Abstract Volume

Mineral Exploration Through Cover

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Primary Industries and Resources SA

- Advances in Landscape Evolution and Regolith Geoscience
- Geophysics and Remote Sensing in Exploration
- Industry Exploration Projects
- Tectonic Provinces and Mineralising Systems

Organising Committee

MINERAL EXPLORATION THROUGH COVER

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OPENING ADDRESS

MINERAL EXPLORATION UNDER COVER IN SOUTH AUSTRALIA

Paul Heithersay
Executive Director, Minerals and Energy Division, PIRSA

In South Australia, discovery in the highly prospective Precambrian Gawler and Curnamona cratons is challenged by cover sediments that are widespread and variable in thickness. These cratons host world-class ore deposits at Olympic Dam and Broken Hill and show widespread indication of mineralisation that allow for confident prediction that an even greater mineral endowment awaits discovery. The challenge is to find tools that will identify reliable vectors to mineralising systems and ensure optimal testing of these by drilling or other techniques that sample the subsurface. The future of mineral exploration and mining, not only in South Australia but elsewhere will reflect the success of discovery and development of large ore deposits concealed beneath cover. Our confidence in the mineral endowment of our local terrains and the widespread cover is an opportunity for a Centre of Excellence in Mineral Exploration in South Australia to provide leadership in this area of research. This was the clear focus of the Government in providing a 4-year grant of funds to establish a Chair for Mineral Exploration at the University of Adelaide.

The challenges for such research are considerable and will be met best by an integrated approach that draws on skills across the geological disciplines. This starts with modelling the basic tectonic framework, heat sources that drive mineralising fluids and structural and chemical controls that impact fluid movement, mineral alteration and ore precipitation. How we recognise and interpret these systems requires the application and integration of geophysical, geochemical, isotopic, mineralogical and spectral techniques. Our most common challenge in exploration is the near miss scenario and the ability to know when to persist or when to go are critical elements of successful exploration. Whether or not these buried ores can be detected in the near surface requires an understanding of the mechanisms of metal mobility through cover, impact of tectonics, weathering and time, and the role of chemical and biological agents in concentrating or limiting dispersion. In the process of exploring through cover we won't neglect the opportunities in the cover sediments such as heavy mineral sands, roll front uranium and stores of thermal energy.

Over the past 10-20 years we have seen substantial progress in most of the required disciplines. The time is right to harness and focus this research to the challenge of exploration through cover in a very focused way. High quality regional geophysics supplemented by detailed infill surveys is highly successful in generating exploration targets and in guiding the tectonic and structural models that underpin the current generation of geological maps. 3D and 4D modelling of basement and surficial geology will be the norm rather than the exception in the future and graduates will be expected to have mastered these methods of data presentation. Predictive modelling of fluid flow, alteration and mineral deposition through the pmd*CRC is providing theoretical and practical solutions to controls on mobilisation of metals and sites of precipitation and accumulation. New tools have been developed to assist with rapid and cost-effective logging of alteration mineralogy and chemistry. This research is showing alteration zones and patterns on a scale previously unrecognisable by conventional logging methods. Research on metal dispersion in deeply weathered terrains has advanced significantly with reliable models for geochemical dispersion developed out of CSIRO Exploration and Mining and through CRC LEME. That work is being extended by LEME into areas of shallow cover with some very exciting results from biological sampling. Finally LEME and GA work on hydro-geochemistry is showing very promising results with great potential application for SA.

The experience of colleagues in the petroleum industry on effective integration of research across disciplines must be drawn upon. What does and doesn't work in practice requires close links with practitioners in the minerals industry. Their experience and advice are essential to any research effort seeking to provide practical solutions to exploration through cover. A strong feed back loop between Industry, Government and the new Centre for Mineral Exploration under Cover will be essential for the Centre's success and the future expansion of the mining industry in South Australia.

And at the end of the day, great geology will lead to great orebodies.

Session 1: Landforms and Regolith

BUTT - SMITH LECTURE

50 YEARS OF GEOCHEMICAL EXPLORATION IN THE GOLDFIELDS

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The application of geochemical prospecting methods in Goldfields mineral exploration effectively commenced in the early 1960s. A broad range of sampling media, including stream and lake sediment, soil, lag, laterite, fresh and weathered bedrock, vegetation, groundwater and soil gas were tested in orientation surveys and/or applied in exploration projects before the end of the 1970s. Most of these are still in routine use.

The major advances over the last 40 years have been in analytical and computer technology. In the 1960s, the commonly used colorimetric analytical methods placed severe limitations on both productivity and detection limits. In gold exploration, this led to reliance on pathfinder elements, particularly the arsenic-gold association. Atomic absorption spectrophotometry, developed by CSIRO during the 1960s, was of great significance in geochemical exploration and proved particularly applicable in the nickel exploration boom which followed the discovery of Kambalda in 1966 and the search for VHMS base metal deposits, which peaked in the 1970s. The development of methods capable of analysing gold to 1 ppb (background) levels, firstly by AAS and more recently ICP_MS, has revolutionised Goldfields exploration since the mid-1980s and marked the emergence of geochemistry as the primary exploration method for gold. Geochemists are still learning how to extract knowledge from the high quality, multi-element data now available from ICP_MS in media such as rock, soil, lag and groundwater.

Computer technology is an indispensible aid to the interpretation and communication of the voluminous geochemical data now being generated. Interpretation methods have progressed from the basic concepts of background, threshold and anomaly to pattern recognition, and multi-variate statistical techniques to incorporate multi-element data into signatures indicative of target ore associations. The diversity of geochemical sampling and analytical methods applied over the past 40 years has resulted in large and complex databases. The application of robust statistical methods and computer visuallisation techniques are crucial to the extraction of useful knowledge from such historic data, as well as new multi-media surveys.

The availability of GPS instrumentation, improved understanding of regolith complexity and selective sampling of pedogenic carbonate for gold, have also enhanced geochemical exploration methods in recent years. Special techniques such as BLEG and MagLag have had lesser impact, and partial digest methods have yet to achieve general acceptance.

Developments over the next decade are likely to see the emergence of hydrogeochemistry as an important technique in concealed and leached terrains. The documentation and interpretation of 3-dimensional multi-element primary dispersion patterns is also likely to be used increasingly to target blind mineralization, particularly in established mining camps. The powerful combination of GPS-controlled low density multi-media geochemical sampling with sensitive multi-element analysis, has been convincingly demonstrated and will become a mainstream tool in regional exploration and geological mapping.

KEYNOTE

USE OF BIOTA IN MINERAL EXPLORATION IN AREAS OF TRANSPORTED COVER

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Biogeochemistry has not been widely used as an exploration technique for Au and base metals in Western Australia because sampling of soils and other surface materials has been reasonably effective in finding new mineral deposits in deeply weathered areas with or without shallow transported overburden. Future discoveries of base metal and Au resources in deeply weathered terrains are likely to occur under several to many metres of transported overburden where soil and lag sampling are likely to be ineffective. As the focus of exploration shifts to these more difficult terrains, bio geochemistry needs to be investigated. This paper presents findings of some recent LEME work on mulga trees that form geochemical anomalies at surface over buried deposits.

We are investigating several gold and base metal deposits in the Yilgarn Craton and of these we will discuss five sites. At these locations, transported cover ranges in thickness from 2 to 25 m. A variety of vegetation samples were collected at each site and procedures were developed for their preparation. Soil samples were also taken 5-10 cm below surface at each site to compare the chemistry of the vegetation and soil. In contrast to soil data, mulga geochemistry shows unequivocal evidence of buried mineralisation and therefore appears to be more effective in certain environments than conventional soil and selective extraction of soil.

