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THE SOUTH AUSTRALIAN REGOLITH PROJECT FINAL REPORT - SUMMARY AND SYNTHESIS

Compiled by
M.J. Lintern

CRC LEME OPEN FILE REPORT 156

March 2004

(CSIRO Exploration and Mining Report 1181F)

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CRC LEME is an unincorporated joint venture between CSIRO-Exploration & Mining, and Land & Water, The Australian National University, Curtin University of Technology, University of Adelaide, Geoscience Australia, Primary Industries and Resources SA, NSW Department of Mineral Resources and Minerals Council of Australia.

Headquarters: CRC LEME c/o CSIRO Exploration and Mining, PO Box 1130, Bentley WA 6102, Australia

This report presents outcomes of a collaborative research project between exploration companies, CRC LEME and the Department of Primary Industries and Resources, South Australia (PIRSA) that commenced in 1996 and continued until late 1999.

Copies of this publication can be obtained from:
The Publication Officer, c/- CRC LEME, CSIRO Exploration and Mining, P.O. Box 1130, Bentley, WA 6102, Australia. Information on other publications in this series may be obtained from the above or from http://leme.anu.edu.au/
Cataloguing-in-Publication:
Lintern, M.J.
The South Australian Regolith Project Final Report – Summary and Synthesis.
ISBN: 0 643 06852 X
1. Regolith - South Australia. 2. Landforms - South Australia. 3. Geochemistry – South Australia. 4. Gold – South Australia. 5. Copper - South Australia

CRC LEME Open File Report 156.

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PREFACE

One of the original objectives of the CRC for Landscape Evolution and Mineral Exploration (CRC LEME 1) at its commencement in 1995 was to establish a research node in Adelaide, as part of an overall strategy to develop mineral exploration procedures for the principal regolith-dominated mineral districts in Australia. Planning for this node anticipated the upsurge in exploration activity in the Gawler Craton, and was greatly assisted by the Department of Mines and Energy South Australia (MESA; now Primary Industries and Resources South Australia, PIRSA) , which was a supporting participant of the CRC. One of the principal drivers was to assist industry in the use of calcrete geochemistry, which was by then being widely used for regional to local scale exploration for gold on the Gawler Craton. Melvyn Lintern had undertaken much of the original research on calcrete geochemistry in the Yilgarn Craton and he transferred from Perth to the MESA office in Adelaide in October 1996 to continue his work in this new district. In collaboration with Malcolm Sheard at MESA, he developed a number of research activities under the broad banner of the South Australian Regolith Project. This involved scientific collaboration between CRC LEME (Perth, Adelaide and Canberra), MESA, universities and the exploration industry from 1996 to 2001. Studies were conducted at sixteen prospects and deposits in the Gawler Craton and Curnamona Province of South Australia. Research themes included regolith-landform mapping, regolith geochemistry, biogeochemistry and hydrogeochemistry, although not all of these were pursued at each site. A number of commodities were examined, but gold was the principal focus. The results of this research are summarized in this report.

In addition to the scientific findings, one of the most important outcomes of the establishment of the CRC node in Adelaide project has been the interest in regolith geoscience that it engendered. A consequence has been that PIRSA, the University of Adelaide and CSIRO Land and Water became Core Partners to CRC for Landscape Environments and Mineral Exploration (CRC LEME2) from July 2000.

Dennis Gee
CEO
CRC LEME 2

Charles Butt
Leader, Shields Program
CRC LEME 1

23rd March 2004

EXECUTIVE SUMMARY

The principal aim of the South Australian Regolith (SAR) Project was "to develop technically efficient procedures for mineral exploration in the major Cratons of South Australia through a comprehensive understanding of the processes of regolith development and landscape evolution and their effects on the surface expression of concealed mineralization". The Project involves scientific collaboration between CRC LEME, PIRSA, universities and the exploration industry from 1996 to 2001. Industry input was a key element throughout the project since most of the case studies herein were based on data provided by companies.

Studies were conducted at sixteen prospects and/or deposits in the Gawler Craton and Curnamona Province of South Australia. In addition, regional studies into dating and isotopes were undertaken. Research themes were regolith mapping, regolith geochemistry, surface geochemistry, biogeochemistry, and hydrogeochemistry. Not all of the themes were included for each study due to different sub-project objectives and resource limitations. A number of commodities were examined including Au, Cu, Ag and Pb, with the overwhelming proportion concerned with Au. Similarities and differences of the research between sites were developed, and models of geochemical dispersion produced. Some of the more important conclusions and recommendations are summarized below:

1. Surficial geochemical sampling programs are sensitive to regolith materials and depth of transported overburden and it is therefore important to establish the regolith stratigraphy and landforms for the area being explored. Remote sensing methods such as radiometrics, aerial photography, Landsat TM, ASTER and AIRSAR can give important information on the nature of the land surface and as an aid to mapping the distribution of surficial materials. Ground penetrating methods such as AEM may give sub-surface information such as the presence and depth of palaeochannels.

2. The construction of large scale regolith-landform maps (preferably more detailed than 1:10000) is recommended. These maps provide information on the distribution of regolith materials but should additionally provide some indication as to the extent of transported materials and thickness at the prospect scale. Small scale regolith maps e.g. 1:100000 provide an overview but have insufficient detail for any sampling programmes.

3. Distinguishing *in situ* from transported regolith is important for exploration as geochemical responses will differ depending on the depth of cover. The presence of cover may be inferred from field regolith-landform relationships, although drilling can provide definitive information. The use of PIMA spectra can in some cases establish transported-*in situ* boundaries. In some circumstances geochemistry can also discriminate between cover sequences and weathered crystalline basement.

4. Calcrete is the best near surface sampling medium for Au and should be used as a first pass geochemical sampling technique. It occurs usually within a metre of the surface and is readily identifiable using dilute acid. It works best as a guide to mineralization where transported overburden is absent or thin (<5 m), and where there is development of saprolite rather than fresh rock close to the surface. Local topography may lead to the development of transported anomalies located away from their source mineralization. For Cu, specific environments (high water table, acidic groundwaters and <5 m of transported material) may lead to upward dispersion of Cu with a precipitation in alunite at the base of the calcrete horizon due to a pH change.

5. Hilly terrain is well suited to stream sediment sampling, and orientation surveys investigating the most appropriate size fraction(s) are recommended at each site.

6. Biogeochemical methods were shown to be of limited application in the Gawler Craton. Understanding over how and why metals accumulate in plants and form anomalies remains limited. Several unexplained anomalies require further testing.

7. In the absence of calcrete, other sample media for geochemical exploration may be used but responses are either weaker or more erratic. Silcrete has been demonstrated to be a credible sample medium for Au exploration provided that it has developed within *in situ* materials. Soil commonly has an aeolian component, so the use of fine or coarse size fractions is recommended in order to remove sand that acts as the chief diluent to elements of interest. Groundwater as a sampling medium was not investigated to any great extent.

8. Although they may have some merit for investigating the nature of anomalies and how they form, partial extractions *per se* are not recommended as conventional total extraction procedures were found to be equally as satisfactory, easier to interpret and more cost-effective. Selective extractions are potentially of greater benefit since they may be used to understand the behaviour of elements in regolith materials. They indicate if it is worth targeting a particular mineral or size fraction in a sample. There are many different types of selective extraction procedures and a few were tested during the course of this project. Tests for utility in finding buried Cu and Co mineralization were unsuccessful.

9. Multi-element geochemistry should be used with caution. Understanding the nature of the mineralization being sought, potential associated pathfinders, the type of regolith material being sampled and the extra cost are important considerations for its use. For Au in the western Gawler Craton, multi-element geochemistry was of limited utility since mineralization was not usually associated with rich concentrations of pathfinder elements such as As or Cu, as may be found in the Yilgarn Craton, for example. Furthermore, the paucity of Fe-rich regolith materials, such as lateritic duricrust or ferruginous lag, meant that these metal-scavenging materials cannot be used systematically in an exploration program.

10. For calcrete, isotope data are consistent with a predominantly marine source for the Ca and a biological origin for the C. This is consistent with other studies on calcretes from South Australia and in other parts of the world. The S isotopes suggest a marine source although the distribution of discrete accumulations of gypsum in certain portions of the regolith at Challenger Gold Deposit are problematic.

M.J. Lintern
Project Leader

March 2004

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Compiled by M.J. Lintern

1 INTRODUCTION

1.1 Background

The Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRC LEME) and the South Australian Primary Industries and Resources Department (PIRSA, formerly MESA) initiated a cooperative agreement recognising the importance of regolith in exploration in South Australia. This resulted in the formation of the South Australian Regolith (SAR) Project which, in turn, provided a framework for sub-projects of case histories and regional surveys to be undertaken within it. On completion of the SAR Project, a summary and synthesis of all these sub-projects was to be conducted and make recommendations as to the appropriate exploration strategies for the different regolith-landform settings encountered. This final report constitutes the summary and synthesis.

1.2 Exploration problems

The exploration problems facing companies in South Australia are similar to those in other Australian states. One of the greatest impediments relates to the antiquity of the Australian continent. The long weathering history of Australia has led to the formation of deep, intensely-weathered terrains dominated by regolith. Chemical weathering, erosion, sedimentation and secondary cementation have served to blanket fresh rocks and mineralization with clay-rich saprolites, duricrusts and transported overburden. South Australia is particularly burdened by this cover, outcrop is scarce, and, moreover, it has a complex landscape evolution dominated by geology of different ages including Palaeozoic, Mesozoic and Cainozoic within which these processes have taken place, usually on multiple occasions. In Western Australia, while weathering during the Tertiary period or earlier has also led to deep weathering, the preservation of lateritic duricrust has provided some relief to the mineral explorer. This material and its degradation products, such as ferruginous lag, has been successfully used by mineral explorers to find new mineral deposits since geochemical signatures of the underlying rock are often expressed within it. However, in South Australia, ferruginous weathering products such as lateritic duricrust are much less abundant, being restricted, to any great extent, to the southern tip of the Eyre Peninsula, Kangaroo Island and the southern Fleurieu Peninsula. This is not to say that Tertiary weathering has not produced lateritic materials in other parts of South Australia, rather than they are no longer present to any great extent. Therefore, mineral explorers are faced with a major problem when exploring in the greater part of South Australia terrain as the geochemical sampling material of choice in Western Australia is absent or poorly represented.

Fortunately, South Australia has an extensive development of calcrete which has also been shown in Western Australia to be an important sampling medium, at least for Au exploration. The calcrete is spread over vast areas of central and southern South Australia. However, great thicknesses of calcrete in South Australia, particularly on the west coast of Eyre Peninsula, may itself be a problem that requires investigation as to its usefulness. Gold anomalies in calcrete are characterized by the following features: Au is concentrated in calcrete near the surface for *in situ* regolith; beneath the surficial enrichment of Au-enriched upper regolith, very low Au concentrations may occur for several tens of metres depth before mineralization is encountered; anomalies commonly extend hundreds of metres. The main problems associated with Au in calcrete anomalies are that 1) drilling the bullseye of the anomaly is commonly unsuccessful 2) high Au concentrations in the surface anomaly do not always equate to strong mineralization in bedrock and 3) there are so many anomalies it is difficult to determine which to drill first.

Another major problem affecting explorers in South Australia has been the paucity of exploration itself due, in part, to the remoteness of the areas, shortage of water, aridity and rough terrain. Apart from early mineral discoveries at the turn of the last century that have been sporadically re-worked, the Gawler Craton, for example, has experienced little exploration. Whereas in Western Australia and Queensland, explorers have been able to draw upon data from existing mines and past exploration, current South Australian mineral explorers have really had to start from a poor knowledge base. In recent years the South Australian government have recognized this problem and launched a series of funded initiatives (*e.g.* TEISA) aimed at kick-starting the mineral exploration industry. This injection of new funds into the industry has led to new drilling and airborne data that have proved to be instrumental in beginning to open up vast areas of South Australia for mineral exploration. The new Au discovery at Challenger is partly attributable to this support.

Regolith research, particularly for mineral exploration, has been deficient in South Australia. There are few published articles on the topic. Various landforms, formations, geological units and soils have been described that may be placed under the regolith banner e.g. the calcareous Bridgewater Formation, but these have not been tested in terms of their exploration potential. Some of the new government funds have been directed towards regolith research and includes the funding of the South Australian Regolith (SAR) Project.

1.3 Objectives

The principal objective of the SAR Project is "to develop technically efficient procedures for mineral exploration in the major Cratons in South Australia through: 1) a comprehensive understanding of the regolith-landforms; and 2) the effects of these processes on the surface expression of concealed mineralization". This was to be achieved with the following specific objectives by undertaking a series of sub-projects at various mineral prospects and through regional studies:

- Establish broad spatial relationships between regolith, landform and bedrock lithotype.
- Establish mineralogical and geochemical characteristics of regolith in different geological, geomorphological and climatic environments.
- Characterize the surface and sub-surface geochemical expression of ore systems in the regolith.
- Establish relationships between geochemical dispersion patterns, weathering processes and evolutionary stages of regolith and landform development.
- Develop appropriate exploration procedures for different landscape situations for each of the Cratons.

Initially, the Project was to include all Shield areas of South Australia including the Gawler Craton, Musgrave Block, Curnamona Province and various minor inliers, but to concentrate initially on the Gawler Craton. Land access difficulties prevented any activities in the Musgrave Craton.

1.4 Strategy

The following project research themes were developed to address the objectives of the project: (i) regolith-landform mapping, (ii) sub-surface regolith geochemistry, (iii) soil geochemistry, (iv) biogeochemistry, (v) hydrogeochemistry and (vi) palaeochannel delineation. Hydrogeochemistry was briefly investigated as opportunities have allowed; the palaeochannel research has largely been addressed by others using an Australian Research Council - Strategic Partnerships with Industry Research and Training (ARC-SPIRT) grant (Hou *et al.*, 2001). The themes were modified and developed over time to provide a framework for base and precious metals exploration using regolith in South Australia. One or more of the themes was addressed in each sub-project.

1.1.1 Regolith-landform mapping

Regolith-landform maps were used to improve:

- Inventories of sampling media
- Classification of sample media
- Selection of sample media appropriate for different geomorphic/geological provinces

- Planning and positioning of geochemical surveys
- Interpretation of geochemical data
- Geochemical dispersion studies
- Understanding of landscape evolution through time

Pilot studies were established, each of which was representative of broader regolith-landform regimes within the Gawler Craton. Ideally, these comprized a core area that was mapped in detail, and an interpreted map of a peripheral area. Field work for regolith mapping commonly involved visits to several hundred sites and observations made to assist with regolith interpretations and map construction. Field data were used to define regolith-landform units from calibrated photo-patterns and used to modulate data interpreted from aerial photography and remotely sensed, geophysical and elevation datasets. Normally, compilations were performed at photo-scale by scanning aerial photographs with overlays attached. However, some studies found available aerial photographs of limited use due to their poor quality. A variety of data sets were used to aid construction of regolith maps at selected sites. These included SPOT-PAN, Airborne gamma-ray spectrometry, HyMap^{TM}, Polarimetric AIRSAR radar and Landsat TM. DEMs (digital elevation models) were generated from aerial photographs, AIRSAR (TOPSAR) or airborne altimeters and were particularly useful to identify subtle landforms and to understand flow vectors for possible geochemical dispersion. Landsat TM is the only cost-effective, operational multispectral dataset of adequate spatial resolution usually available for routine regolith-landform mapping. However, for large scale regolith mapping *e.g.* 1:5000, identification and detailed representation of the distribution of potential geochemical sampling media and the broader surface regolith units was not possible based solely on airborne datasets, and field observations were required. Regolith-landform polygons were scanned and imported into ArcInfo. In addition to the regolith-landform map, thematic regolith material maps were examined for use in planning and assessing surface geochemistry. The real benefits of regolith-landform maps were realised when the data were imported into a Geographic Information System (GIS), and overlaid and compared with other "layers" such as geochemical, geological, geophysical and topographic data.

1.1.2 Sub-surface regolith geochemistry

Sub-surface regolith geochemistry was used to improve:

- Understanding of the processes of geochemical dispersion
- Evaluation of the use of pathfinder elements in exploration
- Selection of sample media
- Delineation of drill targets
- Interpretation of drilling data

Sub-surface regolith geochemistry provided a greater understanding of the distribution of elements associated with mineralization. Different regolith stratigraphy and lithology created distinct environments that controlled the potential for element dispersion from a source. A work plan typically included field and laboratory components. Field work involved description, selection and collection of samples from several drill holes along one or more traverses across the strike of mineralization. Selected drill cutting material was sorted and visually classified into sub-samples. Mineralogical and multi-element geochemical analyses were essential to: 1) understand the distribution of elements in the regolith; 2) explain the occurrence of unusual concentrations of elements; and 3) improve the usefulness of drill cuttings as sample media. Further investigations at a few sites included thin and polished section production, analysis using a Portable Infra-red Mineral Analyser (PIMA), optical and electron microscope studies, isotopic dating, and 3-D modelling of mapping and drilling data to visualize the relationship(s) between geochemical data, regolith stratigraphy and Au mineralization.

1.1.3 Surface geochemistry

Surface geochemistry is, *senso stricto,* a sub-set of regolith geochemistry but, due to the enormous scope and importance of the topic, was considered separately. It involved the geochemistry of regolith material at or close to the surface and included that modified by pedogenic processes. The use of some specific surficial sample media such as lateritic residuum, lag and calcrete has been responsible for the discovery of several significant ore bodies in the Yilgarn Craton. The theme comprised a series of pilot studies that had good regolith-landform mapping control, with the objectives of:

- Developing an understanding of element dispersion patterns and processes
- Determining potential pathfinder elements
- Assisting in the evaluation of sample media
- Refining choice and collection of samples
- Highlighting problems in ongoing and past exploration programs
- Using isotopes to determine source of surficial materials

Studies involved a combination of field and laboratory tasks, commonly with supplementary field visits for follow-up sampling. The studies included the collection of high quality samples from the surface, trenching and specific drilling. This methodology was originally used to establish lateritic residuum and calcrete as sampling media for Au exploration in the Yilgarn Craton. Investigations of material included geochemical and mineralogical analyses, petrography (optical, SEM), electron microprobe studies and interpretation of data.

1.4.1 Biogeochemistry

Biogeochemistry has been investigated extensively in the USA, Canada and parts of the former USSR as a geochemical exploration technique. It has potential as a cost-effective means of geochemical sampling where access is poor or where biogenic dispersion may have occurred, for example through transported overburden. It is a relatively little used technique in Australia because of the success of other techniques such as soil sampling, but may have some potential in areas of transported regolith. Vegetation has the ability to sample broader and deeper parts of the regolith since plant roots are generally very extensive. Vegetation may be involved in the generation of some Au-in-calcrete anomalies. The sister technique, geobotany, is already used at least qualitatively, in regolith-landform mapping, and in the location of stressed vegetation arising from nutritional-toxic effects due to the proximity of underlying mineral deposits.

Due to the low level concentrations of target elements there was a special requirement for the careful collection, processing and analysis of vegetation. Biogeochemical data were interpreted carefully to evaluate the possibility of false anomalies and were considered in context with surface and regolith geochemistry and the underlying mineralization.

1.4.2 Hydrogeochemistry

Exploration using groundwater as a sample medium has been used in some areas of Australia, including South Australia. Its application is similar in concept to biogeochemistry, but at a district rather than prospect scale, since large areas can be potentially evaluated using a small number of samples.

Existing drilling programs can be supplemented with the collection of groundwater samples. Groundwater samples require specialist analysis and data interpretation and usually require integration with regolith and bedrock geochemistry.

Groundwater data for the Gawler Craton and Stuart Shelf was to be compiled from all available sites, including previous CSIRO investigations, various PIRSA groundwater databases and open-file exploration reports. These data were to be processed and mapped, with particular regard to parameters strongly controlling element mobility (especially Au and base metals). These were likely to include TDS, pH, Eh (if available), Fe, Mn, K/TDS (found in Yilgarn studies to be a measure of alunite precipitation) and determinations of mineral saturation. Reasons for regional differences in groundwater characteristics were to be explored.

1.4.3 Palaeochannel delineation

Defining the positions of vast tracts of Tertiary and Mesozoic palaeodrainage networks within the Gawler Craton has been made very difficult by infilling of the channels and later blanketing by both consolidated and unconsolidated regolith materials, yielding an essentially flat terrain. To enable accurate analysis of the geochemical relationships between surficial regolith materials (and vegetation) and mineralized zones, it would be highly desirable to distinguish areas where these materials overlie palaeochannels from those where they overlie residual regolith. This has been demonstrated in a pilot study at Challenger in the Gawler Craton (Lintern and Sheard, 2000), where the geochemical expression in thick consolidated and unconsolidated transported units above an ore body is less reliable than where the cover over residuum is thin. In addition, palaeochannels are potential sites of placer mineralization and the precipitation of uranium, base metals and rare earths.

Potential studies included: (1) hyperspectral datasets; (2) regional-scale, high-resolution digital elevation data; (3) airborne electromagnetic (AEM) data suitably processed to highlight structures in the near-surface region; (4) field spectral measurements; and (5) regolith and landform mapping to elucidate buried palaeochannels within specified regions of the Gawler Craton. In addition, links with the ARC SPIRT-funded Palaeochannel Project in the Sedimentary Terranes Group within PIRSA and Adelaide University were to be forged (Hou *et al*., 2001). Recently, AGSO, with PIRSA and CRC LEME, have initiated an extensive program of AEM surveys over selected areas of the Gawler Craton.

1.5 Study Areas

Studies were conducted at a number of sites, for a variety of commodities, principally in the Gawler Craton (Figure 1). Not all research themes were addressed at each site either because they were inappropriate, or there were resource limitations.

1.6 Sponsors

A number of companies, organisations and institutions have provided financial and in-kind support during the course of the project and are acknowledged below:

Stuart Metals Pty Ltd	Grenfell Resources Ltd
Minotaur Gold NL	Dominion Mining Ltd
Adelaide Resources Ltd	Resolute Ltd
MIM Holdings Ltd	PIRSA
AMDEL Ltd	CRC LEME
CSIRO Exploration and Mining	Geoscience Australia
Lynas Corporation Ltd	University of Adelaide
University of South Australia	University of Melbourne

1.7 Project staff

The project brought together regolith expertise from CSIRO Exploration and Mining and Geoscience Australia (CRC LEME), and PIRSA. Researchers were based in Adelaide, Perth and Canberra. Students, supervised by members of the research group, undertook some of the research.

Original Project Leaders: M. J. Lintern, I. J. Tapley and M. J. Sheard.

Current Project Leader: M. J. Lintern.

Project Staff (full time involvement): M. J. Sheard and G. Gouthas (from March 1998).

Project Staff (part time involvement): L. Shu, M. Skwarnecki, A. J. Cornelius, M. A. Craig, J. Wilford and D. J. Gray.

Honours students: S. Van der Wielen, A. Carragher, D. Povey, L. Gibbons, K. Hartley and A. K. M. Baker.

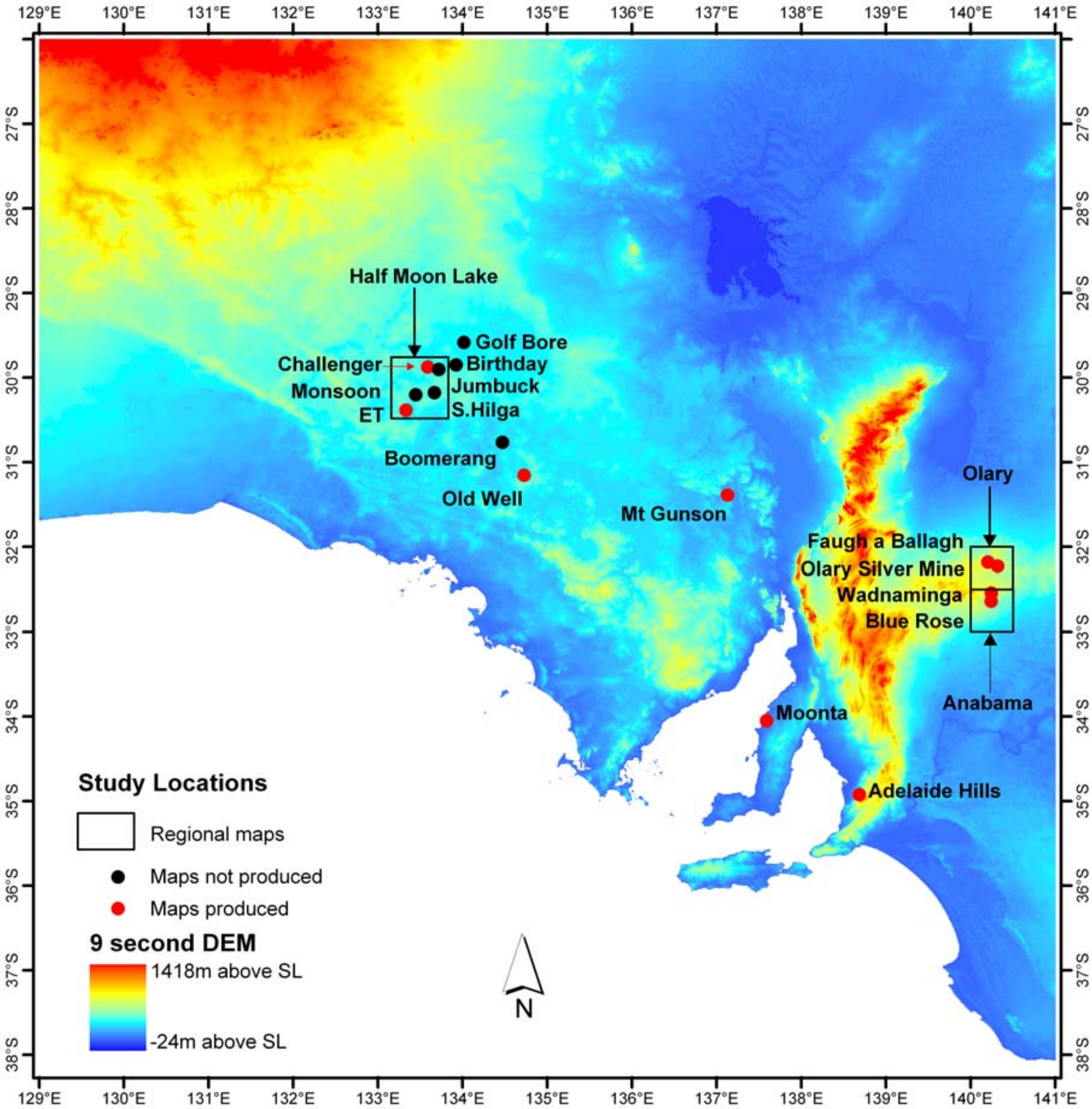

Figure 1: Study areas undertaken for the SAR Project overlain on a DEM: 1) Challenger; 2) Birthday; 3) Mt Gunson; 4) Regional studies; 5) Old Well; 6) Adelaide Hills; 7) Regional studies; 8) Moonta; 9) Jumbuck; 10) Olary (Wadnaminga, Blue Rose, Olary Silver Mine and Faugh-a-Ballagh); 11) Monsoon; 12) South Hilga; 13) ET (Edoldeh Tank); 14) Golf Bore; 15) Boomerang. Study site locations and where site regolith-landform maps were produced are indicated. (DEM from GA).

2 PHYSIOGRAPHY

2.1 Geology

The Precambrian geological record of South Australia spans a period from late Archaean (~2700 Ma) to the end of the Neoproterozoic (540 Ma). Major Precambrian geological provinces are the Gawler Craton, Musgrave Block and part of the Officer Basin, Coompana Block (in the south west), Curnamona Craton and Adelaide Geosyncline including basement inliers. The following geological background to the Gawler and Curnamona Cratons, where all of the studies were conducted (Figure 2), has been largely summarized from the "The Geology of South Australia" (Drexel *et al*., 1993; Drexel and Preiss, 1995).

The Gawler Craton comprises the most diverse association of units. The late Archaean to very early Palaeoproterozoic Sleaford and Mulgathing Complexes (~2700-2400 Ma) form an older basement in the western and northwestern portions, and included para- and orthogneisses (*e.g.* Christie Gneiss at Challenger Gold Deposit) with mafic to ultramafic intrusives and extrusives. Palaeoproterozoic metasedimentary and metavolcanic successions, occurring mainly on the eastern Gawler Craton, include the Hutchison Group (~1900-1845 Ma), Moonta Porphyry (~1735 Ma) and Tarcoola Formation (~1656 Ma). These were multiply deformed and metamorphosed by various phases of the Kimban Orogeny and intruded by syn-Kimban granitoids of the Lincoln Complex (~1850-1700 Ma). Unconformably overlying the Palaeoproterozoic rocks are undeformed to gently folded Mesoproterozoic continental clastic sediments including the acid volcanic sheets of the Gawler Range Volcanics (~1592 Ma). Anorogenic Hiltaba Suite granitoids (~1585 Ma) are widespread on the Gawler Craton, particularly around the margins of the Gawler Range Volcanics. Hiltaba Suite granites are associated with the giant Cu-Au-U deposit at Olympic Dam and Tarcoola Goldfield. The Gawler Craton has undergone no substantial deformation or remobilization since 1450 Ma.

The Curnamona Craton is mostly covered by relatively undeformed Neoproterozoic to Phanerozoic sediments. Mesoproterozoic acid and minor basic volcanics and sediments are inferred to unconformably overlie the metamorphosed Willyama Supergroup of late Palaeoproterozoic age. The supergroup comprises gneissic rocks in the lower part, followed by pelitic, quartzitic and albite-rich calcsilicate metasediments. It was deformed by the Olarian Orogeny (~1670-1600 Ma) and intruded by late Palaeoproterozoic to early Mesoproterozoic granitoids. All units have since been cut by basic intrusives.

The known Phanerozoic record of South Australia is preserved in widespread sedimentary basins, and igneous and metamorphic rocks. Late Palaeozoic sediments are preserved in basins controlled by NE and NW-trending structures, glacially deepened valleys, and as thin mantles over bedrock. Widespread glaciation affected virtually all of South Australia in the late Carboniferous and Early Permian. Ice moved N-NW across the state, scouring bedrock, over-deepening valleys and structural troughs, and depositing lodgement till over parts of the landsurface. The Mesozoic brought global sea level rise and transgression from the north. It deposited a blanket of mudstone and sandstone over the older non-marine clastics, including the northern Gawler Craton. By the mid- to late Cretaceous, the retreating sea, and resumption of terrestrial conditions with low-energy fluvial to lacustrine sediments, marked the end of widespread deposition in the north.

Tertiary strata are widespread in South Australia, in gently downwarped cratonic basins, palaeochannels and as thin sheets in the interior. Continental sediments were deposited on a subdued landsurface, with uplands as presently located. With separation from Antarctica, Eocene marine transgressions into the southern basins deposited marginal marine clastics and extensive, temperate water, platform to deep water carbonates. The Tertiary climate changed from high-rainfall temperature to cool temperate in the early Palaeocene to warmer in the Late Palaeocene and Early Eocene, but still with rainforest. Aridity increased in the late Tertiary, with open woodland and minor forest pockets. Prolonged weathering of a generally subdued landscape which began in the Mesozoic continued in the Tertiary. Laterite formed in the Early Mesozoic-Middle Eocene, mid-Tertiary and late Tertiary, and silcrete during the Late Eocene-Middle Miocene and Late Miocene-Pleistocene.

The Quaternary was characterized by marked climatic and sea-level oscillations, impacting on many geomorphological features. In the interior, cold arid phases (times of dune building, evaporative playa deposition and calcareous dust deposition) alternated with periods of moister climate, increased stream discharge and greatly extended lake systems. This is the period when the present day calcretes were formed.

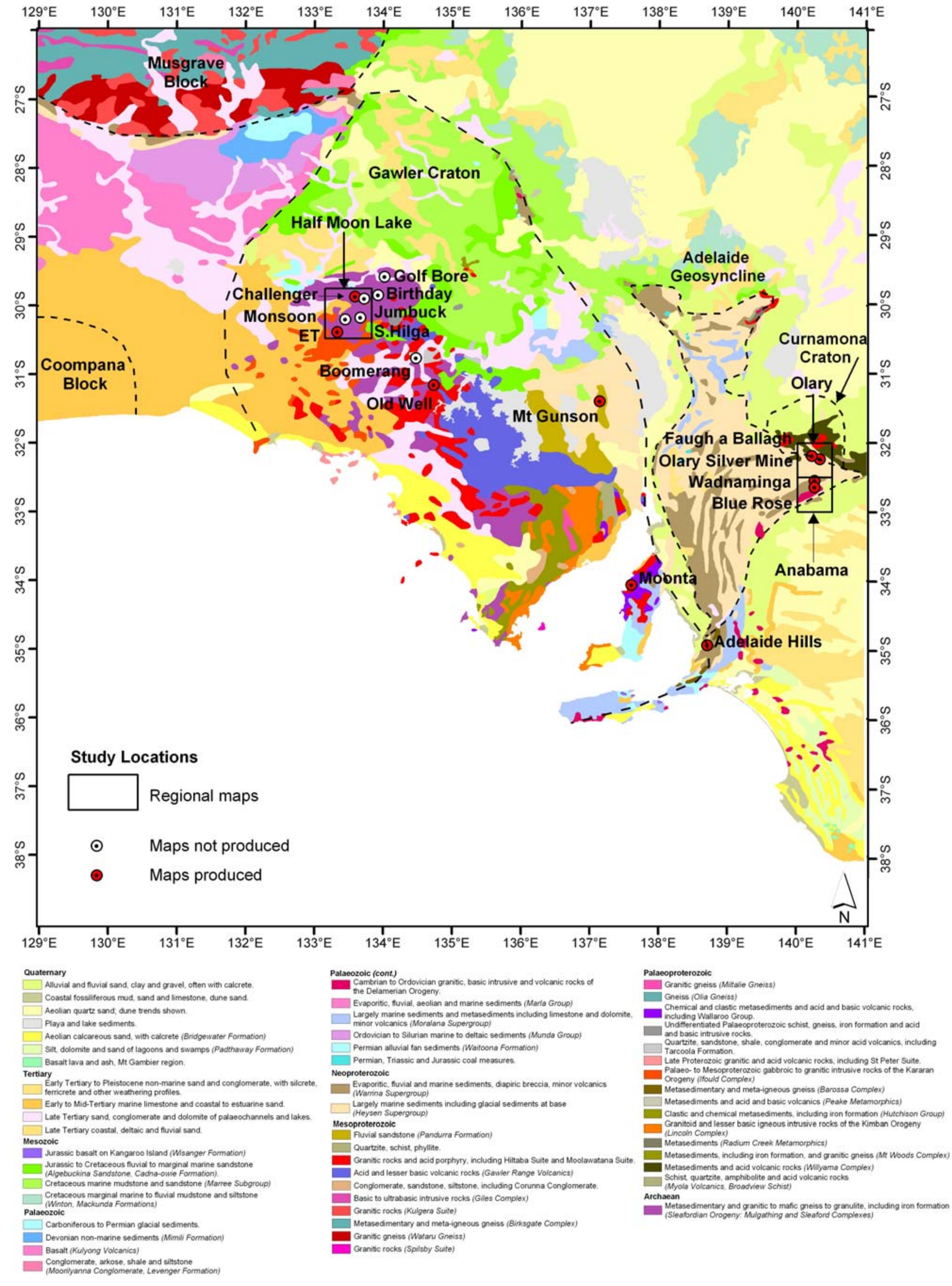

Figure 2: Geology and study areas. Study site locations and where site and regional regolith-landform maps were produced are indicated. (From PIRSA).

2.2 Climate

Most of the case studies are in areas that have <250 mm rainfall per annum (Figure 3). Rain can fall at any time of year, although it mostly occurs as light showers during the passage of winter cold fronts from the south west. Summer daytime temperatures are hot with a general range of 35 - 40°C while in the north east periods over 42°C are common. Winter daytime temperatures are mild to warm with an average range of 16 - 22°C. Frost in winter is common. This aridity is the principal reason for the widespread occurrence of calcrete of South Australia.

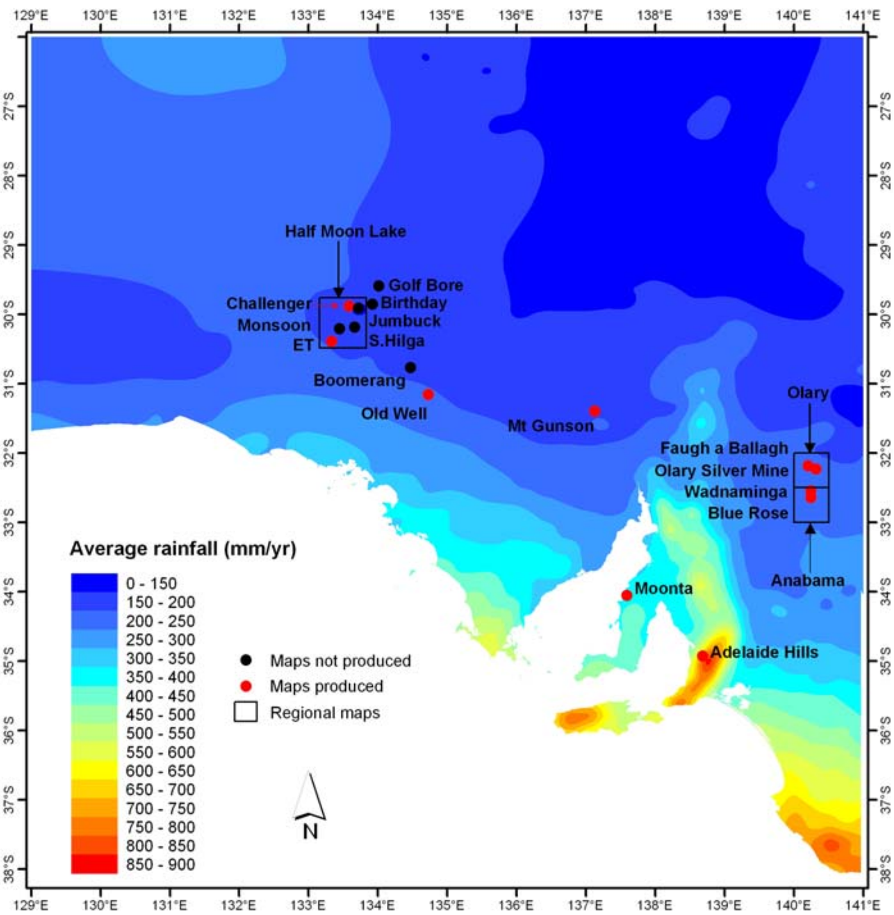

Figure 3: Annual rainfall distribution map for South Australia. Study site locations and where site regolith-landform maps were produced are indicated. (From Commonwealth Bureau of Meteorology).

2.3 Vegetation

The vegetation of South Australia is largely determined by rainfall distributions and primarily consists of chenopod shrublands and grasslands, mallee eucalypt woodlands and open woodlands (Figure 4). Vegetation surveys were conducted at most sites and some biogeochemical studies were undertaken where appropriate.

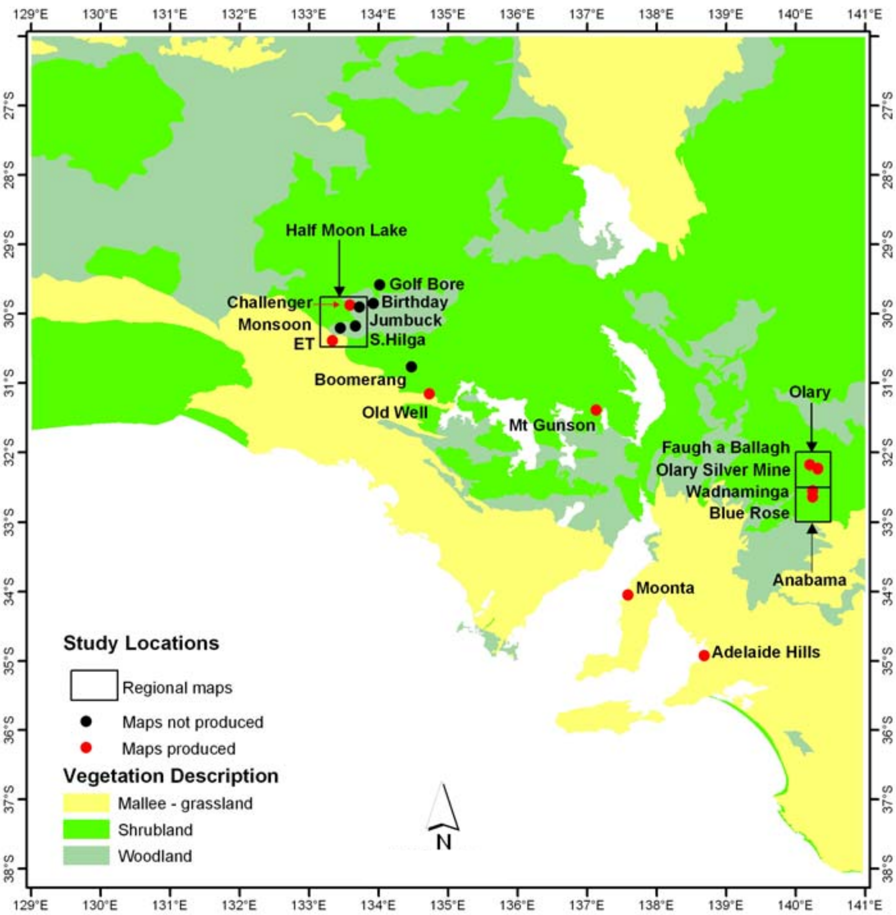

Figure 4: Vegetation types for South Australia. Study site locations and where site regolith-landform maps were produced are indicated. (From Government of South Australia).

3 REGOLITH AND LANDFORMS

3.1 Introduction

There have been few previous regolith-landform maps produced for South Australia. The Curnamona regolith-landform 1:500000 map sheet was the only one produced by CRC LEME prior to the commencement of this project (Gibson, 1996). Descriptions of regolith geology units and sections are mostly restricted to the explanatory notes and/or 1:250000 map sheets produced by the Geological Survey of South Australia. However, the emphasis on the regolith components of the geological map sheets varies depending on the mapping style for each particular sheet. For example, the Barton 1:250000 map sheet (Benbow *et al*., 1995) descriptions, key and sections of the Cainozoic are in much greater detail than the adjacent Tarcoola map sheet (Daly *et al*., 1985) where the emphasis is on the sub-surface extent of the Precambrian. Neither mapping style portrays the degree or depth of weathering of the basement, and consequently the overall thickness or character of the regolith has not been described.

For this project, regional regolith-landform mapping for the Gawler Craton was undertaken on a ~6400 sq km area (Figure 1, incorporating a detailed 625 sq km study). The following descriptions of the regolith-landforms and regolith materials of the western Gawler Craton have been summarized from project reports (*e.g*., Skwarnecki *et al*., 2001; Lintern and Sheard, 1998; Mason and Mason, 1998). On the Curnamona Craton, regolith-landform mapping was undertaken for the Olary Regolith Project, on the Olary and Anabama 1:100000 sheets. Smaller detailed regolith landform maps (*e.g*. 3 km by 3 km) were produced for many of the geochemical case studies (section 4) but no specific study was conducted on the nature of regolith materials for the mapped areas.

Regolith stratigraphy and regolith-landform studies were hampered by the paucity of natural exposures, open cut mines and costeans compared, for example, with the Yilgarn Craton. Thus, errors in the classification of some regolith-landform units are possible based on the interpretation of the nature of surficial features alone. For example, an early draft of the regolith landform map of the Half Moon Lake (Wilford and Craig, 2001) incorrectly classified an upland area as erosional or *in situ* when subsequent AEM studies indicated the presence of a deep palaeochannel, thus indicating landscape inversion.

3.2 Western Gawler Craton regolith-landforms

The area surrounding the Challenger Gold Deposit exemplifies regolith landform relationships typical of the western Gawler Craton. Most of the area is covered by aeolian, fluvial and colluvial sediments. This cover, minimal regolith exposures (either natural or man made) and paucity of drilling, makes the task of determining regolith-landform relationships difficult. The problem has been partly tackled at two levels: firstly a detailed study of the south west quadrant of the Jumbuck 1:100,000 map sheet (~625 sq km, containing the Challenger Deposit) and secondly in a largely interpretive regolith-landform study of the Half Moon Lake area (~6,400 sq km, Figure 1) (Wilford and Craig, 2001). The percentage area covered by the principal regolith landform units are described in Table 1.

Table 1: Principal regolith landform units (as % coverage) for Half Moon Lake and Jumbuck map sheets (from Wilford *et al.*, 1998).

Regolith-landform unit	**Half Moon Lake**	**Jumbuck**
Colluvial sediments	50%	59%
Aeolian sediments	31%	12%
Lags	13%	19%
Alluvial sediments	2%	3%
Lacustrine sediments	2%	1%
Saprolite	2%	6%

Colluvial sediments account for between 50-60% of the total area. They occur on erosional plains, pediments, depositional plains and minor footslopes, and consist of unconsolidated polymictic gravel with varying proportions of sand and clay (Figure 6, Wilford *et al.,* 1998). Aeolian sediments form dunefields and modified sandplains, particularly in the south west corner of the Half Moon Lake area and beyond, where east-west longitudinal dunes are present and appear to be supplied by the Eocene Ooldea and Barton Ranges. The dunes probably drape over basement highs, because windows through the cover are observed in some swales. The aeolian sediments consist of fine-grained reddish quartz sand with variable amounts of clay (Figure 6). Nearly 20% of the Jumbuck map sheet is covered by the "lags" unit (Figure 7). Coarse silcrete lag (up to 10 cm in size) is sufficiently abundant in places (particularly where basement is close to the surface) to form a conspicuous gibber plain e.g. the rise close to the Challenger Gold Deposit. The lag (i) appears to be associated, in part, with an underlying siliceous duricrust (ii) is polymictic and consists predominantly of silcrete with some quartz, calcrete, ferruginous material, rare well-rounded exotic clasts and weathered rock (saprolite) and (iii) is underlain by thin stony soil overlying a siliceous duricrust. Finer lag appears to be locally re-worked by fluvial action into broad sheetwash deposits. Other units such as alluvial and lacustrine sediments are only minor components of the regolith-landform composition (Figure 7).

On a regional scale, subdued upland areas form islands or ridges and are separated by broad depositional plains that host narrow, shallow ephemeral drainage systems in their lowermost parts. The uplands mostly represent weathered Archaean remnants but their true character is mostly hidden by colluvial and aeolian sediments. Challenger is located on such an upland, where the local relief is <50 m. To the south west, massive (>100 m high) Eocene dunes of the Great Victoria Desert form two very broad (>10 km) near parallel ridges several hundred kilometres in length.

Beneath the depositional plains, numerous small palaeochannels have been largely in-filled by Cainozoic and possibly Mesozoic sediments. These form regionally-significant palaeochannel systems down drainage and are partly filled with older sediments (*e.g.* Permian) that eventually drain to the Eucla Basin located to the SW. Two Permian channels (>100 m deep and filled with sediments) have been located close to the Challenger Deposit using AEM. One of the palaeochannels is located beneath a current drainage line whereas the other is beneath a low rise, signifying topographic inversion (see Section A.5.7). On a local scale, the depositional plains are dominated by sand spreads with clay and salt pans common, particularly in the lower areas. The uplands are dominated by low sand spreads with sand dunes of more relief (up to 5 m) in places. The sand dunes commonly have a core of calcrete that may be partly exposed following wind erosion (Figure 8). Bouldery "grey billy" or massive silcrete outcrops punctuate the landscape, particularly on the edges of the upland areas where they may form rare breakaways (Figure 9).

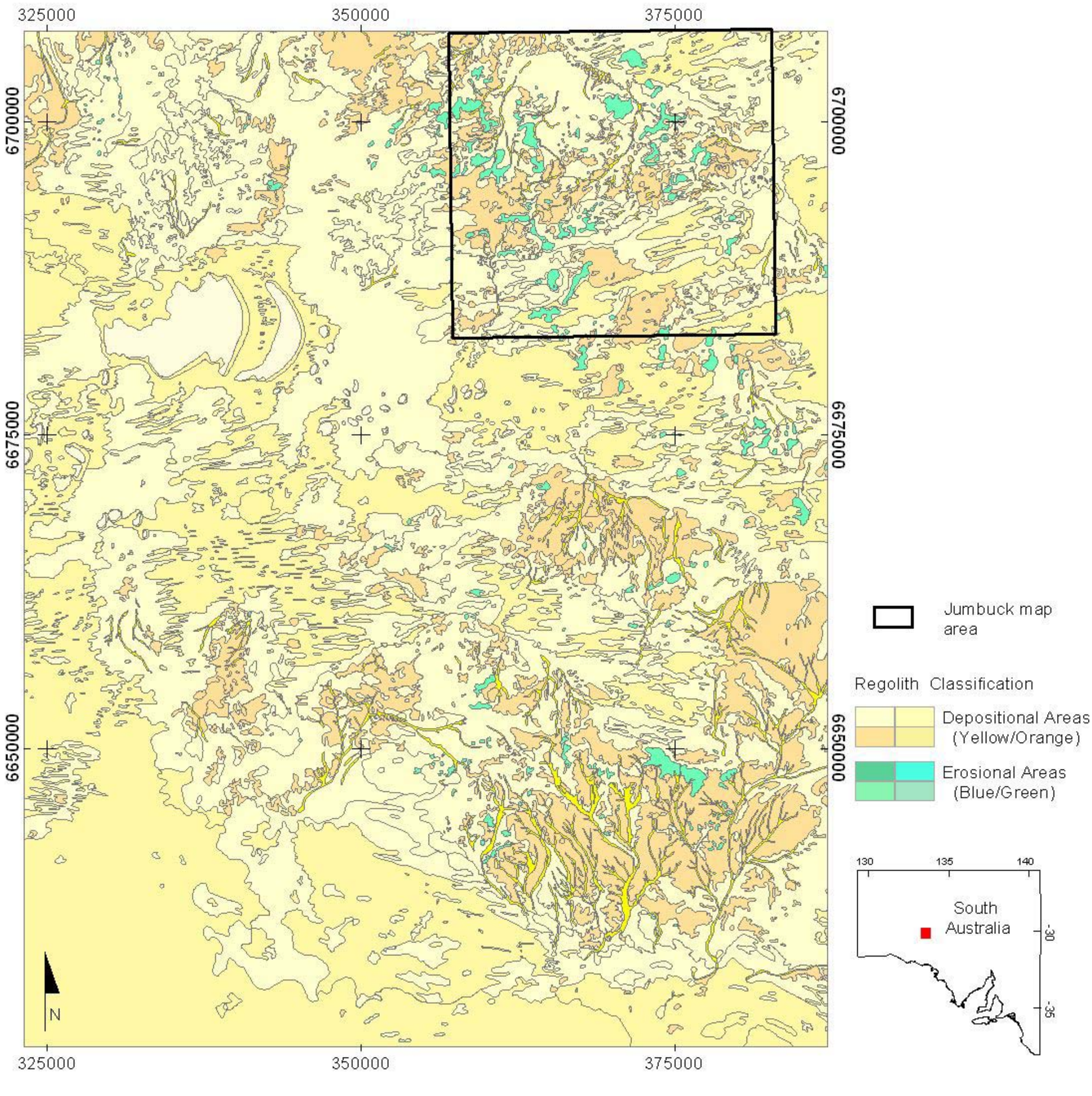

Figure 5: Simplified regolith-landform map of Half Moon Lake. For details of the regolith classification, see Wilford and Craig (2001).

