MULTIPLE HYDROMORPHIC DISPERSION OF GOLD AND ORE RELATED ELEMENTS IN TRANSPORTED OVERBURDEN AT THE LANCEFIELD GOLD DEPOSIT, YILGARN CRATON

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INTRODUCTION

Future discoveries of Au and base metal resources in the deeply weathered terrains of Australia are likely to occur under transported overburden. About 60% of the greenstone sequence in the Yilgarn Craton is covered by transported overburden that ranges in age from Permian to Recent and in thickness from a few centimetres to many tens of metres. Post-depositional weathering and diagenesis of sediments during the last 60 million years have resulted in a variety of poorly- to well-crystalline secondary minerals. This is typified by the Lancefield Gold deposit, where the oxidised orebody is overlain by sediments comprising 10-20 m of mottled Permian fluvio-glacial sediments, 3-8 m of mottled Tertiary palaeochannel clays and 1-2 m of hardpanised colluvium. In such areas, bulk geochemistry of surface materials is not applicable, but partial and selective extraction techniques are increasingly being considered for delineating anomalies. However, these techniques have had mixed success in Australia partly because the element siting is generally not known. In this study, the location of trace elements in the regolith was directly determined using *in situ* optical and electron-optical techniques. A combination of conventional, bulk (XRF, INAA) and micro-analytical techniques covering a wide range of observation scales (X-Ray Diffraction, Scanning Electron Microscopy) have been used to characterise the mineralogy and trace element distribution. *In situ* geochemical analyses were performed on polished thin-sections by electron microprobe and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) to detect dispersion of Au, Cu, As, Zn and Pb in secondary minerals formed in transported overburden. Le Gleuher (2003) and references therein, provide a full description of the LA-ICP-MS technique and the development of its application to regolith samples. Targeting individual mineral phases for chemical analyses enhances anomalies and reveals some which remain undetected in the bulk samples and by partial extraction techniques.

GEOLOGY AND MINERALISATION

The Lancefield Gold Deposit is located 8 km north of Laverton. The bedrock assemblage consists of komatiites, Mg-basalts, massive to pillowed mafic volcanics, carbonaceous shale and chert. The intrusion of the granitoids has deformed the ultramafic stratigraphy in the Lancefield area. The orebody consists of a mineralized zone some 140 m in strike length and 7 to 12 m in width, enveloping a 5 m wide chert unit. The chert unit has a sulphide (pyrrhotite-pyrite-sphalerite-chalcopyrite-arsenopyrite) content of around 15% near the ore zone. Near the chert, the regolith developed on ultramafic rocks also contains significant supergene gold mineralization (Hronsky *et al.* 1990).

WEATHERING OF BEDROCKS

The deposit is situated in a sheet flow plain. The *in situ* regolith profile on the Archaean bedrock is overlain by up to 20 m of sediments. The depth of weathering exceeds 50 m on basalt and is represented by well-developed kaolinitic and ferruginous saprolite. In contrast, talc-chlorite ultramafics are weathered to some 10 m and well-developed saprolite is lacking. Saprock and lower saprolite on ultramafic bedrock largely consists of ferro-magnesian chlorite and talc, with varying amounts of kaolinite, chlorite-vermiculite, quartz, goethite, hematite, ilmenite, chromite and magnetite. However, fractured ultramafics are completely weathered to kaolinite, goethite, hematite and quartz.

POST DEPOSITIONAL WEATHERING OF SEDIMENTS

There are three principal types of sediments:

1. The basal Permian fluvioglacial deposits range in thickness from 10 to 20 m and are partly covered by Tertiary palaeochannel clays and Quaternary hardpanised colluvium and soil. There is a strong tendency for the Permian channels to follow ultramafic lithologies. A thick, deeply weathered Permian fluvial sequence is exposed abutting and unconformably overlying Archaean ultramafic rocks on the SW and W walls of the pit. The wall of the channel is steep to overhanging, in places. The base of the Permian consists of a matrix supported, coarse, boulder conglomerate. The boulders are rounded to angular and include metavolcanic and granitic lithologies with lesser BIF, set in a gritty matrix. The base of the channel sediments is weathered to kaolinite and smectite with abundant detrital quartz. Higher in the profile, the sediments are horizontally mottled; the mottles

accentuating bedding in the Permian sediments which is less obvious in the surrounding matrix. The megamottles (> 200 mm) consist of goethite, hematite, kaolinite, quartz, muscovite and ilmenite;