Present bio geochemistry results are most encouraging and may lead to a practical method for locating mineralisation under transported cover in greenfield areas. We consider this a highly perspective field for future research which LEME is therefore addressing as a matter of priority.

USING BIOGEOCHEMISTRY AND GEOECOLOGY TO EXPLORE THROUGH TRANSPORTED COVER FOR MINERALISATION

Steve M. Hill, Brown, A., Hulme, K., Petts, A., Reid, N., & Mayo, A.
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CRC LEME has been conducting research aimed at understanding and applying biogeochemistry for mineral exploration programs, particularly in areas of extensive transported cover. At the University of Adelaide a research group is emerging that is making significant breakthroughs in the application of biogeochemistry for mineral exploration, and includes examples of mineralisation discovery through transported cover.

Contributing factors important for facilitating this recent development of biogeochemistry for mineral exploration programs include:

- improved analytical techniques with better detection limits that can be conveniently obtained for a large range of elements;
- the development of rigorous and robust sampling and sample preparation procedures and techniques;
- the evolution of regolith-landform mapping approaches and its integration with vegetation mapping, providing important context for biogeochemical samples and used in data levelling and interpretation; and,
- increased knowledge of Australian plants.

This presentation provides an overview of recent research outcomes.

Background: pre-assay considerations

The research program here has been structured according to the flow chart in Figure 1. An important step in this has been the initial development of robust sampling and analytical procedures. These studies have basically employed the sampling and sample preparation procedure outlined in Hill (2003), with some studies, such as Hulme & Hill (2004) developing slight modifications, mainly to adapt to the research facilities available. Important attributes here have been the wearing of powder-free latex gloves, use of paper sampling bags, and the low temperature sample drying prior to milling. Samples generally have not been washed, mostly because of the variable effectiveness of this process, and the problems of sample leaching and contamination during the washing process. Orientation programs including test washing of selected samples, as well as the monitoring of elements typically associated with detrital contaminants, and in some cases microscopic investigations help to further test for detrital contaminants. As a general rule, eucalypts and acacias twigs, leaves and phyllodes have been mostly found to have insignificant detrital contaminants, whereas roots, rough bark, leaf litter and the leaves of some chenopod shrubs and forbs have been more problematic.

In an exploration or research program, orientation plants are usually sampled and tested before more extensive sampling programs. This includes sampling a variety of organs from trees in a variety of geological and landscape settings, and if possible conducting different seasonal sampling programs. Different organs from different plant species have significant differences in their biogeochemical characteristics. This means that an organ of a species that has been effectively employed in one area may not apply to the same organ from different species in other areas. As for the development of most other effective exploration techniques, time spent at the orientation stage of a program usually brings rewards in the long-term. In most of our studies, we have mostly used leaves or phyllodes as the preferred sampling media. This is not only based on biogeochemical characteristics where these organs can provide the strongest expression of underlying mineralisation, but also because leaves tend to be the most convenient, readily available and consistent sampling media.

Time and space are two other important variables to consider when planning a biogeochemical sampling program. Recent results convincingly show that seasonality (usually related to rainfall frequency in arid areas) can have a significant impact on plant chemistry (e.g. Hulme & Hill, 2004). The regolith-landform spatial context is also very important. For instance plants growing along drainage lines typically have different biogeochemical characteristics than the same species growing elsewhere (Brown & Hill, 2004). This partly relates to catenary differences in soil / regolith characteristics, but biological processes in these different settings are also very different. All of our biogeochemical sampling programs are integrated with regolith-landform maps that have proven important in the interpretation of biogeochemical results, in particular the relationships with chemical and physical dispersion processes (e.g. Brown & Hill, 2003).

Biogeochemistry and Geobotany

Two main aspects have been considered in this research:

1. geobotany, which examines the spatial associations of plant species and communities with substrate (typically regolith-landforms); and,
2. biogeochemistry, which examines the chemical associations between biological media and substrate.

Both of these approaches have been employed in the past, and in many cases linked to mineralisation discoveries.

Penetrators and amalgamators

A simple way to interpret many of the biogeochemical characteristics of biota is as either:

1. penetrators, which derive their chemical characteristics from deep in the regolith (such as buried bedrock interface) usually via deep root systems (e.g. well developed ‘sinker’ or ‘tap’ roots); or,
2. amalgamators, which derive their chemical characteristics from wider rather than deeper settings. This may be achieved branching root systems (extensive lateral roots) with biota providing a chemical signature that is a mixture of adjacent substrate chemical properties.

Chenopod Penetration of sheetflow and alluvial regolith, Curnamona Province, SA

Chenopod shrublands include low bushes of saltbush and bluebush, and are widespread across arid and semi-arid Australia. Although low in height, many of these shrubs may live for hundreds of years and can have extensive root systems extending for *over* 10 metres deep. The widespread distribution of these shrubs and their extensive, long-lived root systems make them ideal plants for biogeochemical surveys. One drawback with the use of species has been the abundance of halides within leaf tissues (typically including salt glands) significantly lowering the detection limits for Au. Recent research has been able to overcome halide interference problems in analysis by targeting twigs as the preferable sampling organ (Brown & Hill, 2004). The main species examined have been bladder saltbush (*Atriplex vesicaria*), black bluebush (*Maireana pyramidata*) and pearl bluebush (*Maireana sedifolia*).

Recent results obtained from the White Dam Cu-Au deposit (Brown & Hill, 2004) have shown the ability of bladder saltbush shrubs to reflect mineralisation buried beneath at least 5 metres of barren transported regolith. Equivalent success has also been achieved at the nearby Green & Gold, and Wilkins mineralisation sites using black bluebush.

Acacia Penetrators, Curnamona Province, SA

Australia hosts a wide range of acacia shrubs and low trees, that form major components of semi-arid and arid plant communities. As well as being widespread, some important characteristics to consider when using acacias for biogeochemical surveys include that some species (e.g. *Acacia victoriae*) have prominent tap-root systems (Hill *et al.,* 2005). Also, species and sub-species variation is a very important control on chemical characteristics (Hill, 2003; Hill, 2004). This is well shown by recent results obtained from mulgas growing over Au mineralisation near Tibooburra that do not contain detectable levels of Au, whereas many other adjacent shrubs do. Prickly wattle phyllodes have been effectively used to detection continuations of the Broken Hill Line of Lode beneath transported cover in the Northern Leases area (Thomas *et al*., 2002; Hill, 2004; Hill *et al.* 2005).

River Red Gum Penetrators and Amalgamators, SE Central Australia

River red gums are one of the most widespread large trees in Australia. Their use in biogeochemical sampling programs has demonstrated their ability to both penetrate and amalgamate transported regolith chemistry (Hulme & Hill, 2003; 2004; Hill & Hill, 2003; Hill, 2004). Recent results from the study of this sampling media are discussed in more detail in another presentation at this meeting (Hulme & Hill, this volume), in which the details of the recent discovery of Ag-Pg-Zn lodes extending under the transported cover of Pine Creek has been made near the Pinnacles Mine near Broken Hill.

Mallee Penetrators, Central Gawler Au Province, SA

Research is presently being undertaken to understand the biogeochemical characteristics, dispersion and residence and mechanisms within the mallee woodlands of the Central Gawler Au Province, SA. An ongoing Honours study by Anna Mayo has been sampling a variety of mallee eucalypts across different phases of aeolian deposits north of Wudinna. Geobotanical observations here indicate that different mallee species preferentially colonise different phases of the dune systems, and observations from excavations in the area are most encouraging in showing mallee roots penetrating not only calcareous hardpans but other regolith units beyond tens of metres in depth.