Figure 6: (Left) Colluvial sediments: silcrete outcrops amongst sandy-clay soil over thick (15 m) transported overburden. (Right) Aeolian sediments: low vegetated dunes with minor calcrete and siliceous lag.

Figure 7: (Left) Lacustrine sediments: view of clay pan (middle ground) and lag strewn surface (foreground). (Right) Lags: view across Challenger deposit showing lag in foreground and sparse vegetative cover.

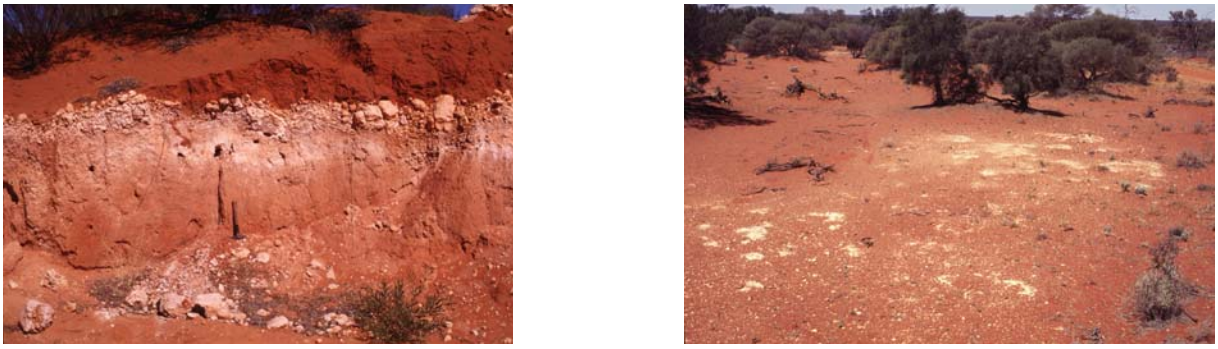

Figure 8: Sand dunes. (Left) Profile through shallow dune showing calcrete. (Right) Exposed calcrete sheet amongst sand dunes.

Figure 9: Silcrete breakaways. (Left) Cockatoo Ridge 20 km NE of Challenger Gold Deposit. (Right) unnamed breakaway (424602E 6645764N).

3.3 Gawler Craton regolith profile characterization

The regolith was studied in detail along a 1.5 km drill traverse (toposequence) across the Challenger Deposit (Figure 10; section A.5). The regolith line traverses two major regolith units: the *in situ* unit consisting of Archaean Christie Gneiss, intensely and deeply weathered to saprolite, and the transported unit consisting of fluvial deposits of Cainozoic or earlier origin.

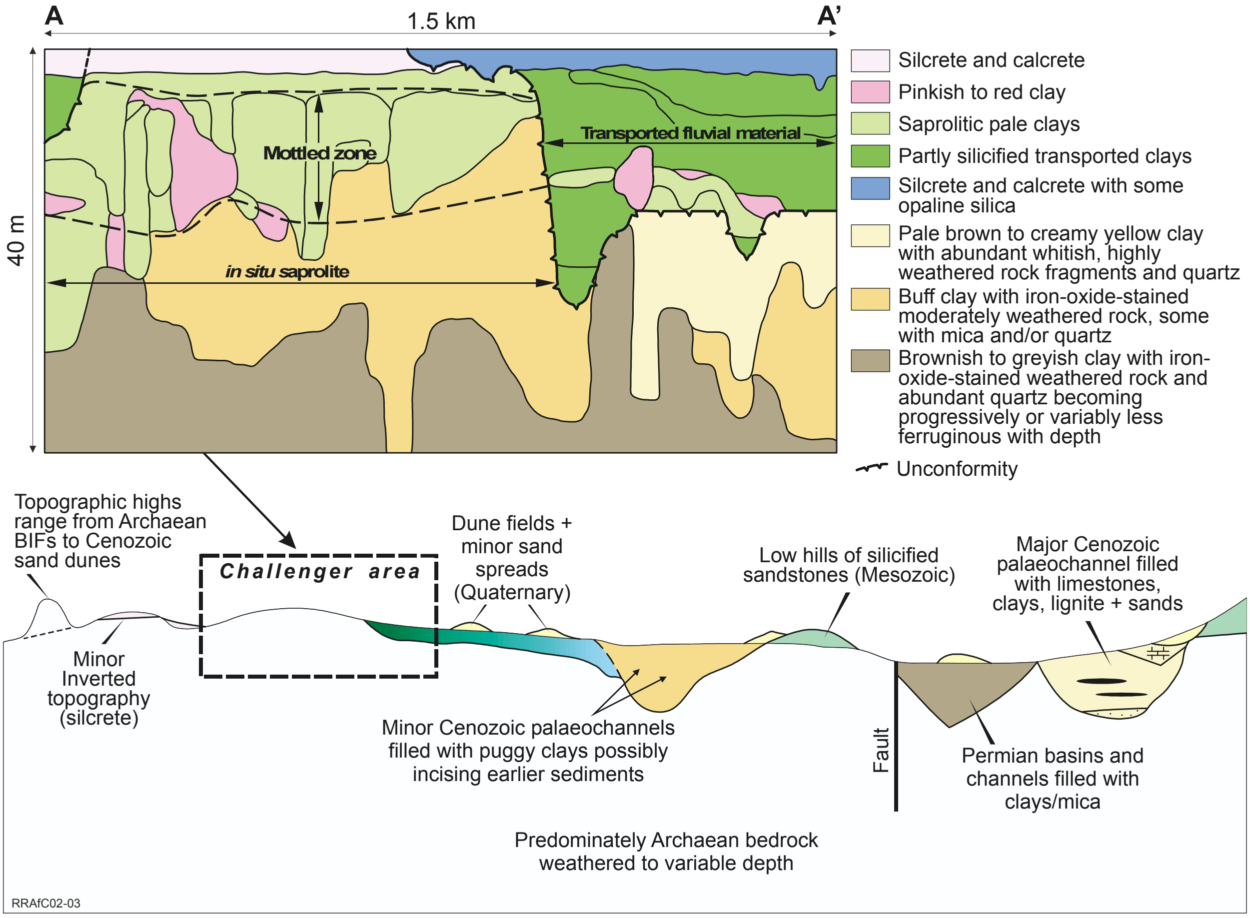

Figure 10: Idealized section through the western Gawler Craton with Challenger detail inset. Cenozoic palaeochannels and Permian basins may have sediments up to 100 m and several hundred metres thick, respectively. Dune fields may have sedimentary sequences in excess of 100 m thick.

In situ regolith unit. The *in situ* regolith broadly consists of a calcareous and siliceous hardpan (0–3 m thick) underlain by variably coloured (mainly yellows and reds) or pale clays, partly ferruginous weathered rocks, commonly with abundant quartz, grading to less ferruginous saprolite and abundant quartz with depth. Micas are common throughout and are found in highly weathered and moderately weathered bedrock. The boundary between highly weathered (mostly clay) and moderately weathered (containing appreciable quantities of partly weathered rock(coarse saprolite)) is highly variable, but commonly lies between 20–40 m (Lintern and Sheard, 1998).

In the upper regolith (0–6 m), weathering has yielded a generally pale-coloured clay-rich saprolite. The clays are predominantly kaolinite, illite and smectite, with residual quartz fragments and clasts, and have been over-printed by a series of Fe oxides and variably cemented by silica and carbonate. Concretions, such as pisoliths, are rare. Within the top 6 m, saprolite of relict weathered crystalline basement gneiss may contain more resistant minerals such as quartz, zircon, ilmenite, graphite, tourmaline, rare garnet and some biotite can be observed in these saprolite fragments. Some of the clay-rich saprolite display features consistent with surficial mechanical break up and dislodgment, to form locally derived slope scree-talus breccias, variably cemented with siliceous and calcareous material. These can contain rounded, resistate mineral grains which have been incorporated, via surficial shrinkage cracks, deeper into the *in situ* profile (Lintern and Sheard, 1998).

Transported regolith unit. The transported regolith occurs principally in the eastern part of the section and consists, from the surface down to ~3 m, of calcrete, silcrete and/or hardpan; from ~3 to ~16 m, white and pink coloured, variably silicified clays and silt (porcellanitic) dominate. Underlying some of the lower portions of the silicified unit are brightly-coloured yellow and red clays of up to 3 m in thickness. Incising the weathered basement at the base of the transported unit are two minor channels, extending down to ~20-25 m. The western (deeper) channel is filled with partly silicified white clay becoming silcrete with depth; this silcrete differs from that found near and on the surface because it contains few quartz clasts. The eastern (shallower) channel is mostly filled with clay (Lintern and Sheard, 1998).

Sediments within the upper part of the transported unit (0–6 m) consist of interdigitating lenses of gravel, sand, silt and clay. The coarser-grained clasts are characteristically subrounded to well rounded, in contrast to the angular quartz fragments of the saprolite. Sedimentary structures, including planar bedding and cross-bedding, are preserved in "grey billy" silcrete outcrop. Similar features are preserved in sub-surface silcrete blocks and corestones. Grains within the silcrete are dominantly well-rounded to subangular quartz, similar to those occurring in the weathered basement. Rare silicified wood (some opalized) consisting of branch and twig fragments, occurs within this palaeochannel sand sequence (see Section A.17.4). Chemical over-printing of this fluvial sequence in several cycles has occurred with the introduction of silica to form silcrete (porcellanite and opaline forms), carbonate, minor gypsum and minor Fe and Mn oxides (Lintern and Sheard, 1998).

3.4 Western Gawler Craton surficial regolith materials

3.4.1 Soils

Soils are predominantly Late Quaternary. Younger sandy-textured soils dominate and have only a small to moderate horizonal texture contrast, minimal pedogenic differentiation, occurring mostly with the sand spreads. However, the older and more pedogenically-organized soils are developed on or near weathering substrates or clay pans. Clay-rich soils are of limited extent along the regolith line and tend to be restricted to drainage sinks (clay pans); most have an alkaline reaction trend and are strongly sodic, with sandy to loamy surface textures (Lintern and Sheard, 1998; Northcote and Skene, 1972). Many soils away from the sand spreads and dunes are gibber-clad primitive lithic-rich lithosols inerosional areas or over alluvial deposits. Soil surface colours were within quite a narrow range, from the reddest (moderate reddish brown, 10R 4/5) to the yellowest (light brown, 5YR 6/6).

3.4.2 Siliceous materials

Siliceous materials occur in a variety of forms including silcretes, claycrete (Mason and Mason, 1998), hardpan and opaline forms (Figure 11-Figure 14). "True" silcretes (vitreous lustre and conchoidal fracture) are common throughout the western Gawler Craton and are commonly associated with rises or plains. They are indurated, extremely brittle and break with a conchoidal fracture where the fracture propagates across the cemented grains rather than around them. Freshly broken silcrete shards commonly have a pungent odour, vitreous sheen, and are very sharp. Silcrete is a secondary cementation feature imposed on existing sediments or weathered rocks. Silcrete covers much of the Challenger area as either outcrop or subcrop.

A variety of *in situ* and transported regolith materials have been affected by secondary Si cementation leading to hardpan, siliceous saprolite and indurated weathered argillaceous material. At Challenger, the base of Si infiltration appears to reach 3 m depth within the *in situ* regolith but increases to >6 m within the transported unit. Silicification of highly sandy transported to gritty saprolitic materials have mostly yielded massive 'true' silcretes, whereas silty to clayey materials have yielded porcellanite, hardpan and claycrete. Sedimentary structures were observed in the silcrete outcrop areas in the transported regolith and included cross-bedding and planar lamellae. Silicified wood fragment fossils were also observed as float (see Section A.17.4).

Shallow (<3 m deep) pit exposures at Challenger revealed an underlying high degree of complexity of siliceous cementing, brecciation, re-cementing and textural variability not evident from the surface. In addition to the siliceous variations, the first 2–3 m of the upper regolith is strongly overprinted by pedogenic carbonates. Opal and porcellanite dominate the profile below 1 m in palaeochannel sediments (under the massive 'grey billy' silcrete), whereas opaline silica is subdominant to minor within silicified saprolite. Generally, much of the massive silcrete is coloured grey to greenish grey to pale yellow-brown, but ferruginous inclusions and staining can yield strong yellows, reds and browns. The porcellanite can be white, cream, yellow and brown; the potch opal can be translucent-greyish, white, cream and yellow. Manganese oxides occur as black, three dimensional dendrite inclusions in some of the opaline silica.

Two generations of silicification are evident although there are no readily observable stratigraphic sequences separating them. However, there is macroscopic evidence that the first generation silcrete has been in-part disrupted by surface processes, mostly mechanical, but also including some minor fluvial-colluvial activity in its upper portions. The second generation silica cementation is mostly isotropic opaline to hyaline in nature and occurs as cutans, layered overgrowths, veinlets and commonly as a clast-cement in breccias. The second event has re-cemented the silcrete scree-talus and colluvium derived from the earlier forms into complex breccias. Very late hyaline silica has formed in some cracks within the pedogenic carbonate.

Clay cementation (hardpan or claycrete) occurs at both the macroscopic and microscopic level. It presents as dense hard mats, blocks and cutans and is commonly associated with cryptocrystalline and isotropic silica. Clay minerals appear to have either deposited from soil water solutions and/or suspensions to form a pervasive cement or cappings to larger clasts. Colours range from cream to yellows and browns and may have dark brown or black Mn staining.

Figure 11: (Left) Loose and cemented silcrete pebbles, some cut to show cutans. (Right) Potch opal some with porcellanite-altered margins (Photographs from Mason and Mason, 1998).

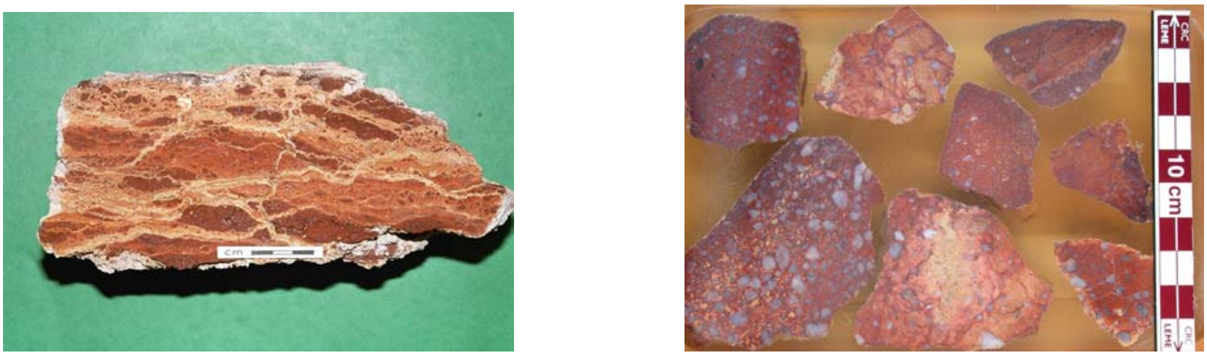

Figure 12: (Left) Calcareous siliceous hardpan (Mason and Mason, 1998). (Right) Sawn faces of red-brown coloured silcrete pebbles with abundant coarse quartz grains.

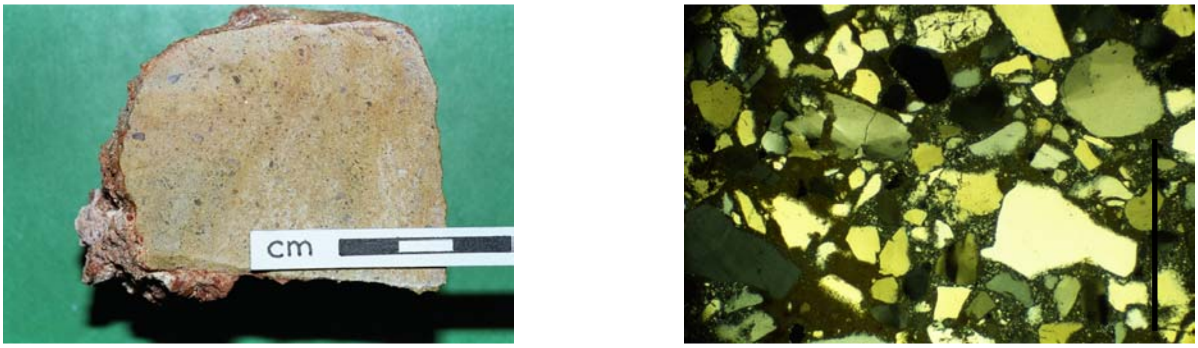

Figure 13: (Left) Silcrete pebble sawn surface. (Right) Photomicrograph of sample on left. Angular fragments of quartz lie in a cement of microcrystalline quartz with diffuse dark patches (lower left) of submicron possibly leucoxene or anatase – cross polarisers. Bar length is 1 mm. (Mason and Mason, 1998).

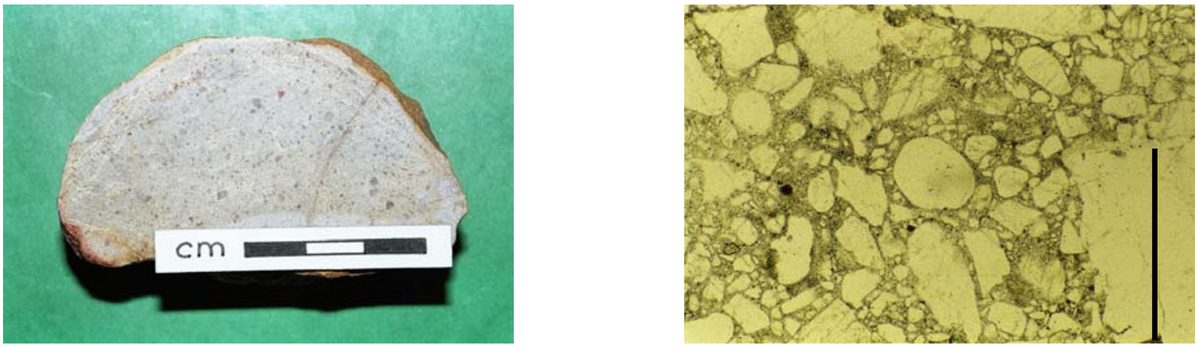

Figure 14: (Left) Silcrete pebble – sawn surface. (Right) Photomicrograph of sample on left. Rounded and angular quartz fragments lie in cryptocrystalline siliceous cement pervaded by submicron dusty material (possibly leucoxene/anatase) – plain polarized light. Bar length is 1 mm. (Mason and Mason, 1998).

3.4.3 Ferruginous materials

Ferruginous materials occur in the Challenger area and elsewhere in the western Gawler Craton but they are not abundant. These materials include: ferruginous lag, ferruginous saprolite outcrop, gravel, granules, fracture linings, rock surface coatings, cutans, minor cements and staining (Figure 15). On the ground surface, the most obvious ferruginous materials are in the form of (i) dark brown to black buck-shot gravel lag (ferruginous granules, Figure 16), (ii) dark brown to near black ferruginous nodules (up to several cm), and (iii) 'desert varnish' and/or a pervasive stain on lags of silcrete and lithic clasts. Subsurface ferruginous materials comprise yellow, brown and red staining, mottles, brown to dark brown gravels, pisoliths and granules as isolated grains/granules or in lens-like aggregates, and as incipient nodules (yellow-brown to brown). Most ferruginous materials have low Fe contents (<10%) although some ferruginous granules and nodules have higher Fe contents (up to 43% as Fe). There are rare ferruginous saprolite outcrops in parts of the western Gawler Craton (Figure 16). Isolated BIF ridges occur in parts of the western Gawler Craton and give range to a particular type of ferruginous material including outcropping saprolite, nodules and ferruginous granular lag. In the southern part of the Gawler Craton (*e.g.* western Kangaroo Island, southern Eyre Peninsula and southern Fleurieu Peninsula), lateritic duricrust is locally abundant.


Figure 15: (Left) Sawn faces and outside appearance of ferruginous saprolite occurring as lag (photographs from Mason and Mason, 1998). (Right) Coarse lag (>2 mm) of calcrete, silcrete and ferruginous granules.


Figure 16: (Left) Ferruginous granules blanket the surface 2 km south of Challenger. (Right) Ferruginous saprolite outcrop (426371E 6643908N).

3.4.4 Calcrete

A wide variation in calcrete morphology occurs within the western Gawler Craton (Figure 17-Figure 22). Loose and aggregated nodules and pisoliths, earthy segregations and powders, and laminated and massive forms develop within substrates of saprolite, residual soils and sand. Many of the indurated forms have complex internal fabrics and structures, suggesting cyclic carbonate deposition, dissolution, disruption and re-cementation. Calcretes commonly contain saprolite (Figure 17), hardpan (Figure 20) or silcrete (Figure 22) as inclusions, which affect their chemical composition. In general, the morphology reflects the texture, porosity and properties of the host material diluted by added carbonate and modified by the precipitation process. Colours ranged from creams to pale pink and pale grey to rich reds and browns.

Most indurated calcrete is found at the base of soil profiles, on top of underlying silcrete or other permeability barriers. Indurated sheets ranged from 10–40 cm in thickness and can form book-like stacks of friable plates up to 1-2 m thick. Commonly the thicker units have horizontal partings and vertical fractures where plant roots are present. The partings generally have smooth upper surfaces, rough under sides and dusty to loamy carbonate in between the plates. In clay pans in the Challenger area, an earthy carbonate powder forms a thin layer 5–15 mm thick (at the clay-silcrete interface, ~0.5 m depth) beneath non-calcareous clay. This is possibly due to leaching of carbonate from the clay by ephemeral ponded water.

Calcrete and similar micro- to cryptocrystalline carbonate also impregnate silicified upper regolith to a depth of ~1.5 to >4.0 m. Most of the indurated morphologies and the dusty to loamy forms expressed in the soil profile are repeated within the silcrete. To accommodate the added carbonate, the silcrete is commonly forced apart along partings, joints and fracture forming a complex breccia or a pseudo-bedded siliceous rock with a strong calcareous nature.

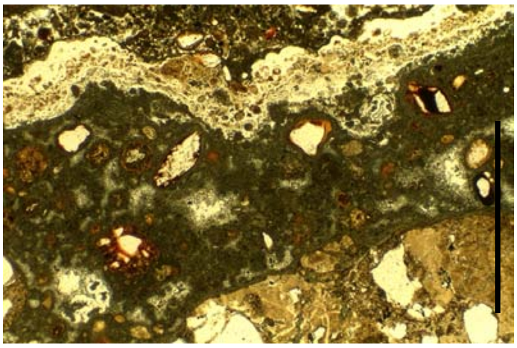

Figure 17: (Left) Sawn cut surface showing saprolite-bearing calcrete. (Right) Plane polarized light image of saprolite fragment (bottom right) overgrown by cryptocrystalline (dark grey) and microcrystalline (colourless) calcite and a colloform lamina of opaline silica (colourless, upper part of view). (Mason and Mason, 1998).

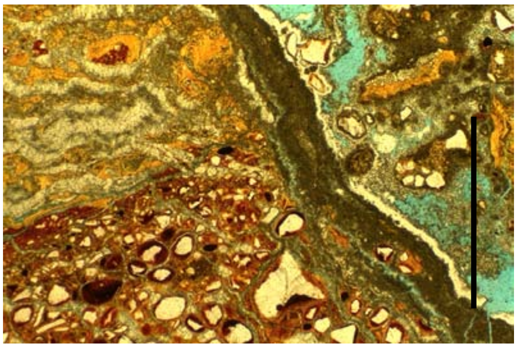

Figure 18: (Left) Sawn surface of claycrete-bearing laminated calcrete. (Right) Plane polarized light photomicrograph of specimen on left showing that a large fragment of claycrete (bottom) has suffered partial replacement by calcite (colourless interstitial fillings) and is cut by calcite veins (top left). These materials have been overgrown by dense cryptocrystalline calcite (turbid dark grey, right), with thin opaline silica lamina (Mason and Mason, 1998).

Figure 19: (Left) Saw cut surface showing complex nodular and laminar calcrete. (Right) sawn cut surface showing saprolite with coating of calcareous cement. (Photography from Mason and Mason, 1998).

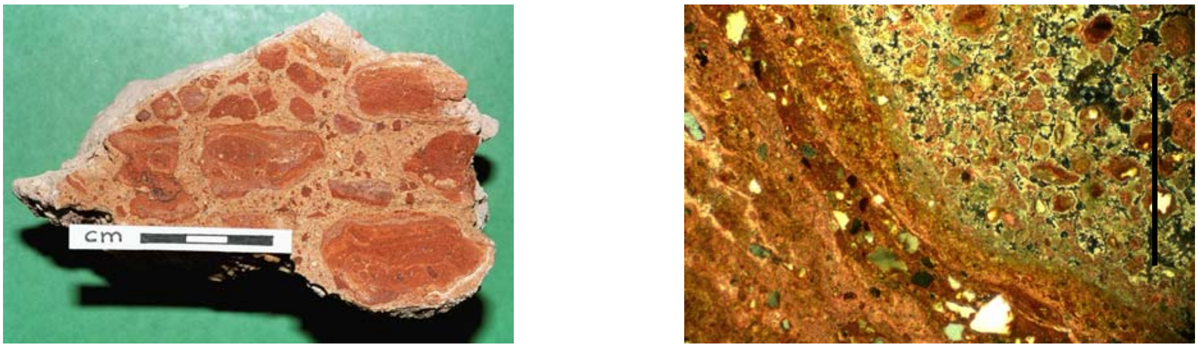

Figure 20: (Left) Sawn surface of claycrete(hardpan)-bearing calcrete. (Right) Photomicrograph of layered parts of the sample composed of cryptocrystalline dense calcite (left) and more porous microcrystalline calcite (right) with minor pore-filling dolomite. Bar is 1 mm. (Mason and Mason, 1998).

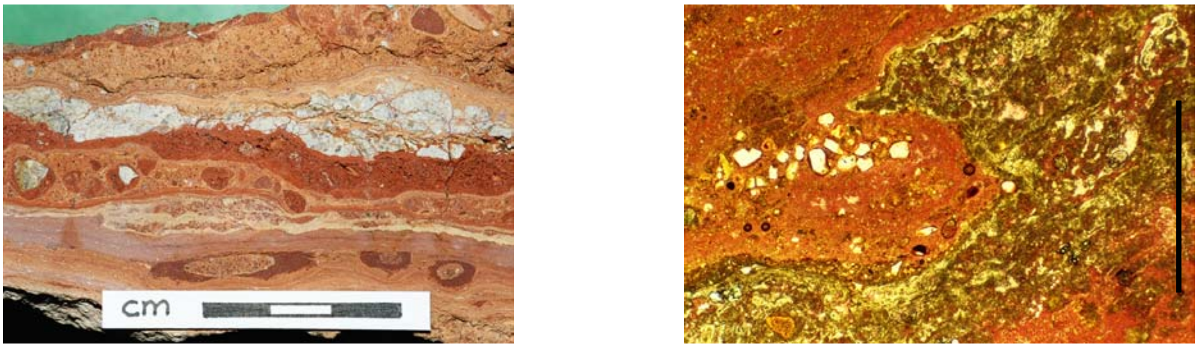

Figure 21: (Left) Sawn surface of siliceous laminar calcrete. (Right) Photomicrograph of sample on left showing dense cryptocrystalline calcite (upper left) with small quartz fragments and a clast-free lamina of opaline silica (small colourless ragged patches). Bar length is 1 mm. (Mason and Mason, 1998).

Figure 22: (Left) Sawn surface of porcellanite-bearing calcrete. (Right) As for left but potch opal remnant in core of some porcellanite. (Mason and Mason, 1998).

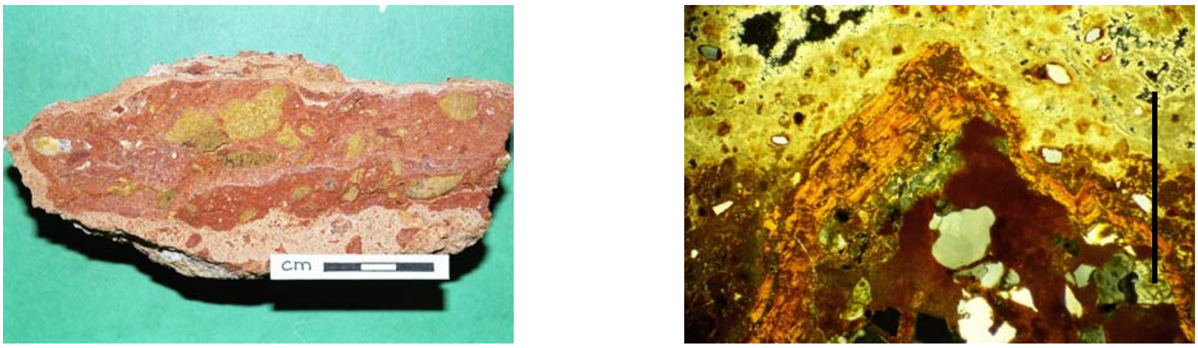

Figure 23: (Left) Sawn surface of calcareous claycrete (hardpan) containing ferruginized saprolite. (Right) A large angular fragment of claycrete (bottom) is overgrown by laminated clay (orange), and cemented by porous microcrystalline calcite (top) with ragged remnant pores (top right). Bar length is 1 mm. (Mason and Mason, 1998).

3.5 Curnamona Craton Regolith

3.5.1 Introduction

Regolith studies of the Curnamona Craton were confined to the Olary Regolith Project and comprised two 1:100000 scale regolith-landform maps (summarized in Figure 24) and four geochemical studies with detailed regolith-landform maps. Studies were not extensive at any sites and so the following synthesis is restricted in scope.

3.5.2 Regolith-landforms

Regolith-landform mapping in the Olary area was primarily based on satellite TM7 imagery and radiometric data, with reference to aerial photography. Based on the interpretation of the satellite images and field observations, the regolith-landform maps of Olary (6933) and Anabama (6932) were produced to the scale of 1:100 000, covering about 5170 km². Three selected sites (Faugh-a-Ballagh, Blue Rose, and Wadnaminga), each about 3 x 3 km in size, were mapped at 1:5000. The fourth site (Olary Silver Mine) was not extensively mapped.

Regolith classification is based on the erosional and depositional regimes modified from Anand *et al.* (1989, 1993, 1997; RED scheme). Lateritic materials or ferruginous duricrusts are scarce and *in situ* units belong wholly to the erosional regime, comprised of materials developed within saprolite or bedrock. Transported units were classified within the depositional regime. The percentage area covered by the regolith landform units are described in Table 2

Table 2: Regolith landform units (as % coverage) for Olary and Anabama map sheets (derived from Skwarnecki *et al*., 2001)

Regolith-landform unit	Olary	Anabama
Transported- colluvial sediments	23%	47%
Transported - alluvial sediments	9%	24%
Erosional - bedrock-saprock-saprolite	70%	29%

The two adjacent map areas contrast markedly in the proportion of regolith landform units. The Olary are is dominated by bedrock-saprock-saprolite (erosional) that crops out in 70% of the area compared with Anabama where only 29% of the mapped area has this unit. Anabama map sheet incorporates part of the northen Murray Basin and is dominated by depositional units that account for 71% of the mapped area.

Although the distinction between erosional and depositional units is straightforward in most cases, care should be taken when examining locally-derived sediments on saprock or saprolite. Such sediments are derived from the weathered rocks directly underneath and thus, *senso stricto*, *in situ* materials seldom occur. However, if these sediments have moved only for a short distance from their origin and still reflect the composition of source bedrock, they should be classified in the erosional regime. For example, a thin layer of colluvium mixed with locally-derived, weathered materials is regarded as belonging to the erosional regime.

Erosional regime. Units of the erosional regime occur in a variety of landform settings (*e.g*., high hills, hills, low hills, ridges, low rises and undulating erosional plains), and are developed on rocks of all ages. For example, Burra Group rocks tend to form low hills and long ridges, or the Anabama Granite forms prominent hills, with little regolith derived from the mechanical and chemical breakdown of the granite. However, not all erosional landforms are as prominent, *e.g.*, colluvial and wash plains comprised of locally-derived detritus). On many of these erosional units, outcrops are abundant and soils are typically skeletal (Figure 25). Thick regolith is relatively rare. Carbonate (calcrete) is rarely developed in regolith units on Olary Domain rocks, but is relatively abundant over Adelaidean rocks (Figure 26). The reasons for this are uncertain, but may involve greater rates of erosion in the Olary Domain, where there is generally more relief, such that calcrete horizons have not been preserved. Another possibility is that sources of Ca (*e.g*., carbonate rocks) are more abundant in Adelaidean terrains.

Depositional regime. Regolith-landform units of the depositional regime include alluvial fans, floodplains, and modern stream channels. These features are generally related to modern drainages and occur in areas of subdued topography (Figure 25). An exception is the valley silcrete and silicified sands and gravels, which may form low rises. Carbonate is relatively abundant in brown soils and alluvium, including those in the Olary Domain.

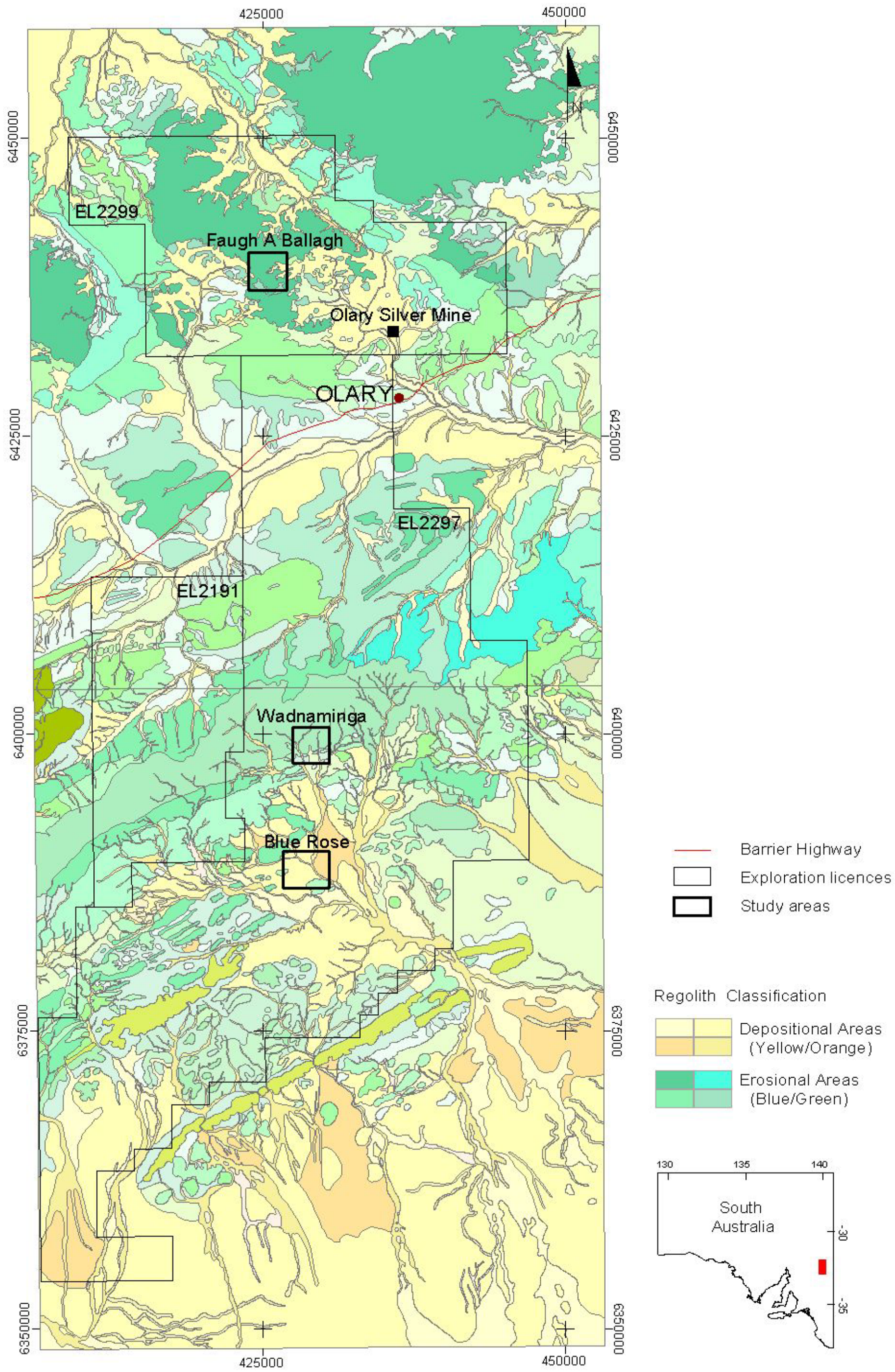

Figure 24: Regolith-landform map showing the four study areas and the exploration licences held by sponsoring company Lynas Corporation Ltd in the Olary area. The two regolith-landform maps (Anabama and Olary 1:100000) that comprise this Figure show the depositional and erosional regolith units. Full unit descriptions and map plans covering this area can be found in Skwarnecki *et al*., 2001.

3.5.3 Regolith-profile characterization

Drilling information was not readily available for most of the sites investigated. A small number of holes at Blue Rose (see Section A.13) indicate that saprolite is highly variable in lithology, mineralogy and thickness (0 to >60 m) and overlies a diverse bedrock ranging from carbonates to siltstones to granites.

At Blue Rose, the transported unit was comprised of colluvial gravels cemented by calcrete/silcrete (~2 m thick) underlain by variable thicknesses of brightly coloured commonly plastic clays and lithic gravels (siltstone, quartz, ferruginous lithic fragments) with chalcedony veining. Calcite is most abundant in the uppermost 2 m, but may persist further down the profile.

3.5.4 Surficial regolith materials

The younger uplifted rocks of the Faugh-a-Ballagh and Wadnaminga study areas have not been subjected to the same intensity of weathering and erosion as those at study sites in the western Gawler Craton. Surficial regolith materials vary but in slopes and rises of erosional units, gravels, pebbles and boulders of partially weathered rock litter the surface and reflect the lithology of the underlying bedrock; soils are skeletal and calcareous (Figure 25). At Wadnaminga (Figure 26) and Blue Rose, exposures in pit shafts and diggings, creek beds and costeans were highly calcareous as were some transported units at Faugh-a-Ballagh. A variety of calcrete types was noted, including nodular, powdery, massive (replacing bedrock), coatings and, (at Wadnaminga in particular), as joints on bedrock. Small creeks in hilly terrain at Faugh-a-Ballagh were choked with fine lags (magnetic and non-magnetic), which may be used as a sampling medium.

In transported units, lower slopes (*e.g.* at Wadnaminga) have thicker colluvium and alluvium and less coarse material than upper slopes, and merge into units of greater thicknesses where the relief is monotonously flat (*e.g.* Blue Rose, Figure 25); here, soils tend to support a finer lag. Alluvial deposits in the larger creeks are commonly strewn with large boulders (> 1 m) reflecting high energy levels.

3.6 Summary

The two study areas have contrasting regolith-landforms, regolith stratigraphy and regolith materials due to many factors including differences in rock-types and orogenic history; these are summarized in Table 3.

Table 3: Regolith characteristics of the Curnamona and western Gawler Cratons.

Feature	Curnamona sites	Western Gawler sites
Landforms	Variable with high relief and minor creek lines in the north and flat terrain with larger creeks and rivers in south.	Generally flat to undulating terrain with ranges of quartzite or BIF provided some higher relief. Creek lines poorly developed. Palaeochannels common. Silcrete breakaways. Seif dunes and sand spreads.
Transported cover	Variable. Transported overburden commonly comprised of coarse colluvial materials.	Transported overburden commonly clay-rich.
Regolith materials	Soils are commonly clay-rich (commonly poorly developed on bedrock). Calcrete commonly nodular to powdery. Lag on surface and collects in creek lines to provide stream sediment sample.	Materials include: soil (sandy to sandy clay); calcrete (laminar, blocky and frequently thick); silcrete; hardpan.
Bedrock	Variable. Sedimentary rocks common.	Mainly gneiss.

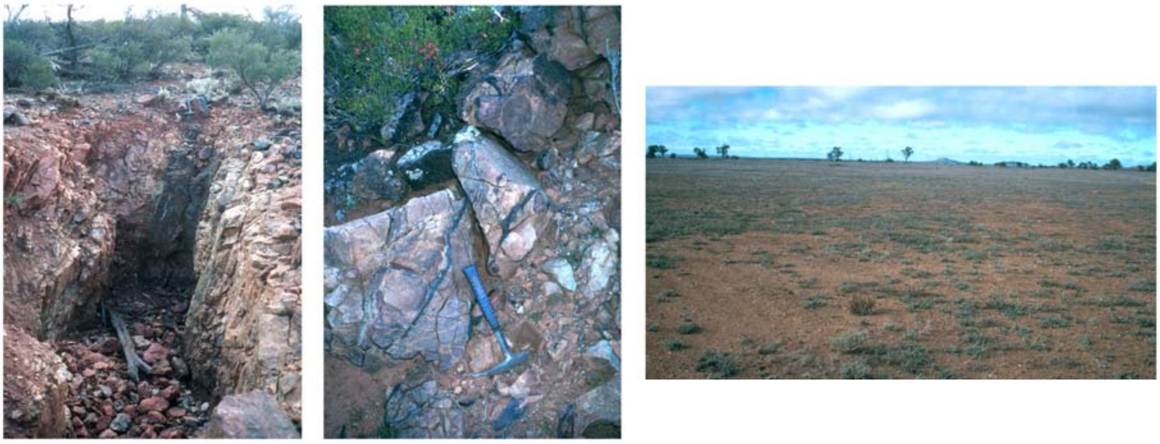

Figure 25: (Left) Old working on chalcopyrite-bearing ironstones vein at Faugh-a-Ballagh with malachite staining; the vein occurs within a coarse-grained quartz-feldspar rock with a pegmatitic texture. (Centre) Brecciated felsic rock with magnetite veinlets at Faugh-a-Ballagh. (Right) General view of Blue Rose prospect, illustrating the flat topography. (From Skwarnecki *et al*., 2001).

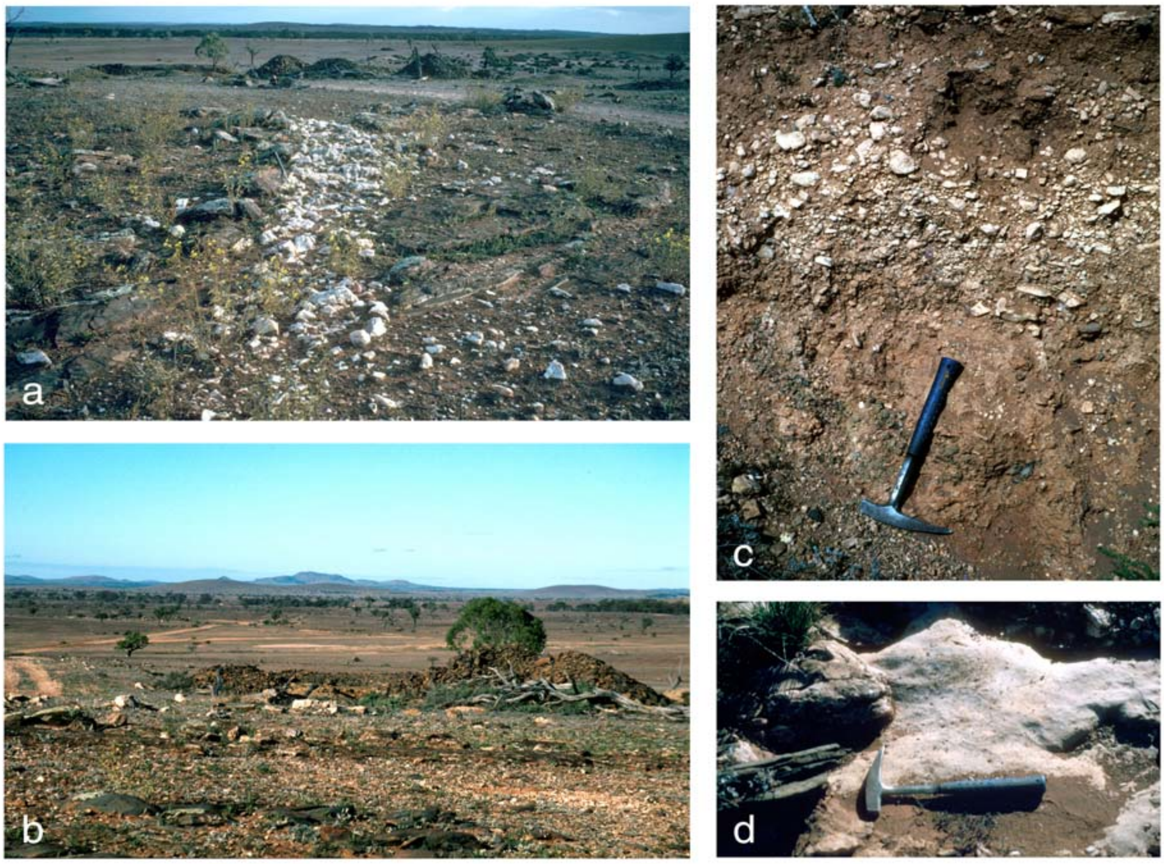

Figure 26: Wadnaminga. (a) A north-south 'indicator' vein at Great Eastern mine; (b), siltstone outcrops and abundant lag at Great Eastern mine; in the middle distance, the hills are formed of Burra Group metasedimentary rocks, whereas the hills on the horizon are formed of Anabama Granite; (c) the soil profile at Great Eastern: an upper horizon of calcareous soil, overlying a layer of nodular calcrete, which itself sits on slightly weathered siltstone; (d) calcrete in creek cementing siltstone and quartz fragments. (From Skwarnecki *et al*., 2001).

4 SUMMARIZED GEOCHEMICAL CASE HISTORIES

Several sets of regolith classification models have been suggested to help provide a framework for stratigraphy, relief, climate and understanding landscape evolution. This approach has enabled particular exploration case histories to be classified according to criteria determined for a particular model to facilitate understanding and to make valid comparisons between case histories. One of the more useful models for (sub-) tropical terrains has been proposed by Butt and Zeegers (1992) who broadly divided the regolith into three Types (A, B and C) based on the degree of preservation of the "complete" weathering profile. Type A models are those in which the profile is complete i.e. fully preserved. The uppermost residual horizon is commonly lateritic duricrust, or soils developed over or from it. Type B models are those in which the profile is partially truncated by erosion (lateritic duricrust absent), so saprolite with quite different geochemical characteristics from the ferruginous horizon forms the uppermost horizon and the parent material of residual soils. Type C models are those in which the earlier regolith has been entirely eroded and bedrock is either buried by transported overburden, outcrops at surface or has thin or skeletal residual soils forming directly from it. To reflect the emphasis on the substantial effect transported overburden has on the exploration geochemistry of weathering mineral deposits, a "T" Type model has been added (Lintern, 2002) and used in the case history studies that follow. Thus, the models of Butt and Zeegers and the Type T model can be summarized below:

1. Type C: saprock-bedrock host with thin mainly residual soil.
2. Type A: saprolite host with lateritic residuum.
3. Type B: saprolite host with no lateritic residuum.
4. Type T: transported overburden present over saprolite.

Geochemical studies were conducted at 16 sites and are described in order of commodity, regolith model (B, C or T) and, finally, depth of transported overburden (Figure 27, Table 4).

The case studies and other regional studies are summarized in the Appendices (A.1 toA.17).

Regolith-landform maps were constructed at 10 sites. Using the RED scheme (Anand *et al.*, 1989; Craig, *et al.*, 1992) the mapped areas were divided into Relict, Erosional and Depositional. The RED scheme, used extensively for construction and interpretation of regolith maps in Western Australia, was slightly modified for use in this project to provide a seamless 3D regolith framework. Lateritic residuum (relict regime) was absent from the case study areas examined although, at ET, some minor silcrete outcrops were mapped in the relict regime, to represent an *in situ* ancient weathered surface that the original definition of residual or relict was intended to represent.

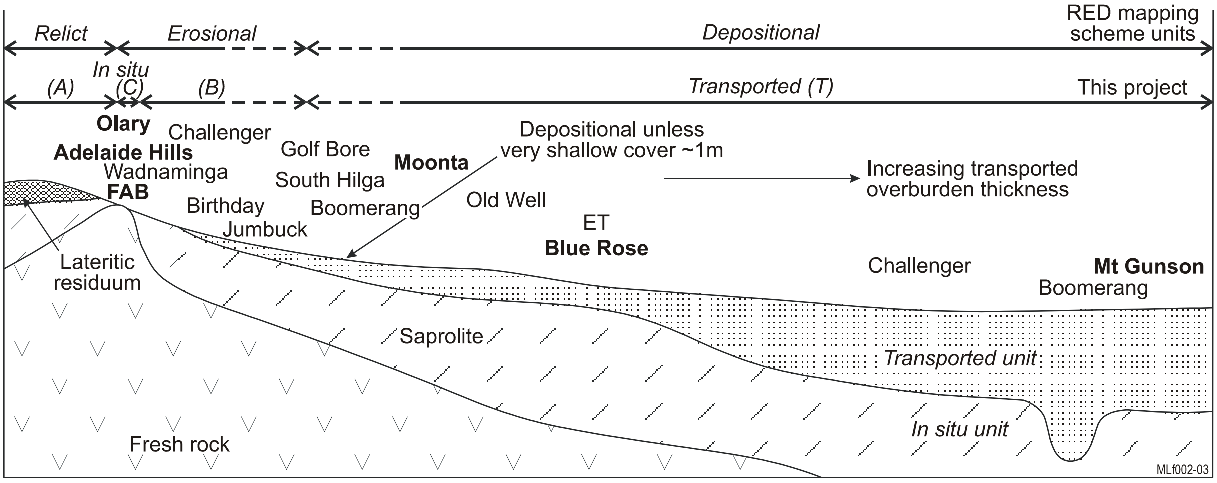

Figure 27: Schematic section showing location of summarized case studies with respect to the regolith profile. Case studies in bold indicate commodities other than Au.

Table 4: List of geochemical study areas and site characteristics. Regolith model refers to the main characteristics at each site: type B is partly truncated (no laterite present); type C has little regolith development; or type T is where transported overburden dominates the regolith.

