CENTRAL GAWLER CRATON – TOWARDS AN INTEGRATED STRATEGY FOR MINERAL EXPLORATION

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BACKGROUND

The central Gawler Craton in South Australia is a semi arid region of Archaean to Proterozoic basement regarded as having high mineral prospectivity but largely covered by thin sediment cover (mostly <30m) with moderate to deep weathering (10m - >100m) preserved in crystalline basement rocks. CRC LEME activities in the region commenced in 1996 following successful application by companies of regolith carbonate "calcrete" sampling to define areas of anomalous Au – a technique developed from CSIRO studies supported through AMIRA, and extended and promoted by LEME (Lintern, 1997; Lintern, 2002). The Challenger Au Mine (~500,000 ozs Au at average grade 4g/t) was an outcome of this exploration approach (Edgecombe, 1997; Poustie & Abbot, 2006). Investigations were initially on Au prospects defined by calcrete sampling, mostly in Archaean terrains. Regolith characterisation and mapping plus geochemical characterisation in 3D were the principle methods employed to provide recommendations on a preferred geochemical sampling strategy and analytical requirements to explore for Au mineralisation in the region (Lintern, 2004). Prospect scale airborne EM and hydrogeochemical sampling were trialled with some useful results, however the general applicability and cost benefit of these techniques remain to be fully assessed (Lane & Worrall, 2002; Worrall & Gray, 2004; Gray & Pirlo, 2005).

The involvement of Primary Industries and Resources, South Australia (PIRSA) as a core participant in a renewed LEME bid in 2001 introduced a broader range of activities, with a focus in LEME on regional data compilations, emphasis on Archaean nickel prospectivity, Mesoproterozoic Au systems, and landscape evolution; the latter largely developed from studies of the sediment cover. Investigations of Tertiary palaeodrainage network and sediment fill were extended to include coastal barrier systems and the potential for mineral accumulation in the transported regolith (Hou & Alley, 2003). This work led to a revised stratigraphy and an evolutionary model for the extensive barrier dunes marginal to the Eucla Basin, originally recognised by Benbow (1990) and in part outlined by present day Ooldea and Barton sand ranges (Hou et al., 2003a; Hou et al., 2003b). Speculation by Hou et al. (2003c) of substantial heavy mineral accumulations in the barrier system, backed by models of possible trap sites based on the revised stratigraphy and dune development, was proved essentially correct with discovery by Iluka Resources, during October to December 2004, of world class resources of zircon at Jacinth and Ambrosia prospects (Hou & Warland, 2005). The total resource at Jacinth and Ambrosia is estimated at 9.2 million tonnes *in situ* heavy minerals of average grade 4.6% and an average zircon assemblage of 48% (Iluka Resources Ltd., 2006). These were followed by further new discoveries by Iluka at Tripitaka in 2005, and Gullivers in 2006. The in-ground value of resources identified in these 4 prospects is in excess of A$4 billion at current zircon prices (Folwell, 2005; Yates, 2006).

Recent LEME activities in the central Gawler include mapping dispersion of Au in sand dune cover, examining the role of vegetation in metal cycling, biomediation of Au in carbonate, clarifying the effect of fluvial deposits on geochemical dispersion, spectral mapping of alteration minerals, both hydrothermal and weathering, in areas of Au mineralisation, and investigating new methods of mapping palaeochannel distribution to the level of detail required for preliminary exploration targeting. The central Gawler Craton was selected by Geoscience Australia (GA), in concert with LEME, for a pilot study of techniques for a regional baseline soil geochemical and groundwater sampling program that ultimately will provide a continent-scale perspective of element distribution to assist mineral exploration and environmental studies. New ideas and approaches continue to evolve from collaboration and interaction with exploration companies and other research groups active in the region, in particular PIRSA Gawler team, GA Gawler mineral promotion project team, and pmd*CRC. New techniques recently applied to Au prospects in the Gawler Craton include spectral core logging using the HyLogger™ system, developed by CSIRO Mineral Mapping Technologies Group, and the CHIM electro-geochemical prospecting technique as modified by Professor Luo at Guilin University of Technology, China. Some recent results are outlined below with comment on how these might impact on mineral exploration strategies in the central Gawler Craton.

FLUID MODELLING AND HOST ROCK ALTERATION

During 2005-06, pmd*CRC completed a preliminary regional thermal-fluid-flow model for the Gawler Range Volcanics/Hiltaba, 1570-1600 Ma, thermal event (Potma & Zhang, 2006). Predictions were based on a model with a regionally extensive, very low permeability blanket of Gawler Range Volcanics (GRV), <2 km thick, underpinned by a 5 km-thick thermal slab at around 10 km depth. A significant focussed fluid flow anomaly developed after around 100,000 years with lateral flow beneath the base of the volcanics and rapid up-flow along shear zones. The model indicates the most prospective sites for mineralisation are within ~200 m of the base of the GRV, especially where reactive lithologies such as mafics or carbonaceous sediments are present, or where large steep structures provide an opportunity for fluid mixing and a geochemical gradient to promote mineral precipitation. Damage zones in the lower GRV are also potential sites for mineral deposition, especially where mafic units are present to give a reactive geochemical trap for Au fluids (Potma & Zhang, 2006). The model points to a much broader range of targets for Au mineralisation in the central Gawler than the focus of recent mineral exploration which has been largely on major shear zones proximal to Hiltaba Suite granite.

