MINERAL EXPLORATION THROUGH AN AEOLIAN DUNEFIELD NEAR WUDINNA, GAWLER CRATON, SOUTH AUSTRALIA: A FRAMEWORK OF PLANT BIOGEOCHEMISTRY AND GEOBOTANY

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INTRODUCTION

Biogeochemistry and geobotany are long-recognised exploration techniques in terrains dominated by transported cover in North America and Europe (Brooks 1972, Erdman & Olson 1985). In Australia these methods have not been widely adopted by mineral explorers because of the greater popularity of other techniques such as remote sensing, regolith carbonate and soil sampling. However, there is growing interest within Australia in the value of biogeochemical prospecting for mineral deposits (Nagaraju & Karimulla 2001) as the focus of exploration shifts to more challenging exploration settings. Future discoveries of base metal and gold resources in deeply weathered terrains are likely to occur under greater depths of transported overburden where the effectiveness of soil and lag geochemical techniques are limited (Anand & Cornelius 2004).

In this project, geobotanical observations and biogeochemistry techniques were used to test the hypothesis that the chemical characteristics of mallee vegetation are related to the chemical characteristics of underlying bedrock lithology. In order to do so we examined components of mallee woodland and shrubland in the Central Gawler Gold Province over varying regolith-landform and underlying geological settings. Various plant organs from a selection of mallee eucalypts and shrub species, and adjacent calcrete and surface soils, were sampled across different phases of aeolian dune deposits north of Wudinna. The specific aims of this research project were to: i) describe the biogeochemical characteristics of widespread and abundant plant species; ii) characterise any possible chemical differentiation between organs within individual plants; iii) compare plant biogeochemistry with regolith-landform setting and underlying bedrock geology; and, iv) consider the implications of these results and interpretations for the design of mineral exploration and environmental chemistry programs.

SETTING

The study site lies to the north of Wudinna near the Adelaide Resources WUD 1 calcrete anomaly (Figure 1). Northern sections of the study transects extend through the southern boundary of the Pinkawillinie Conservation Park. Study transect locations were dependent upon the availability of natural remnant vegetation in the area (much of this area is dominated by wheat fields) and existing and ongoing regolith, geology and exploration studies. Adelaide Resources contributed baseline data, including air photos, maps, geochemical and drill hole data for comparison with the biogeochemical results.

The local geology of the central Eyre Peninsula (Figure 1) is dominated in the east by the high metamorphic grade Archaean Sleaford Complex (felsic and mafic rock with rare carbonate and magnetite-rich units, 2700–2300 Ma), and in the west by the Tunkillia Suite (granodioritic gneiss and quartzite, 1690–1680 Ma). Surface exposures of basement lithologies in the Wudinna district are scarce due to extensive Quaternary aeolian cover and deep weathering to greater than 50 meters (Drown 2003). However, geophysical data from Adelaide Resources suggested that contact between the two major geological units lies within the field site for this study.

The regolith of the area consists mostly of siliceous and variably calcareous sandy sediments forming old dune ridges that are extensive over much of the northern Eyre Peninsula (Parker *et al.* 1985). Four main aeolian dune phases were identified (in order of decreasing age):
Phase 1 - variably indurated siliceous and calcareous discontinuous dune ridges, typically with well-developed petrocalcic soil layers. Regolith carbonates include laminated and massive hardpan, powder and nodular morphologies;
Phase 2 - red-brown clayey sand dunes, with friable powder, minor rhizomorphic and nodular regolith carbonates;
Phase 3 - siliceous, linear sand ridges with sandy podsols (light grey sandy A-horizon and yellow-brown to red-brown B-horizon). These may be subdivided into several further dune types, irregular and sub-parabolic, because they have been extensively reworked.

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Phase 4 - white to light grey siliceous, apedal hummocky dunes. These particularly form along fence lines and roadways, and are interpreted as deflected post-agricultural aeolian mobilisation.