Case study	Site	Metal	Regolith model	Depth of overburden	Depth to mineralization	R-L Map	Biogeochemistry	Partial leach	Other studies
1	Birthday	Au	B	<1 m	30 m	yes	yes	yes	
2	Wadnaminga	Au	B	<1 m	<2 m	yes	no	no	
3	Jumbuck	Au	B, T	1-5 m	20 m	no	no	no	
4	Monsoon	Au	B, T	<1-10 m	30-40 m	no	no	no	
5	Challenger	Au	B, T	<1 m/20 m	<2 m/20 m	yes	yes	yes	dating
6	South Hilga	Au	B, T	1-10 m	25-35 m	no	no	no	
7	Golf Bore	Au	B, T	3 m	20 m	no	no	no	
8	Boomerang	Au	B, T	5 m	20-40 m	no	yes	no	
9	Old Well	Au	B, T	5-10 m	20 m	yes	no	no	
10	ET	Au	B, T	<1-15 m	30 m	yes	yes	no	Hymap
11	Faugh-a-Ballagh	Cu	C	outcrop	0 m	yes	no	no	
12	Moonta	Cu	T	7 m	7 m	yes	no	no	
13	Blue Rose	Cu	T	9 m	9 m	yes	no	yes	
14	Mt Gunson	Cu, Co	T	30-70 m	30-70 m	yes	no	yes	
15	Adelaide Hills	Ag-Pb	C	outcrop	<2 m	yes	no	no	isotope
16	Olary Silver Mine	Ag	B	outcrop	<2 m	no	no	no	

5 DISPERSION MODELS

5.1 Gold mineralization

5.1.1 Introduction

The dispersion of Au and other elements was examined at several prospects including Birthday (Section A.1), Wadnaminga (Section A.2), Jumbuck (Section A.3), Monsoon (Section A.4), Challenger (Section A.5), South Hilga (Section A.6), Golf Bore (Section A.7), Boomerang (Section A.8), Old Well (Section A.9), Moonta (Section A.12) and ET (Section A.10). Geochemical dispersion characteristics at these sites can be summarized by reference to one or more generalized models that incorporate regolith, landform, bedrock and environmental factors. The purpose of the models is to (i) highlight similarities and differences between sites, (ii) simplify patterns of dispersion, and (iii) assist exploration in the sense that they may be able to be used predictively. The models are based, in the first instance, on the thickness of transported overburden. Subtle differences within the models may be due to other factors such as the presence of secondary cementation or accumulations. The robustness of the models is related to the volume and quality of data, and the number of case histories investigated *e.g.* the effect of gypsum was investigated only at Boomerang (Section A.8) and Golf Bore (Section A.7) and so the model presented may not be "typical".

5.1.2 Transported unit thin (<1 m) or absent (Type B)

Type B model relates to where the transported unit is thin or absent and so the *in situ* regolith (weathered bedrock) either outcrops or is covered by only a thin residual/skeletal soil. The soil may contain a proportion of material that has been introduced by fluvial, colluvial or aeolian processes. As for all models, calcrete is ubiquitous in the case studies examined but varies in type and thickness on a local scale. For this regolith type, the calcrete is often siliceous, nodular, laminar or occasionally massive in character. The more massive examples of calcrete frequently incorporate blocks of saprolite and the calcrete is merely a coating or has replaced, probably isovolumetrically, weathered bedrock. The calcrete overlies siliceous saprolite or a thin (few centimetres) transported unit, which is commonly characterized by the presence of rounded quartz and other clasts. However, at Wadnaminga (Section A.2), the siliceous unit is absent and calcrete is developed in residual soils to form coatings on the saprolite (after metasediments).

Surficial Au anomalies are strongest and easily identified for Type B regolith. However, what is often puzzling to the mineral explorer is the common situation where a calcrete anomaly has been established but drilling often does not immediately encounter mineralization. Typically, a zone of low Au in the underlying weathered *in situ* unit occurs and referred to as a pallid, leached or depleted zone, with underlying mineralization. This has been conceptualized as Au moving to the surface in groundwater which evaporates in the calcrete zone depositing metals. Examples from Western Australia largely refute this since Au at the surface is often found to be primary in character (summarized in Butt *et al.*, 1997; Gray *et al.*, 2001). Besides, groundwaters are commonly quite salty but chloride is not a major constituent of the calcrete zone, possibly except in valley situations. An alternative explanation is that Au occurring at the surface has been either concentrated residually from incomplete leaching in the regolith or that the groundwater has never reached the surface and left some Au relatively unaffected. Evidence for the latter comes from careful examination of the exploration data where even the most leached regolith still appears to contain some Au, albeit small in comparison with the mineralization with which it was once strongly associated, prior to the leaching. This Au is exhumed during erosion of the saprolite and is in sufficient concentrations to explain the anomalies that are observed.

The highest Au concentrations in surficial materials are present at Challenger (Section A.5) where Au mineralization virtually outcrops in quartz veins; leaching here is clearly imperfect. Gold occurs in silcrete, calcrete and soils and it is thought that armouring of Au within the silcrete and quartz veins has partially protected it from leaching, or the groundwater was never this high, and thus prevented dilution of the anomaly. The auriferous quartz veins persist into the deeper regolith and so will continue to provide "new" material to the surface when the present surface erodes.

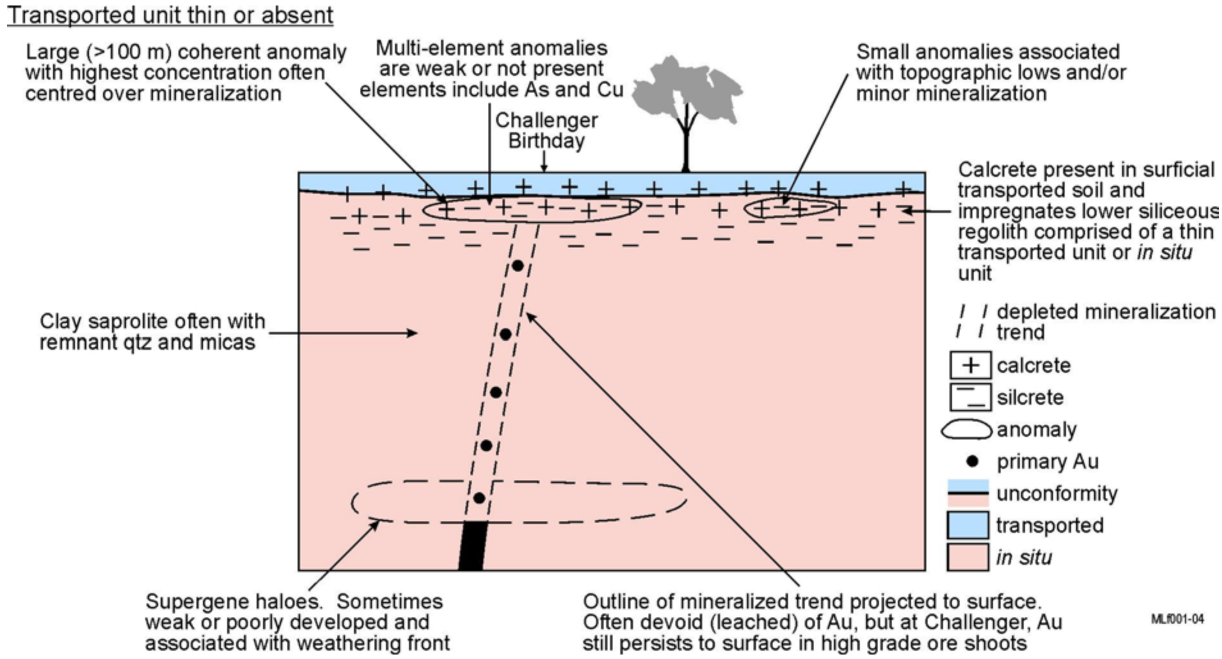

Figure 28: Transported unit is thin or absent (Type B). Exemplified by regolith at Challenger Gold Deposit and Monsoon, Birthday, Jumbuck and ET Gold Prospects.

5.1.3 Transported unit >1<5 m thick (Type T).

Where the transported unit is <5 m thick, colluvium or alluvium covers the *in situ* regolith. The *in situ* regolith usually retains its silicified upper part prior to being buried although some stripping may have occurred prior to burial. Thus, any Au or pathfinders present in the upper regolith may be preserved within the silicified unit. Calcrete is ubiquitous but is developed primarily in the transported unit indicating that it is a relatively recent accumulation. Where calcrete is well developed and the transported unit thinner, carbonate may extend into the *in situ* unit. Calcrete is involved in the dismantling of the silicified upper regolith.

Boomerang has wind blown gypsum (Section A.8). Its presence is due to proximity of salt lakes and its local distribution has not been fully determined. It appears to be restricted to the southern end of the traverse where there is a subtle rise probably concealing a basement topographic high. Investigations at Boomerang suggest that gypsum or gypseous clays may hinder the formation of a geochemical anomaly over mineralization. At Golf Bore (Section A.7), the gypsum is located across the siliceous unconformity and in the upper *in situ* regolith. Gold concentrations are lower in the gypsum horizon (relative to the surface expression) but since Au is patchily distributed in the upper regolith the reductions may not necessarily be due to dilution.

Some geochemical anomalies over mineralization at ET (Section A.10) and Golf Bore (Section A.7) may be due (at least in part) to the presence of mineralization upslope, which may have contributed mechanically-dispersed Au downslope. Thus in these situations it is unclear as to the contribution made by the two possible sources (vertical or lateral) of Au to the surface. Further investigations are required at these sites.

Boomerang (Section A.8) provides the only site where substantial multi-element anomalies (*e.g.* Pb and Zn) occur in the regolith associated with Au mineralization. It is also the only site in the Gawler Craton investigated by this project that occurs in Proterozoic rocks; all the others occur in Archaean rocks. The presence of these metal anomalies provides a larger footprint to mineralization than the supergene halo of Au itself; hence; they may represent a better target for exploration. However, further data are required at other sites in this geological environment.

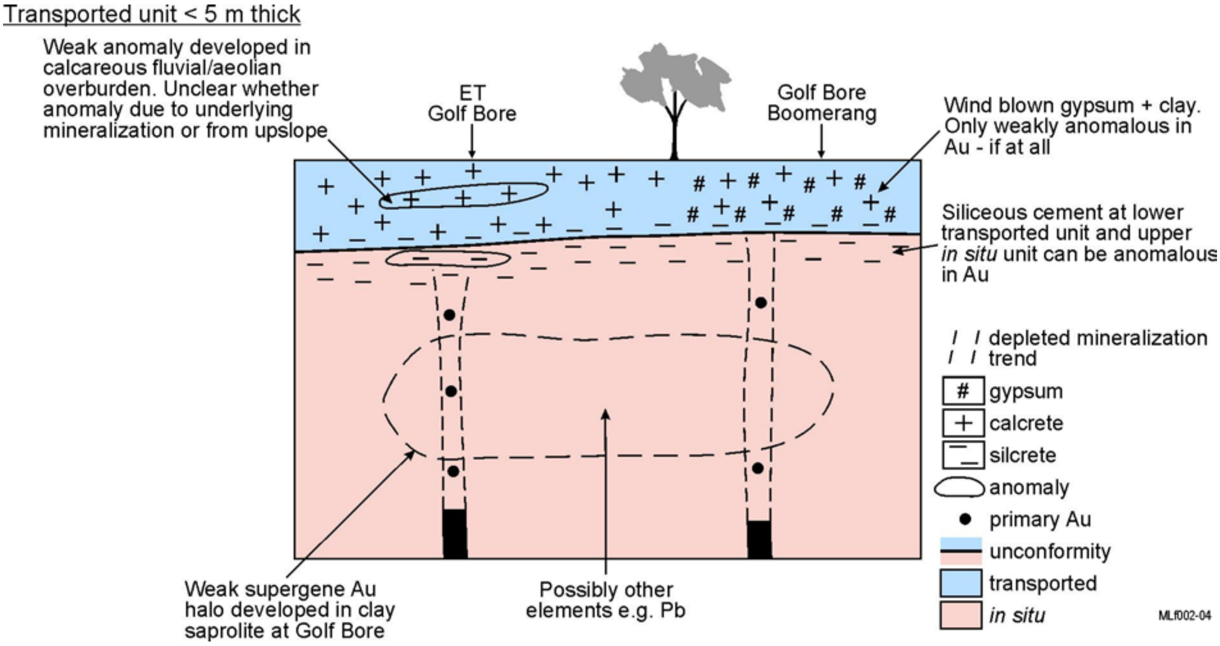

Figure 29: Transported unit is moderately thin at <5 m (Type T). Model exemplified by regolith at Golf Bore, ET and Boomerang.

5.1.4 Transported unit 5-15 m thick (Type T).

Thicker sequences of transported overburden have been demonstrated to be a substantial impediment to exploration in the Yilgarn Craton (*e.g.* summarized in Butt *et al.,* 1997). However in WA, some case studies indicate that calcrete sampling may be effective where transported overburden is only about 5 m in depth *e.g.* Bristow *et al.,* 1996. Transported overburden thicker than 5 m generally has a substantial fluvial component overlying a partly eroded *in situ* regolith. The fluvial component itself may become silicified with time but its exotic nature (containing distally-sourced materials) is commonly bereft of a geochemical signature reflecting buried mineralization over which it now resides. Post-depositional processes, however, may have led to the development of an anomaly in this material *e.g.* through bioturbation from termites. The precise mechanisms of anomaly formation, however, remain unclear.

Calcrete morphology is variable, reflecting the materials within which it is developed or its age. Massive, nodular and laminar type calcretes have developed in sandy material at ET (Section A.10), possibly reflecting sub-surface lateral flows of meteoric water with transportation and precipitation of Ca as carbonate. As with thinner overburden, Au is associated with this massive calcrete and suggests that it too may have been transported laterally since drilling has delineated no mineralization in some cases. However, in other areas, in similar landscape positions, anomalies in sand overlie mineralization and their origins are less clear since downslope transportation of Au cannot be excluded. At Monsoon (Section A.4), South Hilga (Section A.6) and ET (Section A.10), Au anomalies associated with the older land surface are present and appear to be partly preserved (at least) within the silicified material.

In conclusion, it is unclear for many of the anomalies, whether they truly reflect the underlying mineralization (due to vertical processes), or represent lateral mechanical/chemical dispersion from upslope. Drilling densities are mostly insufficient to resolve their status either at regional (Old Well, Section A.9) scale or even at a local (ET, Section A.10) scale to properly explain the processes that lead to the formation. For example, the Old Well-Tunkillia Au anomaly extends for several kilometres and it is unclear whether it is derived from several local sources or from a single source many kilometres away.

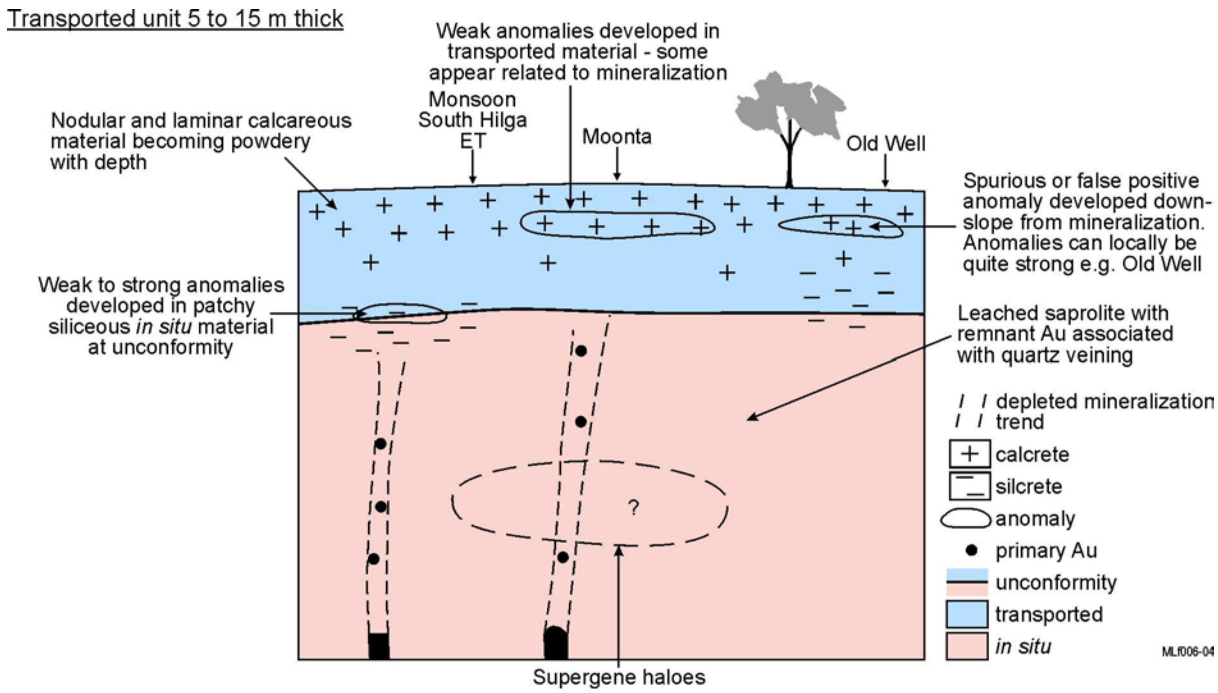

Figure 30: Transported unit is moderately thick at 5-15 m (Type T). Model exemplified by regolith at Monsoon, South Hilga, ET, Moonta and Old Well.

5.1.5 Transported unit >15 m thick (Type T).

Great thicknesses of transported sediments appear to prevent metals from buried mineralization reaching the surface in any detectable amounts. Even if they reach the surface, then, it appears that pedogenic, erosional and other processes will dilute concentrations to such an extent that they become indistinguishable from background.

At Challenger (Zone 3, Section A.5), the data indicates that there is a Au response in calcrete at 0.2-2 m below surface. Mineralization occurs at and below the interface between transported and *in situ* materials at ~20 m depth. However, since *in situ* regolith is close to this site (<100 m), the anomaly may be explained by Au being laterally transported; clearly more work needs to be done in this area to resolve the significance of this anomaly. At Boomerang (Section A.8), mineralization at the base of the palaeochannel is patchy and weak, and the 50 m of transported clay-rich palaeochannel sediments are clearly a barrier to any Au coming to the surface, as there is no suggestion of an anomaly, even in sub-surface calcrete.

Several studies in the Yilgarn Craton (summarized in Butt *at al*., 1997) found no anomalies in transported overburden with thicknesses >10 m *attributable to underlying mineralization*. More studies are required in the Gawler Craton, where infilling sediments are possibly older, to conclude whether this is the case here.

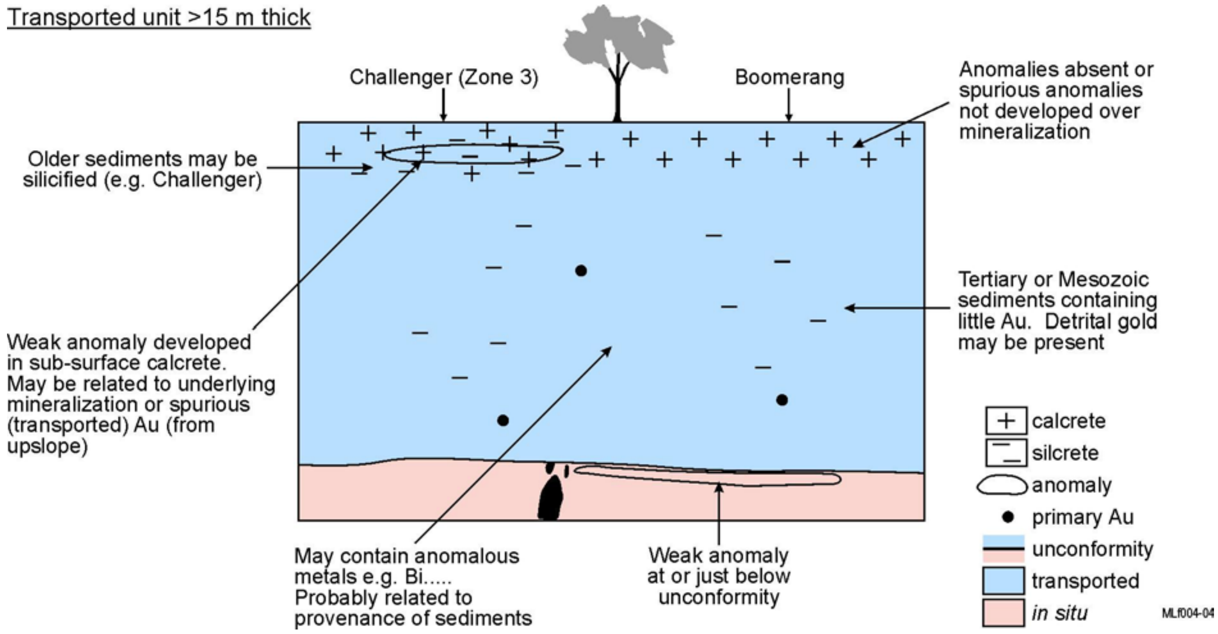

Figure 31: Transported unit is thick >15 m (Type T). Model exemplified by regolith at Boomerang and Challenger.

5.1.6 Discussion

Geochemical anomalies at several Au prospects have been examined, classified and compared using the framework of a series of regolith models based on thickness of transported overburden. Some anomalies in thin transported overburden occur above mineralization although it appears that the thicker the overburden the more unlikely a detectable anomaly will form. Anomalies appear to form in a variety of surficial sediments including soil, calcrete and silcrete and reflect both mechanical and chemical processes.

Landscape evolution and its interactions with “groundwater” appears to have played a major role in modifying the shape, size and location of anomalies. The groundwater in this case is defined as all meteoric water entering the soil. Dating studies (Section A.17.2 – A.17.3) indicate that many Au in calcrete anomalies can potentially occur in recently deposited sediments less than 300K years old. However, the history of how these Au anomalies form may be quite complex. These anomalies have themselves formed from “anomalous” residual Au, originally occurring in saprolite and associated with mineralization, located nearby. Dating indicates that the surface has been silicified at least once during the Tertiary. It is suggested that the silicification has served both to “lock” Au and other elements within regolith material and armour the material against physical and chemical weathering such that the original anomalies have persisted for possibly tens of millions of years. This residual Au not only has direct exploration significance indicating primary mineralization, but also provides the immediate source for the Au in the calcrete. The process is akin to a “slow-release” fertiliser (in this case, the silcrete) providing nutrient (Au) to the soil (calcrete). The Au in calcrete anomaly will persist above mineralization providing that it is still being “fertilized” by the small amounts of relict Au, released from the upper silicified regolith, at a greater rate than its removal by erosion or dilution by aeolian and/or colluvial material. However, once the silcrete begins to break up due to either erosion or chemical processes (*e.g.* by carbonate), then any Au associated with them becomes locally mobilized. Furthermore, once the Au itself becomes released from the siliceous host material its potential to be mobilized over broader areas is much greater and hence anomalies potentially become widely dispersed and diluted from their original host. In some cases, Au released from the silcrete becomes immobilized once again but this time in calcrete; however, this anomaly will be far less stable and persistent than the silcrete-hosted equivalent.

The origin of calcrete has been discussed for many years (Crocker, 1946; Milnes *et al.*, 1983; Quade *et al*., 1995; Anand *et al.*, 1997). In summary, calcrete is believed to be mostly ocean derived with possible rock sources for more localized sources. The isotopic studies conducted as part of this project largely agree with this assessment. The strong oceanic character of the Sr in calcrete is indicative of large scale meteoric and aeolian processes involved in its formation. If Sr (a surrogate for Ca) is derived from the ocean then why should Au accumulate in calcrete, particularly as the studies have shown that much of the Au is mobile? In a process that is not fully understood, some Au in the regolith becomes "water soluble" in the high pH environment of carbonate; it may involve vegetation, as indicated by the presence of Au in plants, or microbes producing ligands in the soil. This "chemical" Au is mobile in soil water and presumably moves both laterally and horizontally in the upper regolith leading to the dispersion of Au to form calcrete anomalies. These typically would move down gradient of their source. Bioturbation, vegetative recycling, diffusion and capillarity may be involved in the movement of Au and other material in the top few metres of the profile. Detrital Au may also be present in the calcrete but this moves mechanically rather than chemically. Clearly, more research is required to better understand this process and the contributions made by each factor.

Multi-element data appear to be only useful where specific elements are associated with mineralization. Many of the sites, particularly in the Archaean of the western Gawler Craton, are not rich in these pathfinder elements and so exploration procedures should probably concentrate on Au as their principal analyte. Wadnaminga (Section A.2) and Boomerang (Section A.8) styles of mineralization had clear multi-element signatures and may benefit from multi-element analyses in conjunction with Au.

5.2 Copper mineralization

Copper dispersion was investigated at Faugh-a-Ballagh (0 m, Section A.11), Moonta (5 m, Section A.12), Blue Rose (10 m, Section A.13) and Mt Gunson (>50 m, Section A.14), with approximate thickness of transported overburden and appearance of mineralization indicated in parentheses. Where primary mineralization outcrops and, therefore, soil cover is thin (Faugh-a-Ballagh, Section A.11), Cu anomalies in soil are small and restricted in size. Stream sediment sampling is useful but samples are strongly diluted by barren country rock and so it is important to use the correct size fraction (*e.g.*, <75 µm). Rock chip sampling is also effective but time consuming. Studies at sites with thin transported overburden such as Moonta indicate that, given the right environment, Cu anomalies are possible in the upper regolith. Here, acid-saline groundwaters, high water tables and calcrete provide ideal conditions for Cu dispersion and precipitation; partial extractions of sub-surface material may be used to better define targets (Mazzuchelli *et al*.,1980). A comparable regolith but a lower water table at Blue Rose, yielded little Cu at or near the surface but a subsurface anomaly in the lower unit of the transported overburden is apparent; this may be sampled by shallow drilling. Where the overburden is even thicker or hydrological-hydrogeochemical conditions are not conducive to metal dispersion, Cu mobility in the transported overburden is not apparent and sampling methods are restricted to interface sampling at the unconformity or deeper drilling *e.g.*, Mt Gunson (Section A.14). Partial and selective extraction techniques of surficial materials only appear to work in cases where more aggressive digests also work *i.e.* where overburden is thin.

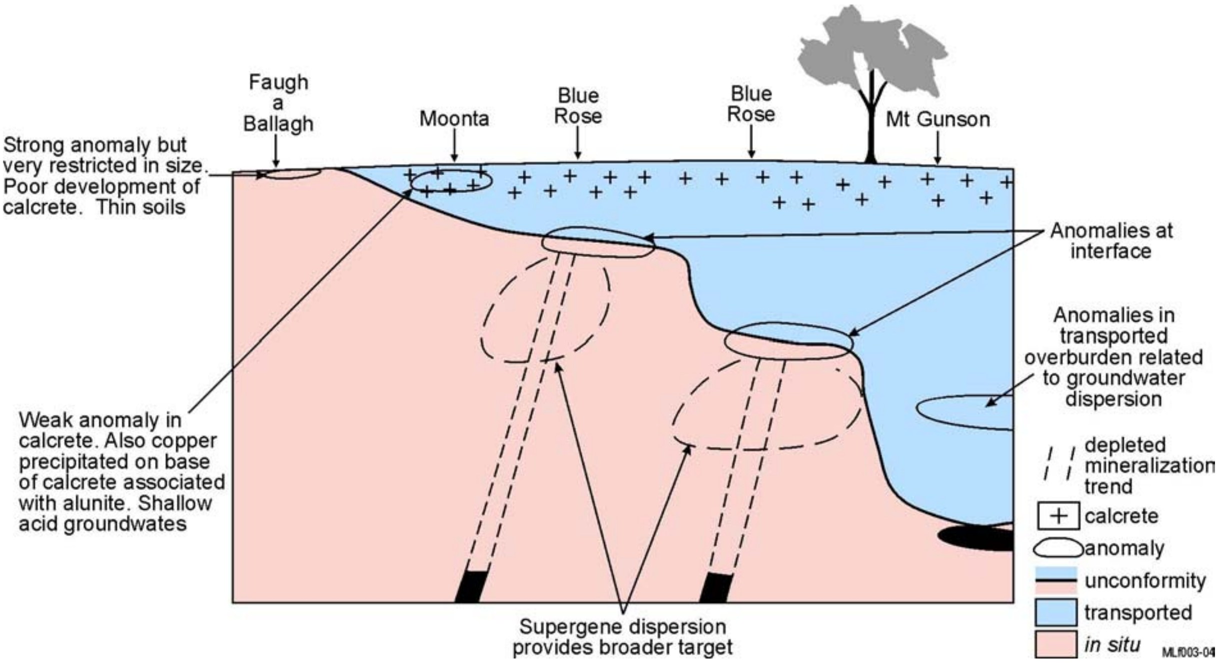

Figure 32: Model showing Cu dispersion from four prospects/deposits with varying degree of transported overburden.

5.3 Lead-silver mineralization

Limited studies for Pb and Ag dispersion were undertaken at two sites: Olary Silver Mine (Section A.16) and the Adelaide Hills (Section A.15). The Olary Silver Mine is an underground operation exploiting an outcrop surrounded by depositional sediments. Sampling of the dumps suggests that mineralization has a multi-element geochemical signature although soil data indicates that Au and Cu are the best pathfinders to mineralization. The strongest responses were in the <75 µm fraction although the <6 mm fraction would be an acceptable compromise since the soil contains mostly clay.

Four groups of regolith materials were sampled in the Adelaide Hills: soils, rock chips, stream sediments and deeper colluvium samples. Collectively the results indicate that Ag concentrations are generally below detection (<1 ppm) compared with Pb, which are generally in the range of 10 to 100 ppm. Concentrations of Pb decrease strongly less than 100 m away from mineralization indicating that geochemical dispersion from Pb-Ag mineral deposits is relatively locally confined. Isotopic signatures of geochemical samples can fingerprint the Pb signature and it is possible to apportion contributions due to anthropogenic sources (contamination) and mineralization. Other limited data from this study indicate that most Pb from the near surface regolith samples taken from the Adelaide Plains is of anthropogenic origin.

6 RECOMMENDATIONS FOR EXPLORATION

1) It is important to establish the regolith stratigraphy and landforms during exploration since surficial geochemical sampling programs are sensitive to regolith materials, landforms and depth of transported overburden. Remote sensing methods such as radiometrics, aerial photography, Landsat TM, ASTER and AIRSAR can give important information on the nature of the topography and as an aid to mapping the distribution of surficial materials. Other ground penetrating methods such as AEM can give sub-surface information such as the presence and depth of palaeochannels, and weathering features.

2) The construction of large scale regolith-landform maps is recommended e.g., 1:5000 for effective prospect-scale exploration. The maps should provide information on the distribution of regolith materials and, where possible, indicate the presence and thickness of transported material. These may be constructed with the aid of remote sensing techniques but ground truthing is desirable. Regional regolith

maps are useful at providing an overview but are not recommended for any sampling programmes as they lack detail.

3) Distinguishing *in situ* (residual) from transported regolith is important from the sampling perspective as geochemistry will give very different response depending on the depth of cover. The presence of cover may be inferred from examining field regolith-landform relationships, but selected quality drilling can provide definitive information. The danger of misidentifying inverted topography is an on-going problem. The use of PIMA spectra has some merit in establishing transported-*in situ* boundaries if good quality drill cuttings are available. REE geochemistry was used at Challenger (Section A.5) to discriminate between cover sequences and weathered crystalline basement.

4) Calcrete is the best near surface sampling medium for Au and should be used as a first pass geochemical sampling technique. It occurs usually within a metre of the surface and is readily identifiable using dilute acid. It works best as a guide to mineralization where transported overburden is absent or thin (<5 m), and where there is underlying saprolite rather than fresh rock. Local topography may lead to the development of transported anomalies located away from their source mineralization. For Cu, specific environments (high water table, acidic groundwaters and <5 m of transported material) may lead to upward dispersion of Cu with a precipitation in alunite at the base of the calcrete horizon due to a pH change.

5) In the absence of calcrete, other sample media may be used but anomalies are either weaker or more erratic. Silcrete has been shown as a potential sample medium for the first time (at Challenger). It can be used for Au exploration provided that it has developed within *in situ* materials. Soil commonly has an aeolian component, so the use of fine (<75 µm) or coarse (>0.5 mm) size fractions is recommended in order to remove sand that acts as the chief diluent to elements of interest. Groundwater as a sampling medium was not investigated to any great extent. Biogeochemical methods may be of limited application for Au exploration in the Gawler Craton. Understanding of how and why metals accumulate in plants is poor; several unexplained biogeochemical anomalies require further testing. Strong anomalies in calcrete do not necessarily lead to strong anomalies in vegetation. Hilly terrain is well-suited to stream sediment sampling (Cu), and orientation surveys, investigating the most appropriate size fraction(s), are recommended at each site.

6) Partial extraction analyses for Cu and Au exploration are not recommended *per se*, because conventional total extraction procedures were found to be equally as effective (similar anomalies), easier to interpret and more cost-effective. Selective extractions are potentially of greater benefit since they may be used to understand the behaviour of elements in regolith materials. They may have some merit for investigating the nature of anomalies and how they form *e.g.*, precipitation of metals on carbonates or adsorption onto Fe. They indicate if it is worth targeting a particular mineral or size fraction in a sample. There are many different types of selective extraction procedures and a few were tested during the course of this project. Their use in finding buried Cu and Co mineralization was investigated but failed, even when the depth of mineralization was only 9 m. Partial extraction undertaken by Mazzuchelli *et al.* (1980) using acid ammonium acetate on samples within and beneath the calcrete was shown to better define the buried Cu mineralization.

7) Multi-element geochemistry should be used with caution. Understanding the nature of the mineralization being sought, potential associated pathfinders, the type of regolith material being sampled and the extra cost are important considerations for its use. For Au in the western Gawler Craton, multi-element geochemistry was of limited use since the Archaean-dated mineralization was not associated with rich concentrations of pathfinder elements such as As, Sb or W, as may be found in the Yilgarn Craton, for example. Furthermore, the paucity of Fe-rich regolith materials, such as lateritic duricrust or ferruginous lag, meant that these metal-scavenging materials cannot be used systematically in an exploration program. Proterozoic Au mineralization had some potential to yield multi-element anomalies and this may be important for finding Au-Cu-Fe-type mineralization.

7 CONCLUSIONS

The South Australian Regolith Project was set up by CRC LEME in 1998 as an "umbrella" project to oversee investigations into the use of regolith in mineral exploration in the major cratons of South Australia. Collaboration with exploration companies, universities and government departments was an important feature of the project. During the course of the project, the geomorphology, regolith geology, mineralogy and geochemistry of sixteen prospects were investigated. In addition, hydrogeochemical, dating and isotope studies provided some background information for understanding the geochemical dispersion processes operating in these highly weathered terrains. The results have been synthesized to find commonalities and differences between sites, and produce models of geochemical dispersion that may be operating. The presence of transported overburden was found to be one of the most important factors and hindrances to exploration. Recommendations to the mineral exploration industry were a major outcome of these investigations.

The use of surficial geochemical techniques has led to a degree of pessimism amongst exploration companies, especially as to the real value of Au in calcrete anomalies in finding economic targets. Of many hundreds of such anomalies, few have been thoroughly investigated and developed into significant prospects. It has been proposed that because there are so many anomalies, a ranking procedure is required so that limited funds can best be used on drilling those anomalies more likely to yield mineralization. As yet, the criteria used to rank anomalies have not been successfully designed, developed and rigorously tested. However, each anomaly that is investigated provides additional information to assist in the establishment of these criteria.

South Australia is dominated by regolith terrains and requires further investigations to develop our knowledge and understanding of the processes that are operating in this type of environment. Exciting developments in geophysics may provide us with information on the sub-surface that drilling can only provide at great expense. Our understanding of how geochemical anomalies form needs to be improved and more substance added to our ideas about when and why anomalies form in some environments and not in others. The project was commenced during the heyday of calcrete sampling and it is interesting to note that this is still the preferred method of surface sampling in South Australia. The conclusion of the project coincides with the opening of South Australia's first large scale Au mine. The Challenger Gold Mine was found using calcrete. However, our understanding of how anomalies precisely form in this important material is the subject of on going research.

8 ACKNOWLEDGEMENTS

The following are thanked for helping to compile this report: the many researchers who provided the data for the case studies and whose works are separately referenced with the case studies in the Appendices; Travis Naughton and Amanda Cornelius for construction of some of the diagrams; funding from various companies and government bodies and, in particular, the CSIRO, CRC LEME and PIRSA; logistics provided by exploration companies on whose ground we worked; and in particular, David Gray, Ravi Anand and Charles Butt for comments on earlier versions of this manuscript. I would also like to give a particular thank you to Malcolm Sheard for his lively discussions, mateship in the field and contributions to many of the case studies.

The Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME) is an unincorporated venture made up of researchers from Australian universities, CSIRO and other government laboratories, private industry and public sector agencies. It aims to develop a greater understanding of Australia's terrain when applied to mineral exploration and environmental management.

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APPENDICES

A.1 BIRTHDAY GOLD PROSPECT (LINTERN *ET AL.*, 2000)

A.1.1 Introduction

The Birthday Gold Prospect was found in 1996 by Minotaur Gold NL by regional calcrete sampling (Figure A 33). It is located in the Gawler Craton, 720 km NW of Adelaide and 120 km NW of Tarcoola. Subsequent infill calcrete sampling located a coherent anomaly peaking at 68 ppb Au. Early shallow (0-60 m) rotary air blast (RAB) drilling outlined a series of parallel bands of Au mineralization located at about 30 m within saprolite; one metre samples returned 1.2, 0.5, 0.7 and 1.1 ppm Au from each respective band.

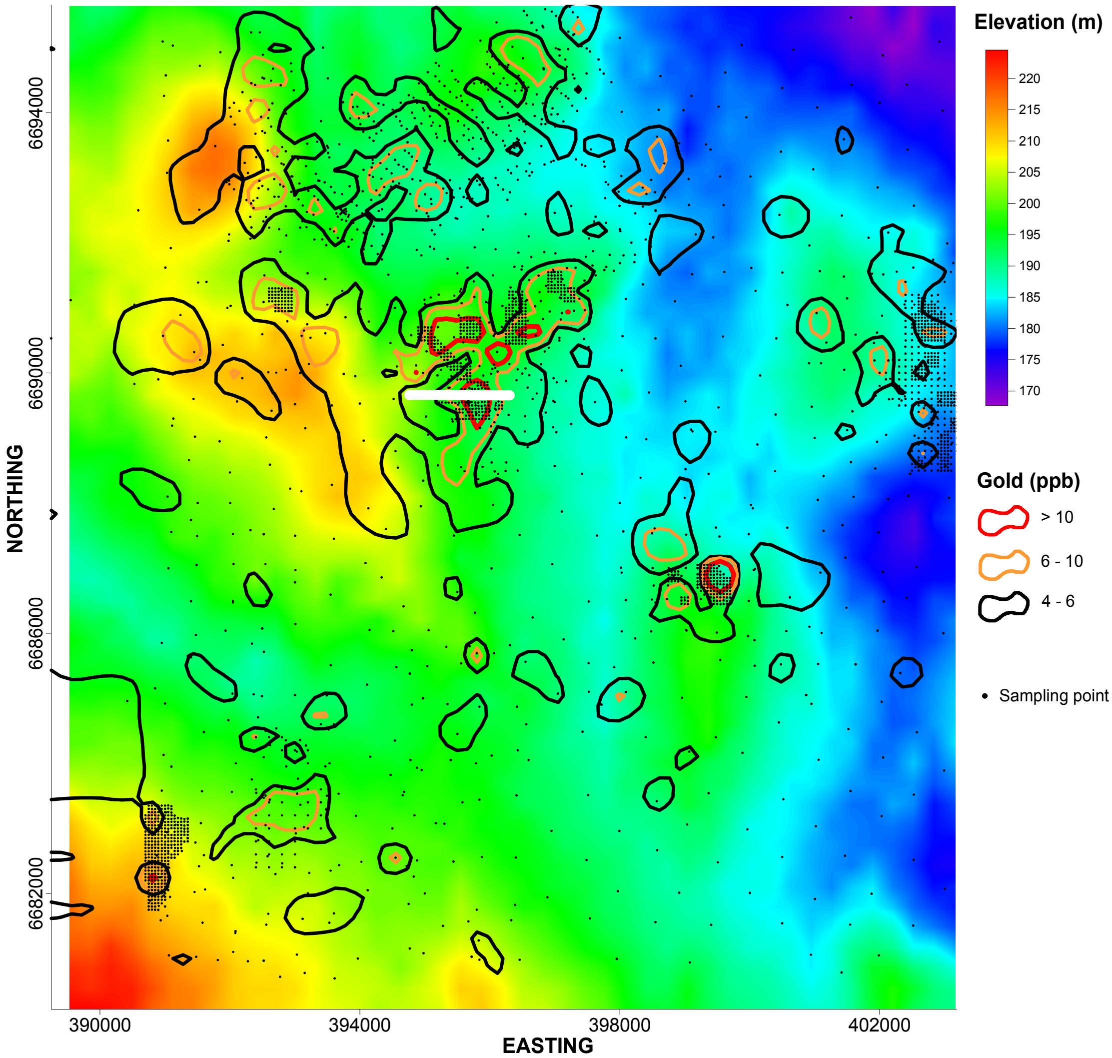


Figure A 33: Gold in calcrete, RL (metres) and sampling location (regolith line) at Birthday Gold Prospect.

A.1.2 Physical features and environment

The Birthday Prospect occupies an area of low topographic relief. Immediately to the north and west lies a low arcuate rise of variably silicified saprolite outcrop partly covered by sand. South and east of this rise is a broad area of alluvial plain and minor sand spreads. A low-angle erosional escarpment has developed on the southern and eastern sides to this rise; the escarpment upper flanks are clad with silcrete gibber and blocks. There is a subdued drainage to the south and east of the rise with some minor clay pans (Lintern *et al.*, 2000). Vegetation consists of chenopod shrubland and open woodlands of mulga and sheoak, with chenopod understorey. The shrubland consists of members of the Family Chenopodiaceae, principally *Maireana sedifolia* (bluebush), *Atriplex vesicaria* and *Scleroleana obliquicuspis*. The climate is arid with rainfall about 150 mm per annum falling mostly in the winter.

A.1.3 Geological setting

The local geology at the Birthday Gold Prospect includes Archaean quartz-feldspar-garnet gneiss, mafic gneiss and ultramafics with significant levels of sulphide (Daly *et al*., 1998). Archaean basement crops out near the drill-defined mineralization and is limited to a small area (100 m square) and consists of Banded Iron Formation (BIF) cross-cut by a stockwork of white to grey hydrothermal quartz veins (many are zoned). Some of these veins (100-500 mm wide) stand proud (by up to 600 mm) of the otherwise flat surface. Further north (5 km), a larger outcrop of silcrete-capped BIF (partly dune covered) forms part of an arcuate ridge-escarpment. Strongly weathered basement outcrop (saprolite and silicified equivalents) can be identified near or on the escarpment or in stream gutters leading away from it. Mafic-ultramafic dykes intrude the crystalline basement sequence at the Birthday Prospect (Lintern *et al*., 2000).

A.1.4 Mineralization

Anomalous Au appears to be associated with ultramafic lenses and their contacts (faulted or folded) with surrounding gneissic lithologies. Follow-up deeper RC drilling intersected altered contact zones with quartz, feldspar, carbonate, and sulphide development and widespread low grade Au mineralization in fresh bedrock (Anon, 1996).

A.1.5 Regolith

Sampling and regolith stratigraphy was undertaken along a ~1.5 km transect across the prospect. The stratigraphy is complex and consists of:

(i) Pedolith (5-10 m thick) of variably weathered clay-rich to a quartz-rich plasmic/arenose zone with mottling/staining of pale yellows, rarer orange and some browns.
(ii) Saprolite (20-30 m thick, pale grey, pale yellow to off-white), overlying a saprock (<1 to ~8 m thick greyish-brown) grading into fresh rock. Mottling/staining is variable;
(iii) Bedrock of felsic, mafic and ultramafic lithologies

The irregular upper surface of the silicified pedolith/saprolite is partly exposed at the far western end of the study area whereas, over the middle to eastern end, it is buried by a variety of thin (<2 m) alluvial and aeolian sediments. This surface is variably silicified, locally forming a pedogenic silcrete, and is overlain by calcrete-impregnated silcrete and/or massive calcrete. Minerals present in the upper regolith include quartz, calcite, gypsum, hematite, mica, K-feldspar, Na-feldspar, goethite, chlorite-smectites and celestite. Quartz is either dominant, or co-dominant with calcite, in all upper regolith samples. Kaolinite is the major clay mineral present with some samples having some smectites. Gypsum appears to be particularly abundant over mineralization. The lower regolith, including the mineralized zones, is co-dominated by quartz and kaolinite. Mica and goethite are present in moderate concentrations. Alunite occurs in minor quantities above mineralization and appears to be related to the appearance of gypsum higher in the regolith and, possibly, to sulphides in the fresh rock. Despite the intense weathering evident by the presence of typical secondary minerals, pale-coloured clays and saprolite in the top 30 to 40 metres, primary minerals such as feldspars, mica and chlorites are still present throughout the upper regolith.

A.1.6 Regolith expression

Sampling, at ~80 m intervals across the land surface, was undertaken of drill cuttings, soil (0-10 cm), lag (various size fractions), calcrete and vegetation (bluebush).

For Au, the geochemical results reveal three principal zones of interest (Figure A 34, zones 1, 2, and A) that are discussed in detail below. Zone A is a Au-in-calcrete anomaly located in the western part of the regolith line. Zones 1 and 2 are zones of weak mineralization, which constitute part of the Birthday Prospect, identified in the lower regolith of the regolith line:

1) Zone 1 mineralization, located at 395245E, attains a maximum concentration of 290 ppb (as determined by drilling) and is overlain by 35 m of essentially barren saprolite;
2) Zone 2 mineralization, centred on 395655E, detected in two drill holes separated by 170 m and attains a maximum concentration of 580 ppb at 35 m beneath barren saprolite.

The two zones are connected at depth (35 m) by a weakly mineralized horizon of supergene Au extending at least 400 m in an east-west orientation that reaches a concentration of about 20 ppb. Mineralization does not outcrop in either zone. Of the elements associated with mineralization (Au, Ba, Cd, Ga, Mo, Nb, Pb, U, V, W and REE) only Au is enriched in both zones. A few of the elements are anomalous in the lower regolith (*e.g.* Au, Ba, Cd, Mo, Pb, S and REE) above mineralization, and fewer still continue so into the upper regolith (Au, S and some REE), with only Au enriched in surficial materials. Most of these elements are probably associated with the sulphides in with mineralization. It appears that Au and, perhaps, S are the only elements that can be confidently used through the regolith in this environment.

Gold is associated with Ca throughout the top 1 to 2 m (Figure A 34). The highest Au concentrations of 16 and 15 ppb are located in adjacent hole samples above mineralization near the centre of the section (zone 2); calcrete nodules from the same location contain 13 ppb Au. A broad zone (400 m) of elevated Au (>5 ppb) is located at 0-2 m depth in the central and eastern part of the regolith traverse and persists, partly, to lower depths (zone 2, 2-6 m) but at decreasing concentrations. Near-surface calcrete in the western part of the section (zone A) contains up to 14 ppb Au, but the drill cuttings from the same location (0-1, 1-2 m, *etc*.) all contain <5 ppb so that the anomaly does not persist much below the surface. In contrast to the Ca of the carbonate, there is little evidence for significant Au associated with Ca in the gypseous clays. Across the section of the regolith line, there appears to be a barren zone with low Au concentrations (<2 ppb) extending from near the surface down to about 30 m depth. At about 35 m, Au is broadly distributed across several hundred metres, including mineralized Zones 1 and 2, with concentrations from about 4 to 20 ppb and is suggestive of a weak supergene zone, possibly related to an earlier water table or redox front. Higher Au concentrations (up to 1.2 ppm) are recorded deeper in the regolith and are probably related to a primary source.

Of most significance are the anomalous Au concentrations in calcrete over mineralization (zone 2, maximum of 13 ppb, Figure A 34) and zone A (14 ppb, Figure A 34) where no mineralization has been identified. Normalising the Au data with respect to the alkaline earth metals had limited effects in enhancing the response over mineralization, and did not remove the apparent spurious anomaly at zone A (Figure A 34). One "calcrete" sample (at hole 500) had particularly low Ca (and Au) concentrations (2.6 %); this sample, although effervescing with dilute acid, was composed primarily of silicified, clay-rich saprolite coated with carbonate, emphasising the need to analyse the sample for Ca to ensure that it is a mostly calcareous. There are pitfalls associated with interpreting Ca data: for example, the carbonate content can be over-estimated since some Ca occurs in other minerals *e.g.* gypsum. Gypsum can be determined by infra-red analysers, XRD or determining S concentrations. However, care should be taken with using S data alone since some S occurs as celestite ($SrSO_4$) and alunite ($KAl_3(SO_4)_2(OH)_6$).

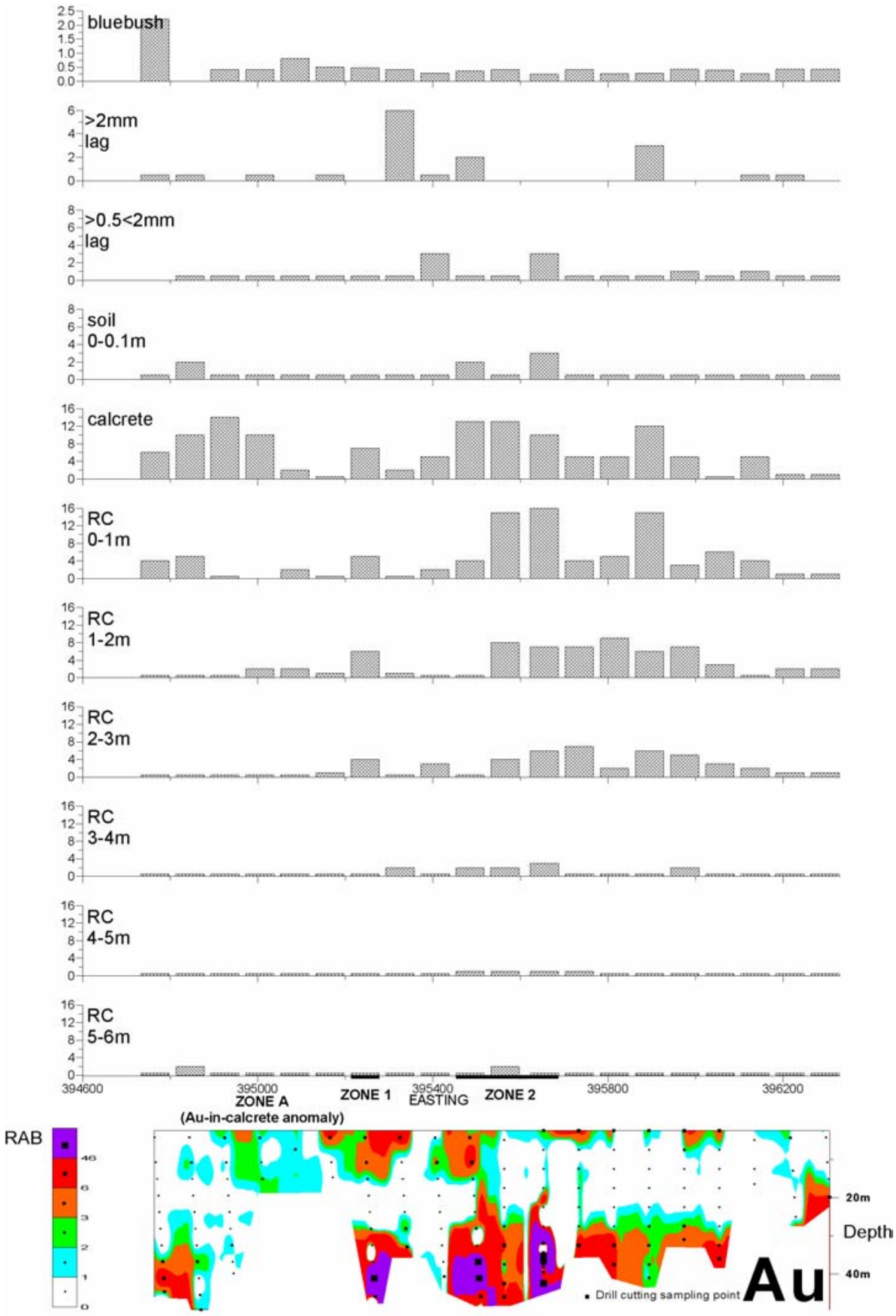


Figure A 34: Distribution of Au for the regolith line across the Birthday Gold Prospect. Black rectangles indicate position of mineralization. (From Lintern *et al*., 2000).

