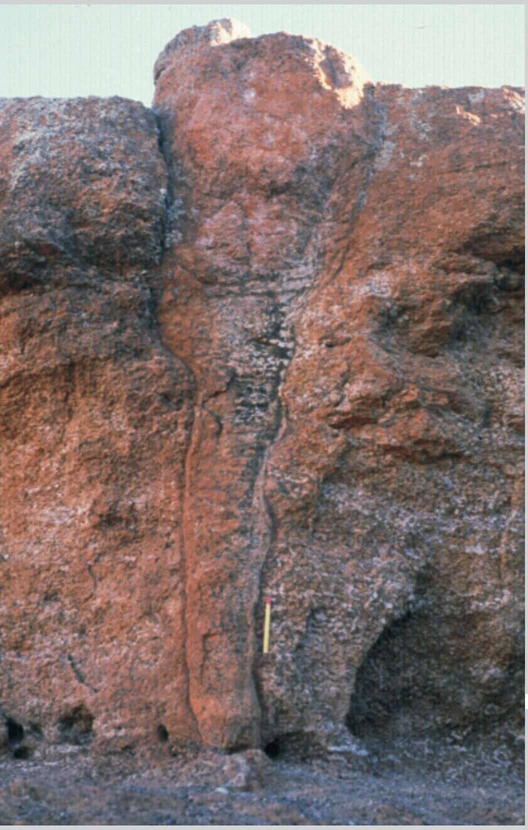
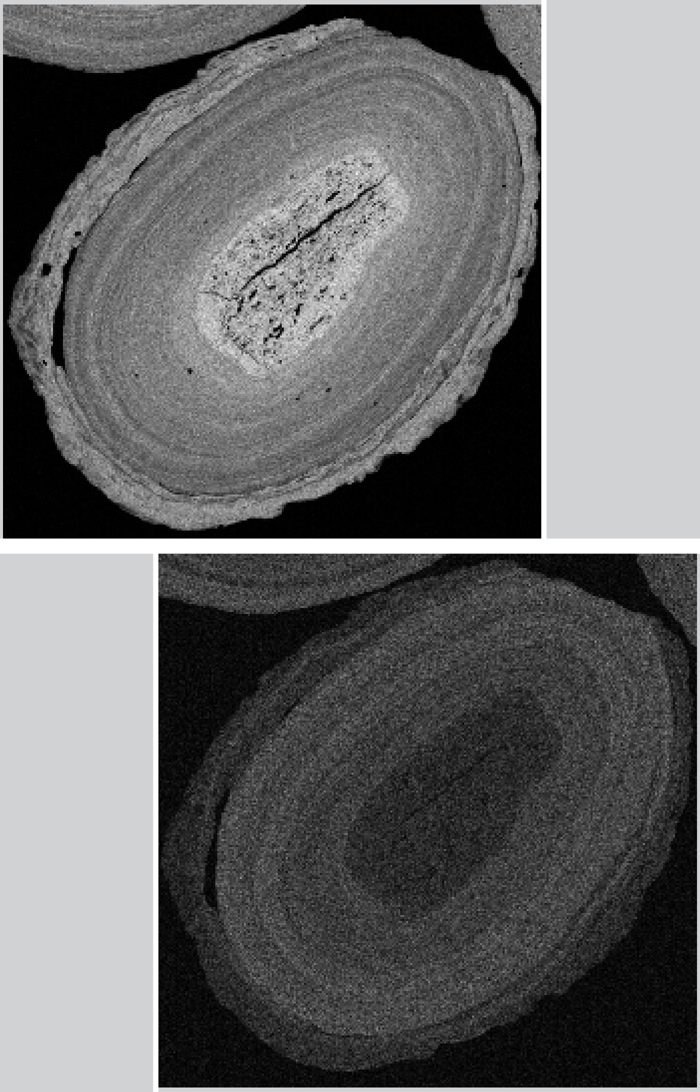
2006
MINERALS EXPLORATION SEMINAR
ABSTRACTS

11 August 2006



A ferruginous columnous structure in ferricrete



Metal distribution in palaeochannel pisoliths

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Convenor

Dr Ravi R Anand

CRC LEME Program Leader: Mineral exploration in areas of cover
CSIRO Exploration and Mining
PO Box 1130, Bentley WA 6102

Email: ravi.anand@csiro.au

11 August 2006

Australian Resources Research Centre
26 Dick Perry Avenue, Kensington (Technology Park, Perth)
Western Australia

COOPERATIVE RESEARCH CENTRE FOR LANDSCAPE ENVIRONMENTS AND MINERAL EXPLORATION

CRC LEME HEAD OFFICE

Dr Steve Rogers
Chief Executive Officer
PO Box 1130, Bentley WA 6102
Tel: 08 6436 8699.
Email: *steve.rogers@csiro.au*

Centre Support Officer
Mrs Sue Game
Tel 08 6436 8695
Fax: 98 6436 8560
Email *crcleme.hq@csiro.au*

CRC LEME WEB SITE: http://crcleme.org.au

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NEW INSIGHTS INTO THE NORTHERN TERRITORY REGOLITH

Ian Robertson (1), Ravi Anand (1) and Mike Craig (2)

(1) CSIRO Exploration and Mining / CRC LEME
(2) Geoscience Australia / CRC LEME
ian.robertson@csiro.au

The Atlas of Regolith Materials for the Northern Territory was prepared as a companion to the 1:2 500 000 regolith map the Northern Territory. Specimens of regolith (329), including weathered rocks, sands and soils and their secondary cemented products (silcrete, ferricrete, calcrete) were collected along some 20 000 km of traversing. These have been combined with specimens collected by CRC LEME in 1998-1999 from the Amadeus Basin.

The regolith materials have been grouped and described according to large-scale regolith terrains and have been split according to their regolith classification. The Atlas is illustrated with 508 annotated photographs of landscape, outcrop appearance, hand-specimen and micrographic details. Most of the specimens have been chemically and mineralogically analysed, to contrast their compositions, including some ‘stable’ elements such as Zr and Ti. Particle size distributions are available for some of the soils and sands.

Regolith materials varied from the apparently unweathered quartzites of the Amadeus Basin to complete lateritic profiles protected from erosion by the Austral Downs chert. Study of the Amadeus Basin quartzites showed that many were actually saprock or even saprolite. Carbonates weather abruptly by solution, leaving little weathered mantle, although cemented scree and calcrete-cemented alluvium are common. The granitoids degrade to grus, where erosion is active, and to saprolite and ferruginous saprolite, where erosion is much less active. The fabric collapses progressively to a mass of shard-like quartz grains in clay that readily erodes to supply outcrop-proximal sands, alluvium, sandplain sand and aeolian sand.

Mafic rocks, siltstones and argillites degrade readily to saprolite, where some primary structures are preserved and then to plasmic and mottled materials where primary fabrics are largely absent. The Brewer Conglomerate is rather unique in that its carbonate-rich matrix dissolves, leaving a loose mass of quartzite clasts that shatter to insoliths on the surface.

There are a variety of silcretes, some clearly formed from Palaeogene-Neogene fluvial, silty, sandy, gritty and conglomeratic sediments; others formed in soils between outcrops of quartzite. Some quartzites adjacent to these silcretes have also been silicified in the process. Although the silcretes formed low in the landscape, probably on the floors and edges of valleys, relief inversion has formed small mesas.

Ferricretes are very variable. Some are cemented scree on the edges of modern drainages. Many consist of ferruginous granules, some containing fossil wood. The granules have been coated with goethite to form an open mesh. Some of these have formed on the margins of karstic depressions in Cretaceous rocks in the north of the Territory. Calcrete has developed on the flanks of hills of Brewer Conglomerate, as sheets and joint fillings in saprolite, as layers of rhizomorphs in alluvium, or as nodules within sand dunes.

Soils and sands have been subdivided into coarse outcrop-proximal deposits, alluvium, sandplain deposits, aeolian deposits, calcareous sands and black soils. They each have characteristic particle size distributions and mineralogies. The outcrop-proximal, sandplain and alluvial deposits probably form a continuum. Small amounts of aeolian material are found in all these. Termites have been important soil turbating agents and termitaria are important features of sand plains throughout the Territory.

LATERITE GEOCHEMICAL MAP OF THE WESTERN YILGARN CRATON

Matthias Cornelius (1), Amanda Cornelius (1), Ian Robertson (1) and Paul Morris (2)

(1) CSIRO Exploration and Mining / CRC LEME
(2) Geological Survey of Western Australia
Matthias.cornelius@csiro.au

The project aim is to establish a geochemical atlas for the Western Yilgarn Craton, using highly selective sampling of lateritic residuum, lag derived from lateritic residuum and lateritic detritus from colluvium. This will provide baseline data and identify major geochemical trends and provinces, both in residual and in depositional terranes that could assist exploration and lead to the discovery of new mineral deposits.

The project is supported by CSIRO EM, CRC LEME, GSWA and MERIWA (M371).

To date, approximately 3000 samples (Figure 1) have been analysed and results for the southwest quadrant (approximately 2000 samples) were published (Cornelius *et al*. 2006).

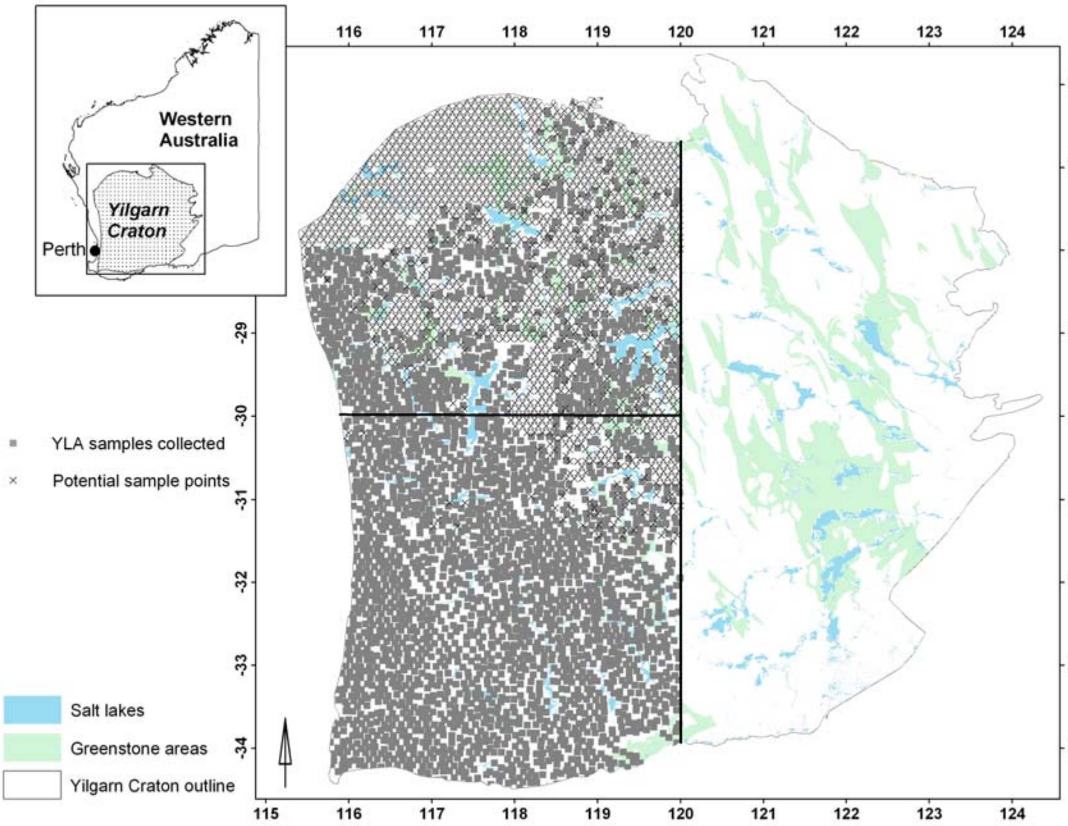

Figure 1. Locations of samples analysed from the western Yilgarn Craton.

Sampling is ongoing in the NW quadrant. Representative samples from various parts of the western Yilgarn and samples both with an unusual and a typical geochemical composition will undergo mineralogical investigation. The project will be completed in 2007.

Highlights of the data set are:

1. Increased Au abundances in the NE part of the southwestern Yilgarn Craton cluster around known gold deposits; their extent may mean more widespread mineralization in some of these areas.
2. A chalcophile element index (CHI6* by Smith and Perdrix, 1983) illustrates potential for Au and base metal mineralization in the westernmost part of the Yilgarn Craton.
3. A pegmatophile index (PEG4* by Smith *et al.*, 1987) shows a regional NW trend north of the Saddleback greenstone belt.
4. Multivariate statistical analysis indicates the potential for mafic-ultramafic remnants outside known greenstone belts.
5. A regional Hg anomaly trends NW over more than 500 km from Wongan Hills in the north to Jerramungup in the south and, further to the east-northeast, along the Proterozoic of the Albany-Fraser Province.

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ACHIEVING THE VISION OF 3-D REGOLITH-ALTERATION MINERAL MAPS

Thomas. Cudahy

CSIRO Exploration and Mining
Thomas.Cudahy@csiro.au

Mapping mineralogy in three dimensions, to better understand the architecture and plumbing of hydrothermal alteration and regolith systems, is now becoming achievable with the arrival of complementary mines-scale and remote hyperspectral sensing systems.

This paper explores this potential based upon drill core HyLogging™ and airborne HyMap mineral mapping capabilities being developed and tested in Australia, including mapping the geometry of “big footprint” Archaean Au alteration in the Eastern Goldfields.

