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**Gas and vegetation geochemistry in
the search for buried ore deposits:
Final report to the Overseas
Development Administration
November 1991**

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INTRODUCTION

Ore deposits which are hidden beneath a thick blanket of overburden are extremely difficult to detect using the standard exploration techniques of soil and stream sediment geochemistry. Soil gas and vegetation geochemistry offer possible solutions to this problem, particularly in arid and semi-arid climatic regions where gas release is not hampered by saturated soil and plant roots penetrate deeply to reach the water-table. Microbial techniques have also been used with some success for exploration in arid areas.

This report provides an essentially non-technical summary of a study of the efficiency of soil, soil gas, vegetation and microbial methods in detecting a buried ore deposit in northwestern Botswana.

STUDY AREA

In the mid-1970's a low-grade stratabound copper deposit near Lake Ngami in northwestern Botswana was investigated by Essex Minerals, a subsidiary company of U.S. Steel. A large number of diamond drill holes were put down in the area where the ore body disappeared under a varying thickness of overburden, thus providing detailed records of the depth to mineralisation beneath the cover. Sparse thorn scrub vegetation is typical of this part of the Kalahari Desert which lacks permanent surface water and has a semi-arid climate. Apart from cattle rearing there is little agricultural activity and there are no settlements within the study region.

The area lies within an ENE-WSW trending sequence of clastic sediments and acid volcanic rocks which have been affected by low-grade metamorphism and tightly folded. A fine-grained calcareous horizon, several metres thick and carrying copper mineralisation with associated silver, is the main ore body. The rocks above the ore horizon (hanging wall) are similar in composition, with disseminated secondary copper minerals, and the footwall rock, below the ore, is a barren sandstone. The mineralised horizon plunges gently to the northeast beneath an increasing thickness of overburden which in the study area comprises varying thicknesses of unconsolidated sands, locally with fossil dunes. These sands are presumed to be windblown in origin and form part of the Kalahari group.

THE SAMPLING PROGRAMME

A cut line, cleared for the original drilling and sampling programme, runs parallel and very close to the surface or sub-surface outcrop of the ore horizon and provided an easy means of access to the area of interest. Using information from company reports and maps it was possible to locate, precisely or approximately, the sites of six diamond drill holes. Sampling was carried

out along traverses at right-angles to the cut line to include these drill sites. Six traverses, spaced over 13.5 km of strike length of the mineralised horizon and varying in length from 30 to 250 m, were sampled. On the basis of the size of geochemical soil anomaly found during the initial company investigation, sample spacings along the traverses were set at 20 or 25 m except in the case of the shortest traverse, adjacent to near surface mineralisation, where a 10 m interval was used.

Two separate sampling exercises were carried out, chiefly to examine the possible seasonal effects of variable soil moisture on the amounts of evolved soil gas. The first, in May-June, 1988, was conducted at the beginning of the winter dry period after a wetter than normal rainy season. The second, in October-November, 1989, took place at the end of the dry season just before the onset of the rains.

The May-June, 1988 Sampling

At each sample site a hole, 30-40 cm deep, was dug and two Kraft paper bags and one small securitainer of soil collected, the former for normal geochemical studies and the latter for degassing and soil gas analysis.

A hollow spike was driven into the ground from the bottom of each hole to give a total penetration at the tip of 60 cm to 1 m. On the spot analyses of the radon, thoron and carbon dioxide contents of the soil gases pumped from the spike were then carried out. On the shortest traverse (No. 6, 30 m) this was the only form of sampling and analysis performed.

A survey of the vegetation on the five longest traverses showed that no single species of tree or shrub was present near every sample site. The most commonly present family was that of the acacias, with small bushes of straight-thorned varieties being found close to almost every location. Mature trees were abundant only on traverse 1. Composite samples of twigs and leaves from several straight-thorned acacia trees or shrubs around the sample site were therefore collected and enough material to fill a 25 x 35 cm, 125 micron thick, polythene bag taken.

The soil was slightly damp at the time of sampling and both the vegetation and the Kraft bags of soil were dried in the sun after collection. The vegetation samples were separated into leaves and twigs and repacked into Kraft paper bags after drying.

The October-November, 1989 Sampling

The 1989 sampling was carried out using sites as close to the 1988 locations as compass and tape measurement would allow, although the original holes could not be recognised. In response to the results from the 1988 programme, the sampling methodology was changed in detail.

