Australian Regolith Geoscientists Association Abstracts No. 1

First
Australian Regolith Geoscientists Association Conference

21-27 February 2010
Arkaroola, South Australia

Abstracts

Compiled by Ian C. Roach

Contents

About ARGA

What is ARGA?

The Australian Regolith Geoscientists Association Inc. (ARGA) is a not-for-profit learned association of regolith practitioners throughout Australia. The Association was set up to provide a mechanism through which people interested in regolith science could keep in touch and share their experiences via newsletters, email, the internet and an annual conference.

The objects of the association are to further the study of regolith geoscience and allied disciplines by:

- Facilitating the exchange of information among members of the association, and, in general, all those interested in regolith science;
- Stimulating interest in regolith geoscience; and,
- Encouraging the practical applications of regolith geoscience research.

The Association welcomes members from all disciplines that may have involvement in regolith geoscience including geology, geochemistry, geophysics, pedology, biology, hydrology, meteorology, agronomy, forestry, etc.

Committee

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Introduction

First ARGA Conference, February 2010

The beginnings of national conferences and symposia in Australia with specific focus on the regolith go back nearly 30 years to the Regolith in Australia: Genesis and Economic Significance conference in 1983 organised by the Bureau of Mineral Resources, Geology and Geophysics (now Geoscience Australia) and the CSIRO Institute of Earth and Energy Resources. Other important forerunners were the Cainozoic Evolution of Southeastern Australia Conference in 1981, the Age of Landforms in Eastern Australia Conference in 1986 and the SLEADS (Salt Lakes, Evaporites and Aeolian Deposits) conferences in 1988 and 1991.

Establishment of the Centre for Australian Regolith Studies (CARS), jointly at Australian National University and University of Canberra, and later the Co-operative Research Centres for Landscape Evolution and Mineral Exploration in 1995, and Landscape Environments and Mineral Exploration in 2001 (CRCs LEME 1&2) saw these bodies take active leadership in organising and facilitating national meetings devoted principally to regolith research between 1994 and 2006. Cessation of CRC LEME in June 2008 created something of a void with no clear successor in the form of a group or organisation that would continue to facilitate a national forum to debate regolith research.

Against this background, *The Australian Regolith Geoscientists Association* (ARGA) was formed, largely by ex-LEMErs, with the specific objective of taking responsibility, in the interim at least, for organising a national forum for discussion of the regolith. Membership of ARGA is open to anyone who has an interest in the regolith. Ideally membership is about participation and hence those who register for, and attend, an ARGA regolith conference automatically receive membership for 4 years. A token payment of Aus$1 ensures continued membership for those who miss a conference or two.

ARGA rules state:

The objects of the association shall be to further the study of regolith geoscience and allied disciplines by:-
a) facilitating the exchange of information among members of the association, and, in general, all those interested in regolith science;
c) stimulating interest in regolith geoscience;
d) encouraging the practical applications of regolith geoscience research.

Organisation of a conference at least once every two years is the primary means of meeting the association's objects, but in addition, the association operates a web site www.regolith.org.au, maintains a list of members with contact details, has opened a web discussion forum and intends to provide a newsletter to inform members on issues in regolith science. Other activities, members wish to organise, are encouraged.

The ARGA committee welcomes members to the first ARGA Regolith Conference at Arkaroola in the spectacular Flinders Ranges and wish all a memorable and enjoyable meeting that will stimulate our ongoing interest in regolith geoscience.

John Keeling and Lisa Worrall on behalf of the ARGA Committee

Program

Sunday 21 February – Adelaide to Arkaroola

7.30	Depart Adelaide
12.30	Meet for lunch at Hawker
4.30	Arrive at Arkaroola
6.00	Welcome drinks
7.00	Evening meal

Monday 22 February – Oral Presentations (North Flinders regional)

9.00-9.30	Official Welcome & House Keeping
9.30-10.00	S.B. Hore & S.M. Hill. Overview of the geological history of the Arkaroola Wilderness Sanctuary, northern Flinders Ranges, South Australia
10.00-10.30	Morning tea
10.30 – 11.00	D. Haberlah. Loess and floods: Late Pleistocene fine grained valley fill deposits in the Flinders Ranges
11.00 - 11.30	V. Normington, S.M. Hill & S.B. Hore. Preservation: an under-rated component of mineral system models for secondary uranium within the Four Mile Embayment, northern Flinders Ranges, South Australia
12.00-1.00	Lunch
1.00 – 1.30	B. Vanderhoek, S.M. Hill & S.B. Hore. Biogeochemical expression of buried uranium mineralisation by rock fuschia (*Eremophila freelingii*) in the northern Flinders Ranges – western Lake Frome Plains, South Australia
1.30 – 2.00	A. Johnson, S.M. Hill & S.B. Hore. Biogeochemical expression of uranium mineralisation and geology by Eucalyptus camaldulensis in the Paralana Creek drainage system, South Australia
2.30 – 3.00	Afternoon Tea
3.00 – 3.30	P.H. Woods & B.M. Jeuken. Hydrogeology of the Beverley area
3.30 – 4.00	S.M. Hill & S.B. Hore. Overview of regolith and landscape evolution of the Arkaroola Wilderness Sanctuary, northern Flinders Ranges, South Australia
7.00	Evening Meal

Tuesday 23 February – Ridgetop Track and Ranges

8.00	Depart Arkaroola
	Mt Oliphant
	Arkaroola Waterhole?
	Coulthard’s Lookout
	Radium Creek Metamorphics
	Waterfall Lookout
	Sprigg Costean
	“The Waterfall”
	LUNCH
	Split Rock Lookout
	Streitberg Prospect
	Sillers Lookout
	Corundum in Radium Creek Metamorphics and No.6 Mt Painter
5.00	Return to Arkaroola
7.00	Evening Meal

Wednesday 24 February – Oral Presentations (National)

9.00 – 10.00	L. Worrall. The CRC LEME Legacy: the outcomes of seven years of regolith research
10.00 – 10.30	Morning Tea
10.30 – 11.00	R.G. Creswell. Qanats: regolith scientists provide water to a parched land
11.00 – 11.30	D.J. Gray, R.R.P. Noble, & N. Reid. Hydrogeochemical mapping of northeast Yilgarn groundwaters
12.00 – 1.00	Lunch

1.00 – 1.30	K.M. Scott. Characteristics of soils at the Hera Au-Zn-Pb-Cu-Ag deposit, Nymagee region, NSW
1.30 – 2.00	M. Thomas, M. Caccetta, T. Cudahy & M. Jones. Satellite imagery and mapping regolith materials: a new ASTER mosaic and product testing in the Gawler-Curnamona
2.00 – 2.30	Afternoon Tea
2.30 – 3.00	I.C. Roach, A.J. Whitaker, M.T. Costelloe, D.K. Hutchinson, S.F. Liu, M.A. Craig & N.C. Williams. Reducing uranium exploration risk in the Paterson Province, WA: mapping paleotopography using regional AEM
3.30 – 4.00	R.A. Eggleton. Images of bauxite
4.00 – 4.30	G.M. Taylor. Regolith oddities
7.00	Evening Meal

Thursday 25 February – Paralana Hot Springs and Four Mile West

8.00	Depart Arkaroola
	Stubb's Waterhole
	Lady Buxton Fault
	Eyre Formation and silcrete
	Parabarana Sandstone
	Paralana Hot Springs (Lunch)
	Four Mile West Lookout
	Bulldog Shale North of Four Mile
	Deadtree Section
5.30	Return to Arkaroola
7.00	Evening Meal

Friday 26 February – Oral Presentations (South Australia)

9.00 – 9.30	L.M. Stoian. Palynology of Cenozoic sediments from South Australia: examples of applications from recent projects
9.30 – 10.00	M.N. Keppel, J.D.A. Clarke, T. Halihan, A.J. Love, & A.D. Werner. Geology and hydrochemistry of selected mound spring environments, Lake Eyre South.
10.00 – 10.30	Morning Tea
10.30 – 11.00	J.L. Keeling: Acid groundwater and halloysite-alunite deposition in Cenozoic terrestrial sediments marginal to the Eucla basin, southern Australia
11.00 – 11.30	B.J. Dietman, S.M. Hill & G.M. Lowe. Regolith and associated geochemical and biogeochemical expression of buried copper-gold mineralisation at the Hillside Prospect, Yorke Peninsula.
12.00 – 1.00	Lunch
1.00 – 1.30	R.C. Dart, S.M. Hill, D.J. Chittleborough & K.M. Barovich. Landscape and pedological controls on the formation of Au-in-calcrete anomalies
1.30 – 2.00	A.J. Fabris. Can partial leach soil surveys be used to explore for gold through dune fields? Examples from Tunkillia
2.00 – 2.30	Afternoon Tea
2.30 –	ARGA meeting. Open discussion on the future of ARGA, the location of the next ARGA conference and volunteers to organise it
7.00	Evening Meal

Saturday 27 February – Arkaroola to Adelaide

8.00	Depart Arkaroola
	David Haberlah may offer a Brachina Gorge detour option
5.00	Return Adelaide

Qanats: Regolith scientists provide water to a parched land!