MINIMUM PROBABILITY METHODS TO ASSESS EXPLORATION TECHNIQUES

Ryan R.P. Noble (1) and Cliff R. Stanley (2)

(1)CRC LEME / CSIRO Exploration and Mining
(2) Acadia University, USA
ryan.noble@csiro.au

A quantitative measure of performance for geochemical exploration techniques over known mineralisation has been established using hypergeometric statistics. The hypergeometric approach uses prior knowledge of which sample sites are in the mineralised section of a study area, and which samples collected over these sites are anomalous, based on the results of a survey using the exploration technique to be tested. The number of anomalous samples (*k*) in the survey that occur over anomalous/mineralised sites (*a*) are determined (*x*). Then, the hypergeometric probability of randomly having *x* (of *k*) anomalous samples occur over *a* (of *t* - total) anomalous sites is calculated. The following hypergeometric formula relates the probability of the anomalous points and false positives to the successful detection of mineralisation (Stanley, 2003).

$$P(x) = \frac{\binom{a}{x}\binom{t-a}{k-x}}{\binom{t}{k}} \times 100\%$$

a = number of predicted anomalous points
x = number of correct anomalous points
t = total sample points
k = number of anomalous points (true and false)

If the resulting probability for the survey is low, it is probable that the results observed are not random, likely that the exploration technique successfully detected mineralisation. The effectiveness of new exploration techniques can be compared without bias to conventional exploration methods using this approach, assisting the mining industry in identifying the most efficient exploration technologies.

The limitation of applying hypergeometric statistics is that the threshold for identifying anomalous and background sites needs to be unambiguous (high geochemical contrast), which is not always the case. Recent improvement of this approach used a step-wise adjustment of the geochemical thresholds between sample concentrations to calculate hypergeometric probabilities for each step. The minimum hypergeometric probability (MHP) from the set of outcomes is the most non-random, optimised, result (Stanley & Noble *in review A*). The threshold level with the MHP describes the effectiveness of the exploration method. This MHP threshold level is also the most appropriate threshold to use for future exploration in the same setting.

A complementary measure of exploration performance is geochemical contrast. Using a similar minimum probability approach to assess accuracy, the Student's *t* distribution is used to create a quantitative measure of geochemical contrast (Stanley & Noble *in review B*). A minimum Student's *t* distribution probability (MTP) can be derived to indicate the technique with the greatest contrast. The Student's *t* distribution probabilities are determined using the means and standard deviations of the anomalous and background populations defined by the adjusted thresholds, the same as the step-wise adjustment used in the MHP. Then, the pooled standard deviations of the two populations are calculated by the formula:

	$\sigma_p = \sqrt{\frac{\sigma_a^2(n_a - 1) + \sigma_b^2(n_b - 1)}{n_a + n_b - 2}}$.	σ = standard deviation n = number of samples a = anomalous b = background

Finally, the (un-paired, two sample, equal variance, one tailed) Student's *t* distribution test statistics (Snedecor & Cochran 1989) are calculated:

	$t = \frac{\mu_a - \mu_b}{\sigma_p \sqrt{\frac{1}{n_a} + \frac{1}{n_b}}}$,	μ = mean

and the associated probability is determined. The resulting *t* test statistic is a relative measure of the difference between anomalous and background populations, and is an appropriate measure of geochemical contrast. Unlike the MHP, the MTP scores from two different surveys cannot be compared unless the surveys have the same number of samples (and degrees of freedom). Because Student's *t* tests assess the probability that two datasets are derived from a single population, lower Student's *t* distribution probabilities will occur when background and anomalous samples exhibit large geochemical contrast. As a result, like the MHP method, the minimum Student's *t* test probability (MTP) method simultaneously determines the geochemical contrast of an exploration method, and defines the best threshold to classify background and anomalous samples.

Soil samples from an orientation survey were subject to two different extractions. The use of minimum probabilities was applied to the results (Figures 1 and 2). Extraction A was determined to be significantly better than Extraction B. The difference in MHP (0.004% versus 6.6%) provides the user with details of the accuracy of the technique, while the MTP gives information of the contrast or precision (0.09% versus 0.07%). To apply these techniques to a field study it is recommended that the MHP be applied first; techniques that pass this test (generally score <5%) are then subject to the MTP assessment to calculate the best method to use. A synthetic example of comparing various extractions from an orientation survey using minimum probabilities is presented in Figure 3. From this plot extraction 1 is the best, 2 and 3 are effective, and 4, 5 and 6 are unsuccessful.

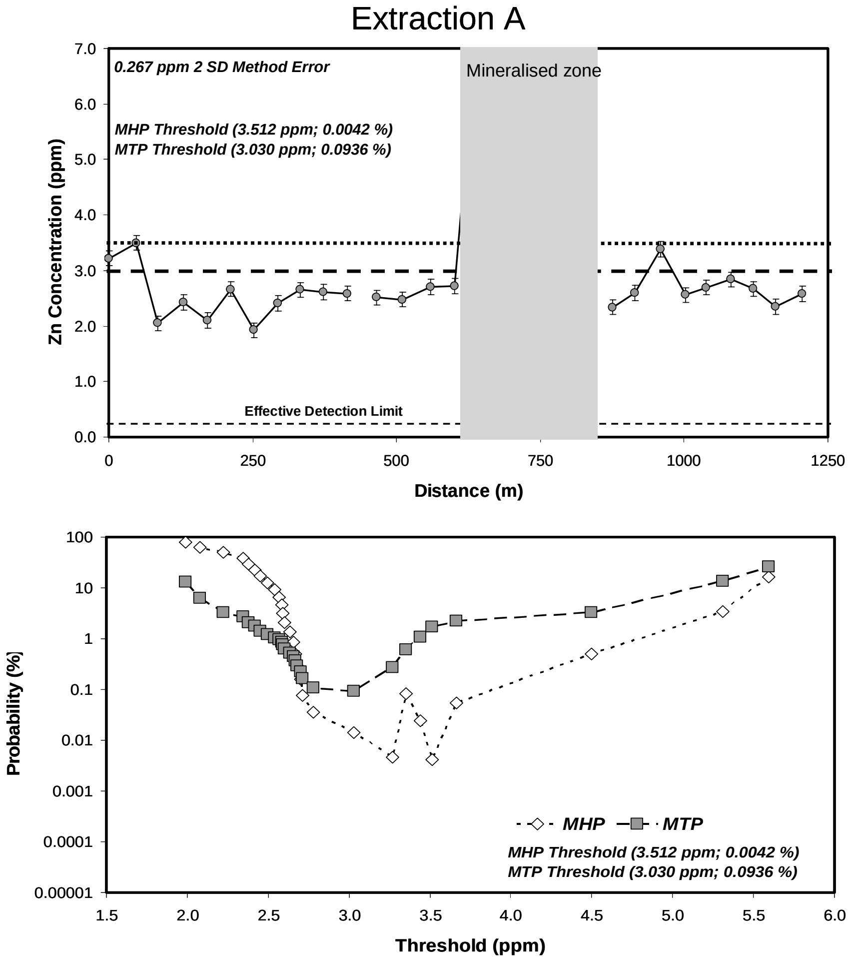

Figure 1: Zinc soil concentrations across an orientation survey using Extraction A. The optimal threshold (MHP) of 3.512 ppm identifies 5 anomalous samples, all of which occur over mineralised sites (gray shading), with no false positives. The hypergeometric probability for this example is 0.0042 %. The optimal contrast threshold (MTP) is identified at 3.030 ppm. The bottom plot shows the step-wise derivation of the hypegeometric and *t* test probabilities and the threshold levels.

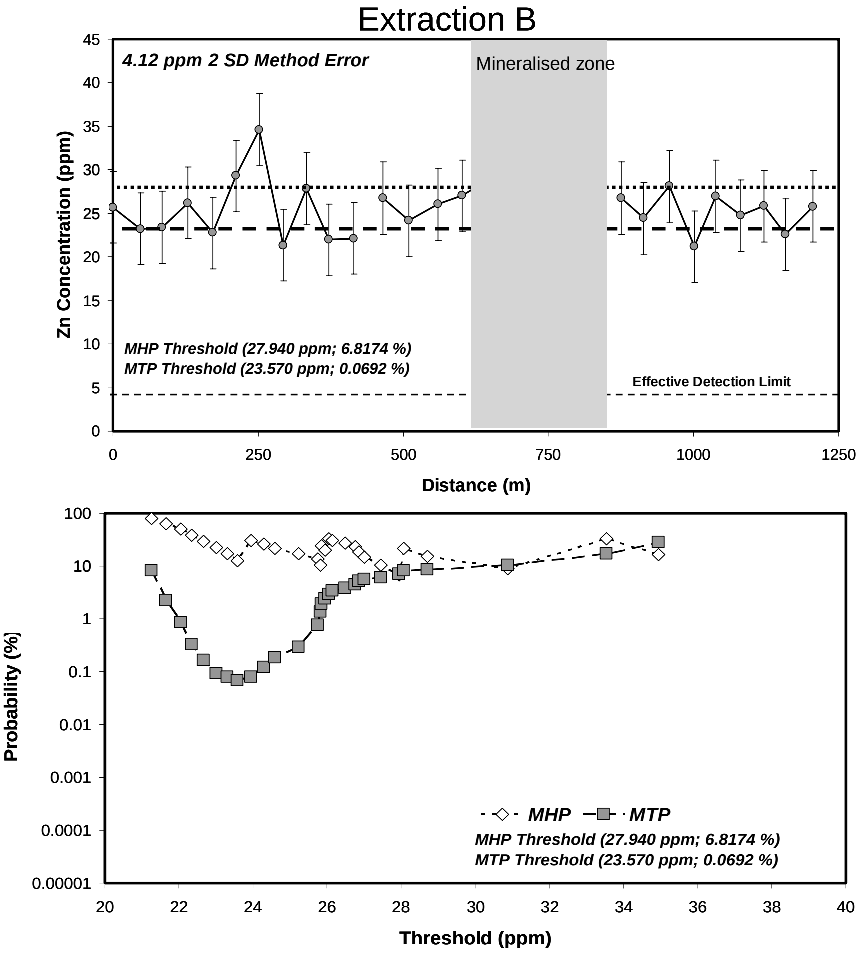

Figure 2: Zinc soil concentrations across an orientation survey using Extraction B The optimal threshold (MHP) of 27.940 ppm identifies 6 anomalous samples, 3 of which occur over mineralised sites (gray shading), with 3 false positives. The hypergeometric probability for this example is 6.8174 %. The optimal contrast threshold (MTP) is identified at 23.570 ppm. The bottom plot shows the step-wise derivation of the hypegeometric and *t* test probabilities and the threshold levels.

The application of minimum probabilities to exploration is not restricted to comparing geochemical techniques. The assessment of accuracy and precision in different sample media i.e. soil horizons, calcrete, litter can also use minimum probabilities to find the best sampling media in a particular setting.

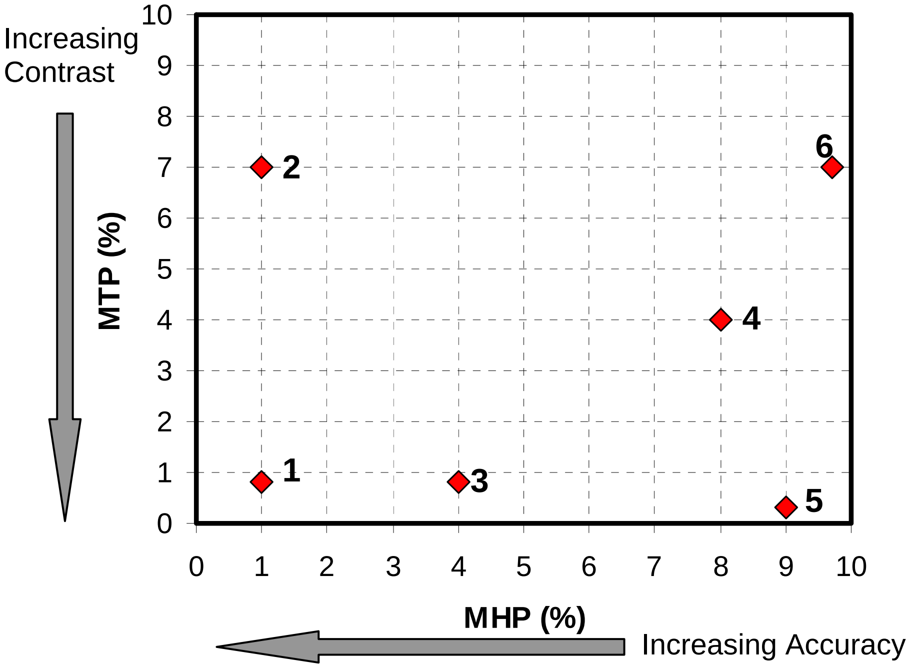

Figure 3: Synthetic plot comparing the results of 6 techniques assessed with minimum probability methods. Accuracy and precision are improved towards the bottom right corner. Extraction 1 is the best, 2 and 3 are effective, and 4, 5 and 6 are unsuccessful.

The objective of this CRC LEME Minerals Exploration Seminar presentation is to provide a general overview of applying minimum probabilities to evaluate geochemical extractions and to demonstrate the benefits of using these techniques to remove interpretational bias. Minimum probability methods allow geoscientists to quantitatively compare the accuracy and precision of competing exploration techniques, improving the chances of exploration discovery.

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A Microsoft Excel® spreadsheet that calculates hypergeometric probabilities ($P(x)$) can be downloaded from http://ace.acadiau.ca/~cstanley/software.html. Future upgrades to this site are planned that will allow the generation of minimum probabilities.

