Vegetation sampling in the Gawler Craton

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Increasingly, mineral explorers are considering the advantages of taking plant samples in mineral exploration programs when trying to explore through transported cover. Some of the advantages of this technique are:

- widespread, and in some places abundant, plant cover across the landscape
- easy access to samples that in many cases are convenient to take
- an ability for plant organs to provide chemical expressions that have penetrated through the transported cover;
- the ability to selectively extract and concentrate some elements (e.g. hyper-accumulators)
- a potential ability to homogeneously amalgamate a chemical signature from an enlarged and potentially heterogeneous substrate
- environmentally passive exploration approach, with minimal site disturbance and need for remediation
- some proven exploration success and expression of buried mineralisation.

The following is a short account of how to take a plant sample as part of a biogeochemical exploration program.

Sampling program

- Decide upon the nature of the survey required, including the area, sample spacing and sample location. Some localities allow for plants to be sampled conveniently along a transect or a grid, whereas others need to be sampled opportunistically (e.g. in sparsely vegetated areas) or along a restricted landscape setting (e.g. trees along creek lines). Sample spacing will depend upon variables such as the plant species targeted, the size of the exploration target and associated dispersion halo.

- Choose a target plant species or several plant species. The best results are obtained when plants of the same species are sampled because their assay results are more comparable. This typically includes one of the most widespread and abundant plant species from the project area that is considered to have a reasonable chance of being deep-rooted. If there is existing knowledge on particular plant species in your area, then this may also influence the choice of target species. Choosing a plant species that is distinctive and easy to identify makes your job easier. In most cases, a small orientation program testing a range of species in different landscape, regolith and geological settings is recommended if time and money allow.
- For your chosen species, a uniform plant organ (e.g. leaves, twigs of similar diameter, bark, wood, fruits, flowers or roots) is recommended for sampling. The more uniform and consistent that your sample is, the more valuable the comparisons between sample assay results will be. As a general rule, plant leaves can be the easiest to sample and prepare for analysis. Try to target leaves of uniform age/ maturity in order to reduce sample variability.
- Temporal variations (especially time of year with respect to seasons or rainfall events in arid areas) can have an impact on the variability in your assay results. Try to sample within a limited time period, and be very careful when comparing assay results from samples taken at different times of year or in different climatic context.
- Plant sample duplicates are important for QA/QC measures. The degree of duplication will depend upon your own protocol; however depending on total sample population size, duplications in the order of one in 10 are typical.

Plant sampling

The general rule here is to obtain uniform, and therefore comparable, samples between your target plants. Assuming that you are targeting a consistent plant species and plant organ, some general considerations include:

- Before sampling, record the sample location (GPS coordinates), type and description of plant, and regolith-landform site information
- Try to avoid sources of environmental contamination such as dust (e.g. from roads, ploughed pastures, drill rigs and mine sites). If possible, it is best to avoid samples that

may be excessively influenced by dust—particularly because washing the sample later is typically less than effective and may leach or further contaminate for some elements. When selecting species to sample, try to avoid those plants that are likely to trap dust (e.g. because of coarse leaf hairs)

- Recommended sample bags are made of unbleached paper (brown paper lunch bags are ideal). These minimise sample sweating and decomposition and add minimal contamination to the sample. The opening of these bags can be folded over once the sample has been collected (avoid metal fasteners for the bags, such as staples or pins, because these can be a source of metal contamination).
- It is recommended that you wash hands, remove jewellery and preferably wear powder-free latex or nitrile gloves for each sample. This minimises contamination while sampling.
- Try to take samples from a uniform height and from around the plant canopy.
- The optimal sample size is still debated between some researchers, and will depend to some extent upon the analytical technique used. Typically, your sample should be no less than 20 g, and ideally several hundred grams (which usually comes to about half to two thirds of a brown paper lunch bag full).

Sample storage and preparation

Sample decomposition and contamination should be minimised during storage. A sheltered well-ventilated site is recommended. Samples may need to be rotated during short-term storage to avoid irregular sweating and decomposition. Low temperature, clean oven drying will desiccate and stabilise the sample. An oven temperature of less than 60° C for approximately 48 hours is recommended. Higher oven temperatures may volatilise some important chemical components from your samples. Once thoroughly dried, samples can be stored in snap-seal plastic bags for longer periods.

The type of preparation required will ultimately depend on the type of analytical technique to be performed. A standard technique suitable for most approaches is as follows:

- Thoroughly clean a mill using a combination of high purity ethanol, paper towel and compressed air. It is important to use the same degree of care to reduce contamination in the laboratory as was used in the field (i.e. wear powder-free latex or nitrile gloves).
- Different people prefer different types of mill. Adequate results have been obtained using household stainless steel coffee and spice mills with rotating blades. The contamination from these mills is less significant for soft plant organs such as leaves.
- Pre-contaminate the mill with a small amount of the sample to be prepared. Use a short milling time and discard this preliminary material before adding the main part of the sample.
- Once the sample is milled to a fine powder (typically a consistency approaching that of talcum-powder), remove it from the mill and store in a labelled, snap-seal plastic bag.
- Re-clean the mill.

Sample analysis

This will depend on time, budget and of course the element suite that you are interested in. Techniques such as ICP-MS, ICP-AES, XRF, INAA and AAS have all been widely and successfully used for the analysis of plant materials.

Standard and certified reference material should be included in your sample batch for submission. These are available for plant material, although presently no materials exist for Australian native vegetation.

For further information please consult CRC LEME's Guide to the use of biogeochemical techniques in mineral exploration in Australia (Hill 2008)

Vegetation sampling in the central Gawler Craton

This section expands on what appears in the text of the Guide to Mineral Exploration through the Regolith of the Guide to the use of biogeochemical techniques in mineral exploration in Australia Central Gawler Craton, South Australia.