R.G. Cresswell

CSIRO Water for a Healthy Country Flagship & Division of Land and Water
Riverside Corporate Park, North Ryde NSW 2113

Long, underground tunnels, built into the sides of valleys, tap the shallow water tables that exist beneath the colluvial aprons of the Middle East, northern Africa and across into Asia. Providing water to irrigate cotton, fruits and oilseeds in country similar to Central Australia, these *qanats* today support nearly three-quarters of Iran's population. Over 300,000 km of low-gradient, narrow tunnels tap unconfined aquifers perched on clay lenses in the colluvial fans of the dry valleys. Roughly 20,000 of these systems exist, with some up to 30 km long, providing an almost continuous water supply, sometimes up to 250 L/s, for the fertile alluvial soils of the valley floors (Wulff 1968).

The specialist surveyor, hired to locate the water source, design and oversee construction of the tunnels and ensure water flow to villages and fields, was thus one of the most important and revered members of society. He was highly paid for his services, and he was a regolith scientist!

Understanding how water moved through the landscape, how the landscape influenced its quality and quantity, how the juxtaposition of particular beds and materials controlled both transport of water and the state of the tunnels was vital if an adequate supply was to sustain the communities the qanat served. Exploratory shafts were dug, up to 80 m deep, to expose the stratigraphy and locate suitable water reserves (that had to be underlain by suitably impervious clays); access and maintenance shafts were dug to allow construction of the tunnels and clay hoops were used to bolster sections of the tunnels where friable materials threatened their integrity.

Qanat tunnels generally had grades of 1:500 to 1:1 500. They are gravity-driven and so self-regulating. In dry periods they may cease flow; in wetter periods, sluice gates may be installed to create artificial weirs and dams in the system to store water. The skill of the surveyor dictates whether a sustainable supply will be realised.

This simple system is found across the globe. Etymologically, Persia appears to be the birthplace, with the technology spreading across northern Africa and southern Europe (and from there to Mexico – though there is evidence of similar systems in use in Chile and Peru prior to the Spanish conquests on the east coasts) and following the Silk Route to Afghanistan, Pakistan and on to China.

References

Wulff H. E. 1968. The Qanats of Iran. *Scientific American* **April**, 94-105.

Landscape and pedological controls on the formation of Au-in-calcrete anomalies

R.C. Dart, S.M. Hill, D.J. Chittleborough and K.M. Barovich

Centre for Tectonics, Resources and Exploration (TRaX), School of Earth and Environmental Sciences, Geology and Geophysics, Mawson Laboratories, North Terrace, Adelaide, SA 5005

Regolith carbonate, especially when indurated (calcrete), has been widely adopted as a sampling medium by many Australian Au exploration companies. Rapid uptake of the medium in geochemical exploration programs, following its reported success in the South Australia Challenger Au deposit discovery, has resulted in poorly constrained sampling methodology with many inconsistencies. Results have therefore been equivocal. Three aspects of regolith carbonate development and association with Au are investigated. These are based on variable spatial scales, ranging from the southern Australian continent, to local area, to individual profile.

On a continental scale, regolith carbonates cover extensive areas of southern Australia. The primary component, Ca, is sourced from mineral weathering or atmospheric sources. Through the use of Sr isotopes to provide a surrogate expression for Ca sources, the source was identified as >90% atmospheric or marine derived. A uniform inland signature is identified, which is attributed to the continual recycling and mixing of marine derived Ca with minimal bedrock input. An external Ca source means that Ca does not have a direct relationship with Au, which is locally sourced from mineralised areas.

On a local scale, a Au-in-calcrete anomaly extending over 20 km^2 and lying over both mineralised (Tunkillia Au prospect, Central Gawler Craton, South Australia) and barren bedrock was investigated. Regolith-landform mapping and geochemistry were used to further identify the zone of elevated Au-in-calcrete. The zone was found to correspond spatially with palaeo- and contemporary drainage systems that currently flow into ephemeral lakes. Regolith carbonate geochemistry of the area shows that the majority of elements have been transported and enriched along these systems. This dispersion pattern and its contemporary landscape expression is complicated by dune fields over mineralisation that partially cover the palaeo-drainage. Millions of dollars have been spent drilling this anomaly with no significant mineralisation found beyond the discrete Tunkillia mineralised zones, yet with the aid of regolith-landform mapping an explanation of the anomaly spatial pattern and dispersion pattern has been provided at very low cost.

On the profile scale, two regolith carbonate profiles from the White Dam Au-Cu prospect were analysed in detail. Mass balance calculations revealed chemical gains and losses for the soil horizon and total profile. The investigation quantified the extensive external Ca input and revealed the position and size of the Au particles. Gold in the profile prior to regolith carbonate development is concentrated at the top of the regolith carbonate horizon as calcite precipitation in void spaces reduces permeability. Ongoing calcite precipitation up the profile locks in the Au, resulting in a Au-in-calcrete anomaly.

Exposure of Au-enriched calcrete horizons to chemical and physical weathering results in decomposition of the material. This material can then be transported in the form of surface lag, which may settle on top of existing and still developing regolith carbonates to form new Au-in-calcrete anomalies that are unrelated to underlying bedrock.

The formation of Au-in-calcrete anomalies in relation to landscape processes is demonstrated. Additional information on landscape setting, gathered while sampling, can therefore improve interpretation of regolith carbonate geochemistry. Exploration companies that take time to understand the landscape setting in this way and react accordingly, can therefore expect improved results.

Acknowledgements

Support for this research was provided by a joint CRC LEME and University of Adelaide PhD scholarship.

Regolith and associated geochemical and biogeochemical expression of buried copper-gold mineralisation at the Hillside Prospect, Yorke Peninsula

Byron John Dietman[1], S.M. Hill[1] and G.M. Lowe[2]

[1]Centre for Tectonics Resources and Exploration (TRaX), School of Earth & Environmental Sciences, University of Adelaide, SA 5005
[2]Rex Minerals Ltd, Ballarat, Victoria 3350

Significant Cu-Au mineralisation with associated high grade U has been discovered in recent drilling by Rex Minerals Ltd within its Hillside Project, Yorke Peninsula, South Australia. Drilling so far suggests that mineralisation has characteristics typical of Iron-Oxide Copper Gold (IOCG) mineralisation. Vegetation, soil and calcrete sampling was conducted with the aim to characterise the surficial regolith geochemical and biogeochemical expression of the buried Cu-Au mineralisation in the Hillside area (Dietman 2009). More specifically, this included:

1. Characterisation of geochemical and biogeochemical signatures within moderate transported cover thickness;
2. Development of a recommended soil geochemical exploration approach for the project area and potentially equivalent settings;
3. Characterisation of soil geochemistry across the mineralised zones and non-mineralised substrate with increasing thicknesses of sedimentary cover; and,
4. Interpretation of recommended soil geochemistry exploration results within the project area, including their possible implications for further mineral exploration.