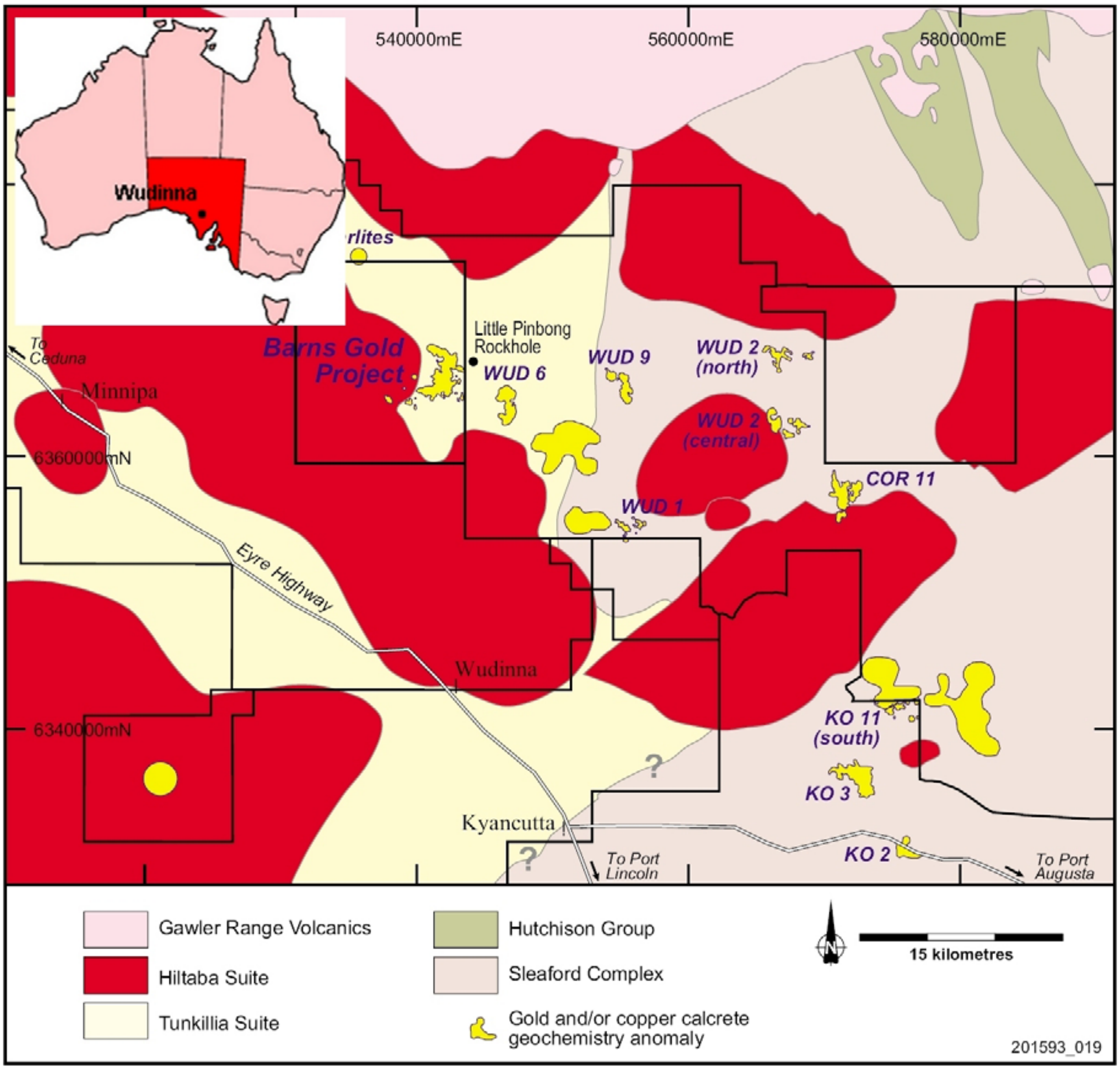

Figure 1: Wudinna district bedrock geology interpretation (Drown 2003) with 1690–1680 Ma Tunkillia Suite to the west and Archaean Sleaford Complex to the east. Pinkawillinie Conservation Park encompasses the northeast corner, in an approximate arc between 540000 mE and 6340000 mN. Inset: location of Wudinna on the Eyre Peninsula, South Australia.

