	- -	0.7250	126
Vernon batholith	- -	- -	1.42 (0.108-2.84)	- -	0.7064	55

TABLE 2: Means and ranges of some* trace elements in biotites and magnetites from the Highland Valley (Values in ppm)

	Cu	Zn	Mn	Ni	Co
BIOTITES					
Fresh (10)	98 (39-163)	349 (172-931)	4195 (1515-11225)	40 (27-75)	56 (35-72)
Weakly Mineralized (8)	883 (474-2644)	292 (216-365)	3250 (2164-4388)	37 (25-54)	58 (47-76)
Strongly Mineralized (9)	2549 (531-5617)	275 (181-421)	3208 (1953-5821)	24 (12-44)	49 (42-54)
MAGNETITES					
Fresh (10)	67 (35-153)	68 (30-122)	-	-	40 (20-49)
Weakly Mineralized (8)	251 (93-846)	54 (38-64)	-	-	40 (34-59)
Strongly Mineralized (9)	576 (122-5451)	59 (39-73)	-	-	33 (24-37)

* Atomic absorption analysis.

CAPTIONS TO FIGURES

✓ FIGURE 1: Location and general geology of Guichon Creek batholith (modified *after* McMillan, 1972).

✓ FIGURE 2: Plot of K versus Rb and K/Rb ratios in rocks of Guichon Creek batholith (Normal crustal ratios = 150-300).

FIGURE 3: Relationship between Rb and Sr in rocks of Guichon Creek batholith (generalized geochemical relationships of Rb and Sr in certain rock types are shown ~~of~~ for comparison; *after* Hedge, 1966).

add number of sample and goodness of fit (r) to figure

FIGURE 4: Distribution of Cu in Guichon Creek batholith in relation to Largen differentiation index.

FIGURE 5: Gain and loss of principal rock constituents through in various alteration ~~and~~ zones ~~mineralization at Valley Copper~~ (3600 level).

FIGURE 6: Schematic model for chemical and mineral zoning and evolution of ore-forming fluids ~~at~~ in Highland Valley porphyry coppers. deposits