The suite of elements chosen for detailed presentation is based on their local abundance and expression of known mineralisation. These include: mineralisation commodity elements (Au, Cu, U); secondary mineral trace element host elements (Al, Fe, Ca); and, pathfinder and mineralisation accessory elements (Ce, Co, Dy, Li, Tl and V). This study highlights the potential of regolith geochemical and biogeochemical sampling to characterise the regolith expression of buried Cu-Au mineralisation. The results from this study have major implications for mineral exploration in landscapes dominated by aeolian transported cover, such as at Hillside, where otherwise the geochemical expression of buried mineralisation within the uppermost soils is typically obscured.

This study supports the use of vegetation (*Eucalyptus gracilis* and *Eucalyptus socialis*), pedogenic calcrete and lower soil horizons as sampling media in regional, prospect and tenement-scale mineral exploration programs. This study has also emphasised the importance of understanding the landscape setting and history of geochemical and biogeochemical samples and using local orientation studies prior to undertaking major sampling programs.

Reference

Dietman B.J. 2009. *Regolith and associated geochemical and biogeochemical expression of buried copper-gold mineralisation at the Hillside Prospect, Yorke Peninsula*. University of Adelaide BSc (Hons) thesis (unpublished).

Images of bauxite

R.A. (Tony) Eggleton

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After each session on a Scanning Electron Microscope I leave with more questions than I had when I arrived. In this slide show I will be looking to the viewers to explain the features that bemuse me. Images from Weipa will include some from the weathering profile, from the bauxite pisoliths, and from bauxitic beetle pupal cases. Bauxite on the southern Highlands of NSW (Canyonleigh) also provides curiosities.

Can partial leach soil surveys be used to explore for gold through dune fields? Examples from Tunkillia prospect, South Australia

A.J. Fabris

PIRSA, PO Box 1671, Adelaide SA 5001

Geochemical soil samples were taken on two traverses over shear-hosted Au mineralisation in Area '223' at the Tunkillia Au prospect, 550 km northwest of Adelaide. The objective was to assess the effectiveness of near-surface soil sampling in locating mineralisation in areas where bedrock is deeply weathered and covered by an aeolian dune field. One sample line was along the crest of a longitudinal dune that cross-cut the mineralised zone, the other along the adjacent swale. Samples were collected from 5-25 cm depth, sieved to <200 µm, and element concentrations determined on partial extractions obtained using sodium pyrophosphate with cyanide.

Gold results for individual survey lines showed highest values over the mineralised zone. Results for the dune traverse, however, gave significantly reduced levels of extractable Au, and an anomaly to background ratio that was much less than for samples collected along the swale.

Near-surface soil sampling and partial leach analysis is potentially a viable and cost effective exploration strategy in the region, provided regolith, landform and vegetation factors are taken into consideration in determining appropriate background values against which individual sample data are evaluated.

Hydrogeochemical mapping of northeast Yilgarn groundwaters

D.J. Gray, R.R.P. Noble and N. Reid

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Introduction

The use of hydrogeochemistry for mineral exploration is increasing in Western Australia. Exploration targets are becoming more difficult to find and greater emphasis is being placed on exploring through deep (>30 m) transported cover and into basin terrains. Groundwater interacts with mineralised rocks and creates a geochemical signature that may be much greater in size than regolith as the groundwater is more mobile than the surrounding minerals. This may reduce the required sampling density, assisting cost effective exploration in covered terrains. Exploration hydrogeochemistry has been developed in Western Australia (Gray, 2001; Gray & Noble, 2006), while Kirste *et al*. (2003), Pirlo & Giblin (2004) and de Caritat *et al*. (2005) have pursued these methods in other parts of Australia.

The objectives of the Hydrogeochemical mapping of the Northeast Yilgarn Craton Project were to compile background hydrogeochemical data and to develop reliable regional hydrogeochemical prospectivity maps to indicate different lithology and styles of mineralisation in the northeast Yilgarn Craton. Groundwater samples were collected either directly from pumping windmills/bores (739 samples) or via a bailer system (680 samples). Field measurements included pH, Eh, EC and temperature. Separate field prepared sub-samples were collected for cation, anion, alkalinity and (using carbon sorption) Au/ PGE analysis. Robust statistical methods were developed to combine bailed and flowing samples using a derived contamination factor that is tailored to the individual measured parameter. Rescaling normal or log-normal data and the creation of indices for lithology discrimination, Au mineralisation, U mineralisation and sulphide mineralisation improved the utility of hydrogeochemical data. These methods can be adapted and applied to other hydrogeochemical data sets.

Results

The use of hydrogeochemical mapping to define prospective areas in the northeast Yilgarn was successful particularly for U and Au by sampling groundwater from farm bores and windmills at the 4-10 km scale. Groundwater chemistry, and particularly the carnotite mineral saturation index, predicted most known U deposits in the northeast Yilgarn Craton. Hydrogeochemical exploration for Au delineated the two world class gold camps (Lawlers and Sunrise Dam), and gave prospectivity estimates for various greenstone belts. Lithological indicators, such as a derived Lithology Index, were able to separate greenstones from granites. The lithology index could potentially be used to map underlying rock through cover using groundwater in basin regions, such as to the east of the northern Yilgarn Craton margin.

The project has demonstrated that groundwater chemistry can effectively map large scale lithological changes, hydrothermal alteration, and mineralisation, and in turn reduce uncertainly about the prospectivity of areas within the northeast Yilgarn Craton. For the industry, the developed methods and interpretation from this study should make it possible to extend exploration into covered environments as most of the northern two thirds of Australia have similar groundwater conditions. New methods of data management have been developed (i.e. contamination index and lithology index) along with models for weathering of ore systems and the expected groundwater signatures. Additionally, this data set can be used as background data that will improve other small scale studies.

References

Caritat P. de, Kirste D., Carr G. & McCulloch M. 2005. Ground water in the Broken Hill region, Australia; recognising interaction with bedrock and mineralization using S, Sr and Pb isotopes. *Applied Geochemistry* **20**, 767-787.

Gray D.J. & Noble R.R.P. 2006. Nickel hydrogeochemistry of the northeastern Yilgarn Craton, Western Australia. **CRC LEME Open File Report 243R / CSIRO Exploration and Mining Report P2006/524**, 133 p.

Gray D.J. 2001. Hydrogeochemistry in the Yilgarn Craton. *Geochemistry: Exploration, Environment, Analysis* **1**, 253-264.

Kirste D., Caritat P. de & Dann R. 2003. The application of the stable isotopes of sulfur and oxygen in groundwater sulfate to mineral exploration in the Broken Hill region of Australia. *Journal of Geochemical Exploration* **78-79**, 81-84.

Pirlo M.C. & Giblin A.M. 2004. Application of groundwater-mineral equilibrium calculations to geochemical exploration for sediment-hosted uranium; observations from the Frome Embayment, South Australia. *Geochemistry: Exploration, Environment, Analysis* **4**, 113-127.

Loess and floods: Late Pleistocene fine-grained valley-fill deposits in the Flinders Ranges, South Australia

D. Haberlah

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Terrace remnants of Late Pleistocene fine-grained valley-fills, at present eroded by ephemeral traction-load streams, are reported from many semi-arid and arid parts of the world (see Haberlah 2007a). While they present promising palaeo-environmental archives for recent geological times such as the Last Glacial Maximum (LGM), for which few other terrestrial depositional records exist, their poorly understood nature has limited their significance. This study examines the fine-grained valley-fill deposits from the Flinders Ranges in South Australia, here called **Flinders Silts**. It establishes the timing, mode and environmental controls of deposition as opposed to their advancing erosion under the current climate.

A **regional chronostratigraphy** based on 124 numerical dates is discussed, of which 43 radiocarbon and 22 luminescence ages were obtained from 12 sections across three major catchments within the scope of this study (Haberlah *et al*. 2010a). Regionally significant intervals of rapid aggradation, relative surface stability and erosion are established. Regional climatic controls are differentiated from intrinsic catchment- and site-specific effects on the system. Further, individual age proxies and age models are critically assessed in how far they reflect depositional events. The final aggradational interval bracketing the extended LGM is discussed in detail on a continuous layered to laminated stratigraphic sequence.