The main vegetation communities in the central Gawler Province include:

- Low open woodlands dominated by sugarwood (*Myoporum platycarpum*), western myall (*Acacia sowdenii*) and mulga (*A. aneura*). This is typically of mixed species composition in the southeast, with mulga becoming more frequent towards the north. Mulga and localised occurrences of pearl bluebush (*Maireana sedifolia*) understorey have been the main plant species biogeochemically characterised from these communities.
- Open mallee shrubland mostly comprising ridge fruited mallee (*Eucalyptus incrassata*), red mallee (*Eucalyptus socialis*), red mallee (*E. oleosa*) and yorrell (*E. gracilis*). A mixed understorey with broom-bush (*Melaleuca uncinata*) and spinifex (*Triodia spp.*) occurs on sand dunes. Callitris pines become a more frequent component to the south (e.g. *Callitris preissii*) and in the east (e.g. *C. glaucophylla*). Many of the mallee eucalypts (e.g. *Eucalyptus socialis* and *E. incrassata*) and spinifex (*Triodia irritans*), and local occurrences of broom-bush and chenopod shrubland species in dune swales and dunefield margins have been biogeochemically characterised from this community.
- Chenopod shrublands, with minimal tree cover such as near the western shores of Lake Torrens, but with black oak (*Casuarina pauper*), mulga and rosewood (*Alectryon oleifolius*) trees in many parts of the central Gawler Province, particularly associated with calcareous soils, and around the margins of many of the ephemeral salt lakes. The main species that have been biogeochemically characterised from this community in the region include pearl bluebush (*Maireana sedifolia*), black oak and local occurrences of mulga and bluebush daisy (*Cratystylis conocephala*).

Target plants

The following provides a brief field description for the main plant species that have been biogeochemically characterised from the region, as well as a brief outline of some of their biogeochemical characteristics for mineral exploration. Plant descriptions are partly after Kutsche and Lay (2003), Moore (2005) and Friebe and Matheson (2006).

Mulga (*Acacia aneura*)

Small upright tree to 14 metres tall, but also forms bushy shrubs 3–5 m tall. Variety of shapes including upright branches, 'Christmas tree' shape (*Acacia aneura var. conifera*). Grey-green phyllodes, mostly narrow-linear, but can be broader, 3–11 cm long × 0.7–3 mm wide, with parallel veins. Yellow, cylindrical flower spikes, 8–25 mm long, usually after significant rain. Papery to woody, brown seed pods, 1–6 cm long and 0.4–2 cm wide. Variable intergrading and hybridising forms, including at least 10 varieties of *A. aneura*.

Mulga is most abundant and widespread in the north of the region—particularly in areas that mostly receive summer rainfall. It is widespread in dunefields—particularly on mid-lower dune slopes—as well as along some drainage depressions within areas of chenopod shrubland. Although it has been extensively biogeochemically characterised elsewhere in Australia (e.g. Hill and Hill 2003; Anand *et al*. 2007), it has had limited study in the central Gawler Province. At Boomerang Au prospect, it provided irregular expressions of buried mineralisation (Lintern *et al*. 2006). At Edoldeh Tank Au prospect, *Acacia* (presumably *Acacia aneura*) phyllodes and small branches had high Au concentrations (>0.4 ppb equivalent dry weight) overlying weak mineralisation. In general, however, it was concluded that there were inconsistent associations between Au in vegetation and Au in calcrete, soil, upper regolith or mineralisation (Lintern *et al*. 2003). Silver had an erratic occurrence, while Cu varied between 2 and 42 ppm equivalent dry weight, but had no association with Cu in soils or drill cuttings.

Black Oak (*Casuarina pauper*)

Variably shaped, bushy to upright tree up to 15 m tall, with dark grey fissured or scaly bark and slender, striated and jointed branchlets 1–2 mm thick. Leaves are 9–12 small pointed scales (resembling triangular teeth) at the tip of cylindrical branchlet nodes. Flowers are unisexual, with male flowers on slender spikes at the end of the branchlets, and female flowers clustered in heads. Fruits are woody cones about 20 mm long with several rows of spiked valves, each containing a winged seed.

Widespread across the central Gawler Province on red sands and calcareous loams of sand plains and dune swales, typically with regolith carbonate close to the surface. Locally abundant on erosional rises and along some watercourses. This species provided a strong expression of buried Au mineralisation at Tunkillia (Lowrey and Hill 2006; Lowrey 2007; Lowrey and Hill *in prep*.) for a suite of elements including: Au (up to 1.3 ppb); As (up to 0.3

ppm), Ce (up to 0.44 ppm), La (up to 0.27 ppm) and Th (up to 0.03 ppm). Branchlets are recommended as the most convenient sampling organ. The black oak's deep penetrating root system and preferential colonisation of dune swales and erosional plains appears to largely account for its success in providing biogeochemical expressions through transported cover.

Red mallee (*Eucalyptus socialis*)

Spreading mallee or multi-stemmed tree, 2–9 m tall, with rough bark on lower trunk and smooth white-grey to pale bronze bark on upper trunk and branches. Young branchlets and stems are typically bright red. Leaves are alternate, thick, dull grey-blue-green, 6–10 × 1-2 cm. White or pale yellow flowers in clusters of 7–15. Buds are 10–12 mm long and 5 mm wide, with long pointed beaked cap. Fruits are rounded or egg-shaped—typically resembling a 'goblet', 5-9 × 5–8 mm, with protruding valve tip.