see sheet attached to Figure

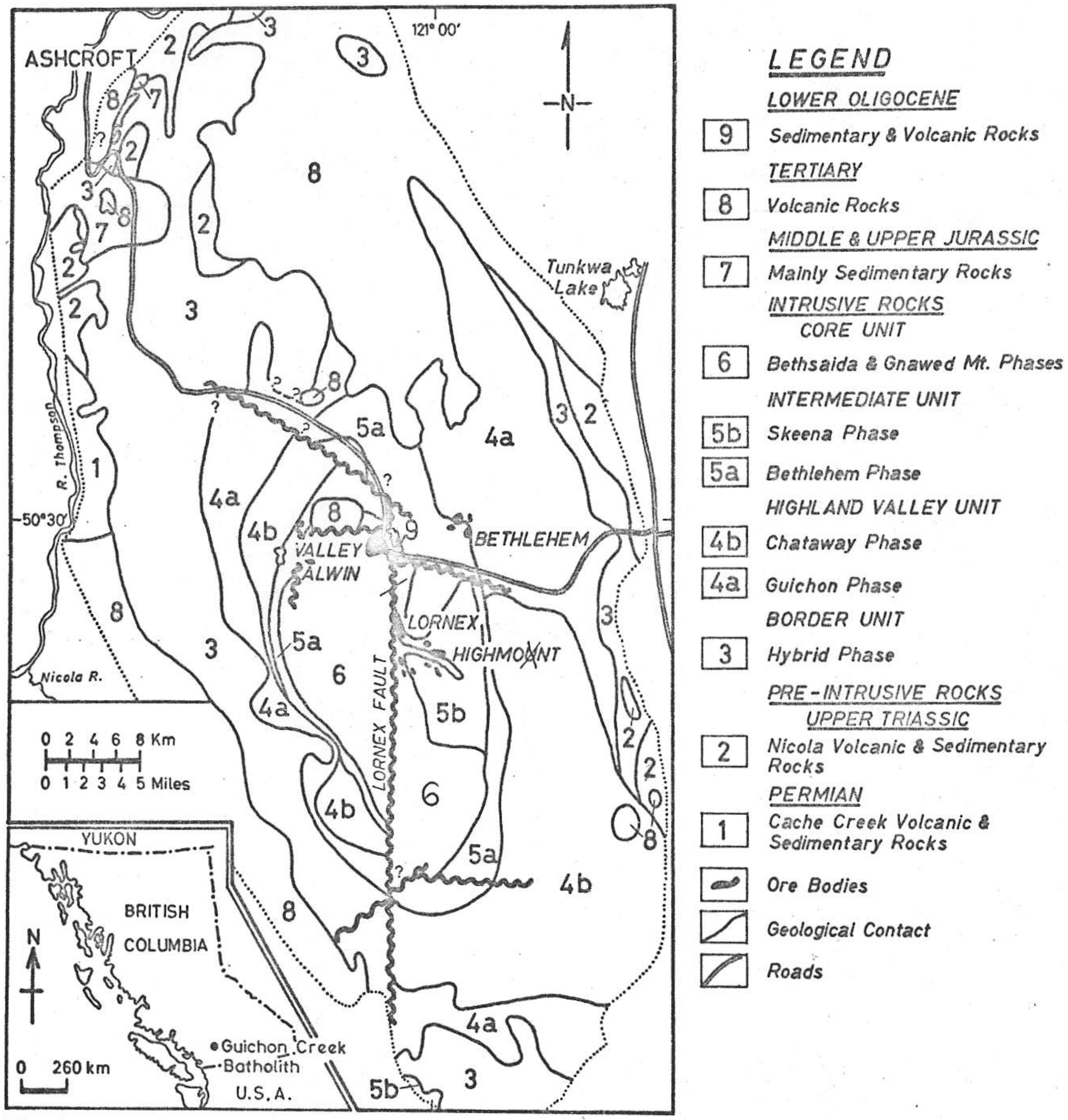


Fig. 1: Location and General Geology of Guichon Creek Batholith. (Modified after McMillan, 1972)