The thickness of these dunes varies and is discontinuous across the field area, with transported regolith ranging from nearly zero thickness over sub-cropping bedrock to tens of metres in depth. In some places different aeolian phases directly overlie weathered bedrock, and in low-lying sites ferruginised and silicified alluvial sediments have been exposed between the dunes.

On the central Eyre Peninsula native vegetation occurs mainly as small remnants on dunes or linear corridors along roads (Specht 1972). The vegetation is mainly mallee shrubland that varies in the composition of the dominant *Eucalyptus* species and associated understorey. Initial geobotanical observations in the present study indicated that different eucalypt species preferentially colonise different phases of the dune systems. Further inspection of farmland excavations in the area showed that eucalypt roots penetrated not only calcareous hardpans below the dunes, but also other regolith units to many metres in depth. This ability of *Eucalyptus* spp to act as excellent 'penetrators' of the transported cover may allow us to determine the biogeochemical signatures of underlying bedrock.

METHODS

Sampling procedure, data collection and mapping

Biogeochemical sampling was undertaken on two intersecting transects selected across the area of study, one 4.75 km long from north to south (N-S), and one 3.75 km long from east to west (E-W). Regolith material and landform type were also recorded over both transects during this time. In June 2005 vegetation was surveyed along two 1.5 km sections of the N-S transect.

A total of 110 biogeochemical samples of ≥ 20 g were taken from dominant trees and shrubs (Table 1) using the protocol of Hill (2002). Along the N-S transect individuals of similar size, age, and health were sampled at 250 m intervals for leaves or phyllodes. Samples of leaves or phyllodes were also taken along the E-W transect at variable intervals in accordance with changes of the dune phase type, to ensure samples adequately targeted the geological contact between the Sleaford Complex and Tunkillia Suite. Coordinates and site numbers were recorded for each collection interval on both transects. Plant tissue of similar age and size was selected to exclude obvious deformities, faunal products or desiccation. Samples were collected as evenly across the plant as possible. Fresh plant samples were placed in paper bags to minimize the amount of sample sweating and decomposition, and sealed by folding the top. A more detailed sampling procedure every kilometre along the N-S transect included different plant organs and underlying litter for comparison; leaves or phyllodes, bark, fruit and underlying litter were compared (number of individuals sampled are given in parentheses) for *Eucalyptus oleosa* (4), *E. socialis* (2), *E. incrassata* (2) *E. brachycalyx* (1), *E. dumosa* (1), *Callitris verrucosa* (1), *Melaleuca uncinata* (1), *Acacia ancistrophylla* (1) and *Allocasuarina muelleriana* (1).

A vegetation survey was carried out to determine geobotanical relationships with the regolith-landforms and basement lithology. Dominant tree cover and understorey species were targeted in a 20-meter wide band along two 1.5 km sections of the N-S transect. Height and GPS coordinates were recorded for all eucalypts. For each GPS coordinate, the dominant understorey species (e.g., *Melaleuca*, *Acacia*) was recorded and understorey complexes were broadly subdivided on the basis of less predominant shrub species. Leaves, flowers and fruit where possible were collected and pressed for taxonomic identification (to be lodged with the Adelaide Herbarium). Species names and botanical descriptions used in identification are after Jessop & Toelken (1986) and Nicolle (1997).