Potential field and EM techniques are used currently to locate and evaluate major shear zones, however an alternate means of locating sites of focussed fluid flow is the recognition of host rock alteration, especially near the base and margins of the GRV. Gold prospects related to the thermal event often show zoned alteration around Au mineralisation, with intense sericite-pyrite alteration and quartz veining proximal to Au mineralisation, and chlorite ± epidote ± hematite distal to mineralisation (Drown, 2003; Ferris & Schwarz, 2003; Skirrow et al., 2004, Budd & Fraser, 2004). HyLogger™ spectral data from drill core at Barns and Tarcoola confirm the association of high sericite content and elevated Au values but also show a change in white mica composition with increased content of phengitic, usually Mg-rich, mica (Keeling et al., 2004, Mauger et al., 2004). At Barns prospect, highest Au content is concentrated on the margins of zones of phengitic-sericite alteration which survives into the lower saprolite and can be tracked with short-wave infrared spectral techniques as zones of high illite content (Keeling et al., 2004). At the prospect scale, sericite alteration can be convincingly mapped in airborne hyperspectral surveys, over fresh or weathered bedrock, as areas of crystalline mica or illite that cut across structural and/or stratigraphic trends. This is demonstrated in a recent investigation of HyMap airborne spectral data over the Tarcoola Gold Field where it is possible to outline areas of sericite alteration and to differentiate reactive carbonaceous shale units that host vein Au mineralisation in Tarcoola Formation metasediments (Mauger et al., in review). Where transported cover is absent or patchy, airborne hyperspectral surveys offer a rapid regional technique to locate zones of hydrothermal alteration within or marginal to the GRV. The suitability of areas for high-resolution airborne spectral mapping can be assessed from satellite spectral imagery such as Landsat TM, or preferable ASTER, to predict the extent of bedrock exposure.

Au DISPERSION IN REGOLITH COVER

LEME studies in 2004 on the Barns Au prospect demonstrated elevated Au values in the lower section of an 8m-high aeolian sand dune on weathered Tunkillia Suite granite gneiss bedrock (McEntegart & Schmidt Mumm, 2004). A trench was bulldozed to expose a full section through the dune and sampling confirmed elevated Au contents to 9.2 ppb associated with increased Ca-carbonate levels in the dune; the highest Au concentration being in a calcareous rhizomorph some 5 m above the residual bedrock (Lintern, 2005). Elevated Au levels were found also in *Eucalyptus* terminals when collected during late summer from individual plants growing on the dune (Lintern, 2005). In a separate study over sand dune terrain extending into the Pinkawillinie Conservation Park, east of Barns, *Eucalyptus* spp. were identified also as the preferred biogeochemical sample media that best reflected bedrock element input (Mayo & Hill, 2005). Biological cycling of Au from the saprolite by deep-rooted vegetation with translocation of Au into the dune via element mobilisation from surface plant litter was proposed (Lintern & Rhodes, 2005). Gold levels in the dune have accumulated since dune formation at around 25,000 years. A mechanism for biologically-mediated co-precipitation of Au and carbonate is proposed to explain the association of Au and regolith carbonate at Barns (Schmidt Mumm & Reith, in press).

In contrast to sand dune fields over weathered bedrock, anomalous Au-in-calcrete developed on Eocene to Miocene palaeochannel sediment fills and younger debris flow deposits, invariably do not reflect mineralisation in the bedrock beneath (Worrall, 2003; Drown, 2005). These areas occupy present or palaeo topographic lows in the landscape and are a focus for groundwater flow both within the channel sediments and from shallow groundwater migrating downslope through saprolite in the surrounding catchment. With the onset of drier conditions since mid Miocene times, high evaporation and lowering of water tables has favoured mineral precipitation and accumulation at these sites, rather than flushing (Anand et al., 2006). Under these circumstances, Au in solution can accumulate in near-surface deposits to give “false anomalies” that are substantially displaced from the original source. Regolith mapping, incorporating available subsurface data, such as that recently completed for the Wudinna North area (Sheard, 2006), will assist in distinguishing the setting for geochemical anomalies and aid in prioritising drill targets. Palaeochannel sediment fill beneath sand dune cover, however remains a challenge for surface mapping techniques.