Fig. 1

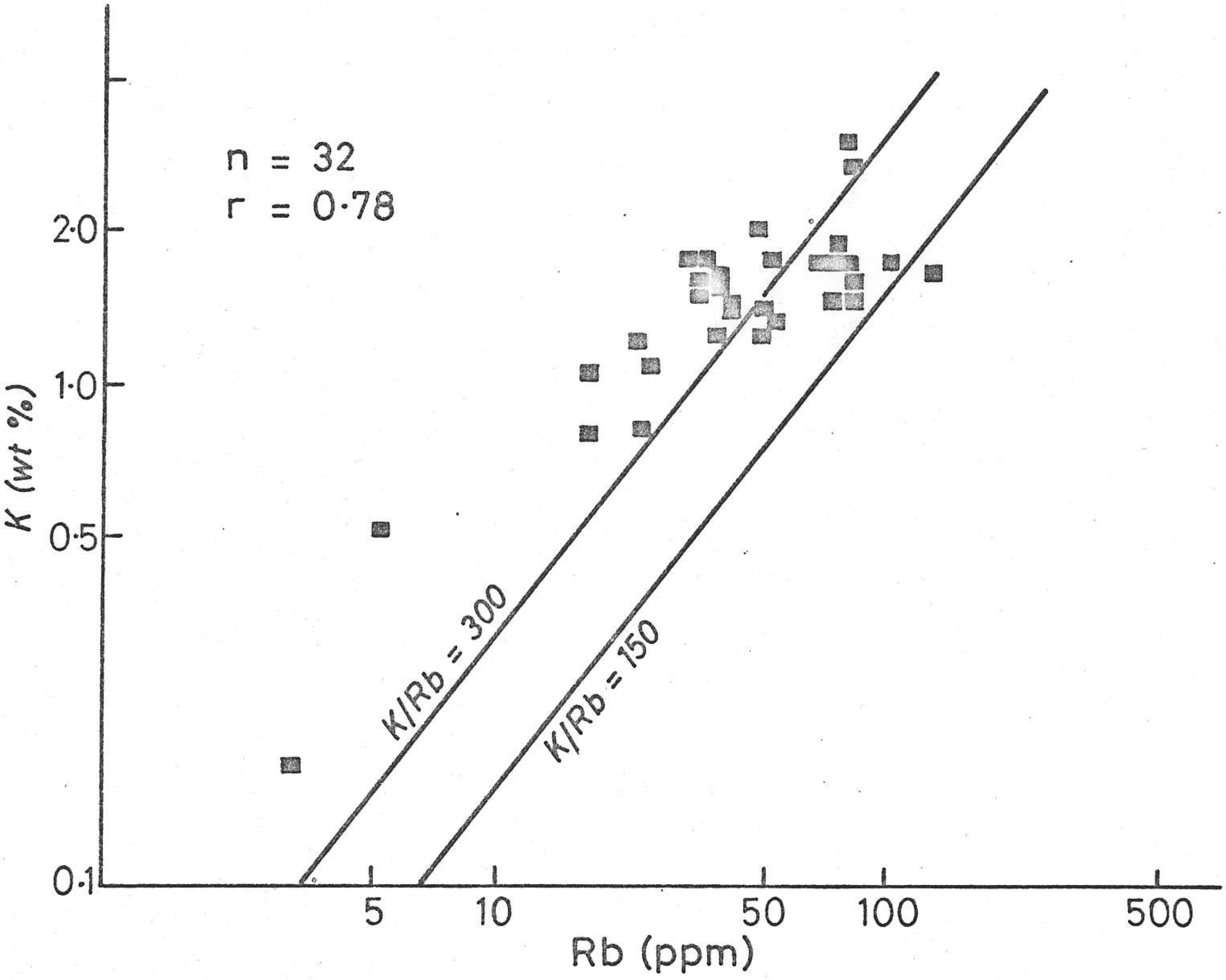
