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RECENT CONTRIBUTIONS TO COPPERBELT GEOCHEMISTRY

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ABSTRACT

Short abstracts are given of some recently completed investigations bearing on the geochemistry of Copperbelt ore deposits. Three detailed investigations were carried out on veins and altered barren zones in the ore-bearing argillites and footwall quartzites at Chambishi, Luanshya and Muliashi. At all three places, hot fluids have locally altered the host rock, formed veins, leached and remobilized sulphides, and in one case, formed breccia. Comparison of samples from selected parts of the orebody and barren rock at Chambishi has shown interesting mineral and chemical trends that may have important bearing on the origin of the ore. An investigation into the use of mercury in prospecting was also undertaken with some positive results.

INTRODUCTION

Orebodies of the Zambian Copperbelt are generally accepted as syngenetic. However, numerous phenomena indicate that diagenetic, metamorphic, or possibly other processes had a modifying, or perhaps even controlling influence on the present occurrence of copper sulphides. In the hope that a better understanding of the rock and ore-forming processes will eventually emerge, detailed investigations of veining and other migration phenomena, as well as larger scope investigations such as the study of element distribution between ore and barren rocks, are being carried out. Eventually, some new information may come forth that will prove useful in prospecting, or in development of the present orebodies.

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VEIN AND ELEMENT MIGRATION

Copperbelt veins have been the subject of much controversy. Veins that are called pegmatites by some (e.g. C a h e n et al., 1970) are called lateral secretion veins by others (e.g. G a r l i c k, 1965). The presence of wallrock alteration is taken as evidence of a pegmatitic origin, and the leaching of copper sulphides from the wallrock as evidence of lateral secretion for all vein constituents.

Current investigations suggest that neither interpretation is, in fact, a satisfactory explanation for the origin of some of these veins. There is a need for vein forming processes to be investigated and labelled without regard to source. Summaries of some completed and partly completed investigations are given below.

A chalcopyrite-bearing vein and associated wallrock alteration, Luanshya Mine

A microcline-carbonate-quartz-chalcopyrite, bedding plane vein was observed in the RL-6 upper orebody of the 6 limb at Luanshya, from the 460 foot level down to the 1060 foot mining level. Along strike, the vein composition varies from dominantly microcline at one extreme, to dominantly carbonate at the other. In the highest (mined out) mine levels, the major vein mineral was quartz, whereas calcite

and microcline form the major vein minerals at lower levels. Minor vein constituents include albite, biotite, muscovite, rutile, and allanite.

The amount and type of wallrock alteration varies as well, but is generally expressed by muscovitization, microclinization, biotitization, and carbonatization. All of the wallrock alteration and vein phases observed can be explained by variations in three principal factors: chemical composition, pressure, and temperature. A vein temperature of 400-500°C and a depth of burial of 3 to 4 km are indicated for the alteration environment by Na/K rations of feldspar (B a r t h, 1951; O r v i l l e, 1963) and by muscovite and kaolinite dehydration curves (C r e a s e y, 1966). At the time of alteration, the wallrock was cooler than the vein solutions at the two points chemically analysed. A higher temperature for the vein is indicated by $2M_1$ muscovite (B u r n h a m, 1962) next to the vein, which gradually gives way to 1M mica in the unaltered wallrock.

Thirteen complete chemical analyses were made from the wallrock and vein from both carbonate and microcline vein phases. These were studied by J o l l y and H a n c o c k (1969) with regard to possible vein forming processes. It is concluded that, on the 960 foot level, Si, Al, Fe, Cu, S, Ti, P, B, Mn, Cr, and Ni were leached from the wallrock and added to the vein fluid, or fixed in more compatible parts of the wallrock during alkali metasomatism and hydrolysis. Vein components not derived locally from the wallrock include: K, Ca, Mg, Na, CO_2, H_2O, Th, Zr, Ce, La, Nd, Sm, Eu, Ga, V, Y, and Yb.

It was not possible to establish the source of the introduced solutions, but some essential characteristics were defined. The vein is the result of hydrothermal fluids of unknown origin, high in alkalies, water, and carbon dioxide, permeating through planes of easy access in the RL-6 orebody. The presence of excess alkalies and carbon dioxide in the altered rock and vein over that of the unaltered rock, of disequilibrium wallrock alteration assemblages; and, of a multi-mineral vein paragenesis suggest that an origin by lateral secretion, or diffusive migration of wallrock material, in a closed system during metamorphism of upper greenschist or lower epidote-amphibolite grade, is not adequate explanation for the origin of this vein.