2. A 3 to 8 m thick Tertiary palaeochannel clay unit overlies the mottled Permian sediments. Kaolinitic clays were deposited in a shallow, sluggish wetland, swampy environment, probably during the Oligocene-Early Miocene. Post-depositional weathering, in particular hematitic megamottling (> 200 mm) has obliterated much of the primary sedimentary fabric. Many of the megamottles have kaolinite and/or smectite-rich zones around their margins. Smectite appears to be authigenic as is suggested by its wavy, irregular morphology. In the upper part of the sediments, hematite has altered to goethite as cutans. Biota appear to have played an important role in hematitisation of these Tertiary sediments compared to the underlying Permian sediments. The elongate shape of the mottles, their dominantly vertical orientation, their decrease in abundance with depth and the fairly uniform depth to which they occur suggests that mottles formed by the removal and reprecipitation of iron around tree roots. The removal of iron around tree roots was probably affected by the microbial decay of organic matter, which generate reducing conditions under which Fe^3 oxides were dissolved and redistributed;
3. A 0 to 2 m thick locally-derived layer of soil, colluvium and alluvium overlies the Tertiary palaeochannel clays. The lower part of the colluvium and alluvium is largely unchanged whereas the upper part has been modified by pedogenesis. The process of hardpanisation formed coatings of poorly crystalline kaolinite, goethite and hematite, Mn oxides and opaline silica. Detrital minerals are hematite clasts, quartz and lithic fragments. Soil is homogeneous and is least affected by the pedogenic processes.

Titanium/zirconium ratios clearly discriminate transported from *in situ* regolith. The ratios vary from 1.86-4.82 in transported overburden to 0.01 in saprock and saprolite.

MINERAL HOSTS FOR AU AND ORE RELATED ELEMENTS

The bulk samples of saprock and saprolite contain high concentrations of As (14-908 ppm), Cu (11-472 ppm) and Zn (44-452 ppm). Gold ranges in abundance from 11-196 ppb. Generally, the concentrations of As, Cu and Zn are higher in ferruginous saprolite than in the clayey saprock and saprolite suggesting migration of these elements in the Fe-rich areas. However, Au does not appear to follow the same trend. Mottled Permian and Tertiary sediments were separated into Fe-rich and clay-rich components. The Fe-rich part consists of hematite, goethite, quartz and kaolinite whereas the clay-rich material contains kaolinite and quartz with small amounts of smectite and muscovite. Gold occurs in both materials, but is slightly more elevated in the clay. Arsenic (66-899 ppm), Cu (21-128 ppm) and Zn (22-124 ppm) are enriched in the Fe-rich part of the Permian sediments but the clays are very low in these elements. The abundances of As (67-209 ppm), Cu (25-71 ppm) and Zn (18-29 ppm) are relatively low in Fe-rich parts of Tertiary palaeochannel clays compared to the underlying mottled Permian sediments. Bulk samples of red clays above the mottled Tertiary sediments contain low levels of Cu (46-58 ppm), As (14-57 ppm) and Zn (10-25 ppm). Gold ranges in abundance from 4-6 ppb. Hardpanised colluvium and soil are relatively low in As (24-51 ppm), Cu (40-47 ppm) and Zn (24-35 ppm).

Targeting individual mineral phases by *in situ* microanalyses has enhanced anomalies and reveals some that remain undetected in the bulk samples. The trace elements used as pathfinders have multiple hosts. Sulphides are weathered to a mixture of goethite and hematite. Chlorite is partially replaced by chlorite-vermiculite. A small amount of kaolinite and goethite observed in saprock results from the alteration of vermiculite layers. The trace elements directly related to mineralisation (As, Cu, Zn, Pb) released by the dissolution of sulphides are incorporated into goethite, hematite, chlorite-vermiculite interstratified mineral. Goethite after sulphides contains abundant As (1,700-15,000 ppm), Cu (3,000-10,000 ppm), Zn (50-340 ppm) and Pb (20-230 ppm). Copper is abundant in the chlorite-vermiculite with concentrations of up to 700 ppm. Zinc and Pb are present in moderate amounts. Goethite formed from the weathering of vermiculite layers contains abundant As (up to 900 ppm), Cu (up to 370 ppm) and Zn (up to 140 ppm). Interstratified minerals were not detected in the saprolite indicating that their vermiculite members have been altered to kaolinite and goethite. This kaolinite and goethite assemblage also contains high concentrations of As (up to 3,600 ppm), Cu (1,500 ppm) and Zn (up to 700 ppm). Ilmenite/pseudorutile has high concentrations of Mn (up to 2.2% MnO) and Zn (up to 11,000 ppm), and low concentrations of As (up to 400 ppm) and Cu (up to 180 ppm).