Tanami Geobotanical Associations Leading to Biogeochemical Penetration?

Research presently underway in the Tanami region is testing the ability of snappy gum (*Eucalyptus brevifolia*) and other eucalypt and acacia trees to provide biogeochemical expressions of bedrock through transported regolith cover. This is being tested at the Coyote Deposit, and Larranganni Prospect in WA, and is proposed for areas further east in NT. Preliminary results show some important geobotanical associations between regolith types and thickness of transported cover in these areas. Nathan Reid is conducting the biogeochemical study as a part of his

PhD program, while Anna Petts is looking at geobotanical (plant distributions) and geozoological (especially termitaria) associations with known depths of transported cover within her PhD (Petts & Hill, 2004).

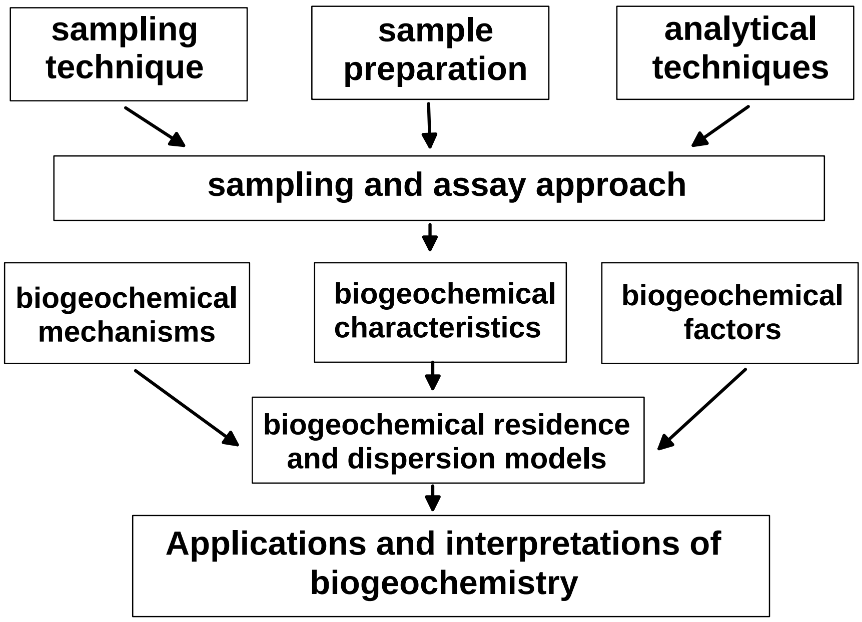

Figure 1: Biogeochemistry research flow chart representing this research program

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THE GENESIS OF CALCRETE - GOLD ANOMALIES

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Gold anomalies (2.5 to 50ppb) in regolith carbonate accumulations such as calcrete and calcareous sands in aeolian sand dunes overlying gold mineralisation in granitoids of the Gawler Craton, South Australia, show a distinct covariance of Au with K and Mg and most prominently with Ca content. This is related to the authigenic formation of smectites and carbonates within the aeolian dunes in the region. However, little is known about the genetic processes involved in the carbonate formation in the semi-arid to arid settings. The formation of the dune systems in Australia can be traced back to at least 100,000 years with distinct peaks 70Ka, 42Ka, 35Ka, 20Ka and 14Ka (Rhodes et al. 2004). The dunes on the Barns prospect are part of the younger part of this spectrum which explains their low degree of induration through illuviation and only subordinate formation of regolith calcrete. We have investigated the geochemical properties of these aeolian dunes along profiles of 2 to 4m depth to quantify the relationship between Au and the carbonate forming elements. Biochemical experiments were carried out to evaluate possible biomediated processes of carbonate formation. Sampling was done using a percussion corer to obtain undisturbed depth profiles of the aeolian sands overlying the gold mineralisation at the Barns prospect, north of Wudinna.

A strongly systematic relationship of Au and Ca-Mg content to depth shows the tight relationship between the gold enrichment in calcrete and the underlying hydrothermal mineralisation. This relationship is continuous from carbonated sands at shallow depth to nodular and massive, partly laminar calrete at greater depth. XRD analysis shows that while Au and carbonate show the strongest relationship, anomalous gold content is also related to authigenic smectites in the dune profile. Intense carbonate formation and concurrent gold enrichment also occurs in the close vicinity of roots penetrating the dune.

Thin section petrography and cathodoluminescence shows that most of the calcrete in the regolith profiles is micritic and only rarely are sparic crystallites identified. Chemical analysis of the samples suggests that gold is present in finely disseminated form rather than particulate.

For the biochemical experiments a set of samples from a depth profile in the dune was taken under sterile conditions. Samples were impregnated with urea, a microbial metabolic breakdown product of amino acids, and incubated for up to 24 hours to test for the presence of the urease enzyme. Samples from near surface contained 10 to 18 mg/l NH_4^+ decreasing to 1 mg/l at a depth of 2.3m over a background of 0.09 mg/l, demonstrating the presence of microbial communities with active urease enzymes. The breakdown of urea has a first order control on [NH_4^+], pH, pCO_2 and especially CO_2 speciation (e.g. CO_3^{2-}, HCO_3^-). In an alkaline environment and in the presence of free Ca^{2+} ions this results in precipitation of carbonate. The genesis of the calcrete and pedogenic carbonate is thus suggested to be at least partly biomediated through reactions like the urea break down.

The demonstrated presence of bio-activity controlling the pH and CO_2-species may also provide insight into possible mechanisms of gold accumulation in calcrete (see *Figure 1*). As demonstrated earlier (e.g. by Korobushkina et al. 1983, Selvakannan et al. 2004, Reith & McPhail 2004), gold is complexed by amino acids in a range of environments. The amino acid transformation to urea through microbial activity would destabilised these Au-AA complexes and result in co-precipitation of carbonate and gold in a coupled process. The biochemical studies also impose the question of the duration of formation of gold anomalies. Ongoing studies show that the area underwent several phases of active dune formation. Detailed mapping of the different stages of dune formation may lead to guidelines for re-evaluating calcrete gold anomalies.

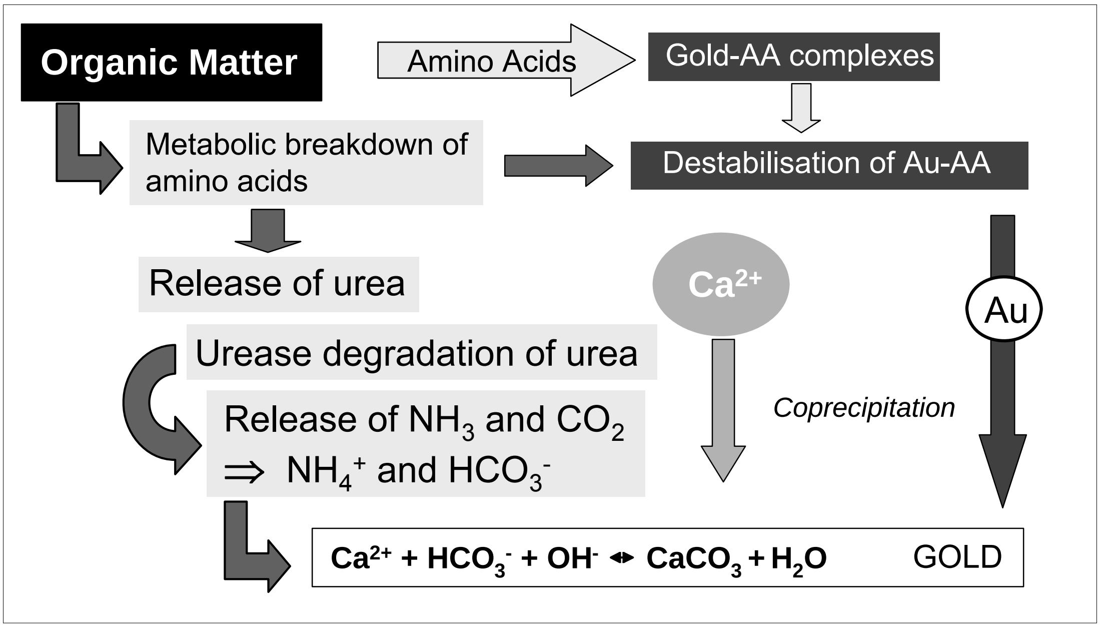

Figure 1: Flow chart of a coupled gold-in-calcrete forming process

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Session 2: Geophysics in Exploration