Muliashi quartz-tourmaline-chalcocite vein

A quartz-chalcocite-tourmaline vein (J o l l y, 1971a) occurs on the 580 foot mining level of Muliashi, section 1488, in the footwall RL-7 of the Roan Antelope Basin. Locally, the RL-7 quartzite is conglomeratic at the top, and at 6.7 m from the RL-6 – RL-7 contact, becomes argillitic. Veins like this one have also been described in the hangingwall RL-5 (M e n d e l s o h n, 1957).

This vein fills a fracture that is nearly perpendicular to the strike of the bedding. The fracture strikes N10E, dips 65°W and follows the length of a mine crosscut for about 20 metres. The fracture in which the vein occurs also offsets older, smaller bedding-plane veins. In one of the offset bedding-planes, quartz from the tourmaline-bearing vein progresses up the bedding-plane for about 40 cm; at this point, a change from clear to smoky quartz occurs. The tourmaline-quartz vein is also noticeably sheared and offset at several places. It is 20 cm at its widest point, gradually tapering downwards to a narrow crack within the more argillaceous part of the RL-7.

Tourmaline is conspicuous in the vein as well as in the wallrock adjacent to the quartz vein, where it forms darkened borders along the full length. Euhedral apatite was also observed as a minor vein mineral. In most places, the tourmaline border is not more than a few inches wide, but near the end of the vein, the borders become wider, extending as irregular shaped dark haloes several feet from the vein into the wallrock. Biotite forms up to 27 percent of the argillitic quartzite, but near the vein, within the tourmalinized borders, it is present in only trace amounts. Plagioclase, like biotite, is also antipathetic to the occurrence of tourmaline. Greisening was observed near the other similar veins (M e n d e l s o h n, 1957) but is not a pronounced feature of this vein.

Regardless of the initial source, there can be little doubt that boron was introduced to the wallrock. The occurrence of the broadest tourmaline haloes around the constricted end of the vein, indicates that this was the "end zone" of the process – the point where strong pressure gradients caused expansion of the gasses into regions of lower pressure – and that the source lies in the direction of the RL-6 – RL-7 contact. The chalcocite constituents were probably derived from a similar source and probably not from

the barren RL-7 host rock. Analyses for copper in this area show a sharp drop in copper content from the chalcopyrite-rich tremolite schist of the RL-6 (1 to 4% Cu) to the quartzites of the RL-7 (.02 to .55% Cu).

The open fracture in which this vein formed was probably filled late in the tectonic history of these rocks. It is possible that hot gaseous waters moved in response to metamorphic pressures along planes of structural weakness, which are, in this case, the bedding-plane contact between the RL-6 and RL-7, and the tension fracture in which the vein occurs. Alternatively, the fluids may have been derived from an external source not related to the metamorphism, but from which the fluids had access along bedding-planes to the point of structural weakness. With exception of the amphibolites, however, no "young" intrusives are known in this area.

Although the quartz may have been derived locally, the concentrations of tourmaline, carbonate, and chalcocite in and near the vein were not derived from the wallrock at the vein site. This vein, then, is not a diffusion (secretion) vein and the pneumatolytic assemblages indicate that moving, active, hot, gaseous waters were responsible for its formation.

Chambishi Breccia Zone

The "breccia" or "shear" zone (J o l l y, 1971b), which crosses the copper mineralization in the ore-argillite in the Chambishi open pit, is a barren zone of irregular width and character and the site of intense albitization, high temperature propylitic alteration, brecciation and veining that occurred during and at the end of the Chambishi tectonic basin development. Shearing and alteration in this zone, which trends N65E and dips 48° to 79°S and extends diagonally across the entire pit (1970), was also observed in the Footwall Quartzite. Although some fracturing and veining continued into overlying beds, the alteration appears to be most intense in the lower part of the ore-argillite and underlying quartzite. Differential subsidence over a structural feature in the underlying rocks during and at the end of tectonic basin development formed new (N65E) fractures along this zone, and also caused certain older (E-W trending S_1, S_2, and S_3) fractures to remain open to the altering fluids. Some of the alteration and veining predates the last minor fracturing, but the most intensive stage of alteration post-dates the major folding event. This is shown by relic folds preserved in altered rock sections, and by the utilization of regional foliation by the altering fluids. The variable dip of the zone owes its expression not only to the utilization of several sets of fractures, but is partly caused by a difference in competancy between the argillite and quartzite (steeper fractures).

