2008
MINERALS EXPLORATION SEMINAR
ABSTRACTS

4 June 2008

CRCLEME
Cooperative Research Centre for
Landscape Environments
and Mineral Exploration

Erosional and weathering processes in action at Mt Magnet, WA

CRC AUSTRALIA

**CRC LEME is
an unincorporated
joint venture between
eight Core Parties:**

Australian National University,
Curtin University of Technology,
University of Adelaide,
CSIRO Exploration & Mining
and Land & Water,
Geoscience Australia,
Minerals Council of Australia,
NSW Department of Primary Industries, and
Primary Industry and Resources South Australia,

**established and supported under
the Australian Government's
Cooperative Research Centres Program.**

Cooperative Research Centre for Landscape Environments and Mineral Exploration

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Convenor

Dr Ravi R Anand

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

Email: ravi.anand@csiro.au

4 June 2008

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: 08 6436 8555
Email: crcleme.hq@csiro.au

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

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CONTENTS

CRC LEME HIGHLIGHTS, BENEFIT AND IMPACT OF REGOLITH GEOSCIENCE R&D

Steve Rogers

CRC LEME
steve.rogers@csiro.au

For the past seven years, CRC LEME, in partnership with our industry end users, has delivered significant benefits to exploration practitioners faced with the vexing task of mineral exploration through cover. By bringing together scientists and partners from the traditionally disparate scientific disciplines of geology, geophysics, geochemistry, soil science, microbiology, molecular biology, biochemistry, hydrogeochemistry, hydrology, plant biology and ecology, LEME has been able to develop a unique approach to the identification of potential zones of mineralisation and determination of mineral transport and transformation processes in landscapes dominated by cover. The knowledge generated has, in turn, provided new tools and 'pre-competitive' geoscience information to explorers. This multi-disciplinary, multi-agency approach would not have been achieved if it was not for the existence of the Federal Governments Cooperative Research Centres Programme, and the funding provided.

Hydrogeochemical techniques to vector in on buried mineralisation have been successfully trialled in the Tanami and Yilgarn, and the application of high energy X-ray techniques has led to significant advances in gold mineral host understanding.

Hyperspectral analysis of surface illite has been identified as a mineralisation vector, and application of hyperspectral surveys to diamond exploration has aided the discovery of two new kimberlites at Pine Creek SA, employing spectral analysis of HyMap data.

The CRC's strategy to focus on biological mechanisms of regolith trace element and mineral transport has delivered significant advances. A highlight has been the isolation of bacteria that precipitates gold in the regolith. The development of phyto-exploration as an effective exploration-through-cover tool has delivered encouraging results. Highlights include the discovery of an extension to the Pinnacles Pb/Zn lode near Broken Hill, partially the result of a River Red Gum leaf geochemical survey, and the detection of anomalous gold concentrations in leaves of the common native grass Spinifex with the observation that its roots penetrate up to 30 metres down into the regolith. The uptake of uranium and thorium by a variety of native Australian plant species has also been demonstrated by LEME researchers in collaboration with Heathgate Resources, demonstrating that phyto-exploration is a viable method for uranium exploration through cover.

Phyto-exploration has significant potential to increase exploration search space, allowing explorers to access culturally sensitive land where techniques such as drilling, involving heavy equipment access, can be unacceptable to traditional owners.

With our State Geological Survey and Primary Industry partners LEME has delivered a number of key 'pre-competitive' geoscience products including the *Northern Territory Regolith Landform Map and Atlas of Regolith Materials, Laterite Geochemical Atlas and Database for the Western Yilgarn Craton, Map of Palaeodrainage and Tertiary Coastal Barriers of South Australia* and the soon to be released Atlas *Queensland Regolith Landform map and Atlas*. The Laterite Atlas and Palaeodrainage map have had significant, quantifiable impacts on exploration activity.

In addition to the 280 Open File Technical Reports, Symposium proceedings and general data, released by LEME, during 2008 CRC LEME will release a series of six regional Exploration Under Cover *Explorers Guides* covering the Tanami, Gawler, Curnamona, Yilgarn, Thomson

Orogen and Cobar provinces. Field guides to Phyto-Exploration, and Hydrogeochemical Exploration, a Digital Atlas of Regolith Maps and a Regolith Geoscience text book (published by CSIRO) will also be released. The CRC has also entered into a collaborative agreement with AMIRA to transfer all relevant LEME technical reports and mineral prospect data into the AMIRA online database, *Data Metallogenica,* an international geoscience and prospect information repository.

All LEME publications are digitally available as .PDF files free of charge from our web site: http://crcleme.org.au. CSIRO will maintain the LEME web-site for five years after cessation of its operations in 2008.

Whilst LEME will officially cease on 30th June 2008, regolith research activity will continue in the Core Participants through initiatives such as: the CSIRO Minerals Down Under Flagship, the AMIRA P778 Predictive Geochemistry in Areas of Transported Overburden project, the PIRSA/University of Adelaide Centre for Exploration Under Cover, and the GA Onshore Energy Initiative. In addition, a bid for a new CRC in Deep Exploration is currently being scoped by AMIRA International, focussing on targeting of buried mineralisation and innovative drilling and real time down hole data acquisition technologies.

AN INTEGRATED APPROACH TO ANOMALY FORMATION AND DETECTION AT THE MOOLART WELL GOLD DEPOSIT

Ravi R Anand, Robert M Hough and Cajetan Phang

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

The Moolart Well gold deposit is located 130 km north of Laverton on the eastern limb of the Duketon Greenstone Belt in a present day N-trending regional drainage corridor. A shallow N-trending palaeochannel, 1-2 km wide, overlies residual regolith with variable depths to bedrock.

The Moolart Well gold mineralisation is hosted by a sequence of diorite, basalt, dolerite and ultramafic rocks within a north-trending shear zone. Economic mineralisation is confined to the weathered zone. There are two styles of mineralisation, namely a shallow ‘laterite’ resource comprising authigenic nodules and pisoliths, carrying 462,000 ounces of Au, and weathered primary mineralisation, carrying 611,000 ounces contained in the saprolite. Drilling of some secondary structures has revealed primary mineralisation in shear zones with quartz and sulphides. Copper and As concentrations are low in both primary and secondary mineralisation.

The ‘laterite’ mineralisation is a coherent sub-horizontal Au blanket consisting of pisoliths formed in sediments. It has an average thickness of 4 m, extends N for over 4 km and 1 km E and, in some areas, approaches within 2 m of the surface. The oxide zone extends from 20 to 70 m depth with similar dispersion to the laterite zone. Oxide mineralisation consists of numerous secondary moderate to steep, east-dipping, gold-bearing structures preserved in the clay-rich residual profile and sub-horizontal supergene Au developed in the lower part of the profile.

A detailed landscape, mineralogical and geochemical study has been used at the Moolart Well gold deposit to investigate the mechanisms of anomaly formation and the best method of detection. This will be discussed at the seminar.

HYDROGEOCHEMICAL EXPLORATION: WHY DO IT, HOW DO YOU DO IT?

David J Gray and Ryan R P Noble

CSIRO Minerals Down Under Flagship, CRC LEME
david.gray@csiro.au

Introduction

Our hydrogeochemical exploration research in CSIRO aims to develop useful regional vectoring techniques to mineralisation using groundwater chemistry, focussed on gold, nickel, VMS and uranium. The view is that hydrogeochemistry is particularly useful for early-stage greenfields exploration and development of regional targets. One present research project is investigating the potential for low (> km) sample density. We can demonstrate that groundwater geochemistry can locate general sulphur alteration as well as specifically targeting NiS and VMS deposits. Alteration haloes around Au targets are also being identified.

We are now looking to assist the industry in utilising this technology. Mechanisms include open presentations, manuals, and one-to-one partnerships with explorers. Robust use of groundwater geochemistry for regional exploration will require development of groundwater evolution models, consistent and realizable sampling/analytical techniques and, ultimately, straight-forward interpretation procedures, all of which are well underway. Examples are provided below.

Methods

Groundwater exploration can use sample media such as farm bores, drill holes and wells, with collection systems like pumping and bailing. We have developed protocols for sampling, measuring and filtration equipment along with the methods and types of samples required for analysis. Analytical options include major anions including bicarbonate with ion chromatography and alkalinity titration (ppm detection), major and trace cations through ICPMS/OES (ppm and ppb detection) and pre-concentration of Au, Pt and Pd on activated C to detect ppt levels of these elements using ICPMS.

Exploration for Nickel Sulphides and other S-rich Deposits (Northern Yilgarn)

This research has concentrated on the development of reliable regional and smaller-scale hydrogeochemical vectors to Ni sulphide (Ni-S) mineralisation in the NE Yilgarn Craton. To achieve this it is critical to understand controls on groundwater expression of Ni-S mineralisation, evaluate larger scale variation in element concentrations, test different collection, sample treatment and analytical protocols to develop cost-effective recommendations for hydrogeochemical exploration, and understand groundwater-induced dispersion processes. We have sampled approximately 500 groundwaters from Wildara/Weebo/Waterloo, Camelot/Harmony, Yakabindie, and the Honeymoon Well Ni prospects, combined with Lawlers/Agnew and background areas.

There is a hydrogeochemical halo around Ni deposits. Most high concentrations of metals associated with the Ni hydrogeochemical signature are indicative of sulphides and mineralisation. Chromium is the best indicator element for ultramafic rocks, whereas Ni, Co and Pt are the best individual pathfinders for Ni sulphide mineralisation.

Hydrogeochemical differentiation and targeting is improved by using Box-Cox transformations and deriving indices from the multi-element data. Particular indices delineate the sulphide signature independent of the type of water i.e. whether the major parameters of Eh and pH are different. A number of different parameters can then be used to identify presence of sulphides, particularly Fe-rich (*i.e.*, uneconomic). These include ones based on consumption or release of sulphate and nitrate during sulphide weathering, groundwater signatures of weathering, acid producing sulfides (Mo+Ba+Li+Al) and Fe-rich sulfides (pH-Eh+Fe+Mn) (*e.g.*, Figure 1A). The

Min index (Ni+Co+W+Pt; Figure 1B) targets enrichment in NiS elements. Subtracting indices (Figure 1C), removes the effect of Ni dissolution during intense weathering of non-mineralised sulphides, and appears to closely match NiS occurrences. Hydrogeochemical sampling for Ni sulphides has significant potential for regional (km scale) to medium scale (100's m spacing) exploration.

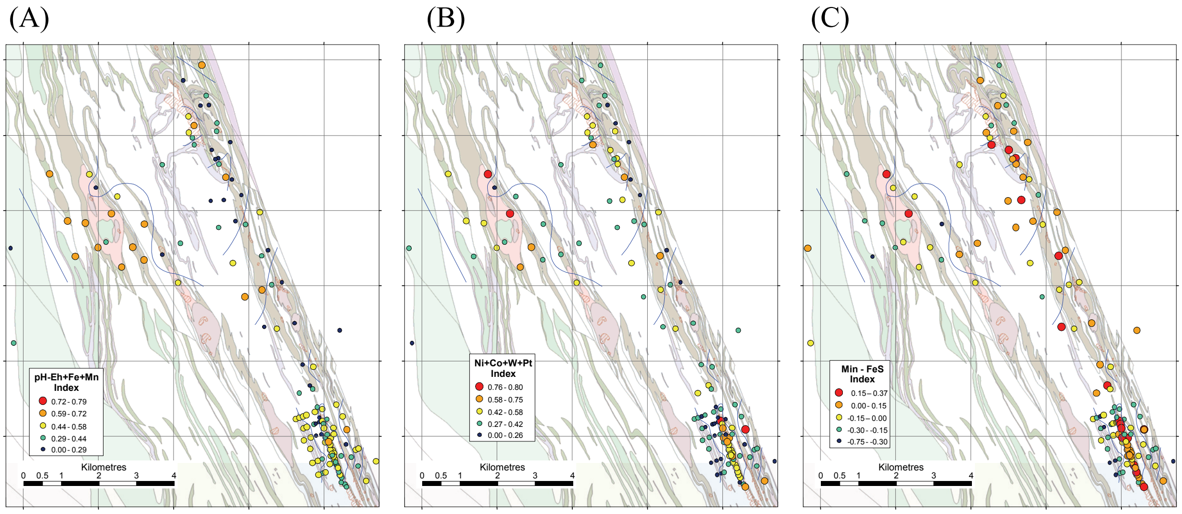


Figure 1: Differing Indices for the Harmony/Camelot area north of Leinster. (A) The FeS Index (pH-Eh+Fe+Mn) indicates the presence of sulphides, and the apparently barren area to the NW shows up more strongly than NiS mineralisation on to the east. (B) The Min Index (Ni+Co+ W+Pt) accentuates NiS. (C) Subtracting these indices (Min – FeS) appears to pick up NiS only.

