A REVIEW OF GEOCHEMICAL EXPLORATION THROUGH DEEP COVER AT KEY PROSPECTS IN THE CURNAMONA PROVINCE: SUCCESSES AND FAILURES

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In the Curnamona Province, stratiform and stratabound Pb-Zn and Cu-Au mineralisation are commonly associated with a regional redox boundary within the Willyama Supergroup stratigraphy. This boundary can be identified from aeromagnetic data, however, the rocks are mostly covered by 10-150 m of transported regolith. Discovery of new mineral deposits in the area would be enhanced by an effective surface technique that allows detection of mineralisation through this thick cover. Numerous geochemical techniques have been used in the Curnamona Province and these provide an insight into the future direction of research.

Standard soil geochemistry has generally been considered effective in detecting mineralisation at shallow depths. In areas of deeper cover, partial or selective extractions have been used. When an orebody weathers, its constituent elements are dispersed by a variety of mechanisms, but for a body that is deeply buried, these tend to be chemical rather than physical. In so doing, these elements tend to be temporarily attached to the surfaces of the mineral grains of the regolith. Since it is often only these surficial atoms that reflect the buried ore body there are benefits in limiting analysis to these rather than measuring the total available. As their name suggests, selective extractions are designed to target certain components of a sample associated with elements dispersed from a weathering ore body (e.g., Fe and Mn-oxides, organic matter). These types of leaches have been successfully used in areas of deeper cover (commonly up to 20-50 m).

Exploration companies have tackled the challenge of effective geochemical prospecting in areas of deep cover in a large variety of ways. Three prospects in the Curnamona Province where extensive geochemical experimentation has taken place include Kalkaroo, Polygonum and Portia.

Kalkaroo

Extensive geochemical programs were undertaken at the Kalkaroo Cu-Au prospect, all of which were hampered by both the depth to the mineralisation and the nature of the regolith. The prospect is covered by 40-60 m of transported cover that includes Tertiary fluvial sands, lacustrine clays and Quaternary to Recent alluvial clayey sand. Primary Cu-Au mineralisation (chalcopyrite-pyrite ± pyrrhotite-molybdenite-gold) is present at approximately 110 m depth in albite-rich ± pyritic metapelites and psammopelites. The mineralisation is stratabound and dips at 40 degrees around a dome structure. The mineralised sequence is overlain by carbonaceous metapelites and is underlain by albite-altered scapolitic metasediments that are strongly magnetic and pyrite poor (Law & Terrill 2001). In addition to the Cu and Au which make up the mineralisation, an As-Mo association has been recognised in the intersected mineralisation.

A degree of innovation and geochemical experimentation has characterised the approach by tenement holders over the past 10 years. In addition to conventional methods, Placer Exploration and Amdel used the Kalkaroo mineralisation as a target during the partial leach development that led to the “Deepleach” series of extractants, now routinely offered. Similarly, Placer was among the early users of Enzyme Leach (Actlabs). Newcrest used a more conventional approach in opting for a strong acid leach but also included Deepleach 11. MIM Exploration repeated many of the previously used extraction techniques and also trialled Deepleach 35 (Amdel), MMI A and B (WAMTECH), BLEG and other experimental methods (various analysts). Thus, to date, methods used have included a four-acid leach, several EDTA leaches, Enzyme Leach, BLEG, aqua regia, MMI, and Deepleaches 11 and 35 (these are summarised in Table 1).

Placer was the first to investigate the use of soil geochemistry at Kalkaroo. A strong acid leach was initially used without significant success. Weaker leaches were then investigated; a survey was done using 4% w/v EDTA extractant. Some success was achieved with a weak anomaly obtained over what was found in later drilling to be significant mineralisation. However, beyond this success, use of the technique proved equivocal. Enzyme Leach has the potential to enhance metal anomalies associated with Fe. No clear success was achieved on any of the lines over mineralisation. Placer also tried varying the sample grain size and used -20 mesh (850 µm) in addition to the standard -80 mesh (180 µm) soil fraction. Results were consistently low but later work showed that either a finer or coarser fraction might have been more satisfactory.

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Newcrest's trial of Deepleach 11 involved three profiles. No significant anomalies were obtained, however, only one of the survey profiles was located over significant mineralisation.

MIM reviewed previous geochemistry and reanalysed samples in areas of highest-grade mineralisation. Samples were taken from 12-20 cm depth and most samples used for partial extractions, sieved to –250 µm. Results from either a four acid leach (hydrochloric, nitric, perchloric and hydrofluoric acids, 'total extraction') or aqua regia (ARM1, Amdel) were used for reference. Also, as part of a MIM-sponsored project, TAFE students took samples to determine the best size fractions for use with Deepleach 11 and 35, and in this case, relative to aqua regia results. Size fractions +2000 µm (aqua regia only), –2000+250 µm, -250+75 µm and –75 µm were used.