The **provenance question** of the fine-grained sediments (see Haberlah 2007b; 2008) and the depositional environment of the Flinders Silts are further addressed by high-resolution particle-size analysis. In order to study the subtle variations within the fine-grained partially-aggregated material, an original parametric sediment-sizing approach is employed (Haberlah & McTainsh 2010). Finally, a range of traditional (carbon isotope geochemistry, magnetic susceptibility) and emerging analytical techniques (QEMSCAN® Automated Mineralogy) are applied to improve our understanding of palaeo-environments promoting aggradation (Haberlah *et al*. 2010b).

In conclusion, arid intervals throughout the last glacial cycle resulted in significant quantities of proximal dust being deposited as loess mantles within the catchments of the Flinders Ranges, acting as a near-longitudinal dust trap in the centre of the Late Pleistocene “dust bowl”. The fine-grained aeolian accessions were repeatedly eroded by low-frequency, high-magnitude precipitation events and redistributed as loess-derived alluvium, congesting narrow gorges and raising the base level for tributaries. Locally, backflooding resulted in the aggradation of layered to laminated slackwater deposits, the most continuous recording at least 12 large and numerous smaller flood events between 24 ka and 18 ka. The synchronous termination of the Flinders Silts coincides with early deglacial climatic amelioration. The re-establishment of a perennial plant cover stabilising both dune fields and slope mantles is discussed as a potential scenario that would have discontinued dust supply to the fluvial system, in turn promoting incision and erosion. The studied aeolian-fluvial interplay of loess and floods has large implications for our understanding of landscape and regolith evolution in semi-arid Australia.

Haberlah D. 2007a. Depositional models of late Pleistocene fine-grained valley-fill deposits in the Flinders Ranges, SA. *In:* Fitzpatrick R.W. & Shand P. (eds). *Regolith 2006—Consolidation and dispersion of ideas*. Cooperative Research Centre for Landscape Environments and Mineral Exploration, Perth, 122-126.

Haberlah D. 2007b. A call for Australian loess. *Area* **39(2)**, 224-229.

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Haberlah D. & McTainsh G.H. 2010. Quantifying particle aggregation in sediments. *Sedimentology* **(in revision)**.

Haberlah D. Glasby P., Williams M.A.J., Hill S.M., Williams F., Rhodes E.J., Gostin V., O’Flanery A., Jacobsen G.E. 2010a. ‘Of droughts and flooding rains’*: an alluvial loess record from central South Australia spanning the last glacial cycle. *In:* Bishop, P. & Pillans, B. (eds) 2009. *Australian Landscapes*. Geological Society, London, Special Publications, **(in press)**.

Haberlah D., Williams M.A.J., Halverson G., Hrstka T., Butcher A.R., McTainsh G.H., Hill S.M., Glasby P. 2010b. Loess and floods: high-resolution multi-proxy data of Last Glacial Maximum (LGM) slackwater deposition in the Flinders Ranges, semi-arid South Australia. *Quaternary Science Reviews* **(in revision)**.

Overview of Regolith and Landscape Evolution of the Arkaroola Wilderness Sanctuary, northern Flinders Ranges, South Australia

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The northern Flinders Ranges hosts one of the most spectacular and scientifically interesting arid zone mountain landscapes in Australia. The landscape history of the region includes prime examples of many key components in the development of Australian intraplate, inland regolith and landscape evolution. These include basin-hinterland interactions as well as the variable influences from bedrock lithology, climate change, sea-level change, tectonics and anthropogenic controls on landscape history and associated regolith development.

Ancient regolith and landscape remnants in the region date back into the Paleozoic and include exhumed land surfaces and minerals altered in surface and near-surface landscape settings associated with the landscape expressions of the Mt Painter - Mt Gee epithermal system. There is also potential for Permian glacial and periglacial regolith and landscape remnants in the area, although apart from possible remnants near Mt Gee and further south near Blinman, their preservation has been limited.

Mesozoic landscape remnants and associated regolith materials are widespread and express the evolution of basin-hinterland relationships associated with the Jurassic-Cretaceous Eromanga Basin as well as small Triassic intramontane basins, such as the Telford Basin, in the northwest. Longterm landscape evolution studies have mostly focussed on the Frome Embayment of the Eromanga Basin, which lies east of the northern Flinders Ranges. The Eromanga Basin sediments here broadly include a lower (Jurassic to Early Cretaceous) non-marine succession that includes the Algebuckina Sandstone and equivalent units. The following Early Cretaceous marine succession includes the Cadna-owie Formation associated with the transition from terrestrial to marine conditions, and then the shallow marine Bulldog Shale. During most of the Mesozoic, the northern Flinders Ranges appears to have been an area of moderate topographic relief with variable distribution of bedrock- and regolith-dominated terrain. Several Mesozoic palaeosurfaces have been recognised across the region, including a sub-Eromanga Basin (pre-Jurassic) surface and other surfaces that are graded to the baselevel of the Early Cretaceous marine transgression.

In the Cenozoic the landscape history of the northern Flinders Ranges was dominated by the development of the Lake Eyre Basin to the northwest, north and east, as well as the Torrens Basin to the southwest. The part of the Lake Eyre Basin that immediately flanks the northern Flinders Ranges is known as the Callabonna Sub-basin. The Lake Eyre Basin and Torrens Basin are interior non-marine basins. The Early Tertiary (Late Palaeocene to Middle Eocene) sediments in these basins include dominantly fluvial sediments of the Eyre Formation in the Lake Eyre Basin and the Cotabena Formation in the Torrens Basin. The landscape at this time was of undulating, well vegetated relief, resulting in quartz and kaolinitic detritus reflecting a highly weathered, but not necessarily a 'peneplain', provenance and hinterland landscape. The Eyre Formation has been considered important in hosting secondary uranium mineralisation at Honeymoon and possibly Four Mile, within the Callabonna Sub-basin to the east of the Ranges. Following deposition of the Eyre Formation, silcrete development appears to have been widespread in the basin area, perhaps initiated by widespread oxidation and acidic weathering conditions. These sediments are followed by Early to Late Miocene, lacustrine and minor fluvial sediments of the Namba Formation (which hosts the Beverley uranium mineralisation) in the Callabonna Sub-basin and the Neuroodla Formation in the Torrens Basin. The Quaternary regolith in the area largely includes fluvial, colluvial (especially sheetwash), aeolian and lacustrine sediments with minor regolith carbonates and gypsum indurations.

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We thank Marg and Doug Sprigg for their interest in our research and allowing access to parts of Arkaroola Wilderness Sanctuary.

Biogeochemical expression of buried uranium mineralisation by rock fuschia bush (*Eremophila freelingii*) in the northern Flinders Ranges-western Lake Frome Plains, South Australia

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The widespread shrub species, rock fuschia bush (*Eremophila freelingii),* of inland Australia, has successfully expressed elevated U contents in both leaf and twig samples at sites of known mineralisation in the Mt. Painter region, South Australia. Leaf material produced reasonable contrast in U concentrations discriminating between sites of buried mineralisation and adjacent non-mineralised sites. Approximately 75% of samples have a U concentration greater than or equal to analytical detection limit (DL). Elements generally occur in higher concentration in twig tissues than leaves, although twigs have a greater tendency to host detrital (dust) inputs. The highest U concentration came from the high-grade historic Hodgkinson U-prospect. Overall, leaves contained 0.05-0.24 ppm U and twigs contained 0.08-0.41 ppm U (1.04-5.86 times higher). Twigs also hosted Re up to 266 times the DL of 0.1 ppm, when leaves contained concentrations below the DL. The elevated Re concentrations in leaf tissue are particularly characteristic of samples from the intrusive granites at the Pinnacles and Needles. Beryllium is also elevated in samples from Hodgkinson and the Pinnacles and Needles sites. A few traditional U pathfinder elements have an association with U in plant tissues including Y, Ce and La on a regional scale and particularly at Four Mile West. Other elements, such as Li and Be, have associations with U in twigs limited to the Hodgkinson prospect. Mineralisation in the Four Mile West area occurs in the Eyre Formation (Four Mile U-prospect) and in the Namba Formation (Beverley U deposit). *E. freelingii* has elevated U from sites over these units at concentrations above the regional biogeochemical average. Other economic elements, such as Au and Ag, were present in low concentrations and returned values ≥ DL in 25.3% and 57.8% of all samples respectively. The Four Mile West sequence hosts the highest Au concentrations, while samples from sites with hematite breccias host the elevated Ag and Zn results. Copper concentrations showed high variation (3.12-32.02 ppm) in all samples but the results do not appear to be closely associated with geological setting.