Golden Delicious Gold Deposit

The Golden Delicious groundwaters are neutral (pH 6.5 - 7.3) and have a similar Eh range to neutral waters from other sites. Golden Delicious is close to Lake Carey and groundwaters are therefore more saline (up to 16% TDS) than the other central Yilgarn sites. Gold probably dissolves as Au chloride, with anomalous concentrations, (0.046-0.18 µg/L; Figure 2), though slightly offset to the west, for 200 m across strike of mineralisation, indicating that groundwater Au could be suitable as an exploration sample medium. Additionally, chalcophile elements that are enriched in *neutral* groundwaters in direct contact with weathering sulphides (*e.g.*, As, Mo, Ag, Sb, W, Tl and Bi) have moderate to high concentrations in the Golden Delicious groundwaters, suggesting that *regional* groundwater sampling might well be effective at locating a deposit with similar characteristics.

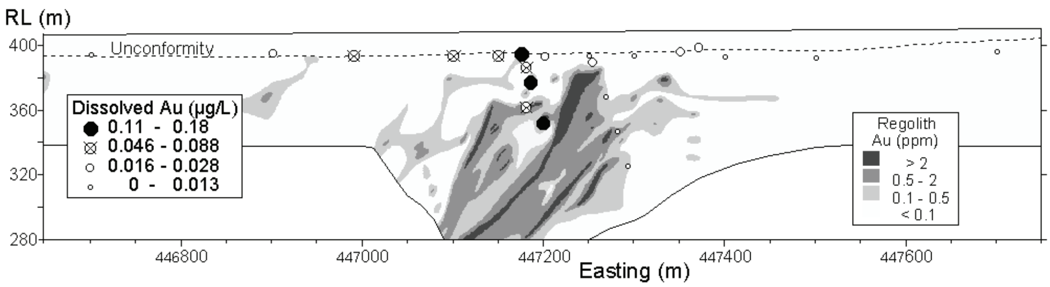


Figure 2: Dissolved Au at Golden Delicious 6790200N (dots), superimposed on regolith Au distribution.

Baxter/Harmony Gold Deposit

The Baxter/Harmony Deposit is located within a depositional plain approximately 10 km west of Peak Hill and some 90 km north of Meekatharra. Groundwaters are neutral and generally similar to groundwaters from the northern Yilgarn Craton. Dissolved Au concentrations are extremely low: 100-1000 times less than in mineralised areas around Kalgoorlie. Despite this, dissolved Au is a pathfinder (Figure 3). Additionally, Sc, Mo (Figure 4), W and, possibly, Rb were observed to have greater groundwater concentrations in areas of Au mineralisation and are more consistent pathfinders in groundwater than Au itself. This elemental suite is similar, though more limited, to those observed elsewhere, and there may be scope for selective extraction of soil or other regolith material. Other elements such as Cr can be used in groundwaters to indicate underlying rocks or other geochemical features. Dissolved As and, to a lesser degree, Ni correlate with As-enriched rocks to the SE.

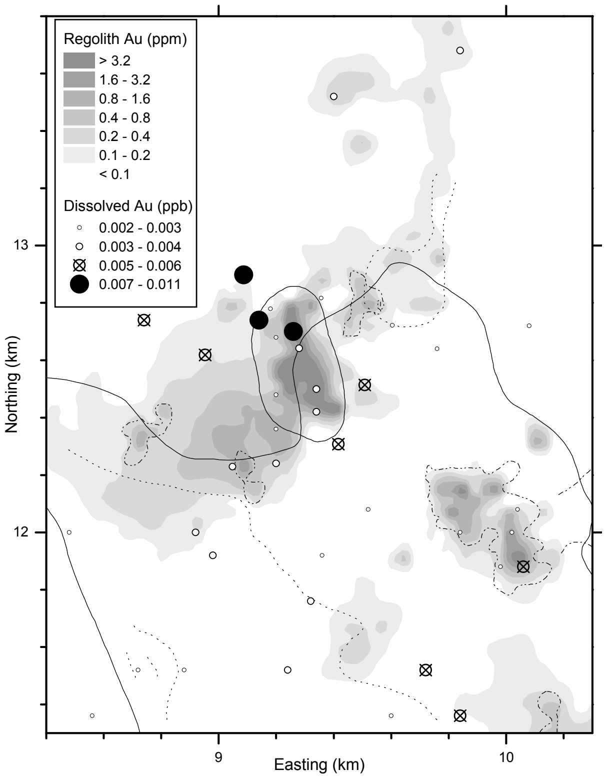


Figure 3: Dissolved Au distribution at Baxter (dots) superimposed on maximum Au contents in the regolith.

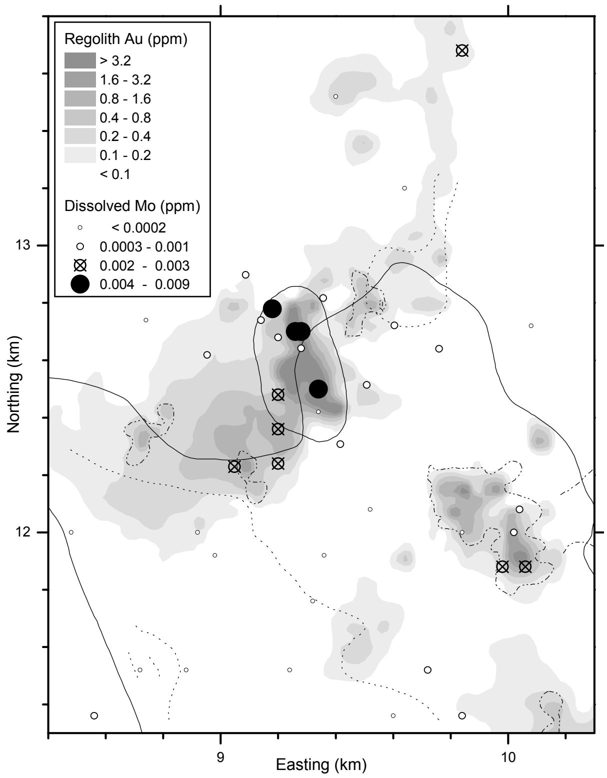


Figure 4: Dissolved Mo distribution at Baxter (dots) superimposed on maximum Au contents in the regolith

Jaguar Base Metal Deposit

The Jaguar Zn-Cu-Ag VMS deposit is located 65 km north of Leonora, approximately 2 km south of the old Teutonic Bore mine. 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.

Ore elements Cu and Zn (Figure 5E-F) have sporadic groundwater anomalisms, which could be missed in broader spaced sampling, though other indicator elements such as Mo give expanded anomalies. Normalised multi-element indices (Figure 5A-D), which combine metals and anionic indicators such as SO∅ˉ, NO„, Mo and W, give broader and more consistent groundwater anomalies.

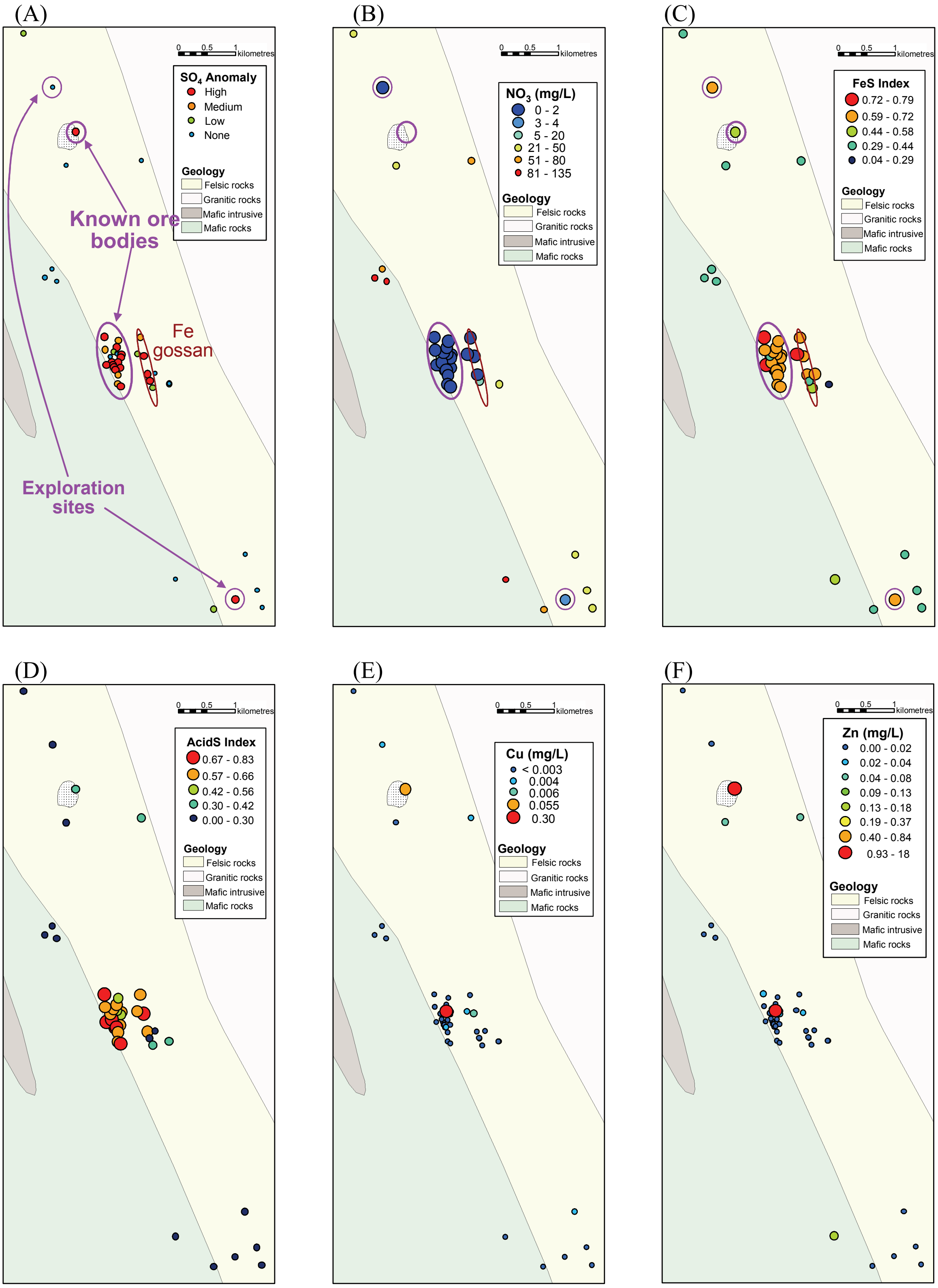


Figure 5: Differing Indices for the Teutonic Bore/Jaguar area north of Leonora. (A)-(D) Various parameters indicate mineralised sites, as well as the barren Fe gossan east of Jaguar. (E)-(F) Elements such as Cu or Zn give extremely anomalous, though sporadic dissolved enhancements.