HOW SO CALLED ORE GRADE 'LATERITE' DEPOSITS FORM: NEW INSIGHTS INTO THE MECHANISMS OF ANOMALY FORMATION

Ravi. Anand (1), Cajetan. Phang (1), Robert Hough (1), Mehrooz. Aspandiar (2), M.F.P. Foo and B. Willis-Jones

(1) CSIRO Exploration and Mining / CRC LEME
(2) Dept Applied Geology, Curtin University of Technology / CRC LEME
ravi.anand@csiro.au

INTRODUCTION

So called 'laterite' hosted Au deposits are common, particularly in the northern Yilgarn Craton of Western Australia. The term 'laterite' comprises ferruginous pisolitic and nodular duricrust and/or loose pisoliths and nodules. Ferruginous pisoliths and nodules contain the principal ore (1 to 5 ppm) at Mt Gibson, Bulchina, Laterite Pit (Bronzewing), Lotus (Mt McClure), Empire, Gourdis, North Pit (Lawlers) and Moolart Well (Figure 1). These are near-surface deposits containing Au, directly beneath which there is generally no economic primary mineralisation. Gold anomalies in ferruginous pisoliths can be several kilometres long and less than a kilometre wide (Figure 2). A number of scenarios have been proposed to account for the source of Au in these deposits and their likely genesis including mechanical transport of Au-bearing ferruginous pisoliths from adjacent mineralisation or secondary enrichment associated with sub-economic underlying mineralisation (Jones and Lidbury, 1998; Paine *et al.*, 2000; Anand, 2000; Warland and Phang, 2000; Willis-Jones, 2000; Smith *et al.*, 2000).

This paper presents new information on (i) the relationship between landscape and deposits (ii) the nature and origin of so called laterite (iii) the occurrence and concentration of Au and trace elements in various minerals and mineralogical assemblages, and (iv) the mechanisms of anomaly formation from a number of gold deposits. Ferruginous pisoliths and duricrust were investigated by a variety of techniques, including bulk chemical composition, XRD, SEM-EDAX, electron microprobe and LA-ICP-MS.

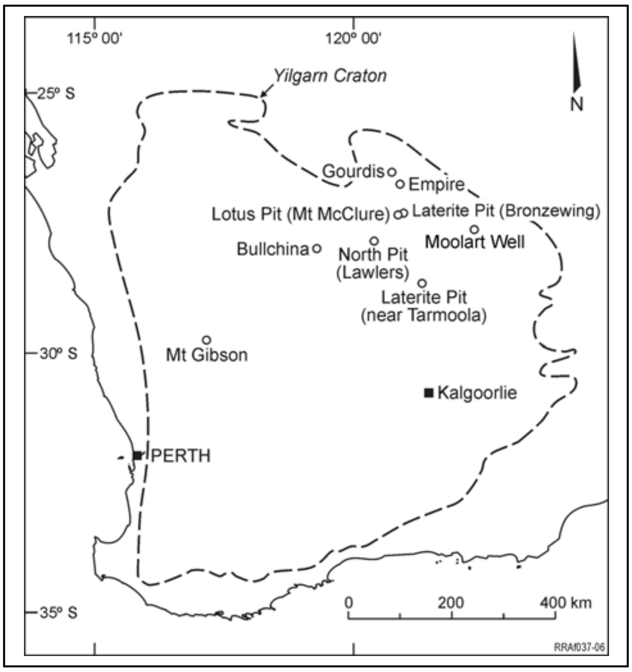

Figure 1. The location of some so called 'laterite' Au deposits in the Yilgarn Craton

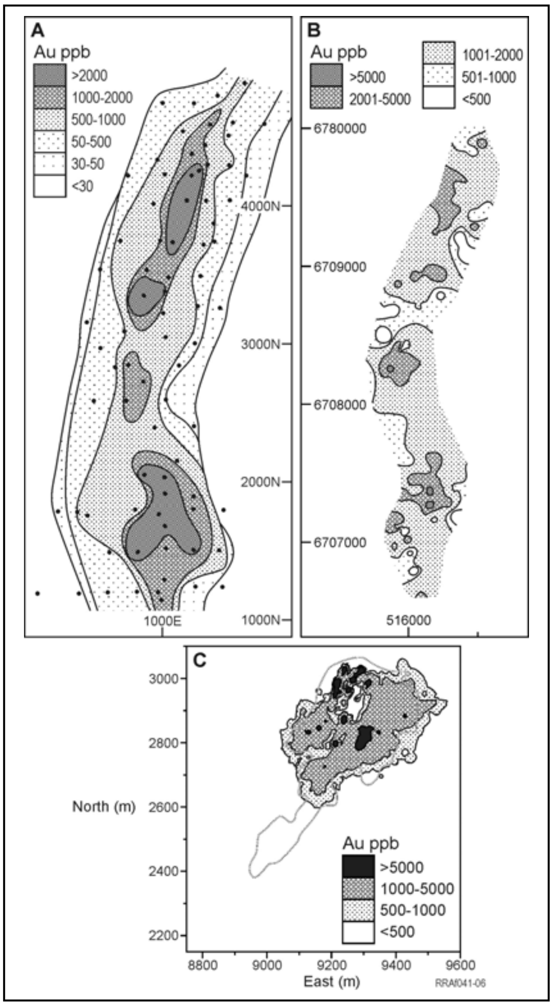

Figure 2. Geochemical dispersion maps showing the distribution of Au from so called 'laterite' deposits: A. Mt Gibson (modified after (Smith *et al.,* 2000), B. Moolart Well (courtesy of Regis Resources and Newmont Australia) and C. Bulchina (after Willis-Jones, 2000).

CHARACTERISTICS AND ORIGIN OF SO CALLED 'LATERITE'

Laterite deposits in Western Australia typically occur downslope from low saprolitic hills and proximal to palaeochannels with less than 5 m of transported cover. The laterite forms a sheet-like deposit which extends for distances of several kilometres beyond the palaeochannel margins. Laterite consists of two units (Figure 3). The highly anomalous upper unit is developed in sediments and is here referred to as pisolitic ferricrete. This is typically a framework supported clayey-sand with varying proportions of 5 to 40 mm sized ferruginous pisoliths and nodules. Except for crude 0.5-1 m thick horizontal beds in places, no primary sedimentary structures are preserved. Pisolitic ferricrete varies in thickness from 2-8 m and is commonly overprinted by later bleaching of iron. The bleached areas are commonly cylindrical and cored by tubes that may be filled with secondary kaolinite or silica. The lower unit of laterite (1-3 m thick) is residual hematite-goethite-kaolinite-rich angular nodules and is derived from the weathering of underlying bedrock. It is here referred to as nodular lateritic residuum. The most diagnostic morphology of nodular lateritic residuum is the preservation of distinctive bedrock fabrics within nodules. In places, sub-angular vein quartz also occurs (e.g., Empire, Lotus). Laterite is generally overlain by sandy soil (<30 cm thick) and gravelly to silty hardpansied colluvium and alluvium (1-3 m).

Petrography of the pisolitic ferricrete shows two main types of pisolith: (i) authigenic red earthy (major type) and (ii) detrital massive black (minor type) (Figure 3).

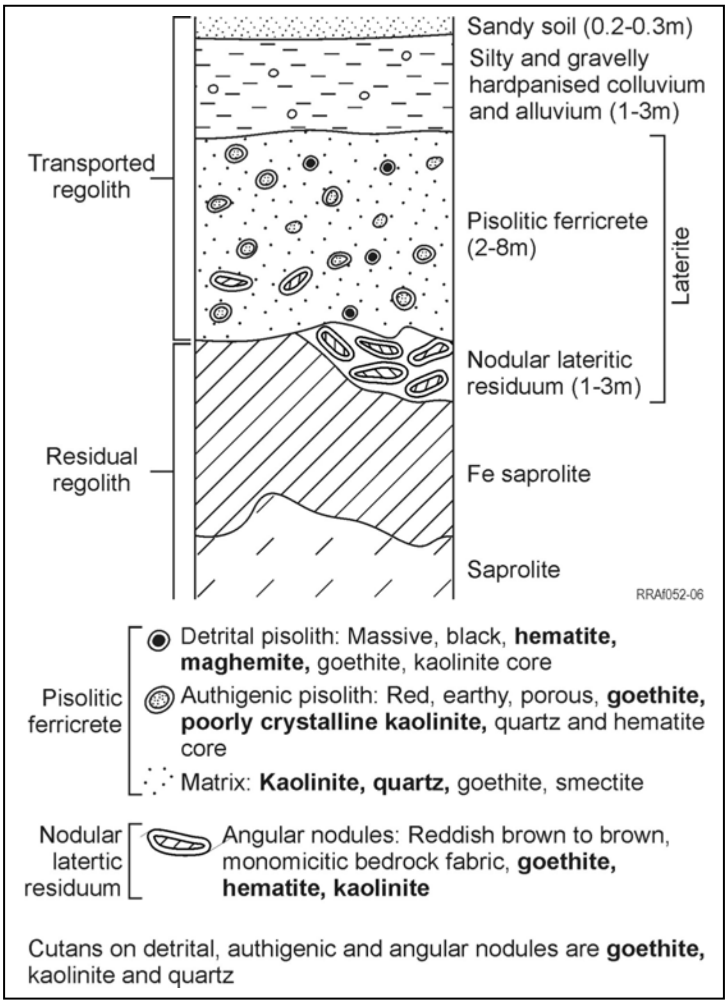

Figure 3. Classification of so called 'laterite'and types of ferruginous pisoliths.

Based on the following observations, red earthy pisoliths are authigenic. Firstly, pisoliths are matrix supported within the clayey sand. Secondly, except for Fe content, the internal mineralogical and textural composition of the ferruginous pisoliths is similar to that of the clayey sand matrix. Forming a minor part of the pisolitic ferricrete are black, magnetic, massive hematite-maghemite-rich pisoliths interpreted to be of detrital origin. These pisoliths are derived from erosion of a ferruginous duricrust. Detrital pisoliths are generally magnetic. Most authigenic pisoliths are clearly discernible in thin section, where they partly or wholly enclose quartz grains deposited as part of the primary matrix. Very fine spherites of poorly ordered kaolinite, generally 1 mm in diameter, are common in the matrix and pisoliths, and are thought to have formed by concentric deposition of clay particles around a central core of kaolinite.

Goethite, introduced later, occurs as cutans on most pisoliths and nodules and may entirely replace hematite pisoliths. The texture and mineralogy of cutans are similar to that of the matrix.

Authigenic pisoliths are characterised by higher concentrations of Al and Si and lower Fe. By contrast, detrital pisoliths and residual angular nodules are dominated by Fe with smaller amounts of Al and Si.

GEOCHEMISTRY AND MICROANALYSIS OF SO CALLED 'LATERITE'

Most of the Au is concentrated in the pisolitic ferricrete and decreases dramatically in abundance in nodular lateritic residuum. At Mt Gibson, authigenic and detrital pisoliths, their cutans and matrix were separated from pisolitic ferricrete and analysed to determine mineralogy and trace element distribution. The separation of cutans from pisoliths was only practical for large pisoliths with 5-10 mm thick cutans. Gold is present in all of the separated materials, but the degree of accumulation in them varies considerably (Figure 4). Authigenic pisoliths have the greatest concentrations of Au (up to 15 ppm), whereas detrital pisoliths generally have the lowest Au concentrations (up to 4 ppm). Significant Au amounts (up to 6 ppm) are present in cutans around detrital pisoliths which may suggest that cutans are significant contributors to the Au of these detrital pisoliths. Similar results were obtained for the Moolart Well Au deposit where gold in authigenic pisoliths is five to ten times more than that contained in detrital pisoliths, these were separated on the basis of magnetic and non-magentic fractions. Gold is also enriched in goethite-kaolinite cutans around detrital and authigenic pisoliths similar to that observed at Mt Gibson. Gold is also present in the fine <250 µm fraction that probably represents matrix materials, but in much lower amounts compared to pisoliths. Gold appears to be broadly associated with goethite, but decreases significantly in abundance with increasing concentrations of hematite.

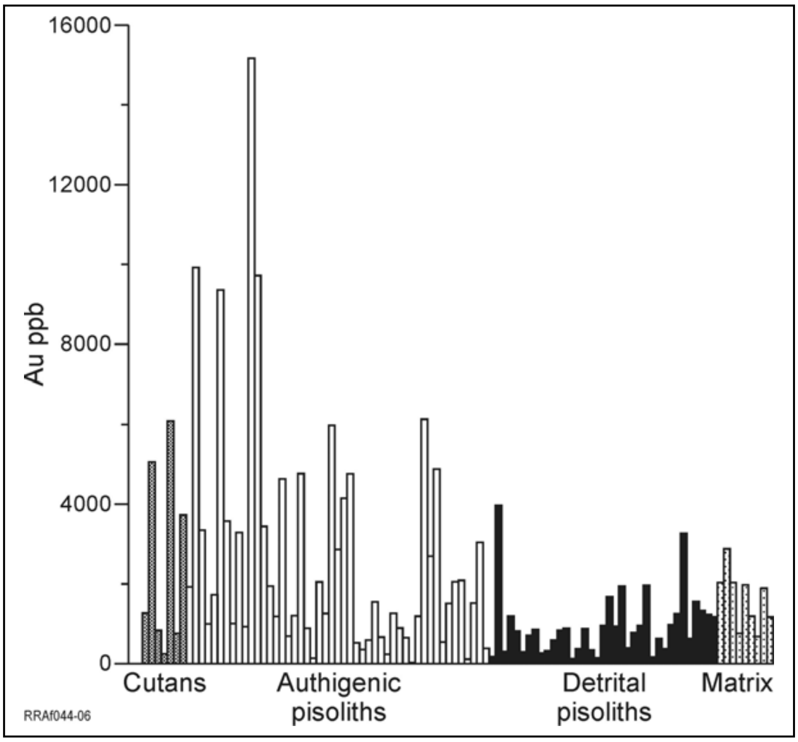

Figure 4. Distribution of Au in various materials separated from pisolitic ferricrete, Mt Gibson.