Sample Preparation

Samples were dried at 60°C for 48 hours according to the Hill (2002) protocol. The grinding protocol was developed during the project after discussion with Hulme and Reid (*pers. comm.*). Impurities were picked out before grinding, and samples were milled in a Breville Coffee 'n' Spice grinder. Species and organ types were ground in consistent order within batches, and younger tissue where present was ground first. The grinder was cleaned thoroughly with ethanol and dried with compressed air between samples, and then a small amount of each sample (i.e., a couple of leaves) was pre-ground and discarded to pre-contaminate the mill prior to grinding the whole sample. Samples were stored at room temperature in well-sealed zip lock bags in the absence of light, and each sample was homogenised before sub-samples were sent to separate laboratories.

Chemical and statistical analyses

Approximately 5 g of each powdered sample was sent to Becquerel Laboratories, Canada, for Instrumental Neutron Activation Analysis (INAA) of 34 elements. Approximately 20 g of each powdered sample was also sent to Genalysis Laboratory Services Pty. Ltd., Perth WA, for Inductively Coupled Plasma analyses (ICP). Samples were analysed by ICP Mass Spectrometry (ICP-MS) and by ICP Mass Optical Emission Spectrometry (ICP-OES) for 13 and 10 elements, respectively.

Conclusions were drawn from visual inspection of data, because it had been taken from un-replicated individuals for this orientation study (Dunn *et al.* 1995), and results were presented visually (Brooks 1972).

RESULTS AND OBSERVATIONS

Biogeochemistry

Regolith-landform diagrams were drawn up for both transects using the data recorded whilst collecting material for biogeochemical analysis. For the sake of brevity a diagram is only presented for the E-W transect (Figure 2a). A geophysical image “1VD_RTP Magnetics” from Adelaide Resources was used to infer the geological contact between the eastern Archaean Sleaford Complex and the western Tunkillia Suite. The contact (55100±250 Easting, Figure 2a) was estimated to be somewhere within a 500 metre-long segment on both transect diagrams.

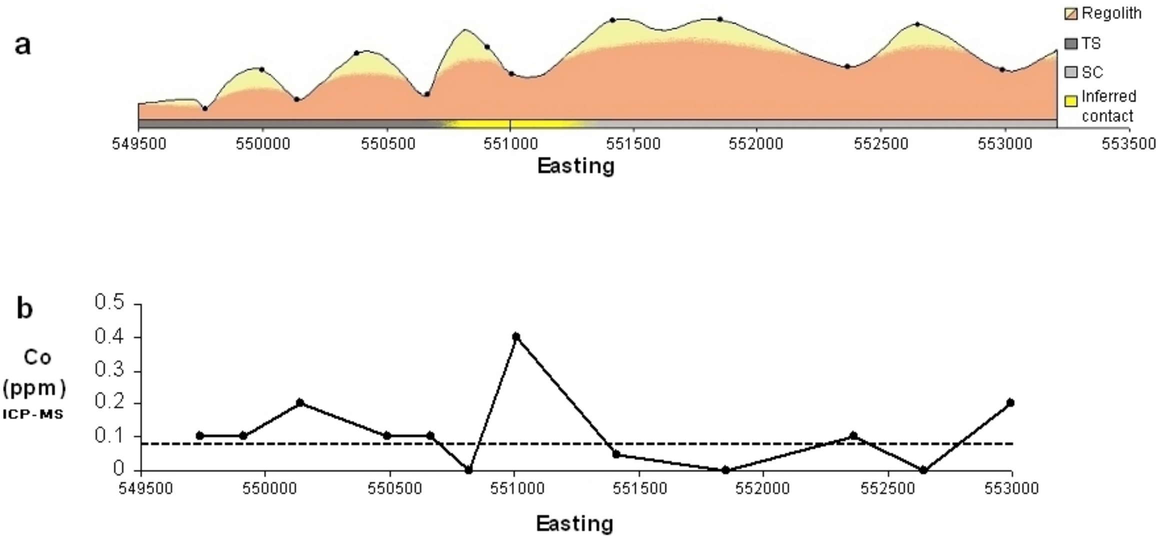

Figure 2: Comparison of regolith-landform with biogeochemistry along the E-W transect: **a)** regolith-landform diagrammatic representation (TS = Tunkillia Suite, SC = Sleaford Complex); **b)** cobalt concentration of *Eucalyptus* spp. (detection limit is represented by a dashed line, and below detection limit values were taken as half the detection limit).