KEYNOTE

NEW FRONTIERS OF APPLIED GEOPHYSICS IN EXPLORATION THROUGH COVER

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Effective geophysical exploration through cover requires the correct application of the most appropriate geophysical method/methods to resolve the exploration problem at hand. Exploring through cover is not just seeking anomalous responses for drill testing, it is also about mapping stratigraphy, structure, alteration and occasionally minerals that may have associated gold mineralisation.

Today, explorers routinely acquire low-level detailed aeromagnetic data as a matter of course, in just about all terrains. We also see the routine acquisition of semi-detailed ground gravity and, on occasion, airborne gravity or airborne gravity gradiometry. In some situations the only effect of cover is to increase the separation between sensor and target, and thus diminishing the detail in the dataset. In other situations the cover may include magnetic units or magnetic minerals, that result from deep oxidation, which adds unwanted 'geological noise' to the magnetic signal of interest. In extreme cases, there may be so much magnetic material in the cover that signal from the basement rocks beneath cannot be resolved. Variations in cover thickness and density also add an element of geological noise to detailed gravity surveys that need to be recognised, although in some surveys, variations in cover thickness may actually be the target.

In direct current (DC) electrical geophysical surveys the cover can present a variety of problems. In some terrains, surficial materials such as aeolian sands or caliche make the direct injection of current into the earth extremely difficult. Often these materials sit above very conductive, deeply oxidised, country rock and/or intervening conductive sedimentary units that severely attenuate primary currents injected into the earth, and the secondary responses. Conductive cover sequences also create problems in the form of electromagnetic coupling between transmitting and receiving arrays. The development of 2-D and 3-D inversion algorithms in the 1990s substantially improved the interpretation of data acquired using routine electrical methods. More recently the development and commercialisation of Distributed Acquisition Systems, such as MIMDAS and Titan, has resulted in substantial improvements in spatial resolution and depth of investigation. Sub Audio Magnetics (SAM) is routinely used in exploration through the salt lakes of outback Australia.

The ability of ground based transient electromagnetic (TEM) systems to explore through conductive cover has been well documented over many years. In recent times the development of airborne TEM systems, such as the Tempest, HoisTEM, NewTEM and VTEM, with the ability to acquire data of similar quality from the air as on the ground for a about 15% of the cost has led to the routine use of these systems for mapping of cover thickness and investigation of underlying geology.

STATE OF THE ART IN GROUND AND AIRBORNE ELECTROMAGNETIC PROSPECTING FOR MINERAL DEPOSITS

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Electromagnetic (EM) prospecting for mineral deposits is based on EM induction principles, where differences in the conductivity structure of the subsurface is detected and this information is used for direct targeting of mineral deposits and alteration systems or mapping of rock units and structures that may host mineral deposits. In general, a wire coil transmitter is used to induce a time-varying **primary EM field** by moving the transmitter over a prospect area or using a fixed transmitter loop sitting over a mineralised zone or borehole. The primary EM field will induce a **secondary EM field** around a conductive ore body or geological horizon sitting in the subsurface. A wire coil or sensitive magnetic receiver is used to record the secondary EM field as a change in signal amplitude and phase shift in the case of **frequency domain** electromagnetics, or as a slow rate of secondary decay in the case of **time-domain** electromagnetics. Most EM systems do not have to come into electrical contact with the ground, and therefore may be employed on moving platforms, such as fixed wing aircraft and helicopters. One form of EM surveying is called magnetometric resistivity (MMR), where electrical current is injected into the ground using grounded electrodes, and current flow into conductive zones in the subsurface is mapped by detecting the EM field generated perpendicular to the direction of current flow.

In the last 30 years, nothing has fundamentally changed in regard to the physical theory and basic methodology behind electromagnetic prospecting. However in the last 10 years, there have been technological advances that have propelled EM prospecting to the forefront of many mineral exploration programs. During this time, there have been a number of mineral deposit discoveries made with the aid of EM prospecting, mostly for nickel sulphide deposits. The technological advances include:

- Digital data acquisition and signal processing technology using sample frequencies greater than 1,000 readings per second (>1 kHz).
- Computing power for rapid data acquisition, data storage, and intensive filtering/processing routines.
- Larger and faster switching transmitter systems, providing cleaner signal and greater power into the ground.
- More channels being recorded and out to longer decay times or frequencies, providing greater depth penetration and resolution.
- Longer stacking times to increase the signal-to-noise response.
- Development of computer code to rapidly image conductivity with depth information, as conductivity depth images (CDIs) and layered earth inversions (LEIs).
- Spatial imaging of conductivity results and anomalies.

- Rapid computer modelling methods used to forward model EM responses of buried conductors for planning EM surveys and to assist with targeting features for drilling.

Lowering of EM system noise and removal of external noise, such as distant lightening strikes ("*spherics*"), has allowed for greater resolution of the conductive overburden caused by regolith materials, primarily saline groundwater and conductive clays. With greater power and resolution, explorers are now able to detect conductive EM targets at great resolution in the upper 100m, and as far down as 400 m depth; even below 100 m of moderately conductive overburden.

Despite the technological advances in the bullet points described above, with tens of millions of dollars invested in improving EM technology, and hundreds of millions of dollars spent on EM surveying globally, the low number of EM discoveries has been somewhat disappointing for most explorers (*yet, the few EM related discoveries made world wide have generated a combined value in the tens of billions of dollars*). Some of the failures of EM prospecting have come about by explorers relying too heavily on EM technology to image buried mineral deposits, when this technology has a number of limitations and requires persistence to prove target sources. By comparison, EM is no where near as effective at finding ore bodies, as seismic surveying is for finding gas deposits.

Mineral explorers need to place more emphasis on using EM prospecting in well defined target corridors, selected using sound geological and ore deposit targeting models, with an understanding of the anticipated conductivity structure in relation to regolith cover, and conductor intensity, size, geometry, and target depth. EM systems can then be evaluated for their ability to provide enough detectable signal to locate buried targets using forward modelling and optimal survey design. With this type of focussed approach, explorers can evaluate the costs and risks of surveying, processing, targeting, drill testing, and follow-up EM surveying before committing to a bad survey plan.