Broad-scale mapping - NE Yilgarn Hydrogeochemical Map

The recent hydrogeochemical mapping of the northeastern Yilgarn (Figure 6) is a proof of concept for broad scale hydrogeochemistry, with potential for mapping, environmental background establishment and mineral exploration across many other areas of Western Australia, especially outside recognized mineralisation belts. This area has relatively fresh, pH neutral and homogeneous groundwaters. Sampling will be primarily windmill based, with 1200+ samples to an approximate 8 km triangular grid (i.e. slightly closer than the 9 km grid used for the Laterite Atlas).

Potential benefits from this project include:
- Better understanding of hydrogeochemistry of the northern Yilgarn. This enables better anomaly contrast and development of indices for exploration.
- Demonstration of the utility of chalcophile (As, Sb, Mo, W) haloes for exploration.
- Improved understanding of the size of alteration systems (in conjunction with hyperspectral studies).
- Providing lithological information in covered terrains.
- Extension of hydrogeochemical exploration to Craton margins that could represent a cost-effective and viable technique for exploration in such areas.
- Additional exploration in the northern Yilgarn (c.f effect of release of the Laterite Atlas), particularly for other commodities (e.g., V, W).
- Environmental quality and health related data (e.g. As, Cr, Pb, NO3).

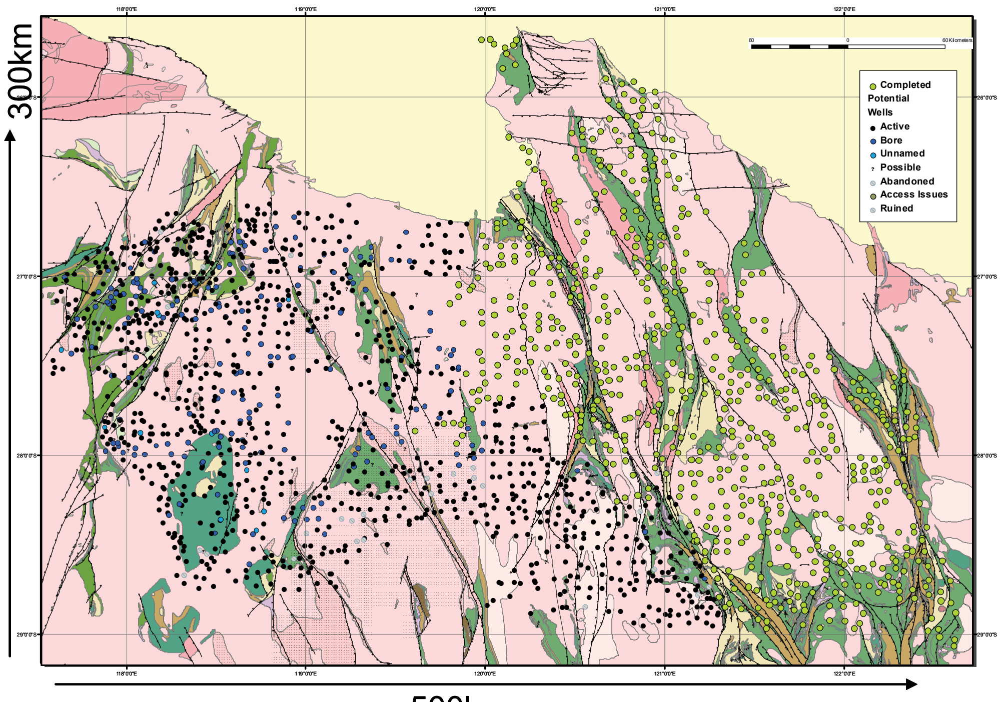


Figure 6: NE Yilgarn groundwater sampling. Green dots denote groundwaters already sampled, black dots are potential bores.

Methods

Groundwater exploration can use sample media such as farm bores, drill holes and wells, with collection systems like pumping and bailing. We have developed protocols for sampling, measuring and filtration equipment along with the methods and types of samples required for analysis. Analytical options include major anions including bicarbonate with ion chromatography and alkalinity titration (ppm detection), major and trace cations through ICPMS/OES (ppm and ppb detection) and preconcentration of Au, Pt and Pd on activated C to detect ppt levels of these elements using ICPMS.

Conclusion

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

Acknowledgements

Research summarized was sponsored from a number of sources, in particular CSIRO/AMIRA P240, P241, P241A, P409, P504, a project on the Mulga Rock palaeochannel system supported by PNC Exploration P/L and MERIWA, and a project on Ni hydrogeochemistry supported by CRC LEME, BHP Billiton, Inco, Lion Ore and Anglo American. The sponsors of all these projects are thanked for their generous support.

GEOCHEMICAL EXPLORATION THROUGH COVER IN NORTH WESTERN VICTORIA

Ryan R P Noble

CRC LEME / CSIRO Exploration and Mining
ryan.noble@csiro.au

The 21st century continues to throw new challenges to the exploration industry as new, economic mineral deposits are becoming more difficult to locate. In the past, north western Victoria has been the source of large resources of gold. However, prospective regions to the north of this area are covered by a thick blanket of Murray Basin sediments making future discoveries more difficult. A study of various sample media, sampling depths and analytical techniques was conducted at the Kewell and Wildwood Au ore bodies, and the surrounding areas of the Stawell Corridor (Figure 1) to assess the exploration potential of geochemical techniques. The mineralisation in this study is below 25-130 m of cover at Kewell and Wildwood. Some pathfinder elements including As show some dispersion into the transported cover, but the elevated concentrations do not extend to the surface (Figure 2). Generally, the cover at Kewell and Wildwood was too thick for interpretable dispersion to the surface, but other exploration techniques may succeed, particularly hydrogeochemistry and regolith sampling at the unconformity between Loxton Parilla sands and Geera clays. Figure 2 shows a significant anomaly for As:Mn using the hydroxylamine extraction in this part of the regolith profile. The hydroxylamine extraction selectively extracts Mn oxides. Using the ratio eliminates the increased element signature in samples that contain more Mn oxides, but are not anomalous. Arsenic concentrations at depth in near-miss RAB or RC drilling would also useful in targeting mineralisation at both Kewell and Wildwood. Thick cover in north western Victoria continues to be problematic for geochemical exploration and the Wildwood-Kewell region is no exception.

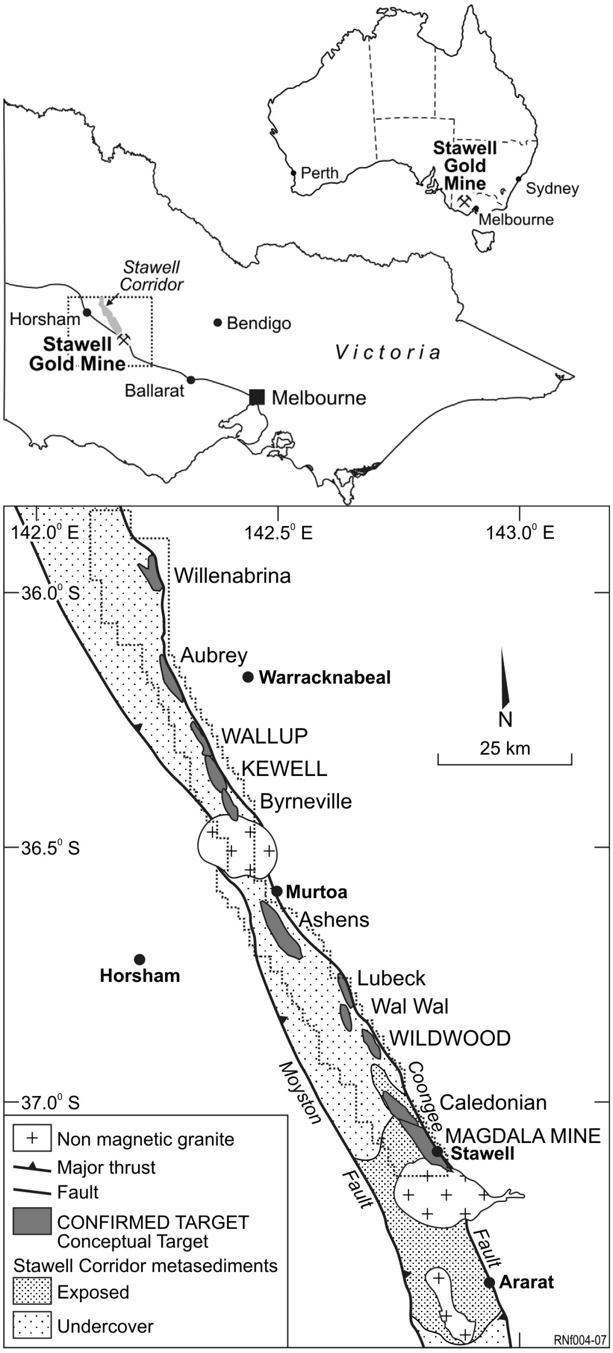


Figure 1. Stawell Zone; geology with targets under Murray Basin cover (modified from Leviathan Resources, 2004).

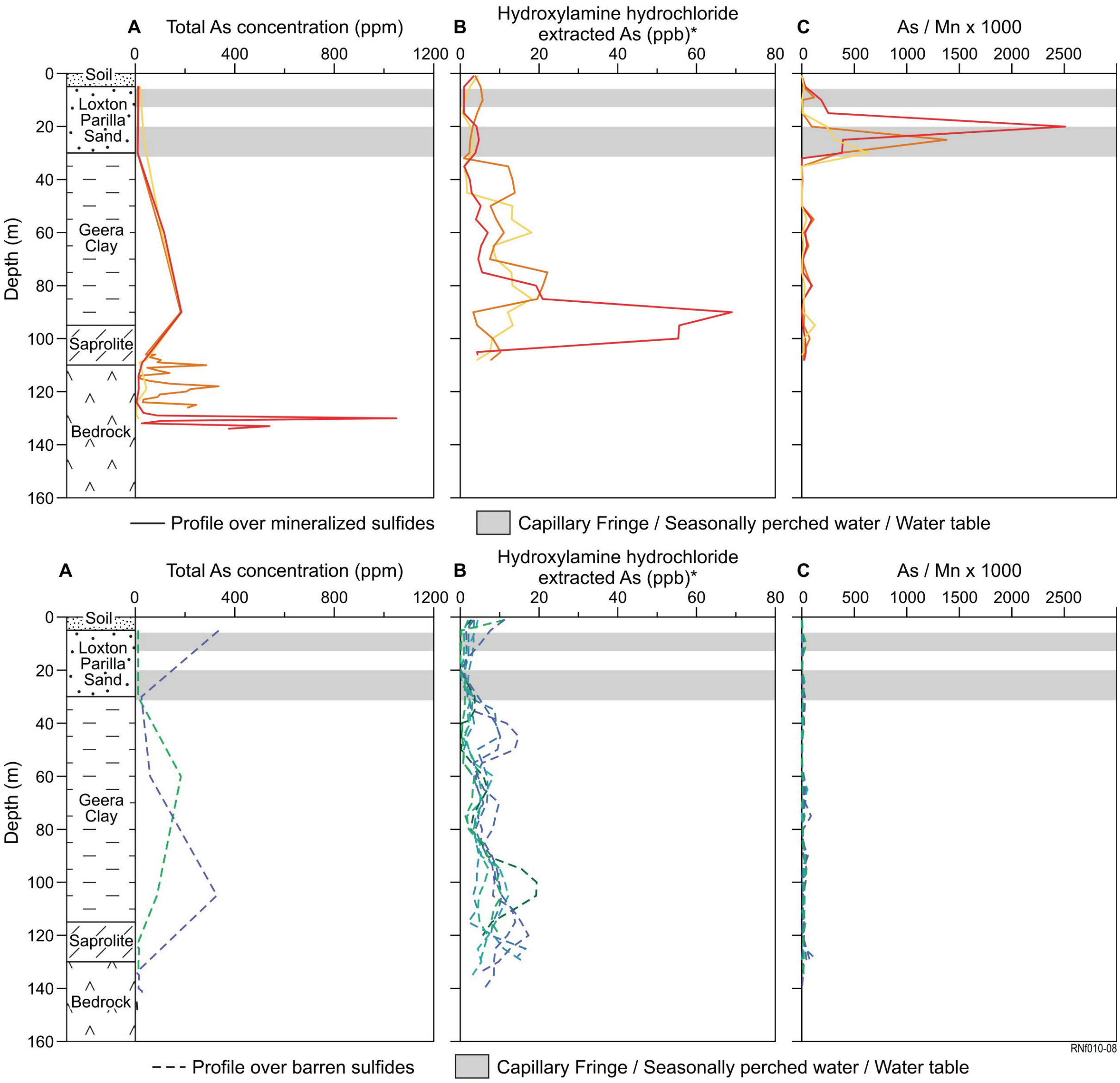


*Figure 2. Regolith profile geochemistry. Total As (A), partially extracted As (B), and the ratio of partially extracted As to Mn (C), based on the partial digest targeting amorphous Mn oxide bound elements. The top set of plots are profiles above mineralization compared with the bottom set of profiles above barren sulfides. * Indicates the data has been smoothed as an average of the nearest neighbouring concentrations to improve pattern recognition.*