Very abundant and widespread on sandplains and dunes across the central Gawler Province. This species has been analysed from Barns (Lintern 2007), north of Wudinna (Mayo 2005; Mayo and Hill 2005) and Tunkillia (Lowrey and Hill, 2006; Lowrey, 2007; Lowrey and Hill *in prep*.). At Tunkillia, it provided an irregular expression of buried mineralisation, with Au content up to 0.6 ppb and U content up to 0.07 ppm, but most other trace metals were elevated away from buried mineralisation (Lowrey 2007; Lowrey and Hill *in prep*.). Although this species was widely sampled at Barns (Lintern 2007), it is difficult to fully assess its biogeochemical characteristics because the results are grouped together with ridge-fruited mallee (*Eucalyptus incrassata*). Samples collected in autumn at Barns, however, appear to provide an expression of buried mineralisation (Lintern 2007).

Ridge-fruit mallee (*Eucalyptus incrassata*)

Multi-trunked tree or mallee with rough bark to 1 m above the ground, then loose, ribbon, cream to grey-brown bark above. Thick, green glossy leaves. Buds and white flowers with red centres in groups of three to seven. Fruiting buds have a beak and the fruits have ribs down the sides.

Widespread and locally abundant on sandy dunes—particularly in the southern central Gawler Province and Eyre Peninsula. This has been sampled at Barns (Lintern 2007) and north of Wudinna (Mayo 2005; Mayo and Hill 2005). The samples collected from Barns during autumn have some potential for expressing buried mineralisation (Lintern 2007); however, most of the assay results from there are grouped with red mallee (*Eucalyptus socialis*).

Red mallee (*Eucalyptus oleosa*)

Multi-trunked tree to 10 m tall or mallee with rough bark to 3 m above ground, with smooth cream to grey to coppery upper bark. Leaves are very glossy green, 5–10 cm × 5–15 mm, with numerous oil glands (distinctive when leaf held up to the light). Flowers cream to white. Buds in groups of 7–13; bud cap is slightly narrower than body resembling an egg in an egg cup.

Widespread and locally abundant on sandy and silty loams typically with regolith carbonate. Recognisable from a distance by its glossy leaves and dense crown. The limited biogeochemical characterisation of this species has been made from the region—restricted to a study north of Wudinna (Mayo 2005; Mayo and Hill 2005).

Horse mulga (*Acacia ramulosa*)

Large, erect, multi-branched shrub, 2–6 m tall. Dull grey-green phyllodes, 8–20 cm long and 1.5–3 mm wide: erect, rigid and linear or cylindrical. Red-brown to grey branchlets with rough, dark grey bark at base. Cylindrical, bright yellow flowers in clusters of one or two. Seed pods are pendulous, cylindrical, 6–13 cm long and 5–10 mm wide, hard and woody.
Widespread on sandy soils of the region. Distinguished from *Acacia aneura* by its multi-stems and cylindrical seed pods. Biogeochemically characterised from the Tunkillia area (Lowrey and Hill 2006; Lowrey 2007; Lowrey and Hill *in prep*.), where it provided an irregular expression of buried mineralisation, with only a slight peak in Au assays (up to 0.3 ppb) over mineralisation. Its preferential colonisation of dune ridges appears to limit its vertical root penetration through transported cover.

Pearl bluebush (*Maireana sedifolia*)

Rounded, bright blue to whitish blue, multi-branched shrub to 1.5 m tall, with branches covered in woolly hairs. Leaves are alternate, succulent, linear to narrow egg-shaped, 4–8 mm long, rounded at the tip. Leaves join straight to the stem, with no stalk. Flowers occur in pairs where the leaves join the stems. Fruits consist of rounded tubes, 2 mm long, and a horizontal wing 10 mm wide. Fruits are glossy yellow and pink to pale brown when dry.

Pearl bluebush is a common perennial throughout the region. It is associated with friable regolith substrates that allow great root penetration, such as fractured bedrock or, most typically, sites with regolith carbonate within 60 cm depth (Cunningham *et al*. 1992). Reported to live at least 150–300 years (Irons and Quinlan 1988). They have a relatively deep tap-root system (up to 3 m), with shallow deciduous feeding roots (Cunningham *et al*. 1992). Flowering and leaf generation is generally in summer. Leaf sampling is relatively simple, especially with the aid of clippers, where mixed leaf and twig samples can be further separated after they fall apart during drying. Care needs to be taken not to confuse this species with *M. astrotricha*, which has stalked leaves (*M. sedifolia* leaves are stalkless).

This is one of the most widely sampled and biogeochemically characterised species from the region, including analyses from Challenger (Lintern and Sheard 1999), Birthday Au prospect (Lintern *et al*. 2000), Boomerang Au prospect (Lintern *et al*. 2006), and Tunkillia (Lowrey 2007; Lowrey and Hill *in prep*.). It generally provides a strong expression of underlying mineralisation, particularly at Tunkillia where there were elevated concentrations overlying buried mineralisation for: Au (up to 0.9 ppb); Ce (up to 0.86 ppm); La (up to 0.38 ppm); Pb (up to 0.44 ppm); and Th (up to 0.13 ppm). Uranium concentrations at Tunkillia were all below detection (0.01 ppm). At Challenger, this species provided an expression of buried mineralisation with Au concentrations up to 0.7 ppb (Lintern and Sheard 1999), whereas results from Boomerang (Lintern *et al*. 2006) and Birthday (Lintern *et al*. 2000) Au prospects were more irregular over mineralisation.

Bluebush daisy (*Cratystylis conocephala*)

Bushy shrub 1–2 m tall and wide with distinctive blue-grey foliage, with a covering of soft hairs on branches and leaves. Leaves are alternate, flat and thick, 5–8 mm long, with rounded tips. Flower heads are elongate, tubular, white, surrounded by several rows of greenish bracts occurring at the ends of stems. Fruit is cylindrical and 6–7 mm long.