Gold contents in soil are generally below or just above detection (1 ppb, Figure A 34). The highest concentration recorded was 3 ppb and occurred over zone 2. Normalizing the Au data with respect to the alkaline earth elements produced a stronger, single point maximum over mineralization.

The lag is polymictic and consists of varying proportions of silcrete, calcrete and ferruginous material. The highest concentrations for coarse and fine lag were 6 and 3 ppb respectively although most samples contain less than 1 ppb (Figure A 34). Coarse lag was generally scarce (except at the western end of the regolith line) and samples were not collected at half of the sites. One fine lag and two coarse lag samples with particularly high Fe contents sampled in the eastern and western ends of the traverse had Au contents below detection, indicating that Fe oxides are not strong trap sites for Au in this environment.

Gold concentrations for bluebush vegetation were close to detection (0.3 ppb) except one sample (2.2 ppb) away from mineralization at the western end of the traverse that requires further investigation (Figure A 34). In Western Australia, concentrations in excess of ~2 ppb have been estimated to be anomalous, although there may be locally higher thresholds (unpublished data, Lintern; Lintern *et al*., 1997). Therefore, most of the concentrations at Birthday Prospect are not significant when compared with data from Western Australia.

The sequential partial extraction data provide information on the relative solubility of Au in the surficial environment and, by inference, the potential mobility of Au. The data indicate important differences that occur in Au solubilities (i) with depth and (ii) between calcrete and drill cuttings (Figure A 35). The main features are summarized below:

1) The proportion of cyanide-soluble Au (the least soluble) increases with increasing depth (48% to 60%). This is interpreted as being due to Au particles within the saprolite being larger than those in the soil.
2) Calcrete has the highest proportion of soluble Au (57%) as indicated by the iodide and water data. This is consistent with other data (summarized in Butt *et al.,* 1997) that suggest Au in the carbonate horizon is relatively mobile.
3) Sum of the sequential extraction concentrations (water+iodide+cyanide) generally agree with the aqua-regia concentrations. This indicates that the general quality of the Au data is acceptable.

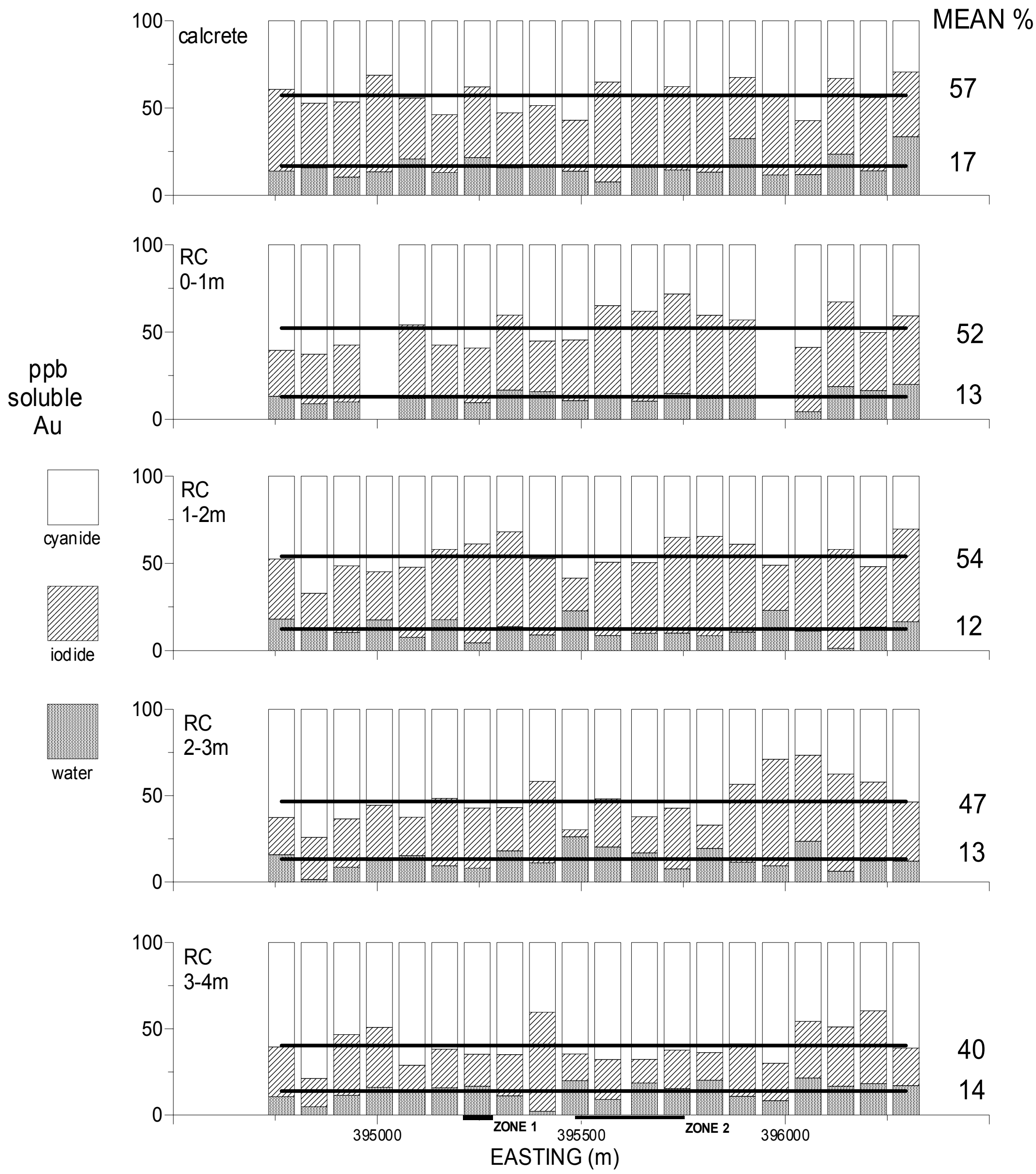


Figure A 35: Partial extraction data for Birthday samples expressed as a % of combined extractable Au. Black lines across histograms indicate mean percentage. Black rectangles indicate position of mineralization. (From Lintern *et al*., 2000).

A.1.7 Conclusions

The results indicate that Au in calcrete nay be successfully used both regionally on a 1.6 km grid, to find a prospect and locally on a 50 m grid, to provide a drill target. The main zone of primary mineralization (Zone 2) was targeted successfully under a Au in calcrete maximum of 13 ppb with a weaker enrichment of 7 ppb over Zone 1. The spurious or false Au in calcrete anomaly at Zone A did not persist below 1 m depth indicating that it might have been displaced from a source upslope. Soil and lag (>0.5<2 mm) were moderately anomalous above Zone 2 mineralization but vegetation was not.

A.2 WADNAMINGA (SKWARNECKI *ET AL*., 2001)

A.2.1 Geological setting

The Wadnaminga Goldfield is located about 30 km south of Olary in the Curnamona Province. Gold mineralization in the Wadnaminga Goldfield is hosted by metasedimentary rocks of the Belair Subgroup, a subdivision of the Adelaidean Burra Group (Olliver and Preiss, 1990). The lithologies comprise interbedded flaggy siltstones, quartzite, micaceous phyllite, medium-bedded dolomite, dolomitic siltstone and quartzite, and silty dolomite, and occur along the northern limb of the Wadnaminga Anticlinorium (Forbes, 1991).

A.2.2 Mineralization

Gold mineralization extends along a strike length of 12 km along the northern margin of the anticlinorium. Records indicate that about 20,000 t of ore (at an average grade of 27 ppm) were mined in the period 1888-1936, predominantly from the New Milo and Virginia deposits (Morris, 1975) to produce about 25000 oz. In the richer northeastern part of the field, quartz lodes occur in sandy siltstone, phyllite and dolomitic groups of the Belair Subgroup and were productive over considerable strike lengths (Morris, 1975). Auriferous quartz veins commonly occur in dark grey, non-calcareous siltstone, typically with disseminated pyrite. The veins are up to 2 m wide (average 30 cm) and commonly fill *en echelon* tension gashes. The rocks strike at about 075°-080° and dip at about 70° NW, whereas the lodes trend WSW-ENE and dip at about 30°S and cross-cut lithological boundaries at low angles. Two generations of veins occur: an earlier barren set, and a later mineralized generation, which may cross-cut earlier veining.

The main minerals found within the veins are quartz and pyrite, with minor galena, chalcopyrite, arsenopyrite, anglesite, cerussite, malachite, goethite, hematite, jarosite, scorodite, calcite, siderite and native Au (Morris, 1975). Petrographic evidence (Henley and Moeskops, 1976) indicates that native Au is present as electrum, typically very fine-grained (<25 µm). It occurs mainly as inclusions or fracture infillings in pyrite, but some also occurs associated with quartz (Gartrell, 1934). Secondary Au, found in the weathered portions of the veins, associated with Fe oxides, anglesite and scorodite, contains no detectable Ag (<0.3%; Henley and Moeskops, 1976). Primary dispersion haloes around the veins are narrow (<50 cm; Henley and Moeskops, 1976). Gold showed high significant positive correlations with As, As, Bi, Cu, Hg and Pb.

A.2.3 Regolith

The erosional regime dominates the regolith, with minor sediments along the creeks. Major landform units are hills formed by siltstones, dolomites and phyllites of the Burra Group, with thin soils and abundant lag. On the lower slopes, particularly in the south, thin colluvial-alluvial soils overlie bedrock. The area is dissected by two major creek systems, with alluvium and fluvial gravel deposited on floodplains. Soils are typically calcareous lithosols.

A.2.4 Regolith expression

A.2.4.1 Rock-chip sample geochemistry

A high-grade ore sample is composed of very coarse-grained, massive pyrite with minor galena in quartz veining from the New Milo workings. It contains 49 ppm Au, 10 ppm Hg, 5150 ppm Pb, 14.5 ppm Ag, 2050 ppm As, 3 ppm Bi, 8 ppm Cd, 165 ppm Cu, 9.74% S, 8 ppm Sb, 7 ppm Se, and 440 ppm Zn; minor amounts of Te (0.4 ppm) and In (0.6 ppm) also occur. This element suite was considered to represent the geochemical signature of the mineralization.

A.2.4.2 Calcrete geochemistry

Elements associated with mineralization (Ag, As, Au, Bi, Cd, Cu, Hg, In, Pb, Sb, Se, Te, Zn): The best responses are generally found in samples from calcrete above the lodes at New Milo and Great Eastern. This is particularly the case for Au, As, Pb and, to a lesser extent, Cu and Zn (Figure A 36). Of the remaining elements, Hg, Sb, Se and Te are below detection limits in calcrete, and In shows no clear association with the lode horizon (with many samples below detection limit), despite anomalous concentrations in high-grade ore. Cadmium and Bi concentrations are sporadically anomalous along the lode horizon, but S concentrations are generally minor.

The elements (especially As, Cu and Zn) have negative correlations with Ca. Notwithstanding the strong association of Au with calcrete, the lack of a strong Ca and Au correlation suggests that the some of the Au may be detrital or associated with rock fragments within the calcrete. The concentrations of ore-associated elements in the calcrete are presumably related to unreplaced quartz veinlets and hydrothermally-altered wallrock fragments within the calcrete. Calcrete downstream from the tailings contains Au at local background levels (18 ppb), suggesting some Au mobility.

Elements associated with hydrothermal alteration (Ba, K, Mg, Na, Rb, Sr, Tl, U, W): These elements (especially K, Na, Rb and Tl) have negative correlations with Ca, suggesting that the calcrete may have been superimposed upon an existing pattern of geochemical dispersion. The concentrations of the elements associated with hydrothermal alteration are presumably related to unreplaced quartz veinlets and hydrothermally-altered wallrock fragments within the calcrete samples collected.

A.2.4.3 Soil geochemistry (augered samples)

Elements associated with mineralization (Ag, As, Au, Bi, Cd, Cu, Hg, In, Pb, Sb, Se, Te, Zn): The best responses are generally found for As, Au (Figure A 36), Bi, Cd, Pb and Zn. The other elements are either below detection limit or close to it. The following dispersion haloes are defined around the lodes:

As – 50 m wide at >32 ppm, or up to 100 m at >19 ppm
Au – 50 m wide at >62 ppb, or up to 100 m at >28 ppb
Bi – 50 m wide (discontinuous) at >0.4 ppm
Cd – 50 m wide at >0.7 ppm, or up to 125 m at >0.3 ppm
Cu – 50 m wide (irregular) at >43 ppm
Pb – 75 m wide at >14 ppm
Zn – 75 m wide at >95 ppm, or up to 125 m at >70 ppm.

Elements associated with hydrothermal alteration (Ba, K, Mg, Na, Rb, Sr, Tl, U, W): Ba, Sr, Tl, U and W form somewhat irregular dispersion haloes around the lodes:

Ba – 150 m wide at >465 ppm
Sr – 50 m wide at >870 ppm, or up to 100 m wide at >525 ppm
Tl – 50 m wide at >0.3 ppm
U – 75 m wide at >1.1 ppm
W –75 m wide at >1.1 ppm.

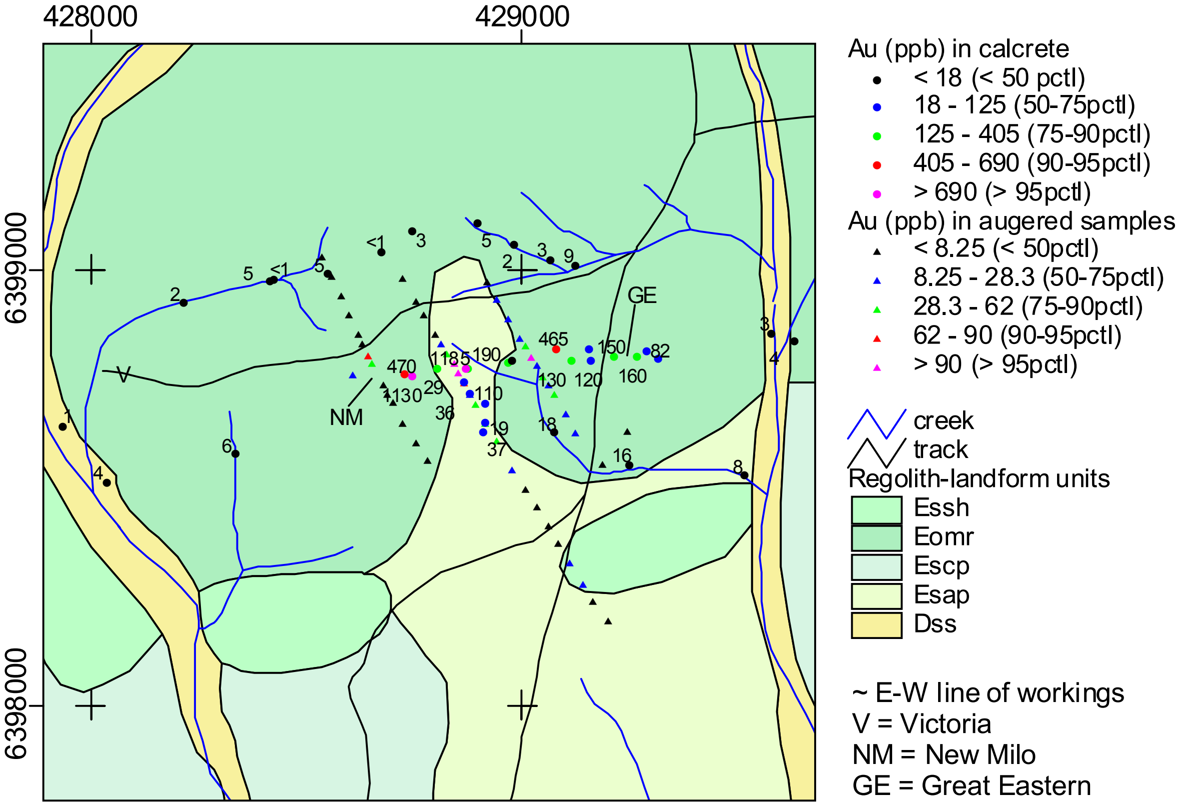


Figure A 36: Distribution of Au (ppb) in soil (augered sample) and calcrete samples, Wadnaminga. Gold concentrations for calcrete are labelled. Regolith-landform units prefixed E signify erosional regime, and D depositional. Full regolith-landform unit descriptions are found in Skwarnecki *et al* (2001).

A.2.5 Conclusions

Auger drilling and calcrete sampling are effective sampling techniques in the environment, although a sufficient density of sample sites (25 m spacings) would be required for calcrete sampling at the prospect scale. Soils would probably be a valid sampling medium and may be more cost-effective than auger or calcrete sampling. The geochemical suite should include: As, Au, Ba, Ca, Cu, Fe, K, Mg, Mn, Pb, U, W and Zn. If soil sampling is chosen, the optimum size fraction would need to be determined by an orientation study.

A.3 JUMBUCK PROSPECT (LINTERN *ET AL.*, 2002)

A.3.1 Introduction

Jumbuck Prospect is about 130 km NW of Tarcoola in the Gawler Craton and lies on undulating terrain in an area occupied by west-trending, linear, Pleistocene sand dunes. These cover deeply weathered and silcrete-capped Archaean basement and overlying clay sediments. The orange dunes form an easterly outlier of the Great Victoria Desert. In part, they infill depressions in the basement with up to 6 m of sand. Vegetation has stabilized the dunes and includes woodland (*Eucalyptus* and *Acacia*), numerous woody shrubs (*e.g.*, *Acacia*, *Eremophila* and *Maireana*) and various ground cover plants (*e.g.*, *Ptilotus*, *Eragrostis*, *Sclerolaena* and *Thyridolepis*). Mineralization is weak despite the size (~2 x 3 km at >3 ppb) of the Au in calcrete anomaly

A.3.2 Regolith stratigraphy

A west-east section at 6690400N was selected for orientation (Figure A 37). Generally the area is covered by aeolian, quartz-rich sand 2-4 m thick, overlying other transported materials on deeply weathered Archaean basement. Dating elsewhere places these sands early into the last quarter of the

Quaternary (Huntley *et al.*, 1999). Colours range from orange to reddish and are caused by thin ferruginous coatings on the quartz-rich sand grains. These sands are uniformly sorted and textured with little or no illuviated silt-clay components and host calcrete as nodules or friable forms, sometimes at more than one level. The sand is generally loose and free running, except where cemented by calcrete, but is mostly stabilized through the presence of deep-rooted vegetation. Beneath the sand, hardpan up to 2 m thick intertongues with a related multicoloured clay facies. Localized silcrete outcrops indicate saprolite and sediment substrates. The unconformity occurs mostly within or just below the silcrete. Between holes JBAR066 and 064 (Figure A 38), a fluvial sediment composed of clay and sandy silt infills a 5 m deep channel. Along the whole section, all pedolith is intensely silicified and the top, forming silcrete; deeper partial silicification has yielded a variably indurated pedolith. Silica has also cemented the upper portion of the channel infill, forming a silcrete horizon of a similar depth to that in the surrounding pedolith. Saprolite is deeper than 30 m. Fresh basement was not encountered, although some of the saprock from holes JBAR066 to 052 (Figure A 38) provide relicts exhibiting a strongly foliated mafic-rich gneiss. A more complex saprolite zone overlies this and is variably coloured and/or strongly mottled. Higher in this sequence, the saprolite becomes weakly coloured to pallid.

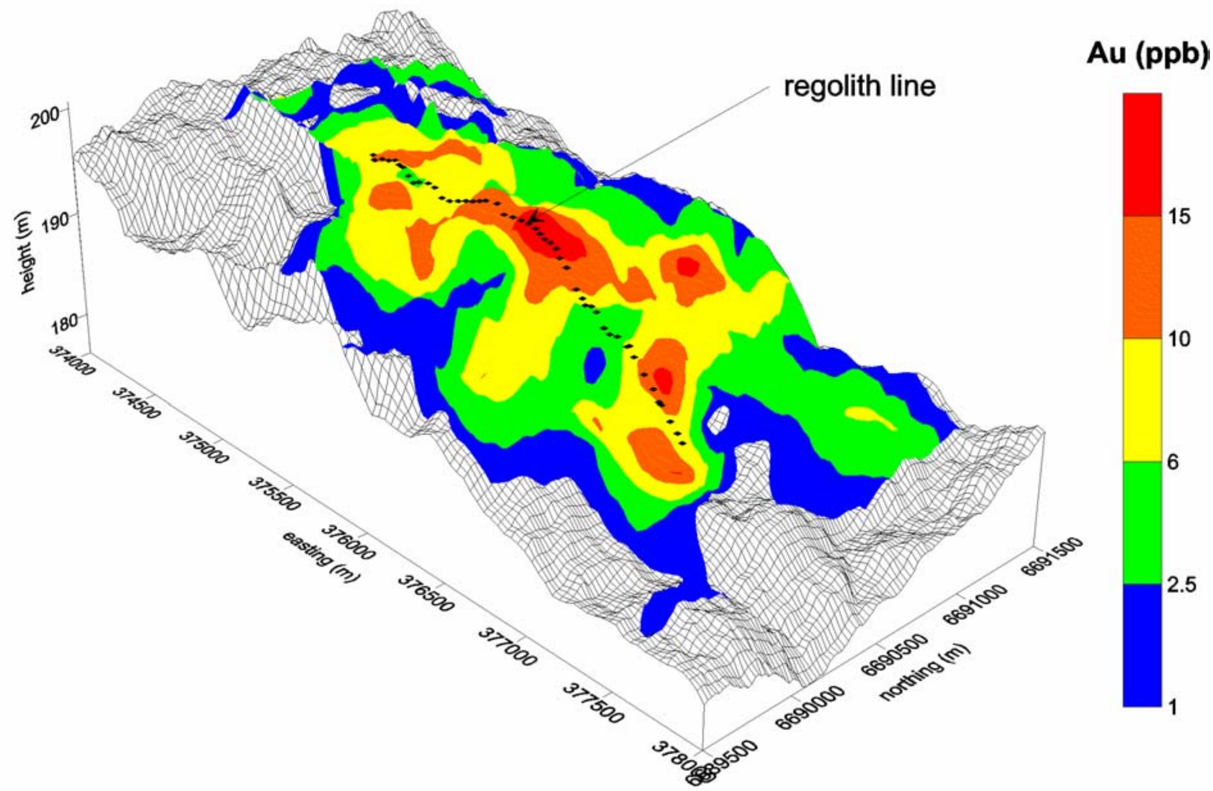
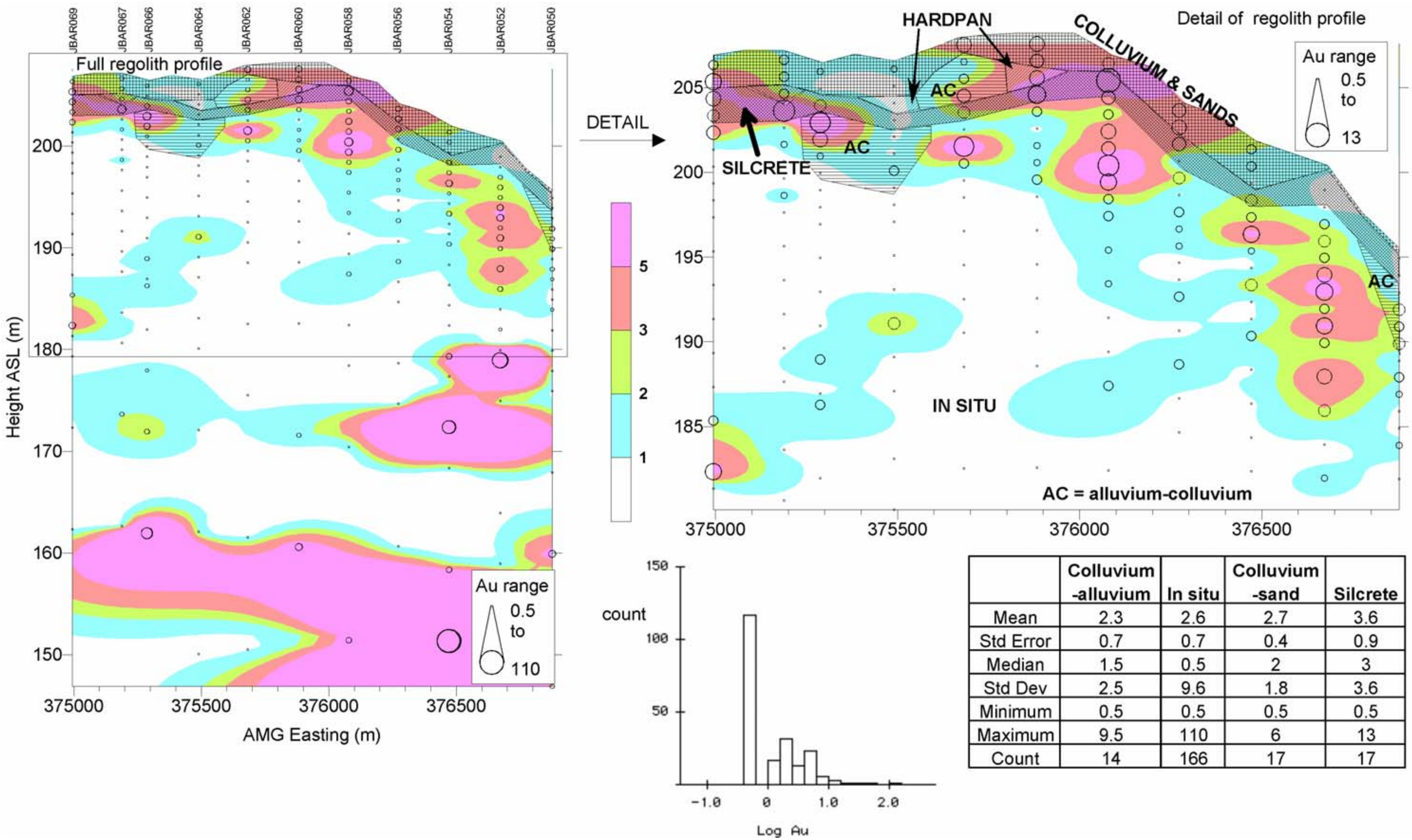


Figure A 37: Detail of Jumbuck Prospect showing Au in calcrete anomaly and regolith (sampling) line (see Figure A 38) overlaid on a DEM. Exposed "wireframe" grid indicates data below 1 ppb. View from south east. Original data supplied by the Gawler Joint Venture.



	Colluvium -alluvium	In situ	Colluvium -sand	Silcrete
Mean	2.3	2.6	2.7	3.6
Std Error	0.7	0.7	0.4	0.9
Median	1.5	0.5	2	3
Std Dev	2.5	9.6	1.8	3.6
Minimum	0.5	0.5	0.5	0.5
Maximum	9.5	110	6	13
Count	14	166	17	17

Figure A 38: Sections showing regolith stratigraphy and Au geochemistry at Jumbuck Prospect. All data are in ppb. See Figure A 37 for section location.

A.3.3 Regolith expression

The Au anomaly in calcrete has a maximum of 20 ppb (Figure A 37). Significant Au concentrations in the lower regolith for the section studied are listed in Table A 5. Above background (>3 ppb) concentrations of Au are found in the transported cover and upper, *in situ* regolith at Jumbuck. The eastern part of the upper regolith has the highest Au concentrations and the maximum concentration (13 ppb) is in a calcrete-silcrete sample towards the centre of the section and on the edge of the slope. Its location corresponds with higher Au concentrations (110 ppb) associated with mineralization (hole 54, 376500E). Lower but still elevated concentrations of Au are found sporadically in surficial calcrete developed in colluvium and sand (Figure A 38, 2-6 ppb).

Iron is highly correlated with As, Cu, Cr, Co, Ni, V and Zn, and moderately correlated with Mg, although the low K concentrations suggest a lack of sericitic alteration.

Table A 5: Highest Au concentrations and other anomalous intervals in drillholes.

Drillhole	Interval (m)	Element concentrations (ppm unless stated)	Regolith type
97JBAR054	50-51	Au 110 ppb	saprock
97JBAR054	29-30	Au 32 ppb	saprolite
97JBAR052	20-21	Au 44 ppb	saprolite
97JBAR066	44-45	Au 21 ppb	saprolite
97JBAR062	15-16	Au <1 ppb Cu 250, Zn 270	saprolite
97JBAR062	11-12	Au <1 ppb Cu 220, As 33, Zn 290	saprolite

A.3.4 Conclusions

Jumbuck is a good example of a prospect characterized by a spatially large, but weak, Au in calcrete anomaly overlying low grade mineralization. Maximum Au concentration in calcrete is 20 ppb and the >3 ppb Au isopach spreads over a ~2 km by 3 km area. The calcrete is associated with dune sands and a relict silcrete outcrop forming a breakaway.

A.4 MONSOON PROSPECT (LINTERN *ET AL*., 2002)

A.4.1 Introduction

The Monsoon Prospect is located in the on flat to undulating terrain about 150km WNW of Tarcoola, Gawler Craton (Figure A 39). Mineralization is patchily distributed with the best interval averaging 1.22 ppm over 6 m at 30 m depth. Archaean basement outcrops and subcrops and is partly overlapped by Cainozoic alluvial sediments with silcrete and calcrete. All basement outcrop is deeply weathered and generally has a 1-2 m thick silcrete capping. Shallow palaeovalleys (>8 m deep) have been filled with Quaternary alluvial deposits and the modern drainage lines follow them. The area is vegetated by sparse *Acacia* woodland and numerous woody shrubs (*Eremophila*, *Senna* and bluebush *Maireana*) directly over the anomaly but is thicker just north of the geochemical anomaly.

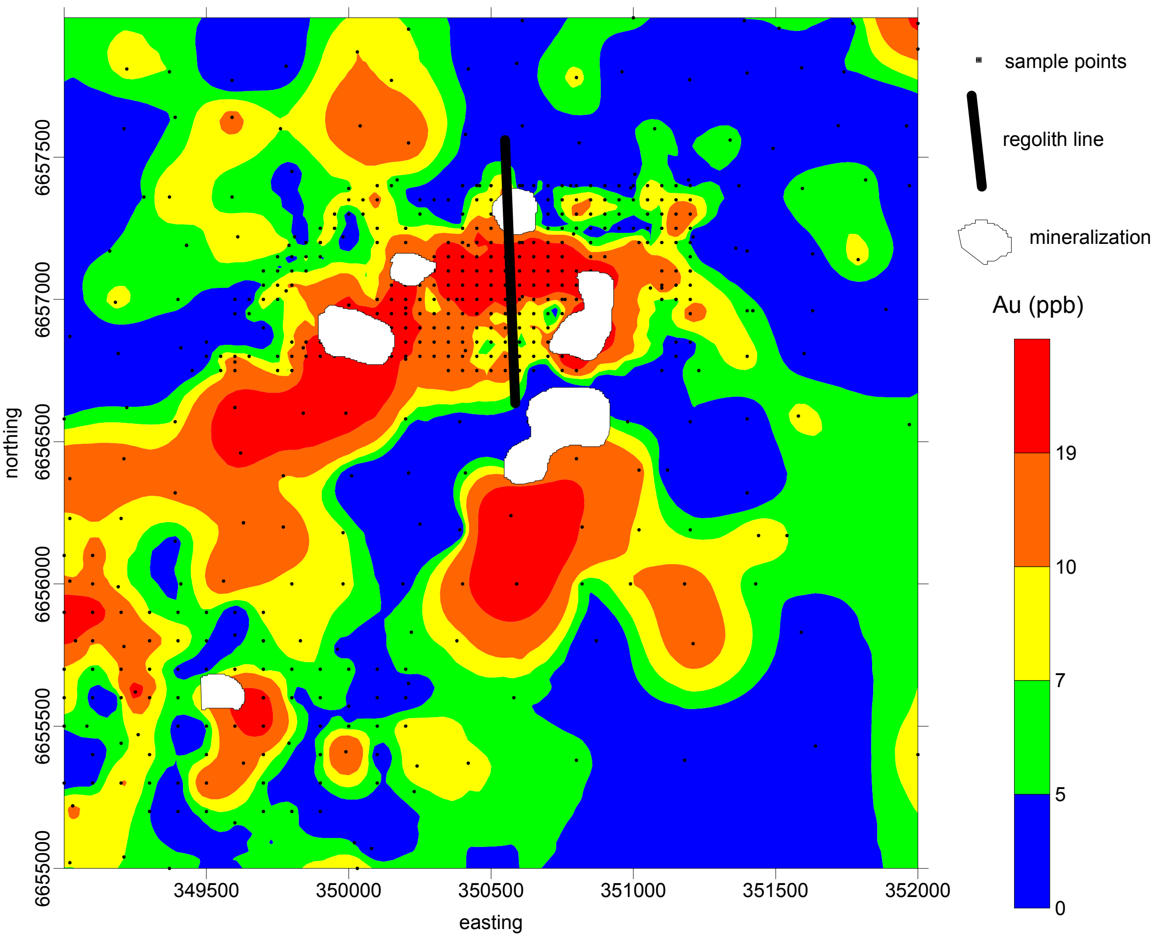


Figure A 39: Detail of Monsoon Prospect showing the calcrete Au anomaly. Data for "regolith line" section shown in Figure A 40. No detailed DEM is available for the area. Original data supplied by the Gawler Joint Venture.

A.4.2 Regolith stratigraphy

The regolith was studied in detail along section 350500E. It reveals a broad wedge of unconsolidated colluvium-alluvium, thickest (8 m) at the northern end of the section (Figure A 40). At the southern end, transported overburden is <1 m thick where localized silcrete outcrop indicates saprolite and sediment substrates. The *in situ*-transported boundary is mostly siliceous.

Calcrete is overlain by thin sandy soils and penetrates several metres into the colluvium-alluvium. Varieties include nodules, earthy powders, coatings (particularly on silcrete), irregular sheets and thick horizons within very porous media. Most indurated calcretes are mildly coloured pale pink to pale orange, but are usually near white where earthy or as infill to silcrete joints.

Calcareous colluvium (<1 m thick) overlies the silcrete at the southern end of the line and is a comprised of lag derived from the underlying silcrete, locally exposed saprolith, and aeolian and slope wash alluvium (Figure A 40). Most clasts are angular to subrounded, ranging from blocks to fine gravel.

At the northern end, two types of alluvium are present. The upper alluvium fills the upper portion of the palaeoslope and consists of loose rounded to subrounded quartz and lithic clasts (Figure A 40). This sediment is much paler in colour than the underlying alluvial unit and contains calcrete as cementing the clasts. The degree of clast rounding suggests a combination of locally derived, short transport history while others are more distally sourced. Much of this material can be assigned to modern creek activity. The underlying dark red alluvium consists of similar loose rounded to subrounded quartz and lithic clasts as the unit above. An irregular upper boundary indicates later incision by the coincidental modern creek. Hardpan, 0-2 m thick, underlies the creek alluvium and overlies a silcrete zone. It contains dark brown to black Mn-Fe oxide cements and/or segregations in clay which is generally carbonate-coated or fracture-impregnated. A strong colour and clay-rich texture makes this unit easily identifiable from all the others. An irregular upper surface to the hardpan suggests it has been partly incised by later fluvial activity.

Silcrete is thickest (2 m) at the southern end of the section and thinnest (<1 m) below the sediment-filled channel where it may have been partly eroded (Figure A 40). There are two separate components, a lower part being silicified pedolith, containing angular quartz grit and relict quartz veins, and an upper part being silicified colluvium, containing subangular to subrounded quartz-rich gravel and an alluvium of well-rounded quartz gravel and pebbles. The unconformity lies within silcrete.

Christie Gneiss forms the crystalline gneissic to granulitic basement. The basement is extensively weathered to >50 m. The grey saprock has some altered feldspars and micas, and is thicker on fine-grained rocks (holes MNAR047-119, Figure A 40). Much of the saprock to lower saprolite is chloritic, indicating the basement is more Fe-, Mg- and Mn-rich. Medium- to coarse-grained lithologies were not encountered but the thicker pallid saprolite at the southern end of the section suggests more felsic forms of the Christie Gneiss occurs there. Quartz veins occur randomly throughout the basement.

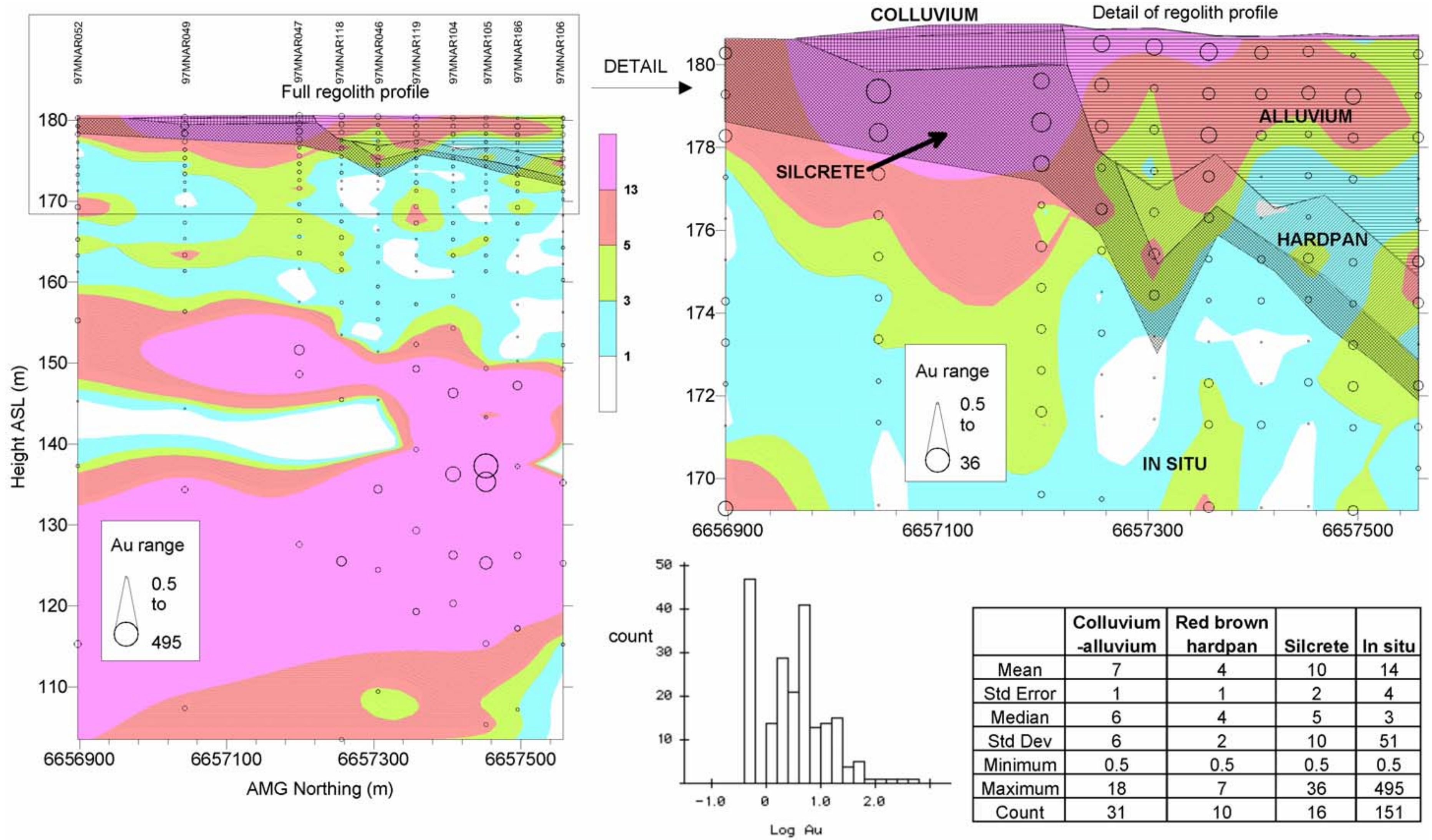
A.4.3 Regolith expression

For the upper regolith, the highest Au concentrations (10-30 ppb) occur in the southern part of the section and are associated with Ca in the siliceous upper saprolite and thin colluvium. Anomalous but lower Au concentrations (10-20 ppb) continue into the calcareous facies of the adjacent alluvium. Gold is only weakly anomalous above mineralization in the siliceous units below the alluvium in the northern part of the section. The dominant factor in the distribution of Au in calcrete appears to be lateral dispersion related to known sub-cropping mineralization occurring to the west (Figure A 41). The Ca vs Au scatter plot is particularly interesting since the strong correlation with surficial Ca suggests that the Au is probably mostly chemically derived since detrital Au would cause spikes in the data. Any evidence of vertical migration of Au to the surface from mineralization located beneath 5 m of transported overburden (and ~30 m of leached saprolite) in the north of the section is obscured by the influence of the adjacent *in situ* anomaly.

Iron correlates with Cu, As, Co and Ni. Some samples rich in S (up to 2.1%) and Fe are also relatively rich in Cd, Zn and Au suggesting some association with sulphides and mineralization (Figure A 42). The co-presence of S and Fe potentially provides a larger drilling target. Gold mineralization is also associated with elevated Cu, As, Tl and Ni (Table A 6).

A.4.4 Conclusions

This case study is typical of a number from the western Gawler Craton. It demonstrates how calcrete can be sampled to show the presence of underlying mineralization within *in situ* regolith. For transported overburden, the buried mineralization is not reflected in hardpan or saprolite at the unconformity and any surface expression in calcrete is obscured by lateral dispersion from the stronger anomaly associated with *in situ* regolith to the south.



	Colluvium -alluvium	Red brown hardpan	Silcrete	In situ
Mean	7	4	10	14
Std Error	1	1	2	4
Median	6	4	5	3
Std Dev	6	2	10	51
Minimum	0.5	0.5	0.5	0.5
Maximum	18	7	36	495
Count	31	10	16	151

Figure A 40: Regolith stratigraphy and Au geochemistry (in ppb) at Monsoon. See Figure A 39 for section (regolith line) location.

Table A 6: Highest Au concentrations and other anomalous intervals in drillholes.

Drillhole	Interval (m)	Concentrations (ppm unless stated)	Regolith type
97MNAR105	43-44	Au 495 ppb	saprolite
97MNAR104	44-45	Au 170 ppb	saprolite
97MNAR105	45-46	Au 320 ppb, Cu 550, Ag 2	saprolite
97MNAR105	55-56	Au 115 ppb, As 450, Zn 950, Ni 1050, Tl 15	saprock
97MNAR105	19-20	Au 2 ppb Se 20	saprolite
97MNAR119	31-32	Au 23 ppb Se 13, Cu 500	saprolite
97MNAR49	24-25	Au 4 ppb As 550	saprolite
97MNAR47	29-30	Au 65 ppb Ni 1350	saprolite

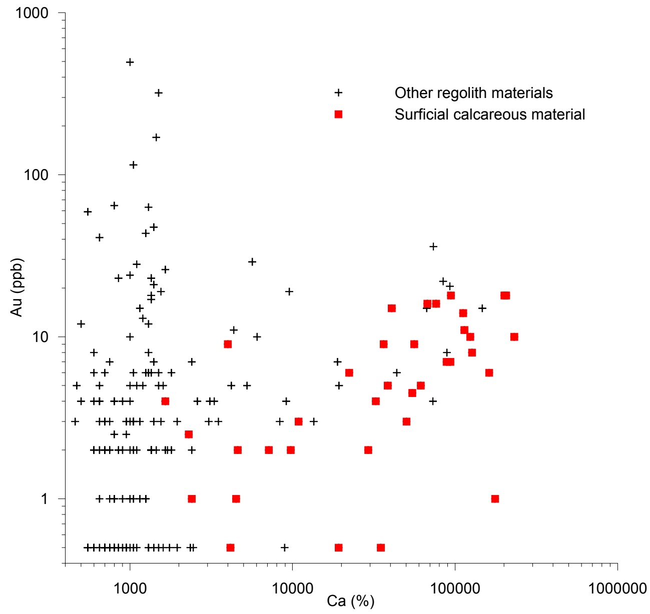


Figure A 41: Calcium vs Au scatter plots at Monsoon for all regolith samples; box symbols indicate highly calcareous surficial samples showing association between Ca and Au;

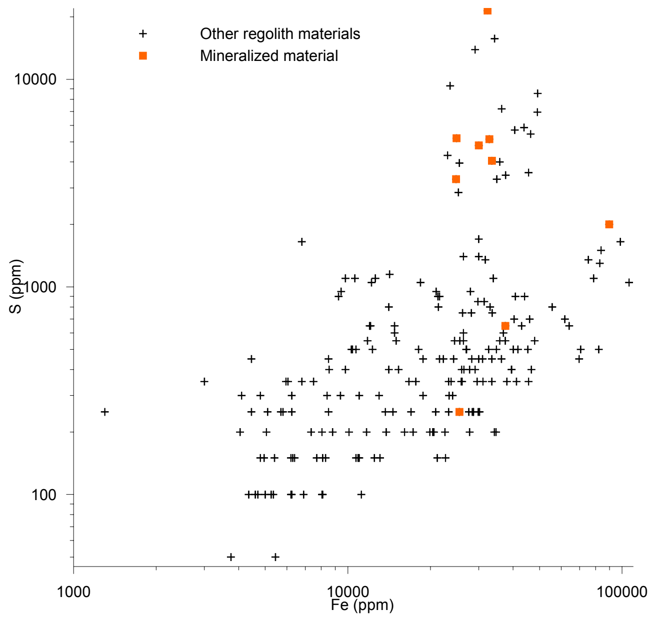


Figure A 42: Iron vs S scatter plots at Monsoon; box symbols indicate mineralized samples.

A.5 CHALLENGER GOLD DEPOSIT (LINTERN AND SHEARD, 1999A)

A.5.1 Introduction

The Challenger Gold Deposit is located in the Western Gawler Craton 750 km NW of Adelaide and 140 km NW of Tarcoola and was initially located by broad spaced (1.6 km) calcrete sampling (maximum of 180 ppb Au), followed by in-fill calcrete sampling (Figure A 43) and drilling in 1995. Gold production commenced in 2002. The deposit is located beneath an expansive plain of several tens of kilometres square with generally low relief (<50 m). Locally, the deposit is located on the flanks of a small rise about two kilometres east of an ephemeral drainage. There is no obvious active drainage within the study area although in the sub-surface there is evidence for small (<1 m) to wide (>1000 m) palaeochannels. The climate is arid with rainfall about 150 mm per annum falling mostly in the winter. Vegetation has been affected by grazing and consists of scattered open low woodland of *Acacia*, *Eremophila* and *Casuarina* (up to 4 m in height) with an understorey of shrubby genera (1-2 m in height).

Regolith studies at the Challenger Gold Deposit were undertaken by several members of CRC LEME and two Honours students, and, as a result, a more detailed understanding of the regolith-landforms, distribution of materials and geochemistry was possible. Several regolith landform maps were constructed for the area including 1:75000, 1:25000 and a 3 x 3 km detailed (1:5000) map. Geochemistry at Challenger was investigated at three levels:

1) Plan distribution of elements in regolith materials over a 3 x 3 km are centred on the main (Zone 1) mineralization;
2) Vertical distribution of elements in regolith materials along a 1.5 km regolith (sampling) line
3) Detailed vertical distribution of elements in eight shallow (<3 m depth) soil pits along the regolith line.

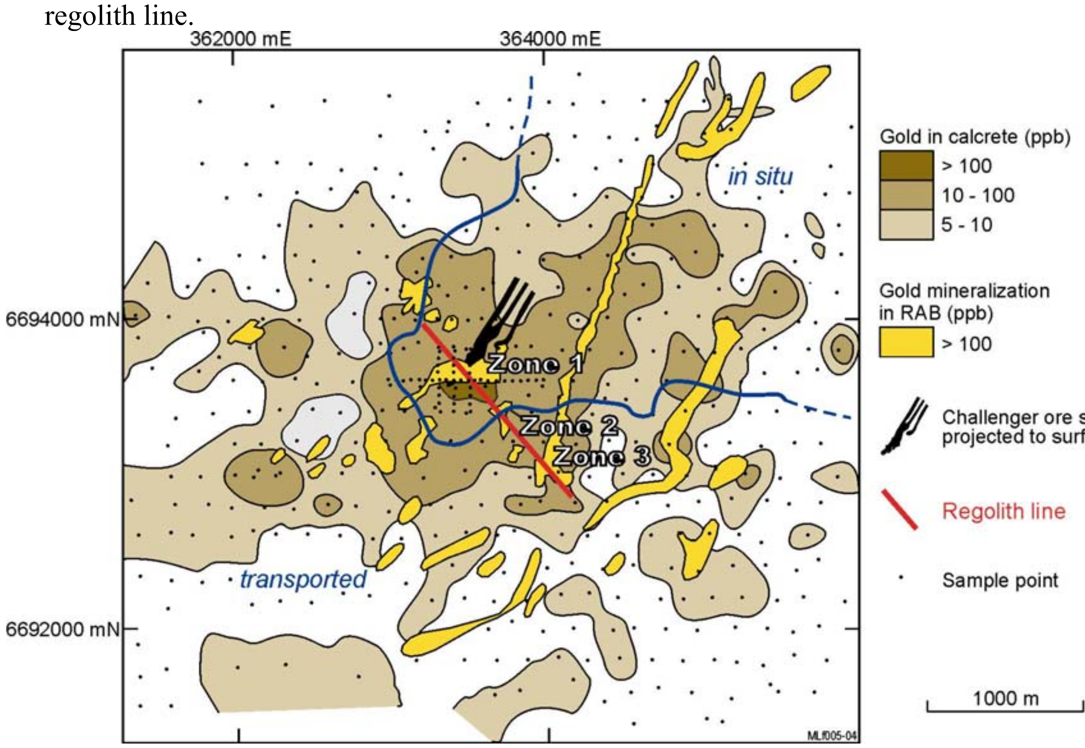


Figure A 43: Gold in calcrete, mineralization, major regolith units and regolith (sampling) line at Challenger Gold Deposit. Some data derived from the Gawler Joint Venture.

A.5.2 Geological setting

Major shear zone development is a major feature of the NW Gawler Craton in which the Challenger mineralization is located. The shear zones act as local conduits for granitoid intrusions. The local host to mineralization is Christie Gneiss which, at this location, is a garnet-rich paragneiss consisting of plagioclase, perthitic K-feldspar, quartz, cordierite, garnet and biotite with minor graphite and Fe-Ti oxides (Bamford, 2001).

A.5.3 Mineralization

High grade Au mineralization (Zone 1) is associated with coarse-grained quartz veins containing minor feldspar, garnet and biotite. Wallrock alteration consists of quartz, K-feldspar and biotite haloes to the veins. Gold mineralization is associated with minor arsenopyrite (cored by löllingite - $FeAs_2$), pyrrhotite, pyrite and rare graphite. Chalcopyrite and bismuth compounds are also noted. Gold occurs as single grains or aggregates in arsenopyrite and inclusions in quartz, K-feldspar and plagioclase (Bonwick, 1997). The estimated size of the deposit is ~ 0.6 million ounces.