PRECIPITATION OF GOLD BY EVAPORATION AND IMPLICATIONS FOR EXPLORATION

Robert Hough[1], Ryan Noble[1], David Gray[1], Ravi Anand[1], Charles Butt[1], Elizabeth Grenik[1], Chris Ryan[1] and Peta Clode[2]

[1] *CRCLEME, CSIRO Exploration and Mining*
[2]*Centre for Microscopy, Characterisation and Analysis, University of Western Australia, Crawley, Perth.*
Robert.hough@csiro.au

The Golden Virgin pit, south of Southern Cross in Western Australia, is a small gold deposit where primary mineralisation occurs as small, high grade quartz veins, blanketed by 30 m of weathered cover. The veins have weathered fracture surfaces lined with different generations of secondary iron oxides, clays and sulphates together with an exceptionally rich population of supergene Au crystals (500 µm). These single crystals also occur with a separate population of 100 nm and smaller single crystals of nanoparticulate colloidal gold. The specific process(es) leading to the reduction of the gold colloid and therefore the precipitation of the gold in this environment is not known. Supergene gold here is Ag-poor, closely associated with halite crystals and sometimes intergrown with barytes. Sulphates have been shown to play an interesting role in the hosting of gold in other regolith profiles. At Whirling Dervish, baryte inclusions as pore filling minerals within silcrete clasts from saprolite contained ppm levels of gold. At the Enterprise Pit, Mount Gibson, alunite acts as a host for ppm level gold in ferricrete developed within transported overburden, it also displays an interesting relationship with gold at Poona, South Australia and at Mount Percy, Western Australia.

The observations at Golden virgin supports the premise that pure gold can be precipitated from saline and slightly acidic groundwater with the occurrence potentially indicating rapid gold deposition if evaporation is the major driver. Inorganic laboratory experiments have confirmed this evaporative process as a mechanism to precipitate gold. These experiments also provide some interesting observations on the crystalline form of nanoscale triangular and hexagonal gold crystals that form even when the gold is precipitated from different ligands. New analytical capabilities in electron microscopy, synchrotron based XRF and PIXE probe element mapping permit the imaging of such nanoscale gold within regolith materials that was previously considered invisible. This form of gold is likely elsewhere in the world where saline ground-waters interact with gold deposits and sulphate minerals may act as an important mineral host. Results of this work are also relevant to studies of silver, copper and platinum transport.

THE COMPOSITION AND CRYSTALLOGRAPHY OF GOLD: IMPLICATIONS FOR ORE GENESIS

Charles R M Butt and Robert Hough

CRC LEME, CSIRO Exploration and Mining
charles.butt@csiro.au

The compositions and crystallography of nugget and particulate gold from sites in Australia, Papua New Guinea, SE Asia and Brazil have been determined by optical and electron-optical procedures. Preliminary results show that there are distinct differences in the characteristics of gold in different geological environments. The majority of specimens have been collected at or near the surface, but all larger (>4 mm) and many smaller ones appear to be hypogene. Many of even the largest masses (up to 8 kg) have internal evidence of weathering. This includes silver depletion on crystal boundaries, and voids, open to the exterior, that are filled with clay, iron oxide or quartz and commonly hosting small particles of pure, supergene gold. Gold specimens from many deposits in Western Australia, Victoria, New South Wales and Queensland have silver contents of 5-15%, and an internal equigranular polycrystalline structure that exhibit fabrics which imply post-depositional deformation followed by annealing at temperatures above 250ºC. Fine particulate gold in soil from Amazonia includes polycrystalline grains with internal silver depletion that probably have a similar genetic history. Some small nuggets from SE Asia, also with annealing fabrics but having a high fineness (<1% silver), are possibly the product of hydrothermal re-mobilization and precipitation. In comparison, some specimens from Papua New Guinea have silver contents 10->30% silver, with variable internal structures including zoning and 'fern-like' crystal habits; these are probably derived from epithermal deposits and have not suffered either deformation or recrystallization since initial deposition. Previous workers have related the fineness of gold to factors such as depth below surface, which in turn relate to temperature and pressure of deposition, and to the effects of weathering. Combining compositional information with crystallographic characteristics offers to provide evidence for the genesis of gold-bearing deposits, including their late thermal and tectonic history.

ORIGIN & LATE THERMAL-TECTONIC HISTORY

Source: salt lake near Kalgoorlie

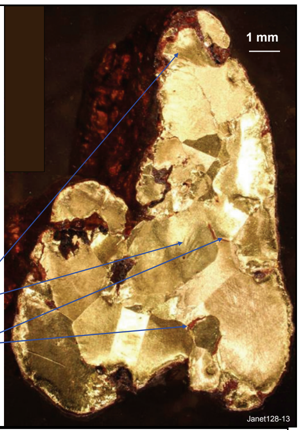
Primary origin indicated by
8-10% Ag;
polycrystalline annealing fabric, with large twinned crystals

Annealing implies extreme deformation prior to recrystallization at >250°C

Undulose extinction implies further mild deformation since annealing event

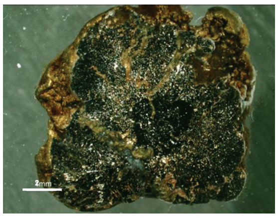
Crystal boundaries are the focus for internal weathering

Janet 12.8



NUGGET WITH LOBED GROWTH STRUCTURES EDIE CREEK, PNG

Optical images



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STILLWELL-EDWARDS COLLECTION, ABE4

ESSENTIAL LANDSCAPE EVOLUTION MODELS FOR URANIUM EXPLORATION PROGRAMS UNDER COVER

Steve M Hill[1], J E Davey[1], M Neimanis[1], C M Dubieniecki[1], D J Gallasch[1], A N Hector[1], M Jennings[1], J M P McMahon[1], R L Wilson[1], and S Hore[2]

1. School of Earth & Environmental Sciences, The University of Adelaide, CRC LEME.
2. Geological Survey, Primary Industries and Resources SA
steven.hill@adelaide.edu.au

The regolith and landscape evolution constrain the expression of bedrock-hosted and the development and expression of palaeodrainage hosted uranium mineralisation in the northern Flinders Ranges – Frome Embayment area of South Australia. This provides the framework within which mineral exploration under cover techniques (such as biogeochemistry / phyto-exploration) can be applied.

Regolith and palaeo-landscape associated with the Mesozoic, Eromanga Basin include the palaeodrainage (fluvial and minor glacial) transport of uranium-rich detritus within a landscape of moderate topographic relief and variable bedrock exposure. Cretaceous marine transgressions extended across low-lying parts of the landscape and deposited chemically reduced clays and silts, which have potential as important chemical traps for uranium. The Mesozoic sediments have since been tectonically disrupted, particularly during the Neogene. Cainozoic regolith and landscape evolution is associated with the Lake Eyre Basin and hinterland development. Palaeogene fluvial deposits associated with the Eyre Formation have been important hosts for uranium mineralisation at sites such as Four Mile and Honeymoon. The landscape at this time hosted highly weathered Mesozoic sediments and limited bedrock exposure. Pedogenic silcrete development was extensive in the later stages and immediately following Eyre Formation sedimentation, and was then followed by fluvial and lacustrine sedimentation of the Namba Formation. Redox-fronts in the Namba Formation have been important for the development of uranium mineralisation at Beverley. Ephemeral fluvial, lacustrine, colluvial and aeolian deposition as well as tectonism and pedogenisis have been spatially and temporally variably dominant in the more recent geological evolution.

The regolith and landscape context has provided an important framework for regolith geochemical and biogeochemical studies that characterise the surficial expression of buried uranium mineralisation. This has included soil, palaeosediment, contemporary stream sediment, regolith carbonate, vegetation, ant and macropod scat samples. Biological interactions through the regolith can provide surficial expressions of buried uranium mineralisation and therefore have applications for mineral exploration and environmental assessments. A wide range of Australian plants, in particular eucalypts, acacias and spinifex, can have U and associated trace elements contents that best relate to subsurface U abundance. In the northern Flinders Ranges-Frome Embayment, the curly mallee and the gum-barked coolibah can contain >5.00 ppm U overlying buried uranium mineralisation, whereas in non-mineralised settings the U contents are typically <0.01 ppm. Many of these plants have root systems that can penetrate beneath the landsurface for at least 50 m and translocate chemical expressions of subsurface uranium concentrations to the above ground plant organs (such as leaves, fruit, twigs). Some Australian animals, such as termites, ants and kangaroos can also host U contents related to subsurface U concentrations. Elevated U contents derived from the subsurface can be associated with animals through their feeding on deep-rooted plant species (eg. kangaroos) or by deep burrowing (eg. termites and ants). Kangaroo scats with >20 ppm U and ants with >13 ppm U have been found in undisturbed sites near U-rich bedrock in the Northern Flinders Ranges – Frome Embayment. In many cases elevated U contents in biological materials will have no relationship to the chemical composition of surficial sediments and transported soils, but instead have greater affinities to subsurface regolith, bedrock and groundwaters.

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REGOLITH-TERRAIN MAPPING IN THE TANAMI

Richard L Langford

Maximum Resources Limited

Written and presented by Richard Langford while a staff member of the Geological Survey of Western Australia. This Abstract appears in the GSWA 2007 Extended Abstracts Regolith-terrain mapping in the Tanami, and permission has been given to reproduce.

The visual representation of landform has a long history, typically captured in landscape paintings and photographs. However, as technology advanced, our view of the Earth's surface was largely overtaken by a desire to measure and map. The development of terrain maps is an attempt to represent multiple perspectives of three-dimensional surfaces in a two-dimensional image. Recent advances are now supporting a trend in many sciences, including regolith-terrain mapping, away from polygonization or parameterization of discrete units back to a picture of the world, often through interactive three-dimensional imaging. The argument herein presented is that effective representation of regolith-terrain must incorporate both temporal- and scale-dependencies in the spectral and topographic expression of the landscape to be visualized.

Producing useful regolith-terrain maps for the exploration industry and other land users relies primarily on the analysis and visualization of topographic and multi-spectral data. In addition, mapping and field characterization within a systematic framework brings benefits in interpretation, and the trend both within Western Australia and nationally is towards both extracting maximum value from imagery and applying more robust mapping methodologies. As a result, our understanding of the intimate relationship between landform, material, and process at the surface is constantly improving. This is a prerequisite for understanding three-dimensional and temporal aspects of the regolith.

The two most useful datasets for regional regolith-terrain mapping are digital elevation models (DEMs) and Landsat TM. Orthophotograph, radiometric, multispectral (ASTER), hyperspectral (HyMap) and radar datasets are all potentially useful, but coverage of remote areas such as the Tanami tends to be patchy. Research and product development for the Tanami, in contrast to areas such as Kalgoorlie, has therefore focused on improving the temporal and spatial analysis and three-dimensional integration of DEMs and Landsat TM.