A range of recent advancements in EM prospecting tools will be shown in the presentation, along with examples of what real EM targets and discoveries look like. Examples of various systems will include:

<u>Time domain EM</u>
recent receivers: quiet dB/dt coils, flux gate sensors, and SQUID sensors
acquisition systems: large transmitter loops, Geoferret, TorchTEM
downhole EM: dB/dt 3 component probes, flux gate 3 component probes
data presentation: CDIs, modelling

<u>Airborne EM</u>
Time domain systems: TEMPEST, Geotem, Hoistem, Vectem
Frequency domain systems: Dighem, Resolve, Hummingbird
data processing and presentation: calibration, CDIs, modelling

<u>MMR</u>
acquisition systems: Sub-audio magnetics (SAM)

It will be shown that EM prospecting is extremely valuable when used for the right reasons, in the right geological and mineral deposit setting, and interpreted with an understanding of EM limitations. EM results used in combination with other forms of geophysical, geological and geochemical exploration information can greatly reduce exploration risk in covered areas where conductivity contrast and conductivity structure can be detected.

GROUND PENETRATING RADAR, A TOOL FOR SHALLOW SUBSURFACE EXPLORATION

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Ground penetrating radar (commonly called GPR) is a geophysical tool that has been developed over the past thirty years for shallow, high-resolution, subsurface investigations of the earth. GPR uses high frequency pulsed electromagnetic waves (generally 10 MHz to 1,000 MHz) to acquire subsurface information. The radar signal is imparted to the ground by an antenna that is in the close proximity of the ground. This signal travels through the material at a velocity, which is determined primarily by the electrical properties of the material. As the wave spreads out and travels downward, if it hits a buried object or boundary with different electrical properties, then part of the wave energy is reflected or scattered back to the surface, while part of its energy continues to travel downward. The wave that is reflected back to the surface is captured by the same antenna or by a second, separate receiving antenna and recorded on a digital storage device. The most common display of GPR data is one showing signal versus amplitude, and is referred to as a trace. A single GPR trace consists of the transmitted energy pulse followed by pulses that are received from reflecting objects or layers. As the antenna (or pair of antenna) is moved along the surface, the graphic recorder displays results in a cross-section record or radar image of the earth. As GPR has short wavelength in most earth materials, resolution of interfaces and discrete objects is very good. However the attenuation of the signals in the earth materials is high and depth of penetration seldom exceed 15 m though the target detection has been reported under unusually favourable circumstances at depths of about 50 m. Attenuation of the signal is mainly dependent on the electrical properties and on the number of minor interfaces, which will scatter the signal. Presence of water and clay soils increase the attenuation and thus decreasing the penetration.

Electromagnetic waves travel at a specific velocity that is determined primarily by the electrical permittivity of the material. Permittivity is the property that describes the ability of a material to store electric energy by separating opposite polarity charges in space. Relative dielectric permittivity (previously called dielectric constant) is the ratio of the permittivity of a material to that of free space. The velocity is different between materials with different electrical properties, and a signal passed through two materials with different permittivities over the same distance will arrive at different times. The two earth materials, which cause important variations in the EM responses in a GPR survey, are water and clay. At GPR frequencies, the polar nature of the water molecules causes it to contribute disproportionately to the displacement currents, which dominate the current flow. Thus, if significant water is present, the permittivity will be high and the velocity of propagation of electromagnetic wave will be lowered. Clay minerals with their trapped ions behave similarly. Additionally, many clay minerals also retain water. Large variations in the velocities and attenuation are the cause of success (target detection) and failure (insufficient penetration) for GPR surveys in similar geological setting. Simplified equation for attenuation and velocity is:

$$v = (3x10^8)/k^{1/2} \text{ and } a = 1.69\sigma / k^{1/2},$$

where, ‘v’ is the velocity (m/s); ‘k’ is the relative dielectric permittivity; ‘a’ is the attenuation (db/m) and ‘σ’ is the conductivity (mS/m).

GPR equipment normally consists of a radar control unit, transmitter and receiver antennae, and suitable data storage and/or display devices. The radar control unit generates synchronized trigger pulses to the transmitter and receiver electronics in the antennae. These pulses control the transmitter and receiver electronics in order to generate a sampled waveform of the reflected radar pulses. Antennae are transducers that convert electrical currents on the metallic antenna elements (usually simple bowtie dipole antennae) to transmit electromagnetic waves that propagate into a material. Antennae radiate electromagnetic energy when there is a change in the acceleration of the current on it. Lower frequencies provide greater penetration with less resolution and higher frequencies provide less penetration with higher resolution. Resolution of a few centimetres can be obtained with high frequency antennas (1 GHz) at shallow depths, while lower frequency antennas (10 MHz) may have a resolution of approximately one meter at greater depths. The distance between station locations, the sampling rate, the towing speed and the frequency of the antenna determines horizontal resolution.

There are three main modes of GPR operations, common offset and common mid point reflections and transillumination. The most common mode of GPR data acquisition is the reflection profiling method in which a radar wave is transmitted, received and recorded each time the antenna has been moved a fixed distance across the surface of the ground, in a borehole, or across any other material that is being investigated. In addition to surveys on land and ice, surveys can also be made in lakes and rivers with low conductivity water. Integration of GPR data with other surface geophysical methods, such as seismic, resistivity, or electromagnetic methods, reduces uncertainty in shallow subsurface characterization and it is now widely accepted as a field screening technology for characterizing and imaging subsurface conditions. Examples of GPR studies from around the world and Australia along with various data processing and viewing techniques would be discussed in detail.

HYLOGGING APPLICATIONS IN EXPLORATION.

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Recent developments in proximal sensing have moved spectral geology one step closer to being a routine tool aiding geologists in their search for economic mineralisation. Mounting a hyperspectral spectroradiometer over a robotic table has enabled thousands of metres of diamond drill core to be measured for their spectral response between 400nm and 2500nm at a rate of approximately 75 metres per hour. By interpreting mineral signatures from the spectra, the subsurface dimension of ground truthing afforded by this technique begins to connect fresh rock, through the regolith, to the surface materials observed from aircraft and satellite.

Called the "HyLogger", CSIRO have integrated three instruments into a single package:

- a hyperspectral spectroradiometer recording a full wavelength visible and infrared spectrum every 1cm;
- a high resolution linescan camera recording a continuous 3 band digital image at 0.1mm resolution; and
- a laser profilometer measuring the height of the upper surface of the core at 0.2mm resolution.

Interpreting the data generated at a rate of 3 Gigabytes per day requires specialised software: a developmental core-logging version of "The Spectral Geologist" (TSG) package. With this it is now realistic to examine statistical distributions of minerals downhole. Linked with assay data, geologists have a powerful new tool for understanding their drilling results in the context of deposit paragenesis.

The purpose of scanning rocks at high spatial resolution with this selection of detectors is to enable the objective logging of mineralogy along the entirety of the drill core, particularly if the spatial frequency of any alteration mineralogy is not clear (e.g. narrow altered veins or intensely bleached rocks). Linked with a high resolution image this information has the potential to revolutionise the work of the logging geologist. By emphasising the mineralogical content lithological boundaries can be more accurately identified, new models can be developed based on otherwise indistinguishable clay, mica, chlorite and carbonate species, and relationships of alteration mineralogy to assay values can be quickly identified.

Over the course of recent campaigns in South Australia, 60,000 metres of diamond drill core were scanned. The holes selected from the core library and company drilling are considered to be signature drill holes covering representative geological domains across South Australia.

The Barns gold prospect north of Wudinna, Eyre Peninsula has been one site selected by CRCLEME for recent investigations aimed at testing new methods to assist with evaluating or prioritising Au-in-calcrete anomalies that might have general application in the Central Gawler Gold province.