Overview of the Geological history of the Arkaroola Wilderness Sanctuary, northern Flinders Ranges, South Australia

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The Arkaroola Pastoral Station and surrounding region provides excellent and well-exposed examples of South Australia's geological history ranging from passive still-water deposition of sands and silts to explosive brecciation of granites infilled with hot percolating mineral-rich fluids. The Arkaroola region is therefore of considerable geological interest to those wishing to view, study and interpret the numerous examples and varying styles of sedimentation, intrusion, alteration, fluid-flow and mineralisation events. Access to key locations in this area of rugged terrain is limited to walking the creek beds, climbing the peaks and ridges or along the restricted vehicle tracks.

In simple terms the sequence of geological events can be presented as :

1. Deposition of Mesoproterozoic basement, followed by deformation, metamorphism, sodic alteration, burial and uplift;
2. Intrusion of Mesoproterozoic granites into the pelitic, psammitic and calcic Mesoproterozoic basement and extrusion of Mesoproterozoic volcanics, followed by uplift and erosion;
3. Commencement and continued burial of the Mesoproterozoic sequences by the less-metamorphosed Adelaidean metasediments and volcanics in a rift-setting which was reversed by the Delamarian Orogeny;
4. High heat flow and associated fluid-flow, alteration and localised formation of S-type Ordovician granite and mafic pegmatites;
5. Uplift, erosion of Adelaidean metasediments and volcanics exposing areas of, and brecciation of, the Mesoproterozoic basement which was intruded by uranium-rich hematitic fluids and later siliceous fluids;
6. Mesoproterozoic basement and surrounding Adelaidean sequences overlain by Mesozoic and Cenozoic sediments; and,
7. Continued uplift and erosion of Mesoproterozoic basement, Adelaidean sequences, Mesozoic and Cenozoic sediments due to the east-west compressional regime the Australian Continent is presently experiencing.

Central to Arkaroola Pastoral Station is the Mt Painter Inlier (MPI), from where uranium is believed to be the source for the secondary mineralisation located in the surrounding Cenozoic sediments, which is the current focus for explorers in the region. The MPI predominately consists of Mesoproterozoic metasediments, granites and gneisses of which many are highly anomalous in uranium such as the Yerila, Mount Neill, Box Bore and Terrapinna granites. The granite zircon ages range from 1580 to 1560 Ma and the youngest detrital zircons ages within the hosting Mesoproterozoic Radium Creek Metamorphics (Freeling Heights Quartzite) gave ~1590 Ma. The MPI has been affected by two Proterozoic deformation events in addition to the Cambro-Ordovician Delamerian Orogeny. This orogeny also affected the Adelaidean sediments and metasediments (900 to 500 Ma) that flank the MPI to the west and south.

Post-Delamerian hematitic and granitic breccias are located within a north-east trending 10 km wide zone of the southern MPI, where discrete lenses of high-grade uranium mineralization have formed. This brecciation maybe part of Ordovician (440 Ma) thermal event; continued evidence is being gained supporting its affect on many of the lithologies in the region at this time.

The younger sediments to the east of the MPI contain minable uranium mineralisation (e.g. Beverley Uranium Mine and Four Mile Prospects) and excellent examples of neotectonism along the range-front.

Biogeochemical expression of uranium mineralisation and geology by *Eucalyptus camaldulensis* in the Paralana Creek drainage system, South Australia

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Leaves from *Eucalyptus camaldulensis* (river red gum) were sampled within the Paralana Creek catchment extending from the northern Flinders Ranges onto the Lake Frome Plains (Johnson 2009). This sampling program provides a catchment expression of the landscape biogeochemistry and as such is designed to better constrain the biogeochemical expressions associated with landscape (catchment) setting and the underlying geological substrate (e.g., bedrock, regolith and groundwater). There are significant biogeochemical expressions of the major bedrock types in the catchment, in particular a distinction between the Yudnamutana Creek tributary, which hosts hematite breccia (e.g., Hematite Valley) and vein style (e.g., Hodgkinson Prospect) U mineralisation and the northern Paralana Creek tributary, which mostly hosts U within granites (e.g., British Empire Granite). Samples from the ranges generally show much higher U contents than samples from the plains, expressing the U-rich, bedrock dominated stream headwaters. There is a lower and more subtle variation in U content within the plains and the U2/Th results appear to give a better expression of potentially mineralised settings. In particular, a zone along Paralana Creek immediately to the east of the rangefront has locally elevated U2/Th similar to the biogeochemical expression of the Four Mile West mineralisation (Neimanis *et al.* 2007) in a similar geological setting further north. Some samples from the ranges also contain elevated Re (up to 1000 ppb), such as near tributary confluences in the Hematite Valley area, and warrant further consideration.

This study demonstrates that river red gum biogeochemistry can be used to regionally compliment more traditional geological mapping and mineral exploration approaches. It has significant advantages over other approaches in that it is cost and time efficient, and has minimal cultural and environmental impact. The samples are small and light and therefore ideally suited to collection on foot and from remote and poorly accessible areas such as the Paralana Creek headwaters.

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Acid groundwater and halloysite-alunite deposition in Cenozoic terrestrial sediments marginal to the Eucla Basin, southern Australia

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Halloysite and alunite are associated with Cenozoic fluvial and lacustrine sediments deposited in inset valleys, swamps and backshore lagoons of an extensive palaeodrainage network that formerly discharged into the marine Eucla Basin of southern Australia. Alunite and halloysite are secondary precipitates formed by interaction of acid groundwater with the sediment and are concentrated often where a shallow water table is affected by high rates of evaporation. Their occurrence reflects the change to drier climatic conditions as the Australian continent drifted northwards during the Cenozoic. Groundwater acidity in the Cenozoic aquifer systems is due primarily to oxidation of pyrite-rich, lignitic sand and clay lenses within mainly Early Eocene sands. Oxidation ensued as the water table was lowered by the combined effects of episodic sea level fall, increasing aridity and uplift of the southern margin of the Australian continent. Conditions conducive to formation of secondary halloysite and alunite have existed in the region possibly from Late Eocene-Early Oligocene times to the present day. While few alunite samples from the area have been reliably dated, a K/Ar age of 4.9 Ma was obtained by Bird *et al*. (1990) for alunite near Kanowna in Western Australia and Benison *et al*. (2007) described recently-formed alunite and kaolin precipitates in acid-saline playa lakes aligned along Cenozoic fluvial channels on the south-eastern Yilgarn Craton.

Chemical precipitates of alunite and halloysite from acid groundwater are not uncommon in the Australian landscape, but typically form discontinuous deposits of only a few centimetres thickness. The longevity of conditions conducive to acidification of groundwater, and the wide extent of reduced fluvial and marginal marine sediments, particularly on the eastern Eucla margin, create a situation where substantial thicknesses of secondary deposits may accumulate in areas of groundwater ponding or discharge. At Lake Ifould, King (1953) reported up to 12 m thickness of alunite-rich sediment with kaolin (halloysite), and at the Barton halloysite site, 50 km north of Immarna rail siding, 4 m thickness of halloysite was intersected below 5.5 m of sand and limestone (Whitby 1976). Investigation of the Barton site showed halloysite makes up between 20 to 70% of the sediment and forms as regular tubes, 0.5-4.0 microns length and 0.05-0.08 microns diameter, that show a high degree of alignment. Associated minerals are halite, gypsum, alunite, quartz and hematite.