To compare biogeochemistry across transects, data for leaves and phyllodes sampled along the N-S and E-W transects were obtained by INAA for Sb, As, Ba, Br, Cd, Ca, Ce, Cs, Cr, Co, Eu, Au, Hf, Ir, Fe, La, Lu, Mo, Ni, K, Rb, Sm, Sc, Se, Ag, Na, Ta, Te, Th, W, U, Yb, Zn and Zr. Data was obtained from ICP-MS analysis for Ba, Be, Bi, Cd, Co, Ga, In, Mo, Nb, Nd, Pb, Sn, Sr, and by ICP-OES analysis for Al, Cu, Mg, Mn, Ni, P, S, Ti, V, Zn. No single biogeochemical species was present throughout either transect to maintain the required sample density. *Eucalyptus* was the only genus present at every sampling site; therefore an analysis combining all five *Eucalyptus* species was used. These combined data were represented graphically for each element along both N-S and E-W transects, for comparison with regolith-landform diagrams. One example, the chemical signature of Co by INAA, is given in Figure 2b. When comparing all graphically represented biogeochemical data with the regolith-landform diagrams, no obvious changes in element concentration from one side of the geological boundary to the other were observed. Instead, the high and low points in the biogeochemical data closely followed the regolith-landform patterns from Phase 2 swales to Phase 3 dunes and back, with high concentrations at swales and low concentrations at dunes.

To compare biogeochemistry among species, the dataset (as above) for leaves and phyllodes along the N-S and E-W transects was re-examined. Graphical comparison of different tree and shrub species revealed element concentration variation among species. Within each species for which multiple samples were obtained, element concentrations appeared relatively constant compared with variation among species. A comparison of the highest and lowest element concentrations among species is presented in Table 1. Generally, all *Eucalyptus* species had moderate element concentrations, while *Callitris verrucosa*, *Acacia ancistrophylla* and *Melaleuca uncinata* had much higher concentrations of most elements.

Analysis of different plant organs showed that for all elements except Na, Br, Mg, Zn, S and P, concentrations were highest, often by 3-4 times, in litter of all species compared with other plant organs. Among species, Na and Br were generally highest in fruit and leaves compared with other organs. However, for Mg and Zn, no one organ was consistently higher than the others among species. Sulphur was highest in the leaves, closely followed by litter, and K was highest in the leaves and fruit of most species. Analysis of the element concentrations of three fruit stages (unopened buds, new fruit and old fruit) in *Eucalyptus oleosa* showed no obvious distinction between different age groups.

Table 1: A comparison of all species included in biogeochemical analyses. Phases refer to the dune regolith-landforms described in the Setting section. The potential as an indicator species in biogeochemical surveys is summarised.

Biogeochemistry Species	Dune Phase	Element Concentrations High	Element Concentrations Low	Potential as indicator
Eucalyptus brachycalyx	1 and 2	Al, Ce, Nd	Mn, Zn	Average, widespread on swales
*Eucalyptus dumosa**	3	-	Mg	Average, not widespread
Eucalyptus incrassata	3	Ba, Ce, Mn, Na	Al, Br, Cu, Mg, S, Zn	Good, widespread on dunes
Eucalyptus oleosa	1 and 2	Br, Co, Cu, Zn	Mn, Mo	Good, widespread on swales
Eucalyptus socialis	3	Mn, Sn	Al, Mo, S	Average, widespread on dunes
*Callitris verrucosa**	2 and 3	Al, Ba, Ce, Fe, Mo, Na, Sm, Sc, Sr	Br, Cu, S	Poor, due to possible dust contamination.
Acacia ancistrophylla	1 and 2	Al, As, Br, Cu, Fe, Zn	Na	Good, but not widespread
Melaleuca uncinata	3	Cd, Mg, Mo, Ni	Ba, Mn	Good, but not widespread
*Melaleuca lanceolata**	1 and 2	Mg, Na, S	-	Poor, not widespread
*Leptospermum coriaceum**	3	-	-	Poor, not widespread
*Allocasuarina muelleriana**	3	Co, La, Sc	-	Poor, not widespread