Much of the Au present is too fine grained to be resolved by scanning electron microscopy (SEM). At Mount Gibson, where it is visible under the SEM, Ag-poor dendritic, presumably secondary gold occurs within cavities of both detrital and authigenic pisoliths. Gold has even been observed under the hand lens in some of the broken pisoliths at Mt Gibson and Empire. Gold grains were separated from pisolitic ferricrete and nodular lateritic residuum and ferruginous quartz veins from Lotus, Laterite, Empire and Bulchina (Anand, 2000; Paine *et al*., 2000; Warland and Phang, 2000; Willis-Jones, 2000). The Au grains were examined under SEM to investigate their morphology, and an energy Dispersive X-ray Analyser (EDAX) was employed to determine the semi-quantitative composition of the grains. The grain size is typically larger (>150 µm) in samples derived from the quartz vein than in the ferruginous pisoliths (typically <100 µm). Grains from ferruginous quartz veins are irregular and xenomorphic, typical of a primary origin. Silver was present, however all the grains had some spots where Ag was depleted with respect to the bulk. Gold from pisolitic ferricrete and nodular lateritic residuum is a mixture of primary and secondary grains based on Ag composition, and the latter category dominates. The Au grains are commonly etched and often exhibit euhedral crystal faces. Most of the grains are depleted in Ag. The separated grains are of course a small proportion of the total contained gold but nonetheless provide an interesting indication of differential provenance.

Broad trends in the distribution of Cu, As, Pb, Bi and Sb in the pisolitic ferricrete exist. Arsenic and to a lesser extent Cu occur in authigenic pisoliths and cutans. By contrast, Pb, Bi and Sb and to a lesser extent As, occur in detrital hematite-rich pisoliths. Microanalysis of various mineral phases suggests broad goethite-Cu, kaolinite-Cu, goethite-hematite-As, and hematite-Pb-Bi-Sb associations.

MECHANISMS OF ANOMALY FORMATION

The data from the sites in this study suggest multi-stage local to distal hydromorphic, biogenic and to a lesser degree mechanical dispersion of Au, As, Cu, Pb, Bi and Sb in pisolitic ferricrete to form ore-grade deposits. This dispersion can be linked to the relative ages of pisolith formation and the weathering history.

The occurrence of detrital and authigenic pisoliths suggest they have formed at different times under different bioclimatic regimes. Though there is no direct dating of Fe oxides available from the pisolitic ferricrete at the sites investigated, stratigraphic relationships and the dating of goethite from palaeochannel sediments in the Kalgoorlie region suggest that authigenic pisoliths may have formed during the mid Miocene-Pliocene. Dating ((U-Th)/He) of goethites from concentric pisoliths that formed *in situ* or syndepositionally within the palaeochannel sequence range from 22-24.4 Ma in the Kalgoorlie region (Dr Mark Paine written communication, 2006) whereas near surface pisoliths from channel Fe deposits of the Hamersley region are about 18 Ma (Heim *et al*., 2006). Stratigraphically across the Northern and Southern Yilgarn, the pisolitic ferricrete in question overlies the palaeochannel sequence and is hence younger than 18 Ma. Dating of late-stage cavity filling authigenic goethite from the pisolitic ferricrete near Kalgoorlie ranges from 3.3 to 3.7 Ma (Dr Mark Paine written communication, 2006). These results provide a minimum age for the goethitisation. The climates during their formation were seasonally drier (though rainfall was still higher than present) and warmer. Detrital pisoliths are older than Mid Miocene and are interpreted to have formed during Early to Mid Tertiary. The climate was probably warmer and wetter to cool temperate and the vegetation was dominated by conifer forests.

The following stages of regolith development and geochemical dispersion are envisaged to form extensive Au anomalies in pisolitic ferricrete.

(i) Maghemite in detrital pisoliths of pisolitic ferricrete at depth indicate material was once at the land surface. Maghemite can be formed by heating of goethite and hematite during bush fires (Anand and Gilkes, 1987). Thus, detrital pisoliths are interpreted to have formed near the surface in upland areas when the water tables were high resulting into incorporation of metals (Pb, As, Bi, Sb, W Au) into Fe oxides from either primary mineralisation or the primary dispersion halo. The style of primary mineralisation either as Au, Au-As-Cu or Au-Cu-As, Bi-Sb determines the nature of metals in Fe oxides. Although much less abundant, both primary and secondary Au were incorporated in pisoliths. Reduced concentrations of Cu in detrital pisoliths may simply be due to ejection of Cu during the transformation of goethite to hematite. Hematite would have been more abundant at the surface whereas goethite was more common deeper in the weathering profile. These pisoliths were subsequently mechanically dispersed into the lower parts of the landscape to form an accumulation of detrital pisoliths.

(ii) A transition towards arid conditions form the Mid-Miocene onwards combined with erosion of previously formed ferruginous pisoliths and clays, filled the lower parts of the landscape with detrital components. The widespread distribution, sheet-like geometry and crude horizontal bedding together with evidence of extensive bioturbation in the pisolitic ferricrete, suggest deposition by vertical accretion within a low-energy fluvial environment, such as the proximal (near channel) part of a floodplain. The sediments were subjected to intense post-depositional biological and chemical alteration.

Near-surface groundwaters leached Fe, Au and to a much lesser extent Cu and As from the upland mineralised and unmineralised areas and migrated downslope through the topographically lower saprolite and overlying flood-plain deposits. During wetter periods, these leaches would have been flushed from the region, but the onset of arid conditions reduced the rate of groundwater migration and promoted stagnation in lower parts of landform occupying flood plain deposits. Due to their morphology and a permeability contrast with the surrounding saprolite, the flood plain deposits were the loci for groundwater accumulation and subsurface flow. Interaction with abundant organic matter would have caused groundwater to become acidic and reducing, promoting the partial dissolution of Fe-rich fragments and soils. Soluble Fe^{2+} released from dissolution of Fe-fragments and Fe-saprolite would then migrate, hydrolyse and oxidise to Fe^{3+} and reprecipitate as goethite at the groundwater-atmosphere interface. Gold from upland may have been transported chemically as Au-organic complexes (Bowell *et al.*, 1993) to its present position and then be adsorbed by goethite. Gold-cyanide complexes produced by the weathering of sulphides can result in long surface water dispersion (~3 km) compared to thiosulphate (Bowell *et al.*, 1993; Leybourne *et al.*, 2000).

With the onset of drier conditions in the Mid Miocene, water tables withdrew from the upland areas and groundwaters accumulated in topographic lows. The water table deepened at a rate of ~1.2-1.5 m/m.y. from ca. 36 Ma onwards (Heim *et al.*, 2006). This process would have continued throughout the Neogene, with goethite and Au precipitation occurring in the pisolitic sediments and upper saprolite to form the highly anomalous pisolitic ferricrete. This mechanism is supported by the distribution of fine Au in the authigenic pisoliths and cutans developed around detrital pisoliths. Post-depositional localised bleaching of pisolitic ferricrete may have redistributed Au, Cu and As removing them partly from the matrix and concentrating them in the goethitic cutans of detrital pisoliths.

IMPLICATIONS TO EXPLORATION

- Large Au anomalies in pisoliths are not necessarily associated with large primary deposits.
- Recognition of three pisolith types (detrital, authigenic and residual) is essential for determining the origin of an anomaly. Detrital hematite-maghemite pisoliths preserve the multi-element geochemical characteristics (Pb, As, Bi, Sb and Au) of a nearby primary source whereas goethitic authigenic pisoliths may concentrate Au from local to distal sources. The areas from which gold and Fe have been removed lead to the formation of leached saprolite. Angular nodules will generally reflect the signature of underlying minor primary mineralisation. However, Au, As and Cu in late stage goethite of cutans developed around detrital and authigenic pisoliths and nodules results from the redistribution of metals from the pre-existing anomaly particularly from the matrix.
- Anomalies in goethite-rich ferruginous saprolite can also be developed in a similar process as in authigenic pisoliths, geochemical data should then be interpreted with caution.

- The style of primary mineralisation, associated accessory elements and multi-element dispersion trends must be taken into account.
- Mapping of palaeotopography is important for determining the source of anomalies in pisoliths.
- Many more so called ‘laterite’ deposits are still to be discovered (particularly in the northern Yilgarn Craton). Less discoveries are probable in the Kalgoorlie region largely because of the differences in the weathering history between the two regions.

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HYDROGEOCHEMISTRY FOR EXPLORATION IN THE NORTHERN YILGARN CRATON, WESTERN AUSTRALIA

David J. Gray

CSIRO Exploration and Mining / CRC LEME
david.gray@csiro.au

Introduction

Groundwaters in the northern Yilgarn are neutral and commonly of low salinity. This leads to very different groundwater signatures than, for example, the acid/saline groundwaters near Kalgoorlie. The use of groundwater in exploration in the northern Yilgarn area is discussed with reference to various sites.

Baxter/Harmony Gold Deposit

The Baxter/Harmony Deposit (previously known as the Contact Deposit) is located approximately 10 km west of Peak Hill and some 90 km north of Meekatharra. The region is arid, characterized by a low, irregular rainfall averaging 200 mm per annum. Thin vegetation cover consists largely of mulga and other drought-resistant shrubs and grasses. The deposit is located within a depositional plain with the Robinson Ranges to the west, the southerly extension of the Horseshoe Range to the north and rises and low hills to the east and south. The deposit was discovered in 1991 with mining commencing in mid-1995. Groundwaters are neutral, with a similar Eh range to other neutral groundwaters from the Yilgarn Craton. A marked divergence from sea water element ratios suggests that the major ion concentrations are strongly controlled by local lithological or hydrological factors.

The Baxter groundwaters have extremely low Au concentrations (Figure 1), commonly 100-1000 times lower than in mineralized areas around Kalgoorlie. Despite this, Au (Figure 2) does show value as a groundwater pathfinder. Additionally, Sc, Mo (Figure 3), W and, possibly, Rb were observed to have greater groundwater concentrations in areas of Au mineralization and at this site are better pathfinders in groundwater than Au itself. This elemental suite is similar, though more limited, to those observed at other sites. These elements may have scope as target elements for selective extraction of soil or other regolith material. Other elements can be used in groundwaters to indicate underlying rocks or other geochemical features. For example, dissolved Cr concentrations correlate closely with the presence of ultramafic rocks, even for highly weathered lithologies. Dissolved As and, to a lesser degree, Ni correlate with a zone of As-enriched rocks to the SE of the study area.

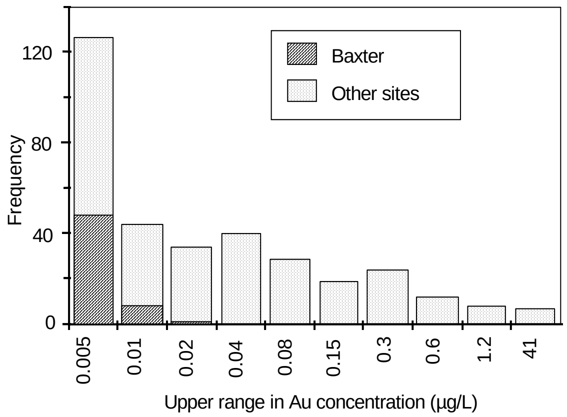


Figure 1: Histogram of dissolved Au concentrations for groundwaters from Baxter and other sites.

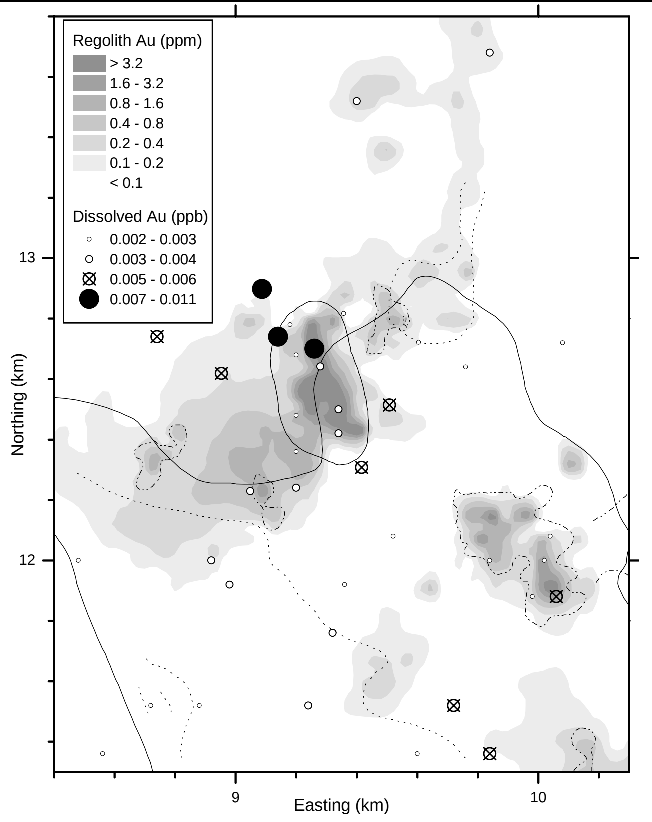


Figure 2: Dissolved Au distribution at Baxter (dots) superimposed on maximum Au contents in the regolith.