While alunite deposits have been exploited in the past in Western Australia as a source of potash, these are no longer of commercial interest. Tubular halloysite is widely distributed and is often associated with kaolinite as a product of weathering or hydrothermal alteration of other silicate minerals. Large and relatively pure deposits where halloysite can be readily separated to give a commercial product are, however, quite rare. Largest production is presently from North Island New Zealand where halloysite, from hydrothermally altered and weathered rhyolite, is exported mainly for use in quality whiteware ceramics manufacture. Recent research into applications of tubular halloysite as a functional filler to reinforce polymer products and as nano-scale containers for the controlled release of active agents identify possible new markets with strong growth potential. New demand is likely for deposits able to produce halloysite tubes with predictable and consistent physical dimensions. The conditions under which halloysite is deposited in sediments on the margin of the Eucla Basin may prove to be an ideal environment to form such deposits.

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Geology and Hydrochemistry of Selected Mound Spring Environments, Lake Eyre South, South Australia

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The spring mounds at Lake Eyre South are roughly domed-shaped sedimentary accumulations of chemical and clastic sediments that collect in the vicinity of artesian springs (Williams and Holmes 1978; Habermehl 1982; Boyd 1990b). These sedimentologically diverse isolated wetlands occur in some of the most arid parts of Australia, provide habitat to a diverse community of organisms including a number of endemic species of aquatic flora and fauna (Ponder 2002; Fensham and Price 2004) and have potential as palaeohydrological records.

A number of studies were undertaken at a selection of mound springs located within the south-western corner of the Great Artesian Basin, South Australia, including analysis of mound spring sediment and water samples. Based on these studies, the ancient and modern carbonate deposits are interpreted to be "tufa" or fresh, cool-water carbonates (Pedley 1990), with the key diagnostic features being a pronounced microbial and macrophyte influence on sedimentary textures and an abundance of aquatic macrofaunal bioclasts. Furthermore, ancient and modern sediments within the examined spring environments most closely resemble formations within either a paludal or low energy shallow fluvial environment (Pedley 1990, Pedley *et al.* 2003). In addition, calcrete forms at depth within the vadose zone within the general vicinity of water discharge and dissipation.

Mineralogically, carbonates were found to be composed of largely low-magnesian calcite, with lesser concentrations of high-magnesian calcite or dolomite. The presence of dolomite was confirmed in a number of samples using stained thin sections.

Field observations indicate that the degassing of dissolved carbon dioxide and the subsequent precipitation and accumulation of calcium carbonate in the spring environment will shift over time based on the flow rate of water, the initial saturation of dissolved calcium carbonate, and the ongoing maturity of the mound. In general, areas of precipitation and accumulation of calcium carbonate are closely associated with areas of current hydrophyte coverage

Results obtained from this study of selected mound springs are compared to studies of other arid-region terrestrial carbonate depositing environments internationally. Albeit the reference list of such sites in the published literature is uncommon, notable differences between the mound spring environments of the Lake Eyre south region and many of the other sites are found, including the long and relatively stable supply of water via a long-lived artesian groundwater source.

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Preservation: an under-rated component of mineral system models for secondary uranium within the Four Mile Embayment, Northern Flinders Ranges, South Australia

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This investigation into the constraints and near surface and surficial expressions of secondary uranium mineralisation uses a range of media including soil, stream sediments, regolith carbonates, plant leaf samples and macropod scats (Normington 2009). The analysis presented and considered here includes U and Th concentrations as well as U/Th and U^2/Th ratio values. Uranium concentrations alone do not provide a reliable expression of buried mineralisation because they may be derived from the U-rich bedrock provenance within the adjacent northern Flinders Ranges, rather than exclusively from the underlying secondary mineralisation. This is particularly the case for stream sediment and inland tea tree (*Melaleuca glomerata*) results. Transported U can be geochemically constrained as U and Th concentrations are both elevated, however their concentrations in contemporary surficial detritus derived from the ranges generally decreases with distance from to the ranges. Sub-surface secondary mineralisation is expressed in river red gum (*Eucalyptus camaldulensis*) and *Eremophila sp.* biogeochemistry, and is particularly emphasized by high U^2/Th values.

An exploration model was synthesised during this study, where the significance of preservation within the geological record following uranium accumulation more fully explains the occurrence of secondary U mineralisation. The new model includes:

Source → Transportation → Accumulation/Trap → Preservation

This model had been synthesised into a three-dimensional schematic that further demonstrates the relationships between the four components within the model. The interaction of the components largely dictates the behaviour of the mineralisation and the likelihood of the mineralisation being preserved and therefore increasing the possibility of the mineralisation being economically mineable. This is particularly important within tectonically active and erosional settings, such as flanking the northeast Flinders Ranges rangefront (e.g., partly constraining the extent of mineralisation at Four Mile) and within faulted blocks underlying the Lake Frome Plains.

This model has contributed to the high ranking of the exploration potential for a further six regional targets that best exhibit the above factors and therefore may potentially host secondary U deposits.

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Regional AEM surveying of the Frome Embayment area, SA: enhancing regional geological understanding for uranium exploration

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Geoscience Australia (GA) is planning a third regional airborne electromagnetic (AEM) survey under the Australian Government's Onshore Energy Security Program (OESP). The survey includes the South Australian side of the Frome Embayment and parts of the southern Eromanga Basin, northern Adelaide Fold Belt, Curnamona Craton and northwestern Murray Basin. Planning is based on a flight line spacing of 5 km, covering the equivalent area of about six 1:250,000 map sheets along the South Australian side of the South Australia-New South Wales border.

The Frome Embayment-Olary-Murray Basin region of South Australia is one of Australia's most highly prospective areas for uranium and base metals and is also prospective for gold and heavy mineral sands (HMS). The region hosts the *in situ* leach (ISL) Beverley uranium mine, the recently approved Four Mile ISL uranium mine, active uranium developments at Goulds Dam and Honeymoon and numerous other uranium prospects including Crocker Well, East Kalkaroo, Glencoe, Mt Gee, Mt Victoria and Oban. Further afield, uranium occurrences are noted in the southern Eromanga Basin within the Marree 1:250,000 map sheet area and in sediments draining south from the Curnamona Craton into the Murray Basin in the Olary 1:250,000 sheet area. Other mineral occurrences in the area include the Portia (Au), Kalkaroo (Cu-Au-Mo), White Dam (Au), Mutooroo (Cu-Co) and Brooks Bore (HMS) deposits and the inactive Radium Hill mine (U).

Models of uranium deposition (McKay and Miezitis 2001) vary across the proposed survey area including: sandstone-style deposits at Beverley, Four Mile, Honeymoon, East Kalkaroo, Goulds Dam, Glencoe and Oban; intrusive-style deposits at Radium Hill, Crocker Well and Mt Victoria; and, breccia complex deposits at Mt Gee. Uranium mineralisation occurs within rocks of the Paleoproterozoic-Mesoproterozoic Curnamona Craton (most notable for hosting the world class Broken Hill Pb-Zn-Ag-Au deposit) and Cenozoic cover rocks of the Eyre Basin and Murray Basin, overlying the Mesozoic Eromanga Basin.

The proposed AEM survey will cover many of the environments where there is known uranium mineralisation. It will characterise the electrical properties of regolith and bedrock materials to the depth of AEM penetration, leading to an improved understanding of the utility of the AEM method across the region. The survey will also aid the understanding of near-surface stratigraphy in a regional context across the Frome Embayment where previous knowledge comes from a series of remote oil exploration drill holes. In addition, the survey will provide new data on:

- Near-surface stratigraphy in the Eyre Basin;
- The location of buried strand lines which may host HMS resources in the Murray Basin; and,
- Regional information for groundwater resources.

The proposed AEM survey may also help:

- Better characterise the distribution of sandy and silty units of the Namba Formation, e.g., the Beverley uranium deposit;
- Map out Cenozoic paleovalleys incised into bedrock, e.g., the Honeymoon uranium deposit;
- Map out topographic highs in the Mesozoic landscape which may have controlled Cenozoic paleovalley distributions; and,
- Map out fault systems which could control uranium fluid movement.

