Cooperative Research Centre for Landscape Environments and Mineral Exploration

CRC LEME Minerals Brief

Regolith Science in Mineral Exploration

February 2004

FROM THE CEO

Welcome to the LEME Minerals Brief. We intend this to be a succinct quarterly update of progress in applying regolith science to mineral exploration. It is directed primarily to geoscientists in the exploration and mining industry.

CRC LEME is the cooperative research centre for regolith geoscience with some 130 contributing researchers from eight core parties around Australia. We undertake research and technology developments for mineral exploration, as well as for natural resource management. LEME undertakes collaborative research on agreed projects using a reservoir of participants' researchers from one or more of the core parties. LEME also conducts one-on-one multidisciplinary research with external parties, including industry, under suitable funding arrangements. Research proposals from industry are welcome. This Minerals Brief presents scientific advances from just some of its many projects within its core programs, and includes contributions from LEME postgraduate students. Details of the full range of our programs, portfolio of projects and publications are available on our website: **http://crcleme.org.au**.

Dennis Gee - CEO, CRC LEME dennis.gee@csiro.au

METAL MOBILITY IN REGOLITH

Frank Reith at Australian National University (ANU) is looking at the role of microbes (heterotrophic bacteria) in the dissolution, transport and stabilisation of gold in regolith. On the dissolution side, selective sequential leaching suggests that gold in soil is mostly associated with exchangeable clay-bound and carbonate-bound fractions, as well as organic fractions. Most of this gold can be extracted in the laboratory with mild organic leachates in the presence of living microflora, whereas in sterilised samples, little or no gold is mobilised. The dissolution agent may be amino acids, organic acids or cyanide secreted from common soil heterotrophic bacteria – such as *Chromobacterium violaceum*.

On the precipitation side, Frank notes that micronuggets (0.1-1.0mm) have the form of budding cells of *Pedomicrobium australiensis* of 0.5µm size, now presumably fossilised by native gold. He demonstrates in the laboratory that microbes in the soil are active, and capable of precipitating amorphous ferrihydrite on planted gold flakes in a form identical to the micron-scale fossil buds. Some species of bacteria (and fungi) are able to accumulate gold in cell walls, replacing ferrihydrite. DNA staining on gold flakes shows the presence of biofilms on natural gold flakes, and hopefully will determine the precise nature of the precipitating organism. frank.reith@anu.edu.au

Ryan Noble at CUT is looking at dispersal mechanisms of gold, arsenic and antimony, in the vicinity of buried gold deposits near Stawell (Victoria). In the process he is investigating the use of bacterial leaches in partial extractions of regolith samples, which have the potential to enhance the geochemical signature of underlying mineralisation. Results are encouraging in

recognising regolith-covered gold deposits using soil bacteria leaching. Here the regolith cover is about 100 metres of Murray Basin sediments. Multi-element suites from bacterial leaches were compared with partial leach media such as weak acid, weak H_2O_2 and total digest HF. The bacterial leach seems to be picking up patterns not identified by the other leaches. These anomalies are being further investigated. noblerr@ses.curtin.edu.au

Chris Gunton at ANU is studying the chemical trapping mechanisms of groundwater-borne metals in regolith, with an initial focus on adsorption of $Cu_{(II)}$ onto synthetic goethite. Previous studies show increased adsorption at higher pH, but Chris is studying the effect of salinity by varying NaCl over a wide range. His laboratory work shows with increasing salinity, adsorption of $Cu_{(II)}$ increases, the opposite of what was expected. This confirms that goethite is a preferred sampling medium, and implies in a hypersaline oxidising environment, the copper dispersion halo will be minimal. Thus copper anomalies (even at low levels) will be meaningful. Wider implications include the possibility that copper accumulations and anomalies could form in oxidised parts of the regolith where less saline waters mix with saline waters. christopher.gunton@anu.edu.au