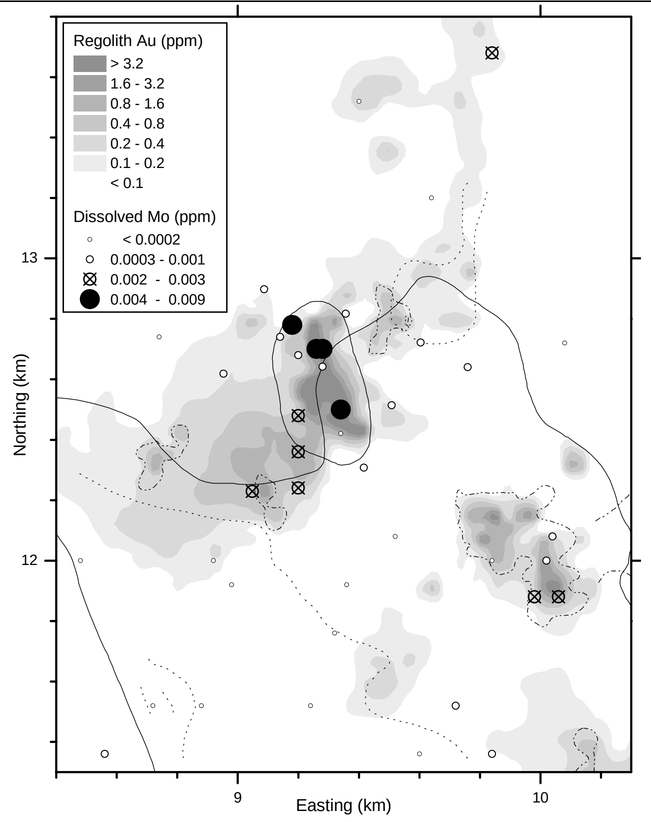


Figure 3: Dissolved Mo distribution at Baxter (dots) superimposed on maximum Au contents in the regolith

Harmony Nickel Deposit

Harmony Ni deposit is situated 11 km NE of Leinster. Mineralization occurs over a thin 1.2 km north striking peridotite unit dipping to the west at approximately 80°. It is composed of pyritic massive Ni sulphides ranging from 1.0 to 5.5% Ni, overlying low-grade (< 1.0% Ni) disseminated sulphides in olivine peridotite. Oxidation occurs to 50 – 70 m depth. Groundwaters are low salinity and are commonly neutral (pH range 6.4 – 7.7). However, lower pH values (5.0, 5.9) were observed in two holes, possibly indicating sulphide oxidation, as might higher Eh and Fe values than other northern groundwaters.

Groundwaters are distinguished as mineralized where the drill holes intersected the mineralized vein. Ratios of mineralized/unmineralized medians for elements (less the two samples with [Ni] > 50 mg/L) are shown in Figure 4. Nickel and Co show a strong contrast between mineralized and unmineralized groundwaters. Dissolved Mo, As, Cr, V, Ge and Cu (and possibly Zn and Ca) are also enriched in the mineralized groundwaters. The U, Rb and Pb depletion may reflect lithological factors (*i.e.*, these elements tend to be low in ultramafic rocks), whereas the low HCO_3 may be a reflection of sulphide oxidation producing acidity and therefore removing dissolved HCO_3.

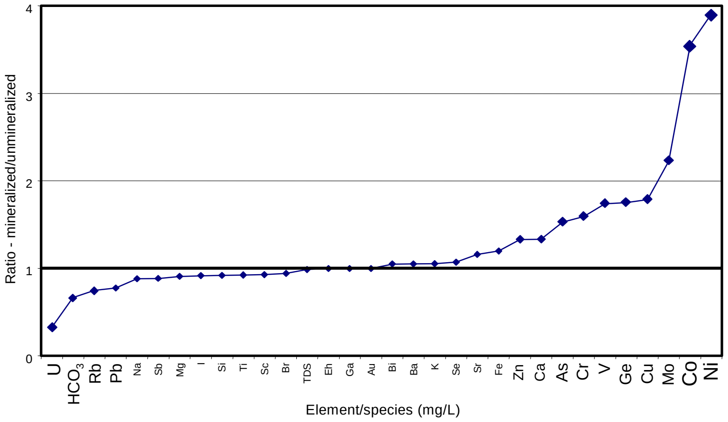


Figure 4: Ratios of mineralized/unmineralized medians for groundwaters at Harmony Ni deposit

Dissolved Ni (Figure 5) and Co are clearly enriched along the mineralized ultramafic unit, as are Mo, Cu, Ge and V. Dissolved Pt, Pd, W and Re are, although low, also enriched along the mineralized zone. On the other hand, Cr (Figure 6) shows a broader anomaly reflecting the extent of ultramafic rocks, whereas As is only enriched along the northern part of the mineralized zone. Thus, hydrogeochemical sampling of groundwaters at Harmony was successful in locating the Ni sulphide mineralization and may be of use in the detection of further deposits in similar areas.

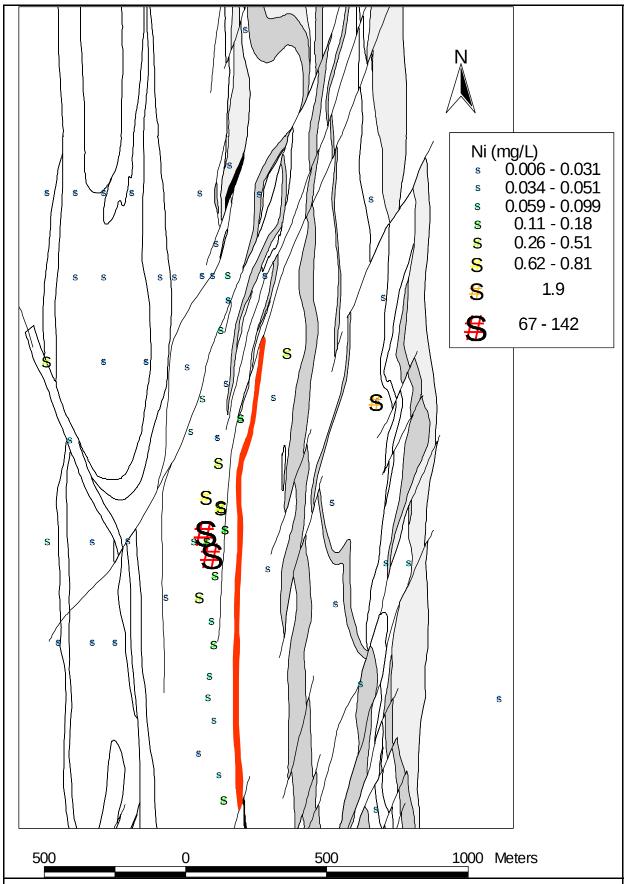


Figure 5: Dissolved Ni distribution at Harmony.

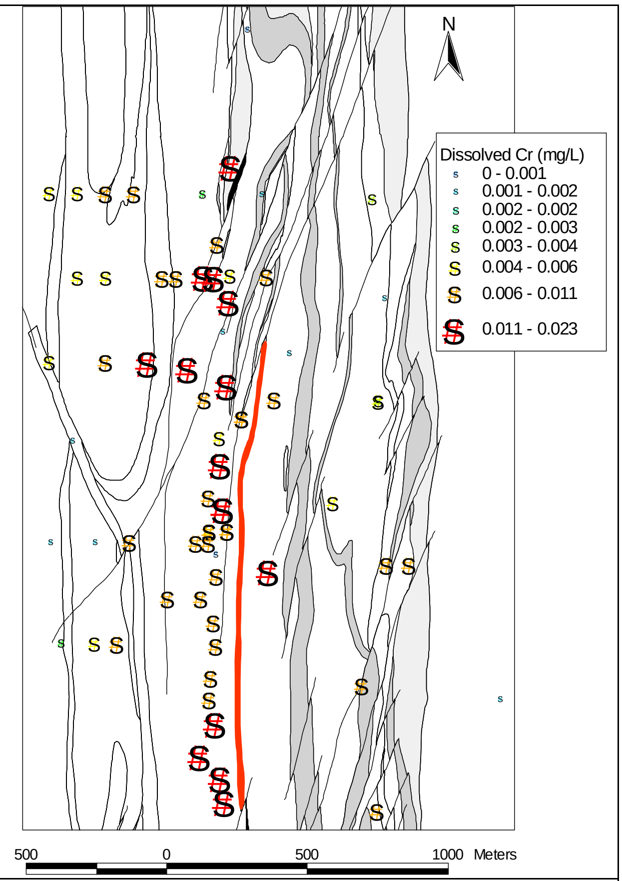


Figure 6: Dissolved Cr distribution at Harmony.

Jaguar Base Metal Deposit

The Jaguar deposit is located 65 km north of Leonora, approximately 2 km south of the old Teutonic Bore mine. The top of the Jaguar Zn-Cu-Ag VMS ore body is 250 m below the surface. A stratabound primary metal halo around the deposit is interpreted to extend to the palaeosurface which is covered by up to 15 m of colluvium and alluvium. Mineralisation is associated with a package of metasediments that can be traced along strike over several kilometres. The deposit comprises a mining reserve of 1.6 million tonnes at 3.7% Cu, 11.73% Zn, 0.72% Pb and 120 g/t Ag. Although depleted relative to primary concentrations, significant concentrations of Zn (up to 1200 ppm), Cd (up to 0.85 ppm), Sb (up to 33 ppm), Se (up to 190 ppm), Tl (up to 3 ppm), Cu (up to 400 ppm), In (up to 0.5 ppm) and Pb (up to 135 ppm) occur in the weathered zone just below the transported cover.

Dissolved concentrations of ore elements such as Cu (Figure 7) or Zn show highly sporadic high values, which could well be missed in broader spaced groundwater sampling. However, use of other indicator elements, such as Mo (Figure 8) give expanded anomalies. Further research is showing that normalised multi-element indices, which combine metals and anionic indicators such as Mo and W, can give broader and more consistent groundwater anomalies.

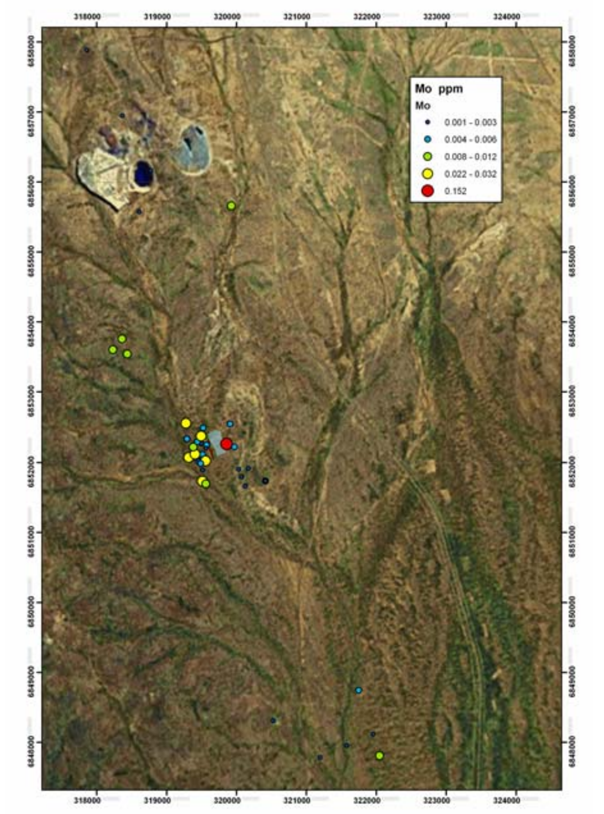


Figure 7: Dissolved Cu distribution at Jaguar.

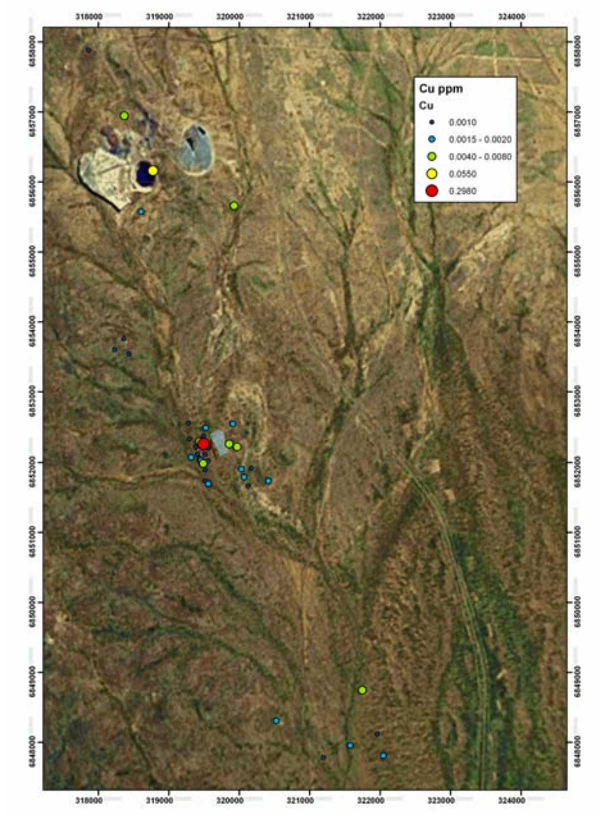


Figure 8: Dissolved Mo distribution at Jaguar.

Conclusion

Thus, results indicate exploration potential for groundwater in such environments, even where highly weathered rocks are overlain by transported material. Additionally, the elements enriched in mineralized groundwaters may also form part of a suite of elements that may yield a geochemical expression by selective extraction.

A NEW INSIGHT INTO GOLD GRAINS AS AN EXPLORATION TOOL

Robert Hough (1), Charles Butt (1), Steven Reddy (2) and Michael Verrall

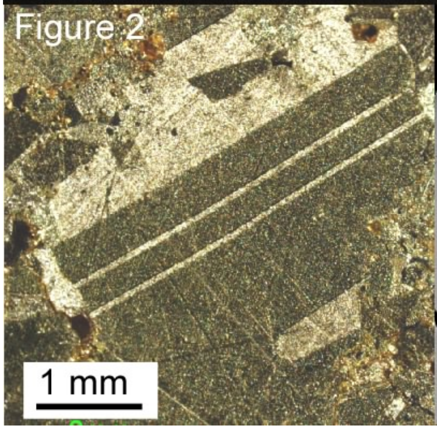
CSIRO Exploration and Mining / CRC LEME
(2) Department of Applied Geology, Curtin University of Technology
Robert.hough@csiro.au

Native gold occurring in different geological settings and from a wide range of climatic environments has been studied extensively. (Fisher, 1935; Boyle, 1979; Wilson, 1984; Freyssinet et al., 1989; Groen et al., 1990; Bowell et al., 1993; Youngson and Craw, 1995; Knight et al., 1999; McCready et al., 2003; Lengke and Southam, 2005; Reith et al., 2006). Most of these studies have been of small (10-500µm) grains, with very few of nuggets (Fig. 1) that we define as being >4mm or >1g. Although such nuggets are rare they provide an important insight into the nature of gold in the near surface environment, they also provide an important resource to develop our wider understanding of the more general chemistry and microstructure of native gold.