In view of the difficulty of the target, it was not surprising that no element/leach combination could be universally relied upon to give a coherent anomaly, directly over known mineralisation. Among the partial leaches, Deepleach 11 generally gave better results than Deepleach 35, MMI A (Cd, Cu, Pb, Zn), MMI B (Ag, Au, Co, Ni, Pd) or Enzyme Leach. Enzyme Leach was noteworthy principally for the 55 elements used (some semi-quantitatively) but in spite of this, none unequivocally indicated mineralisation, although thallium (Tl) showed some promise. BLEG can also be considered a partial leach and was used for elements Au, Cu and Ag. None of these reflected mineralisation. The trial with EDTA that initially sparked interest in partial leaches ultimately did not yield reliable results either, although a number of analytical issues remain unresolved.

The TAFE results (for Deepleaches 11 and 35) show concentrations of target elements usually increased with reducing grain size and more importantly under the circumstances, resulted in more easily recognised anomalies. It is presumed that this would also be true for other approaches but has not been demonstrated.

Overall, for the strong acid attacks (four-acid, aqua regia) Ag, As, Mo and W all showed some indication of mineralisation but with no clear or consistent anomalies. Of these, perhaps Mo was most consistently elevated over mineralisation. Lag samples (+2 mm, aqua regia) did not give results that correlated with underlying mineralisation.

Polygonum

Mineralisation at the Polygonum prospects occurs at a variety of stratigraphic levels and includes four styles of mineralisation. These are:

1. Stratiform to stratabound Cu-Au-Mo zone in albitic ± magnetite metasediments;
2. Stratiform to stratabound Zn-Pb-Ag (Mn, W, Mo, As, Co, Cu) zone in interbedded calc-silicate and albite-altered metasediments;
3. Broken Hill-type (BHT) Pb-Zn-Ag in fine-grained, garnet-rich interbedded pelite and psammite; and,
4. McArthur River-Mt Isa-style Zn-Ag-Pb (Cu) stratigraphically above the other target zones in pelitic rock units.

Testing of this broad stratigraphic package for economic mineralisation is made difficult by approximately 150 m of transported cover. This cover consists of ?Adelaidean, ?Cretaceous, Tertiary and Quaternary sediments in varying degrees of consolidation. In 1998, BHP Minerals trialled soil sampling over the Polygonum prospects. Samples were collected from the weakly calcareous zone, believed to mark the base of maximum soil moisture evaporation. The trial resulted in apparently coherent bulk cyanide leach Ag and Cd anomalies over known and interpreted BHT-style mineralisation. This was in spite of 150 m of transported cover and up to 60 m of weathered bedrock (Hedger & Dugmore 2001). Subsequent work by the current exploration licence holders, Platsearch NL (in joint venture with Inco Limited), attempted to validate these results.

A comprehensive survey was undertaken (Leyh & Corbett 2001) involving a line of approximately 5 km with samples taken from both the shallow rhizomorphic carbonate zone (0.3-3 m) and a deeper, nodular and laminated calcrete zone (1-10 m). Samples were collected using an auger mounted on a Toyota Landcruiser 4WD. Rhizomorphic carbonate accumulations were digested using cyanide (BLEG), aqua regia and the proprietary selective leach, Terra Leach 1, from Genalysis. Nodular and laminated calcretes were digested in aqua regia. Although slightly erratic and at relatively low level, a BLEG/ICPMS Ag anomaly from rhizomorphic carbonate was obtained which was similar to the anomaly reported by BHP and, although perhaps not strictly anomalous, recognisable in the Terra Leach results. Similar, high-background features were common to the profiles for a number of elements (i.e., Cu, Zn, As, Co Mn and Ni) determined by aqua regia/ICPOES using rhizomorphic carbonate samples. This gives credence to the view that they reflect geomorphological/geological entities. In addition, a broad, intense BLEG Ag-Cd-Zn anomaly was obtained from a nearby area of presumed McArthur River Style Zn-Ag-Pb (Cu) mineralisation (Paragon Group). The anomaly was also obvious in the aqua regia/ICPOES results for both the Ag and Cd from the nodular and laminated calcrete samples.

Surprisingly, aqua regia/AAS analysis of the nodular and laminated calcrete produced quite different element patterns to comparable analyses done using rhizomorphic carbonate. Although now believed to result from contamination, a 1.6 km wide zone, highly anomalous for Au (up to 131 ppb) Ag, As and Cd was found in a position believed to be prospective for Cu-Au. However, the results could not be repeated and contamination, possibly from the auger bit may have been the cause (Leyh & Corbett 2002).

Other stratigraphic positions have been regionally associated with more subtle features on the geochemical profile, where validity is a function of repetition in a number of elements rather than intensity for any one element (Leyh & Corbett 2001).

Portia

The Portia and North Portia prospects have been the subject of several detailed geochemical and regolith studies (Tan 2001, Harrington 1996, Hughes 1995). The Cu-Au-Mo mineralisation occurs in finely-laminated, carbonaceous metasediments (Tan *et al.* 2005). Saprolite can be in excess of 90 m thick and this is in turn overlain by 50-75 m of Tertiary and Quaternary clays, sands and silts (Tan *et al.* 2005).