Alistair Usher at ANU is studying gold geochemistry and mobility in hypersaline brines. Preliminary gold solubility experiments have highlighted the need to develop a new analytical method for the analysis of trace levels of gold in solution. Suitable mineral phases have been identified, new experimental apparatus designed (ie a Schlenk line) and a new laboratory is being commissioned. Concurrently, a spectrophotometric study of oxidised gold chloride species in hypersaline solution has been undertaken in collaboration with researchers at Monash University and the CRC-LEME node in Adelaide. Experimental data will be used to identify the important $Au_{(III)}$ chloride complexes and derive their thermodynamic properties. The results will be used to help predict gold leaching, transport and deposition in saline and hypersaline brines in regolith and identify optimal environments for exploration.
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BIOGEOCHEMICAL EXPLORATION

Research under the direction of **Steve Hill** of Adelaide University (AU) is revisiting the vexed question of biogeochemical sampling for metals. **Karen Hulme** also at AU is focussing on river red gums (*E camaldulensis*) which present an ideal sampling medium because of their widespread occurrence in the transported regolith in arid environments, their confinement to watercourses, and their extensive tap roots. Orientation sites have been set up in the Curnamona Craton, on the basis of proximity to various styles of mineralisation. Multi-element analyses have been done on leaves, twigs and bark, with repeat sampling to test for seasonal variation. Significantly, two sites over gold mineralisation had detectable gold with 0.6–1.4 ppb Au in twigs, and 0.2–0.4 ppb Au in leaves. There are significant levels of As, Cu and Zn in leaves and twigs. All other elements in the suite of 24 were below detection. These preliminary results offer promise of a convenient sampling medium in areas of transported arid regolith.
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EXPLORATION SPIN-OFF FROM ACID SULPHATE SOILS

Research on the environmental geochemistry of acid sulphate soils (ASS) at CSIRO Land & Water has spin-offs for mineral exploration. ASS in saline seeps develop in advance of a rising watertable as a result of land clearing, and bring salt and other solutes to the surface. These seeps present opportunities for regional mineral exploration.

In the Mt Lofty area (SA) **Marian Skwarnecki** and **Rob Fitzpatrick** (CSIRO LW) have released a model to account for high metal discharges. In areas with sulphide-rich basement rocks, rising ground waters can be rich in sulphate, and have elevated As, Pb and Zn. These become further concentrated by evaporative transpiration. In soils of high organic carbon in waterlogged conditions, cyanobacteria reduce these sulphates, forming secondary framboidal

pyrite and micro-filamentous authigenic sphalerite in soils near the surface. With further rise of the watertable these re-oxidise and produce scums and gels of Al and Fe hydroxy minerals (eg ferrihydrite) in discharge areas, with element concentration. This pilot study identified a multitude of anomalies, many of which correlate with known mineralisation, and some of which are new unexplained anomalies. This new sampling medium has potential to produce enhanced anomalies of large footprint, drawn from a wider basement substrate. rob.fitzpatrick@csiro.au

Andrew Baker at AU is using lead isotopes to model the interaction of groundwater with bedrock (including mineralisation), in the vicinity of ASS seeps. The lead isotope signatures from mineralised basement extend for about one kilometre in groundwaters. The lessons for exploration are that soils in ASS seeps are good sampling points to detect blind mineralisation, but the bulls-eye anomalies are not necessarily point-source with respect to mineralisation. andrew.baker@student.adelaide.edu.au

Also **Steve Rogers** of CSIRO LW Adelaide is looking at the role of sulphur oxidising bacteria in the formation of ASS. Rather than a phyllogenic approach, he is researching functional attributes of the bacterial genes that encode the enzymes responsible for biogeochemical oxidation. These attributes derive from the molecular analysis of extracted DNA from field samples, which in turn enables the reaction kinetics of a large diversity of bacterial 'species' to be defined. The application of functional molecular biology to the organisms (both oxidising and reducing) involved in the formation of ASS may have application in designing new bioleaches for mineral exploration and mineral processing. steve.rogers@csiro.au