Primary gold is usually an alloy that commonly contains 5->50% Ag (electrum), whereas most secondary gold is commonly purer (<1% Ag) (Boyle, 1979; Freyssinet et al., 2005). Secondary electrum does occur, though it is considered rare (Webster and Mann, 1984, Bowell et al., 1993). It is the shape and the chemistry of gold grains that are used most widely for interpretations of provenance, especially in differentiating a primary hypogene origin, from one that is secondary and related to supergene processes. Crystallography is rarely considered unless the gold clearly displays it (e.g. delicate crystal forms).

In order to develop a new approach we have revealed the internal crystallographic microstructure of a representative set of gold nuggets from regions as far apart as tropical Queensland to the Eastern Goldfields of Western Australia (Fig. 1). All of the nuggets show a randomly oriented polycrystalline internal microstructure that is characteristic of thermal annealing (Fig. 2) and therefore of a primary hypogene origin. They all contain appreciable silver that is homogeneous through the nuggets, apart from at some grain boundaries. These thin areas of silver depletion (Fig. 3) have been widely reported as both rims to grains and as veinlets/cracks that propagate through the interior of grains (e.g. Knight et al., 1999).

For the first time we have shown that this depletion interior to the gold occurs along these crystallographic grain boundaries, the veins and cracks are in fact grain boundaries between individual crystals.



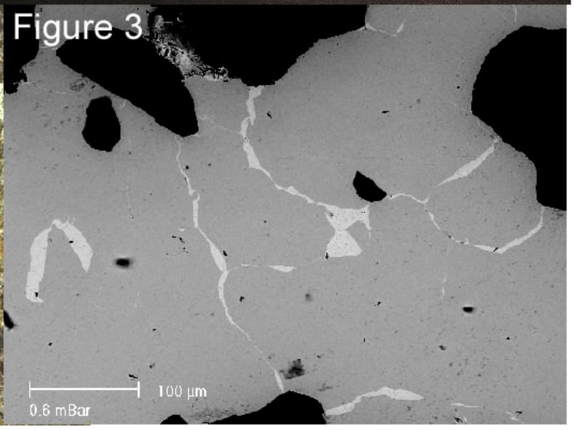


Figure 1. An 8kg gold nugget from Victoria. Figure 2. Optical micrograph of a twinned crystal from the interior of a nugget imaged in a polished section. Figure 3. Back-scattered electron micrograph (SEM) of a polished section of a nugget revealing the thin bright zones of Ag depleted native gold, these occur along crystallographic boundaries.

The depletion is a result of weathering of the alloy with the more soluble Ag being preferentially dissolved, leaving a pure gold rim to the grain boundary. Rather than the process being one of complete dissolution and reprecipitation it appears that acid oxidising fluids can penetrate along networks of dislocations that provide relative permeability to the alloy, thus only Ag is removed, once the pure gold rim forms the reaction is stopped.

The external surface of these nuggets sometimes also show a separate population of mostly anhedral gold crystals of high purity similar to those reported in the literature as rims and coatings on grains (Freyssinet et al., 1989; Youngson and Craw, 1995; Lengke and Southam, 2005; Reith et al., 2006). In these cases, we note that the gold in the rim is of high purity and is not epitaxial to the host.

Crystallography is a key component of gold grain and nugget studies that has largely been overlooked, probably in part due to difficulties in sample preparation. It provides crucial evidence for deciphering different mechanisms of gold enrichment and weathering and therefore for wider interpretations of provenance and transport that are used during exploration. All of the Australian nuggets studied indicate a primary hypogene origin for their formation but with modification by secondary processes, in effect the nuggets are themselves weathering.

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ADVANCES IN AUTOMATED REGOLITH LOGGING

Tim Munday

CSIRO Exploration and Mining / CRC LEME
tim.munday@csiro.au

No Abstract available

BIOGEOCHEMICAL PENETRATION FOR MINERAL EXPLORATION THROUGH TRANSPORTED COVER IN REGOLITH-DOMINATED LANDSCAPES

Steve Hill, Nathan Reid & Anna Petts

School of Earth & Environmental Sciences, University of Adelaide / CRC LEME,
steven.hill@adelaide.edu.au

Previous mineral exploration through regolith has been particularly focussed on applying “black box” components of the regolith as geochemical sampling media. Many of these approaches have had some exploration success, however eventually their limitations have restricted their continued application. The result has been “boom to bust” or “feeding frenzy” cycles in the promotion, adoption and disappointment in many sampling media. A major reason for this cycle ending in disappointment largely relates to the lack of knowledge of what constrains the geochemical characteristics of these media, as well as knowledge of the process and the targeting of specific and therefore consistent components of the regolith.

This presentation demonstrates how the application of novel and innovative regolith sampling media, such as plant samples, should operate within the context of regolith and landscape evolution history frameworks, which are equivalent to geological / tectonic evolution model frameworks when considering mineral systems and their bedrock hosts. Unconstrained results may make for interesting presentations in the short-term but can ultimately lead to disappointment.

Of particular importance here are the identification and understanding of regolith interfaces (the boundaries between specific zones in the regolith). These include boundaries between: transported and *in situ* regolith; redox conditions, contemporary and palaeo-groundwater (hydromorphic) boundaries; and unconformities within transported cover. The recent developments in the use of biota in the Curnamona, Gawler, Thompson and Tanami have been successful because of the development of a systematic and consistent sampling approach, as well as consideration given to their setting with a regolith and landscape evolution framework, as well as the particular interface or zone of the regolith that is being conveniently targeted by these media.

The Tanami is a classic example of a highly prospective region that has had exploration success reduced because of the extensive regolith that extends across the landscape. Well over 90% of this landscape is regolith-dominated, but so far nearly all of the significant mineral exploration success has occurred where the transported regolith is either thin or absent. This challenge is not only the case for the Tanami, but large parts of Australia also dominated by regolith and therefore it acts as a major exploration impediment in this state. This presentation looks at a multi-disciplinary approach that has been developed through recent CRC LEME research in the Tanami, and how this is providing a necessary framework and new approaches to exploring in its regolith-dominated terrains.

This research has included developing an understanding of individual components of this landscape and how each of these interacts, and then in turn how this impacts on the near surface expression of buried mineralisation. Of particular importance has been the cycling, dispersion and residence of chemical elements within biological systems, such as the major trees, shrubs and grasses as well as termites and their termitaria. The snappy gum as well as some other *Eucalyptus* and *Corymbia* trees, have shown potential to be an important sampling media for regional exploration programs, and in some cases are providing chemical signatures closely related to the underlying groundwater systems and the enlarged multi-element “footprints” of buried mineralisation. The deeper penetration of the roots of spinifex hummock grasses have greater potential for more local (detailed tenement and prospect) sampling programs, and in many ways perform in ways equivalent to drilling down to the base of transported regolith (without the high drilling and access costs and with minimal environmental impact). Termitaria have been used to provide both some surficial indication of the depth of transported cover, as well as amalgamated chemical signatures of the underlying regolith.

This approach is also being tested and developed in parts of the Curnamona, Gawler and Thompson as well as having potential for areas such as the Musgraves, and in the search for commodities such as precious metals, base metals, uranium and diamonds.

BIOGEOCHEMICAL RESEARCH FOR EXPLORATION

Ravi. Anand

CSIRO Exploration and Mining / CRC LEME
ravi.anand@csiro.au

Despite some impressive advances in exploration technology in the last two decades, geochemistry remains the prime direct sensor in the armoury of explorers. This is because many mineralisation styles have polar symmetry – that is pipe or sheet-like bodies of generally vertical dimension. Inevitably, they cut the Earth's surface and become disturbed in the regolith. However, most surface expressions of mineralisation in residual regolith terrains have been identified and tested by explorers, many of them with considerable success. There remains now only the subtle expression of near surface ore bodies, and most importantly, the undiscovered mineralisation under sedimentary cover which presents a special challenge. Of even greater challenge, from the geochemical viewpoint, are the non-polar blind ore bodies that are encased in lithified rock.

There is growing need to make surface geochemistry effective for exploring across depositional landscapes with shallow to deep transported cover and often complex regolith, using techniques such as partial and weak selective extractions and gas analysis. However, these techniques have been found to be only partly successful in delineating buried ore bodies, especially in Australia. The particular mechanism (s) and their effectiveness in transferring metals associated with mineralisation upwards through the often complex transported overburden is poorly understood. This lack of understanding complicates and limits the interpretation of geochemical datasets, and precludes the discrimination of negative from null results. The different transport mechanisms based on the main transport medium, can be grouped into four categories: *hydrogeochemical, gaseous, vegetation and bioturbation*. Most of these mechanisms are influenced by microbial reactions and the nature and evolution of the transported cover.

The vegetation biogeochemical cycle, where plants bring metals from the subsurface to the surface, has long been advocated as a predictive metal transfer tool in the northern hemisphere and parts of the tropics. The greatest potential for biogeochemistry lies in areas of transported overburden, where tap roots and, if the cover is shallow, some lateral roots, may access weathered bedrock and deep groundwaters. There is widespread vegetation cover across nearly all climatic, geological and regolith-landform environments in Australia and, consequently, a wide choice of plants for biogeochemical sampling. However, this choice is constrained by the need for the plants to have (i) deep tap roots and (ii) a sufficiently extensive distribution at the scale of the survey. Plants have evolved to mitigate the stress caused by the dry climate and nutrient-poor soils that prevail over much of Australia. One adaptation is dimorphic root systems with shallow lateral and deep tap (or sinker) roots. The latter may reach depths of 40 m or more and are able to access water and nutrients deep in the regolith, especially during dry periods. Uptake of trace elements by plants is facilitated by production of organic ligands by plant roots. Australian native plants produce cyanide, oxalate and citrate and it is likely that these and other compounds dissolve trace elements.

This paper presents recent findings of studies on vegetation growing in Au and base metals tailings as well as the planned future work under the AMIRA P778 project "Predictive geochemistry in areas of transported overburden".

GEOMICROBIOLOGY, REGOLITH AND IMPLICATIONS FOR EXPLORATION

Frank Reith (1) and Andreas Schmidt Mumm (2)

(1) CSIRO Exploration and Mining / CRC LEME
(2) Adelaide University / CRC LEME
frank.reith@csiro.au

Mineral provinces characterized by outcropping hard-rock mineralization are well explored and currently being depleted; thus, the challenge for mineral exploration is to move into areas where thick layers of regolith conceal potential mineralization (Smith, 1996). In Australia, vast regions are covered by deeply weathered residual regolith as well as transported cover of up to 100 meters, which may conceal underlying mineralization (Taylor and Eggleton, 2001). Here dispersion and re-concentration of trace elements occurs, which leads to the formation of regolith anomalies, *eg.* gold-in-calcrete anomalies, and secondary mineralization, *eg.* gold grains and nuggets. Microbial processes are known to control the mobilization, distribution and speciation of many trace metals and metalloids (eg. As, Se, Mo, Sn, Sb, Te, Hg, W, Cd, Hg, Pb, U, Ag, Cu) under a wide range of environmental conditions, and thus may control the formation secondary enrichment zones (Ehrlich 1996a,b). To generate the understanding of the relationship between microorganisms, their geochemical environment and processes relevant to mineral exploration exploration geomicrobiology has emerged as a new area of research.

Evidence from previous studies had indicated that micoorganisms may play a role in the environmental cycling of gold (eg., Mossman *et al.*, 1999). In our recent research we have for the first time studied the microbial cycling of gold in the Australian regolith to assess if microbial influences on the formation of secondary gold anomalies in soils and calcretes as well as the formation of gold nuggets (Reith *et al.*, 2005; Reith and McPhail, 2006; Reith *et al.*, in press; Reith and McPhail, *in press*, and Reith and Rogers, *in preparation*; Schmidt Mumm and Reith, *in press*). Our research has shown that microbiota resident in auriferous Australian soils and deeper regolith materials from moderate, semi-arid and tropical sites are capable of mediating a geomicrobiological cycle of gold, as shown in Figure 1. The indigenous microbiota in biologically active soil microcosms were able of solubilizing up to 80 wt.% of the gold contained in these materials during the first 50 days of incubation, after which the solubilized gold was re-adsorbed by mineral- and organic soil fractions. In contrast, no gold was solubilized in sterilized microcosms incubated under otherwise identical conditions. Molecular (PCR-DGGE, cloning and sequencing of 16s rDNA) and physiological profiling (CLPP) of bacterial communities during the incubation of the microcosms combined with amino acids analyses indicated that changes in the structure of the bacterial community from carbohydrate- to amino acid-utilizing populations occurred concurrently with and appear to be linked to the observed solubilization and re-precipitation of gold. Molecular profiling also allowed the differentiation of bacterial communities from auriferous and adjacent non-auriferous soils. These results in combination with results of *Bacillus cereus* spore counts, which were up to 1000 times higher in soils that displayed gold concentrations of 150 to 1000 ppb compared to soils with background gold concentrations, and microcosms amended with dissolved $AuCl_4^-$, suggest that the presence of highly mobile gold in the regolith as observed at many Australian sites may influence the composition of the resident microbiota.