Locally abundant on calcareous soils on sand plains. Resembles *Maireana sedifolia* from a distance and these species can coexist; leaves are distinctly flattened upon close inspection. This species has only been biogeochemically characterised from Tunkillia (Lowrey 2007; Lowrey and Hill *in prep*.), where it provided an expression of buried mineralisation—particularly with high concentrations for the elements: Ag (up to 18 ppb); Au (up to 1.4 ppb); Ce (up to 0.91 ppm); La (up to 0.42 ppm); Pb (up to 0.69 ppm); Th (up to 0.13 ppm); U (up to 0.02 ppm); and Zn (up to 21.9 ppm).

Broom-bush (*Melaleuca uncinata*)

Shrub to 3 m high with erect slender stems and papery bark. Leaves alternate, 2–6 cm × 1–1.5 mm, with a fine pointed curved or hooked tip. Flowers cream to yellow in dense, spiky, globular heads. Fruit are smooth, 1.5–2.5 mm across in tight clusters along branches.

Widespread across the region, particularly within dunefields. This species has been biogeochemically characterised from Barns (Lintern 2007) and north of Wudinna (Mayo 2005). The Au results from autumn sampling at Barns provided the best expressions of buried mineralisation (Lintern 2007), particularly for bark (up to 3.6 ppb), litter (up to 0.7 ppb) and terminal shoots (up to 0.4 ppb). Other elements expressing buried mineralisation included Cs, Sn and In in bark and Pb in terminal shoots.

Spinifex (*Triodia irritans*)

Slow growing, long-lived, tussock-forming perennial grass with sharp cylindrical leaves. Leaves up to 30 cm long and 1–5 mm wide. Clumps with flower heads up to 1.5 m tall and can form rings and lobes several metres across. Roots may extend to tens of metres in depth.

Widespread and locally abundant on red sandy dunes, especially on crests, typically with mallee trees. It is occasionally found on rocky hills and rises with very well-drained soils. A short transect along a dune-crest across mineralisation Tunkillia provided an expression of underlying mineralisation in samples that had been ashed before analysis, particularly for: Au (up to 0.3 ppb dry weight equivalent); As (up to 0.172 dry weight equivalent); Ce (up to 0.6 ppm dry weight equivalent); and La (up to 0.24 ppm dry weight equivalent). This supports previous descriptions and interpretations of spinifex being deep-rooted (Reid *et al*. 2007).

Case studies

Tunkillia

This prospect is dominated by linear dunefields in the west and south, sheetflow-dominated erosional plains in the east and depositional plains in the north. Early exploration defined a kilometre-scale greater than 10 ppb Au-in-calcrete regional anomaly, which was followed by an estimated more than $15M of drilling. To date, several discrete mineralised zones have been defined underlying parts of the regional calcrete anomaly, but large parts of the bedrock underlying the Au-in-calcrete anomaly are not mineralised. Recent studies have identified the importance of extensive lateral transport and dispersion of calcrete clasts within palaeo-drainage systems extending from a palaeo-ridge near the Tunkillia mineralisation (Dart *et al*. 2007).

Biogeochemical study here by Thomas (2004) included a suite of common plants, but did not assay for Au. The results summarised here are derived from an Honours study by Lowrey (2007), with a preliminary study program published in Lowrey and Hill (2006) and full details recently submitted for publication (Lowrey and Hill *in prep*.). Sampling in this study was mostly along a transect that crossed a series of longitudinal dunes including:

1. sites with anomalous Au-in-calcrete and overlying two mineralisation occurrences
2. sites with anomalous Au-in-calcrete, but not overlying mineralisation
3. sites outside of the anomalous Au-in-calcrete zone and not overlying mineralisation.

The biogeochemical transect found that leaves, branchlets and phyllodes from the main species growing in dune swales and across erosional plains (*Casuarina pauper, Cratystylis conocephala* and *Maireana sedifolia*) were the best at expressing underlying mineralisation within an elemental suite including Au, Ce, La, Th and U. Species growing on dune crests (e.g. *Eucalyptus socialis, Acacia aneura* and *A. ramulosa*) tended to have irregular biogeochemical affinities with the transported chemical characteristics of the dune sands, with the exception of spinifex (*Triodia irritans*), where ashed samples from dune crests provided an Au expression of underlying mineralisation. Samples of *Eucalyptus concinna* from dune-swale margins tended to have elevated U contents (up to 0.11 ppm) compared with other species in the area that typically contain close to detection limit levels of U (0.01 ppm) (Lowrey 2007; Lowrey and Hill *in prep*.). This study demonstrated the potential for plant biogeochemistry exploration approaches to be efficient and beneficial components of mineral exploration programs in regolith dominated terrains. It recommends an optimum sampling season corresponding to periods of dry surface soils—typically in late summer and early autumn—as well as constrained regolith-landform context and careful discrimination of plant species and target sampling organ.

Barns (Lintern 2004; 2007)

A vegetated longitudinal dune within wheat fields overlays Au mineralisation at about 35 m depth. Mineralisation was originally discovered from an Au-in-calcrete regional surface anomaly (>2.5 ppb Au with a maximum of 49 ppb). The regolith profile consists of approximately 8–15 m of dune sands, over leached saprolite underlain by fresh mineralised bedrock. The dune overlying mineralisation provided a luminescence age between 17000 (± 1300) and 26,300 (± 1300) years, and has provided the basis for calculating the rates of calcrete anomaly generation and constraining biogeochemical inputs (Lintern 2007). Regolith carbonates occur within the dune sand and the top of the saprolite, and are interpreted to have obtained most of their Au by biological processes: mainly involving plants (Lintern 2007) and micro-organisms (Schmidt-Mumm and Reith 2007).