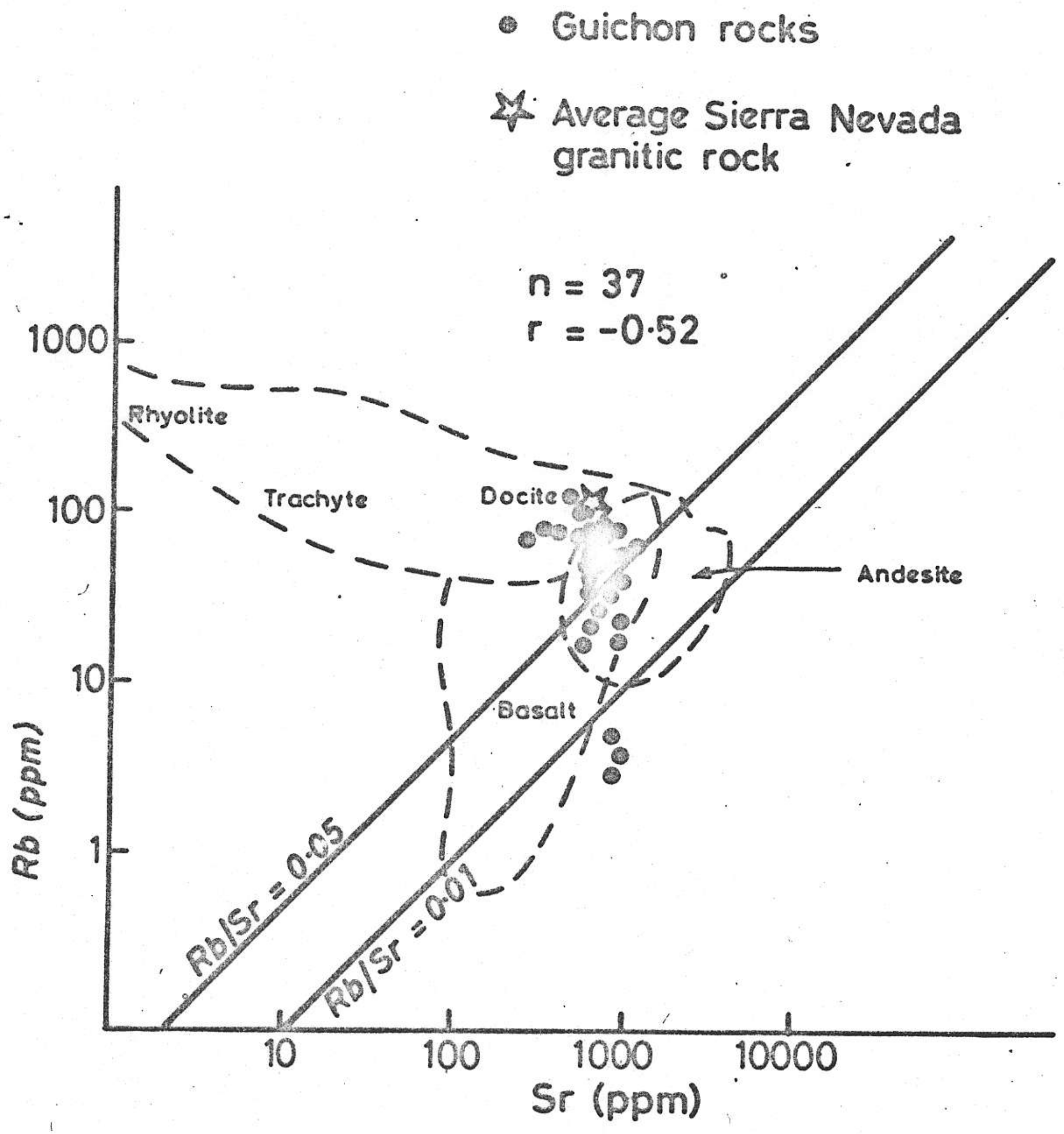