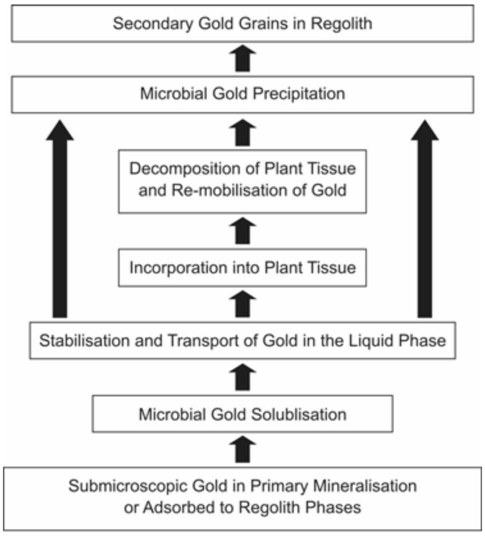

Figure 1
Conceptual model linking the processes of gold solubilization, transport, precipitation and authigenic gold nugget formation to form a geo(micro)biological cycle for the behavior of gold in the regolith.

Scanning electron microscopy (SEM) revealed bacterial pseudomorphs on untreated secondary gold grains from two field sites used in this study. The presence of active bacterial biofilms on the surface of gold grains was confirmed using confocal stereo laser microscopy (CSLM) combined with nucleic acid staining. Molecular profiling showed that unique, site-specific bacterial communities are associated with these gold grains, which differed from those dominating the surrounding soils. 16S ribosomal DNA clones belonging to the genus *Ralstonia* and bearing 99 % similarity to *Ralstonia metallidurans* were present on all 16S rDNA positive gold grains from both locations, but were not detected in the surrounding soils. The ability of *R. metallidurans* to actively accumulate gold from solution was then successfully tested suggesting that *R. metallidurans* may contribute to the formation of secondary gold grains and nuggets in the regolith.

The association of gold with calcrete and calcareous sands in the regolith has been established through numerous studies conducted many samples from southern and western Australia and has become the preferred strategy in large parts of Australia. The genesis of pedogenic carbonates has been ascribed to abiotic inorganic and biologically mediated precipitation of carbonates in regolith profiles, and both mechanisms have been observed in the natural environments (Castanier et al., 1999a,b; Stumm and Morgan, 1996). Mass balance estimates by Castanier et al. (1999a,b) suggest that the heterotrophic microbially mediated carbonatogenesis accounts for the most of the formation of these carbonates rather than pure abiotic processes. One of the most common microbial processes leading to the formation of carbonate in a wide range of terrestrial environments are the ammonification of amino acids and the degradation of urea and uric acid (Castanier et al. 1999).

Schmidt Mumm and Reith (*in press*) assessed gold in calcrete anomalies (2.5 to 50 ppb) and microbial degradation of urea in regolith carbonate accumulations in aeolian sand dunes of 2 to 4 m thickness overlying gold mineralisation in granitoids of the Gawler Craton in semi-arid South Australia. The results of the microbial study suggested that the genesis of the calcrete and pedogenic carbonate may be biomediated through reactions the microbially mediated urea break down, which occurred in all samples in a depth profile and provided a pH and pCO_2 environment conducive to carbonate precipitation. Schmidt Mumm and Reith (*in press*) therefore proposed a coupled model of bio-mediated and inorganic mechanisms that control gold and calcrete precipitation as shown in Figure 2. Urea is a product of the metabolic breakdown of purine and amino acids such as arginine in bacterial cellular processes through which microorganisms derive nutrition and energy (Vogels and Drift, 1976; Cunin *et al.*, 1986). If the amino acid breakdown can be applied to those involved in gold complexing, the process would have a destabilising effect on the gold-amino acid complexes. The urea released in the break down of these amino acids is transformed by the urease to CO_2 and NH_3 establishing pH and pCO_2 (or aCO_3^{2-}) conditions conducive to biologically mediated carbonate precipitation in the calcrete bearing environments. Together with the destabilised gold amino acid complexes this process potentially provides a tight link between carbonate formation and related gold enrichment in calcretes. This has model has recently been substantiated in a laser ablation ICP-MS study of microbially precipitated carbonates, that were enriched in gold by factors of up to 100 compared to the surrounding microbial growth medium.

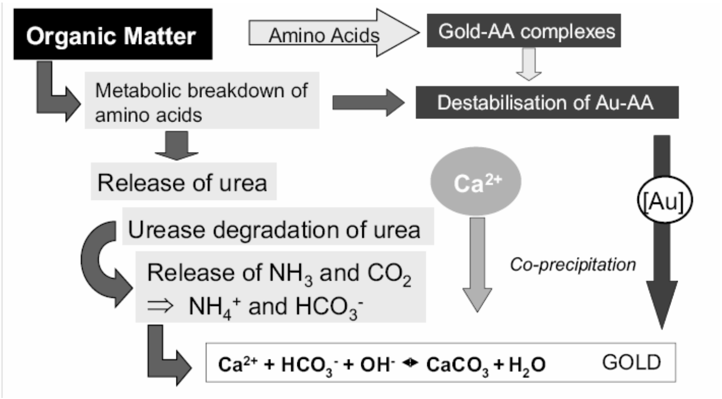

Figure 2
The coupled biologically mediated and abiotic model for the Au enrichment in calcrete
(from Schmidt Mumm and Reith, in press).

In our studies we have thus shown for the first time that microbiota resident in Australian regolith are capable of actively mediating a biogeochemical cycle of gold in the environment. Furthermore, we have discovered evidence for a number of processes and organisms that may be associated with this cycle. By identifying these and further geomicrobial processes leading to the dispersion and accumulation of trace elements in the regolith, and quantifying the reaction kinetics of these processes, the new field of exploration microbiology will help mineral explorers to develop predictive biogeochemical modelling tools (Figure 1). Ultimately, we will be able to incorporate appropriate data into numerical geochemical models to predict dispersion, transport and concentration of trace elements in and around mineralised zones. Identification of the microbiota and microbial processes that control the solubilization, transport and precipitation of trace metals in the regolith will lead to the discovery of indicator microorganisms and genes, and the development of microbial biosensors for underlying mineralization.

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SEQUENTIAL EXTRACTION OF METALS ADSORBED TO CHARCOAL

Yamin Ma and Andrew W. Rate

School of Earth and Geographical Sciences, University of Western Australia
may01@student.uwa.edu.au

Introduction

Up to 50% of the soil carbon store (dependent on soil type) in Australia consists of charcoal, given the high frequency of fires (Skjemstad et al. 1998). Charcoal is highly porous has a large surface area. As a result, it strongly adsorbs organic compounds and metal ions and has been used in the recovery of metals from various industrial processes (Gustafsson et al. 2003). It is therefore possible that the immobilisation of metals through their interaction with natural charcoal may be significant. Testing this hypothesis becomes problematic considering the typically small size (<53µm (Skjemstad et al. 1998)) of charcoal particles that occur naturally in Australian soils. Manually isolating such charcoal particles has proven difficult and exhaustive in the past. Hence, in this study, we test the robustness of a typical sequential extraction technique by applying it to naturally occurring charcoal that has been spiked with five different concentrations of metals (Al, Cr, Cu, Ni, Zn, Ag, Pb). Soils mixed with this spiked charcoal were also sequentially extracted in the same manner.

Method

Cleaned charcoal samples were ground and spiked with a metal-ion cocktail consisting of Al, Cr, Cu, Ni, Zn, Ag and Pb at a range of concentrations. The spiked charcoal was then sequentially extracted with a scheme based on that of Hall et al. (1996) and consisted of the following five extractions in the order: 1) 1.0M Sodium acetate, pH 5 (targeting the acid-exchangeable-carbonate fraction), 2) 0.1M sodium pyrophosphate (organic fraction), 3) 0.2M ammonium oxalate + 0.1M oxalic acid; pH 3 (amorphous iron/manganese-oxides), 4) 1.0M hydroxylamine hydrochloride (crystalline iron/manganese oxides) and 5) residual (1:1 *aqua regia* digest). Samples of the charcoal were ashed to obtain total adsorbed values and to calculate metal recoveries i.e. sum of individual extraction fractions ÷ total digested from ashed charcoal. Soils with charcoal added to them were sequentially extracted in a similar fashion.

Results

The majority of metals added to the charcoal were extracted in the fractions targeting both the amorphous and crystalline iron and manganese oxides, at low metal concentrations (see Figure 1 and 2). At higher concentrations of metals added to the charcoal, the concentrations extracted change according to the extractant used (Figure 1). At these concentrations, the metals were mostly extracted from the adsorbed-exchangeable-carbonate fraction (Figure 1). Reasonable recoveries of metals were obtained from the sequential extraction (80%-130%).

In the soil experiment, the total amount of metals extracted increased with the percentage of metal-spiked charcoal added (Figure 3). The extraction shows similar concentrations reporting to the same fractions as that of the charcoal-only results. However, metal recoveries varied widely and may be a result of sub-sample variability.

Discussion

Why would the metals be extracted in this pattern? Sequential extractions are time dependant and readsorption of metal ions onto charcoal surfaces could have occurred (Hall and Pelchat 2005), particularly since charcoal has a large and highly porous surface area. Additionally, the effectiveness of the extractants may be kinetically inhibited and subsequently lower concentrations of metals extracted. On the other hand, because charcoal comprises of highly disordered, polyaromatic sheets metal ions can migrate into these spaces and hence, would require fairly aggressive chemical conditions, such as the hydroxylamine hydrochloride.

Conclusion

Our results demonstrate that a selective sequential extraction is inadequate for quantifying the amount of metals sorbed to charcoal in soil since the extraction is concentration dependant. Hence, quantifying the significance of charcoal as a trace element sink in "real" soils is as yet, unattainable.

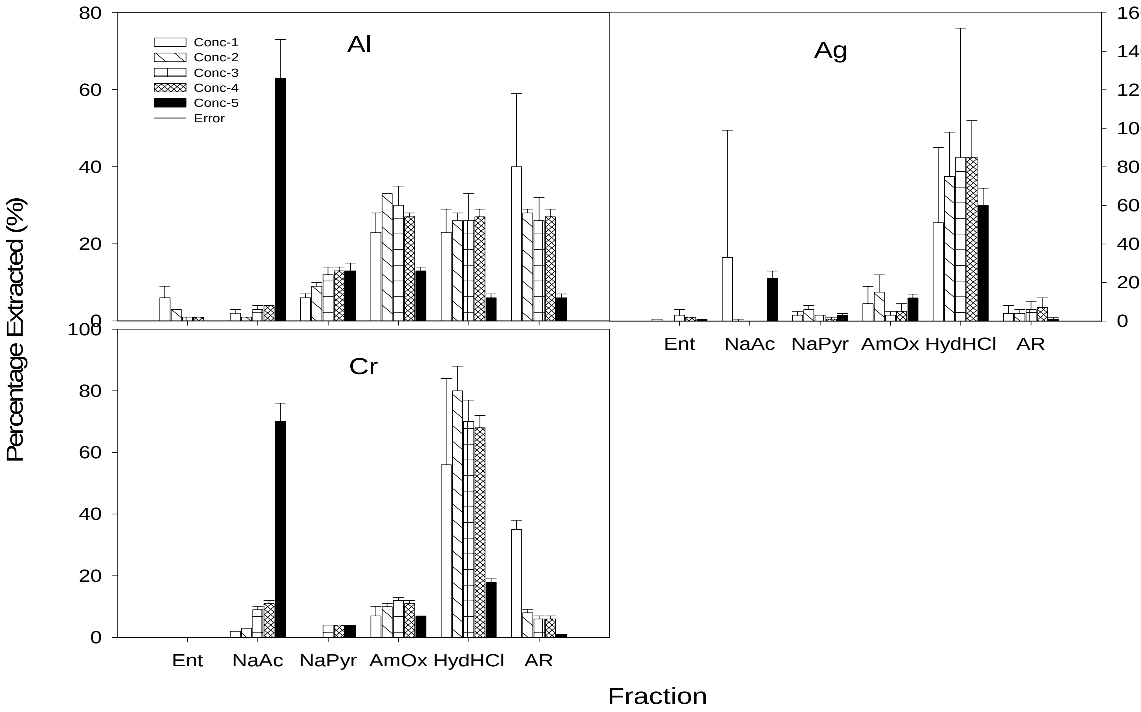

Figure 1 - Percentage of total metal extracted from charcoal for alumiunium, chromium and silver in each fraction for each level of metal addition. Ent- entrained, NaAc- 1.0M sodium acetate (pH 5), NaPyr- 0.1M sodium pyrophosphate, AmOx- 0.175M ammonium oxalate in 0.1M oxalic acid (pH 3.0), HydHCl- 1.0M hydroxylamine hydrochloride and AR- 1:1 aqua regia after ashing. Error bars represent standard errors of means. Cr and Ag show a similar extraction pattern in that most of the metals are extracted in hydroxylamine hydrochloride. All metals show an increase in the sodium acetate fraction at high concentrations of metals