Melaleuca uncinata and interchangeable samples of *Eucalyptus incrassata* and *E. socialis* terminal shoots (mixture of leaves, adjoining twigs and fruits from the end 20–30 cm of branches) were sampled. Samples were assayed by ICP-MS and INAA. In a September 2003 sampling program, the maximum Au concentration in plant samples was 1.3 ppb for *Melaleuca* and 0.8 ppb for eucalypts; however, these occurred away from the known extent of mineralisation. Later sampling programs in June 2004 and April 2005, found higher and more cohesive results, with maximum Au concentrations over mineralisation varying according to plant species and sampling medium, such that:

Melaleuca bark (3.6 ppb) > *Eucalyptus* bark (2.9 ppb) > *Eucalyptus* litter (1.7 ppb) > *Eucalyptus* terminals (1.1 ppb) > *Melaleuca* litter > (0.7 ppb) > *Melaleuca* terminals (0.4 ppb).

Elements with elevated concentrations in plant samples over mineralisation from the September 2003 sampling included: for eucalypts, Ag (maximum 22 ppb); Bi (maximum 32 ppb); Pb (maximum 210 ppb); Sb (maximum 14 ppb); and W (maximum 150 ppb); and, for *Melaleuca*, Co (maximum 600 ppb); Pb (maximum 215 ppb); and Ta (maximum 2 ppb) (Lintern 2004). From the April 2005 sampling, sites overlying mineralisation were best expressed by: Li in eucalyptus bark; Pt and Bi in eucalyptus terminal shoots; Cs, Sn and In in *Melaleuca* bark; and Pb in *Melaleuca* terminal shoots. Many elements showed an inconsistent relationship between dune height and element concentration, except perhaps for W in eucalypts and Ta and Au in *Melaleuca*, from the September 2003 sampling. Lintern (2004) concluded that many of the vegetation anomalies were not coherent, and that vegetation may not provide a practical alternative to sampling calcrete in these settings; however, a later study recommends a 200 m sampling spacing for vegetation as a suitable exploration approach at this site (Lintern 2007). This may be largely due to later, more-comprehensive and constrained sampling, as well as significant seasonal variations with the concentrations of most elements in April having nearly double the mean concentrations of September.

Other studies

Smaller biogeochemical studies have also been conducted in other parts of the central Gawler Province.

At Challenger, bluebush (*Maireana sedifolia*) samples provided a general expression of mineralisation for Au (with up to 0.7 ppb and a background of 0.1–0.2 ppb Au), and, to a lesser extent, As, Cr and W (Lintern and Sheard, 1999).

Bluebush samples from the Birthday Au prospect (Lintern *et al*. 2000) provided Au concentrations close to the analytical detection limit (0.3 ppb), although one sample had a concentration of 2.2 ppb, but was located away from known mineralisation.

At the Edoldeh Tank Au prospect, *Acacia* (presumably *Acacia aneura*) phyllodes and small branches at soil sampling sites (Lintern *et al.* 2003) provided high Au concentrations (>0.4 ppb equivalent dry weight) overlying weak mineralisation, but it was concluded that no consistent associations occur between Au in vegetation and Au in calcrete, soil, upper regolith or mineralisation. Silver had an erratic occurrence in vegetation, while Cu varied from 2 to 42 ppm equivalent dry weight, but it had no association with Cu in soils or drill cuttings, and As was not considered a reliable indicator of mineralisation.

A study located within the linear dunefield north of Wudina, and overlying the Adelaide Resources 'WUD1' Au-in-calcrete anomaly—as well as the buried contact between the Sleaford Complex and the Tunkillia Suite—sampled a range of plant organs from widespread species. This mostly included the common eucalypt species (*E. incrassata, E. oleosa* and *E. socialis*) and broom-bush (*Melaleuca uncinata*) (Mayo 2005; Mayo and Hill 2005). Although the results did not provide a strong discrimination of the underlying geological boundary, and Au assays were below or close to the analytical detection limit, they demonstrated the importance of regolith-landform controls on species distribution and biogeochemistry (with species in swales and colonising order dunes tending to have higher trace metal contents), as well as biogeochemical differences between plant species and plant organs.

At the Boomerang Au prospect pearl bluebush (*Maireana sedifolia*) leaves and small branches and *Acacia* phyllodes and bark were sampled. However, it was concluded that "vegetation Au concentrations are not particularly useful at delineating mineralisation" (Lintern *et al.* 2006). The sample population here was small (n = 26), and the vegetation was irregularly spaced—limiting the significance of this study. The sampling season was not recorded.

Conclusions

Despite a series of biogeochemical case studies in the region, the characterisation and understanding of the biogeochemistry of widespread and abundant plant species is poorly constrained, with the exceptions of the studies at Tunkillia and Barns. What emerges, however, is that some of the mallee eucalypts (e.g. *Eucalyptus socialis*, *E. incrassate*, and *E. concinna*), broom-bush (*Melaleuca uncinata*) and many of the species that colonise dune swales and erosional plains, such as pearl bluebush (*Maireana sedifolia*), black oak (*Casuarina pauper*) and bluebush daisy (*Cratystylis conocephala*), have potential to be used in programs exploring through transported cover. In particular, the ability of plant biogeochemistry to provide a penetrative geochemical expression helps to test or prioritise surface geochemical anomalies, such as Au-in-calcrete responses. It can also be used to test for the geochemical 'fertility' of subsurface geophysical signatures, as well as provide first-pass chemical expression of palaeodrainage and structurally extrapolated targets under cover. This exploration technique also has a very low environmental and cultural impact. Regolith-landform context, seasonality and species and plant organ differentiation appear to be major controls on plant biogeochemistry that need to be constrained if this approach is to be successfully used.