The analysis and visualization of Shuttle Radar Topography Mission (SRTM) DEM data has been very effective for regional regolith-terrain mapping. Applying multi-scale analysis to resample the original data has produced the best visualization of what is essentially a level landscape (Fig. 1). Resampling the original 90-m resolution data to 270 m, although counter intuitive, has also been very effective in the visualization of regional landform patterns.

Multi-band remotely sensed image data contain information on landscape pattern and temporal changes that are underutilized in regolith-terrain and bedrock mapping. Among the reasons for this loss of analytical opportunity are the need for improved methods for the systematic extraction of patterns, and the ever-increasing volume and diversity of remotely sensed image data. The merging of Landsat TM data for a range of epochs for use in terrain mapping, producing what are now termed Landsat TM^3 images (Landsat TM Temporal Merge Terrain Mapping), effectively tackles the challenge of producing a consistent set of images in an area dominated by seasonal vegetation changes and fire scars. While most users would naturally focus on the most recent images as being of most value, identifying persistent patterns in the landscape that relate to geological materials is best accomplished by removing the short-term effects. The most recent image may be the worst in terms of fi re scars, floods, and revegetation. A simple arithmetic mean of data for the Tanami from 1994 to 2005 produces images with improved colour depth and enhanced geological material discrimination that will effectively compliment the detail available in high-resolution orthophotographs (Fig. 2).

The visualization of the regolith-terrain in the Tanami using SRTM DEMs and Landsat TM[3] shows that there are numerous colluvial and sheetwash fans up to 20 km across below extensive footslopes, with obvious implications for geochemical sampling, even though the area is masked by eolian sand modified by sheetwash. These regional landform models also contribute to the development of physiographic regions and their component mapping units, which complement the regolith–landform images. A complete synthesis of the regional hierarchy for the Tanami has been completed, and more detail is being extracted from the images as the mapping progresses.

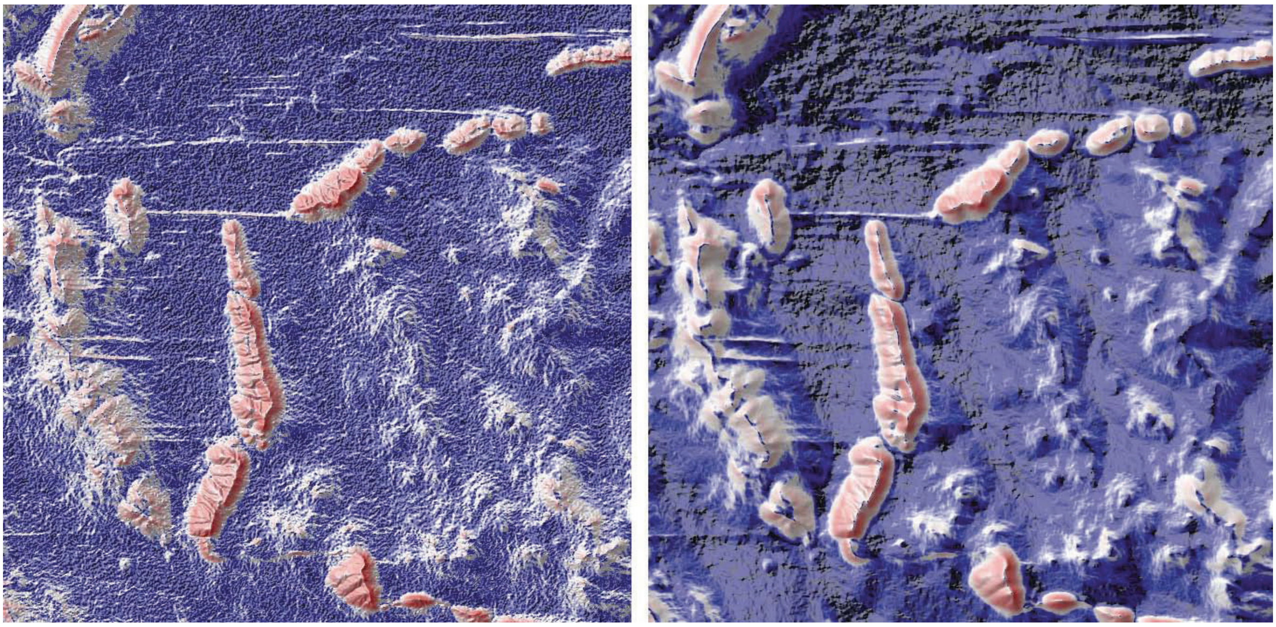

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Figure 1. **Hill-shaded slope derived from original SRTM elevation data (left) and multi-scale resampled data (right) for the BALWINA 1:100 000 map sheet. Slopes in the white areas are about 1°**

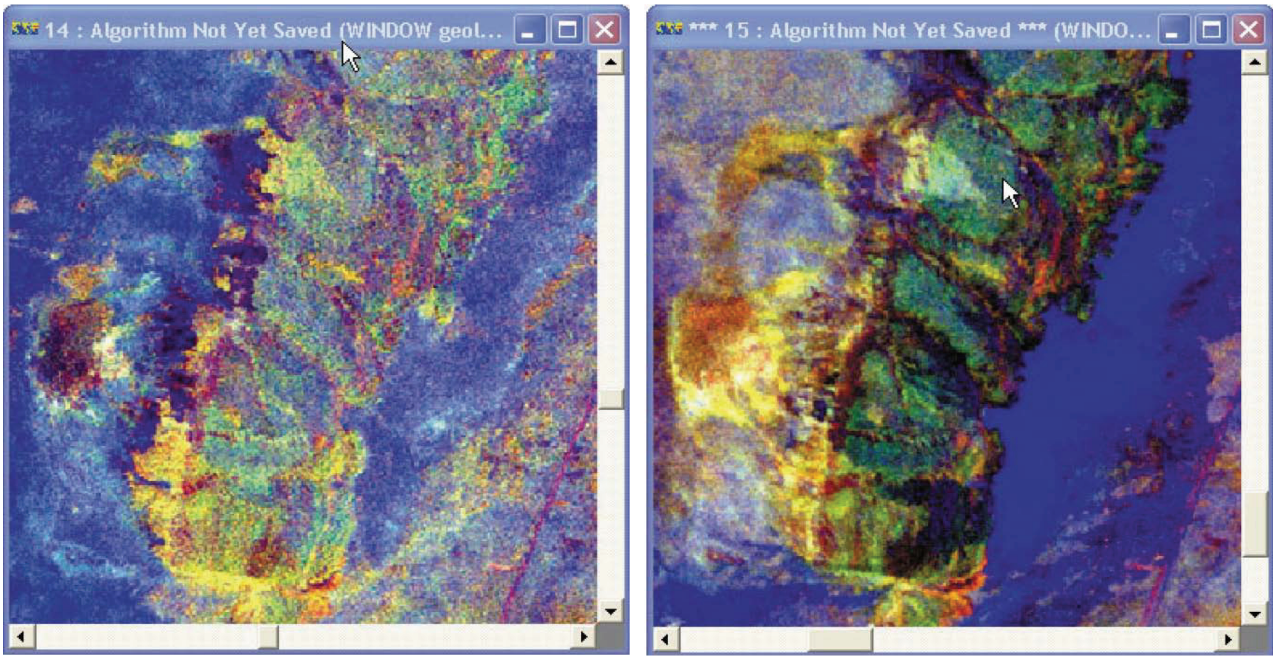

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Figure 2. **Landsat TM ratios 5/7, 4/7, 4/2 for 2005 (left) and 1994 to 2005 Temporal Merge (right). Southwest corner of the BALWINA 1:100 000 map sheet, north of Balgo**

SEISMIC EXPLORATION OF ORE DEPOSITS IN WESTERN AUSTRALIA

M Urosevic[1], **Anton Kepic**[1], E Stolz,[2] and C Juhlin[3]

1. Dept. of Exploration Geophysics, Curtin University of Technology
2. Gold Fields Limited. 3. Uppsala University, Dept. of Earth Sciences, Sweden
kepic@geophy.curtin.edu.au

This presentation was prepared for Exploration 2007, and Dr Kepic will incorporate recent developments for the LEME Minex Seminar June 08

Exploration for mineral deposits in a predominately hard rock environment is often quite difficult because of the structural complexities of the regolith and fresh rock. Potential field geophysical methods are typically used to detect major structures that may lead to the location of prospective targets. However these methods have low spatial resolution at depth and are limited to directly detecting shallow targets. The seismic reflection method is considered the most powerful geophysical method for detailed mapping of structures in petroleum exploration, but until recently has been considered to be of limited use in exceptionally complex hard rock environments such as the Yilgarn Craton, Western Australia.

To fully evaluate the feasibility of the seismic reflection method to explore for mineral deposits in this region, Curtin University's Department of Exploration Geophysics initiated an experimental program in 2004 that was supported by several major mineral exploration companies and the State Government research institute. Initial 2D seismic images clearly demonstrated that reflection seismic data is of great value to the mining industry. This research program has expanded over the last few years and evolved from basic 2D field trials at an experimental level to a stage where seismic methods have become a method of choice for precise targeting of extensions to existing deposits and mapping new mining targets. Novel seismic data processing and imaging techniques were successfully introduced into this program, and were a key element in encouraging industry to pursue further work. The improved image quality, combined with borehole log information has enabled expansion of the mining activities and the generation of several new exploration prospects. Thus, the stage is now finally set for the application of 3D seismic reflection methods. Additional support for 3D seismic has come from an analysis of off-plane events from crooked seismic surveys. A simplified cross-dip analysis and pseudo-3D pre-stack depth migration highlight the true 3D nature of the structures and establishes necessity for the application of full 3D seismic surveys. Planning for several large 3D seismic surveys to follow on the initial 2D studies are now underway.

Here we present an overview of the developments and achievements, over the past four years in the application of seismic reflection methods for mineral exploration in Western Australia.

TOWARDS GLOBAL HYPERSPECTRAL MAPPING OF SURFACE MINERALOGY: FUNDAMENTAL INFORMATION FOR UNDERSTANDING EARTH'S SOILS AND GEOLOGY

Thomas Cudahy[1], Mal Jones[2], Matilda Thomas[3], Carsten Laukamp[4], Rob Hewson[1], Mike Caccetta[1], Peter Caccetta[5], Andrew Rodger[1], Mike Verrall[1] and Fitri Agustin [6]

*1. CSIRO Exploration and Mining. 2. Geological Survey of Queensland. 3. pmd*CRC, Geoscience Australia. 4. pmd*CRC, James Cook University. 5. CSIRO Mathematics and Information Science. 6. Curtin University of Technology*
Thomas.cudahy@csiro.au

INTRODUCTION

Global-scale mapping of surface mineralogy is now becoming possible using remote hyperspectral sensing technologies. Global-scale mineral maps have now been generated for Mars using thermal infrared hyperspectral data collected from the Mars-orbiting Thermal Emission Spectrometer (*TES*- http://jmars.asu.edu/data/), including maps of feldspar, pyroxene, olivine and quartz contents. Other mineral maps of Mars are now being assembled using the recently launched Compact Reconnaissance Imaging Spectrometer (*CRISM* - http://crism.jhuapl.edu/), including sulphates, kaolinite, illite/muscovite, chlorites, carbonate and water/ice (www.lpi.usra.edu/meetings/7thmars2007/pdf/3270.pdf).

In contrast, even though mapping the mineralogy of the Earth's land surface can improve understanding and management of Earth's resources, including:

- monitoring of soils (acid sulphate soils, salinity, soils loss and soil carbon);
- better characterising regolith materials (e.g. transported versus in situ);
- discovery of new mineral deposits using alteration vectors; and
- more accurate environmental assessments during resource exploitation (baseline mapping, monitoring and mine closure criteria).