Soil samples were collected in the same manner as in 1988 but some traverse lines were extended and additional samples were taken for microbial analysis to see if this innovative methodology could be used in the Botswanan environment.

Gas samples were also extracted from the soils in the same manner as in 1988, but although radon and thoron were measured in the same way as in the earlier exercise other gases were sampled differently. Arsine, carbon dioxide, carbon disulphide, chlorine, dimethyl sulphide and mercaptan (CH_3SH) were all measured *in situ* using Draeger tubes. Mercury was collected on silver coils and molecular sieves (5A and 13X) were employed to collect sulphur species.

Few leaves were present on the acacia bushes and trees and sampling was confined to twigs from mature trees on traverse 1 to see if a more uniform sample type would be more effective than the composite samples collected in 1988.

LABORATORY ANALYSIS

All soil samples were air-dried, sieved and the <125 micron fraction retained for analysis. Soil samples from the 1988 collections were analysed using X-ray fluorescence (XRF) methods for As, Br, Cl, F, I, S, Sb, Se, Th, and U, and by atomic absorption/inductively coupled plasma emission spectroscopy (AAS/ICPES) for Ag, Bi, Ca, Cd, Co, Cu, Fe, Mn, Mo, Ni, Pb, and Zn. Because of the low levels found for many of these elements the soil samples collected in 1989 were analysed for a much reduced element suite, consisting of Ca, Cu, Fe, Mn, Pb and Zn, using AAS/ICPES.

Vegetation samples were dry-ashed before analysis. The weight of ashed material from the 1988 sampling was too small to permit analysis by XRF and was therefore analysed only by AAS/ICPES for the same element suite as determined on the soils. The 1989 samples yielded a greater weight of ash and were analysed by XRF for Ag, As, Bi, Ca, Cu, Fe, Mn, Mo, Ni, Pb, S, Sb, Sr, Th, U and Zn; a range of elements which included all of those showing significant variation in the 1988 data plus some additional ones.

Soil samples from the 1988 collection and molecular sieves from the 1989 programme were degassed by heating and the evolved gases analysed for sulphur

species using a gas chromatograph equipped with a flame photometric detector configured for the specific detection of sulphur compounds. Mercury was determined by flameless AAS after the silver coils had been degassed by heating.

SUMMARY OF RESULTS

Using the data from diamond drilling and surface geology/geochemistry, gathered by Essex Minerals in the course of detailed exploration work, cross sections predicting the depth and sub-outcrop position of the ore body were constructed for each of the 6 traverse lines sampled during this study. Depths to the ore body varied from 1-2 m through 12, 40 and 45 m to 80 m.

Soils

Only Cu showed any consistent relationship to the position of the mineralized horizon. A well defined anomaly of almost 330 ppm Cu marked the position of the ore body where the cover was only 1-2 m thick. The maximum Cu concentration in the traverses where the cover ranged from 12-80 m was 60 ppm with a minimum value of 7 ppm. There were, however, broad highs in the Cu profiles over the position of the mineralization except where the cover was only 12 m thick. In this latter case the highest Cu values were displaced approximately 25 m into the hanging wall.

Vegetation

The vegetation samples collected in 1988 were separated into leaves and twigs and analysed separately.

Where the overburden was thinnest a clear Cu peak, coincident in position with the peak in soil Cu values, could be seen in the data for leaves, but in twigs the highest Cu concentration occurred over the unmineralized sandstones in the footwall to the ore body. With the exception of Zn in twigs, none of the other elements showed a direct relationship to the location of the mineralization.

In the traverses where the ore horizon was more deeply buried patterns of variation were generally inconsistent and direct relationships to the position of the mineralization difficult to discern. Element concentrations in twigs and leaves often, but not always, varied in a similar manner but the patterns often bore no resemblance to patterns of variation in the soils. Copper maintained the closest relationship, in both twigs and leaves, to the position of the mineralized unit.

The 1989 sampling, in which only the traverse with the thinnest overburden was studied and an attempt was made to collect twigs of consistent thickness, in

general confirmed the previous findings. Copper showed a clear peak over the hanging wall immediately above the ore bearing horizon and fell sharply over the footwall region. Broad hanging wall haloes of high values were also found in As, Ni, S and Zn. The highest levels of As, Ni, S and Zn, however, occurred further into the hanging wall near the start of the traverse where they were accompanied by high Mo and Pb concentrations. The significance of this is not clear but the high trace element levels may be related to a minor accumulation of the scattered sulphide mineralization known to occur above the ore horizon.