*species from which a single sample was obtained are indicated by an asterisk

Geobotany

Forty-nine plant species, including seven mallee *Eucalyptus* species, were recorded during the vegetation surveys on the 1.5 km southern and northern sections of the N-S transect. A strong relationship was observed between regolith and vegetation cover, particularly at the "association level" defined by Specht (1972); at this level soil types support the same vegetation structure and upper stratum species but differ in lower stratum composition. The southern linear section could be divided into two association levels (Associations 1 and 2) and the Northern Conservation Park section could be divided into three association levels (Associations 3, 4 and 5):

- Association 1. Tall open shrubland dominated by *Eucalyptus oleosa* (red mallee) and *E. brachycalyx* (gilja) with occasional *E. gracilis* (yorrell) at the association margins. The understorey was dominated by *Acacia ancistrophylla* var. *lisophylla* (turpentine), and could be further subdivided into three complexes. Association 1 occurred on dunes of Phase 2 red-brown clayey sand and occasional exposures of calcareous Phase 1. On Phase 1 and lowest swales of Phase 2, the understorey could be subdivided into a fourth species complex.
- Association 2. Low open shrubland dominated by *Eucalyptus socialis* (red mallee) *E. incrassata* (ridge fruit mallee) and *E. dumosa* (white mallee) with occasional *Eucalyptus pileata* (capped mallee) over an understorey of *Melaleuca uncinata* (broombush) and *Triodia irritans* (spinifex). The understorey could be further subdivided into three complexes. Association 2 was confined to Phase 3 and Phase 4 dunes.
- Association 3. Tall open woodland dominated by *Eucalyptus oleosa* and *E. gracilis* with occasional *E. brachycalyx and Callitris* sp. (cypress pine) in low lying areas. The understorey was dominated by *Pittosporum angustifolium* (native apricot) and *Geijera linearifolia* (sheep bush), and could be further subdivided into four complexes. Association 3 occurred on Phase 2 red-brown clayey dunes and occasional exposures of calcareous Phase 1.
- Association 4. Open shrubland dominated by *Eucalyptus incrassata, E. socialis* and *E. dumosa* with occasional *Eucalyptus pileata* and *Callitris verrucosa* (southern cypress pine) over an understorey of tall *Melaleuca uncinata* and *Triodia irritans.* The understorey could be further subdivided into two complexes. Association 4 occurred on Phase 3 and Phase 4 dunes.
- Association 5. Open shrubland of *Melaleuca uncinata* (broombush) over a single understorey complex. Association 5 occurred only on low plains with ferruginous sediment exposures within Phase 2 red-brown clayey dunes.

DISCUSSION AND CONCLUSIONS

The biogeochemical results showed no evidence of a change in chemical signature from east to west or from north to south at the inferred bedrock contact. Therefore, we can conclude that at this study site, the chemical characteristics of the vegetation and underlying bedrock were not directly related. In contrast, the biogeochemical results showed that there was a correlation between regolith type and chemical signature. From this we conclude that the chemical characteristics of the vegetation gave an accurate description of the regolith-landform chemical characteristics. The chemistry of the regolith could directly relate to the underlying bedrock via weathered saprolite, and the vegetation chemistry may thus reflect the bedrock.

However, it seems more likely that because they are aeolian driven, the chemical characteristics of the regolith-landforms in this study mask the underlying bedrock chemistry and make bedrock lithology difficult to define.