Fig. 2



● Guichon rocks
☆ Average Sierra Nevada granitic rock
n = 37
r = -0·52
1000
100
10
1
Rb (ppm)
Rhyolite
Trachyte
Dacite
Andesite
Basalt
Rb/Sr = 0·05
Rb/Sr = 0·01
10
100
1000
10000
Sr (ppm)

Fig. 3

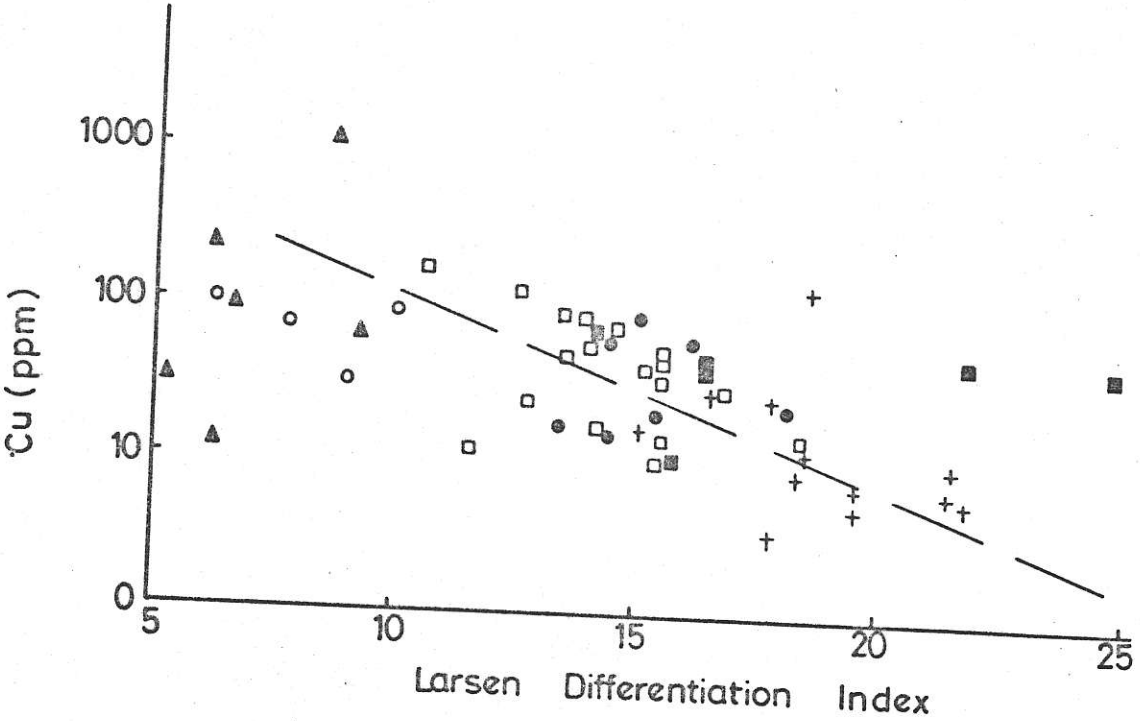

1000
100
10
0
Cu (ppm)
5
10
15
20
25
Larsen Differentiation Index

Fig 4

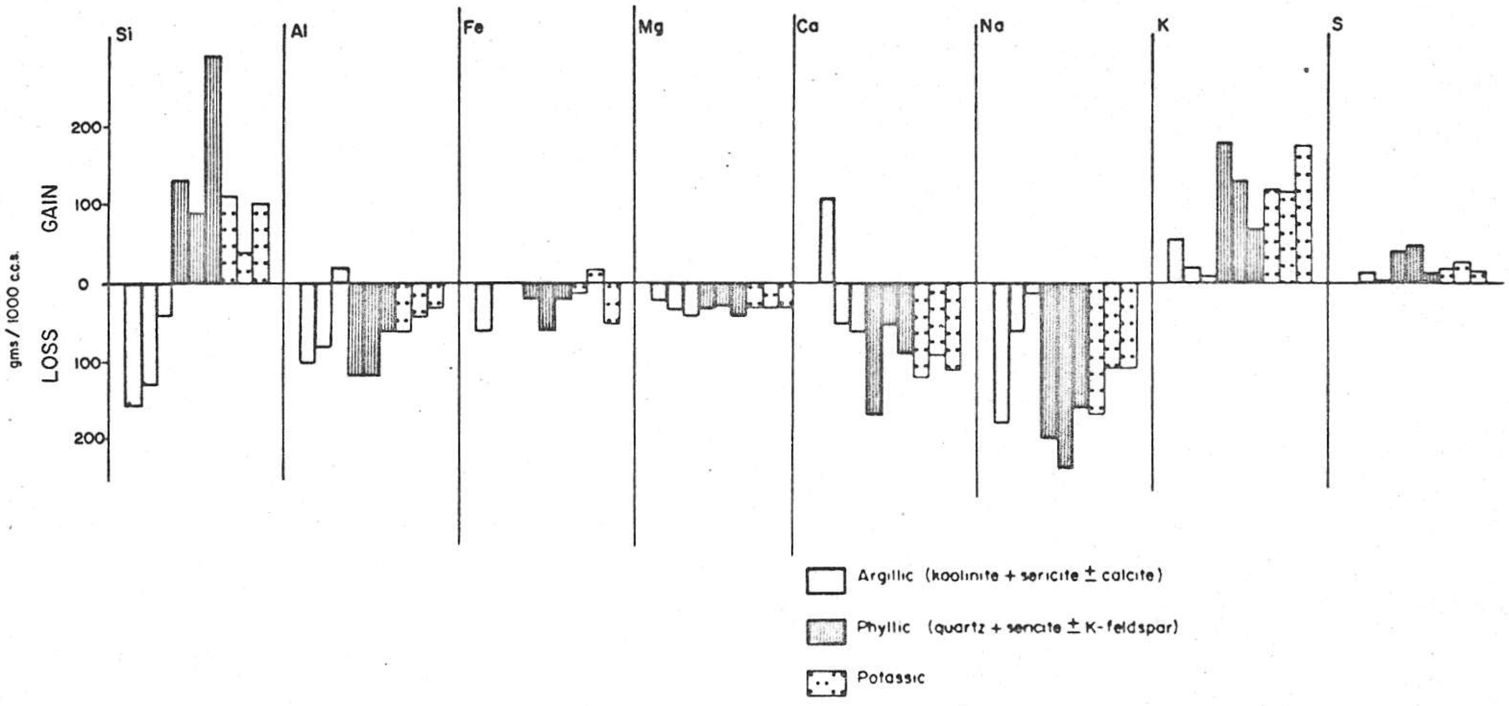

Si
Al
Fe
Mg
Ca
Na
K
S
gms / 1000 c.c.s.
GAIN
LOSS
200
100
0
100
200
Argillic (kaolinite + sericite ± calcite)
Phyllic (quartz + sericite ± K-feldspar)
Potassic