The Frome survey will build on the excellent results from earlier surveys in the Paterson region of Western Australia and the Pine Creek region of the Northern Territory, which were both successful in enhancing geological understanding for minerals explorers.

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Reducing uranium exploration risk in the Paterson Province, WA: mapping paleotopography using regional AEM

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The Paterson airborne electromagnetic (AEM) survey is Australia's first regional AEM survey under the Australian Government's Onshore Energy Security Program (OESP), flown between September 2007 and August 2008. The survey was flown over the Archean eastern Pilbara Block, the Paleoproterozoic Rudall Complex and the Neoproterozoic Yeneena Basin (the latter two comprising the Paterson Orogen) and on-lapping sediments of the Neoproterozoic-Paleozoic Officer Basin and Paleozoic-Mesozoic Canning Basin. The survey was flown at line spacings of 6, 2, 1 km and 200 m covering a total area of 45,330 km^2 and targeted known mineral deposits and other highly prospective rocks under cover. The survey provides pre-competitive data to reduce exploration risk primarily for uranium but also for other metals and will assist in the assessment of groundwater resources for local indigenous communities and mineral exploration.

The survey data provide new insights into the electrical nature of regolith and bedrock materials in the Paterson region. The data reveal much of the Archean and Proterozoic basement to be resistive apart from moderately to highly conductive rocks of the Archean Jeerinah Formation (part of the Fortescue Group near the Woodie Woodie Mn deposits), the Neoproterozoic Tarcunyah Formation (part of the Officer Basin) and Neoproterozoic carbon-bearing pyritic shales of the Broadhurst Formation (which hosts the Nifty Cu deposit). Phanerozoic materials have variable electrical conductivity: Permian glaciogene sediments dominate the Paleozoic geology and are weakly to moderately conductive in comparison to Precambrian units; Mesozoic sediments tend to be resistive to weakly conductive; and, Cenozoic sediments including sand sheets and dunes tend to be resistive. Numerous salt lakes occur within the survey area and are moderately to strongly conductive. The salt lakes are mostly associated with paleodrainage systems including the Wallal, Percival and Disappointment Paleovalleys, which themselves are weakly to moderately conductive overall. The inferred conductivities of Phanerozoic materials decrease gradually from east to west most likely through mixing of saline and fresh groundwaters, especially near the Oakover River in the west and the Wallal Palaeovalley in the northeast.

The AEM data have been inverted using a GA-developed layered earth inversion technique. Part of this technique uses a gridded 3-dimensional percent data influence (PDI) surface which indicates the depth below ground at which the inversion results become unreliable. In effect the PDI surface is an "AEM go-map" showing the variability in depth penetration of EM signals, allowing explorers to determine whether EM is suited to their tenement. The PDI surface can also show discrete conductors which may be related to alteration and mineralisation. The inverted data has been combined with a drill hole database containing over 4,300 public-domain drill logs (Roach 2009) allowing us to interpret the depth to the Paleozoic and Mesozoic unconformities over a large swathe of the area and more accurately determine depth to basement to assist in planning future drilling. The inverted data also indicate extensions of the highly prospective Yeneena Basin and Rudall Complex under the cover of the Canning Basin. This was only previously hinted at by other geophysical techniques.

The data set reveals the region's potential for further uranium mineralisation in addition to the unconformity-related systems already known at Kintyre, Mt Sears and Sunday Creek. There is scope for further uranium discoveries using sandstone (roll-front, paleochannel or tabular), valley calcrete and perhaps even Kazakhstan-style exploration models.

Results from the Paterson AEM survey show that regional AEM date can reduce exploration risk by showing where EM techniques can be effectively applied, by determining 3D basement-cover relationships and by highlighting regional structures or discrete conductors that may host mineralisation.

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Characteristics of soils at the Hera Au-Zn-Pb-Cu-Ag deposit, Nymagee region, NSW

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The Hera polymetallic deposit occurs under thin alluvial cover on a slope adjacent to a silicified hill, 5 km SE of Nymagee and 80 km SE of Cobar, close to the eastern edge of the Paleozoic Cobar Basin (Skirka *et al*. 2004; Skirka & David 2005).

Sixty-one surficial soil samples from two traverses across the deposit and two traverses up to 1 km away from the deposit were collected. Eleven samples were used for an orientation study in which 8 different size fractions (+4 mm, -4 +2 mm, -2 +1 mm, -1 mm +500 μm, -500 +250 μm, -250 +125 μm, -125 +63 μm and -63 μm fractions and a magnetic fraction were prepared and chemically analysed. That study revealed that the fine soil fraction tends to have the highest Au, Al, Ba, Ca, Co, Cu, K, Mg, Mn, Ni and S contents whereas the magnetic fraction has the highest Ag, As, Cr, Fe, Mo, P and Pb. Cadmium and Zn seem to be elevated in both these fractions. Magnetic material forms a substantial portion of the coarser soil fractions, so the -4 +2 mm soil fractions are also enriched in Fe, Ag, As, Cr, P and Pb. Because these 3 soil fractions provide the maximum amount of information about particular elements within the soils, the -4 +2 mm, -63 μm and magnetic soil fractions were prepared from the remaining samples. Analysis revealed that, although there were consistent Au and Pb anomalies in the three soil fractions above mineralization, the best Au anomalism (>4 ppb) was present in the fine soil fraction and Pb (>100 ppm) was best developed in the coarse and magnetic soil fractions. Arsenic anomalism was also best developed in the coarse and magnetic fractions above mineralization (As >20 ppm and >30 ppm respectively) but such anomalism was not as extensive as for Pb. Zinc anomalism was best developed in the fine soil fraction (Zn >50 ppm) but it is also extensively developed at slightly lower abundances (Zn >40 ppm) in the coarse soil fraction over mineralization.

Although Au anomalism is best seen in the fine (-63 μm) soil fraction, this fraction is subject to potential contamination by aeolian material and preparation of such a soil fraction is labour-intensive. The coarse and magnetic soil fractions tend to show rather spotty Au anomalism but such anomalies are associated with coherent As, Pb and Zn anomalies so that, with their ease of collection, they may represent the most robust sample media for exploration in the Hera region.

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Palynology of Cenozoic sediments from South Australia: examples of applications from recent projects

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Palynological processing and analysis of geological samples is a service provided by PIRSA, Geological Survey Branch, to assist exploration companies and other stakeholders with determining the age of sediments, and to reconstruct vegetation and depositional environments. Palynomorphs, which include pollen, spores, dinoflagellate cysts and acritarchs, are useful for stratigraphic correlation across basins and are good indicators of marine and non-marine deposition. Palynomorph assemblages are more diverse and better preserved within coaly facies, compared to sediments with less organic matter. Samples for analysis are processed by Lyn Broadbridge in PIRSA's Palynological Laboratory. A Zeiss photomicroscope is used for scanning slides, and specialised software is employed for statistical analysis of the data. Results from recent collaborative projects with exploration companies are included below.

The Pirie Basin Palynostratigraphy project was initiated in 2005 to refine understanding of the basin structure and to expand, in particular, the palynological data available for the Kanaka Beds. Palynology of core and cuttings from historical drillholes between Wallaroo and Port Pirie, on the eastern side of the Pirie Basin, establish sediment deposition from Middle Eocene (in Tickera 1 and KT1 drillholes) to Late Eocene-Early Oligocene (upper sequence of KGD1, Tickera 1 and KT1 drillholes), Early-Middle Miocene (PB3) and Late Miocene-Early Pliocene (PP15). Exploration for sediment-hosted uranium on the western Pirie Basin by Uranium SA provided additional samples in 2009. Sediments deposited on bedrock are Late Eocene in age and palynomorphs indicate a predominantly fresh water environment. These are correlated with the top of the *Nothofagidites asperus* Zone (Stover and Partridge 1973; 1982). While older sediments are not evident in the drillhole, some contain reworked Cretaceous spores from an, as yet, unknown source.