EXPLORATION UNDER TRANSPORTED REGOLITH

The Western NSW Regolith project led by **Patrice de Caritat** of Geoscience Australia (GA) aims to stimulate mineral exploration in regolith-dominated terrains by providing knowledge on regolith landforms and geochemistry of transported regolith. A focus is the Teilta 1:100K sheet, where groundwater, calcrete, gypsum and plant samples have been collected and analysed. This data will be combined with basement geology to provide a 4-D model of landscape evolution and geochemical dispersion. Major and trace element concentrations, isotope ratios and geochemical modelling enable the detection of sites near sulphide accumulations under as much as 100 m of sediments in the basins around Broken Hill. Groundwater is emerging as a sampling medium to give vectors to mineralisation under cover. Groundwater has been analysed for S, Sr and Pb isotopes. Some groundwater around Broken Hill has contents of sulphur significantly greater than can be accounted for by normal rainfall, evaporation or mixing with connate waters. Most importantly, those samples have ^{34}S-depleted sulphur indicating likely derivation from basement mineralisation.
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The Girilambone project, led by **Ken McQueen** (ANU), is developing methods to assist mineral explorers in regolith-dominated areas of the western Lachlan Fold Belt. It is also building an understanding of regolith-related controls on target-pathfinder element dispersion in the region and establishing a geochemical data base for background variation. Scientific advances include:

- Development of regolith-landform mapping methods for mineral explorers, and for routine map production.
- Characterisation of the aeolian component (geochemical diluent) in soils
- Improved understanding of lag geochemistry in the Cobar area.
- New geochemical targets for gold exploration

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Chlorite-sericite alteration associated with gold mineralisation at the Tunkillia Prospect of the Central Gawler Gold Province has been mapped through transported cover by integrating interpreted aeromagnetic and airborne electromagnetic data. **Lisa Worrall** and **Richard Lane** (GA) used aeromagnetic data to define zones of magnetite destruction in regional structures and AEM to locate chlorite-sericite alteration within these zones. AEM can map chlorite-

sericite alteration in this region because deep weathering has enhanced the contrast between the electrical properties of altered and unaltered rocks.
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Ian Lau and **Tom Cudahy** (CSIRO EM) successfully calibrated spectral characteristics of the newly-acquired wide-band ASD field spectrometer with those of the HyMap™ airborne scanner. The ASD identifies, by spectral signatures, iron oxides, phyllosilicates and carbonate minerals at the surface, as well as clay minerals. Trial swathes over the White Dam gold deposit show that the airborne scanner can detect the boundary between *insitu* regolith (including saprolite) and transported regolith, from the kaolinite crystallinity index. Thus we have a prototype of an airborne system to rapidly map regolith minerals. The next step is to map regional alteration trends in *insitu* regolith, no matter how degraded.
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In the pursuit of making geochemistry work through transported regolith **John Keeling** (PIRSA) described evidence of upward capillary movement of copper-bearing solutions into transported clays 5 – 15 m thick, above the Poona (Moonta SA) Cu–Au deposit. Atacamite nodules were developed in transported kaolin/illite/smectite clays and in thin seams of alunite-halloysite clay. This happens where there is direct contact between transported clay and underlying weathered porphyry. The alunite-halloysite is interpreted to form by acid-sulphate weathering of the transported clay. Here we have additional means of detecting mineralisation using spectral logging to identify alunite-halloysite in the transported regolith.
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K P Tan of ANU found no detectable pathfinder elements in the 40-70m thick transported regolith above the Portia Cu-Au deposit in SA. However he found strong geochemical signals in the palaeovalley fills at the interface with the weathered saprolite. The geochemical signals are from locally distributed saprolite clasts. kokpaing.tan@ga.gov.au