Most of the vein components within the zone could have been derived from the immediate wall-rock, with the exception of sodium. Sodium was abundantly added to parts of the zone. Copper, sulphur, iron, and potassium minerals were replaced by soda and carbonate minerals in the altered ore-argillite. The replaced mineral constituents probably migrated to more favourable vein sites as albitization and carbonatization of the rock proceeded. Turbulence caused by boiling during release of CO_2 as fluids encountered pockets of lower pressure caused localized brecciation. Vein minerals include albite, microcline, phlogopite, quartz, carbonate, and trace amounts of epidote and barite. Anhydrite cavities (?), molybdenite, and chlorite were observed at one place in the upper part of the system, and in another, small amounts of sulphides were also observed in the carbonate veins above the ore horizon. The Na/K ratio in coexistent feldspars (B a r t h, 1951; O r v i l l e, 1963) and the association of other vein minerals indicate that the temperature of vein formation in the zone was between 350 and 450°C. The soda and carbon dioxide-rich fluids may have been derived from the underlying footwall quartzites as heated pore and connate waters were driven upwards to the margins of the tectonic basin. The nearby intrusions (now amphibolites) may have contributed heat to the altering fluids, and possibly even some of the soda. The mineral association and type of alteration (propylitic) resemble that described for recent hydrothermal zones, such as the Salton Sea, U.S.A., and Wairakei, New Zealand (E l l i s, 1969).

ELEMENT DISTRIBUTION IN THE ARGILLITE AT CHAMBISHI

Samples were collected in stratigraphic succession, from the base to the top of the ore-bearing argillite at Chambishi, and along a single layer within the

argillite, extending across several mineral zones into barren rock. Ninety chemical analyses were made on chip samples, each representing from 2 to 10 feet of rock section. Over 200 petrographic thin sections were also made, from which 50 modal analyses were carried out. In addition, 90 mineral norms were calculated from the chemical analyses by computer. The computer program used in calculating the minerals from chemical analyses is based on a method originated for Copperbelt rocks (J o l l y, 1970). These data were collected for determination of recognizable characteristics that might relate to the origin of the ore.

Chemical analyses of barren and ore-bearing samples along the same bed show (J o l l y, in preparation) consistent and significant relationships between certain elements and norm minerals. These relationships appear consistently in a variety of data analysis techniques that were applied, each of which illustrates a different facet of the interrelationship. The results indicate that it is presumptious to draw conclusions based on one simple data analysis technique. It is a multi-faceted problem and must be approached as such.

The philosophy of V i n e and T o u r t e l o t (1970) has proved useful in simplifying the analysis of the argillite components. If these deposists are syngenetic, a relationship should exist between metal content, the environment of deposition, the paleotectonic setting, and the evolutionary stage of development. A sediment may be visualized as consisting of 3 distinct parts: the detritus, the chemical and the organic fractions. The diagenetic environment may be visualized as consisting of essentially two phases: the solid phase (detritus) and the liquid phase (pore solutions filling spaces between grains). If a relationship could be established between the sulphides and one or more of these sediment fractions, this would provide a significant clue to ore genesis.

Factor analysis applied to chemical data of the argillite shows that an inverse relationship between the variables of the detrital fraction (Si + A1 + K) and the variables of the chemical fraction (Ca+ CO_2 + Mg + Mn + Na) is the dominant factor explaining the variation in the suite of rocks tested. Copper has a strong correlation with the occurrence of Fe, Mg, Mn, and P, and is also related to a change in chemical phase of the sediment. P is positively correlated with Cu in the ore-bearing rocks, but is highest in the barren samples where it is positively correlated to Fe and Mg. Sulphur, on the other hand, was found to vary inversely (high negative correlation) with an $Al+H^+$ (mica) factor. The inverse relationship of sulphur to alumina is a function that might be expected to result from a simple interplay of detrital with organic or chemical sedimentation. Preliminary observations suggest that, in the argillite, sulphur may be of an entirely different origin to copper.