Fig 5

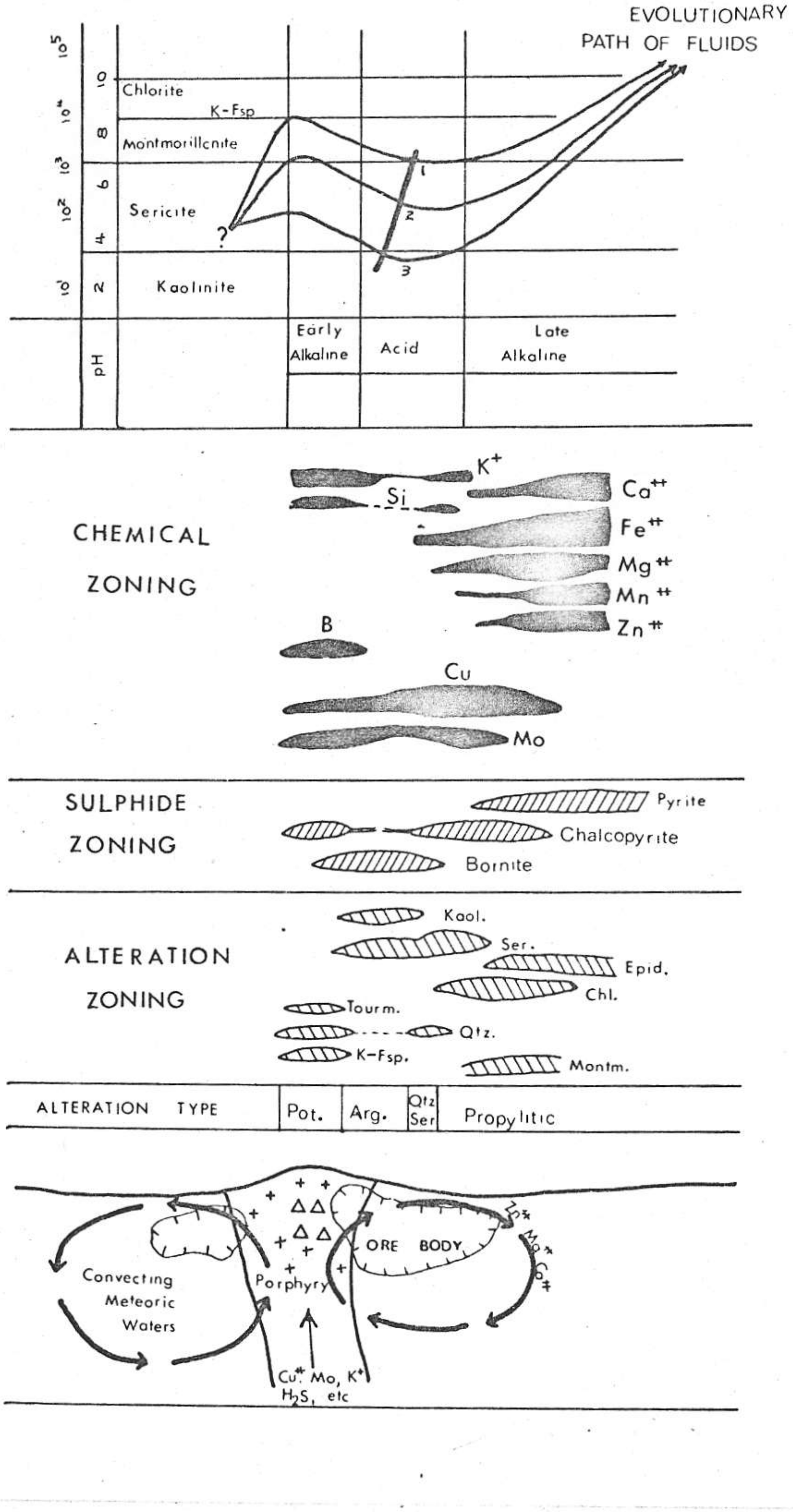

EVOLUTIONARY PATH OF FLUIDS
10^5
10^4
10^3
10^2
10^1
10
8
6
4
2
Chlorite
K-Fsp
Montmorillonite
Sericite
Kaolinite
?
1
2
3
pH
Early Alkaline
Acid
Late Alkaline
CHEMICAL ZONING
K^+
Si
Ca^{++}
Fe^{++}
Mg^{++}
Mn^{++}
Zn^{++}
B
Cu
Mo
SULPHIDE ZONING
Pyrite
Chalcopyrite
Bornite
ALTERATION ZONING
Kaol.
Ser.
Epid.
Chl.
Tourm.
Qtz.
K-Fsp.
Montm.
ALTERATION TYPE
Pot.
Arg.
Qtz Ser
Propylitic
ORE BODY
Convecting Meteoric Waters
Porphyry
Cu^{++}, Mo, K^+, H_2S, etc
Zn^+
Mn^+
Ca^+

Fig 6