CHINESE CHIM

While calcrete sampling in the Gawler Craton has been effective in identifying areas of elevated Au, the anomalies are often broad and do not necessarily reflect the attitude of underlying mineralised structures. Often ground geophysical surveys and a substantial number of drill holes to the top of fresh bedrock are required to define the trend of mineralisation and give some indication of geological controls that can be used to site RC holes to test mineralisation at depth. Additional surface techniques are required to help assess and prioritise Au-in-calcrete anomalies.

In September 2005, trial surveys using a Chinese variant of the CHIM electro-geochemical technique as developed by Professor Luo of Guilin University, was completed over the down plunge extension of gold ore shoots at the Challenger Au Mine, 240 km NW of Glendambo (Keeling et al., 2006). The survey was conducted using specially coated carbon electrode pairs individually wrapped in acid resistant paper and connected via insulated copper wire to a disposable 9 V DC battery. The electrodes were buried at around 0.2 m depth and 0.6 m apart, the area moistened by the addition of 1 litre of 30% HNO_3, then covered with soil. After 48 hours the electrodes were exhumed, paper wrapping removed and discarded, and the coatings removed and retained for analysis. The samples of electrode coating were digested in warm concentrated HNO_3 and elements in solution determined by ICP-MS. Results were reported as µg of contained metal per electrode. A soil sample was also collected from the base of the electrode pits at each site, prior to placing the electrodes. The soils were crushed and sub-sampled for measurement of electrical conductivity and mercury analysis. The remainder of the soil sample was analysed for a suite of elements using aqua regia digest and analysis by ICP-MS.

Lou's working hypothesis is that geochemical dispersion of metal ions is driven largely by electrical effects within the orebody, facilitated by groundwater, and arising from a combination of intergranular effects from mixed metal sulphides, primary zonation of ore minerals, and oxidation effects. Ion dispersion is in part a function of the strength of the electrical field developed within the orebody. Loosely held ions dispersed to the surface remain under the influence of the field. A small current applied at the surface can remove a weakly held ion that will be replaced by another mobile ion. It follows then that a small current applied for a sustained period will collect sufficient ions to give an anomaly that reflects shortest distance from surface to the most electrically active area of mineralisation.

Results for arsenic (As) on Line B, closest to the pit, showed reasonable correspondence with the known position of 'blind' ore shoots at depths of between 120 and 210 m below surface. On Line A, 400 m to the northeast, the shoots are projected to be at between 320 and 410 m below the surface. Elevated As values are present only over the shallowest shoot (Keeling et al., 2006). While results are inconsistent they give encouragement in being able to define drill targets more precisely than data from soil sampling and further work with the technique is planned for 2007.

PALAEOCHANNEL MAPPING

The availability of satellite Landsat images in the 1970s provided the first overview of remnants of an extensive network of large palaeorivers that drained across the northwest of South Australia into a former marine Eucla Basin, >100 km inland from the present day coastal margin. We now know that rivers draining the Musgrave Province delivered the bulk of zircon that was carried easterly by longshore drift to be concentrated in heavy mineral deposits in beach barrier systems adjacent to the present day Ooldea Range (Reid & Hou, in press). Eocene to Miocene palaeorivers with headwaters in the Gawler Craton are today prime exploration targets for sandstone uranium. For gold exploration, knowledge of the distribution of channel fills is critical for prioritisation of geochemical anomalies. LEME projects on the Gawler have focused largely on regional distribution of palaeodrainage networks (Hou et al., 2003). Most detailed study has been made of the Kingoonya Palaeochannel (Hou, 2004) that examined palaeochannel architecture, sediment fill and flow dynamics, 3D modelling, sequence stratigraphy and biostratigraphy.

Development of a regional framework of palaeodrainage has relied heavily on remotely sensed data supported by relatively sparse drill hole information and few field exposures. The Shuttle Radar Topography Mission (SRTM) during 2000 provides the best available digital elevation model over the area at ~90 m resolution. This gives useful detail for the main trunk and major subsidiary drainage for palaeodrainage from the Musgrave Province west to Tallaringa and portion of the Garford palaeoriver. Infill by younger sand spreads and dunes of the Great Victoria Desert limit the usefulness of this data set south of Garford. Satellite data from NOAA-AVHRR, Landsat TM and ASTER have been used to highlight features associated with palaeodrainage sediments, but are best interpreted in conjunction with DEM and available surface geology (Hou & Mauger, 2005). Airborne electromagnetic and ground gravity techniques are favoured for exploration-tenement scale delineation of palaeochannel fills although poor contrast between sediment fill and deeply weathered basement in some areas give misleading interpretation. The upsurge in drilling for sandstone uranium will produce subsurface geological information and samples that will substantially add to present knowledge. As this information and associated geophysical data become available, LEME has a role in integrating the data to update and modify our present interpretation of palaeodrainage and to develop models for uranium dispersion and precipitation in channel sediments.

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