There has been no international effort to achieve this opportunity, except via the Japanese multi-spectral ASTER sensor (www.gds.aster.ersdac.or.jp) onboard the US TERRA satellite (http://terra.nasa.gov/). However, ASTER can only provide information about mineral groups because of its relatively low spectral resolution (14 bands), in contrast to hyperspectral systems like the airborne HyMap sensor (www.intspec.com), which has over 100 spectral bands and thus can capture the often narrow, subtle diagnostic signatures of specific minerals. Thus ASTER represents the only "mineralogically tuned" instrument to date that has collected complete coverage of the Earth's land surface, though there has been no coordinated effort internationally to transform the "raw" ASTER image data (L1B or L2) into global maps of mineral groups. The opportunity for hyperspectral mineral mapping of the Earth has largely been left to the private sector, which has impacted on data access (cost and timeliness), reliability of sensor performance, cross-calibration of sensors/data and standardisation of derived geoscience products. This lack of coordination/standardisation has resulted in many users of this technology being unsatisfied, especially as many of the delivered geoscience products have suffered from significant omission/commission errors, with few studies providing real ground validation of the derived geoscience products (Cudahy and others, 2005). The temporal effects of vegetation have also hindered the acceptance this surface mapping technology (only the top few microns are measured).

As a step towards achieving the vision of accessible global-scale, accurate maps of mineral abundances and minerals chemistries, a 2 year project was established in July 2006. This involved the Geological Survey of Queensland (GSQ)(www.dme.qld.gov.au/mines/hyperspectral.cfm) and CSIRO Exploration and Mining (www.csiro.au/science/ps16a.html) with close collaboration with Geoscience Australia (www.ga.gov.au), James Cook University, Curtin University and supported by the Queensland Governments Smart Exploration/Mining initiatives (www.dme.qld.gov.au/zone_files/geoscience_pdf/webbrochure.pdf), CSIRO Minerals Down Under (MDU - www.csiro.au/science/MineralsDownUnder.html), the Cooperative Research Centres for Predictive Mineral Discovery (pmd*CRC) Landscape Environment and Mineral Exploration (LEME) and HyVista Corporation (www.hyvista.com). This project involved the collection of 25000 km^2 of airborne HyMap imagery (~250 flight-lines at 5m pixel resolution) and associated ground and laboratory validation data from along major structural/geological corridors across Queensland. In addition, a large ASTER study of the Mount Isa Block was established by Geoscience Australia and its collaborators and built on previous work of pmd*CRC (van der Wielen *et al.*, 2005). This project involved using CSIRO's software for cross-calibrating and reducing to ground reflectance 140 ASTER scenes followed by implementing effective band combination and masking techniques to generate geoscience information products that were subsequently validated using the processed HyMap and ground data (Thomas et al., 2008).

This paper presents salient ASTER and HyMap results for the Mount Isa area and how these can contribute to the vision of global maps of surface mineralogy for better understanding of the Earth's soils and geology.

REMOTE SENSING DATA AND PROCESSING

Figure 1 presents a "calibrated" ASTER mosaic of 140 scenes spanning the Mount Isa Block (a significant base metal mineralised terrain in north west Queensland), together with the location of the airborne HyMap blocks acquired in 2006 and 2007. These ASTER scenes were collected over a 6 six year period, from all times of the calendar year (summer through to winter), with scene selection based on availability and cloud coverage. The airborne HyMap surveys were in the spring of 2006 and 2007. Approximately 200 flight-lines were collected at approximately 5 m pixel resolution from the Mount Isa area; others were also collected for Georgetown, Hodgkinson and Pajingo areas in NE Queensland. These were collected in blocks of 12-20 overlapping flight-lines. Combined, the total volume of raw ASTER and HyMap data (radiance at sensor and ground reflectance) for the Mount Isa area is approximately 600 Gigabytes.

Generating seamless mineral maps from these remote sensing data is non-trivial and requires correction for a range of phenomena, including instrument effects (e.g. ASTER SWIR "additive" crosstalk effect), atmospheric effects ("additive" molecular/aerosols and "multiplicative" transmission effects as well as solar irradiance), surface directional scattering (bi-directional reflectance distribution function or BRDF) and surface compositional mixing (e.g. linear mixing of plants and soil/rocks). Ideally, users should not have to worry about processing to remove these complex effects. These issues should be taken care of with standardised processing routines that deliver a reliable suite of products for the user to interpret.

Several suites of software were developed by CSIRO to cross-calibrate and process the multi-scene data to pre-competitive geoscience products. One package, called *C-SatMAP*, was designed for processing multi-spectral ASTER data. Another, called *C-HyperMAP* was developed for processing multi-scene hyperspectral data.

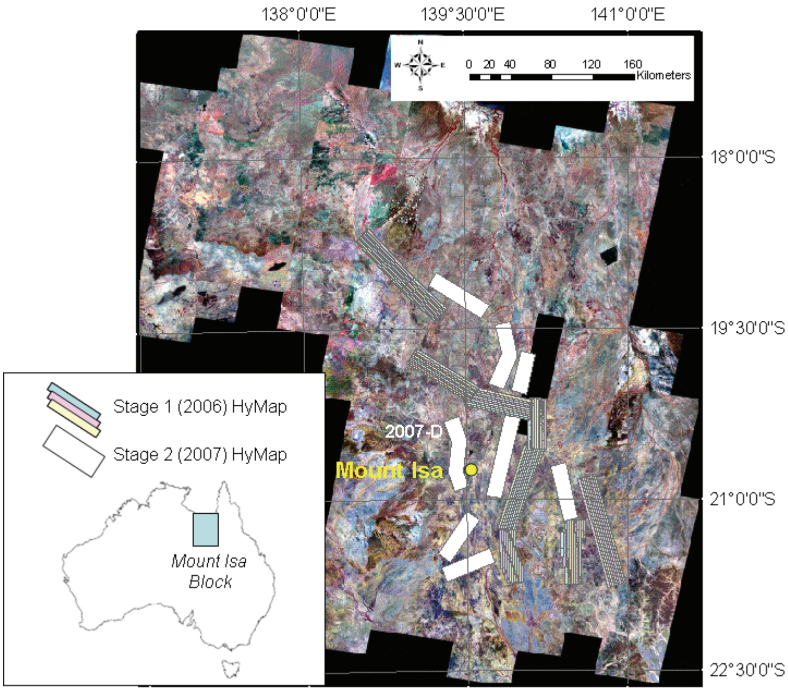


Figure 1. *Coverage of ASTER and HyMap imagery over the Mount Isa inlier, Queensland, Australia. The township of Mount Isa and HyMap Block 2007-D are shown for reference.*

The underlying strategy for generating geoscience information products from these sensors is:

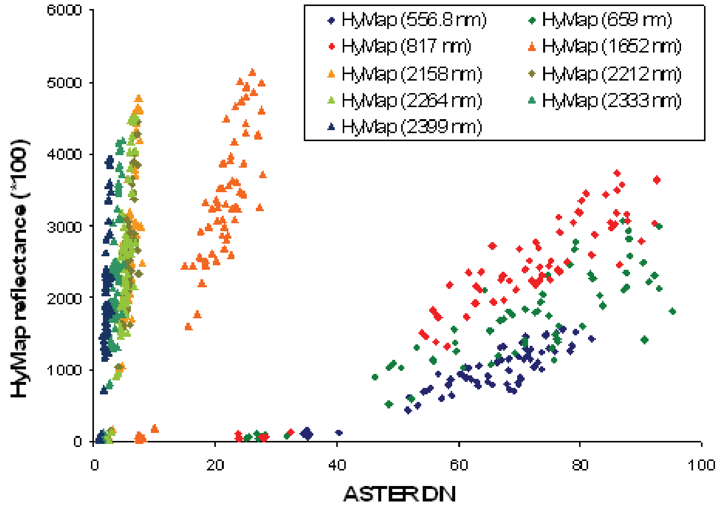
- Avoid levelling and statistics-based methods;
- Use a physics-based reduction model;
- Ensure that data are well calibrated to radiance at sensor or ground reflectance;
- Remove any/all complicating effects/parameters through normalisation;
- Assume that mineral abundances/compositions/crystallinities are proportional to diagnostic absorption depths/wavelengths/widths, respectively;
- Capture the diagnostic absorption information using: (1) continuum band ratios; (2) fitted polynomials; and/or (3) fitted gaussians/lorentzians;
- When the major diagnostic mineral absorption is not present in a pixel, then that mineral is not present, that is, the "background" is defined as the absorption hull. Pure pixels (100% abundances) are gauged using library mineral data (particle size >250 μm);
- Ideally, use multiple absorption features to identify specific minerals ;
- Mask out any spectrally overlapping materials (ideally should be modelled out); and
- Assume linear mixing at the pixel-scale for mixtures of soil/rock with vegetation (dry and green), which enables rescaling of apparent to absolute mineral abundances.

RESULTS

ASTER Data Calibration to Reflectance

The cross-calibration of the ASTER Level 1B imagery was conducted using software developed by CSIRO Mathematics and Information Sciences developed for processing Landsat Thematic data (www.cmis.csiro.au/rsm/research/index.htm). This software uses a Kernel-type approach that reduces the various physical effects (date, lat/long, view and solar angles, BRDF, atmosphere) to a spatially-dependent, linear combination of spectral bands. The accuracy of this cross-calibration was tested using the airborne HyMap reflectance data, convolved to the ASTER response functions, for over 60 regions of interest collected from five blocks (Figure 1). The results (Figure 2) show significant correlation for all 9 "reflected" ASTER bands with the regression relationships generating the gains and offsets necessary to reduce the cross-calibrated

ASTER data to ground reflectance, including removal of additive effects caused by aerosols and SWIR crosstalk.



Band number	band centre (nm)	R^2	gain	offset
1	556	0.8126	29.792	-958.54
2	661	0.7595	36.574	-901.22
3	807	0.898	51.474	-1249.814
4	1656	0.83	232.84	-1654.99
5	2167	0.73	754.41	-1726.21
6	2209	0.75	715.13	-1467
7	2262	0.72	812.4	-1695.37
8	2336	0.7	1027.03	-1321.1
9	2400	0.65	1679.3	-1484.4

Figure 2: *(left) Scattergram showing the regressions between ROIs collected from the cross-calibrated ASTER data and convolved HyMap reflectance data for all nine ASTER bands; (right) Table showing the resultant R^2, gains and offsets for each ASTER band.*

ASTER and HyMap Pre-competitive Geoscience Products

Suites of mineral maps were generated from the calibrated ASTER and HyMap data (Table 1) and are available as public pre-competitive data, together with ancillary data, metadata and methods used generate the products, via ftp using the webpage (www.em.csiro.au/NGMM). Examples, of the ASTER Mount Isa mosaic "Al-clay content" and "Al-clay composition" products are shown in Figure 3. These represent broad estimates only of the Al-clay group minerals, which includes: kaolin (kaolinite, halloysite, and dickite), white mica (illite, paragonite, muscovite, phengite) and Al-smectite (montmorillonite, beidellite). The colours in Figure 3 in theory range from kaolin in blue through to phengite in red, though both can be complicated by vegetation and the later by the presence of Mg-OH minerals, which is shown in Figure 4. That is, non-Al-OH minerals like carbonates, chlorite-epidote and amphibole have high values for the Al-composition product and so data must first be masked to only include those pixels that contain significant Al-clay content.