In this investigation, rapid spectral analysis of drill samples was used to examine the relationship between alteration mineralogy and Au concentration as a means of mapping vectors to Au mineralisation in fresh or weathered bedrock. Samples from 3 cored holes and a selection of RC chip trays were scanned using CSIRO's HyLogger. All samples and Au assay values were provided by Adelaide Resources Ltd.

Results from the Barns prospect show Au mineralisation is associated with increased white mica (sericite) content and a decrease in chlorite content (Keeling, Mauger and Huntington, 2004). Variation in gold content is reflected in changes in white mica chemistry. Higher gold values correlate with increased proportion of white mica of phengitic composition as interpreted from a change to longer wavelengths of the white mica absorption feature at around 2200nm. Zones of elevated white mica content are recognisable in the lower saprolite of weathered bedrock as areas of high illite content in the HyLogger data. In the upper saprolite, kaolin and iron oxides dominate and spectral techniques are not able to confirm the extension of white mica-rich zones into this part of the weathered profile.

Another site of the CRCLEME Mineral Mapping SA project is the Tarcoola Goldfield. Twelve cored holes from the Perseverance gold prospect near the 'Blocks' goldmine show a distinct kaolin/iron oxide mineral distribution that defines the weathered zone in which the presence of smectite and sulphate minerals correlate with supergene gold enrichment. Hydrothermal alteration, as hematite and sericite, is pervasive in the primary host rocks but positive correlation between white mica chemistry and elevated gold values was not confirmed from this data set (Mauger et al, 2004).

Future directions for the development and application of this technology include the building of an additional thermal infrared core logger to detect framework silicate mineralogies and an already-developed, prototype, companion instrument, HyChips, for semi-automated logging of drill chips and pulps, at the rate of thousands of composite metres per day.

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Session 3: Industry Exploration Projects

KEYNOTE

EXPLORING UNDER COVER – AN EXPLORERS VIEW

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What will assist the discovery of more mineral deposits under cover? Apart from strong commodity prices, big exploration budgets and persistence, a vital ingredient is new knowledge of what we are looking for and new exploration techniques. By consideration of the exploration process, from area analysis, previous work, new surveys, target identification and testing, the roles of research organisations in providing the required new knowledge are examined.

A series of under cover successful discovery case histories are reviewed to try to understand what processes have been important in each discovery. Those reviewed include: Tennant Creek, Olympic Dam, gold in the Yilgarn, Thalanga East, Waterloo, Challenger and Callie. The differences between greenfields and brownfields exploration programs are also considered. An important issue is when a discovery can be claimed and how reported company exploration results should be interpreted.

Explorers always want to discover ore as close to the surface as possible. This inevitably places importance on regolith studies. Indeed several mineral deposit types, such as heavy mineral sands, paleochannel uranium and bauxite are present in the regolith, so regolith studies are a priority. Even if the regolith itself does not represent ore, it may contain characteristic signals in both chemical and physical secondary dispersion that can vector towards ore discovery. The subject of primary and secondary haloes is examined with a view to enlarging the size of targets and increasing the chances of recognition.

The continuum between empirical and conceptual exploration strategies is discussed. The importance of improving our knowledge of both strategies is emphasised. This leads to a discussion of research priorities for each type of organisation which will complement each other and be mutually beneficial.

EXPLORATION THROUGH COVER - FROM PROMINENT HILL TO TUNKILLIA

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The cover in South Australia presents a formidable impediment to exploration, but significant advances are being made in our ability to explore through it. Of paramount importance to effective exploration are models based on sound physical principles, whilst simultaneously taking into account the masking effects of the multitude of styles of cover that may be present.

Prominent Hill comprises a large accumulation of metal and associated alteration products only 100m below the surface, including an inferred resource of 97 Mt at 1.5% copper and 0.5 g/t gold, but displays no detectable geochemical signature in a variety of surficial geochemical techniques, including conventional soils, mobile metal ion, calcrete and lag sampling. In the Mt Woods region, geophysics, particularly gravity, remains a key exploration technique.

At Tunkillia, calcrete geochemistry was instrumental in the discovery of the Area 223 resource as well as gold mineralisation at Nuckulla Hill. Few other areas of gold anomalism have been found elsewhere along the Yarlbrinda Shear Zone. A critical appraisal of the cover sequence in the area indicates that in most of the intervening area between Tunkillia and Nuckulla Hill, although hosting calcrete, the cover is not conducive to the calcrete methodology. The intervening area has not been sterilised and new techniques of exploration through the cover need to be established. Electrical methods to be field tested shortly by Minotaur as to their suitability for drill targeting, include dipole-dipole IP, gradient array IP and Airborne EM.

Adelaide Resources Limited

GEOCHEMICALLY DRIVEN EXPLORATION IN THE CENTRAL GAWLER GOLD PROVINCE

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Adelaide Resources Limited has been exploring for gold deposits over a large area on the northern Eyre Peninsula for the past nine years. The project area is almost entirely covered by a thin veneer of aeolian sand and occasional alluvium, and bedrock is generally deeply weathered. Bedrock exposure is rare.

Prior to Adelaide Resources' program, exploration of the basement for a range of metals including gold, copper and other base metals had been strongly geophysically driven and was notable principally for a failure to return even modestly encouraging results.

Following the introduction of surface calcrete geochemistry to South Australia by Dr Kevin Wills (formally Exploration Director of Adelaide Resources) the company was able to employ a geochemically driven exploration strategy in its search. The use of calcrete geochemistry, coupled with follow-up bedrock geochemical RAB/aircore drilling has proven to be a technically successful approach. Three gold deposits (Barns, White Tank and Baggy Green) have been discovered and a number of other gold mineralised systems recognised. No economic mineral discovery has yet been made however the geochemically driven approach has demonstrated that gold mineralisation is widespread in the project area.

Despite the apparent success of the calcrete – bedrock geochemical drilling strategy, many situations confront the explorer which restrict its effectiveness. These limitations are discussed to highlight areas where further scientific endeavour may prove of worth for undercover explorers.

Calcrete has significant limitations as an exploration technique in many circumstances. The method works only if sufficient concentrations of carbonate are present in the soil profile yet large regions within the project contain very low or negligible carbonate content. Some of these regions are almost certainly prospective but are un-explorable using carbonate geochemistry as it is currently applied.

The calcrete method is further restricted by the presence of even relatively thin alluvial sediments overlying weathered bedrock. Sheets of alluvium as little as 10 metres thick sandwiched between calcrete-bearing aeolian sand and weathered basement appear to totally block the geochemical signal.

The combination of areas of low carbonate coupled with areas underlain by restrictive depths of alluvium reduces the effectiveness of calcrete geochemistry on the project area to an estimated 40%.

Alluvium filled palaeo-channels present a further frustration. Palaeo-channels have the capacity to displace geochemical anomalism from source and present "transported anomalies". Due to the ubiquitous aeolian sand cover, the presence of shallow alluvial sediments in palaeo-channels is often impossible to determine prior to obtaining drilling information.

One promising observation made during the company's exploration which may assist in detecting transported anomalies from in-situ features is that palaeo-channel transported geochemical features exhibit relatively high silver concentrations in calcrete compared with anomalies situated above source, although the geochemical process causing this phenomena is unclear.

Further limitations with the calcrete-bedrock geochemical drilling approach arises during the drill testing phase of the process. The calcrete anomalies often present targets that are several square kilometres in size. Regolith variations exert a strong local control on calcrete anomaly magnitude and simply drilling anomaly peaks has proved to be a risky practice, while drilling the entire target in sufficient density to gauge its significance may prove prohibitively costly.

