REGOLITH MINERAL HOSTS FOR GOLD AND OTHER BASE METALS

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INTRODUCTION

During the weathering of mineral deposits, trace elements are displaced from their original host minerals, are dispersed, and can subsequently occur in newly formed secondary phases in the regolith. In sedimentary cover, post-depositional weathering and diagenesis lead to the formation of a variety of secondary minerals. Of most interest are clay minerals, poorly crystalline minerals and Fe and Mn oxides. Such mineral phases will interact geochemically with weathering fluids, and so have the potential to trap trace elements. This may create an anomaly in a specific mineral phase. The associations between trace elements and minerals can be partially derived using statistical analyses of bulk geochemical data supported with a relatively simple qualitative study of the mineralogy of the regolith. Selective sampling such as size fractions or selective extraction techniques improves the result but in these techniques it is generally not known which mineral is hosting the anomaly. In this study, the physical location of the trace elements in the regolith was directly determined using *in situ* techniques. A combination of conventional, bulk (XRF, INAAA) and micro-analytical techniques covering a wide range of observation scales (X-ray diffraction, Scanning Electron Microscopy) have been used to characterize 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-ICPMS). Le Gleuher (2003 a; b) and references therein, provide a full description of the LA-ICPMS technique and the development of its application to regolith samples.

This paper reports preliminary results on mineral-trace element associations in regolith developed over mineralized rocks at the Lancefield South and Enterprise (Mt Gibson) Gold Deposits.

LANCEFIELD SOUTH GOLD DEPOSIT

Geology and mineralization

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 ore body 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 content of around 15% near the ore zone and near to the chert the regolith developed on ultramafics also contains significant supergene gold mineralization (Hronsky et al., 1990).

Regolith

The deposit is situated in a sheet flow plain. The *in situ* weathered profile on the Archaean is overlain by up to 20 m of sediments. The depth of weathering exceeds 50 m on basalt. By contrast, talc-chlorite ultramafic is weathered to some 20 m. Palaeomagnetic dating of hematite indicates a long and complex weathering history with different weathering ages (Late Carboniferous to Late Miocene) in different parts of the profile (Dr Brad Pillans, CRC LEME/ANU, written communication, 2004).

There are three principal types of sediments.
(i) The basal Permian fluvioglacial deposits range in thickness from 10 to 20 m and are partly covered by Tertiary palaeochannel clays and hardpanised colluvial deposits. 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

wall 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, bouldry conglomerate, consisting of a variety of rounded and angular metavolcanic and granitic boulders and some BIF, set in a gritty matrix of similar material, interbedded with gritty cross-laminated sandstones. The base of the channel sediments are largely dominated by quartz, kaolinite and smectite and are derived from a mixed felsic-mafic provenance. Higher in the profile, the sediments are mottled; the mottles accentuate the gritty, polymictic fabric of the Permian sediments but this is less obvious in the surrounding matrix. The megamottles consist of goethite, hematite with kaolinite aggregates, and fine-grained ilmenite. Some are of hematitic kaolinite with ilmenite and muscovite. Others consist of kaolinite, quartz and minor muscovite.

(ii) A 3-8 m thick Tertiary palaeochannel clay overlies mottled Permian sediments. Post-depositional weathering, in particular, megamottling (>200 mm) has obliterated much of the primary sedimentary fabric. Many of the megamottles have a kaolinite and/or smectite-rich zone around their margins. Kaolinitic zones contain rare, milky, extremely fine grained quartz grains. In the upper part, hematite has altered to goethite. Biota appear to have played an important role in ferruginisation of sediments. Judging from the elongate form of the mottles, their dominantly vertical orientation, their decrease in abundance with depth, and the fairly uniform depth to which they occur, it can be inferred 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 generates reducing conditions under which Fe^3 oxides can be dissolved and redistributed.

(iii) A 0-2 metre thick layer of soil and hardpanised colluvium overlies the Tertiary palaeochannel clays. It consists of quartz, hematitic clasts, kaolinite and poorly crystalline goethite and opaline silica formed as coatings around the quartz grains.

Bulk geochemistry and *in situ* microanalysis
The bulk samples of saprolite contain high concentrations of As (90-600 ppm), Cu (40-620 ppm) and Zn (50-430 ppm). Gold ranges in abundance from 11-196 ppb. Mottled Permian and Tertiary sediments were separated into Fe-rich and clay-rich components. The Fe-rich part consists of goethite, hematite, quartz and kaolinite whereas the clay-rich material contains kaolinite, smectite and quartz. Gold occurs in both the materials, but is slightly more elevated in the clay. By contrast, As (43-899 ppm), Cu (21-115 ppm) and Zn (10-140 ppm) are enriched in the Fe-rich material but the clays are very low in these elements. The Fe-rich materials of Tertiary palaeochannel clays are enriched in Cu (25-160 ppm) and Zn (10-85 ppm) but contain low levels of As (14-67 ppm) compared to the underlying mottled Permian sediments. Bulk samples of hardpanised colluvium are relatively low in these elements.