In the mottled Permian sediments, As (up to 3,000 ppm), Cu (up to 630 ppm) and Pb (up to 145 ppm) are strongly concentrated in Fe oxides. Hematite has preference for As and Pb, but Cu is concentrated in goethite. Kaolinite is extremely low in trace elements.

Hematite and goethite in Tertiary clays are low in As (up to 370 ppm), Cu (up to 160 ppm), Pb (up to 180 ppm) and Zn (up to 70 ppm) compared to the underlying Permian sediments. In the overlying hardpanised colluvium, all ore-related elements are present but at relatively low concentrations. Poorly crystalline goethite has As (up to 150 ppm), Cu (up to 100 ppm), Pb (up to 145 ppm) and Zn (up to 60 ppm). These metals are absent in opaline Si.

Selective extractions are employed in the analysis of soils and sediments to provide information on the association of metals with particular phases. Three sequential selective extractions (0.1M hydroxylamine, 0.25M hydroxylamine and sodium dithionite) were employed to dissolve Mn oxide minerals, "amorphous" Fe oxides and crystalline Fe oxides, respectively, from Permian, Tertiary and Quaternary sediments. The data clearly show that all As and Zn, and 50% of the Cu are dissolved in crystalline Fe oxides in Permian and Tertiary sediments. However, in some cases, the amounts of As and Zn dissolved have exceeded the total amounts present in the sample. The remaining undissolved Cu in Permian sediments largely occurs as copper oxide or copper carbonate. The reverse is true in Quaternary sediments where only half of the As is dissolved in crystalline Fe oxides and Cu and Zn are slightly dissolved (< 10%) in extractions. This may suggest that much of Cu and Zn is present in lithic and clastic material that are not dissolved by selective extractions.

CONCLUSIONS

The nature and age of the regolith impose a strong control on the dispersion of elements in transported overburden. At Lancefield there is evidence from palaeomagnetic dating of multiple oxidising (weathering) events; for example, pre-Permian, Late Cretaceous (60 Ma), Miocene (10 Ma) and post hardpan events (Dr Brad Pillans, CRC LEME/ANU, written communication, 2004). Three stages of dispersion of As, Cu, Pb, Zn and Au in sediments can be related to these weathering events. Hydromorphic dispersion of Cu, As, Pb and Au in Fe oxides by groundwater processes have been important in Permian and Tertiary sediments during Late Cretaceous and Miocene when water tables were high. The climate was wet, moderately warm, and the vegetation was dominated by conifer forests and woodlands. During this period, metals from the underlying mineralisation have been incorporated into crystalline secondary minerals and anomalies over mineralization can be recognized by a variety of methods outlined above. The role of vegetation can not be ignored in Tertiary sediments for two reasons. Firstly, biota have played an important role in formation of hematite. Secondly, much reduced abundance of As in goethite in Tertiary sediments compared to the underlying Permian sediments may partly be due to its rejection by plants.

The dispersion of Cu, As and Pb is subtle in the upper hardpanised colluvium but can be detected by careful *in situ* chemistry and mineralogy of poorly crystalline goethite and hematite. Since the Quaternary sediments were deposited, concealing mineralisation, metals from the mineralisation have only been incorporated into the most labile of secondary minerals such as poorly crystalline goethite and hematite. At Lancefield, groundwater is more than 25 m below surface, and additional mechanisms are necessary to transfer metals from the water table upwards. Dispersion in the hardpan is probably related to bioturbation and vegetation. Roots tapping into either the mineralised Tertiary sediments or the anomalous groundwater may have picked up trace elements which are then recycled into the soil. Copper, Pb, Zn and As are subsequently leached from the soil and trapped into secondary Fe oxide coatings. Recent work on plant-metal relationships in the Yilgarn Craton suggests that plants do take up ore-related metals from mineralisation at depth.

Mechanical dispersion is the major dispersion process in soil horizon and there does not appear to be any hydromorphic dispersion. This is also indicated by minimal or no pedogenic activity.

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