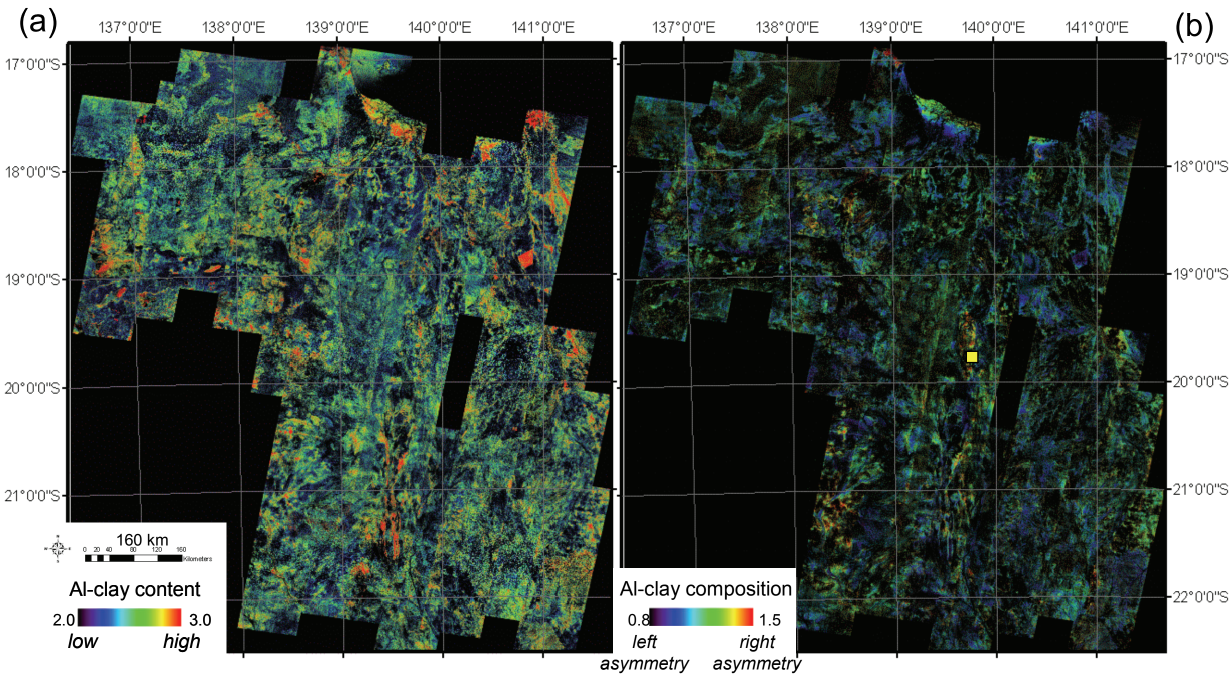


Figure 3: *(a) Calibrate Mount Isa ASTER mosaic processed to generate: (a) Al-clay content; and (b) Al-clay composition. The location of the detailed study area is shown by the white box.*

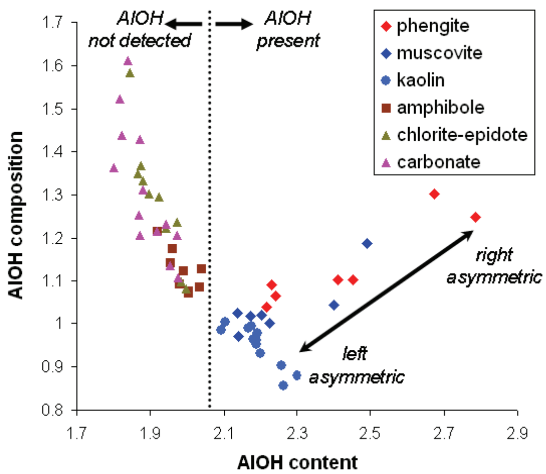


Figure 4: *Scattergram of selected Mount Isa field sample ASD spectra, classified by their dominant mineral types, convolved to ASTER bandpasses and then processed to generate apparent Al-clay content [ASTER band ratio $(B_5+B_7)/B_6$] versus apparent Al-clay compositions (B_5/B_7). Note that masking based on "Al-clay content" (vertical dotted line) is required to accurately separate and measure the "Al-clay composition".*

Mineral Abundances Independent of Vegetation

Vegetation, both dry and green, impacts on the apparent content and composition of minerals at the pixel level. CSIRO is developing methods that measure and then remove the effects of green and dry vegetation to generate "absolute" abundances of minerals at the pixel-scale. However, ASTER lacks bands positioned over the diagnostic cellulose absorption at 2080 nm (lignin absorption @2320 nm region is compromised by MgOH and other mineral absorption) and so is currently only corrected for green vegetation (Figure 5b). In contrast, estimates of green and dry vegetation can be made from the hyperspectral data (Figures 5c and 5d). Using these, the HyMap Al-clay content data were corrected for the effects of dry and green vegetation, as shown in Figures 5e and f. Note the differences between these two Al-clay products, especially in the northwest part of the study area. Success measures of this vegetation-mineral unmixing are the disappearance of tracks/roads, the continuity of geology and correlation with "deeper sensing" data like radiometrics (Figure 6a).

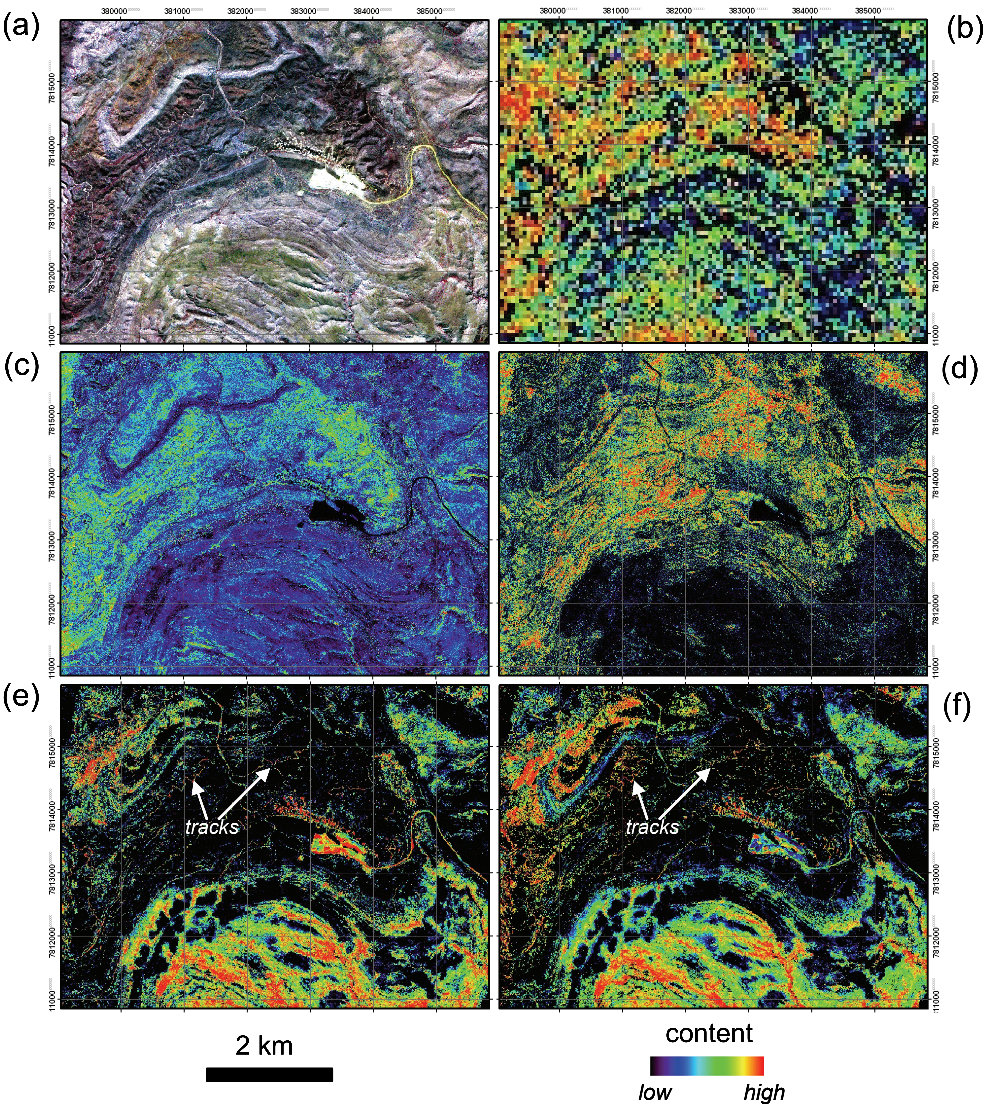


***Figure 5**: Mosaic of HyMap and ASTER images from the same study area (white box in Figure 4b), including: (a) HyMap false colour composite; (b) ASTER Al-clay content unmixed of green vegetation (30 m pixels); (c) HyMap derived green vegetation content; (d) HyMap derived dry vegetation (cellulose) content; (e) HyMap Al-clay content before removing the vegetation content; and (f) HyMap Al-clay content after removing the green and dry vegetation components.*

Mineral Mapping

In contrast to the processed ASTER data, the processed airborne HyMap imagery, allows for specific mapping of Al-clay minerals, including the abundance of kaolinite (Figure 6c) and illite/muscovite (Figure 6d - which have been processed to remove the vegetation components), as well as the level of tetrahedral Si^{4+} for Al^{3+} (Tschermak) substitution (balanced in the octahedral sheet by trivalent for divalent cations) in the white mica, i.e. white mica composition (Figure 6e). The geology comprises quartz/feldspathic sediments that can essentially be classed into two groups based on the presence or absence of white mica (warm versus cool colours, respectively).

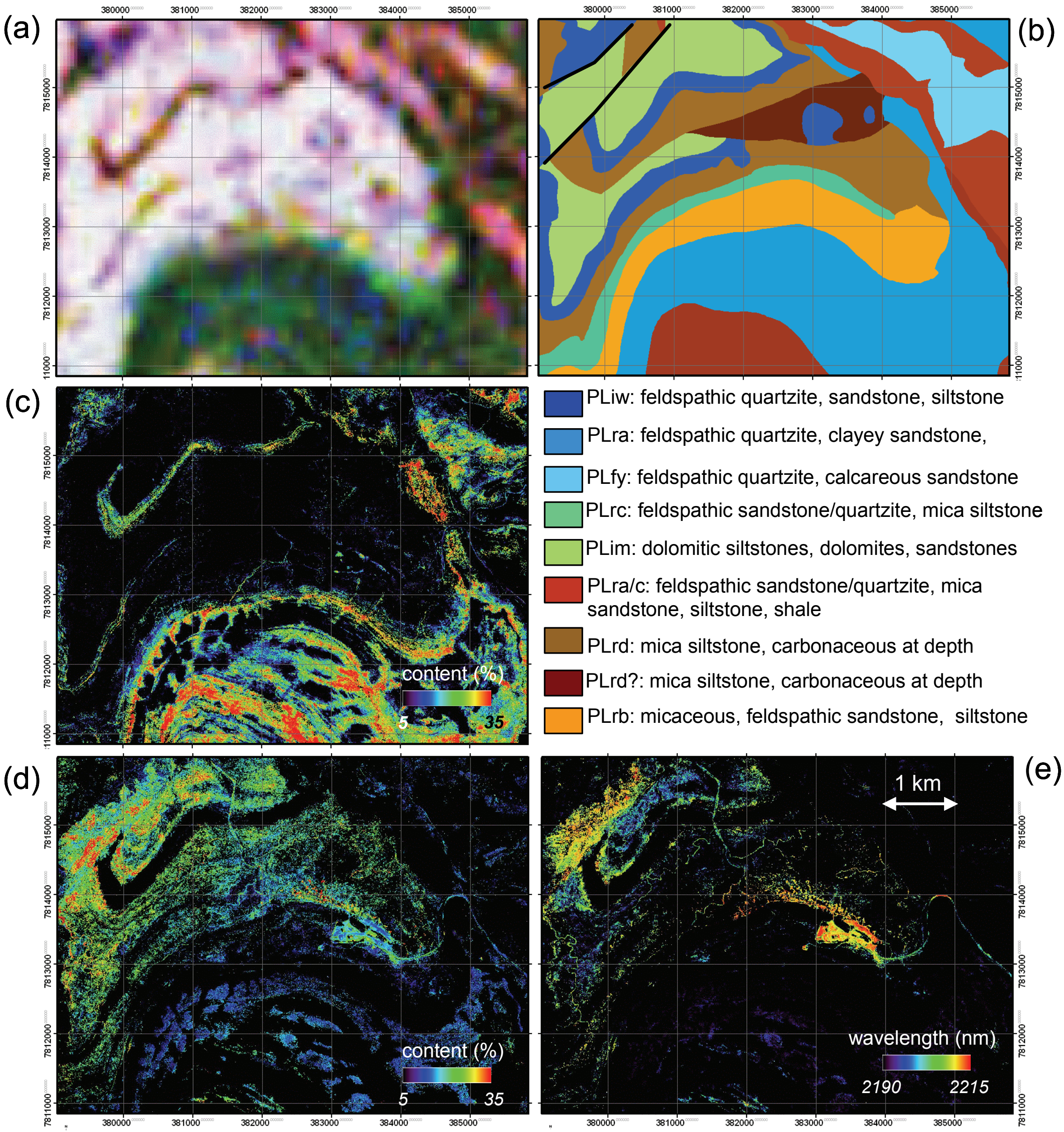


Figure 6: *Mosaic of processed airborne data and geology from over the study area, including: (a) airborne radiometrics ternary image (R G B: K,Th,U); (b) published 1:100,000 scale geology with legend below; (c) HyMap kaolinite content; (d) HyMap white mica content content; and (e) HyMap white mica composition. The HyMap derived images reveal mineralogical contrasts and fine structural detail not reflected in the radiometrics or geological map.*

The effectiveness of the HyMap vegetation unmixing is obvious when comparing the HyMap white mica content image (Figure 6d) versus the airborne radiometrics image (Figure 6a). These images show the same high level of K-rich minerals within a folded unit (white in the radiometrics image), except for a thin quartzite (*PLiw*). The published geology does not map well these same K-rich units, which suggests that the geology can be updated. This also has implications for soil mapping as radiometric data has often been used for mapping soils in Australia (www.asris.csiro.au/index_ie.html) though these data do not enable the direct mapping of "clay" minerals, with for example, K-rich areas being possibly illite/muscovite, K-feldspar or another K-rich mineral.