A.5.4 Regolith landforms and regolith stratigraphy

The small scale regolith-landform map of the area indicates the dominant regolith-landform to be depositional (Craig *et al.*, 1999). Erosional (*in situ*) units comprise the remainder and mostly consist of highly weathered bedrock. A large scale regolith map was constructed by Povey (2000) and indicated six regolith units (Figure A 44). There is very little outcrop and no lateritic duricrust; ferruginous materials (mostly ferruginous granules) are locally abundant but generally scarce. Landform processes are mostly erosional and appear to be limited to rare fluvial sheet flow leading to local re-distribution of surficial regolith materials, including colluvium and lag, and a general lowering and planation of the landscape. Aeolian processes are evident from the occurrence of minor sand dunes and by the presence of ubiquitous wind-blown carbonate. Beneath the surface, intensive weathering has produced a regolith dominated by kaolinized saprolite and remnant quartz veining associated with felsic lithologies, and sericite, chlorite, carbonate-altered saprolite related to a post-mineralization intrusive suite of mafic and ultramafic dykes. Infilled palaeodrainages mainly consist of poorly crystalline kaolinites that have undergone various degrees of silicification. The upper regolith over the *in situ* and transported units has been variably silicified and then recently calcreted.

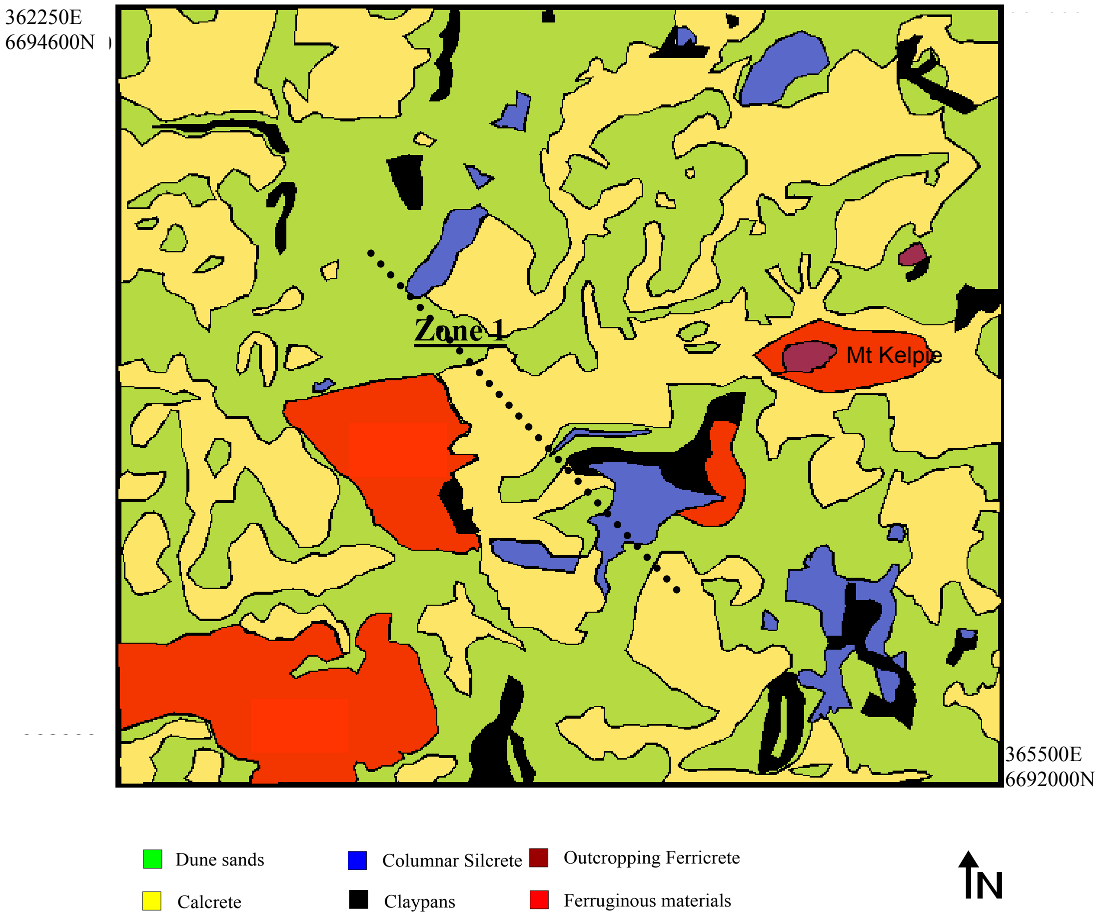


Figure A 44: Detailed regolith map of the Challenger area. Location of Zone 1 mineralization is labelled. Dotted line is the regolith (sampling) line used in the study of Lintern and Sheard (1998). (After Povey, 2000).

A.5.5 Regolith expression

A geochemical survey of regolith materials over a 3 km x 3 km grid provided information on subtle differences in Au distribution for calcrete, soil and two types of lag (Povey, 2000; Figure A 45). The Au in calcrete and soil showed similar distributions but soil Au concentrations were much lower. The calcrete appears to indicate Zone 1 mineralization better than soil but this may be an artefact of the sampling data, with more calcrete samples used here. Some lag over mineralization was also anomalous in Au (Figure A 46).

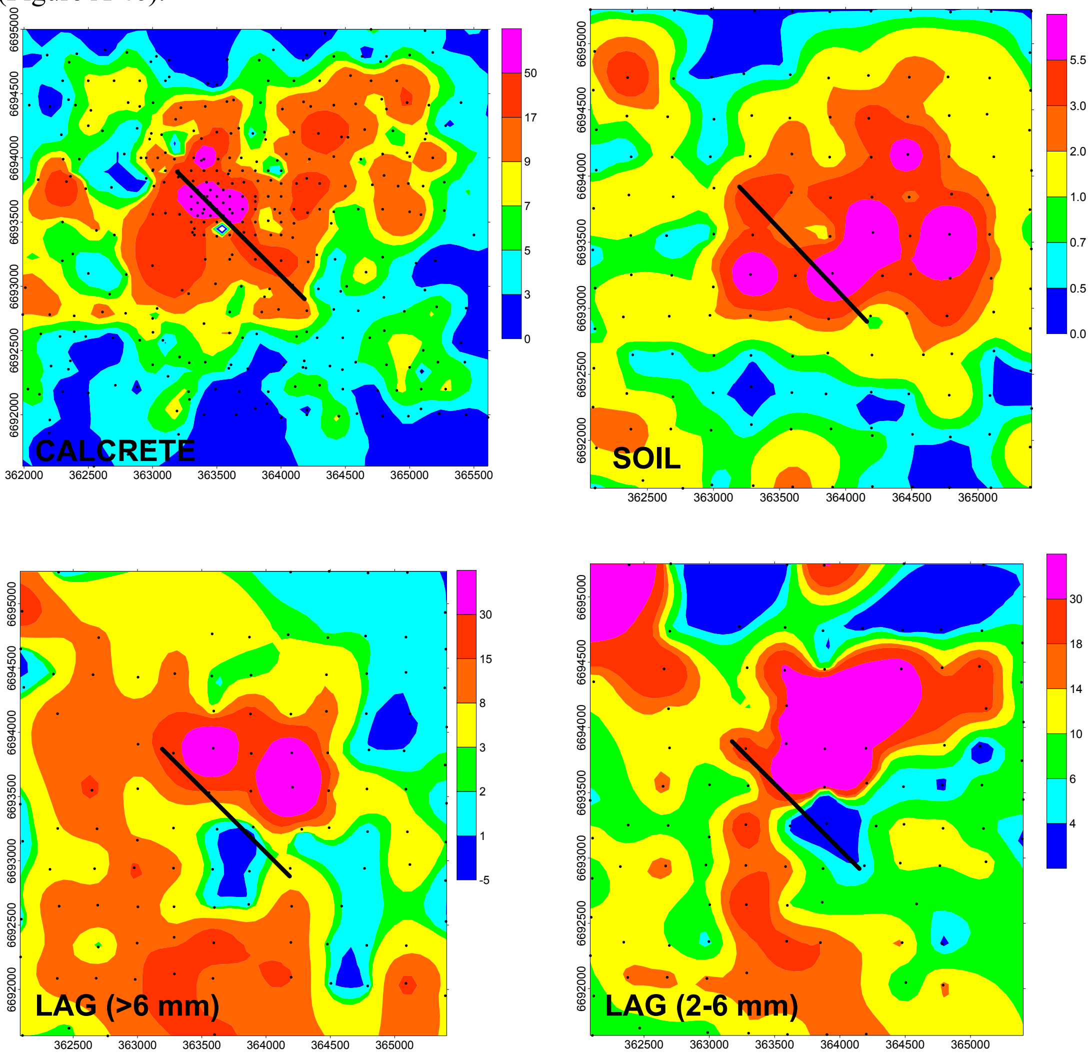


Figure A 45: Gold distribution in four regolith materials. Regolith line shown in black. (After Povey, 2000).

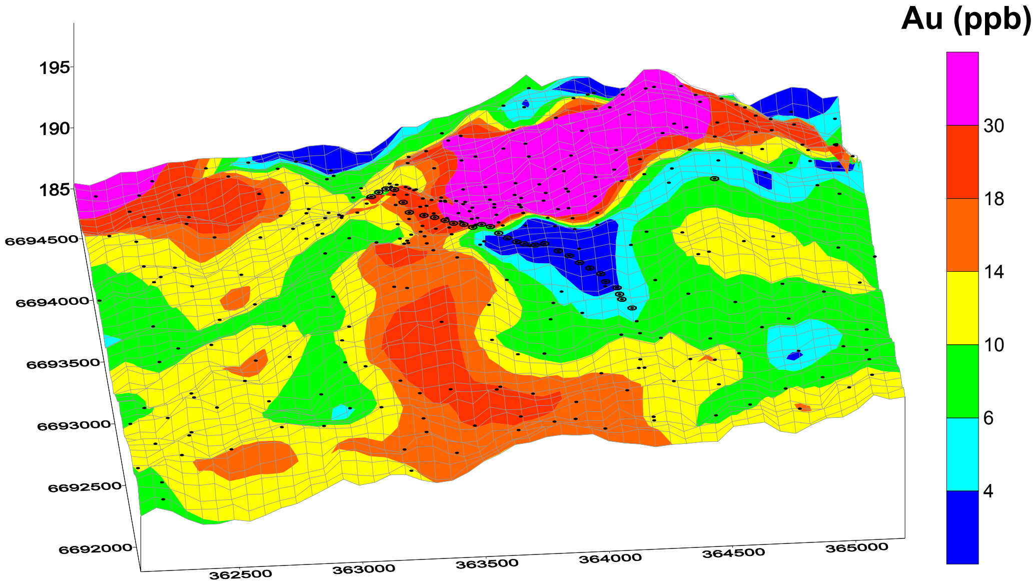


Figure A 46: Gold (ppb) in fine lag draped over a wiremesh DEM. Large black dots signify sampling points on regolith line. Small dots locate sampling points.

Thirty shallow holes (0-6 m) were drilled along the regolith line, approximately perpendicular to strike (Figure A 47), in order to study the upper regolith in detail. The lower regolith was sampled, to ~60 m depth, using cuttings (from pre-existing drill holes) at intervals along the regolith line that corresponded with the upper regolith drill cuttings.

The regolith line crossed three zones of mineralization. Zone 1, the main mineralization, subcrops at 1-2 m depth and is semi-continuous from the lower regolith to the surface. Zone 2 mineralization also subcrops just below the surface and occurs about 400 m to the south east of Zone 1; it is characterized by a sub-surface zone ~20 m deep depleted in Au. Zone 3 is located beneath ~20 m of transported overburden about 800 m to the SE of Zone 1. Other zones of mineralization in the area were not studied. In addition to sub-surface material, surficial regolith materials were sampled. Further details of the study can be found in Lintern and Sheard (1998).

Gold concentrations in surficial calcrete reach a maximum of 2370 ppb over Zone 1 (Figure A 47); this particularly high concentration is because of coarse Au, derived from the quartz veining, incorporated in the calcrete. Anomalous values (~>10 ppb) extend for about 500 m over Zone 1 and about 200 m over Zone 2 (maximum of 52 ppb); no Au or other element anomaly was detected in surficial calcrete over the buried Zone 3 mineralization. For other elements, the response over Zone 1 was more subdued and erratic with As and Cu, and, possibly, Ce, Cr, Fe, K, Mg, Rb, S, Th and V exhibiting one- or two-point anomalies. A response was not detected over Zone 2 mineralization except perhaps for Cu and Zn. Some smoothing of the data was achieved after normalising the chalcophile elements with respect to Fe.

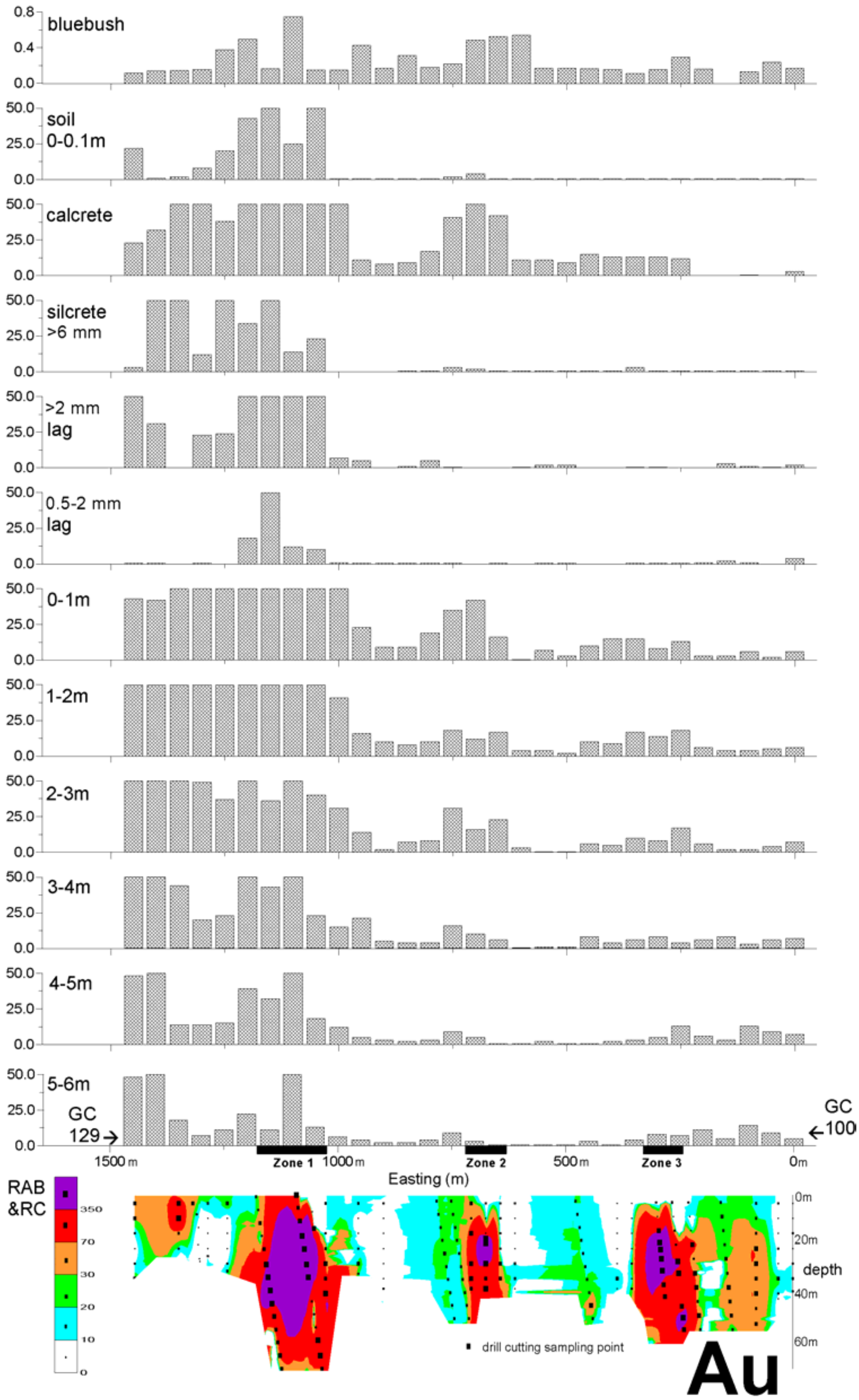


Figure A 47: Distribution of Au in the regolith at Challenger. Data have been truncated to a maximum of 50 ppb in order that lower concentrations can be more easily examined. (From Lintern and Sheard, 1999a).

A series of eight, 3 m deep pits were excavated along the regolith line to enable detailed geochemical and stratigraphic examination of the relationships between (i) silcrete and calcrete, and (ii) silcrete/calcrete and mineralized saprolite. Gold abundances in soil pit profiles are extremely variable but there appears to be a general association between Au and Ca (Figure A 48). The highest Au concentration (~100 ppm) was recorded at 2.0 m in pit GCP122, over Zone 1, although the Au concentration for the soil was only 250 ppb. For adjacent profiles from the same pit located within 5 m of each other, near surface sample concentrations of 35, 250, 380 and 900 ppb were recorded, indicating the extreme variability close to mineralization where there is probably detrital Au present. The high Ca concentration (15%) at the base of pit GCP122 is almost entirely due to the presence of gypsum; the Au concentration here is 760 ppb. Interestingly, Au concentrations of the order of 20-30 ppb in GCP 106 (over Zone 3 mineralization) are relatively higher than in adjacent pits GCP110 and 100 (no mineralization) suggesting the possibility of Au enrichment related to mineralization.

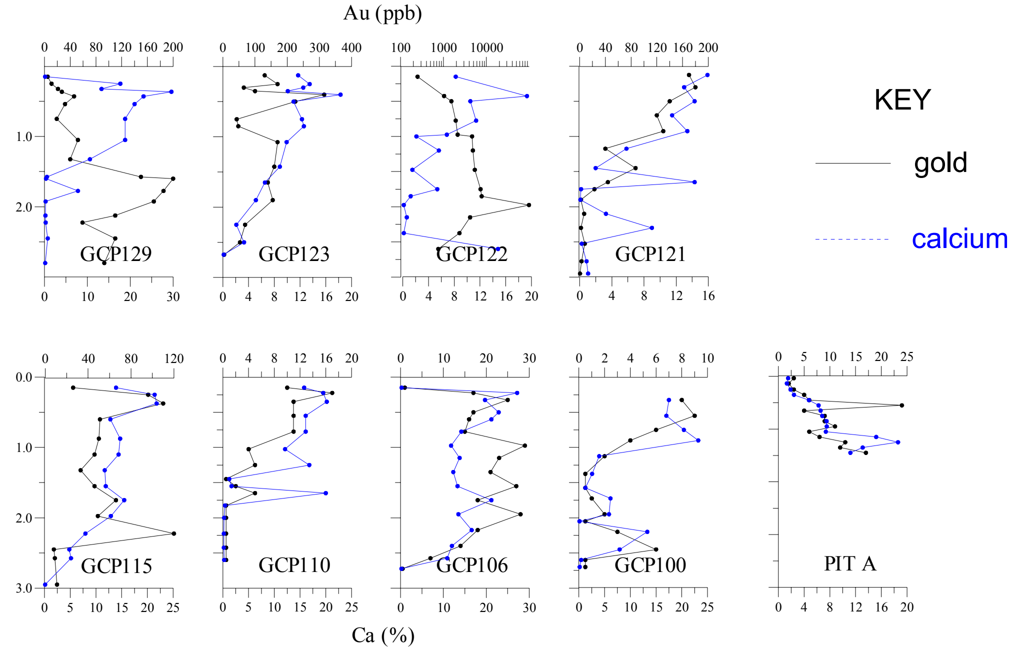


Figure A 48: Concentration-depth profiles for Au and Ca for the soil pits. All pits except pit A are located along the regolith line and their numbers correspond with the drill holes in Figure A 47. (From Lintern and Sheard, 1999a).

A.5.6 Geochemical summary

Whereas it appears that near outcropping mineralization can be relatively easily detected using a variety of elements and sample media, the outlook for exploring in transported overburden in the Challenger area is less certain. Further investigations are required at Zone 3, located beneath approximately 20 m of palaeovalley sediments, to test whether locally anomalous concentrations of Au, Bi, W, Mo and Fe-normalized elements (*e.g.* Cu and As), detected in upper regolith drill cuttings and in soil pit GCP106, are related to underlying mineralization or some other factor.

Calcrete is ubiquitous and is recommended as the best sample medium for detecting Au mineralization in the *in situ* regolith unit providing broad, high-contrast anomalies for several elements, in particular, Au, and to a lesser extent, As and Cu.

In summary, the Challenger studies indicate that elements in the regolith, other than Au, associated with mineralization fall into two broad groups: sulphide-related (Ag, As, Bi, Cd, Cr, Cu, Fe, Mo, S, Se, Zn and possibly W) and alteration-related (Ba, Cs, K, Rb, Tl). The specific use of these elements and others as pathfinders depends on the sample medium to be used and the regolith setting. Elements that appeared to be present in anomalous concentrations in regolith materials, specifically over the three zones of mineralization, are summarized in Table A 7.

Table A 7: Anomalous concentrations of elements over the 3 zones of mineralization in different materials and vegetation at Challenger. (From Lintern and Sheard, 1999a).

Regolith line component	**Zone 1** (*in situ*)	**Zone 2** (*in situ*)	**Zone 3** (transported)
Lower regolith	**Au Ag As Bi Cd Cr Cs** Cu **K Mo** Rb **S Se Tl W** Zn	**Au Ag As Bi** Cd Cr Cu **K Mo Rb S Tl** Fe Zn	**Au** Ag **As** K Mo Rb W
Upper regolith (0–6 m)	**Au As** Bi Ba *Cd* **Cr** Cs **Cu Fe K Mo Rb S Se Tl** V Zn	**Au As Cr Cu Fe Mo S Se V** Zn	As* Cu* Mo W (possibly Au)
Silcrete	**Au** *As Ag* Bi Cd Tl *Th* Fe *W*	Au Cd **Cu**	
Calcrete	**Au As** Ba Cr Ce **Cu** Fe K Mg Rb S Th V	**Au** Cu Zn	
Ferricrete**	Au As Cr Cu Mo Se		
Lag	**Au As Cu K Na Rb W**	Bi Cu	
Soil	**Au** Ag As **Cu** Na *Mo* P **S** Se *W*	Au K Mo Na W	
Vegetation	**Au As** Cr **W**	**Au**	

Cu*, As* - anomalous once normalized with respect to Fe
Ferricrete** - not systematically collected since it does not comprise a major surface component.
Bold - strongly anomalous and/or showing more than a single peak maximum.
Italics - having a broad anomaly in the western end of the regolith line without being specifically associated with Zone 1 mineralization.
Underlined – element not associated with mineralization but, nevertheless, anomalous.

A.5.7 Challenger 3D modelling (van der Wielen, 1999; Gray, CRC LEME, 2002, written communication

Detailed studies of the Challenger area included 3D modelling of the surface regolith and transported overburden by van der Wielen (1999), which has been integrated with company logging. Thus the units differentiated are:

(i) transported overburden (thin hardpan overlying a silt horizon commonly 10-20 m thick, with gravels at the base;
(ii) completely-, highly, moderately- and weakly-weathered residuum;
(iii) rock, unweathered apart from limonite staining of cracks;
(iv) bedrock

Both Zone 1 (Main Challenger ore body) and Zone 2 mineralization show depletion at the completely- to highly-weathered interface (Figure A 49). At the Zone 1 this depletion is incomplete and residual Au is maintained to the surface, albeit at lower concentration, whereas at Zone 2 the depletion is complete.

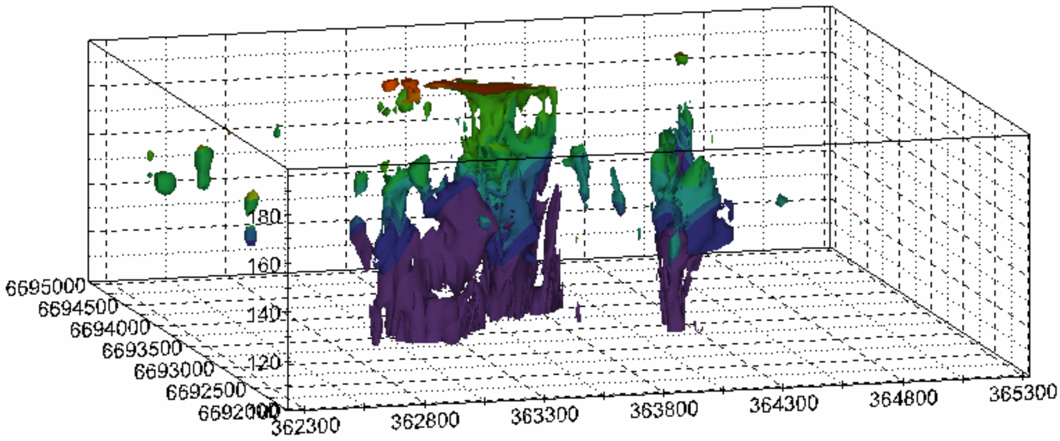


Figure A 49: Gold distribution at Challenger using a 70 ppb cut off, showing the top of the supergene Au enrichment zone at the completely- to highly-weathered interface. Key: purple – bedrock, blue – limonite stained, light blue – weakly weathered, aqua – moderately weathered, dark green – highly weathered, green completely weathered, yellow/orange/red – transported units.

An airborne electro magnetic survey (AEM) clearly delineates two major N-S palaeochannels to the west of the ore-body (Figure A 50). There appears to be poor correlation with mineralization or logged regolith stratigraphy within the ore body area.

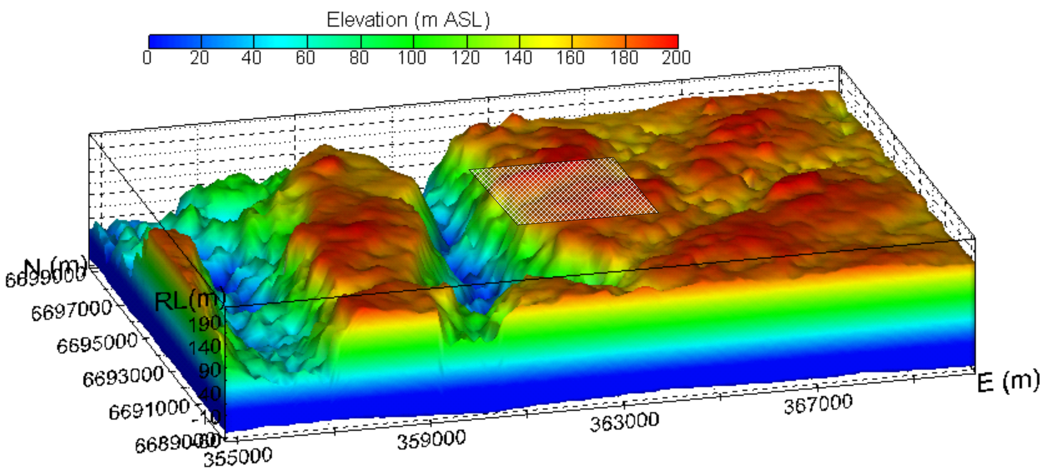


Figure A 50: Elevation of the base of the conductor from AEM. Hatched area indicates area of regolith map and geochemistry shown in Figure A 44 and Figure A 45. Note the two deep palaeochannels to the west of the hatched area.

A.5.8 Conclusions

The presence of transported overburden has a profound effect on the expression of mineralization in the regolith. The case study highlights the importance of identify transported units for geochemical sampling. Thus, while calcrete sampling is particularly effective in erosional (*in situ*) regolith, its use over depositional regime does not appear to be as nearly as effective. Areas of low Au concentrations in calcrete (the null case) should be further investigated to see if samples are located in transported material, in which case, drilling may be more effective. It appears that the broad Au in calcrete anomaly over Challenger (Figure A 33) is more related to chemical and mechanical down slope dispersion of Au from erosional regime regolith. In areas of erosional regolith, alternative sample media such as shallow drill hole cuttings, soil, silcrete, vegetation, lag and possibly gypsum may be used with caution if calcrete is absent and the appropriate thresholds applied. The study identified several elements apart from Au that may be used in the search for mineralization.

A.6 SOUTH HILGA PROSPECT (LINTERN *ET AL*., 2002)

A.6.1 Introduction

The South Hilga Prospect is located about 130 km WNW of Tarcoola. Mineralization is sub-economic and includes 8 m at 3.03 ppm from 22 m and 9 m at 1.4 ppm from 19 m. It is situated on a very gentle gradient with higher elevations to the north. The geochemical anomaly (Figure A 51) is located above Archaean basement, and within calcareous materials, 2-4 m deep, developed within shallow (<10 m) Cainozoic alluvial deposits. The basement is deeply weathered (>70 m) and generally has a 1-1.5 m thick silcrete duricrust capping. The saprolite is variably coloured with yellows and browns near the more mafic zones in the centre of the line or is otherwise pallid. Most of the palaeotopography has been completely infilled with Cainozoic alluvial deposits, yielding the near flat surface that supports *Acacia* woodland with numerous shrubs (*Eremophila*, *Senna*, *Sclerolaena* and *Maireana*). A west-east oriented section (Figure A 52) along 6660300N was selected for study.

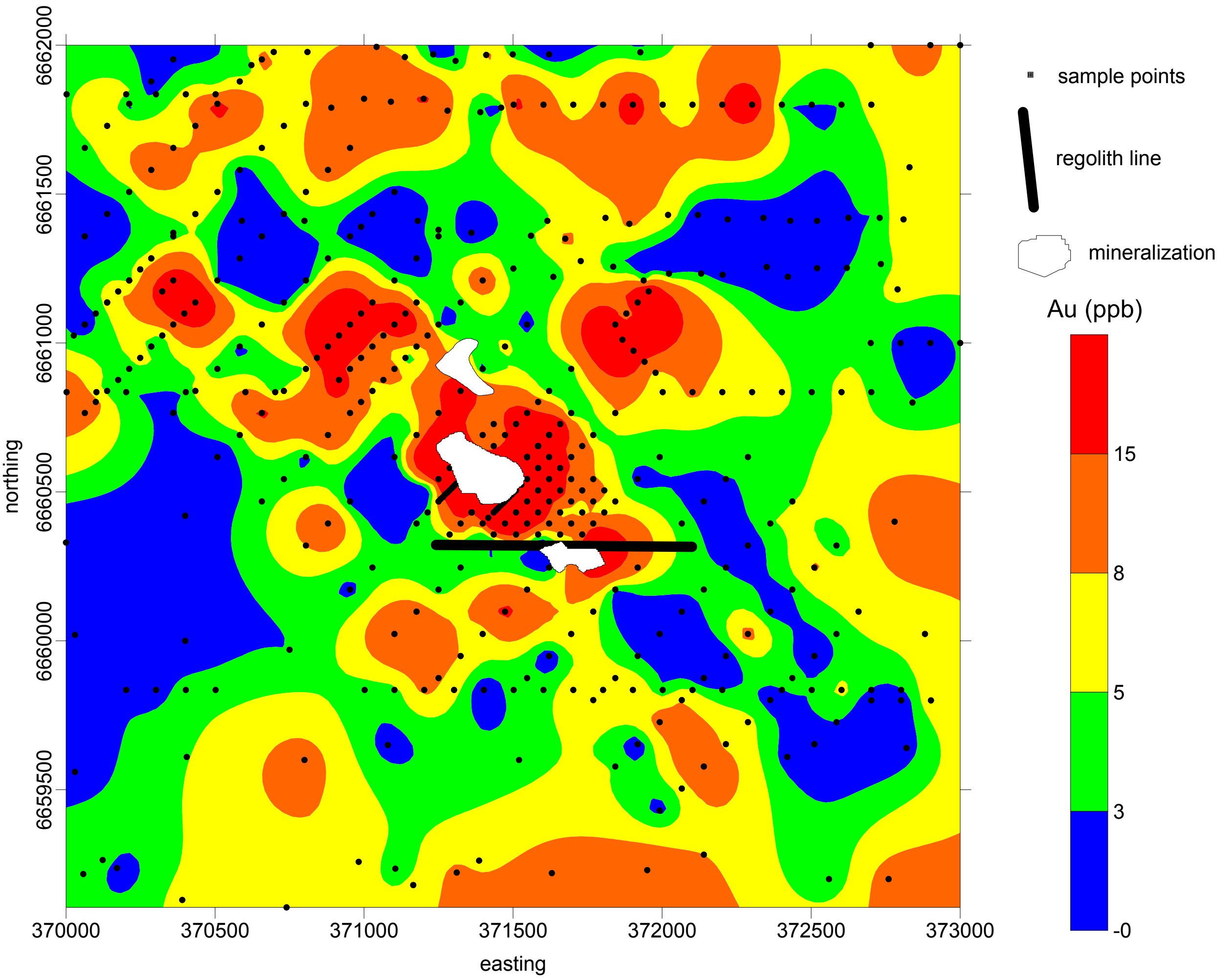


Figure A 51: Detail of South Hilga Prospect showing calcrete Au anomaly, mineralization (~>0.1 ppm Au maximum in drill hole sample) and regolith line (section 6660300N, Figure A 52). No detailed DEM is available for the area. Original data supplied by the Gawler Joint Venture.

A.6.2 Regolith stratigraphy

Calcrete occurs throughout the upper regolith within the soil profile and upper colluvium-alluvium as distinct near-white horizons, nodules, earthy powders, coatings and irregular, 0.5 m thick, low-density bands. The red brown alluvium-colluvium covers the site to an average depth of 2-3 m and also infills two distinct channels at the centre of the section to total depths of 10 m. The channels coincide with two mafic basement zones that have been preferentially eroded prior to infill. Much of the upper sediment is probably related to Quaternary alluvial fans flanking higher ground to the north, but the lower parts are significantly older, darker coloured and partly indurated. Generally, the materials consist of rounded to subrounded quartz and lithic clasts (fine sand to cobble size) but it is dominantly a gravel-rich, clast to matrix supported unit. Poor clast rounding suggests dominantly short colluvial transport.

The top of the pedolith is intensely silicified, forming silcrete; deeper partial silicification has yielded a variably indurated pedolith. Silcrete is 0.5-1.5 m thick but thin (<1 m) or absent below the sediment-infilled channels. Within it are two separately sourced components, the lower part is a silicified pedolith containing angular quartz grit and relic graphite grains, the upper part is silicified colluvium, containing subangular to subrounded quartz-rich gravel and an alluvium of well-rounded quartz gravel and pebbles. The silcrete is pale grey to cream and yellowish.

Christie Gneiss is the crystalline gneissic to granulitic basement rock of garnet-bearing quartz-feldspar-mica. Quartz veins are rare. Much of the more regional saprolite is pallid and appears to be felsic but between holes MHP079 and SHAR145, a strongly mafic variant occurs as two distinct zones or bands, steeply dipping to the east. Here the saprolite is strongly coloured in yellow to brown and at depth is intensely chloritic.

A.6.3 Regolith expression

The greatest Au concentration (2.2 ppm maximum) is in the centre of the section about 30 m below surface in strongly ferruginous, yellow-brown, mafic saprolite and forms part of a mineralized interval averaging 8 m at 1.3 g/t (Figure A 52). It is associated with moderate concentrations of Cu (mean 120 ppm) (Table A 8). As adjacent holes are relatively poor in Au, mineralization is probably confined to narrow veinlets. Above mineralization, however, anomalous Au is continuous through the 10 m deep transported material to the surface and includes 840 ppb Au in the silcreted interface sample. Maximum concentrations in the transported regolith (960 ppb at 6-8 m) are associated with slightly calcareous samples in the buried channel close to the unconformity adjacent to mineralization. In nodular calcrete, samples reach up to 100 ppb Au above mineralization. However, all the transported overburden samples are downslope of mineralization to the north and so the origin of the anomalous concentrations is equivocal. Further sections and 3D visualization of this data are required to investigate the source of the anomaly.

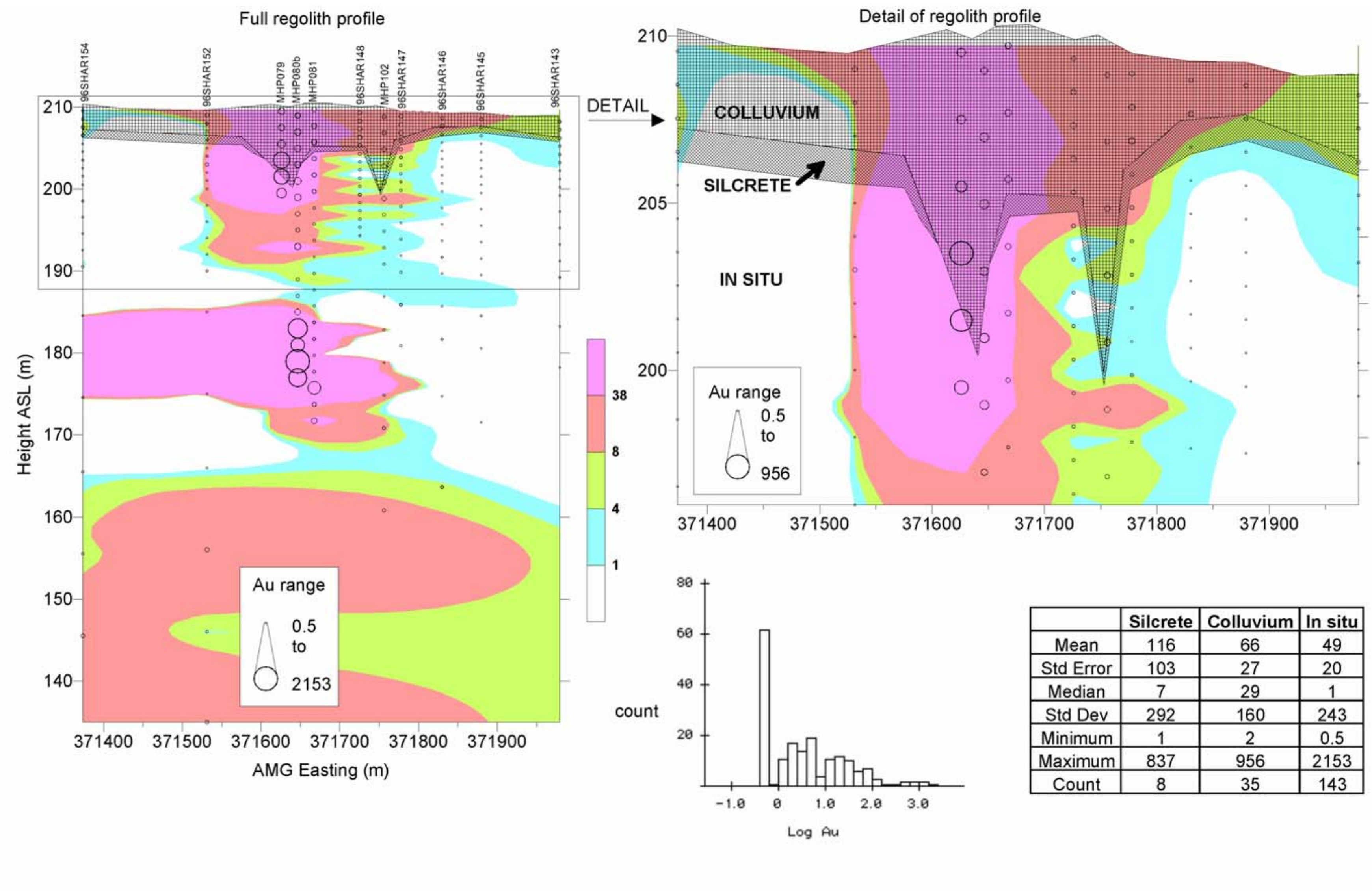
Iron concentrations associated with the weathered mafic rocks are particularly high in Fe but low in Mg (Figure A 53a). Iron is moderately associated with Zn, Ni, Mn, As and Co (*e.g.*, Figure A 53b), probably due to adsorption on Fe oxide.

Table A 8: Highest Au concentrations and other anomalous intervals in drillholes.

Drillhole	Interval (m)	Concentrations (ppm, Au in ppb)	Regolith type
MHP080B	26-34	Au 1340 ppb, Cu 120	saprolite
MHP079	4-12	Au 560 ppb	colluvium/alluvium and saprolite
MHP081	34-36	Au 530 ppb	saprolite
96SHAR147	13-14	Au<1 ppb As 250, Sb 14	saprolite
96SHAR152	63-64	Au 3 ppb Zn 370, Ni 1150	saprolite
96SHAR145	24-25	Au <1 ppb Pb 340	saprolite

A.6.4 Conclusions

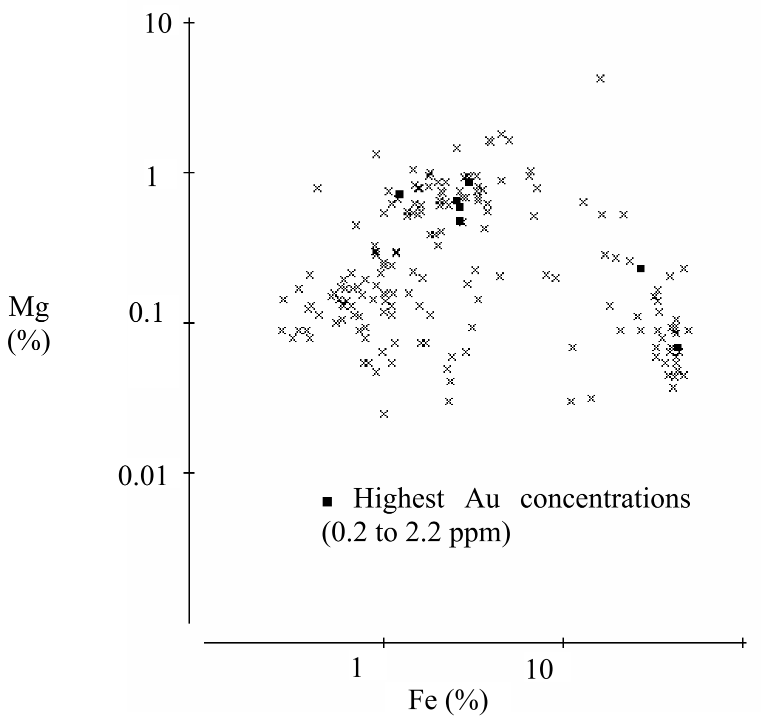
The South Hilga case study indicates that weathering has led to a 20 m thick saprolite zone depleted in Au. The old land surface and samples immediately beneath it still retain significant concentrations of Au particularly in the silcrete. Calcrete in the transported overburden is also highly anomalous but, due to the topographic effects, the origin of this Au is equivocal.



	Silcrete	Colluvium	In situ
Mean	116	66	49
Std Error	103	27	20
Median	7	29	1
Std Dev	292	160	243
Minimum	1	2	0.5
Maximum	837	956	2153
Count	8	35	143

Figure A 52: Regolith stratigraphy and geochemistry of Au (ppb) at South Hilga regolith line. See Figure A 51 for location.

a)



b)

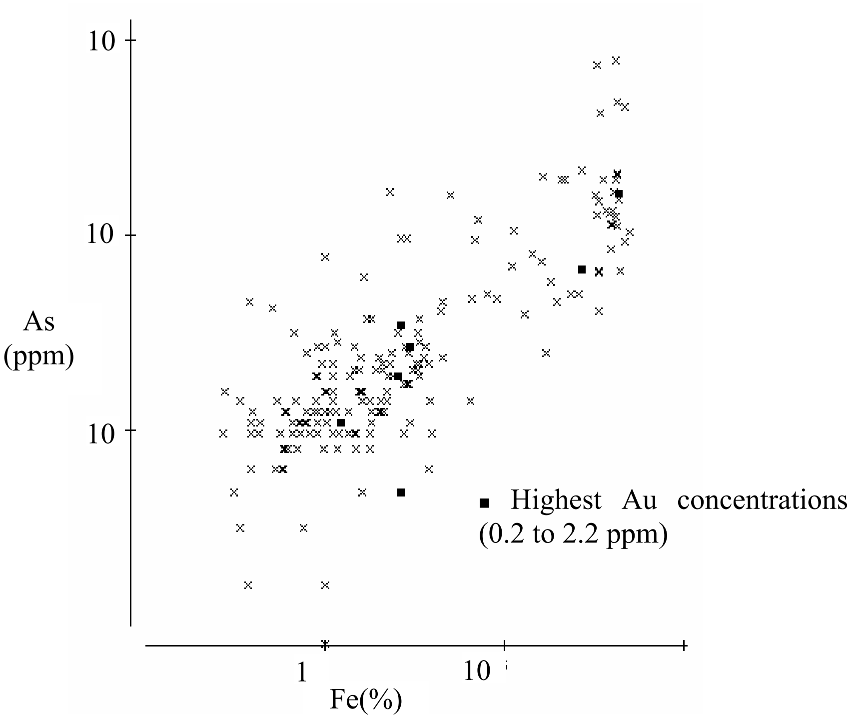


Figure A 53: Scatter plots for selected elements at South Hilga. Box symbols indicate samples with the highest Au concentrations (0.2 to 2.2 ppm)):
a. Fe v Mg. Note the cluster of high Fe and relatively low Mg (lower right) that indicates highly ferruginous saprolite (derived from a mafic source);
b. Fe v As. Some pathfinders, *e.g.* As, are adsorbed onto Fe oxides (goethite).

A.7 GOLF BORE PROSPECT (LINTERN *ET AL*., 2002)

A.7.1 Introduction

Golf Bore Prospect lies 36 km NE of the Challenger Gold Deposit. Mineralization appears to be restricted to a narrow corridor running diagonally across the prospect where an inferred resource of 0.72 million tonnes grading 3.29g/t for 76,814 ounces of gold has been reported (Dominion Mining NL data). There is a surface geochemical anomaly (maximum 260 ppb Au, Figure A 54). Aeolian sand partly covers deeply weathered, silcrete-capped Archaean basement. Westerly-trending Pleistocene seif dunes at the prospect are an easterly outlier of the Great Victoria Desert and infill depressions in the basement with up to 6 m of quartz sand. Several outcrops show where silica has cemented alluvial, colluvial and *in situ* materials into a single silcrete horizon. Vegetation is open woodland (*Eucalyptus* and *Acacia*), numerous woody shrubs (*Acacia*, *Eremophila* and *Maireana*) and other plants (*Ptolitus, Eragrostis* and *Atriplex*).

A combined west-east oriented regolith section on 6726500N and 6726600N was selected to investigate the surface geochemical anomaly and mineralization identified by drilling (Figure A 54, Figure A 55).

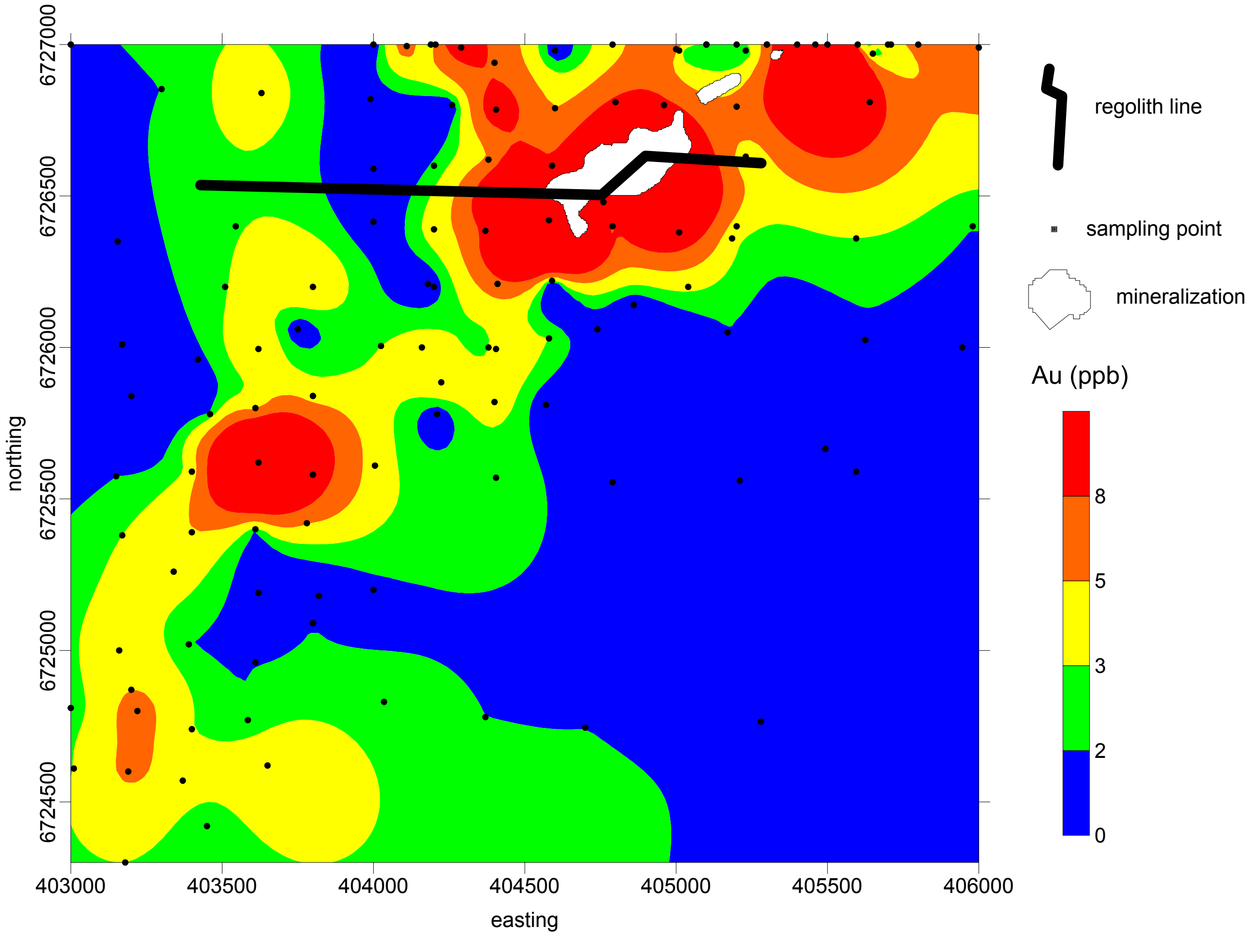


Figure A 54: Detail of Golf Bore Prospect showing Au-in-calcrete anomaly. Black dots are sample points; black line is sampling section (Figure A 55). No detailed DEM available for the area. Original data supplied by the Gawler Joint Venture.

A.7.2 Regolith stratigraphy

Aeolian dune sand blankets the western and eastern parts of the section (Figure A 55). Colours range from orange to reddish and are caused by thin ferruginous coatings on the quartz-rich sand grains. These sands are uniformly sorted and textured with little or no illuviated silt-clay components. Calcrete occurs in the dunes as nodules to earthy or low-density forms. The sand is generally loose free running, unless cemented by calcrete but is mostly stabilized from erosion through the presence of deep-rooted vegetation.

Crystalline gypsum occurs across the section, within or below the siliceous horizon, the pedolith and upper saprolite (white cross hatching in Figure A 55). It ranges from colourless to honey yellow and forms matts of pencil-sized or smaller interlocking crystals.

Calcrete occurs across the upper regolith within the dune sand, exposed silcrete and thin soils. Nodules are dominant within the dunes, but earthy powders or coatings occur in the upper hardpan, with laminated coatings to joint infill on silcrete. Colouring is usually pale pink or pale orange but near white on silcrete or where low density earthy bands have formed.

Hardpanized colluvium-alluvium 0-3 m thick, underlies the aeolian dune sand and overlies the silcrete. The hardpan contains dark brown to black Fe and Mn oxide cements and/or segregations; any clay may also be partly silicified or otherwise indurated. Quartz-dominated sand- to gravel-rich materials with a strong fluvial character also occur, but the unit appears to be dominantly clay matrix supported. Between holes GBAR243 and 088, an infilled channel-like depression feature was intersected, containing red-brown hardpan.