In 1994, Pasminco Exploration conducted an orientation survey using the partial extractions, 2% EDTA, 1% HNO_3 and the ‘total extractant’, aqua regia. Results showed an irregular correlation with mineralisation. A follow up sampling program to trial MMI was run later in the same year. For this survey, samples were collected from 20-30 cm depth and sieved to approximately –2 mm (Hughes 1995). The elements Cu, Pb, Zn, Ni, Cd, Au, Ag, Pt and Pd were determined. Effective elements appeared to be Zn, Ag, Cd and Pb, with Ag showing best anomaly contrast and Zn the best correlation with known mineralisation.

In 1998, a wider-ranging calcrete and partial leach soil sampling programme was carried out. Sampling involved taking a soil sample from between 15 and 20 cm and “calcrete” samples from between 50 and 100 cm. Soil samples were analysed using a cyanide, a weak nitric acid-potassium iodide and aqua regia leach (Amdel and Aminya Laboratories). Calcrete samples were analysed using BLEG (Au, Cu and Ag) and a four-acid leach, by Amdel. With soils, both partial leach methods reportedly gave subtle Au, Cu and Zn anomalies but calcrete results were not given (Hudson *et al*. 1999). A weak cyanide leach was considered to be the most effective digest in the Portia area but similar trials over North Portia and Shylock prospects did not produce similarly positive results. Hudson *et al.* (1999) noted that on a broad scale, soil geochemistry could be used to map out basic regolith units, e.g., vegetated clay flats generally gave higher results than poorly-vegetated sand dunes. The need for data levelling using geomorphological attributes was suggested.

Although surface soil results were encouraging, attention was focussed on subsurface geochemical samples. From the early stages of exploration, Pasminco Exploration routinely analysed Lower Tertiary sediments and saprolite, as well as fresh bedrock. Anomalous concentrations of Au in samples from around the base of the Tertiary led to more detailed studies into using these as a means of identifying underlying mineralisation. Lawie (1997) reported highly anomalous Au values in what was initially interpreted as *in situ*, highly-weathered bedrock. Interpretation was complicated by oxidation and kaolinisation at the base of the overlying clay (Namba Formation). Gold anomalism was also reported within the lower Namba Formation indicating mobilisation of Au. Later, Tan (2001) showed that Au in the kaolin-rich clay unit termed ‘Portia unit’, occurred within Tertiary sediments, just above the Tertiary-basement contact. This unit represents channel-fill sediments associated with the Eyre Formation, a widespread unit in the southern Curnamona Province. Gold in this unit is attributed to local basement mineralisation (Tan 2001). Tan’s study of element distribution and associations in the regolith profile showed that basement mineralisation could be confidently predicted by analysis of ferruginous saprolite (elevated Cu, Mo, Pb, Au and As) and in some cases, the lower Namba Formation. Unusually, analytical work in this study for most elements was by XRF.

Geochemical sampling of the regolith has been trialled in the Curnamona Province using a variety of techniques with a mix of successes and failures. Surveys have resulted in low-order anomalies over mineralisation but suffer from poor repeatability or reliability. No one technique stands out as being successful in all situations. Anomalies resulting from partial extractions are generally preferred to those from ‘total’ extractions and most exploration companies have concluded that partial extraction soil sampling is a useful regional scale exploration tool. There have been enough encouraging geochemical results in areas of deep cover throughout the Province to justify further research on surface geochemical techniques.

Table 1: Summary of potentially successful techniques. Refer to original reports for further details.

Method	Kalkaroo	Polygonum	Portia
4 acid leach	✗ (Placer) **?** Ag, As, **Mo**, W (MIM)	✓ rhc; Cu, Zn, As, Co, Ni, Mn over BHT-style min.	
Aqua regia	✗	✓ rhc; Ag and Cd over BHT style min. (BHP) ✓ rhc; Cu, Zn, As, Co, Mn, Ni over BHT style min. ✓ nc; Ag and Cd over McArthur River-style min. (Platsearch)	✗
BLEG	X	✓ rhc; **Ag**, Cd, Zn over BHT-style min. ✓ rhc; **Ag**-Cd-Zn over McArthur River-style	
EDTA	**?** Cu (4% EDTA)		✗ (2% EDTA)
MMI	✗		**? Zn**, Cd, Pb, Ag
Enzyme Leach	✗ (? Tl)		
Deepleach 11	✗ (Newcrest) ✓ Mo, ?As, ?W (MIM)		
Deepleach 35	✓ Mo, ?As, ?W		
1% HNO3			✗
Weak NaCN			✓ Au, Cu, Zn
Weak HNO3 + KI			✓ Au, Cu, Zn
Terra Leach 1		✓ rhc; Ag	

Rhizomorphic carbonate (rhc); Nodular carbonate (nc). ✗ = unsatisfactory, **?** = possibly usable, ✓ = usable.

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