The trace elements used as pathfinders have multiple hosts. The saprolite largely consists of talc and kaolinite with small amounts of smectite, interstratified minerals, goethite, ilmenite and chromite. Kaolinite is the main weathering product in the saprolite, but hosts only small quantities of trace elements as indicated by *in situ* microanalysis. In the saprolite, trace elements are concentrated in minerals of marginal abundance such as Fe oxides, smectite and interstratified. The trace elements directly related to mineralization (As, Cu, Zn) released by the dissolution of sulphides are incorporated in goethite and smectite. A significant amount of Cu and Zn occurs in smectite. Manganese oxides also contain Zn. Trace elements related to the host rock occur as residual in primary minerals (e.g., chromite) or mobilized and integrated into other secondary phases in their alteration products.

In the mottled Permian sediments, As is strongly concentrated in Fe oxides. Copper and Zn, both present in the primary mineralization in sulphides, are hosted by Fe oxides. Kaolinite is extremely low in trace elements. Mottled Tertiary clays are very low in As but Cu and Zn are present in significant amounts in Fe oxides. In the overlying hardpanised colluvium, Cu and Zn are concentrated in poorly crystalline goethite. Copper and Zn are absent in opaline Si.

ENTERPRISE DEPOSIT (Mt Gibson)

Geology and regolith
The Enterprise Pit Gold Deposit is about 300 km NNE of Perth and is located within the colluvial-alluvial plains. The Au-bearing bedrock comprises quartz veining in sheared basalt with mixed sulphides of pyrite, pyrrhotite, chalcopyrite, sphalerite and galena. This is overlain by some 20 m of bleached saprolite composed of white kaolinitic clays and occasional green smectitic clays together with quartz veins (up to 1 m thick) and occasional ferruginous dykes, presumably from the alteration of basic dykes. In situ regolith is overlain by transported overburden principally consisting of two Tertiary and Quaternary sedimentary units. Slabby to pisolitic ferricrete is formed in Tertiary sediments. These were originally sandy-clay to clay-rich sediments that have been modified to form pisoliths by the introduction of hematite and goethite. The pisoliths consist of hematite, kaolinite, quartz and goethite. The matrix and nodules of the ferricrete contain fine clay spherites thought to have been derived from granites. The uppermost sandy to sandy-clay unit is 3-4 m thick and has been subjected to calcification and silicification to produce calcrete and hardpans, the top 1-2 m is hardpanised. Within this unit sub-horizontal to horizontal laminations have developed commonly marked by thin coatings of precipitated Mn-oxides.

Bulk geochemistry and *in situ* microanalysis
The bulk sample of sulphide rich bedrock of basalt contains high concentrations of Au (>20 ppm), Ag (88 ppm), As (363 ppm), Zn (954 ppm), Cu (375 ppm) and Pb (1120 ppm). These elements are generally depleted in the saprolite though localised concentrations do occur associated with sub-vertical quartz veining and isolated ferruginised zones. The slabby, ferricrete is anomalous with up to 587 ppb Au detected in one sample, and white clay in-between slabby layers containing 112 ppb Au. Arsenic concentrations occur in areas of ferruginisation (20-50 ppm), even in the saprolite, and reach 85 ppm in slabby sediments. The hardpanised sediments and calcrete near the top of the profile yield little As but appreciable Au concentrations (128-436 ppb). Using this bulk geochemistry, we targeted polished thin sections of Au and/or As rich samples for *in-situ* micro-analysis using LA-ICPMS.

The *in-situ* analyses are able to identify areas of Au enrichment in the samples and in most the trend mirrors that of the bulk geochemistry with As, Cu and Zn all having a preference for Fe-rich areas. In the slabby ferricrete the Au, As, Cu and Zn are contained in the minor hematite rich clasts rather than the dominant matrix which comprises quartz, goethite, kaolinite and hematite. Interestingly, the white clay within these slabby zones contains appreciable Au. LA-ICPMS identified the kaolinite as a local host for Au but with little As. The Fe-stained kaolinite shows a slightly higher enrichment in Au together with higher As and Cu.

The gravelly red-clays that contain clasts comprising small clay and hematitic spherites or balls in a matrix of hematite, kaolinite and quartz show As closely associated with Fe-rich areas, but both mineralogies of spherite are relatively Au-poor. In the uppermost sequence of hardpanised colluvium and calcrete high concentrations of Au are found in the calcareous matrix. Silica-rich areas in the matrix of the hardpan (kaolinite+ amorphous silica) are also rich in Au and the hardpan analyses yield more Cu than in calcrete. Some highly anomalous values were obtained using LA-ICPMS on the calcrete, preliminary observations would suggest this represents grains of Au in the sample to produce a nugget effect in the analyses. It should be noted however, that Au grains were not observed in these samples during SEM observations indicating they may still be very fine-grained.

CONCLUSIONS
Sediments at the Lancefield and Entreprise deposits display complex history of kaolinisation, ferruginisation, calcification and silicification, with Au and trace metals being concentrated in several mineral hosts. In most cases *in-situ* analysis was able to identify the mineral or mineralogical structures that act as hosts for Au, As, Cu and Zn at the thin section scale. It has been shown that targeting individual minerals and mineralogical phases provide a potential tool to enhance geochemical anomaly detection.

It appears that metal enrichment in various mineral phases developed in sediments at Lancefield and Entreprise have resulted from dispersion from the underlying mineralization. Possible mechanisms of dispersion and its implications to exploration will be discussed.

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