Ray Smith (CSIRO EM) is working on recognition of criteria diagnostic of base-metal sulphide deposits in basal units of transported cover. Currently, his focus is the basal lateritic conglomerate that forms the thin cover surrounding the Golden Grove Gossan Hill Cu-Zn-Au VHMS deposit, using CSIRO orientation sampling carried out before disturbances from mining operations. His approach is to establish what textural and compositional features can be recognised in clasts, lateritic nodules and other detrital grains in the basal conglomerate. The work involves extensive scanning electron microscope and electron microprobe investigations. His intent is to then translate findings from this and other orientation studies where cover is thin to establish models for exploration where cover is hundreds of metres thick. raymond.e.smith@csiro.au

Annamalai Mahizhnan (CUT) has studied the red-brown hardpans in the Eastern Goldfields (WA). He found that hardpans occur well south of the Menzies Line which therefore does not mark the southern boundary of red-brown hardpan in the Yilgarn Craton. The cement in these well indurated clastic hardpan sheets is composed of disordered kaolinite and opal A. As such the hardpan would not normally be expected to have post-cementation chemical reactivity or permeability, in which case the only possibility of geochemical gold lies with detrital flakes, despite the abundance of goethite/hematite in nodules that would absorb up hydromorphic gold. Yet these sheets have calcrete replacements that do represent a suitable sampling medium for hydromorphic gold.
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Rob Hough, **Cajetan Phang** and **Ravi Anand** at CSIRO EM, Perth continue to study mineral phases and mineral associations that act as hosts for trace levels of metals in regolith materials. In hardpans and clastic ferricrete immediately above the primary/supergene gold deposit in the enterprise Pit (Mt Gibson gold project), they micro-mapped eminently detectable gold using LA-ICPMS and SEM(BE). Gold occurs with a number of mineral hosts including kaolinite, hematite clasts, hematite cutans, and calcite. This is consistent with late stage hydromorphic dispersion of gold in transported regolith. ravi.anand@csiro.au

REGIONAL MINERAL EXPLORATION

Baohong Hou (PIRSA) has published a series of articles on identifying Tertiary palaeodrainages on the Gawler Craton, SA. Two new papers address facies and sequence stratigraphy of Eocene valley fills (*Sedimentary Geol*, 163: 111-130); and heavy mineral sand (HMS) deposit models based on facies interpretation and stratigraphy of fluvial and marine units (*AJES* 50: 955-965). The models substantially revise earlier ideas of HMS accumulation in the massive and complex coastal barrier sands forming the Ooldea, Barton and Paling Ranges. Renewed HMS exploration interest in the area has been driven in part by these new models. hou.baohong@saugov.sa.gov.au

Peter de Broekert (ANU/CSIRO) has completed a PhD study of palaeochannel sediments in the Kalgoorlie region. He developed a 3-D lithofacies model to predict the style of the fill and to reconstruct the palaeogeography. ravi.anand@csiro.au

Mark Paine at Curtin University of Technology (CUT), whilst looking at landscape evolution in western Victoria, has developed a rapid method to quantify a diverse suite of heavy mineral grains using the AutoGeoSEM. The SEM can count 10,000 heavy mineral grains per hour. Heavy minerals with a simple unique composition and X-ray spectrum, such as chromite, ilmenite, zircon, monazite, spinel, rutile, Fe oxides and xenotime can be readily distinguished. This will enable the identification of heavy mineral facies relationships, which will give HMS miners a means to predict distribution of grade. mark.paine@csiro.au

INTEGRATED GEOPHYSICS

An integrated project coordinated by **Stewart Greenhalgh** is the 3-D inversion and interactive modelling of gravity and magnetic data, including magnetic vector processing and gravity gradiometry. stewart.greenhalgh@adelaide.edu.au

The Adelaide University group has created computer algorithms for recovering the distribution of density, magnetic susceptibility and direction of magnetisation of regolith and bedrock from surface measurements of gravity and magnetic tensor data. The inversion approach is based on the theory of Genetic Algorithms and can incorporate prior constraints. The models are three-dimensional. The programs were written in Matlab but are being converted to C. A synthetic data set was set up and tested using regolith information from the White Dam mineral prospect in SA.