The solution to this problem taken by Adelaide Resources has been to design initial drill patterns aimed at detecting the flat lying supergene gold plumes that disperse laterally from weathered primary mineralisation thus presenting a larger target. Positive results are followed up by progressively reducing drill centres in an attempt to locate the primary sources of these flat lying plumes.

This approach worked successfully in the case of the Baggy Green discovery, however other anomalies returned highly promising early drill stage results but failed to develop into robust primary targets, despite considerable investment of exploration funds.

Companies are now moving away from conducting purely geochemical exploration in the Gawler Craton, with geophysical techniques once again playing important roles. However a better understanding of the abilities and limitations of calcrete and supergene geochemistry through further investigation, and a concomitant refining of the application of these tools will serve to further increase the chances of exploration success in the Central Gawler Gold Province.

HEATHGATE RESOURCES PTY LTD

PALAEO-CHANNEL URANIUM EXPLORATION

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Palaeo-Channel uranium deposits can be included as part of a “Sandstone Uranium Deposits” classification. Sandstone deposits have generally formed in fluviatile to marginal marine sedimentary environments in which uranium was mobilized under oxidizing conditions and deposited within a reduced environment or at an oxidation-reduction interface within the sandstone. Such “roll front’ deposits make up a significant portion of the worlds uranium deposits and are major sources of past and future world uranium production (Powder River Basin, Colorado Plateau, Kazakhstan Basins). Fluviatile palaeochannels as are developed within the Tertiary of South Australia (Frome Basin and Gawler Craton) are excellent conduits for transporting and precipitating uranium in potentially economic deposits. Known deposits include Beverley, Honeymoon, Gould’s Dam, Oban, Warrior and Yaranna.

Exploration for uranium in buried palaeo-channels requires an understanding of uranium source rocks, regional geology, structure, palaeo-channel morphology and oxidation-reduction recognition criteria. Exploration techniques to locate identify and map palaeochannels include airborne and ground geophysics (gravity, EM, aeromagnetic). Location of deposits within palaeochannels requires considerable drilling (generally rotary mud drilling), geophysical logging (particularly electric logs and gamma ray or direct reading uranium tools such as PFN), subsurface geological mapping and sedimentological and stratigraphic interpretation. Within the Beverley area, the task is particularly complicated because the host Beverly palaeochannel sands within the Namba Formation are difficult to distinguish from the underlying sediments using surface geophysical methods, increasing the importance of drilling and geological interpretation.

Buried palaeo-channel uranium deposits, if located below the water table, may have the potential to be mined using in situ leach mining methods as at Beverley.

ADVANCED SOFTWARE INTERPRETATION TECHNIQUES TO HELP FIND SUBSURFACE MINERAL DEPOSITS

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Session 4: Tectonics and Mineralising Systems

KEYNOTE

DEVELOPING TECTONIC FRAMEWORKS FOR POORLY EXPOSED BASEMENT TERRAINS

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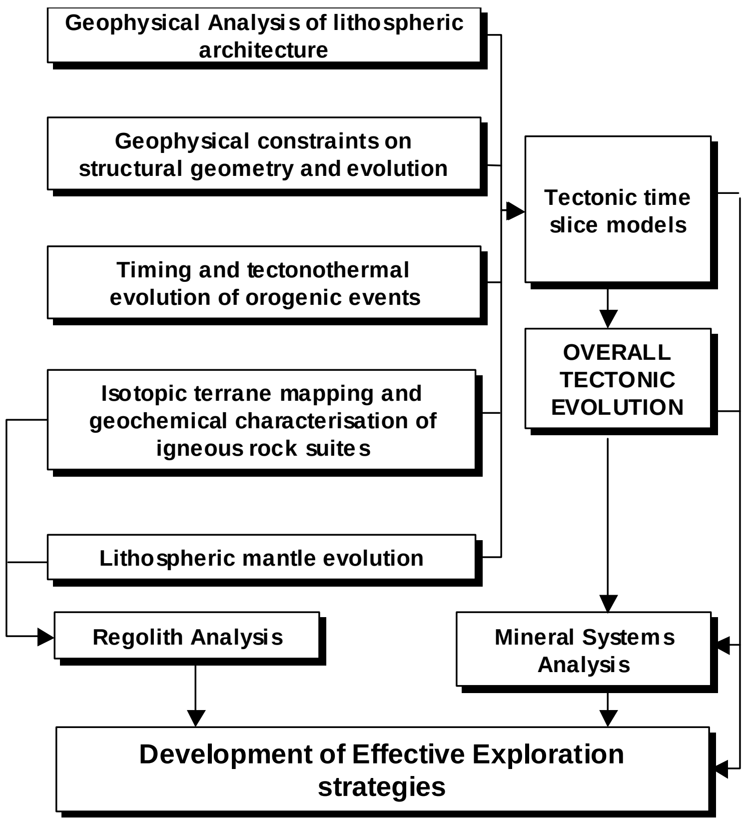
The development of effective new mineral exploration strategies in complex basement terrains is increasingly reliant on integrated data-rich tectonic models that describe the full terrain history. Such tectonic models allow a systems-based approach to mineral exploration, where the potential for certain styles of mineralisation can be ranked against terrain evolution variables such as denudation depth, magmatic styles structural histories and thermal regimes which directly affect the likelihood of deposit generation and preservation.

In South Australia we face a major challenge to understand the geological framework of large and comparatively poorly exposed areas such as the Gawler Craton. This region for example is internationally known for hosting the immense Olympic Dam Fe-oxide Cu-U-Au-REE deposit, and has further been enhanced by the Prominent Hill discovery and the growing recognition of the central Gawler Au province. However despite containing a number of highly prospective rock systems such as the late Archaean Harris Greenstone Belt and the eastern Gawler Craton Cu-Au province, in comparison with other Australian terrains of late Archaean and/or Palaeoproterozoic age (e.g. Yilgarn Craton, North Australian Craton, Curnamona Province), the volume of mineral exploration activity is comparatively small.



A program currently underway at the University of Adelaide, in collaboration with partners Mineral Resources Group of South Australia and Monash University, is to develop constrained tectonic models for the evolution of the major basement provinces in the southern Australian Proterozoic.

The approach being adopted is to effectively remote sense large-scale but poorly exposed or inaccessible areas using a set of tools (Figure 1) that integrate across a range of scales and processes. The outcomes of these projects are designed to form inputs into more targeted mineral systems analysis and exploration, and form an obvious compliment to the Centre for Mineral Exploration Under Cover currently being established at the University of Adelaide.

CURNAMONA TECTONICS AND MINERALISATION

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The Curnamona Province has long been considered one of Australia's premier base metal provinces essentially on the back of the giant Broken Hill deposit. However, compared to other geological provinces with similar tectonic evolutions (e.g. Mt. Isa Inlier) there has been a lack of exploration success throughout the Curnamona Province. This does not necessarily mean that the Curnamona terrane is less endowed, or is less prospective. In this abstract we will consider several key tectonic elements of the Curnamona Province and place mineralisation into the context of tectonic processes.

One of the biggest limitations in determining the tectonic setting and evolution of the Curnamona Province and other Proterozoic terranes is that their outcrop and geophysical extents are such that plate boundaries and terrane margins are often not preserved, thus making it difficult to determine the tectonic setting of individual provinces by studying them in isolation.