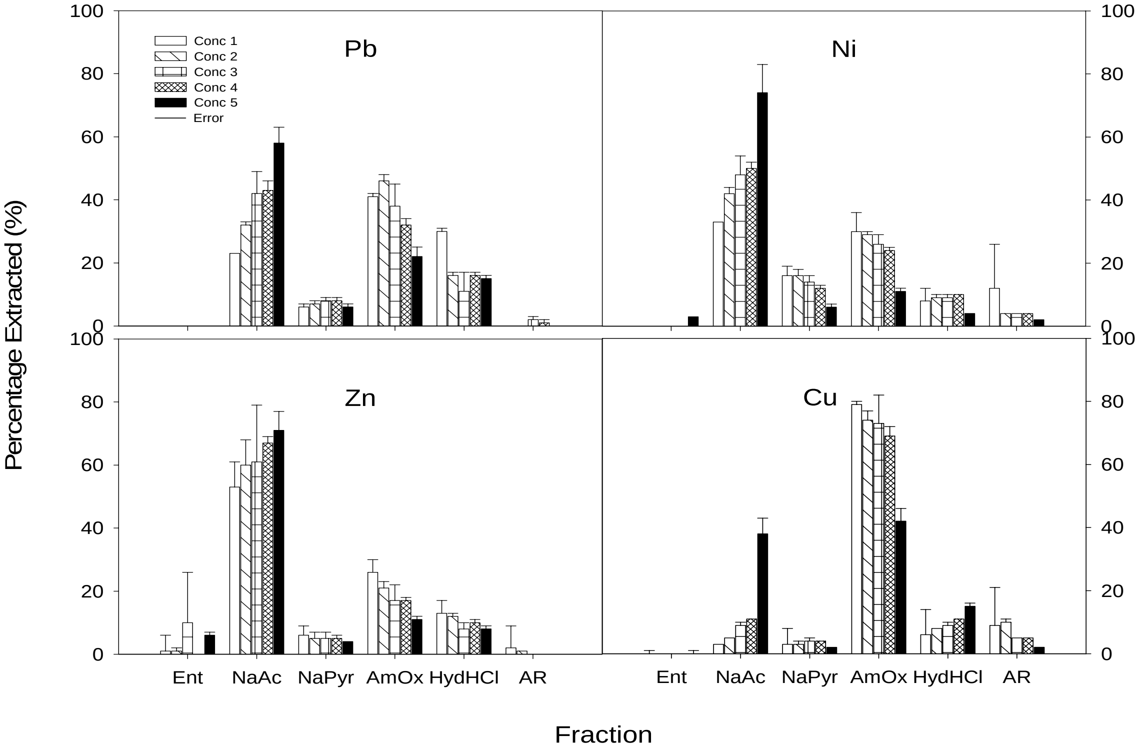

Figure 2- Percentage of total metal extracted from charcoal for lead, nickel, zinc and copper in each fraction for each level of metal addition. Ent- entrained, NaAc- 1.0M sodium acetate (pH 5), NaPyr- 0.1M sodium pyrophosphate, AmOx- 0.175M ammonium oxalate in 0.1M oxalic acid (pH 3.0), HydHCl- 1.0M hydroxylamine hydrochloride and AR- 1:1 aqua regia after ashing. Error bars represent standard errors of means. All metals show an increase in the sodium acetate fraction at high concentrations of metals added (Cf. Figure 1). This figure shows that the majority of these metals were extracted in the ammonium oxalate fraction. This is particularly evident in the results for Cu.

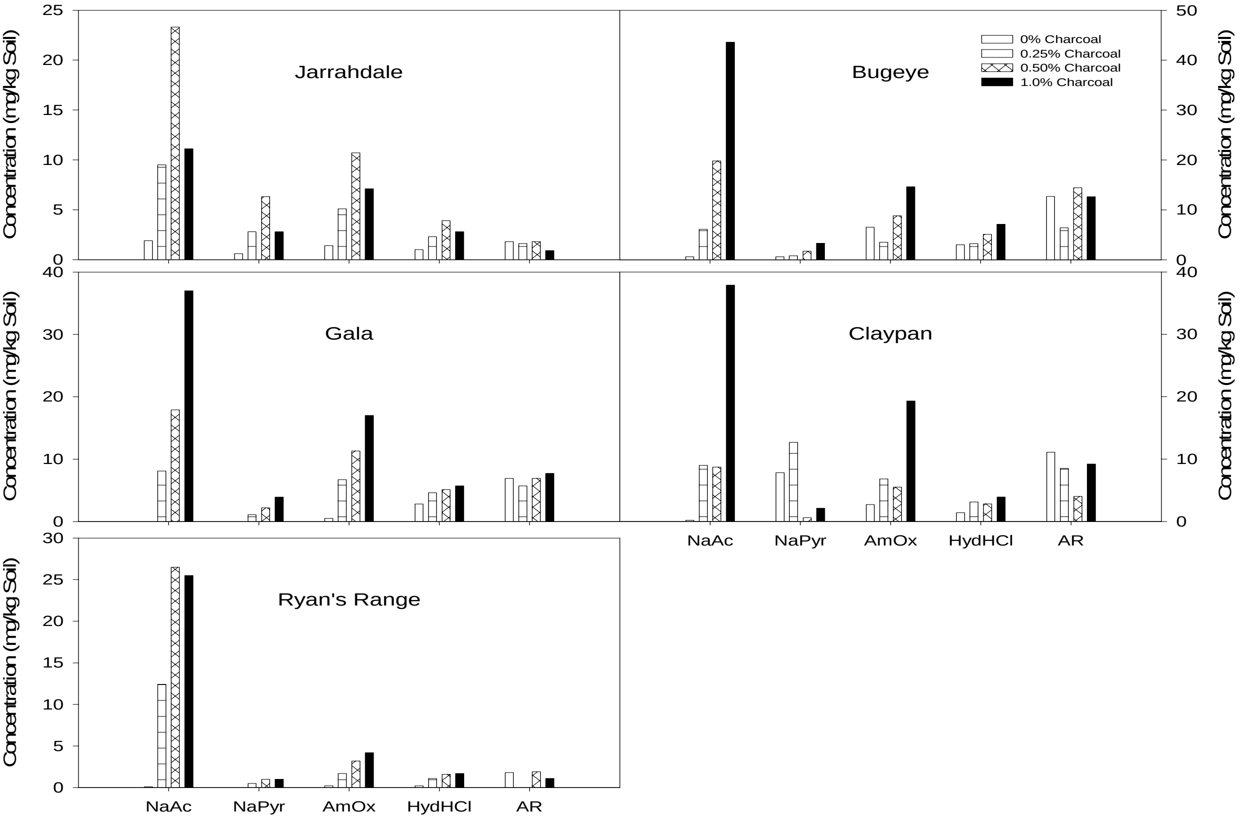

***Figure 3**- Concentration of Pb extracted in sequential selective fractions, as a function of amount of metal-spiked charcoal added from different soils, NaAc- 1.0M sodium acetate (pH 5), NaPyr- 0.1M sodium pyrophosphate, AmOx- 0.175M ammonium oxalate in 0.1M oxalic acid (pH 3.0), HydHCl- 1.0M hydroxylamine hydrochloride and AR- 1:1 aqua regia after ashing. The extraction results show a similar extraction pattern to that of the charcoal only experiment at Concentration-5 (Cf. Figure 2 and 3).*

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TRANSIENT ELECTROMAGNETIC SIGNATURES OF REGOLITH LANDFORMS – A CASE STUDY

John Joseph

University of Adelaide / CRC LEME
john.joseph@adelaide.edu.au

Among the geophysical methods, electromagnetics (EM) have the broadest range of instrumental systems and remarkably wide range of applications. The main physical property involved in EM technique is electrical conductivity (σ), which is a measure of how easily electric current can pass through a material (some times this property is represented as its reciprocal (1/σ), which is called as the electrical resistivity, ρ). Conductivity within the subsurface is a complex function of several variables, which includes the conductivity of the material or rocks (depending on their chemical/ mineralogical composition), its porosity, conductivity of pore fluids, degree of saturation etc.

EM techniques can be classified as (1) transient or time domain (TEM) systems, where the measurements are made as a function of time, and (2) frequency domain (FEM) systems which use one or more frequencies. The conductivity of the ground is measured by inducing an electrical field through the use of time-varying electrical currents in transmitter coils located at or above the surface of the ground. These time-varying currents create magnetic fields that propagate in to the earth and cause secondary electrical currents, which can be measured using receiver coils either while the primary field is transmitting (in FEM) or after the primary field has been switched off (in TEM). Depth-resistivity soundings are mainly done using TEM, while mapping of lateral conductivity contrasts are predominantly done using FEM.

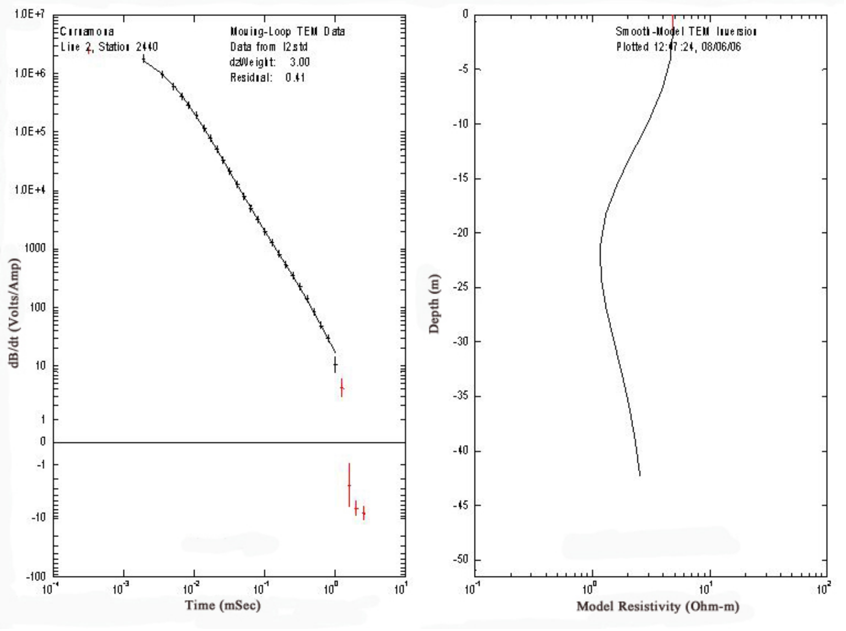

Figure 1; TEM response obtained from one of the recent surveys. Left one shows the decay curve of the secondary magnetic field and the right one shows the 1-D depth-resistivity profile obtained after applying smooth inversion technique.

Bodies of regolith land-forms with same provenance and subjected to similar weathering process could possibly produce spatially coherent EM responses. But in general regolith materials do not posses unique conductivity values. This could obviously be due to the influence of pore fluid conductivity and the extent of saturation. So it may be difficult to construct a reference chart of conductivity values for different regolith landform units. This situation made the base metal explorers to consider the regolith materials as major sources of noise. But later it has been realised that mapping of conductivity variations within the regolith landforms have an application as an adjunct for detecting discrete conductor.

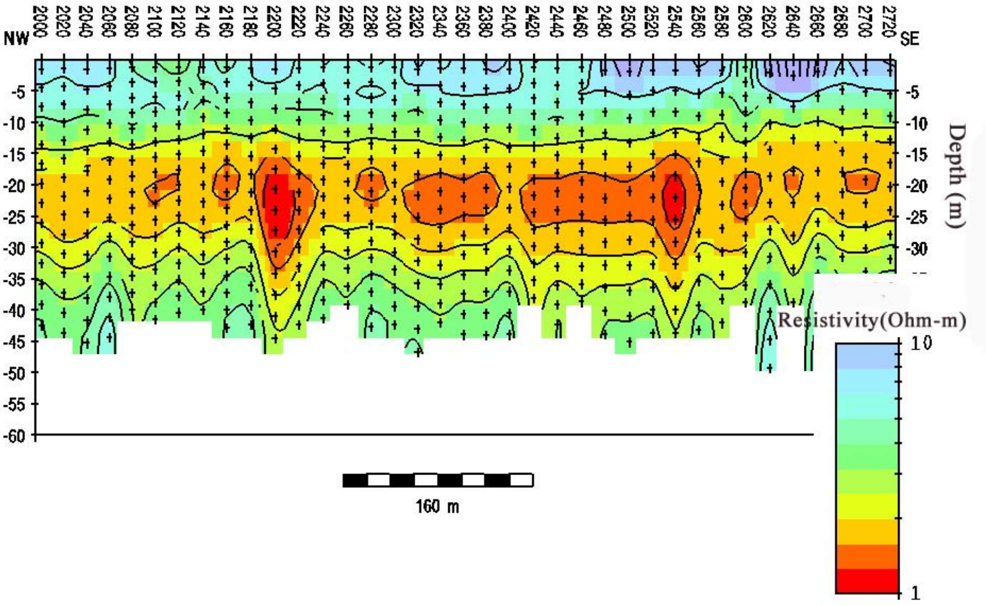

Figure 2; Two-dimensional depth-resistivity profile of the regolith materials imaged along one of the TEM survey lines at Kalkaroo mineral prospects, South Australia. The shallow subsurface in this survey region is comparatively less resistive due to the presence of various regolith landforms. A very low resistive (highly conductive) zone is clearly seen between 20-30m depth indicates the presence of high clay content.

Right now a wide range of simple to use, compact EM instruments are available for mapping electrical conductivity to depths of less than a metre to several hundreds of metres. These EM systems along with modern data processing techniques are capable of imaging the conductivity distribution as a function of depth, which in turn enhanced the quality of information on subsurface materials and thus simplifies the geological interpretation. However, additional geological, geochemical or geophysical constraints or a combined approach of all these methods could certainly lead to better understanding of the subsurface geology. Here in this presentation we shall discuss the results of a TEM survey conducted for imaging the shallow subsurface conductivity distribution at one of the mineral prospects in South Australia and comparison of these results with other geological information. This survey was conducted as a part of an on-going CRC-LEME sponsored multi-disciplinary project with an objective of enhancing the ability for exploration in areas of regolith cover.

USING AIRBORNE GRAVITY GRADIOMETRY TO FIND NEW GOLD DEPOSITS

Anton Kepic

Dept Exploration Geophysics, Curtin University of Technology / CRC LEME
kepic@geophy.curtin.edu.au

Abstract not available.

SEISMIC REFLECTION FOR GOLD AND NICKEL TARGETS IN WA

Anton Kepic

Dept Exploration Geophysics, Curtin University of Technology / CRC LEME
kepic@geophy.curtin.edu.au

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