REFERENCES

Anand RR, Cornelius M and Phang C, 2007. Use of vegetation and soil in mineral exploration in areas of transported overburden, Yilgarn Craton, Western Australia: a contribution towards understanding metal transportation processes. *Geochemistry: Exploration, Environment, Analysis* 7, 267–288.

Cunningham GM, Mulham WE, Milthorpe PL and Leigh JH, 1992. *Plants of western New South Wales.* Inkata Press, Melbourne.

Dart RC, Hill SM, Barovich KM and Chittleborough DJ, 2007. Improving the reliability of Au-in-calcrete anomalies through the use of regolith-landform mapping and detailed assay analysis: in Cooper BJ and Keeling JL (editors) Regolith mineral deposits and environment. 5th Sprigg Symposium, *Geological Society of Australia, Abstracts* 87, 7–10.

Friebe M and Matheson B, 2006. *Shrubs and trees of the Great Victoria Desert* (Field Guide). Friends of the Great Victoria Desert Parks, Adelaide.

Hill SM, 2008. *Guide to the use of biogeochemical techniques in mineral exploration in Australia.* CRC LEME, Perth.

Hill SM and Hill LJ, 2003. Some important plant characteristics and assay overviews for biogeochemical surveys in western New South Wales: In Roach IC (editor) *Advances in Regolith. Proceedings of the CRC LEME Regional Regolith Symposia 2003.* CRC LEME, Perth, 187–192.

Irons NM and Quinlan EE, 1988. A review of information relevant to the mulga rangelands of western New South Wales. *Soil Conservation Service of New South Wales Technical Report*.

Kutsche F and Lay B, 2003. *Field guide to plants of Outback South Australia.* Department of Water, Land and Biodiversity Conservation, Adelaide.

Lintern MJ, 2004. Preliminary biogeochemical studies at Barns gold prospect, Gawler Craton, South Australia. *CRC LEME, Open File Report* 168.

Lintern MJ, 2007. Vegetation controls on the formation of gold anomalies in calcrete and other materials at the Barns Gold Prospect, Eyre Peninsula, South Australia. *Geochemistry: Exploration, Environment, Analyses* 7, 249–266.

Lintern MJ and Sheard MJ, 1999. Regolith studies related to the Challenger Gold Deposit, Gawler Craton, South Australia. *CRC LEME, Open File Report* 78.

Lintern MJ, Sheard MJ and Gouthas G, 2000. Regolith studies related to the Birthday Gold Prospect, Gawler Craton, South Australia. *CRC LEME Open File Report* 79.

Lintern MJ, Tapley IJ, Sheard MJ, Craig MA, Gouthas G and Cornelius AJ, 2003. Regolith Studies at Edoldeh Tank (ET) gold prospect, Gawler Craton, South Australia. *CRC LEME, Open File Report* 150.

Lintern MJ, Sheard MJ and Gouthas G, 2006. Regolith studies at the Boomerang Gold Prospect, central Gawler Craton, South Australia. *CRC LEME Open File Report* 203.

Lowrey JR, 2007. *Plant biogeochemical expression of gold mineralisation buried by an Aeolian dunefield: Tunkillia, South Australia.* Hons Thesis, Department of Geology and Geophysics, University of Adelaide.

Lowrey JR and Hill SM, 2006. Plant biogeochemistry of Au-mineralisation buried by an Aeolian dunefield: Tunkillia SA: in Fitzpatrick RW and Shand P (editors) *Regolith 2006 – Consolidation and dispersion of ideas*. CRC LEME, Perth, 217–220

Lowrey J and Hill SM, (submitted). Plant biogeochemical expression of Au-mineralisation buried by an aeolian dunefield: Tunkillia, South Australia. *Australian Journal of Earth Sciences.*

Mayo AM, 2005. *Plant biogeochemistry and geobotany in an aeolian dunefield of the Central Gawler Gold Province.* BSc. Hons Thesis, Department of Geology and Geophysics, University of Adelaide.

Mayo AM and Hill SM, 2005. Mineral exploration through an aeolian dunefield near Wudinna, Gawler Craton, South Australia: a framework of plant biogeochemistry and geobotany: in Roach IC (editor) *Regolith 2005. Ten Years of CRC LEME. Proceedings of the CRC LEME Regional Regolith Symposia 2005.* CRC LEME, Perth, 223-228.

Moore P, 2005. *A guide to plants of inland Australia*. Reed New Holland, Sydney.

Reid N, Hill SM and Lewis DM, 2008. Spinifex biogeochemical expressions of buried gold mineralization: the great phyto-exploration penetrator of transported regolith. *Applied Geochemistry* 23, 76–84.

Schmidt Mumm A and Reith F, 2007. Biomediation of calcrete at the gold anomaly of the Barns prospect, Gawler Craton, South Australia. *Journal of Geochemical Exploration* 92, 13–33.