In this talk we consider the evolution of the Curnamona Province in the context of the continental reconstruction of Giles et al., (2004), in which the Curnamona Province is rotated 52° counter clockwise such that it is placed immediately adjacent to the southern extent of the Mount Isa terrane. When the major mineral occurrences are plotted in this reconstruction space a remarkable pattern is revealed. The Curnamona Province is located at the intersection of two mineral belts characterised by different deposit types. The first belt trends in a north-northwest orientation and contains major sediment-hosted Pb-Zn-Ag deposits including the giant Broken Hill, Cannington, Mt Isa, Century, and HYC. The second Belt is a north-south trending belt of Iron Oxide Cu-Au mineralisation that extends from the Gawler Craton, through the Curnamona Province and into the Eastern Fold Belt of the Mount Isa Block. The significance of these belts is yet to be fully realised but implies some kind of fundamental architectural or tectonic control of mineralisation.

One of the biggest hurdles in understanding the evolution of the Curnamona Province is the relatively limited exposure of temporally distinct and relatively thin package of rocks (i.e., Willyama Supergroup). This is further exacerbated by the intense strain and metamorphism associated with the ca 1600-1590 Ma metamorphism. This is in stark contrast with the Mt. Isa Inlier which preserves a more than 300 million years of the rock record and records tectonic processes that range from upper crustal basin development through to mid-crustal orogenesis. Consequently there are many lessons about sediment hosted Pb-Zn-Ag mineralisation that can be learned from the Mt Isa Inlier. Recent tectonic studies (e.g., Betts et al., 2003) in the least deformed parts of the inlier have shown that mineralisation seems to have been favoured by:

1. Long-lived lithospheric extension, elevated heat flow, episodic uplift and crustal reworking that resulted in the formation of K- and Pb-rich igneous rocks, and their subsequent recycling into the sedimentary basin where they behaved as aquifers for basin fluids, promoting convective fluid migration.
2. A protracted extensional basin history (ca. 1800-1600 Ma) that enabled fluids to circulate within the basin for extended periods, increasing their salinity and metal concentrations.
3. The development of extensional fault architectures that were reactivated during later basin history, and became conduits during mineralization events.
4. A switch to sag-basins where the basin geometry and evolution is dominated by the effects of thermal subsidence of the lithosphere, resulting in development of anoxic basin conditions that were chemically favourable for mineralization.
5. Transient episodes of tectonism that may have reactivated basinal faults or maintained elevated heat flow. Each of these would have promoted the migration of fluids through metal-rich source rocks and promoted tectonic reactivation and development of deformation-induced dilatancy, which allowed fluid migration to shallower levels into suitable geochemical and structural traps, at or near the basin floor.

The rock record of the Curnamona Province precludes assessment of many of these factors, particularly as there is uncertainty as to what the composition of the pre-Willyama basement is, and to date an extensional fault architecture has not been defined. Nevertheless, the Willyama Supergroup does record a transition from extension to thermal subsidence and associated anoxic basin conditions. The Willyama Supergroup also appears to have undergone episodes of tectonic reactivation at ca 1640 Ma and again at ca 1620 Ma.

The discovery of the Portia mineralisation in the Benagerie Ridge suggests that the Curnamona Province may be part of a larger system of Iron oxide Cu-Au mineralisation along the eastern margin of the Proterozoic Australian continent. The largest of these mineral systems is Olympic Dam in the eastern Gawler Craton. Whilst the tectonic setting of Gawler Craton is controversial and subject to ongoing research, mineralisation does appear to have followed a period of transient voluminous felsic magmatism (ca 1595-1570 Ma) associated with the interaction of a mantle plume and continental lithosphere. The preservation of dominantly felsic magmas (Hiltaba Granites and Gawler Range Volcanics) in this environment is quite unusual but can be explained by a plume-modified orogenic system (Murphy et al., 1998) in which a subducting slab migrated over a plume, resulting in a switch to compressional tectonism associated with flat subduction. A compressional regime may have restricted decompressional mantle melting, and promoted heat conduction, followed by melting of the lower crust, and hence felsic magmatism. The focus of Iron oxide Cu-Au mineralisation along an eastern belt of the Gawler Craton may reflect the influence of lithospheric-scale structure that evolved during the continental collision associated with the Kimban Orogeny at ca 1740-1690 Ma. The distribution of the felsic magmas along the eastern Proterozoic provinces shows that they get progressively younger to the north, consistent with migration of the continent over a hotspot. Interestingly, the distribution of Iron Oxide Cu-Au mineralisation also follows the distribution of felsic magmatism.

The Curnamona Province is located along this hotspot track. Moreover, it displays many of the same characteristics as the Gawler Craton at the time of Olympic Dam deposition. For example, voluminous felsic magmas (Benagerie Volcanics, Bimbowrie Granites) were emplaced in the southern and central province following a period of crustal shortening (Olarian Orogeny, ca. 1600-1590 Ma), and recent geophysical analysis reveals the presence of several deep-seated crustal-scale structures, some of which lie directly underneath regions of voluminous magmatism. These crustal-scale structures appear to pre-date the Olarian Orogeny and may have had a direct influence on magma ascent.

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CRUSTAL STRUCTURE OF THE OLYMPIC DAM REGION, EASTERN GAWLER CRATON: CONSTRAINTS FROM DEEP SEISMIC REFLECTION PROFILES

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Two nearly orthogonal deep seismic reflection profiles acquired in the northern Stuart Shelf, and centred on the Olympic Dam Fe oxide Cu-U-Au deposit, clearly image the cover successions and the structure of the cratonic basement around the deposit. Along the line of the profiles, sequences of the Pandurra Formation, Adelaide Rift Complex, and the Stuart Shelf have total thicknesses varying from ~300 m to over 6 km. Known upper crustal units of the basement, e.g., Burgoyne batholith, Gawler Range Volcanics, Wallaroo Group, and Donington Granitoid Suite, were also clearly imaged. The mid-crust is dominated by a sub-horizontal, internally packaged, partly mafic layer up to ~5 km thick. The lower crust contains a north-dipping transcrustal shear zone, which does not appear to separate crust identifiable as discrete terranes. However, the lower crust farther to the northeast may be a distinct terrane, as it is relatively homogenous and characterised by sub-horizontal, rather than dipping, reflectivity. The seismic Moho occurs at about 40-42 km depth. The upper crust contains dipping seismic events interpreted as thrust complexes, which may have provided first-order fluid pathways for the minerals system. Excepting orthogneisses of the older Donington Granitoid Suite, the only plutonic body imaged is the Burgoyne batholith of the Hiltaba Suite.

WHAT'S THE GAWLER CRATON LIKE UNDER THE REGOLITH? INSIGHTS INTO TECTONIC ARCHITECTURE FROM GEOPHYSICS

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The Gawler Craton is an immense area (approximately the size of Germany) largely covered by regolith (~90% areal cover). For all this, the Gawler Craton potentially holds rich rewards for explorers who can see through the cover to the basement endowed with Cu, Au, U, Fe, possibly Ni, and diamonds.

Over the last three years, research undertaken at the University of Adelaide, along with our partners at Geoscience Australia and PIRSA, has been applying a suite of tools and techniques that combine sparse quantitative geological information with potential-field and electrical geophysical methods to allow us to see through the cover. Our ultimate aim is to critically evaluate key events in the tectonic evolution of the Gawler Craton, despite its poor exposure. Our starting point is the identifiable mineralogical sources of geophysical anomalies, working up through their igneous, metamorphic and structural habitats, to produce 2.5 and 3D maps of terrane-scale features.

I will present some examples of the techniques that we have been developing and applying--using examples from the Adelaide Fold Belt (Gawler Craton under very deep cover), Olympic Dam, the Fowler Belt, and the remote northern Gawler Craton--and show how these are contributing to the improved understanding of the geology and analysis of diverse minerals systems under cover.