Curtin researchers have experimented with aeromagnetic inversion for bedrock depth for hydrology purposes, as well as processing gravity data for manganese target discrimination at Woodie-Woodie. Potential field modelling has also assisted locating mineralisation at the Agnew Gold Mine, and for environmental monitoring applied to timber plantations. Gravity and magnetic methods were trailed in connection with kimberlite area selection and targeting.

Philip Heath at AU is developing 3-D automated inversions of potential field tensor data. He has created several algorithms that can determine physical properties of regolith - such as specific gravity, magnetic susceptibility and direction of magnetisation. Models are based on theoretical surface measurements of gravity and magnetic tensor data. They are created via an inversion routine based on the theory of Genetic Algorithms, a well-established method for the inversion of large non-linear problems. philip.heath@student.adelaide.edu.au

Margarita Norvill of CUT has developed a new signal processing technique for harmonic noise removal in electrical and EM geophysical data, and for spherics removal with arrays of sensors. The method manages noise sources that are difficult to suppress. The processing begins by removing the harmonic noise for each sensor, then the spherics noise is attenuated using the sensor array. The algorithms are quick enough to run on a PC. Experimentation of the method on field data demonstrates that it is able to dramatically improve the signal-to-noise ratio. The signal is extracted without significant distortion, thus preserving it characteristics and any interpretation of the data. The application of this algorithm to other

data sets should allow electrical/EM geophysical methods to see more deeply in environments where these methods often perform poorly. mnorville@geophy.curtin.edu.au

Anousha Hashemi of CUT is developing innovative EM techniques for exploration for high-grade manganese ore under cover in the East Pilbara of WA. Conductivity depth images (CDIs) were successfully created in EmFlow by experimenting with different parameters, such as Tau value, to find the best processing solutions. EM conductivity mapping using CDIs correlated with half of the known manganese ore zones, and drilling of several new EM targets in areas of regolith and sedimentary cover discovered five manganese ore bodies. Holistic interpretation of Mn ore occurrence in relation to hydrothermal Mn deposition will be done using 3D imaging of geophysical and geochemical data, processing ground IP and EM surveys, and running XRD samples for Mn mineralogy. hashemia@geophy.curtin.edu.au

SPECTRAL LOGGING

PIRSA, CRC LEME and GA combined to contract a prototype spectral core logger (HyLogger) developed by CSIRO Mineral Mapping Technologies group. From October 2003 to mid January 2004, HyLogger was housed at PIRSA's Glenside Core Store. Under the direction of **Alan Mauger** (LEME team leader) over 30,000 m of drill core were scanned. The output is an objective mineralogical log coupled to a high-resolution digital image of the core. Spectra were recorded at 1 cm intervals with mineralogy determined from characteristic spectral absorption features in the visible to shortwave infrared range (400– 2300 nm). LEME priorities include:

- characterisation of regolith on the Gawler and Curnamona cratons,
- shear-hosted gold and copper/gold systems on the Gawler Craton
- sediments hosting uranium mineralisation at Beverley and Honeymoon in SA.

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Cajetan Phang and **Ravi Anand** at CSIRO EM are developing practical automatic interpretation tools for logging regolith materials available as core, drill chips, or pulps. They determined mineralogy of 11,000 samples from Gidgee mine area and Moolan Well prospect in the northern goldfields of WA. Interrogation of these large data sets is being supplemented by data sets (1400 samples) to constrain the interpretation of spectral data. Kaolinite crystallinity index was able to discriminate residual from transported regolith.

In a similar exercise, **Balbir Singh** and **David Gray** (CSIRO EM) applied infrared spectroscopy to log the regolith and gold-associated alteration at St Ives. About 4,000 samples in two traverses were analysed. Interpretations were supported by detailed characterisation of 200 representative samples. They could successfully recognise the sediments, saprolite, saprock and rock type from the spectroscopic data.
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