Thomas M, 2004b. Biogeochemical data ranges from Tunkillia Prospect, Central Gawler Craton, South Australia: in Roach IC (editor), *Regolith 2004*. CRC LEME, Perth, 362–364

Summary of Plant Species in the central Gawler Craton sampled for Biogeochemistry

SPECIES	DESCRIPTION	DISTRIBUTION	SAMPLING & PREPARATION	BIOGEOCHEMISTRY
 *Eucalyptus socialis* **Red mallee**	Spreading mallee or multi-stemmed tree, 2-9 m tall, with rough bark on lower trunk and smooth white-grey to pale bronze bark on upper trunk and branches. Young branchlets and stems bright red. Leaves alternate, thick, dull grey-blue-green, 6-10 x 1-2 cm. White or pale yellow flowers in clusters of 7-15. Buds are 10-12 mm long and 5 mm wide with long pointed beaked cap. Fruits rounded or egg-shape, resembling a 'goblet', 5-9 x 5-8 mm with protrouding valve tip. Long-lived with deep and spreading roots	Very abundant and widespread on sand plains and dunes across the Central Gawler Province.	Leaves clean and easy to pick. Need to be well dried to avoid smearing in mill.	At Tunkillia it provided an irregular expression of buried mineralisation with Au contents up to 0.6 ppb and U contents up to 0.07 ppm, but most other trace metals were elevated away from buried mineralisation (Lowrey, 2007; Lowrey & Hill, in prep.). Widely sampled at Barns (Lintern 2007) but difficult to fully assess because results are grouped with other eucalypts Samples collected in autumn at Barns, however, appear to provide an expression of buried mineralisation (Lintern, 2007).
 *Eucalyptus incrassata* **Ridge-fruit mallee**	Multi-trunked tree or mallee with rough bark to 1 m above the ground, then loose, ribbon, cream to grey-brown bark above. Thick, green glossy leaves. Buds and white flowers with red centres in groups of 3-7. Fruiting buds have a beak and the fruits have ribs down the sides. Long-lived with deep and spreading roots	Widespread and locally abundant on sandy dunes, particularly in the southern Central Gawler Province and Eyre Peninsula.	Leaves clean and easy to pick. Need to be well dried to avoid smearing in mill.	This has been sampled at Barns (Lintern 2007) and north of Wudinna (Mayo, 2005; Mayo & Hill, 2005). The samples collected from Barns during autumn have some potential for expressing buried mineralisation (Lintern 2007), however most of the assay results from here are grouped with red mallee (*Eucalyptus socialis*).
 *Eucalyptus oleosa* **Red mallee**	Multi-trunked tree to 10 m tall or mallee with rough bark to 3 m above ground, with smooth cream to grey to coppery upper bark. Leaves are very glossy green, 5-10 cm x 5-15 mm, with numerous oil glands (distinctive when leaf held up to the light). Flowers cream to white. Buds in groups of 7-13, bud cap is slightly narrower than body resembling an egg in an egg cup. Recognisable from a distance by its glossy leaves and dense crown. Long lived and deep-rooted	Widespread and locally abundant on hills and valleys, especially with calcareous soil	Leaves clean and easy to pick. Branches bend if canopy out of reach. Need to be well dried to avoid smearing in mill.	Limited biogeochemical characterisation of this species has been made from the region, restricted to a study north of Wudinna (Mayo, 2005; Mayo & Hill, 2005).
 *Triodia irritans* **Porcupine grass**	Slow growing, long-lived, tussock-forming perennial grass with sharp cylindrical leaves. Leaves up to 30 cm long and 1-5 mm wide. Clumps with flower heads up to 1.5 m tall and can form rings and lobes several metres across. Long lived and very deep-rooted	Widespread and locally abundant on red sandy dunes, especially on crests, typically with mallee trees. Occassionally found on rocky hills and rises with very well-drained soils.	Clean outer leaves but very spikey!!! Inner leaves can be dusty. Resinous residue in mill requires non-polar solvent to remove.	A short transect along a dune-crest across mineralisation Tunkillia provided an expression of underlying mineralisation in samples that had been ashed prior to analysis, particularly for: Au (up to 0.3 ppb dry weight equivalent); As (up to 0.172 dry weight equivalent); Ce (up to 0.6 ppm dry weight equivalent); and, La (up to 0.24 ppm dry weight equivalent) (Reid in prep.). Supports previous decriptions of spinifex being deep-rooted (Reid et al., 2007).
 *Acacia aneura* **Mulga**	Small upright tree up to 14 m tall, but also forms bushy shrubs 3-5 m tall. Variety of shapes with upright branches, 'Christmas tree' shape (*Acacia aneura var. conifera*). Grey-green phyllodes, mostly narrow-linear, but can be broader, 3-11 cm long x 0.7-3 mm wide, with parallel veins. Yellow, cylindrical flower spikes, 8-25 mm long. Papery to woody, brown seed pods, 1-6 cm long and 0.4 – 2 cm wide. Variable intergrading and hybridising forms, including at least 10 varieties Long lived and deep-rooted	Mulga is most abundant and widespread in the north of the region, particularly in areas that mostly receive summer rainfall. It is widespread in dunefields, particularly on mid-lower dune slopes, as well as along some drainage depressions within areas of chenopod shrubland.	Clean phyllodes but can resist removal from twigs. Easy to mill phyllodes.	At Boomerang Au Prospect (Lintern *et al.,* 2006) it provided irregular expression of buried mineralisation. At Edoldeh Tank Au Prospect, Acacia (presumably *Acacia aneura*) phyllodes and small branches had high Au concentrations (>0.4 ppb equivalent dry weight) overlying weak mineralisation. In general, however, it was concluded that there were inconsistent associations between Au in vegetation and Au in calcrete, soil, upper regolith or mineralisation (Lintern *et al.,* 2003). Silver had an erratic occurrence, while Cu varied between 2-42 ppm equivalent dry weight but had no association with Cu in soils or drilling results.