Silcrete is thickest (2 m) at either end of the section and is thinnest (<1 m) to absent below the channel. It generally contains two separately sourced components, the lower part being silicified residual pedolith containing angular quartz grit with relict graphite grains and the upper part being silicified colluvium containing subangular to subrounded quartz-rich gravel and well-rounded alluvial quartz-rich gravel to pebbles. Part of the silcrete may have been removed by erosion within the central channel feature and appears to be missing totally at hole GBAR093.

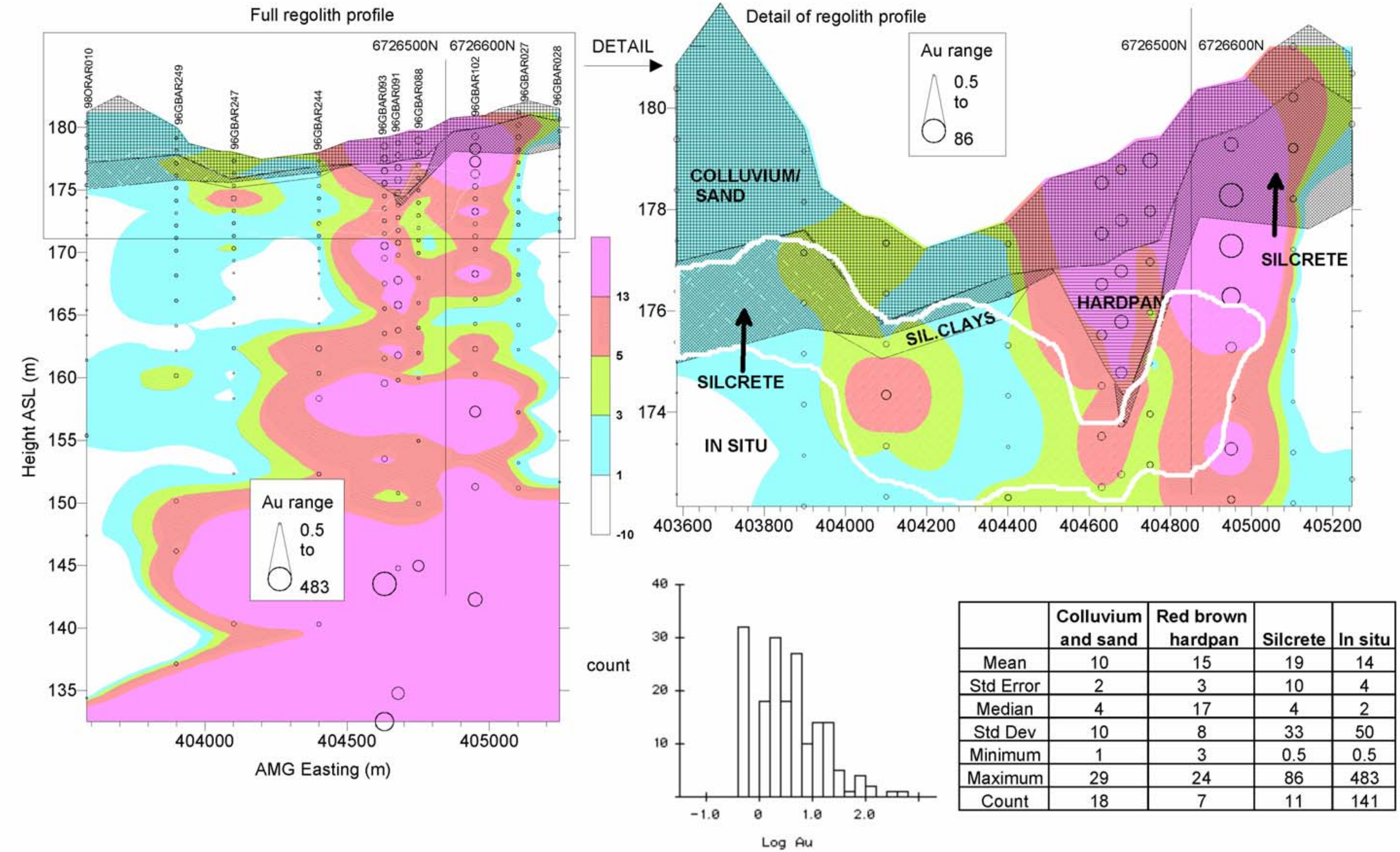
Christie Gneiss forms the crystalline gneissic to granulitic basement and is deeply weathered to depths >30 m. Much of the saprock to lower saprolite is chlorite-rich, indicating a mafic bulk composition. Many drill cuttings from 10-30 m are sericite-rich. Coarse-grained varieties were not encountered but the freshest fine- to medium-grained saprock displays strongly foliated quartz-feldspar-biotite-muscovite gneiss. A more mafic character is expressed in holes GBAR093-028 where chlorite is a common weathering product. Quartz veins occur randomly or in clusters throughout the section; they have colours from translucent grey, blue or black and zoned variants thereof.

A.7.3 Regolith expression

Gold concentrations in calcrete (n=6) sampled from the section above mineralization have a mean concentration of 20 ppb against a background of about 3 ppb (n=8) (Figure A 55). The calcrete has developed in about 2 m of colluvium over a siliceous (non-calcareous) hardpan also containing elevated Au concentrations similar to those found in the calcrete. The highest Au concentrations (85 ppb) are in silicified saprolite immediately beneath a Au- and Ca-rich silcreted horizon indicating a possible origin for the Au anomaly. Unfortunately, the corresponding colluvium and sand above these materials was not sampled due to poor drill spoil condition, so it was not possible to establish whether the Au anomaly is continuous to the surface. The effect of gypsum on the distribution of Au is unclear. Gold concentrations are not anomalous (<10 ppb) and they appear to be slightly diluted relative to the surface.

Gold is weakly correlated with As, Mn and W in drill cuttings. Some of the more significant correlations between major and trace elements are found in Table A 9. Selected drillhole intervals with elevated Au and base metal concentrations are summarized in Table A 10.

The saprolite and saprock are relatively rich in Fe, Mg, As, Co, Cr, Cs, Cu, Mn, Ni and Zn, derived from cordierite, garnet, feldspar and biotite in the bedrock. Higher in the profile, these minerals have largely weathered to kaolinite and muscovite (sericite), with a subsequent depletion of the chalcophile and siderophile elements. However, the upper regolith still retains the elemental signatures noted at depth, though at a lower concentration.



	Colluvium and sand	Red brown hardpan	Silcrete	In situ
Mean	10	15	19	14
Std Error	2	3	10	4
Median	4	17	4	2
Std Dev	10	8	33	50
Minimum	1	3	0.5	0.5
Maximum	29	24	86	483
Count	18	7	11	141

Figure A 55: Regolith stratigraphy and Au (ppb) distributions from Golf Bore. White hatching area indicates gypsum. Location of section shown in Figure A 54.

Table A 9: Associations between major and trace elements.

Major Element	Trace element association	Interpretation
Ca	S and Sr	gypsum, calcrete
K	Ba, Cs, Rb, Tl and (mainly) light REE	white micas
Mg	Co, Cu, Cs, Fe, Mn and Zn	adsorption by Fe oxides and/or original mafic composition
Ti	Th, Nb and U	Similar ionic radii (Nb).

Table A 10: Selected drillhole intervals with elevated Au and base metal concentrations.

Drillhole	Interval (m)	Analyses (ppm except Au)	Regolith type
96GBAR102	22-23	Au 85 ppb, As 145	saprolite
96GBAR93	46-47	Au 284 ppb, As, 120	saprolite
96GBAR93	35-36	Au 483 ppb	saprolite
96GBAR249	19-20	Au 5 ppb Cu 420, As 100	saprolite
98ORAR10	25-26	Au 2 ppb Cu 600	saprolite

A.7.4 Conclusions

The Golf Bore case study indicates that elevated Au concentrations in calcrete can be found in thin (<6 m) colluvium alluvium over mineralization. Gold also occurs in silcrete over mineralization also and may indicate an immediate origin for the Au in transported overburden. The effect of gypsum is unclear with Au concentrations not notably diluted or enhanced.

A.8 BOOMERANG GOLD PROSPECT (LINTERN *ET AL*., 2004 (in prep.))

A.8.1 Introduction

The Boomerang Gold Prospect is located 10 km SW of Tarcoola and 650 km NW of Adelaide in Proterozoic rocks of the Harris Greenstone Belt of the Gawler Craton. The prospect is located beneath a gypseous and calcareous dune ion the edge of a saline drainage system bordering the Great Victoria Desert. There is little regional relief, but dunes covering basement highs provide local relief up to 5 m. Vegetation is sparse and dominated by low open woodland of *Acacia* and *Casuarina* with an understorey of chenopods and other drought-tolerant plants; the area is heavily grazed. The climate is arid with rainfall about 150 mm per annum falling mostly in the winter. Two regolith lines or sections were examined at Boomerang but only the longer, north-south line (449200N) will be discussed here (Figure A 56). The line cuts through a broad palaeochannel, 40 m deep, in its northern part as indicated in Figure A 57.

A.8.2 Geology and mineralization

Air-core drilling has revealed widespread Au mineralization at or near the base of weathering in rocks ranging from quartzo-feldspathic gneissic rocks to relatively undeformed coarse grained mafic rocks. Deeper drilling has indicated that Au in bedrock is largely associated with quartz veining, commonly in altered and brecciated zones. Lead, Cu, Ni, and Zn appear to be associated with some mineralized samples (Table A 11).

A.8.3 Regolith

The drill cuttings from the north-south traverse on 449200N indicate *in situ* and transported regolith units (Figure A 57). The unconformity is difficult to accurately determine due to the nature of the drilling and the presence of a gypsum-rich dune. Transported units are thinner in the south of the traverse and consist of calcareous and gypseous clays overlying mottled and coloured clays grading to saprolite, and partially weathered rocks derived from a variety of lithologies (Figure A 57). The PIMA was used to determine selected mineralogy on certain holes (Figure A 58). Interpreted features of the PIMA spectra include the:

1) poorly crystalline kaolinite of the transported regolith unit;
2) generally higher proportion of smectites in the *in situ* unit;

3) presence of gypsum in thin cover above *in situ* unit but not the palaeochannel; and
4) chlorite associated with the green clays.

Table A 11: Selected drillhole intervals with elevated Au and associated base metal concentrations.

Drillhole	Interval (m)	Analyses (ppm except Au in ppb)	Regolith type
BG47	48-52	Au(1700), Cr(1000), Cu(125), Pb(500), Ni(550), Zn(1500).	saprolite
BG30	44-48	Au(1300), Cu(115).	saprolite
BG47	44-48	Au(1200), Cu(110).	saprolite
BG46	44-48	Au(860), Cr(1150), Ni(750),	saprolite
BG44	44-48	Au(650) no other data	saprolite
BG47	52-54	Au(630), Ni(600) Pb(550), Zn(1100).	saprolite
BG46	20-24	Au(470), W(43).	clay-rich saprolite
BG47	32-36	Au(450), Pb(1200).	clay-rich saprolite
BG46	48-51	Au(417), Cr(1150), Ni(490).	saprolite
DD3	139-140	Au(3850), Ag(4.5), As(280), Cr(700), Pb(1200), Zn(900).	bedrock
DD3	140-141	Au(580), Ag(14), Cr(850), Pb(9900), Zn(550).	bedrock

A.8.4 Regolith expression

Two zones of mineralization (Zones 1 and 2) are crossed by the N-S section. At Zone 1, Au concentrations increase with depth to the bottom of hole and form an anomaly with a width of ~600 m. A similar dispersion halo (200 m), albeit weaker, is observed at the base of a palaeochannel. However, the highest concentration here is more related to quartz veining marking Zone 2 mineralization. By comparison with palaeochannel-related Au dispersion in the Yilgarn Craton, an investigation of a possible Au source upslope of the line investigated could be of benefit.

Discrete calcrete Au anomalies (as defined by the 10 and 20 ppb contours) are present at Boomerang (Figure A 56). There is a moderate association between the anomalies in calcrete and mineralization at Zone 1 (Figure A 59), but, other anomalies are only weakly associated with mineralization, if at all.

Vegetation Au concentrations are not particularly useful at delineating mineralization (Figure A 59); in addition, vegetation is sparse and bluebush (the most widespread of the plant species) is only present over the calcareous/gypseous dunes. Surface lag (>0.5 mm) is widespread but Au data are either below (or close to) detection levels or do not indicate underlying mineralization. The calcrete data (derived from the company database) indicates a moderate association with mineralization but the highest Au concentration (35 ppb) occurs in the northern part of the regolith line over thick, barren palaeochannel sediments, and corresponds with a similar sample for coarse lag. The reason for this is uncertain but this sample is part of an arcuate calcrete Au anomaly that extends to the south west 300 m, and located on a (dune) ridge which requires some follow-up investigation. Non-calcareous soil (0-0.1 m) Au is not anomalous over mineralization but shows sporadic peaks (3 ppb) along the regolith section. Drill cuttings from the top 6 metres indicate “anomalous” Au concentrations (>8 ppb) in the top 3 to 4 metres but that these mainly occur over the palaeochannel and not over mineralization. The lack of anomalous Au in the sub-surface over Zone 1 mineralization may be due to dilution by gypsum.

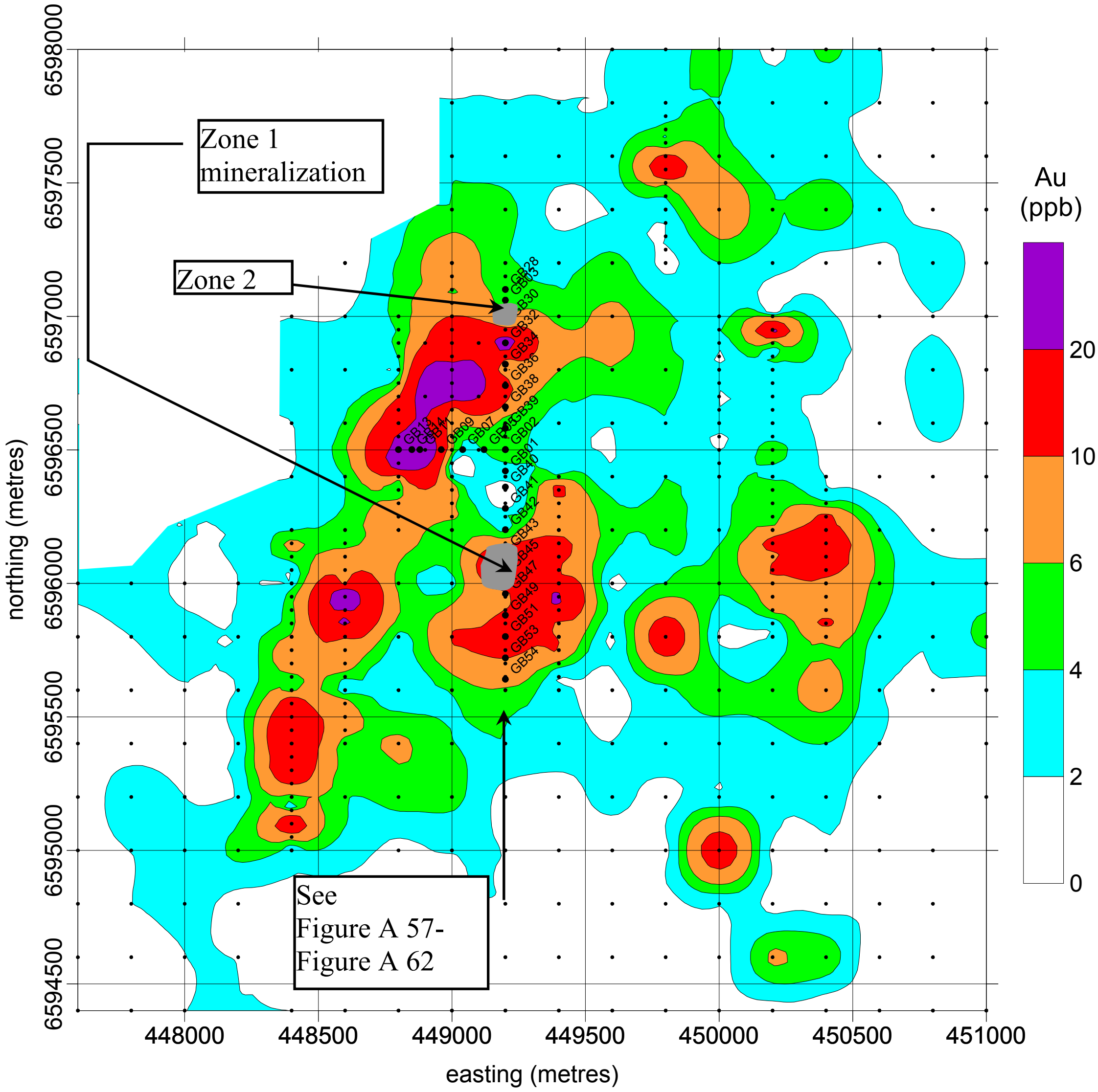


Figure A 56: Boomerang Gold Prospect showing two intersecting sections selected for detailed study (drill holes labelled), contoured calcrete Au anomalies, mineralization (greyed areas) and calcrete sample locations. Data supplied by Grenfell Mining NL.

Apart from Au, several other elements are anomalous in the regolith above mineralization. The most notable of these is Pb, which has a broader footprint (>800 m) than Au and extends south beyond the extent of the section (Figure A 60). Anomalous Pb (>100 ppm) extends to near the surface (3-4 m) in the southern part of the line. Other anomalous elements are Cu, Zn, Ni, Sb and As; correcting for Fe content further defines the As anomaly (Figure A 61).

In the transported regolith unit of the palaeochannel, Bi (Figure A 62), W, U, Nb, Ti, Mo and Ag are anomalous relative to the adjacent *in situ* regolith unit. The reasons for this have not been determined but may reflect higher concentrations of these elements in country rock, with physical and/or chemical mobilization into the palaeochannel.

A.8.5 Conclusions

The Boomerang Gold Prospect indicates that surficial regolith expression of Au above mineralization is present but its tenor may be subdued by the presence of the gypsum dune. In the deeper regolith, leaching of Au in the clay-rich saprolite has probably occurred leading to a zone of depletion. Possible supergene processes have led to a broader footprint to mineralization in the deeper saprolite. Pathfinder elements, especially Pb and As may indicate mineralization in the clay-saprolite.

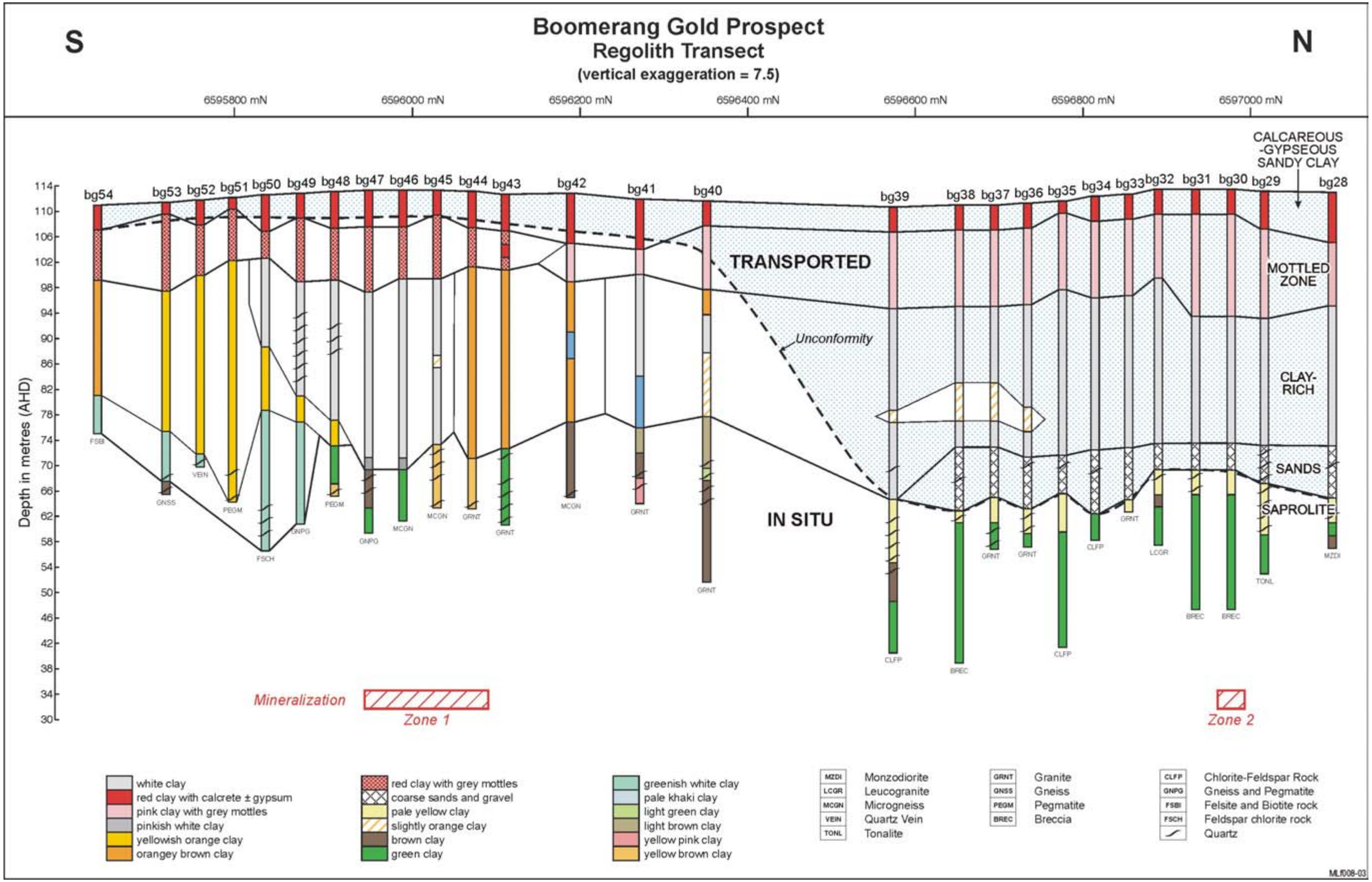


Figure A 57: Regolith section (449200N) from Boomerang Gold Prospect. See Figure A 56 for location of regolith line section. Saprock lithology courtesy of Grenfell Mining NL.

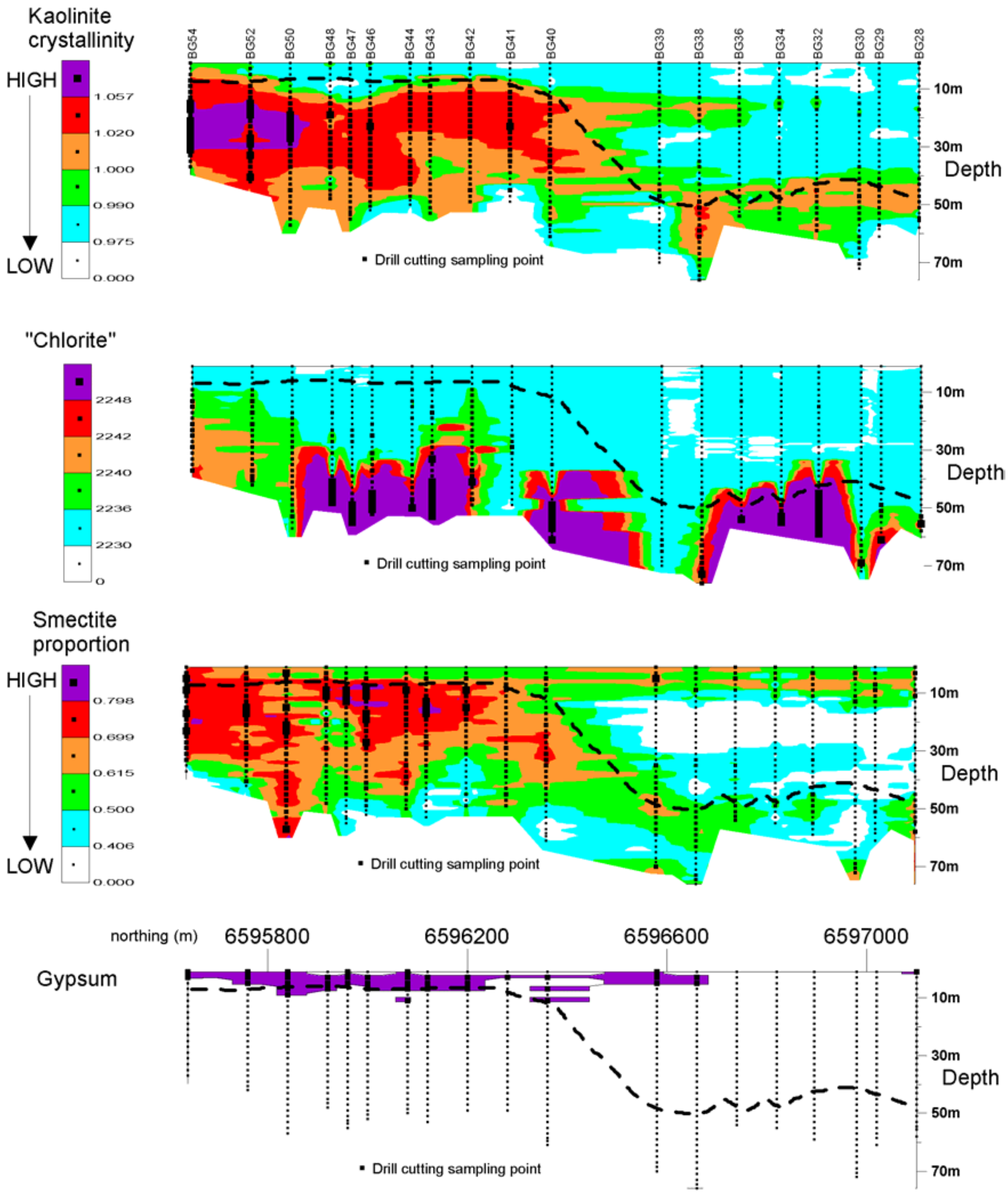


Figure A 58: Contoured mineralogy (arbitrary units) derived from PIMA data for selected holes from Boomerang (449200N). Kaolinite crystallinity calculated from peak mean value at 2180 nm divided by 2164 nm. "Chlorite" refers to a maximum peak location at the specified wavelength (nanometres) indicated in the scale but may not be specifically be a chlorite; variation may be due to different phases. Smectite proportion estimated from relative absorption depth at 1915 nm added to deepest absorption at 2265 nm. See Figure A 56 for location of regolith line section. Dashed line indicates unconformity. (From Lintern *et al.*, 2004 (in prep)).

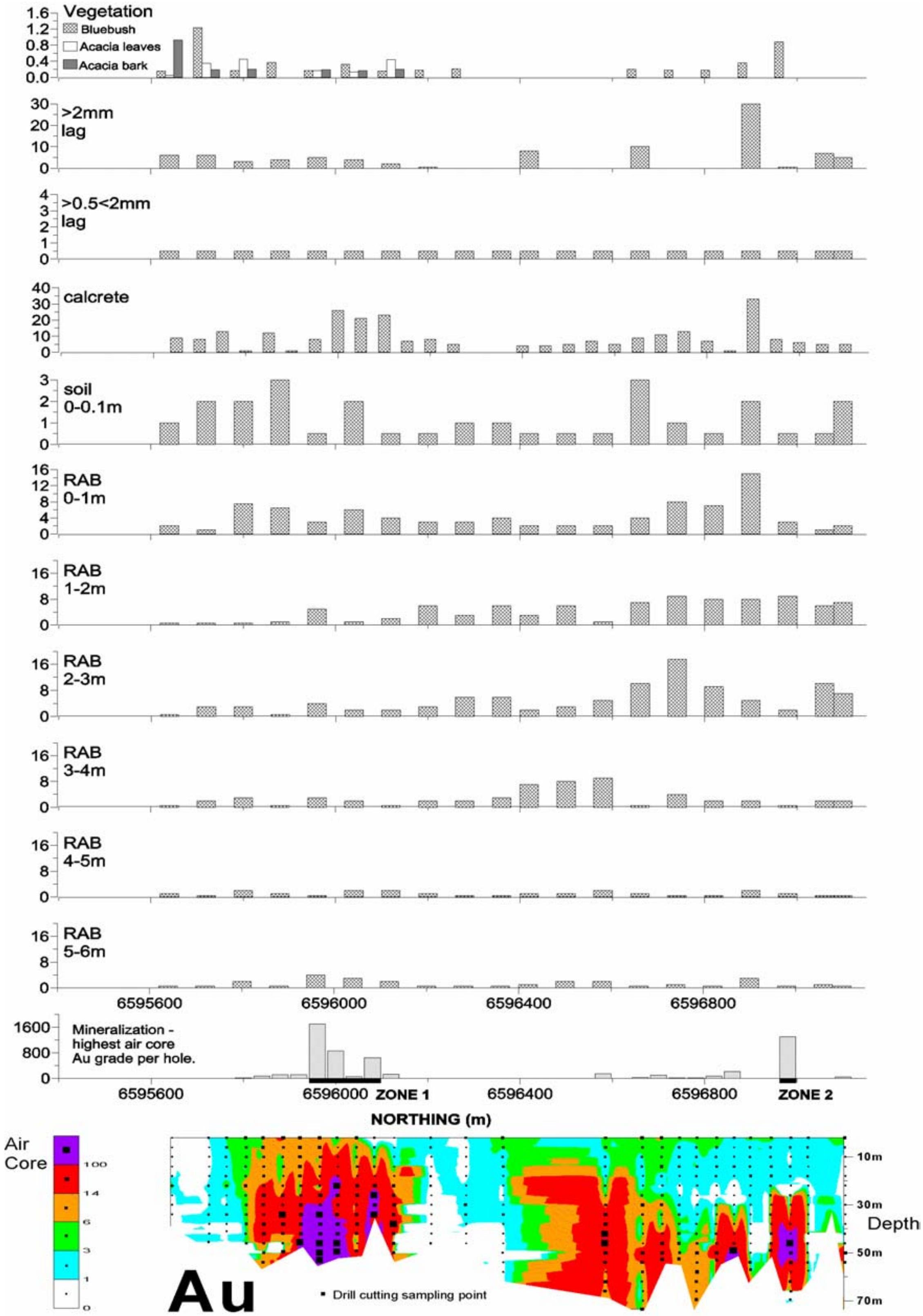


Figure A 59: Gold regolith geochemistry at Boomerang prospect (449200N). Data in ppb. See Figure A 56 for location of section. Dashed line indicates unconformity. (From Lintern *et al*., 2004 (in prep)).

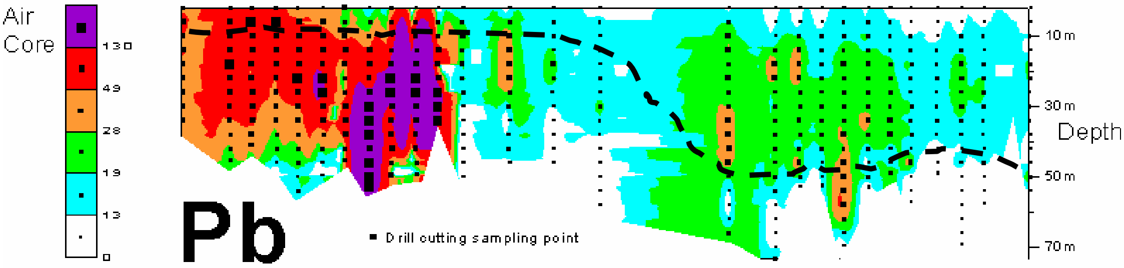


Figure A 60: Lead (ppm) distribution at Boomerang (449200N). Dashed line indicates unconformity. (From Lintern *et al*., 2004 (in prep)).

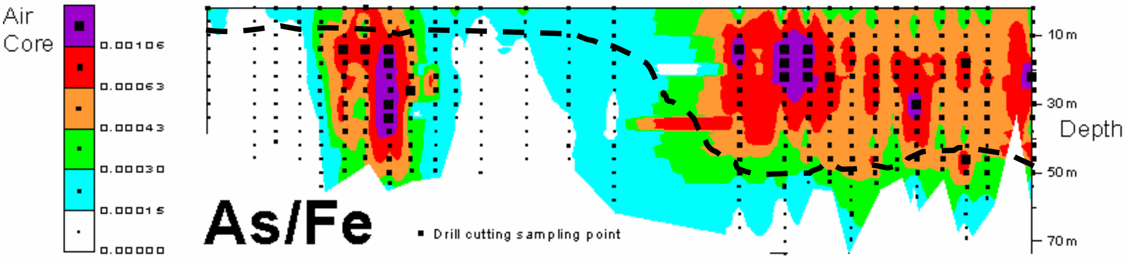


Figure A 61: Arsenic distribution (corrected for Fe content) at Boomerang (449200N). Dashed line indicates unconformity. (From Lintern *et al*., 2004 (in prep)).

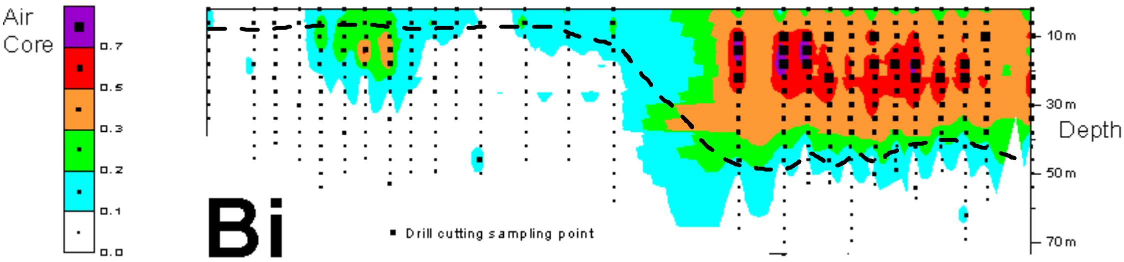


Figure A 62: Bismuth (ppm) distribution at Boomerang (449200N). Dashed line indicates unconformity. (From Lintern *et al*., 2004 (in prep))

A.9 OLD WELL GOLD PROSPECT (GIBBONS, 1997; GIBBONS AND LINTERN, 1998)

A.9.1 Introduction

The Old Well Gold Prospect is located about 30 km SSE Tarcoola. It was discovered after regional calcrete surveys identified a substantial Au anomaly. Subsequent in-fill sampling by MIM Exploration located a longitudinal anomaly >19 ppb Au extending over 4 km in a north-south direction to the southern boundary of their tenement. It appears that the anomaly is the northern extension to a much larger anomaly (10 ppb, 15 km in length) associated with the Tunkillia Gold Prospect (Figure A 63) and is associated with a large drainage feature that extends north from Tunkillia to Old Well and beyond. The area is semi-arid with average annual rainfall of 170 mm and evaporation in excess of 3000 mm. Pearl bluebush (*Maireana sedifolia*) is prominent throughout the area and in places is the only substantial vegetation occurring in large open plains. Mulga is mostly restricted creek channels and other vegetation includes saltbush, *Melaleuca, Casuarina*, *Acacia* spp. and *Eremophila*. The vegetation was used, in part, as a surrogate for construction of the regolith-landform map.

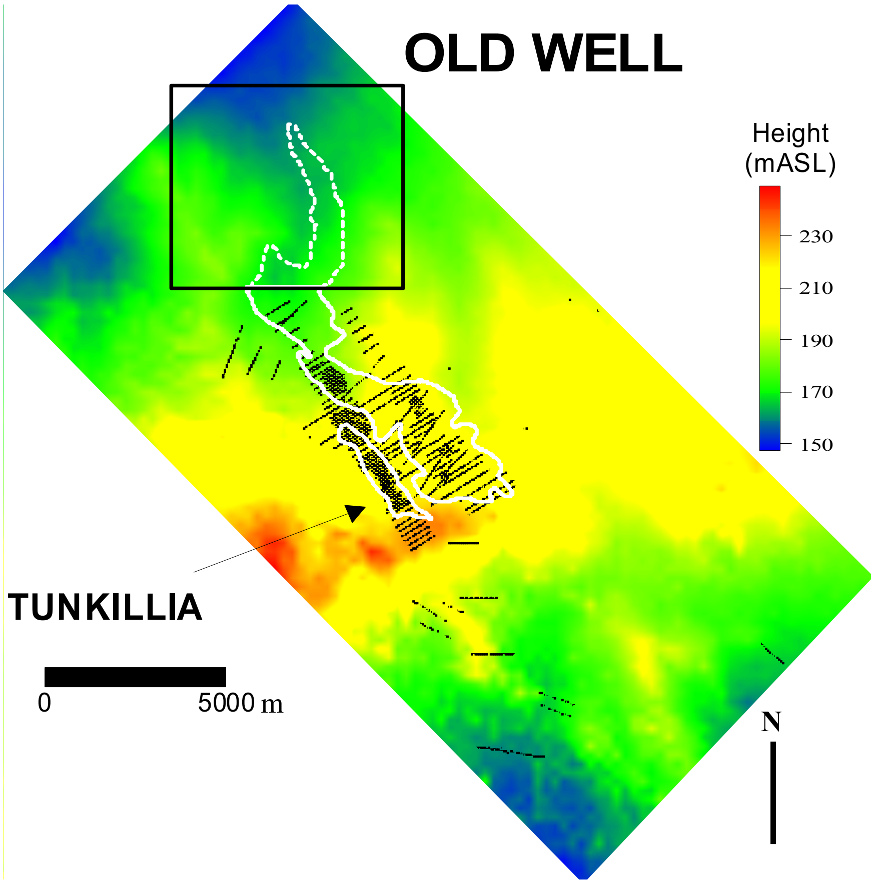


Figure A 63: Gold in calcrete, mineralization and topography. Old Well study area outline in box (see Figure A 64). Gold in calcrete anomaly (10-20 ppb Au) outlined in white. Black lines indicate drilling at Tunkillia prospect.

A.9.2 Geological setting

Old Well is located in Quaternary alluvial sands and gravels; calcrete appears ubiquitous. The crystalline basement is Proterozoic Hiltaba Granite, a mainly pink leucocratic medium to coarse-grained biotite-granite or adamellite, porphyritic in places, with associated veins of microgranite and aplite (Blissett, 1980). The area has low relief with eroding remnants of variably weathered granite within a larger area of thin to thicker sequences of transported material. An ephemeral creek runs north-south through the prospect draining to the north.

A.9.3 Mineralization

Before the discovery of Tunkillia, the nearest mineralization was discovered and mined around the turn of the century at Tarcoola, Earea Dam and Glenloth (30 km west). Mineralization was discovered at Glenloth in 1893 and consisted of Au associated with Cu, Mo, Pb, Zn, As and Sn within sheared Glenloth Granite and Mulgathing Complex Kenella Gneiss (Daly, 1993). The Glenloth Goldfield closed in 1962 having produced 315440 g of Au from 14620 t of rock with an average recovery grade of 21.7 g/t. Mineralization at Tarcoola and Glenloth is dated at Middle Proterozoic and is probably related to Hiltaba Suite Granite emplacement and associated metalliferous fluids at a time of shallow heat sources and intense crustal deformation (Nelson, 1994). The newly discovered Tunkillia contains a total of 10.5 million tonnes grading 2.2 gpt for ~730,000 ounces, with the planned pit (to a depth of 180m), having a head grade of 2.4 gpt (Helix Resources Ltd).

A.9.4 Regolith

Regolith-landform mapping was undertaken using vegetation as a surrogate for surficial regolith features (Gibbons, 1997). The area was mapped into eighteen erosional and depositional zones with the former being mainly represented by remnant granite outcrops and low hills; it is summarized in Figure A 64.

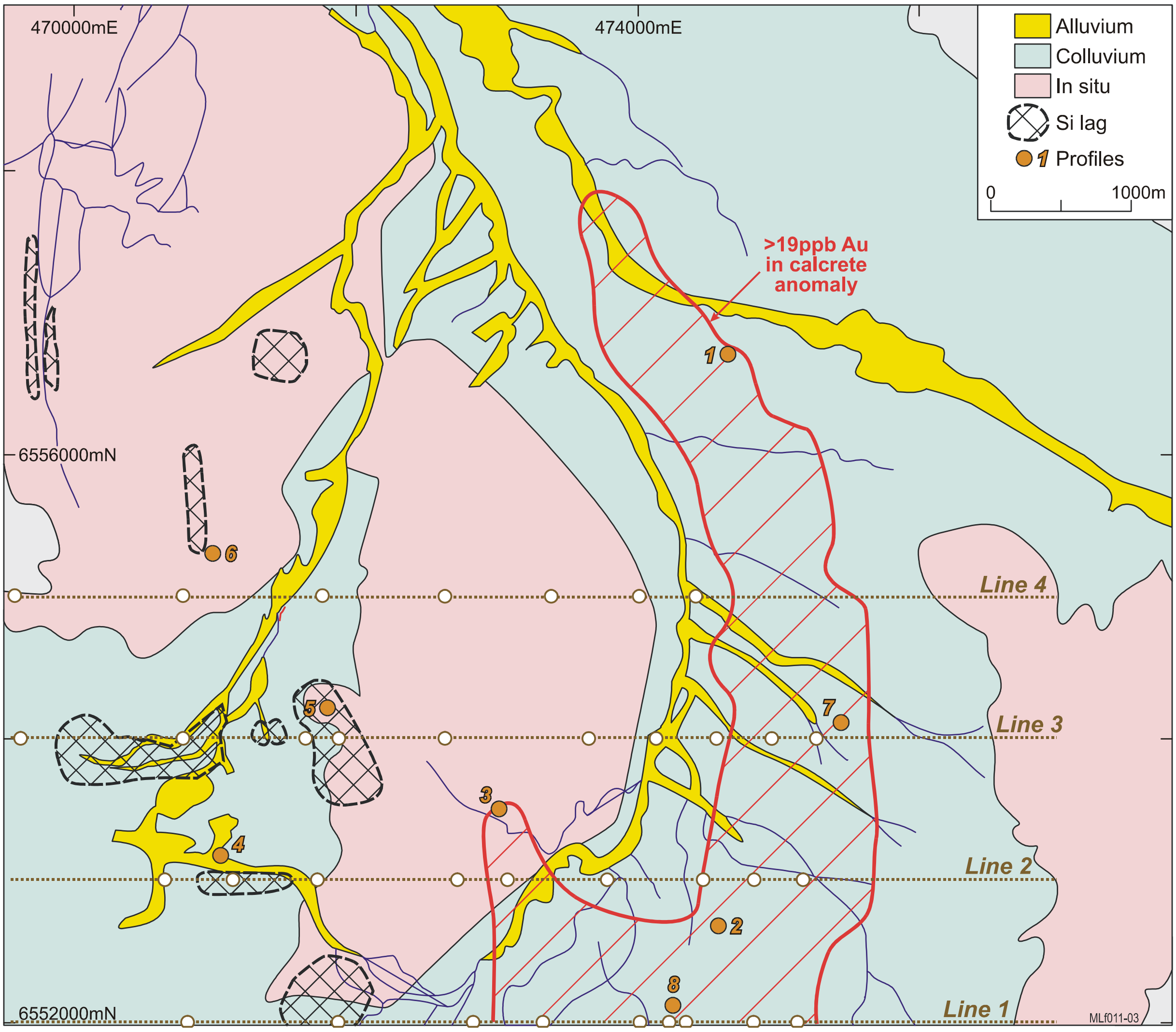


Figure A 64: Sample locations and regolith at Old Well Gold Prospect. Regolith stratigraphy and mineralization for Lines 1-4 is shown in Figure A 65. Gold anomaly extent courtesy of MIM Exploration. (After Gibbons and Lintern, 1998).

Drilling to 6 m was specifically undertaken at eight sites and supplemented routine exploration drilling along four lines (Figure A 64); the shallow drilling was carefully undertaken to ensure good sample recovery and low cross-hole contamination. Shallow pits were dug at each site (average depth of 0.6 m) so that soil profiles could be sampled in detail. Additional information on Au distribution was obtained from the regional calcrete sampling program.

The regolith stratigraphy is variable but is generally comprised of (Figure A 65, Figure A 66):

1) a sandy clay soil (0-1 m);
2) calcrete (1-2 m);
3) ferruginous sands (0-15 m);
4) silcrete including silicified basement (0-5 m); and
5) saprolite after Hiltaba Granite

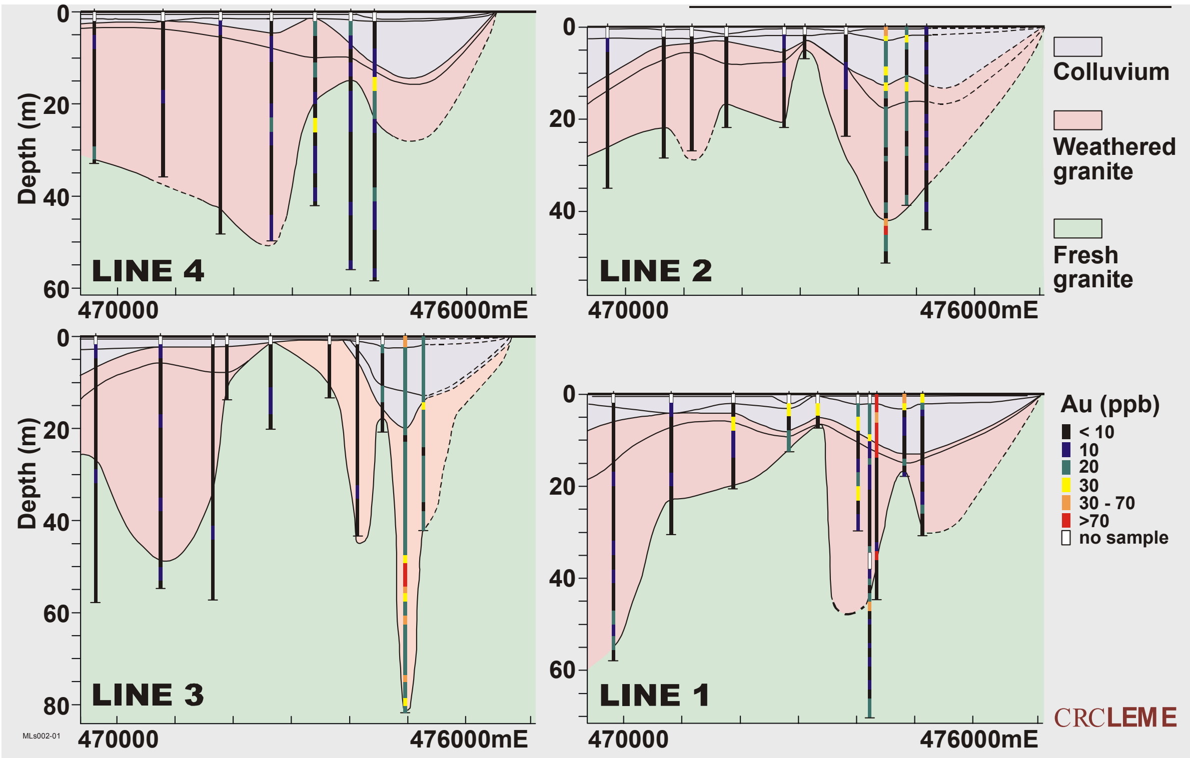


Figure A 65: Regolith stratigraphy and mineralization at Old Well Gold Prospect. For locations see Figure A 64. Gold data courtesy of MIM Exploration. (After Gibbons and Lintern, 1998).

Calcretes were heterogeneous and had prominent reddish and black staining in some samples. Many calcretes were siliceous with a distinctive pink colouration. Nodular, massive and laminar calcrete forms were observed but the vertical distribution of the different morphologies was not consistent between locations. Calcretes consisted principally of low Mg calcite with no dolomite detected, but with some kaolinite and palygorskite. SEM investigations showed biological features in the calcrete including bacterial filaments.

A.9.5 Regolith expression

Despite the areal extent of the calcrete Au anomaly, to date mineralization is sub-economic at Old Well. A strong association between Au and Ca was observed within the soil pit profiles, although other Au maxima occur in sediments not associated with Ca (Figure A 66). For example, at Location 8, significant Au concentrations (>100 ppb) occur in consolidated ferruginous sand. Features of the large regional Au in calcrete anomaly (>19 ppb) at Old Well are that (i) it is located within the consolidated sands of the transported overburden, (ii) its longitudinal shape parallels the current drainage and (iii) underlying weak bedrock mineralization is sporadically present but not necessarily related to the anomaly.

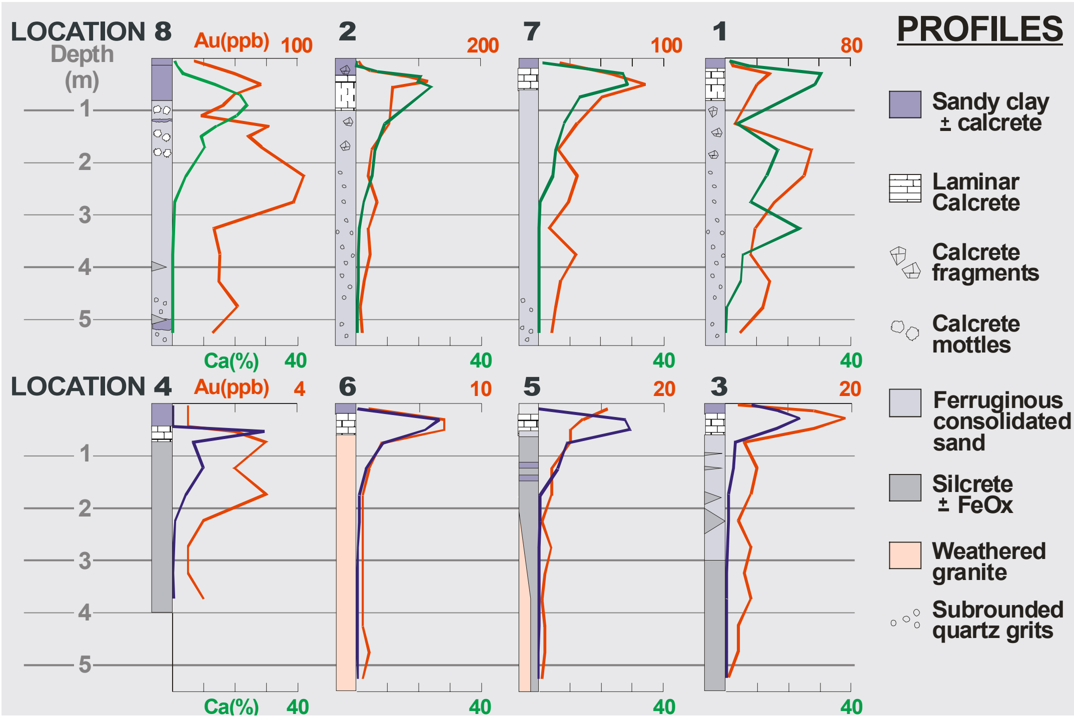


Figure A 66: Stratigraphy, Au and Ca distributions in the upper regolith at Old Well Gold Prospect. For locations see Figure A 64. (After Gibbons and Lintern, 1998).

A.9.6 Conclusions

The results suggest that the source of the Au for the large calcrete Au anomaly is from outside the mapped area. The Old Well anomaly is part of the larger anomaly associated with the Tunkillia Gold Prospect upslope to the south and be related to i) detrital and or chemical Au dispersion from a general source area, such as Tunkillia and/or ii) a more local source within the north-south trending mineralized system, following the axis of the (palaeo-)drainage system and being concentrated within it. The very high Au concentrations (>100 ppb) in individual samples taken from Old Well suggest a more local source overprint to the general dispersion train.