Gases

In the 1988 sampling the *in situ* measurement of radon (Rn), thoron (Tn) and CO₂ showed that CO₂ and, to a lesser extent, Tn were effective in delineating the position of the ore horizon through depths of 1 m and 12 m of overburden and also gave some indication of its position when the thickness was 40 m (Ball *et al.*, 1990). In the 1989 sampling, at the end of the dry season, CO₂ values were uniformly low and no patterns which could be related to the position of the buried mineralization could be discerned. Emissions of both Rn and Tn had increased, at least twofold and in most cases considerably more, but there were no obvious relationships to the position of the ore horizon. The differences in gas emissions between the two sampling exercises are most probably related to the degree of soil moisture. Moist soils promote sulphide decomposition reactions which provide substantial inputs of CO₂ to the soil atmosphere whilst at the same time inhibiting the flow of Rn and Tn. Conversely, dry conditions favour gas flow but inhibit decomposition.

Degassing of soil samples collected in 1988 gave no positive results for any of the sulphur species measured. Better results were obtained from the molecular sieve materials used in the 1989 sampling. Carbonyl sulphide (COS) and carbon disulphide (CS₂) were the only gases positively identified but showed good correlation with the location of the orebody where the cover was thin (1-2 m) and up to 12 m thick. Above this thickness of overburden the gases could not be detected or showed no direct relationship to the location of the sub-surface mineralization. The 13X molecular sieve material gave more consistent results than the 5A type, the latter sometimes showing peaks unrelated to mineralization.

Mercury was identified in only two traverses. In traverse 1, with an overburden thickness of 1-2 m, mercury showed a peak over the sub-outcropping position of the ore horizon, but gave even higher values at the western end of the traverse where only minor hanging wall mineralization is thought to be present. In traverse 2, where the overburden is approximately 45 m thick, the highest mercury value occurred above the ore body, but the general pattern was erratic and values rose again at the western, unmineralized end of the traverse.

Microbial methods

In arid zones of the western U.S.A. measurement of *Bacillus cereus* population concentrations in soils has proved useful in exploration for metalliferous mineralization (Watterson, 1985). Splits of soil samples from the study area were therefore sent for bacteriological analysis to Cereus Exploration Technologies Inc. of Nevada. With the exception of traverse 2 (overburden thickness 45 m), where the pattern of *B. cereus* distribution was rather erratic, the results show that microbial methods are effective in indicating the position of buried mineralization. High population counts for *B. cereus* occurred over the hanging wall zone with a rapid decrease in the footwall. The thin ore horizon was not well delineated but a broad high over its position in traverse 4, where the cover is 80 m thick, indicates the potential of the method.

CONCLUSIONS

Of the four exploration techniques tested, soil geochemistry proved the most effective in consistently outlining the location of the buried ore body and in being easiest to collect and interpret.

Vegetation geochemistry gave some useful data but the results were more difficult to interpret than those from conventional soil geochemistry and produced occasional high values which could not be related to known mineralization. These could be misleading in an exploration programme. Moreover, the vegetation samples were more difficult to collect and process than soil samples and were also influenced by seasonal factors.

Gas geochemistry, too, was influenced by seasonal factors, notably the moisture content of the soils, and was more difficult to interpret than the soil data. The chief advantage of using gas geochemistry lies in the ability to make *in situ* measurements and given the right conditions the method can provide useful data which will allow immediate decisions on the progress of an exploration project to be made.

Microbial methods depend on the metal content of the soils and so have no strong advantage over soil geochemistry. They are however relatively simple to carry out, requiring only simple apparatus and conditions. In this respect microbial methods may be very suitable for exploration work in developing countries and merit further evaluation.

DISSEMINATION OF RESULTS

A paper describing the use of gas geochemistry in mineral exploration in Africa has been published (Ball et al., 1990) and a further paper and

technical report comparing gas, vegetation, soil and bacterial media in exploration are in preparation. The use of gas geochemistry has been demonstrated to mining companies and small scale miners from several African countries.

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