 *Acacia ramulosa* **Horse mulga**	Large, erect, multi-branched shrub, 2-6 m tall. Dull grey-green phyllodes, 8-20 cm long and 1.5-3 mm wide, erect, rigid and linear or cylindrical. Red-brown to grey branchlets with rough, dark grey bark at base. Cylindrical, bright yellow flowers in clusters of 1-2. Seed pods are , pendulous, cylindrical, 6-13 cm long and 5-10 mm wide, hard and woody. Moderate life span and shallow dense matted roots	Widespread on sandy soils of the region	Clean leaves and easy to pick. Easier to remove leaves from twigs when dry. Easy to mill leaves.	Biogeochemically characterised from the Tunkillia area (Lowrey & Hill, 2006; Lowrey, 2007; Lowrey & Hill, in prep.), where it provided an irregular expression of buried mineralisation, with only a slight peak in Au assays (up to 0.3 ppb) over mineralisation.
 *Melaleuca uncinata* **Broombush**	Shrub to 3 m high with erect slender stems and papery bark. Leaves alternate, 2-6 cm x 1-1.5 mm, with a fine pointed curved or hooked tip. Flowers cream to yellow in dense, spiky, globular heads. Fruit are smooth, 1.5-2.5 mm across in tight clusters along branches. Moderate life span and moderate root depth	Widespread across the region, particularly within dunefields.	Leaves easy to reach but difficult to remove from twigs. Easier to separate leaves and twigs when dry. Easy to mill leaves.	Biogeochemically characterised from Barns (Lintern, 2007) and north of Wudinna (Mayo, 2005). The Au results from autumn sampling at Barns provided the best expressions of buried mineralisation (Lintern, 2007), particularly for bark (up to 3.6 ppb); litter (up to 0.7 ppb) and terminals (up to 0.4 ppb). Other elements expressing buried mineralisation included Cs, Sn and In in bark and Pb in terminals.
 *Casuarina pauper* **Black oak**	Variably shaped, bushy to upright tree up to 15 m tall, with dark grey fissured or scaly bark and slender, striated and jointed branchlets 1-2 mm thick. Leaves are 9-12 small pointed scales (resembling triangular teeth) at the tip of cylindrical branchlet nodes. Flowers are unisexual, with male flowers on sleder spikes at the end of the branchlets, and female flowers clustered in heads. Fruits are woody cones about 20 mm long with several rows of spiked valves each containing a winged seed. Long lived and deep-rooted	Widespread across the Central Gawler Province on red sands and calcareous loams of sand plains and dune swales, typically with regolith carbonate close to the surface. Locally abundant on erosional rises and along some watercourses.	Branchlets clean and easy to sample	Provided a strong expression of buried Au mineralisation at Tunkillia (Lowrey & Hill, 2006; Lowrey, 2007; Lowrey & Hill in prep.) for elements including Au (up to 1.3 ppb); As (up to 0.3 ppm), Ce (up to 0.44 ppm), La (up to 0.27 ppm) and Th (up to 0.03 ppm). Branchlets recommended as convenient sampling organ. Its deep penetrating root system and preferential colonisation of dune swales and erosional plains appears to largely account for its success in providing biogeochemical expressions through transported cover.
 *Maireana sedifolia* **Pearl bluebush**	Rounded, bright blue to whitish blue, multi-branched shrub to 1.5 m tall, with branches covered in woolly hairs. Leaves are alternate, succulent, linear to narrow egg-shaped, 4-8 mm long, rounded at the tip. Leaves join straight to the stem with no stalk. Flowers occur in pairs where the leaves join the stems. Fruits consist of rounded tubes, 2 mm long, and a horizontal wing 10 mm wide. Fruits are glossy yellow and pink to pale brown when dry. Reported to live at least 150-300 years (Irons & Quinlan 1988). Relatively deep tap-root system (up to 3 m) with shallow deciduous feeding roots (Cunningham *et al.* 1992).	Common perennial throughout the region. Associated with friable regolith substrates that allow root penetration, such as fractured bedrock or sites with regolith carbonate within 60 cm depth (Cunningham *et al.* 1992).	Leaf sampling is relatively simple, where mixed leaf and twig samples can be further separated after they fall apart during drying. Samples need to well ventilated before drying to avoid sweating and decomposition. Leaves mill easily once dried.	Most widely sampled species from the region. Generally provides a strong expression of mineralisation, particularly at Tunkillia where there were elevated concentrations overlying buried mineralisation for: Au (up to 0.9 ppb); Ce (up to 0.86 ppm); La (up to 0.38 ppm); Pb (up to 0.44 ppm); and, Th (up to 0.13 ppm). Uranium concentrations at Tunkillia were below analytical detection (0.01 ppm) (Lowrey, 2007; Lowrey & Hill, in prep.). At Challenger it provided an expression of mineralisation with Au concentrations up to 0.7 ppb (Lintern & Sheard, 1999), whereas results from Boomerang (Lintern et al., 2006) and Birthday (Lintern et al., 2000) Au prospects were more irregular.
 *Cratystylis conocephala* **Bluebush daisy**	Bushy shrub 1-2 m tall and wide with distinctive blue-grey foliage, with a covering of soft hairs on branches and leaves. Leaves are alternate, flat and thick, 5-8 mm long, with rounded tips. Flower heads are elongate, tubular, white, surrounded by several rows of greenish bracts occurring at the ends of stems. Fruit is cylindrical 6-7 mm long. Long lived and deep rooted Resembles *Maireana sedifolia* from a distance and these species can coexist; leaves are distinctly flattened.	Locally abundant on calcareous soils on sand plains.	Leaf sampling is relatively simple, where mixed leaf and twig samples can be further separated after they fall apart during drying. Samples need to well ventilated before drying to avoid sweating and decomposition. Leaves mill easily once dried.	This species has only been biogeochemically characterised from Tunkillia (Lowrey, 2007; Lowrey & Hill, in prep.), where it provided an expression of buried mineralisation, particularly with high concentrations for the elements: Ag (up to 18 ppb); Au (up to 1.4 ppb); Ce (up to 0.91 ppm); La (up to 0.42 ppm); Pb (up to 0.69 ppm); Th (up to 0.13 ppm); U (up to 0.02 ppm); and, Zn (up to 21.9 ppm).