A.10 ET PROSPECT (LINTERN *ET AL*., 2002; LINTERN *ET AL*., 2003)

A.10.1 Introduction

The ET Gold Prospect is located about 150 km west of Tarcoola. The surface geochemical anomaly (maximum Au 115 ppb, Figure A 67) is in undulating terrain (<35 m relief) of Archaean basement outcrop and subcrop, partially overlain by westerly trending Pleistocene linear sand dunes. The maximum Au (115 ppb) is located on top of a silcrete breakaway. All basement outcrop is deeply weathered and generally has a 1-2 m silcrete duricrust cap. The breakaway ridge, comprised of abundant silcrete lag, scarce massive silcrete and rare saprolite, provides a window through the sand cover. Orange sand dunes form an easterly fringe to the vast Great Victoria Desert. They partly mantle the basement palaeotopography by infilling many depressions with quartz sand and clay (<15 m thick) where vegetative cover is substantially denser and taller. The vegetation is a complex mosaic of different plant communities. Sand spreads and dunes support woodlands, open woodlands and mallee over shrublands, dominated by large trees and woody shrubs (*Acacia*, *Eucalyptus*, *Cratystylis*, *Scleroleana*, *Casuarina* and *Senna*). Areas with thin cover support woodlands and open woodlands over open shrublands of woody shrubs and trees (*Casuarina*, *Senna*, *Eremophila*).

The study at ET was undertaken in two phases. In the first phase, an initial north-south orientated section (340200N) was selected in the eastern part of the prospect to investigate dispersion in transported overburden, which is up to 11 m thick here. In the second phase, the rest of the prospect was investigated in more detail including (i) 3D visualization of the regolith volume and Au distribution, (ii) construction of a regolith map and (iii) use of remote sensing technologies to identify regolith materials (Figure A 69) and (iv) sampling soil, lag, calcrete, drill cuttings and vegetation on a whole of prospect scale (the area shown in Figure A 67).

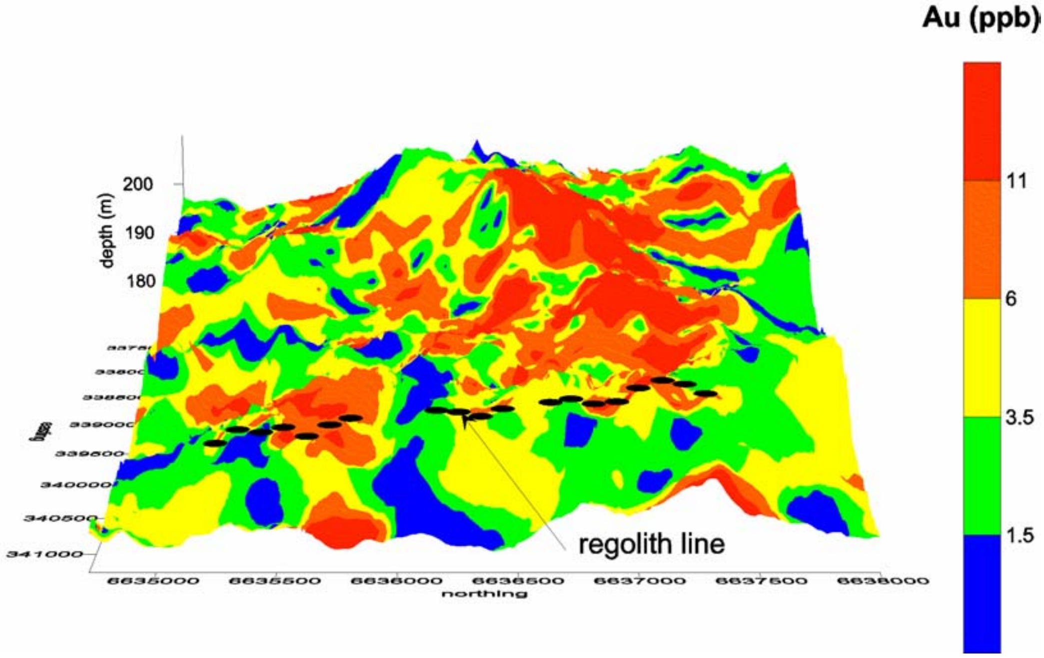


Figure A 67: Detail of ET Prospect showing Au in calcrete anomaly and regolith line drillholes (from preliminary study) overlaid on a DEM. Viewed from east. Original data supplied by the Gawler Joint Venture.

A.10.2 Mineralization

The maximum Au concentration obtained from the drill cuttings database was 0.685 ppm (GJV data) (Table A 12); one sample collected by CRC LEME recorded 0.8 ppm. Mineralization is weak and patchy (Figure A 68). Drilling at ET was restricted to RAB with only 14 holes reaching the fresh rock.

Table A 12: Maximum Au concentration, hole name, depth to mineralisation, and depth of transported overburden of sample with the 3 highest Au concentrations in ppm (Gawler Joint Venture data).

Hole	Maximum Au	Depth to mineralisation	Depth of overburden
ETAR119	0.67	50-51	2.5 m
ETAR151	0.69	40-41	6 m
ETAR167	0.68	40-44	2 m

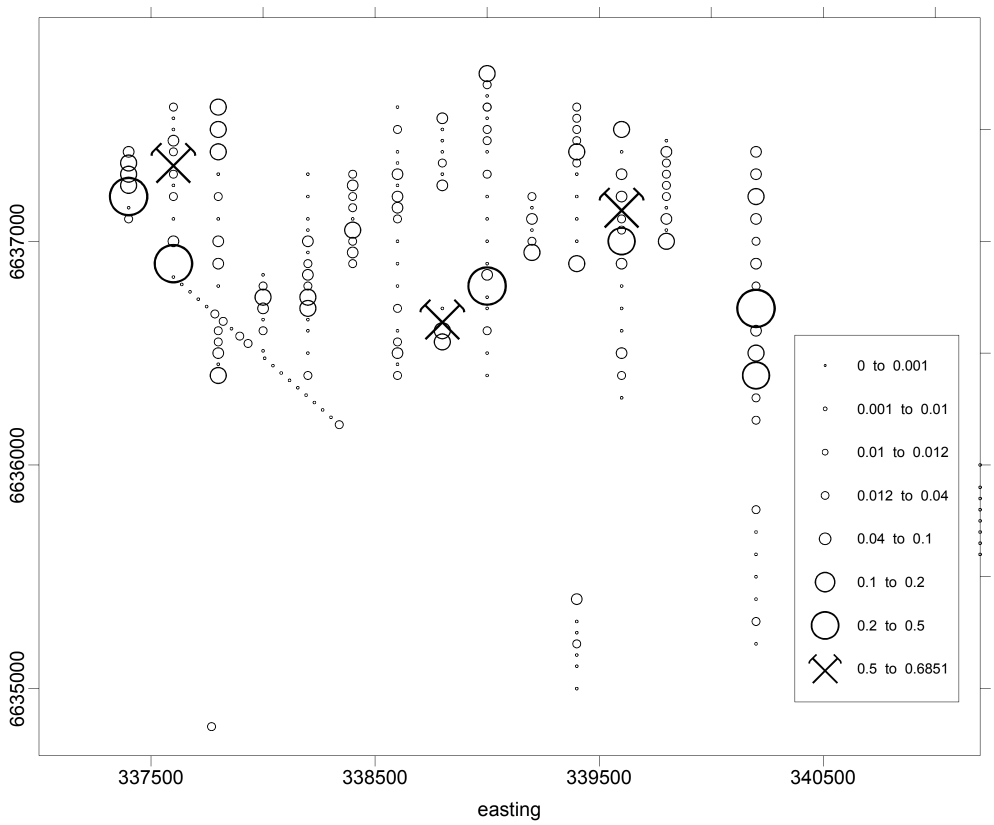


Figure A 68: Maximum Au (in ppm) in RAB cuttings at ET (from GJV data).

A.10.3 Regolith Stratigraphy

Calcrete occurs as nodules and coatings (including joint infill in silcrete) in the near-surface saprolite and at depth in transported clayey sands. Most indurated calcretes are pale pink to pale orange. Calcrete is common in the dune sand and penetrates the siliceous saprolite where the dune sand is absent or thin. Variable Mg contents suggest that some of the carbonate is dolomitic.

Aeolian dune sand blankets a large portion of this prospect and forms a significant dune field. These sands are uniformly sorted and textured with some illuviated silt-clay components forming denser dune cores. On 340200N, the sands range from <1 m to 8 m thick. The sand is generally loose, free running, unless cemented by calcrete or clays.

Hardpan is 0-2 m thick, underlies dune sand and overlies silcrete. In places, this clay-rich material is partially coated near its top by earthy carbonate. Its strong colour and clay-rich texture make this unit distinct, and the irregular upper surface indicates it has been partly incised by later fluvial activity. Silcrete is thickest at the southern end of the section (approximately 1.5 m) and thinnest (<1 m) below the sediment-infilled channel, where some silcrete may have been eroded.

Christie Gneiss forms the crystalline gneissic to granulitic basement and is extensively weathered to >30 m. The grey to brown saprock is thicker where more fine-grained lithotypes occur. A complex variably coloured saprolite overlies the saprock. Much of the saprock to lower saprolite is variably chloritic, indicating an intermediate to mafic composition, although such rocks were only intersected by drill holes ETAR186-188 (Figure A 70). Coarse-grained gneiss was not encountered in this section, but occurs elsewhere. In contrast, the thicker pallid saprolite at the northern and southern ends of the section is more felsic. Quartz veins occur throughout the basement and vary from white, grey blue or dark blue, some are zoned

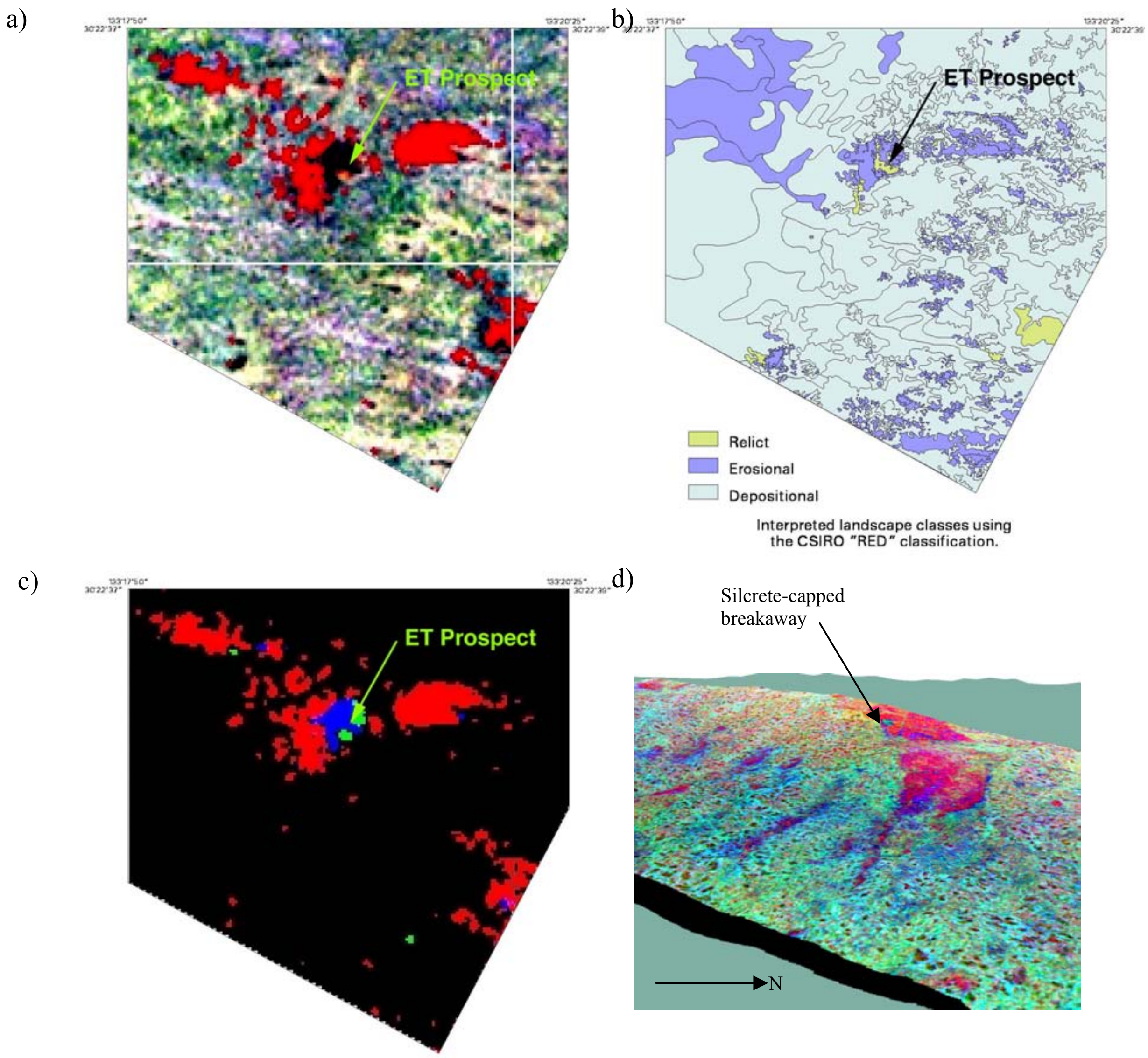


Figure A 69: Regolith mapping products from the ET study: a) A colour composite image of AIRSAR bands, using Spectral Angle Mapping, (overlaying Landsat TM 247 image) highlighting in reds the interpreted locations of silcrete exposures including silcrete gravels; b) areas thematically classified into relict, erosional and depositional regimes; c) Landsat TM imagery showing extent of silcrete and calcrete gravels (red), saprolite (green) and massive silcrete (blue); d) A 3-D perspective view of colour composite image of HYMAP endmembers 6:5:4, overlaid on the TOPSAR DEM and viewed from the east, looking west across a 2.5 km swath of the prospect. Scene width for a-c is 4 km. (Adapted from Tapley (2003) and Craig (2003)).

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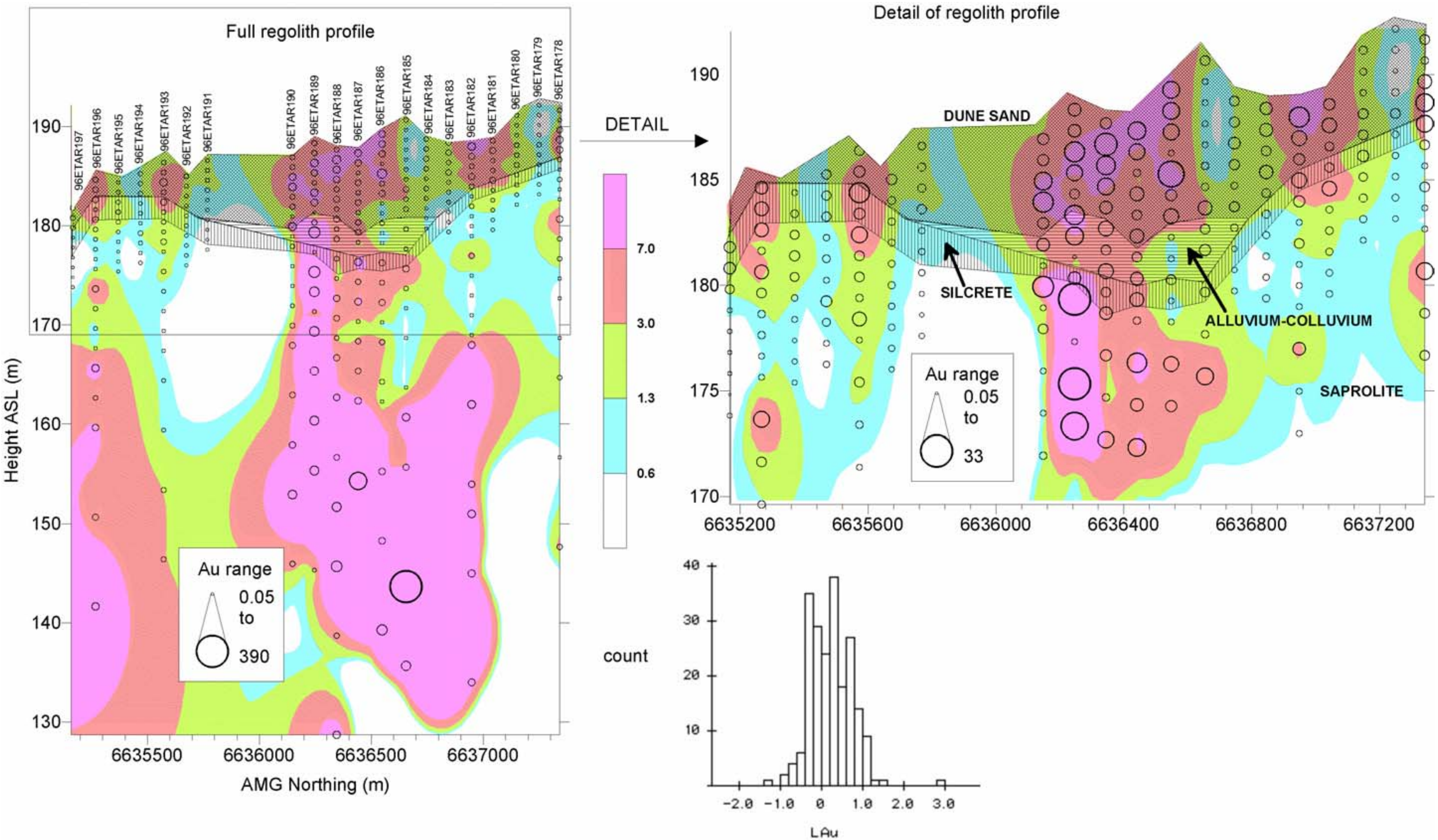


Figure A 70: Regolith stratigraphy and Au distribution at ET. All data in ppb. See Figure A 67 for location of section.

A.10.4 Regolith expression

Element concentrations are primarily governed by regolith type. Element abundances in transported material (dune sand) are (i) generally lower than for other regolith materials, except for Ca, Sr and, to a lesser extent, Au (Figure A 72a), (ii) correlated with one another and (iii) restricted in their concentration ranges due to sediment mixing *e.g.* Fe and Ga (Figure A 72b). Concentrations of pathfinder elements, commonly associated with Au, are generally low e.g. As, Cu and Ni, Table A 13.

On 340200N, Au concentrations in the dune sand are surprisingly high (maximum 21 ppb, Figure A 70)) considering that the dunes are probably only a few hundreds of thousands of years old at most (Huntley *et al*., 1999). One Au concentration (ETAR189, 33 ppb) occurs close to the interface between the *in situ* and transported regolith units and may be attributable to detrital Au in silicified alluvium at the base of the palaeochannel. Another very high Au concentration of 755 ppb Au was subsequently re-analysed at 0.1 ppb and was also located at the interface and is also suggestive of either detrital Au or analytical contamination. Higher Au concentrations in the dune sand appear to be not necessarily restricted to the calcrete but can also be relatively high in the carbonate-poor surrounding material. Gold concentrations in the dune sand do not necessarily reflect higher Au concentrations in the upper saprolite or mineralization in the lower saprolite.

Table A 13: Highest Au concentrations and other anomalous intervals in drillholes for section 340200N.

Drillhole	Interval (m)	Analyses (ppm unless stated)	Regolith type
96ETAR185	47-48	Au 390 ppb	saprolite
96ETAR187	33-34	Au 101 ppb	saprolite
96ETAR196	17-18	Au <1 ppb Cu 320	saprolite
96ETAR188	42-43	Au 30 ppb Ni 1400	saprolite

From the second phase of study (Lintern *et al*., 2003), it was concluded that,

1. The main Au anomaly in calcrete is associated with a thinly covered, topographic high of *in situ* (residual) regolith flanked by lower lying deeper sand. It is not directly coincident with the main Au anomaly found in the upper regolith, which is further east along the ridge. The reasons for this are unclear since there is a strong association with Au and carbonate in the drill cuttings.
2. The drilling data suggest that neither the main anomaly in the upper regolith nor that in calcrete is fully explained by the current understanding of the extent of mineralization. Further drilling in both areas is recommended.
3. Multi-element geochemistry has limited value in delineating new anomalies but can support the Au data. For example, Ag (cyanide-soluble) is anomalous over the Au anomalies occurring in calcrete and the 0-1 m drill cuttings. However, Cu (cyanide-soluble) is much more related to lithology than mineralization. Arsenic from lower saprolite appears to be following a structural trend and may be related to mineralization.
4. Whereas many anomalies in *in situ* regolith are directly related to mineralization, there are several examples where the surficial data are not easily explained by the drilling data. The Au has either been dispersed from its source and seemingly concentrated, or the drilling has been inadequate.
5. The best evidence for an anomaly occurring in transported overburden is hole ETAR 070 (Figure A 71). Gold concentrations in drill cuttings reach 35 ppb in calcareous sand over weak mineralization at 25 m. A nearby calcrete sample has a Au concentration of 50 ppb. In section, there is no mineralization on the upslope ridge and Au in calcrete on the ridge attains a maximum of 10 ppb. Further detailed studies are continuing in this area.
6. In some locations there are no surficial Au anomalies over concealed mineralization. This suggests surficial regolith materials cannot be relied on to detect all mineralization at the prospect scale. Alternatively, the mineralization may be so weak that it does not form an anomaly or be discontinuous, in which case the data reflect the real situation and there is no vertical dispersion.
7. Vegetation Au data (0.5 km x 0.5 km grid) can potentially provide additional exploration targets, but their failure to substantiate existing anomalies in calcrete reduces the confidence in their use. The highest Au concentrations appear to be more related to transported overburden, suggesting that vegetation may be responding more to run-off from sub-cropping on the ridge.

8. Soil sampling (0.5 km x 0.5 km grid) appears to delineate the main calcrete Au anomaly but is probably responding more to the presence of thin overburden above underlying anomalous calcrete.

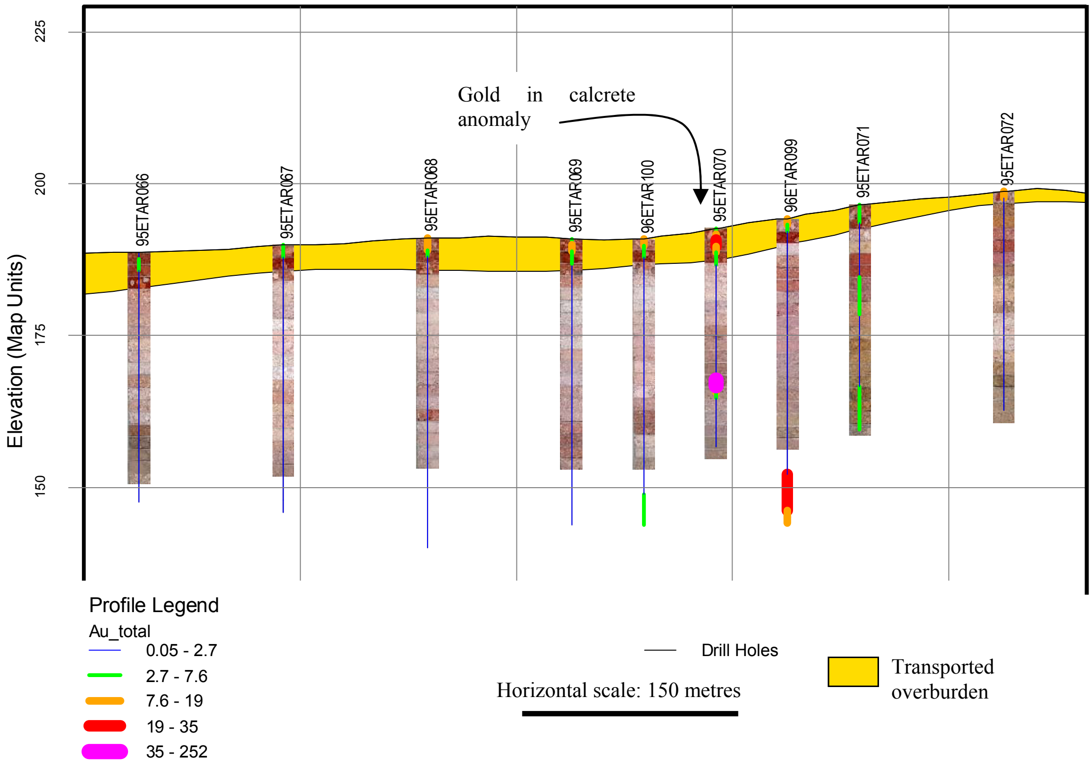


Figure A 71: Gold in calcrete anomaly in transported overburden over mineralization. Photographs of chip trays behind the drill hole traces show colours of the regolith. Section constructed from ArcView using software specifically written for this project.

A.10.5 Conclusions

The multi-disciplinary approach at ET proved to be especially useful in interpreting geochemical anomalies and establishing regolith controls. Regolith mapping greatly benefited from Landsat TM data and digital elevation models. Regolith stratigraphy and mapping of regolith materials is important for any exploration programme since different sampling media give different responses. Calcrete appears to be the best sample medium for exploration at ET:

1. Regional calcrete sampling by the GJV followed by in-fill calcrete sampling discovered the ET Gold Prospect.
2. It is more practical to collect calcrete than other upper regolith samples. Silicification is a severe hindrance to power auger sampling.
3. Calcrete appears to be better than the sandy soil as the former appears to be "seeing through" at least limited thicknesses (<5 m) of sandy transported overburden. However, calcrete does not detect all buried mineralization and further work needs to be undertaken in this area.
4. There is possible evidence for lateral (down slope) movement of Au in transported overburden and that this Au is primarily located in calcrete. Thus, calcrete can potentially provide large anomalies for broad-based sampling programmes.

a)

b)

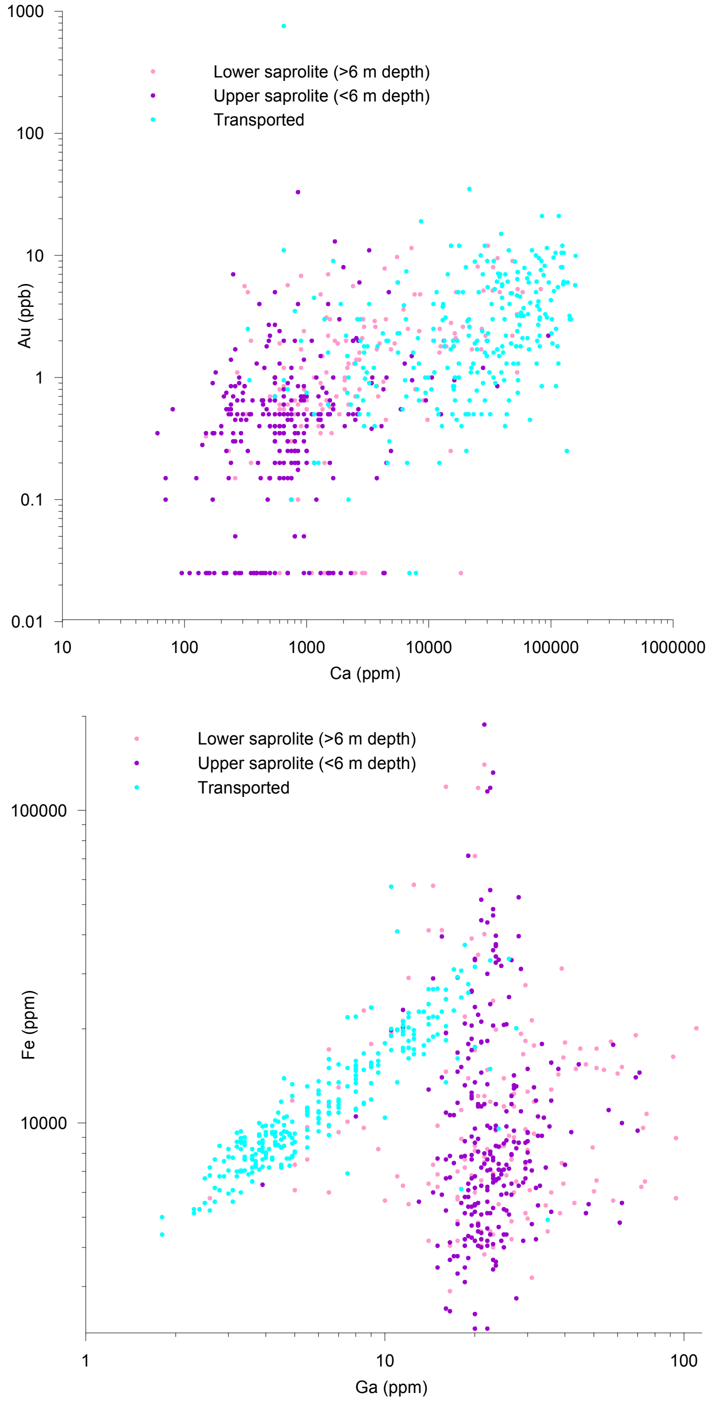


Figure A 72: Scatter plots (logarithmic axes) for a) Ca v. Au and b) Fe v. Ga.

A.11 FAUGH-A-BALLAGH (SKWARNECKI *ET AL*., 2001)

A.11.1 Introduction

The Faugh-a-Ballagh prospect is located about 20 km northwest of Olary. An orientation study was conducted to determine the dispersion potential for elements associated with Cu mineralization in hilly terrain and associated outwash plains. Samples were taken of soils, stream sediments and rock chips.

A.11.2 Geological setting and mineralization

Minor Cu mineralization was discovered in the 1880s associated with magnetite-bearing ironstone veins and disseminations in rocks of the Outalpa Inlier of the Olary Domain. The prospect area is in the lower stratigraphic suites of the Olary Domain, namely the Composite Gneiss Suite (basal unit), the Quartzofeldspathic Suite, and the Calc-silicate Suite.

Stratabound Cu mineralization occurs in the Upper Albite Unit of the Quartzofeldspathic Suite, at the contact with the overlying Calc-silicate Suite in magnetite-bearing quartzofeldspathic rocks (Beckton, 1993). The mineralized zone extends for about 2 km in strike. Malachite and azurite on fractures and as coatings are the most obvious expressions of mineralization. Several magnetite veins have been prospected by shallow trenching and a few veins contain disseminated chalcopyrite.

A.11.3 Regolith

Most of the area belongs to an erosional regime. The dominant erosional regolith-landform unit is high hills formed by slightly weathered gneisses and schists and, on Faugh-a-Ballagh Hill, the presence of ironstones (magnetite-rich, with variable amounts of hematite and quartz). Soils are skeletal to colluvial, and there is little or no deeply-weathered regolith. Strongly incised and narrow creeks dissect the hills. Flat alluvial plains occur in the west and east. The soils developed on the alluvium are locally calcareous.

A.11.4 Regolith expression

A.11.4.1 Ironstones

The ironstones fall into two chemically-distinct groups: (i) ironstones derived from Cu mineralization and (ii) barren ironstones. Mineralized ironstones have greater Au, Al, Cu, K, Mg, Ti, Zn, Ag, REE, Y, Ga, In, Rb, Sr, Th and U whereas in the barren group, Fe, V Mo, Sn and Te concentrations are greater. Concentration levels of the remaining elements (As, Ba, Bi, Ca, Cd, Co, Cr, Cs, Hf, Mn, Na, Nb, Ni, P, Pb, S, Sb, Se, Tl, W and Zn) are similar in each group. Sulphur concentrations are greater in mineralized samples only where sulphides occur. The lower Fe concentrations in mineralized ironstones may reflect the introduction of silica.

A.11.4.2 Stream-sediment geochemistry

Sixteen samples of <2 mm stream sediments were collected from the creek draining the zone of mineralized ironstones on Faugh-a-Ballagh Hill. Fifteen samples were collected from the main creek, but one sample (FABSS15, Figure A 73) was collected from a small tributary draining ironstones with Cu mineralization (along the orientation soil-lag line). Downstream samples immediately south of this tributary entry into the main creek are anomalous (>20 ppm) compare with background (<20 ppm). Three <2 mm stream-sediment samples were sieved into four size fractions 0.5-2 mm, 180-500 µm, 75-180 µm, and <75 µm). The 2-6 mm fraction was also collected and analysed.

Stream-sediment sampling suggests that dispersion of Cu and other elements is very limited in the <2 mm fraction (Figure A 73). Only Cu, In and Tl appear to be directly associated with the mineralized zones. The abundances of In and Tl and dispersion distances are low and these elements are unlikely to be useful pathfinders.

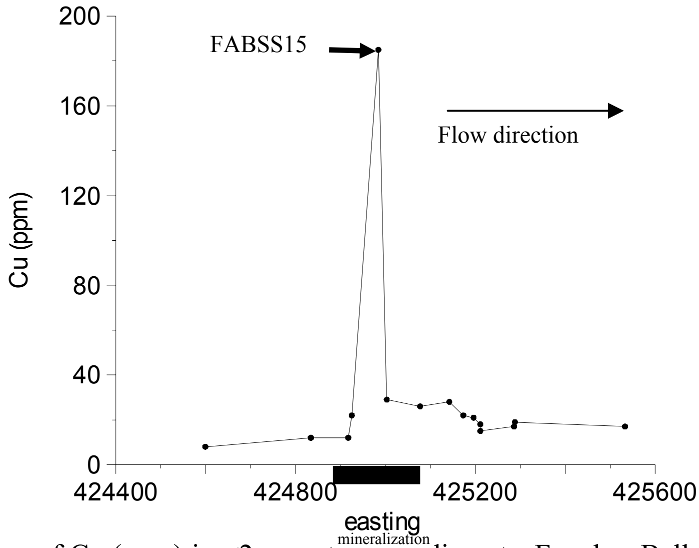


Figure A 73: Distribution of Cu (ppm) in <2 mm stream sediments, Faugh-a-Ballagh. (After Skwarnecki *et al*., 2001).

The finer fractions (especially the <75 µm fraction) of stream sediments are a potentially superior to the <2 mm fraction. Copper concentrations (>100 ppm) and dispersion distances (>100 m) appear to be greater than for the <2 mm fraction. However, further investigation of the <75 µm fraction is required to better define element dispersion characteristics.

A.11.4.3 Orientation soil-lag traverse

Twelve samples were collected on a N-S traverse about 135 m long across E-W trending ironstone veins with disseminated chalcopyrite and pyrite and/or malachite and azurite staining. The following fractions have been sieved: 2-6 mm, 0.5-2 mm, 180-500 µm, 75-180 µm, and <75 µm. The soils on the traverse are generally red brown and sandy, particularly in the vicinity of the ironstones.

The results of the soil orientation survey suggest that Cu is the only reliable indicator of mineralization (Figure A 74). The fine fractions (<180 µm) are probably the best fractions, although a bulk <6 mm fraction would be a practical compromise.

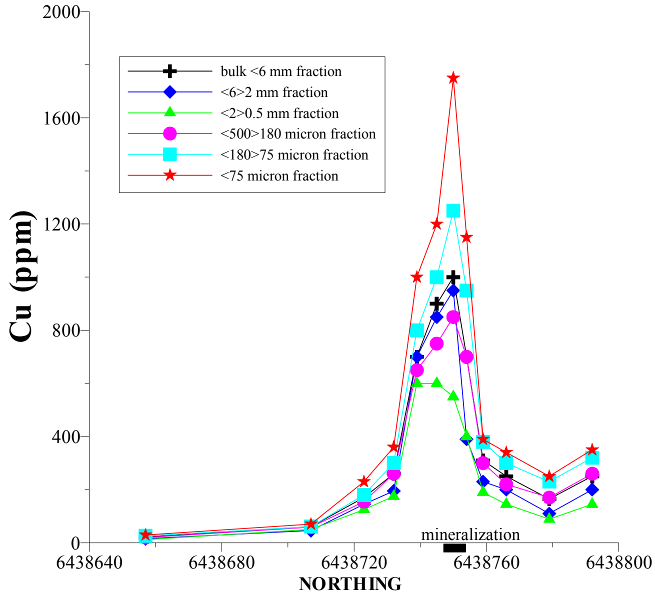


Figure A 74: Distribution of Cu (ppm) in soil in various size fractions along the orientation traverse. (After Skwarnecki *et al*., 2001.)

A.11.4.4 Regional <6 mm soil sampling

Soil samples were collected on a triangular 400 m by 400 m grid over the whole prospect, with 100 m by 100 m infill on Faugh-a-Ballagh Hill (Figure A 75). Regional <6 mm soil sampling indicate that Cu and Au are the most consistent elements in delineating mineralized zones. Arsenic, Bi, U and W are locally anomalous, but their usefulness as pathfinders may be limited. The most prospective areas appear to be southern slopes of Faugh-a-Ballagh Hill and the east-west shear zone. There is also potential in albitic rocks to the southwest.

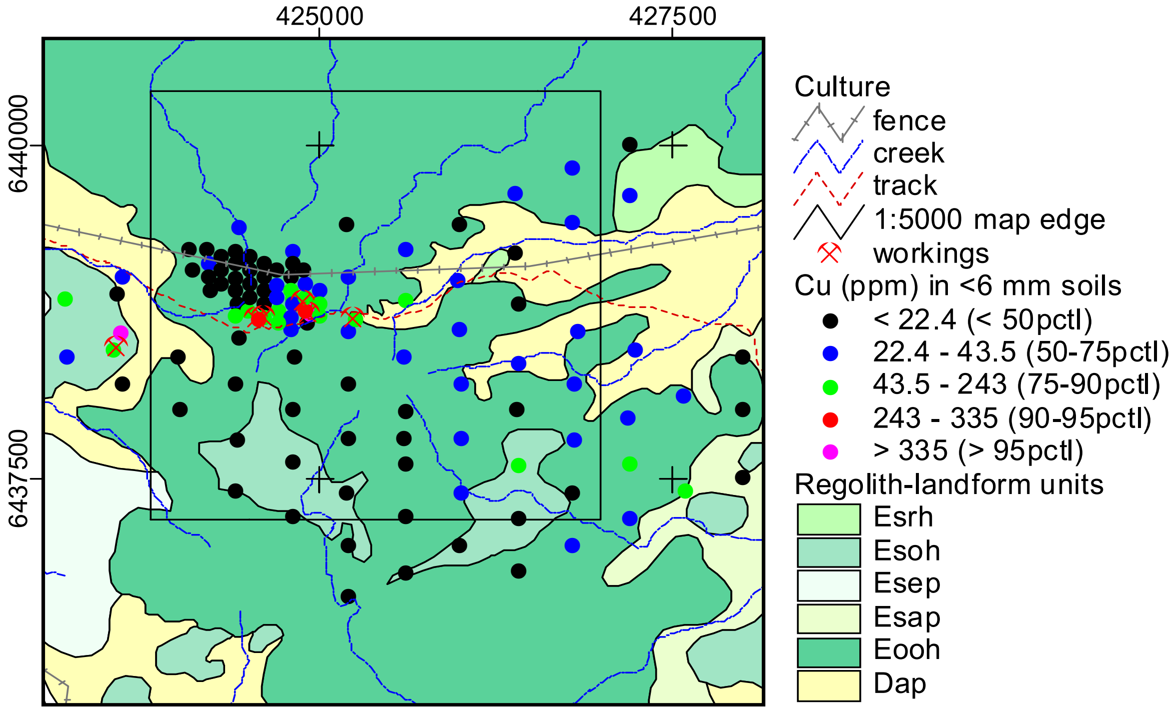


Figure A 75: Distribution of Cu (ppm) in <6 mm soils, Faugh-a-Ballagh. Full regolith-landform unit descriptions are found in Skwarnecki *et al* (2001). Regolith-landform units prefixed E and D denote erosional and depositional regimes, respectively. (After Skwarnecki *et al*., 2001.)

A.11.4.5 Magnetic versus non-magnetic fractions

Stream sediments: The magnetic fractions of three samples were separated, and both the magnetic and non-magnetic fractions were analysed. The non-magnetic fraction consists dominantly of quartz, with some feldspar and minor hematite; the magnetic fraction is dominantly magnetite, with minor amountsof quartz and feldspar (in composite grains). Concentrations of Bi, Co, Cr, Fe, Ga, Mn, Mo, Nb, Ni, Te, Th, V and Zn are greater in the magnetic fraction, reflecting a possible association of these elements with Fe and/or Mn oxides. The concentrations of Al, Ba, Ca, Cs, Cu, K, LREE, Mg, Na, Rb, Sn, Sr and Ti are greater in the non-magnetic fraction, reflecting their occurrence in silicates, carbonates, *etc*. The concentrations of the remaining elements (Ag, As, Au, Cd, Hf, HREE, In, P, Pb, S, Sb, Se, Th, U, W and Y) are similar for each fraction.

Soils: Four <2 mm soil samples were separated into magnetic and non-magnetic fractions and analysed. Most elements (including Cu) do not exhibit a consistent pattern of distribution between the magnetic and non-magnetic fractions. Bismuth, Co, Fe, Mn, Mo, Ni, S, Te, V and Zn are consistently greater in the magnetic fraction, whereas the converse is true for Ag, Al, Ba, K, Na, Rb and W.

Lags: Four 2-6 mm lag samples were separated into magnetic and non-magnetic fractions, and analysed. Most elements (including Cu) lack consistency in their distributions between the magnetic and non-magnetic fractions, or between magnetic, non-magnetic and bulk samples. Only Au, Bi, Ca, Co, Cr, Fe, Mn, Nb, Ni and Se concentrations are consistently greater in the magnetic fraction, whereas the reverse is true only for P.

A.11.5 Conclusions

Soil appears to be the most effective medium. The <6 mm fraction appears to be adequate, but the finer fractions (<180 µm) may be more effective. Stream sediment sampling (<2 mm fraction) indicates that Cu dispersion is very limited, although the results obtained for the <75 µm fraction indicate wider dispersion and greater abundance. There is no useful improvement using magnetic fractions of soil, lag or stream sediments. The geochemical suite for any further exploration should include As, Au, Bi, Cu, Fe, Mn, U and W. Lithological indicators, such as Na and Ca, could also be considered (for calc-silicate or albitic rocks).

A.12 MOONTA (HARTLEY, 2000)

A.12.1 Introduction

Moonta is located on the Northern Yorke Peninsula, approximately 120 km north west of Adelaide. Palaeoproterozoic rocks form basement to the Northern Yorke Peninsula and are comprised of metasediments and metavolcanics. Overlying the Proterozoic basement is a sequence of sediments including Cambrian sandstone, Quaternary clays and aeolian units. Annual rainfall is 300-400 mm, with the majority of precipitation occurring during winter. Groundwater is saline.

The distribution of elements was investigated in relation to Cu-Au mineralization in a series of profiles at two open cut mines in the Moonta area. Additional sampling was performed at other "background" locations in the area. A regolith map was constructed to provide context to the study.

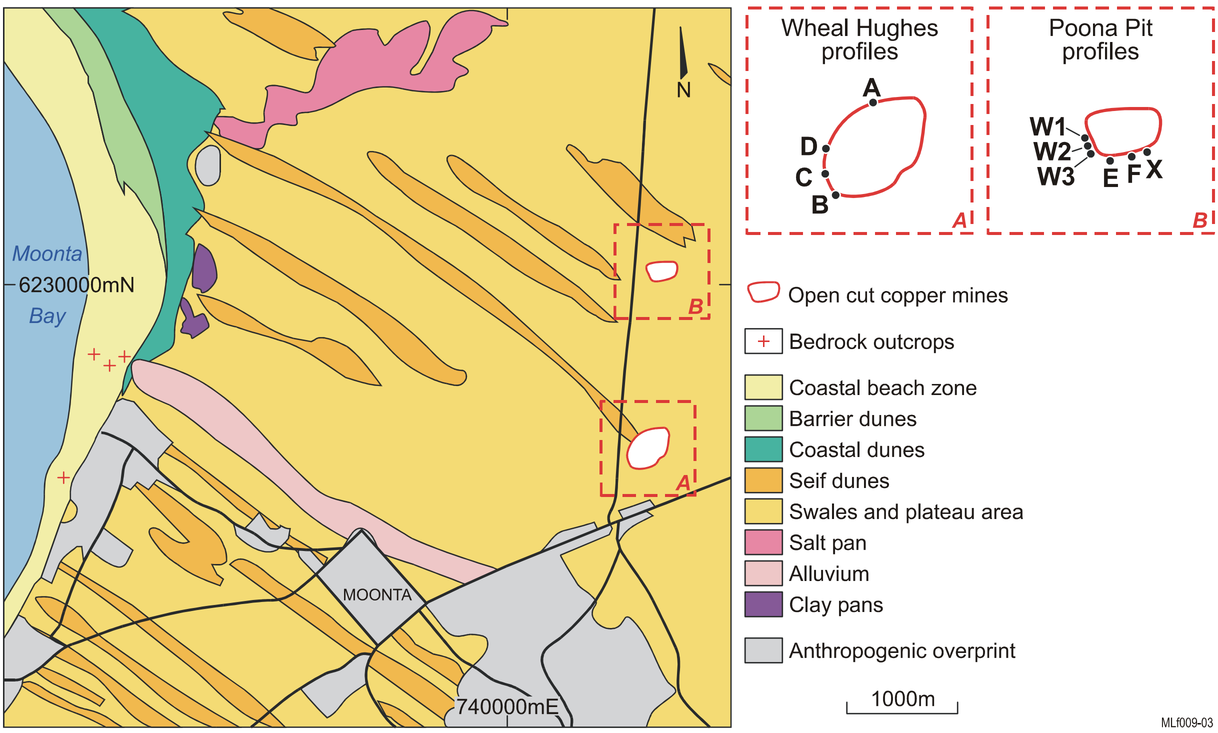


Figure A 76: Regolith map showing location of pits and other sampling points. (After Hartley, 2000.)

A.12.2 Local geology

The study area includes the township of Moonta, the Poona and Wheal Hughes pits to the north-east, and coastal sections to the west. Outcrop is sparse, but extensive drilling has shown that the Moonta Porphyry forms the basement to the area. The Moonta Porphyry extends from Moonta to Kadina and is host to Cu-Au mineralization. It is a feldspar-porphyric, rhyolite-dacite body. Euhedral and glomeroporphyric (*i.e.* intergrown clusters) phenocrysts are predominantly plagioclase but have undergone potassic metasomatism to form microcline (Conor, 1995).

A.12.3 Mineralization

The Moonta region is highly anomalous with respect to metals including Cu, Au, Pb, Zn, Mo, Ni, Co, U and Ce (Conor, 1995). Copper was discovered at Moonta during 1861 with mining operations producing a total of 170,000 tonnes of copper metal valued at 10.7 million pounds from 1860 until 1923. Ore totalling 475,000 tonnes, averaging 4.0% copper and 1.0 g/t Au, was mined from both the Poona and Wheal Hughes mine from 1988-1993 (Adelaide Resources, 1996).

The wall rocks at Poona Pit and Wheal Hughes show varying degrees of secondary kaolinization and Wheal Hughes mineralization has associated tourmaline. The shape of the Poona Pit reflects the lenticular nature of the main lode, with offshoots of mineralization occurring in the hanging wall. The ore body dips ~50^{o} towards 40^{o}N with a strike of 070^{o}. The ore body is truncated to the WSW and ENE by steeply dipping faults striking ~32^{o} (Conor, 1996). Principal mineralization includes chalcopyrite and pyrite with minor bornite, Au and native copper. Important secondary minerals included covellite, chalcocite, digenite and djuriette (Janz, 1990). Lodes at Wheal Hughes are structurally similar to those at Poona Pit. The footwall and hanging wall lodes, ~2-5 m wide, parallel each other and are joined by a 'middle' lode. As with Poona Pit, the lodes at Wheal Hughes are also structurally constrained (Conor, 1996).

A.12.4 Regolith

The flat to gently undulating landscape at Moonta generally reflects the underlying weathered basement surface. Most subcrop is covered by 5 to 10 m of flat-lying Quaternary clays and aeolian sediments that have been impregnated with calcrete. The study area can be separated into 4 broad geomorphic divisions: a narrow coastal strip with minor outcrops of highly weathered bedrock, a gentle undulating area dominated by crests and swales of relic seif dunes, low-lying drainage areas, and a higher plateau area to the east. Exposures in the pits and beach cliffs provide information on the regolith stratigraphy. It comprises an *in situ* unit of Moonta porphyry and a transported unit consisting of four zones: Cambrian sandstone, clay, calcrete and soil (Figure A 77). In Poona Pit the sandstone unit is absent.

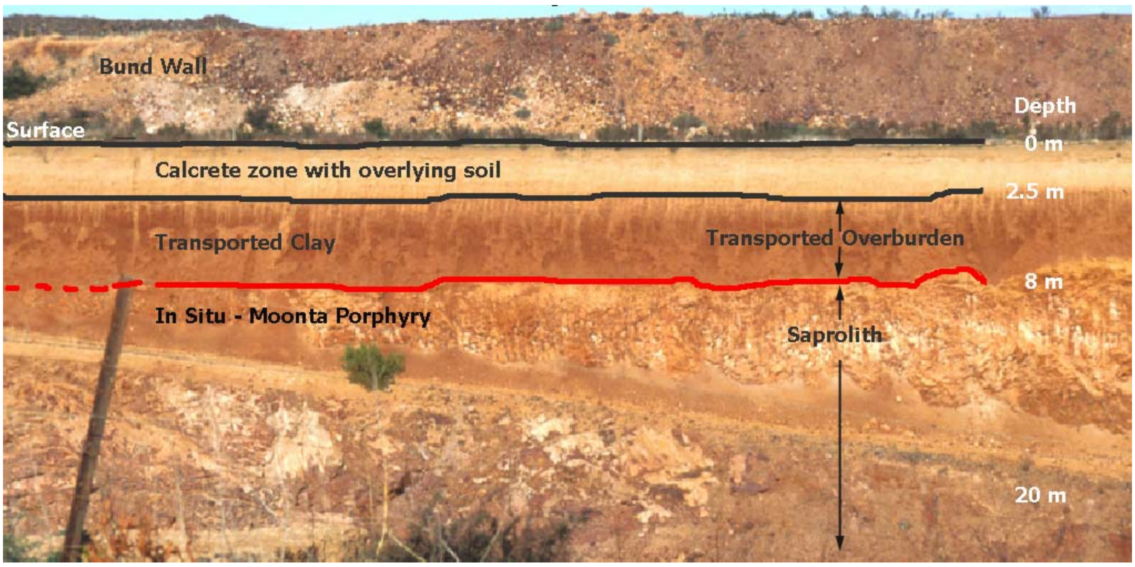


Figure A 77: Part of the south face of Poona Pit showing different regolith units. Wheal Hughes Pit is similar but in addition has a wedge of Cambrian Sandstone between transported clay and the saprolith (Moonta Porphyry) (Photograph from Hartley, 2000).