The dolomite-rich *PLim* unit shows strong K-mica enrichment, including pronounced variations in the white mica composition especially in the NW part of the study area (Figure 6e). Note how the Al-poor micas (blue tones in Figure 6e) dominate this unit north of a NE-SW trending, sinistral fault and to some degree by proximity to the quartzites, suggesting Si-enrichment (relative to Al) of the possible fluids that generated the nearby white micas.

Of particular note is the fact that the open pit mine apparent right-central in the mage (Figure 5a) is associated with Al-poor mica (long wavelength = phengite: red tones in Figure 6e). Though not presented here, the HyMap "opaque" product reveals a thin, continuous, bedding-parallel unit with in the mapped "carbonaceous" *PLrd* which intersects the current open pit mine. This unit could represent a "reduced" rock that may have provided a strong geochemical contrast for oxidised Si-rich fluids to precipitate their dissolved metals. If this speculation is correct, then even within this small study area there exist other mineralogically-similar sites that may represent viable exploration targets.

CONCLUSIONS

ASTER and HyMap studies in the Mount Isa area have demonstrated the potential for mineral mapping using large area (volume) survey data sets. The first results of successfully removing both the green and dry vegetation components at the pixel level have been demonstrated. This type of processing will enable mapping of the "absolute" abundances of minerals to be generated, independent of surface vegetation cover, which has often been considered a problem by many potential users. These studies also show that the opportunity exists today for the current ASTER data archive to be transformed into global-scale geoscience information products. However, the relatively low spectral resolution of ASTER limits its ability for mapping specific minerals and their physicochemistries as well as the possibility for removing the effects of vegetation, especially dry plant materials. In contrast, hyperspectral systems like HyMap provide data suitable for measuring and mapping specific minerals and for unmixing the effects of vegetation. In theory, airborne systems can be used to collect relatively inexpensive regional data by flying at high altitude and generating pixels at a resolution of approximately 20 m. Although not completely matching the performance of airborne systems, the improved spectral resolution of new satellite sensors soon to be launched will also advance the potential for generating a mineralogical map of the Earth.

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ADVANCES IN SPECTRAL LOGGING

Cajetan Phang[1], Tim Munday[1], Jon Huntington[2], Sasha Pontual[3], Sarah Williams[4] and Helen Waldron[4]

1. CRCLEME, CSIRO Exploration and Mining. 2. CSIRO Exploration and Mining. 3. AusSpec International. 4. Genalysis Laboratory Services Pty Ltd (now a member of Intertek Group)
Cajetan.phang@csiro.au

Spectral logging using reflectance spectroscopy in the visible, near and shortwave infrared (350 - 2500nm) is increasingly being adopted by mineral exploration companies in Australia to acquire mineralogical data. The advent of the automated Hychips systems developed by CSIRO, (http://www.csiro.au/resources/HyChipsFactsheet.html), has made spectral logging rapid and easy to use. It has advanced capabilities, such as a digital camera with ~0.2 mm resolution and a profilometer to register sample height and core breaks. Geologists can easily visualise the materials scanned and at the same time use the spectral results of large-scale drill or bench sampling programs to rapidly and objectively determine the mineralogy of regolith profiles, distinguishing between transported and in situ regolith, alteration systems, host rocks, ore systems and ore feeds.

A comparative study between pulps and chips with Genalysis indicates that chips give the best spectral contrast for spectral logging. By exploiting the differences in the spectral properties such as depth, shapes and wavelengths of diagnostic absorption minima of minerals, various spectral indices can be built to characterise the mineral system/geological environment. Spectral characteristics have been found to be site specific and hence, it is imperative that orientation or characterisation studies of a site be undertaken before large scale spectral logging. Orientation studies using a combination of XRD mineralogy, petrographic thin sections, geochemistry or geophysical attributes help to underpin the likely spectral behaviour of the mineral system, from which logical models can then be built for say, the prediction of geochemical characteristics and the detection of particular minerals of interest. Site specific auxiliary spectral libraries can also be developed to identify similar spectral responses elsewhere.

There is also a parallel development by AusSpec International (http://www.ausspec.com/) at making spectral mineralogy more accessible to the non expert through GESSL (The Geological Environment Specific Spectral Libraries). GESSLs for various environments are completed or being developed for lateritic regolith profiles, epithermal and porphory systems and Archaen greenstone settings.

Spectral logging has allowed various spectral indices to be developed for a variety of purposes, such as albedo to map out oxidation zones, KCI index for transported/residual zones, MgOH/FeOH ratio to measure relative proportions of chlorite to carbonate and the Mg minerals, and AlOH wavelength to ascertain composition of white mica. The changes in the AlOH wavelength from shorter to the longer wavelength in a profile can indicate a transition from muscovitic sericite to phengitic sericite, the latter composition often used as an empirical vector associated with proximity of mineralisation.

The future for spectral logging will include the incorporation of a Thermal Infrared (TIR) logging capability with the existing Hylogging technology, although it is likely to be several years before that sees widespread application.

REGOLITH ATLAS AND MAP OF QUEENSLAND

Ian D M Robertson[1] and Michael A Craig[2]

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

A collaborative regolith team from CRC LEME, GA, GSQ and CSIRO commenced a contract with GSQ to generate a regolith map and regolith atlas for the whole of Queensland. A similar project of this type concluded in June 2006 and involved mapping and characterising regolith for the whole of the Northern Territory; this has been used as a model for this project.

The main aim of this very broad regolith project is to establish a regolith-landform map at 1:2.5 million, based on an underlying 250 k compilation. This is to be supported by a regolith materials atlas, describing the variety of regolith materials, where they occur and what their broader identifying characteristics might be, and a broad account of the oxidation event history of the regolith as determined by palaeomagnetism. The project commenced with a state-wide regolith traverse, to set the scene for subsequent more detailed investigations. Specimens for palaeomagnetic dating were collected to establish when oxidation events occur to fit this information into the emerging picture of major weathering periods across the continent. Early results suggest that the principle oxidation event may be early Tertiary. Although this new regolith information will be contained in the maps and atlases, even greater regolith detail will be contained in the supporting GIS. The fieldwork has documented approximately 6000 site-specific descriptions of QLD regolith and landforms for the map.

Some 255 regolith materials have been characterised with field, cut slab and photo-micrographic detail. These data have been entered into a database, which will be an invaluable guide to generating a robust, well-calibrated interpretation of Queensland's regolith character and its distribution. To this has been added major and minor geochemistry (21 analytes) for all specimens, XRD mineralogy for all specimens, and laser diffraction particle size analysis of incoherent materials such as soils and sands.

Output from this project will include a hardcopy map of the Queensland regolith at 1:2 500 000, a 250 k scale GIS, a picture-rich Atlas in hard copy and pdf formats and a picture-rich interactive regolith database with included geochemistry and mineralogy.

Mapping and characterising the regolith of an entire state in two years demanded much of cutting-edge techniques and customized commercial software to handle the massive data volumes generated. Short timelines for such a large undertaking demanded the best of our logistics; thorough project scoping, organization and fieldwork planning.

Team Members: Mike Craig (Project Leader, CRC LEME/GA), Ian Robertson (CRC LEME/CSIRO), Matilda Thomas (GA), Mal Jones (GSQ), Joanne Morrisson (GSQ), Tessa Chamberlain (NRW), Ben Harms (NRW), Brad Pillans (CRC LEME/RSES).

AN OVERVIEW OF CRC LEME EXPLORERS GUIDES AND THEIR IMPLICATIONS TO MINERAL EXPLORATION

Lisa Worrall[1], Ken McQueen[2], Steve Hill[3], John Keeling[4], Adrian Fabris[4] and Ravi Anand[5]

1. CRC LEME, Geoscience Australia, 2. University of Canberra, CRC LEME University of Adelaide. 4. CRC LEME, Primary Industries and Resources SA. 5. CRC LEME, CSIRO Exploration and Mining
lisa.worrall@ga.gov.au

The CRC LEME Explorers' Guide Series is about the regolith; that cover of weathered material between fresh rock and fresh air that blankets much of Australia. More specifically it is about exploration for mineral deposits in regolith-dominated terrains. Mineral exploration is never easy. Of the thousands of prospects chosen for evaluation each year only a very small percentage are deemed to be sufficiently prospective to justify follow-up work, and of these only a handful at best will go on to yield economic mineral deposits. Intelligent and informed exploration must increase the chances of success and a greater understanding of regolith types and regolith processes can only help to shorten the odds in favour of the explorer.

The CRC LEME *Guide for Mineral Exploration through the regolith in the Cobar Region, Lachlan Orogen, New South* Wales has been already being released and Guides to the Thomson, Curnamona, Gawler, Tanami and Yilgarn regions will be released shortly.

This presentation discusses the guide concept and highlights the outcomes of CRC LEME research on developing effective mineral exploration strategies in each these terrains.

A GUIDE FOR MINERAL EXPLORATION THROUGH THE REGOLITH IN THE YILGARN CRATON, WESTERN AUSTRALIA

Ravi R Anand

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

The CRC LEME Explorers' Guides are designed to help mineral explorers understand and work in the Australian regolith. This guide is for the Yilgarn Craton. The Yilgarn Craton is one of the world's principal mineral provinces, with considerable resources of gold, nickel and bauxite, as well as lesser amounts of a wide range of other commodities. As such, it is a major area for exploration. However, large parts of the Yilgarn Craton are covered by deeply weathered regolith which poses considerable difficulties for exploration. This guide is designed to assist mineral explorers working in the regolith-dominated terrains of the Yilgarn Craton. It provides a synthesis of the nature and evolution of the Yilgarn landscape and regolith and advice on appropriate exploration strategies for exploring in both *in situ* and transported regolith. The guide is based on current knowledge and best practice, but should not be seen as the last word.

The introductory chapter describes the geological framework, basement rocks and the principal types of ore deposits in the Yilgarn Craton. The regolith chapter describes the weathering history, nature and characteristics of *in situ* and transported regolith, effect of weathering on element distributions and mapping the regolith in 2D and 3D. The following chapters describe the key challenges in exploration and exploration strategies for gold, VHMS and Ni sulphide deposits on both regional and district-scale exploration. The last two chapters describe the sampling, sample preparation, analysis and analytical control, and some fundamental points to consider in an exploration program.