It is also apparent that the sulphides were not merely "dumped" as detritus into an otherwise uniform sediment. This can be shown by a mineral comparison test, based on volume for volume dis-

TABLE 1

Summary of percent lost or gained for each mineral (norm), as it varies from the amount found in the average barren rock, in volume percent. All samples were taken from the same stratigraphic unit within the argillite exposed on the east and south pit walls at Chambishi. The volume of sulphide is subtracted from the orebearing samples and the remaining constituents are recalculated to 100 percent. The affected rock without sulphide is then compared to the barren.

Sample type	Apatite	Carbonate	Plagioclase	Biotite	Muscovite	Microcline	Quartz
Av. (17) barren	1.50	4.20	2.00	20.30	21.70	31.40	18.40
Chalco-pyrite (4)	–79%	– 9%	+ 186%	+ 1.8%	– 32%	+ 25%	– 20%
Bornite (12)	– 31%	+ 37%	+ 54%	– 17%	– 24%	+ 30%	– 18%
Chalco-cite (16)	– 45%	– .2%	+ 94%	– 9%	– 5%	+ 17%	– 20%
Average ore (39)	– 45%	+ 16%	+ 110%	– 11%	– 14%	+ 19%	– 17%

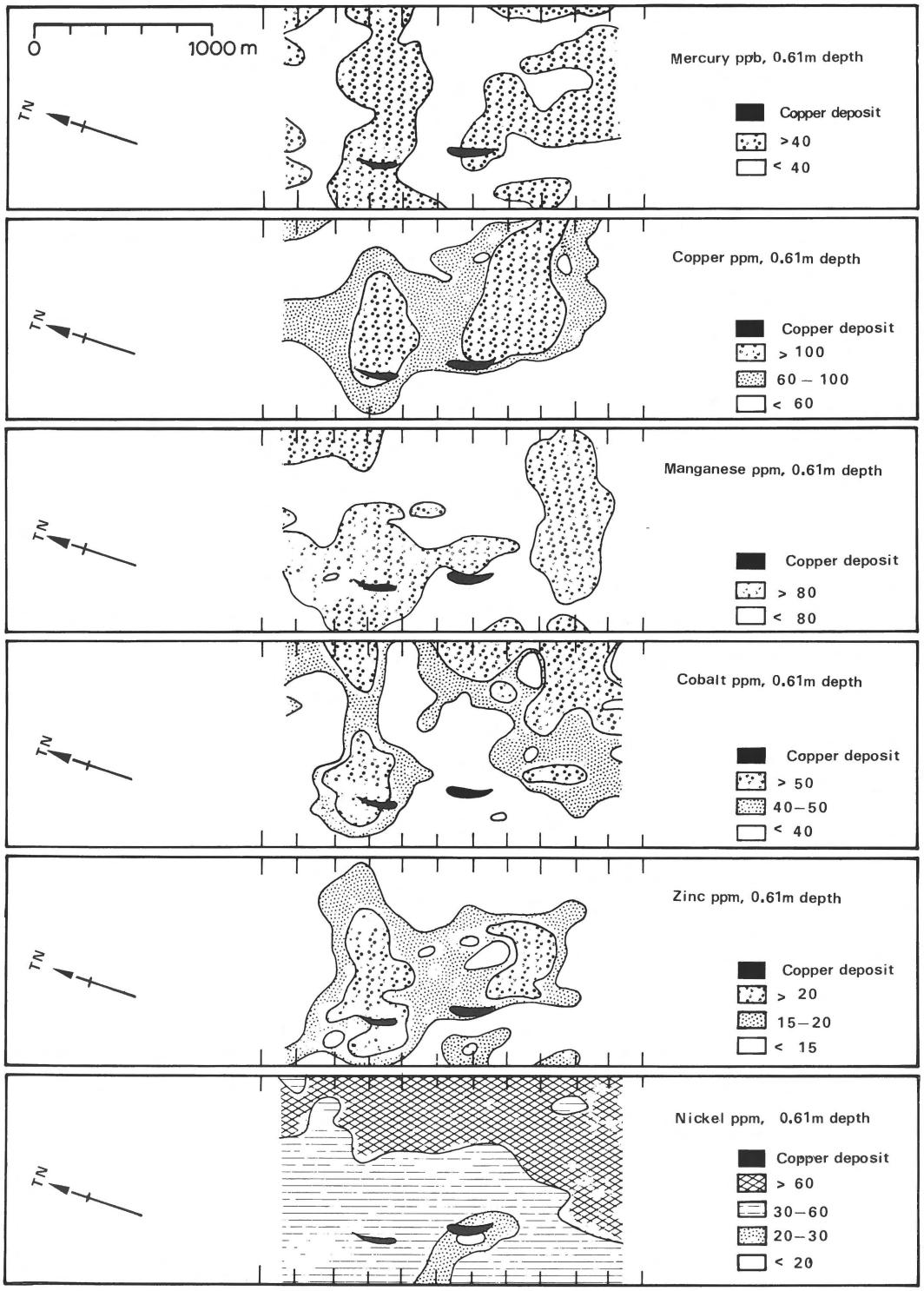

Fig. 1
Geochemical maps showing distribution of Hg, Cu, Mn, Co, Zn, and Ni relative to sub-outcrop copper deposits. Drainage is towards the east.

placement. It is not possible to show that metasomatism or ion exchange did or did not occur between copper and selected constituents with this or similar tests; it can only show that volume for volume mineral displacement did not occur and that certain mineral trends are present in the data despite the minor manipulation. A summary of the percent change for each mineral component for the average (17 samples) barren rock is given in table 1.

Further comparison showed consistent variations between mineral zones, as well as between barren and ore-bearing rocks with regard to relative amounts of biotite, muscovite, and feldspar present. The colour of biotite in thin section is also different in barren (green) and ore-bearing rocks (brown). This same observation has been made elsewhere in the Chambishi basin (A. A n n e l s, pers. comm., 1970). This is a reflection of the change in oxidation state in the biotite iron (a high Fe^3 +/Fe^2 + is green; H a y a m a, 1959) as well as a change in the ratio of Mg to Fe in the biotites. The amount of biotite also varies between ore and barren, and between mineral zones. This is brought out by both a study of petrographic modes and a comparison of normal minerals. The chalcopyrite and barren zones contain the most biotite, but the barren and chalcocite zones contain the most total mica (biotite + muscovite). The increase in muscovite in the chalcocite zone may be caused by secondary (weathering) processes. The muscovite/microcline ratio is lowest in samples of the bornite zone.