There was a close geobotanical relationship between the chemical signatures of species associations and regolith-landforms. On this basis, an easily identified plant association could be targeted for regolith-specific sampling. Sampling one association within a single regolith-landform would remove the masking effect of variation due to regolith-related biogeochemical signature, and simplify the identification of changes in bedrock chemistry.

The *Eucalyptus* spp. sampled in this study were concluded to be ideal indicator species for biogeochemical analyses (Table 1), on the basis that the chemical signature of the genus include some atypical elements, and because the genus is widespread and easy to sample. *Callitris verrucosa*, *Acacia ancistrophylla* and *Melaleuca uncinata* also contained unusual elements. However, none make good candidate indicator species because *C. verrucosa* vegetation was observed to be particularly prone to dust contamination, and *A. ancistrophylla* and *M. uncinata* were very restricted in their local and regional distributions.

Leaves of *Eucalyptus* spp. were concluded to be the only practical sampling choice. Contamination by dust was evident in bark samples, particularly in fibrous *Melaleuca* bark. Fruit of most species was often unavailable or too seasonal. However, fruit sample size or number may be increased where, as in the case of *Eucalyptus oleosa*, fruit of various ages do not vary in element concentrations. Not surprisingly, litter shared a similar chemical signature to the underlying regolith with which it was commonly observed to be contaminated; therefore, leaf litter would be better replaced by soil geochemical sampling.

This study has highlighted the importance of recording regolith-landform type when conducting any biogeochemical study. We have established the usefulness of leaves as biogeochemical samples in Eyre Peninsula mallee, and have established baselines for the use of *Eucalyptus* as potential indicator species in future biogeochemical studies of underlying bedrock in South Australia.

REFERENCES

ANAND R.R. & CORNELIUS M. 2004. Vegetation and soil expression of the Jaguar Base Metal Deposit, Yilgarn Craton. *In:* ROACH I.C. ed. *Regolith 2004*, CRC LEME, pp. 7-8.

BROOKS R.R. 1972. *Biological Methods of Prospecting for Minerals.* John Wiley & Sons, New York.

DROWN C. 2003. The Barnes Gold project – discovery in an emerging district. *MESA Journal* **28**, 4-9.

DUNN C.E., HALL G.E.M., COHEN D., CATT P. & LINTERN M. 1995. *Applied biogeochemistry in mineral exploration and environmental studies.* Short course notes from the 17th international Geochemical Exploration Symposium. The Association of Exploration Geochemists.

ERDMAN J.A. & OLSON J.C. 1985. The use of plants in prospecting for gold: A brief overview with a selected bibliography and topic index. *Journal of Geochemical Exploration* **24**, 281-304.

HILL L.J. 2002. Branching out into biogeochemical surveys: a guide to vegetation sampling. *In*: ROACH I.C. ed. *Regolith and Landscapes in Eastern Australia*. CRC LEME, pp. 50-53.

JESSOP J.P.& TOELKEN H.R. 1986. *Flora of south Australia.* Vol. **I-IV**. Fourth edition. The Flora and Fauna of South Australia Handbooks Committee, D.J. Woolman, Government Printer, South Australia.

NAGARAJU A. & KARIMULLA S. 2001. Geobotany and biogeochemistry of *Gymnosporia montana* – a case study from Nellore Mica Belt, Andhra Pradesh. *Environmental Geology* **41**, 167-173.

NICOLLE D. 1997. *Eucalyptus of South Australia*. Lane Print Group, South Australia.

PARKER A. J., FANNING C.M. & FLINT R.B. 1985. Geology. *In:* Twidale C. R., Tyler M. J. & Davies M. eds. *Natural History of Eyre Peninsula*. Royal Society of South Australia, Adelaide, pp. 21-45.

SPECHT R.L 1972. *The Vegetation of South Australia.* Second edition. Adelaide Government Printer, South Australia.

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