The Cronje Dam Prospect, on the north-western margin of the Murray Basin, was drilled by Mega Hindmarsh Pty Ltd targeting palaeochannel style uranium mineralization. The terriginious sediments are difficult to correlate with established stratigraphic units in the Basin. Samples from both historical and current drillholes were investigated over the period 2006-2009 (unpublished data). The earliest sediments in the area are Late Eocene-Early Oligocene, and can include traces of reworked Cretaceous taxa. Recent exploration drillholes, however, are in sediments of Early-Middle Miocene age, correlated with the *Canthiumidites bellus* Spore-Pollen Zone (Macphail 1999).

PACE drilling in the Eyre Peninsula by Lynch Mining Pty Ltd targeted a Mn-Pb-Zn anomaly in basement rocks. Overlying sedimentary rocks, intersected in PACE drillhole BLDD01, were sampled over the interval 27 to 69 m, where black clayey soft lignite, or sandy and lignitic clay, were intersected. Sediment age is Late Eocene to Early Oligocene, correlated with the Upper *Nothofagidites asperus* Spore-Pollen Zone. Palynomorphs include a mixture of freshwater algae and shallow marine dinoflagellate cysts, possibly a coastal swamp (also includes a few sponge spicules). The presence of large fragments of plant cuticle indicate little or no transport from the source.

In addition, palynology has been used successfully, in collaboration with Heathgate Resources and Quasar Resources, to date sediments from the Four Mile Uranium deposits. Projects are ongoing on palaeodrainage to the Eucla Basin, with investigations recently completed for Tasman Resources and Mega Hindmarsh Resources. Data from open file projects now provide an extensive resource of palynology data from across the state. These are available on the PIRSA Biostrat Database, which is accessible online through SARIG.

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Satellite imagery and mapping regolith materials: a new ASTER mosaic and product testing in the Gawler-Curnamona

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Mapping of regolith materials at the regional and continental-scale for environmental, agricultural and resource exploration is advancing through the integration of satellite and airborne systems, and a new generation of remote sensing methods. These include the multi-spectral Japanese ASTER sensor onboard the US TERRA satellite which has collected images since 1999 and now has an image archive effectively covering the Earth's land surface three times over. By comparison, airborne hyperspectral surveys are very limited in their areal coverage, however these can be used to calibrate satellite imagery over wide areas. New approaches and collaborative efforts have been produced as part of a large multi-agency project to facilitate uptake of these techniques. Calibration of the lower spectral and spatial resolution ASTER with higher resolution HyMap has been very promising, and following an initial large ASTER mosaic program in Queensland, a new similar sized mosaic and preliminary products have been made for the Gawler-Curnamona region.

This new work builds on collaborative research undertaken by Geoscience Australia, the Commonwealth Scientific Industrial Research Organisation (CSIRO) and state and industry partners. In 2008, a study by this group on the world-class Mount Isa mineral province in Queensland, used an extensive HyMap survey, to calibrate ASTER imagery and produce a series of fourteen images showing surface mineralogy, vegetation, and landform textures. The thematic images make satellite map products more accessible to non-specialist users and easily integrate with other datasets in a GIS. This has considerable application for mapping geomorphic processes and chemical dispersion pathways, and targeting surface sampling for mineral exploration.

The work has demonstrated that regolith materials and thickness can be inferred in regolith-dominated terrains. This is of great interest to mineral explorers in regolith dominated terrains. Geochemical information about alteration chemistry associated with footprints of mineral systems can be acquired by analysing spectral ground response, particularly in short-wave infra-red. Key surface materials and chemistries that can be mapped include clays and magnesium, iron and aluminium oxyhydroxides. Information on mineral composition, abundance and physicochemistry (including crystallinity) for minerals such as kaolinite can also be obtained. The derived kaolin image can be used to identify transported versus in situ regolith material.

New software for ASTER calibration using high-resolution HyMap imagery, and testing for compensation for atmospheric residuals, lichen and other vegetation cover effects has been developed by CSIRO and can calibrate and process terabytes of multi-scene images. Preliminary mosaics of some ~110 ASTER scenes and related mineral group products are in testing and development for the Gawler-Curnamona region in South Australia, and it is hoped that these data will be able to provide a ready to use aid to identifying and mapping unconsolidated regolith material and underlying bedrock and alteration mineralogy.

Hydrogeology of the Beverley Area

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The Beverley and nearby sedimentary uranium deposits are located in the Frome Basin immediately east of the Northern Flinders Ranges, approximately 550 km north of Adelaide in South Australia. Currently the Beverley deposits are being mined using In-Situ Recovery (ISR) methods (Jeuken *et al.* 2008). ISR mining is proposed at the nearby Beverley Four Mile and Beverley North deposits.

The hydrogeology in the vicinity of the Beverley Mine, some 16 km east of the Flinders Ranges, consists of three main aquifers (Heathgate 2008):

- Willawortina Formation (surface to ~95 m below ground level (bgl)
- Beverley Sand and other minor sands (ore bearing) in the Namba Formation (105-140 m bgl)
- Eyre Formation Sands (~200-220 m bgl)
- Great Artesian Basin (GAB) – Cadna-Owie Formation (330-380 m bgl).

Aquitards separate the mined sands from the overlying and underlying aquifers. Groundwater in the Namba Formation is essentially stagnant, bounded within discontinuous palaeochannel structures. The Willawortina and GAB aquifers exhibit, and the Eyre Formation is inferred to have, a gentle hydraulic gradient to the south-east towards the regional groundwater discharge feature of Lake Frome.

The Four Mile deposits are located at about 4 km distance to the Flinders Ranges. They are in an uplifted graben-style embayment of the Frome Basin ('Four Mile Embayment') and not directly connected to the Beverley mine aquifer or the GAB (Heathgate 2009b). The Four Mile East deposit is hosted in the Eyre Formation and the Four Mile West deposit in a Cretaceous diamictite unit equivalent in age to the Bulldog Shale. These lie directly over bedrock; the GAB aquifers are absent. The Willawortina Formation is present but unsaturated and groundwater flow in the Tertiary/Cretaceous Diamictite aquifer system is towards the north-east, the 'exit point' of the Four Mile Embayment. From there it joins the regional flow in the Eyre Formation towards Lake Frome in the south-east.

Just outside the 'exit point' of the Four Mile Embayment and close to the range front is the Pepegoona deposit of the Beverley North project (Heathgate 2009b). At this site mineralisation is found largely in the Eyre Formation. Hydrogeologically the site is part of the Frome Basin proper, with a thick stratum of clayey Bulldog Shale underlying the deposit. Whilst the Namba and Willawortina Formations are present the former is clayey and the latter dry. The groundwater gradient in the Eyre Formation is south-east towards Lake Frome.

A robust understanding of the local and regional hydrogeology, coupled with stringent groundwater management practices (Armstrong & Jeuken 2009), ensures that there is no credible risk from mining at Beverley to the GAB (CSIRO 2004) nor groundwater users in the district (Heathgate 2008, 2009a).

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The CRC LEME legacy: the outcomes of seven years of regolith research

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The Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME) was established in July 2001 and was successfully concluded in December 2008. CRC LEME research focused on the nature of the regolith and regolith forming processes. This research was principally directed towards two objectives:

- Improving the effectiveness of mineral exploration; and,
- Developing appropriate environmental management strategies.

CRC LEME demonstrably achieved both these objectives, for example:

- A new understanding of the history of the landscapes developed on the margins of the Eucla Basin led directly to the discovery of world class heavy mineral sands deposits and the opening up of a new mineral province: and,
- New models about the formation of Acid Sulfate Soils (ASS) led to the development of new protocols for the rapid assessment of the extent and character of potential ASS enabling a rapid response to urgent government requests for advice about appropriate risk management strategies in the Murray Darling Basin.

However, it could be argued that the importance of the regolith research carried out in CRC LEME goes beyond the achievement of LEME's objectives. New data on the regolith have led to questions about old geological thinking, for example, new geochronological data on the age of regolith materials have raised questions about models underpinning sampling strategies routinely employed by many mineral explorers.

In the post-CRC LEME world the challenge for ex CRC LEME partners is how to grow the CRC LEME legacy so that regolith geoscience continues to advance in support of mineral exploration and effective environmental management for the benefit of all Australians.