MERCURY IN ZAMBIAN SOILS

Field testing of the mercury prospecting technique (J o l l y, 1971c) was carried out in detail over a large area that included two known copper deposits. Scattered soil and rock samples from other areas of Zambia were also analysed for mercury. The mercury analyses were done by Barringer of Canada. The existence of mercury anomalies over Copperbelt mineral occurrences was substantiated. Other factors, in the area under detailed investigation, such as soil colour and the abundance of Co, Cu, Mn, Ni, and Zn were also determined by atomic absorption on the samples collected; not only to facilitate the interpretation of mercury occurrence, but also for the information that they might contribute to the general understanding of element distribution in soils associated with the ore deposits. To aid in the interpretation of multi-element data, factor analysis techniques were applied.

It was concluded that a study of combined analyses of copper, cobalt, zinc, manganese, nickel, and mercury may be used effectively to aid in distinguishing ore-associated anomalies from those caused by particular rock types or abnormal drainage accumulations of elements. Certain elements and soil colours can help to reveal the underlying rock type, and structure. For instance, high nickel content and yellowish brown (locally some reddish-brown) soil colours were found to outline the occurrence of amphibolite in the area studied. Fig. 1 shows geochemical maps of mercury, cobalt, copper, manganese, nickel, and zinc from a part of the area studied. The location of the two copper sub-outcrops are also shown on the maps for comparison. The point of highest element content in soils is not necessarily above the point of its origin. Many factors seem to concentrate an element at a particular point, notably drainage, rock structure and porosity, chemical behaviour of certain elements, Eh, pH, rainfall, bedrock composition, and the exposure of the orebody to surface. The size of the mineral occurrence cannot be predicted by the size and intensity of the anomaly produced.

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