A veneer (0-20 cm) of grey to dark grey coloured silty-sandy, calcareous soil is vegetated with low shrubs and weeds. Due to the fine particle size, the soil is considered to be predominantly aeolian in origin. This overlies a pale cream to orange coloured sandy clay impregnated with carbonate, trending with depth from calcitic to dolomitic. Calcrete morphology includes sub-rounded pea-sized (0.5-2cm) pisoliths, nodular calcrete and larger cobbles (5-10cm) calcrete. Pisoliths with green coatings of malachite were present at Poona Pit. Alunite occurs at Poona Pit and along the coast immediately beneath the calcrete. It occurs as thin (<3 cm), white sub horizontal seams. A sharp upper boundary between the alunite seam and overlying calcrete is evident, while the lower boundary is diffuse. This suggests that the precipitation of the alunite was probably associated with the upward migration and evaporation of water. A red brown clay underlies the calcrete The clay is thought to have been deposited during the Pleistocene. The thickness of the transported clay varies from a depth of 2.5 m at Wheal Hughes and increases in depth towards the north, where it reaches a depth of 4 m at Poona Pit. The mineralogy consists of kaolinite, smectites, illite, and halloysite with minor rutile; the proportion of halloysite increases with increasing depth. The lower metre of transported clay is mottled at both pits but Fe staining is weaker at Wheal Hughes. The mottling can be attributed to redox reactions that occurred within the clay, probably in response to fluctuations of the water table. The transported clay contains (i) lenses of angular rock fragments that generally range from 1-3 cm in size and (ii) rounded-subrounded quartz grains.

At Wheal Hughes a sandstone unit occurs between the transported clay and the Moonta Porphyry. It is coarse-grained, cross-bedded and fractured and consists of angular quartz grains with minor K-feldspars grains. In hand specimen, the alteration of the K-feldspars to a white clay is evident. Minor silcrete clasts with noticeable ‘rinds’ were intercepted at the boundary between the transported clay and sandstone unit within one of the profiles sampled from Wheal Hughes. The presence of the ‘rinds’ suggest that the silcrete formed elsewhere and has since undergone pedogenic modification. The sandstone is up to 4 m thick at Wheal Hughes and outcrops along the coast as low lying platforms.

Weathered Moonta Porphyry is exposed in both the Poona and Wheal Hughes Pits. Any pedolith developed above the Moonta Porphyry has been stripped away prior to the deposition of the Cambrian sandstone unit that unconformably overlies the Moonta Porphyry at Wheal Hughes. Mottling of the upper Moonta Porphyry below is characterized by large (>5 cm) sub-horizontal, red, Fe-rich material. Saprolite is predominantly pale cream coloured clay with a predominantly kaolinite mineralogy; albite, quartz and microcline are also present. Primary structures of the original material have been destroyed; however, some major jointing and quartz veins are still recognizable.

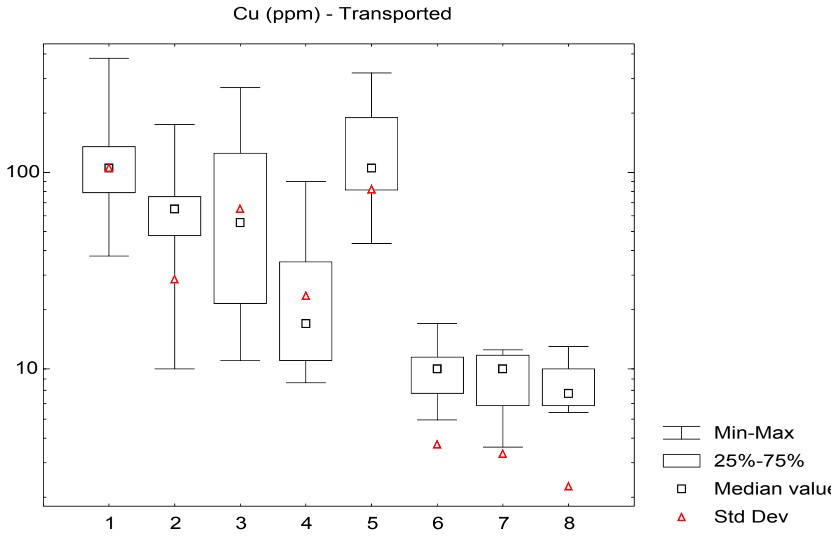
A.12.5 Regolith expression

A.12.5.1 Introduction

Ten regolith profiles were sampled from the mine pits. Additional background grab and profile samples were taken from coastal exposures at Moonta, Balgowan (30 kms to the south) and Ardrossan (50 km to the south-east). The soil data should be interpreted carefully, due to possible contamination by wind-blown and drainage-borne dust from previous mining activities; some elements have concentrations in the surface soil samples, one order of magnitude greater than the sub-soils.

A.12.5.2 Copper

All material from the mine pits including soil, calcrete, transported clay, alunite seams and sandstone, had higher Cu concentrations than background samples (Figure A 78), suggesting that these are related to the underlying mineralization.



MINERALIZED MATERIAL
1 Soil –Pits (n=8)
2 Calcrete – Pits (n=89)
3 Clay – Pits (n=140)
4 Sandstone – Pits (n=11)
5 Alunite Seams – Pits (n=11)

NON-MINERALIZED MATERIAL
6 Coastal Transported Clay (n=9)
7 Coastal Alunite Seams (n=4)
8 Coastal Sand Dune (n=10)

Figure A 78: Copper concentrations within different materials taken from the transported regolith. Note higher concentration of Cu in sample media from mine pits (1-5), in comparison to the sample media from the coast, at least 2 km distant (6-8). Adapted from Hartley, 2000.

Profile data indicate that Cu abundances generally increases with depth through the calcrete zone and transported clay into the *in-situ* (residual) regolith within the Poona Pit profiles, which suggests the concentrations of the Cu in the transported overburden is related to the underlying mineralization (Figure A 79). Maximum Cu concentrations occur:

1) at the boundary between the calcrete and the transported clay (*e.g.* 89 ppm profile F), or very near to the boundary (*e.g.* 88 ppm profile X). In most cases these maxima correspond to the alunite seams (*e.g.* profile X, F, W1, W2 and W3).
2) at the unconformity between the transported and *in-situ* units, in Poona Pit profiles (*e.g.* 105 ppm profile E) and at the boundary between the transported clay and the underlying sandstone in Wheal Hughes profiles (*e.g.* 165 ppm profile WH99C and 38 ppm within profile WH99D).
3) at a depth of approximately 4 m within the transported clay of the Poona Pit profiles W1 (120 ppm), W2 (210 ppm), and W3 (220 ppm) corresponding to a change in mineralogy from smectite to kaolinite.

The distribution of Cu is associated with that of Fe throughout the entire depth of all profiles at both Poona and Wheal Hughes Pits (Figure As 17b and 17c). This is best represented in the upper 2.5 m of Poona Pit profile X. The similar distribution of Cu and Fe most likely relates to the effective adsorption and incorporation of Cu^{2+} onto Fe oxides and clay minerals.

A.12.5.3 Gold

Material from the mine pits, in particular the soil, calcrete and alunite seams, contained higher concentrations of Au (>10 ppb for the calcrete from the mine pits) than the transported clay and alunite seams from the coastal areas where the Au concentrations were generally below the detection limit of 0.1 ppb. Approximately 50% of the samples from the coastal sand dunes contained <1 ppb Au with a maximum of 2 ppb.

High Au concentrations (up to 10 ppb) are present in the upper 2-2.5 m of regolith at Poona Pit, which corresponds to the calcrete zone. Gold concentrations tend to reach their maximum just below the surface (*i.e.* ~0.5 m depth) in these profiles, and peaks also occur at the boundary between the calcrete and transported clay zones, some of which correlate with the alunite seams (*e.g.* Poona Pit profile W1).

Gold concentrations at Wheal Hughes are consistently lower (<3 ppb) in the calcrete zone in comparison with Poona Pit profiles (Figure A 80). The 'noise' of Au data in the Wheal Hughes profiles is due to many samples being near or below the detection limit (*i.e.* <1 ppb). The greater concentration of Au in profiles W1, W2 and W3 is most likely due to the proximity of a mineralized vein. Gold concentrations within the transported clay for profiles from Wheal Hughes are generally <1 ppb.

As with Cu, Au concentrations consistently have a maximum at a depth of 3.80 m within the transported clay in Poona Pit profiles W1, W2 and W3 that relates to a change in clay mineralogy.

An unusual high (220 ppb) concentration of Au occurs within the transported clay zone in Poona Pit profile F. This peak occurs directly below one of the alunite seams.

Gold and Ca generally behave similarly in all Poona Pit profiles. However, minima of Au at approximately 1-1.35m depth in Poona Pit profiles X (3.1 ppb Au), E (2.3 ppb Au) and F (3.5ppb Au), do not correspond to decreases in Ca concentrations. The Au minima are possibly related to a change in calcrete morphology from nodular to predominantly pisolitic. The relationship between Au and Ca at Wheal Hughes is not as clear, due to low Au concentrations.

A.12.6 Conclusions

The presence of 5-10 m of Quaternary transported clay conceals outcrop at Moonta. However, geochemical signatures are present within the overburden that can lead to the detection of underlying mineralization. Relatively high concentrations of Cu and Au, at the boundary between calcrete and transported clay (commonly associated with alunite seams), are probably due to upward migration of acid, saline, groundwater precipitating metals with the increase in pH due to calcrete. Copper-Fe, and Au-Ca are associated in the transported unit of the regolith. Gold is especially concentrated in the calcrete. Background concentrations of Cu and Au in coastal profiles 2 km west of Moonta suggest that geochemical dispersion away from mineralization may be limited.

The findings from this study are similar to earlier studies at Kadina 10 km to the north east (Mazzuchelli *et al.*, 1980). Here, a study of Cu distribution was conducted over an area with relatively shallow overburden (5-10 m) similar to Poona Pit. Copper was distributed in narrow zones (to 15 m wide) in saprolite with >1000 ppm Cu surrounded by ~90 m wide dispersion haloes defined by the 250 ppm contour. Analysis for cold-extractable (acid ammonium acetate) Cu gave a 'mushroom-shaped' anomaly, with the strongest part immediately beneath the calcrete-clay interface. Low-order anomalies extended through the calcrete and were evident in the topmost samples at 1.5 m depth. The extractable-Cu response at the calcrete-clay contact was similar in location and dimensions to that obtained by saprolite sampling, but was more evenly distributed. Accordingly, shallower, more widely-spaced drilling could have been used in the initial stages of exploration without appreciable risk of missing significant anomalies. The extractable Cu pattern was considered by Mazzuchelli *et al.* (1980) to be due to continuing upward migration of Cu in highly saline acidic groundwaters, with some lateral dispersion occurring prior to fixation in the zone of high pH, represented by the calcrete. The cold extractable Cu response at the base of the calcrete was most probably related to the presence of alunite.

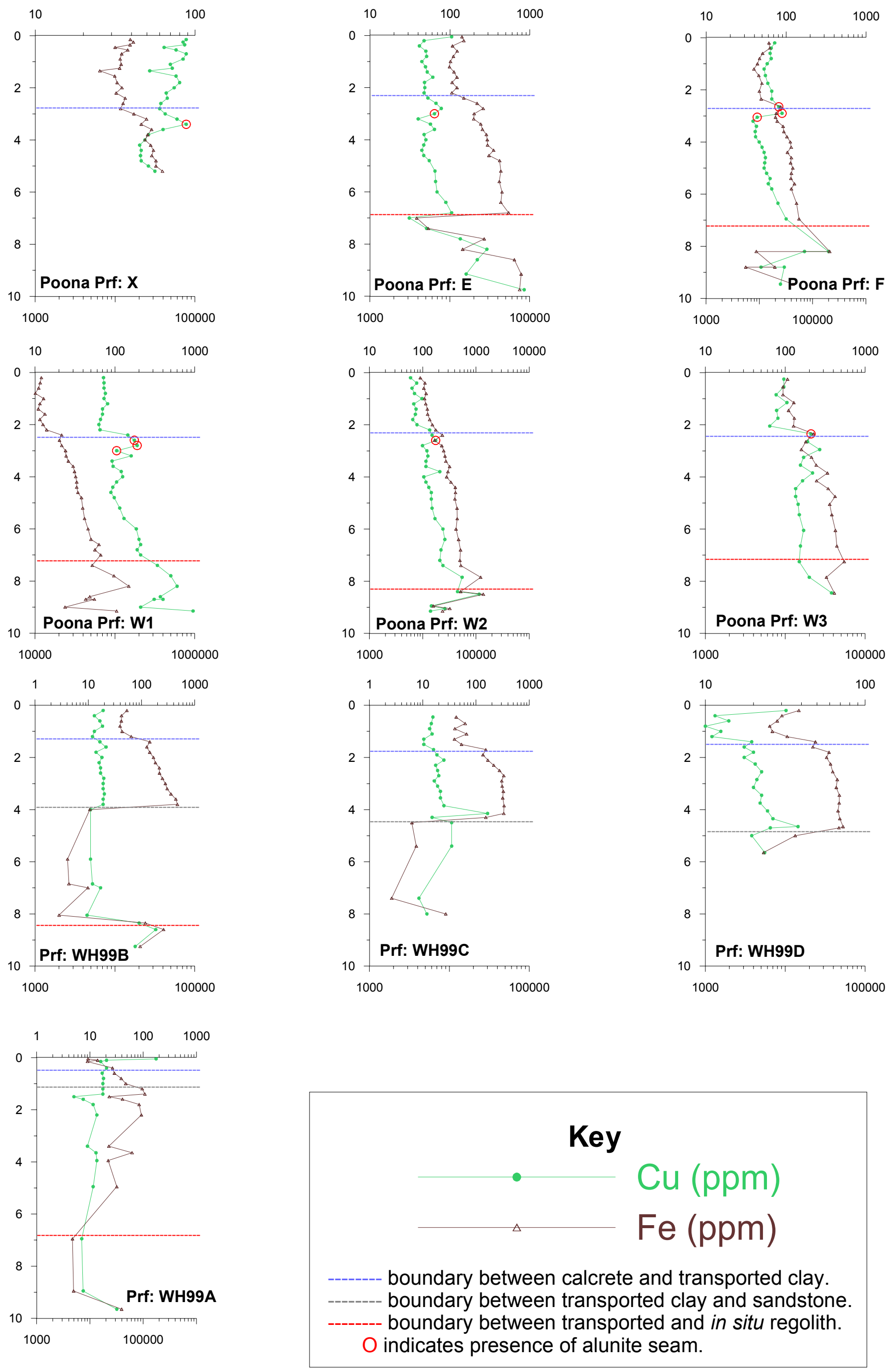


Figure A 79: Copper and Fe concentrations for Poona and Wheal Hughes mine pits. Y axis is depth (m). Top axis is Cu and bottom axis is Fe. (After Hartley, 2000.)

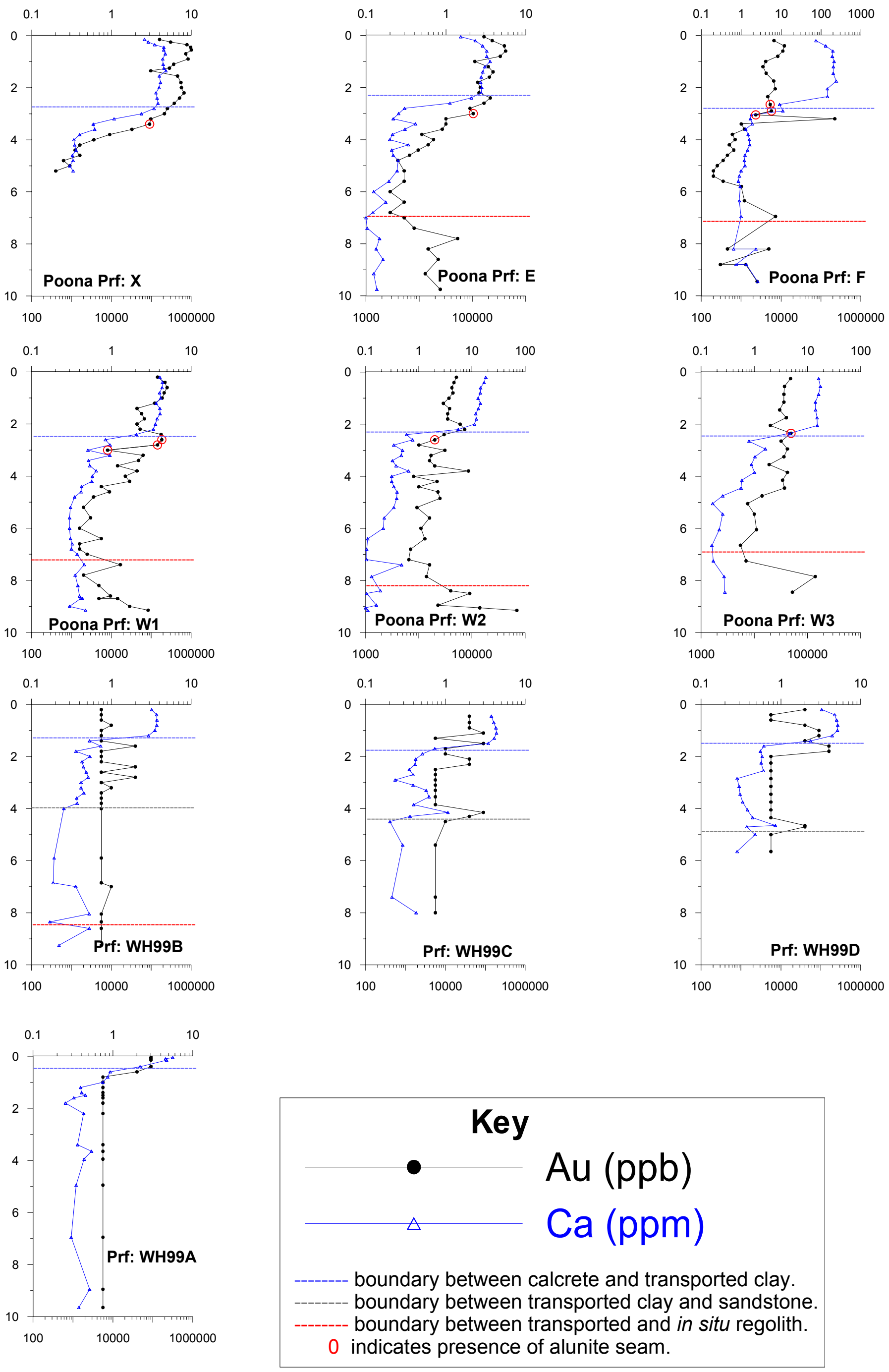


Figure A 80: Gold and Ca concentrations for Poona and Wheal Hughes mine pits. Y axis is depth (m). Top axis is Au and bottom axis is Ca. (After Hartley, 2000.)

A.13 BLUE ROSE (SKWARNECKI *ET AL.*, 2001)

A.13.1 Introduction

The Blue Rose prospect is located in depositional terrain about 40 km south of Olary. The area was selected for exploration because of a coincidence of a prominent aeromagnetic anomaly (thought to be an intrusive rock at depth) with the junction of several faults. Initial exploration by Dominion Metals Pty Ltd, investigating magnetic features in the general district, drilled several widely-spaced RAB holes and intersected "skarn assemblages and high-level potassic intrusive rocks within Adelaidean metasedimentary rocks" (Shelton, 1999). Anomalous Cu intervals were intersected in some of the holes. Lynas Gold Corporation initially drilled RAB and aircore holes, intersecting anomalous Cu in the general area of the magnetic anomaly. Subsequent RC drilling targeted several geochemical and IP anomalies. Eighteen holes were drilled, the best intervals being 88 m @ 0.39 % Cu (Shelton, 1999).

Sampling and regolith-landform mapping was undertaken over a 3 x 3 km area. Six traverses over, and parallel to, mineralization were augered to refusal. One line (428820E) over mineralization was selected for detailed sampling (augered samples, soils, lag, magnetic vs non-magnetic size fractions) and analysis (including partial leach).

A.13.2 Geological setting

The Blue Rose prospect occurs on the southern limb of the Wadnaminga Anticlinorium in metasedimentary rocks of the Adelaidean Burra Group (Forbes, 1991) in similar lithological units to the Wadnaminga Goldfield. To the south, Burra Group rocks have been intruded by the early Ordovician Anabama Granite, composed of coarse-grained anhedral microcline, quartz, orthoclase, oligoclase and biotite (Forbes, 1991). Some associated dykes (*e.g.*, at Anabama and Netley Hills) have undergone high-level hydrothermal alteration to pyritic quartz-muscovite greisen with minor amounts of chalcopyrite and molybdenite. Greisen also occurs at Giles Nob (about 13 km ENE of Blue Rose) and as narrow veins at Blue Rose. Weathered granitic rocks crop out on the south side of the prominent creek in the southeastern corner of the prospect. It is uncertain whether this outcrop is part of the main Anabama Granite, or a dyke related to it.

A.13.3 Mineralization

Mineralization occurs in impure dolomites (dolomite- and calcite-rich metasedimentary rocks) containing disseminated sulphides, biotite, serpentine, tremolite, talc and chlorite. The higher-grade zones contain disseminated chalcopyrite, but not all sulphidic zones are mineralized. The presence of serpentine also appears to be generally indicative of mineralization. Another feature of the mineralized zones is the marked recrystallization of alteration minerals, which proceeds along grain boundaries.

A.13.4 Regolith

There is very little outcrop at Blue Rose, where the topography is singularly flat. Most of the area is in a depositional regime (Figure A 81) although, transported overburden may be only 2 m thick, in some parts of the prospect. The area is bisected diagonally by a major creek system. Gentle rises, with bluebush, signify areas where calcrete occurs at relatively shallow depth. Apart from minor outcrops in the creeks in the north and east (some mineralized), highly weathered (silicified) exposures occur on the southern side of the major creek in the southeastern part of the prospect.

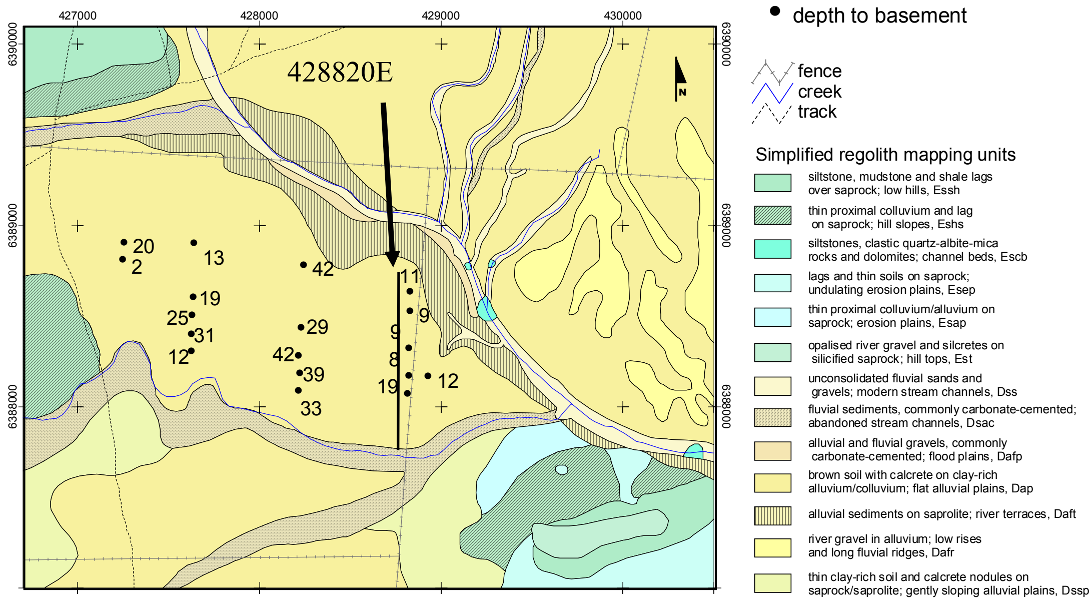


Figure A 81: Regolith-landform map of the Blue Rose prospect showing depths to base of transported cover (in metres) from RC and RAB drilling. Blues and greens signify *in situ* regolith or outcrop. Sampling line 428820E (used for detailed study) is labelled. (After Skwarenecki *et al*., 2001).

The general stratigraphic sequence of the transported overburden, from the top downwards is:

i) calcareous soil,
ii) calcrete-silcrete horizon,
iii) colluvial gravels and clays, cemented by calcrete, silcrete and chalcedony,
iv) clays with chalcedony veining,
v) plastic mottled clays, locally with white/grey plastic clays at the base, and
vi) white clays and quartz gravels.

An example of a cross-section through transported and residual regolith is shown in Figure A 82 (428820E). The residual regolith consists of a complex interdigitation between saprock and saprolite in the north, whereas in the south, the profile is simpler, with saprolite overlying saprock. Saprolite along the section consists of vermiculite-rich clays.

In the south, the dominant rocks are carbonate-rich, with thin horizons of clastic albite-quartz-mica rock. The carbonate rocks are characterized by disseminated mica and sulphides, and locally with tremolite and serpentine, but mineralization is restricted to the southernmost drill holes (BRRC10-11). In the north, the clastic units appear to be more abundant.

Medium-grade Cu zones (1000-5000 ppm) in bedrock (about 10 m wide) have produced a significant dispersion halo, at least 170 m wide in saprolite and saprock, extending into the basal section of transported cover.

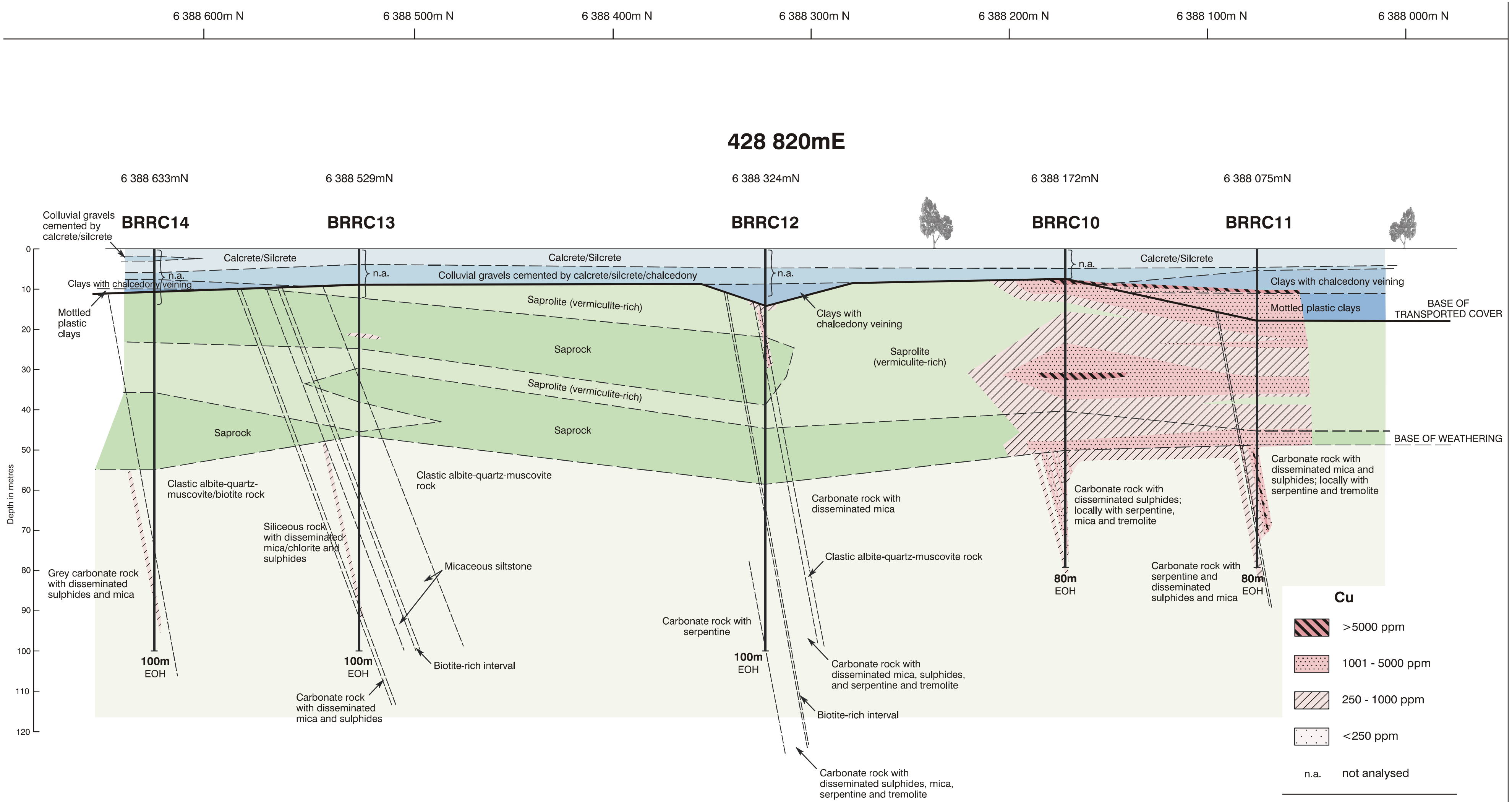


Figure A 82: Simplified geological cross-section on line 428220E at Blue Rose, showing interpreted distribution of Cu (ppm). (From Skwarnecki *et al*., 2001).

A.13.5 Regolith expression

A.13.5.1 Geochemistry of mineralized intervals

In fresh bedrock, significant Cu intervals are associated with anomalous Bi, Cs, In, K, Mo, Rb, S, Se and Tl concentrations. The correlation between Cu and Au is weak. In regolith, Cu-rich intervals contain greater Al, As, Cr, Fe, Ga, Na, Ni, REE, Ti, V, and Y, but lesser Cs, K, Mg, Mn, Rb and S concentrations than fresh rock. Copper correlates positively with Co, In, Se and Sn (concentrated in chalcopyrite), but not with Au (which correlates positively with Bi and Te) or Mo (which correlates positively with Se). The abundance of most of the other elements are dependent upon lithology. Those elements most abundant in the dolomitic rocks are K, Mn, S, Cs, Rb, Tl and, to a lesser extent, Ba and Ca; those most abundant in silicate rocks are Al, Cr, Na, Ti, V, REE, Y, Ga, Sr, Th and Zr.

A.13.5.2 Geochemistry of augered samples

Samples were collected from 0.2 m and 0.7 m, depending on the degree of penetration by the auger. Augering indicated a soil horizon (of variable thickness) overlying calcrete (typically nodular). The >6 mm fraction was analysed to enrich the sample with carbonate nodules and reduce the amount of wind blown fine material.

Element abundances are generally greatest where transported cover is known to be relatively thin (<6 m), west of the fence line, and in the south (see Figure A 83 for location). To the east of the fence line, interpretation of the data is hampered by uncertainties in the thickness of transported overburden. Auger drilling failed to provide unequivocal indications of mineralization. However, at the southern end of the far western-most traverse 427250E, a multi-sample Au >6 ppb and Cu >40 ppm anomaly occurs that requires further investigation (Figure A 83).

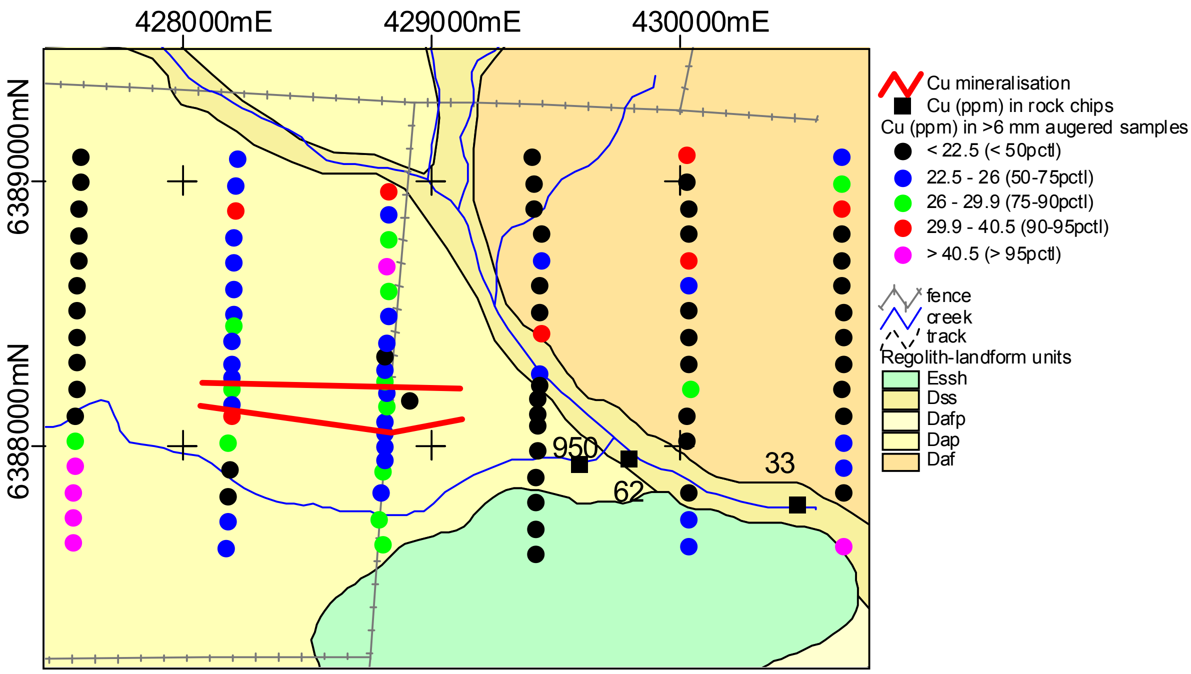


Figure A 83: Plan of Cu (ppm) distribution in >6 mm augered samples (soil and calcrete) and rock chip samples (labelled), Blue Rose. Full regolith-landform unit descriptions are found in Skwarnecki *et al.*, 2001. A simplified regolith-landform unit code is used here: units prefixed D correspond to depositional, E is erosional. (From Skwarnecki *et al.*, 2001).

A.13.5.3 Soil geochemistry

Soil sampling (<2 mm fraction) over the mineralized zone on grid line 428820E failed to detect any unequivocal evidence of mineralization (Figure A 84). Infill sampling over the Cu anomaly at the southern end of grid line 427250E corroborated the earlier auger drilling results and has yielded a zone up to 125 m wide, with coincident Au-Cu anomalies (up to 280 ppm Cu and 21.5 ppb Au). This indicates that there is no advantage in using auger drilling where the transported overburden is thin and where soil sampling (0-10 cm depth) is equally effective. Where transported overburden is thick (>6 m), neither soil sampling nor auger drilling are likely to yield useful samples.

A shallow pit was excavated to 0.5 m immediately over mineralization to expose powdery and nodular calcrete below a thin soil. Samples were collected over 10 cm intervals down the profile, to determine the distribution of elements. Concentrations of most elements (either associated with Fe oxides or diluted by carbonate) are greatest in the uppermost samples. Copper concentrations decrease slightly down the profile (from 30 to 20 ppm). However, there is little difference between the 0-10 and 10-20 cm samples, indicating that the depth of soil sampling is not critical. Gold shows little variation with depth (~4 ppb).

A.13.5.4 Lag geochemistry

The magnetic lags are Fe-rich (Figure A 84~50% Fe). Gold is generally below detection limit (1 ppb) and Cu concentrations are minor (<50 ppm). There is no relationship between lag geochemistry and the mineralization. The uniform composition of the lag and the local concentration by sheetwash suggest that the lag has been transported and its composition is likely to be independent of the local substrate.

A.13.5.5 Partial leaches

Soil samples (<2 mm fraction) were collected at 50 m intervals at 10-20 cm depths along grid line 428820E, over the mineralized zone. The results are plotted in Figure A 84, where the data for partial leaches is compared with that for <2 mm soil, >6 mm auger, <6 mm auger and 2-6 mm lag samples. None of the partial leaches gives any indication of the mineralized zone, where transported overburden varies between 8 and 19 m in thickness.

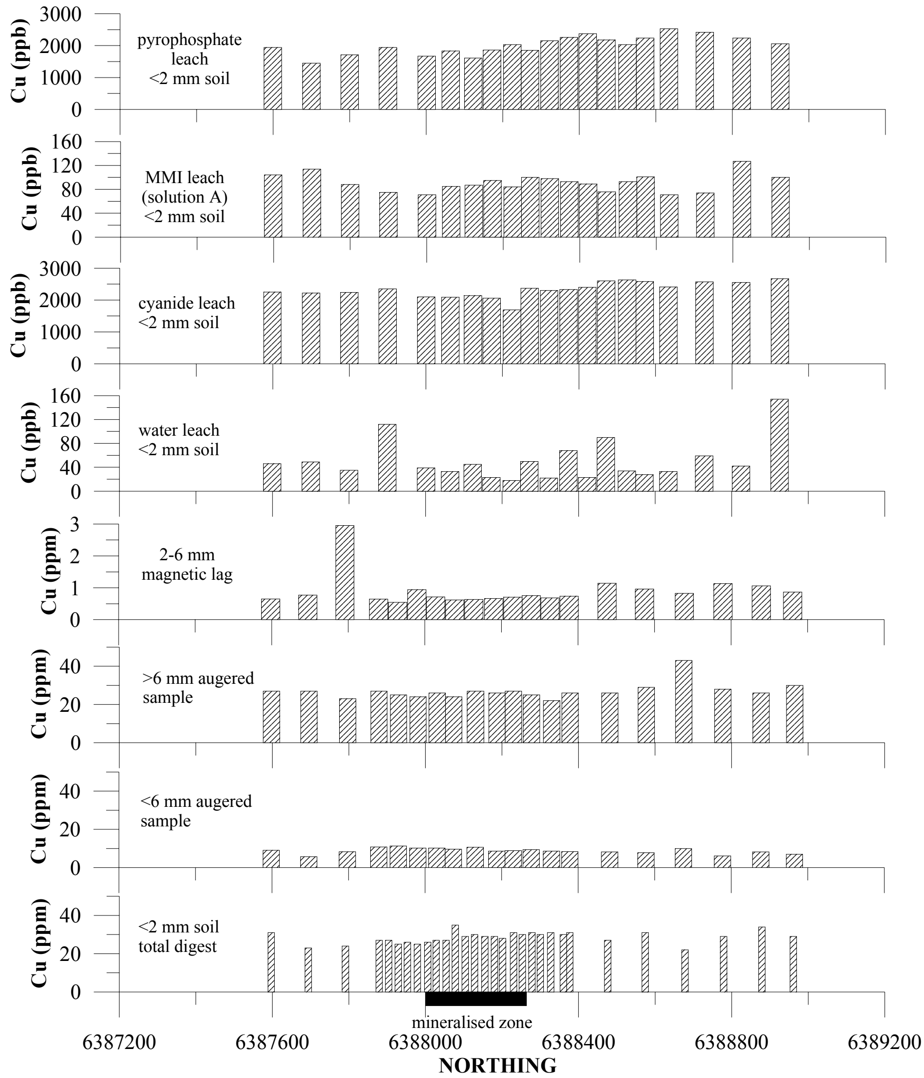


Figure A 84: The concentration of Cu (ppm) in soil (<2 mm, 0.1-0.2 m depth) along grid line 428820E showing the responses from various sample media and partial leaches. Note that the presence of mineralization has not been identified in the partial leach analyses. The lag, soil and calcretes sample analyses were determined by ICP-OES after dissolution by mixed acid digest. (From Skwarenecki *et al*., 2001).

A.13.6 Conclusions

The failure of conventional and partial leach analyses to detect Cu mineralization, even though transported cover is locally only 8-9 m thick, indicates that surficial samples are unlikely to be an effective sample medium. Drilling is the only reliable technique particularly where transported cover is >6 m thick. Broad zones of Cu dispersion in saprolite and basal parts of the transported overburden provide a larger target than the primary zones themselves and suggest that interface sampling may be an effective technique.

A.14 MT GUNSON AREA COPPER DEPOSITS (LINTERN *ET AL*., 1998; CARRAGHER, 1999)

A.14.1 Introduction

Mount Gunson is located 400 km NNW of Adelaide on the Stuart Shelf. Exploration on the Stuart Shelf has been hampered by the presence of cover in the form of salt lakes, sand dunes and thick, barren units of the Adelaidian sequence. Dune soil, in particular, has been largely ignored as a potential sample medium, and exploration strategies to date have mostly concentrated on drilling to saprolite and bedrock. Cattle Grid Mine and Windabout Prospect were the two sites examined in the Mt Gunson area.

Advantage was taken of the exposures from the open cut mining operations at Cattle Grid. High quality samples were collected from pit faces, and regolith stratigraphy was easily observed and documented during the sampling phase. At Windabout Prospect, studies were undertaken at two backhoe-excavated pits, two diamond drill hole cores from locations adjacent to the pits to provide information from deeper in the regolith and a soil traverse with the emphasis on the effectiveness of partial extraction techniques.

A.14.2 Regional geology and mineralization

The Mt Gunson Copper deposits occur in the Neoproterozoic Stuart Shelf, overlying the eastern edge of the Gawler Craton (Figure A 85). They lie 60 km west of the Torrens Hinge Zone, which separates the Shelf from the Adelaide Geosyncline and coincide with a NNW trending transcontinental gravity lineament (the G2 corridor), that continues through the Olympic Dam Deposit (O'Driscoll, 1986; Preiss, 1993).

Mineralization occurs in several units of the Adelaidian and pre-Adelaidian sequence, but principally in the Pandurra Formation, Cattle Grid Breccia, Tapley Hill Formation and Whyalla Sandstone. Two major styles of mineralization are recognized at Mt Gunson and exemplified by the two areas studied (Figure A 86). In the Cattle Grid open cut mine, mineralization generally occurs at the interface between the Pandurra Formation and the Whyalla Sandstone. According to Van Herk *et al.* (1975), the ore is flat-lying, stratiform and epigenetic, lying beneath 15 to 35 m of Whyalla Sandstone and up to 10 m of Quaternary sand. The mineralized unit (termed Cattle Grid Breccia) consists of a blanket of brecciated, silicified, red bed Pandurra Formation sandstone, averaging 4.5 m in thickness (Williams and Tonkin, 1985; Preiss, 1987).

At the Windabout Prospect, Cu mineralization is much deeper and is largely confined to black calcareous shales of the Tapley Hill Formation that, in the area studied, occurs between 65 m and 97 m depth, with a general thickness of the order of 15 to 25 m. Tregolana Shale and Whyalla Sandstone separate it from the Quaternary units. The richest Cu grades (average 1-3% Cu) occur at the base of the Tapley Hill Formation at about 70 m, and the indicated mineral resource is 18.7 Mt of Cu at 1% and Co at 0.05%. No Cu data are available for the lower regolith above the Tapley Hill Formation although Cu concentrations in the Whyalla Sandstone immediately above the Tapley Hill Formation is generally of the order of 10 to 100 ppm.

A.14.3 Landforms and vegetation

The area surrounding the local high point of Mt Gunson (259 m AHD, ~100 m above the surrounding terrain) has relatively low topographic relief and is dominated by low rises related to Proterozoic outcrop and/or near-surface occurrences. The Cu deposits are located just west of Pernatty Lagoon, which is one of a number of large, rectilinear and approximately north-south orientated dry salinas in this region. Cainozoic sediments, in particular, the Quaternary orange sand dunes and related sand spreads, mantle the pre-Cainozoic land surface and impose a local and regional topographic pattern (~ E-W, Figure A 87). Aeolian dust (clay, silt, carbonate and gypsum) has been incorporated by illuviation and solution into the otherwise sandy Cainozoic sedimentary landforms. *Acacia* and minor *Callitris* were the most common type of large shrub and tree found on the dunes. *Maireana aristostricha* and *Atriplex* were the most common plant found in the dune swales.

A.14.4 Regolith

The available mine pits provide an excellent window into the regolith, which is otherwise poorly exposed in this area. Tertiary and Quaternary weathering and concomitant cementing processes have modified the regolith. Transported overburden is ~70 m thick at Windabout and 25-45 m thick at Cattle Grid. Crystalline gypsum veining is common within the Quaternary sand spreads and appears to pre-date the carbonate influx and usually underlies it. Large (cm scale) individual euhedral gypsum crystals are also found in the red-mottled gley clays that overlie the Stuart Shelf sediments at Windabout. These gley clays are probably either Mid- to Late Tertiary or early to mid-Quaternary in age and may represent slow deposition under water-logged conditions. Carbonate occurs as silt, sand, earthy coatings and segregations, or as more indurated forms of calcrete-grain cement/coatings, pisoliths and nodules. Carbonate is generally present throughout the Quaternary sands in the Cattle Grid area but, at Windabout, it is restricted to near the surface and to the base of the sands (16-17 m) just 2 m above the gley clays.

Manganese-rich materials are present as ped cutans, gypcrete coatings or inclusions and occur low in the Cainozoic sand profile (>6 m). A distinct narrow zone of dark Mn-rich material (precipitated from groundwater) was observed in two profiles at Cattle Grid.

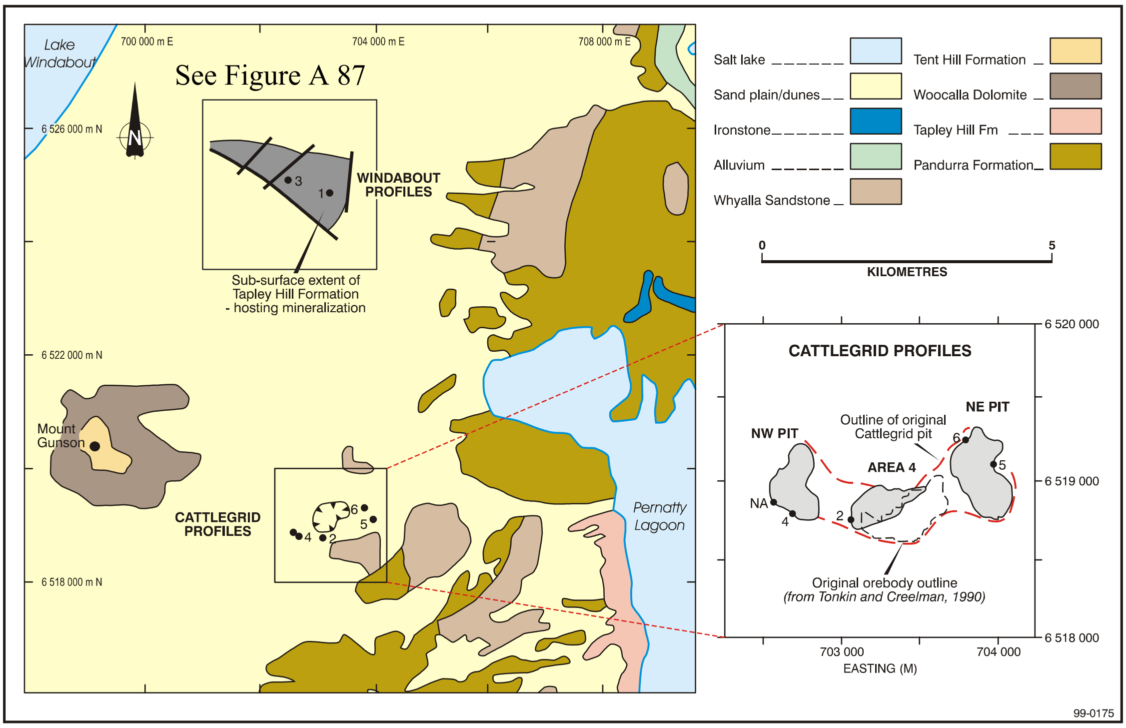


Figure A 85: Location of profiles (1-6), geology and prospects in the Mt Gunson area. Extract from the Torrens 1:250000 geology sheet.

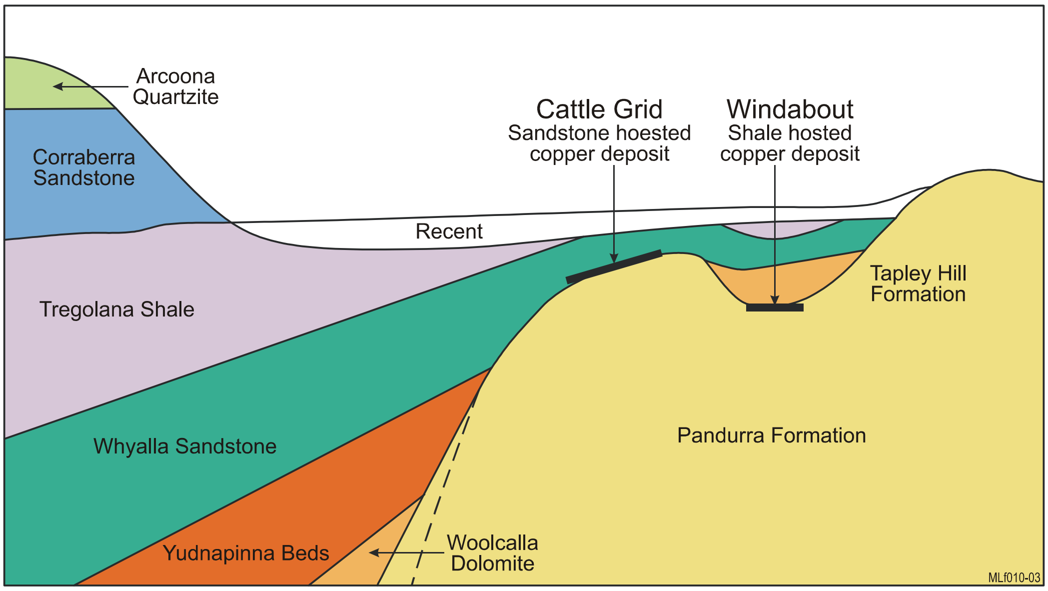


Figure A 86: Mt Gunson area showing two styles of Cu mineralization. (After Tonkin and Creelman, 1990).

A.14.5 Regolith expression

Three reagents (Chao, 1984) were sequentially used on an aliqout of pulverized sample to examine the vertical nature of the solubility of selected metals (Ca, Mg, Fe, Ag, As, Au, Bi, Co, Cr, Cu, Ni, Pb, Th, U and Zn) in three different phases in six regolith profiles (Figure A 85). The three reagents were (i) pH 5 acetate solution (for the carbonate and surface adsorbed metals phase), (ii) 0.1 M hydroxylamine (Mn oxides phase) and (iii) 0.25 M hydroxylamine (amorphous Fe oxides phase). A separate aliqout of sample was dissolved using a triple acid digest to enable calculation of a fourth "insoluble" phase.

At Cattle Grid, anomalous but erratic total metal concentrations of Co, Cu, Ni and Zn were found in the soil. Manganese staining is common throughout the soils but only in three profiles (2, 5 and 6) is Mn sufficiently concentrated to be clearly visible on the pit face from several metres distance. Here, highly anomalous concentrations (>1000 ppm) of Cu were associated with Mn oxides, which occur as grains, flakes, fragments and as coatings on sand grains and larger sandstone clasts. The Windabout profiles showed generally lower concentrations for most base metals and chalcophiles (Cu, Ni, Pb and Zn) compared with Cattle Grid and background. In contrast, Co appears to be anomalous at Windabout in the top 20 cm and appears to be associated with Mn in the calcrete horizon; however, in a subsequent study by Carragher (1999) elevated Co values were not substantiated (see below). The gypseous horizon immediately beneath the calcrete has generally lower concentrations of Co and Cu.

Only minor proportions of the total Fe are dissolved with the reagents, with the greatest dissolution for 0.25 M hydroxylamine, consistent with this reagent dissolving amorphous Fe oxides. As a whole, extractable Mn is 50% or more of the total Mn, with most dissolved Mn in the pH 5 acetate solution, possibly representing trace Mn substitution in calcite, separate phase rhodochrosite or highly soluble Mn oxides. For the selected Mn-rich samples (*i.e.*, Profile 2 at 6 m and Profile 5 at 7 m), virtually all of the Mn is soluble, with most extracted with 0.1 M hydroxylamine, which is designed to dissolve separate phase Mn oxides. These samples also have high concentrations of total and extractable Co, Cu, Pb and, possibly, U. The data suggest an association between certain metals (Co, Cu, Pb and Zn) and total Fe and Mn content. In particular, there is a linear trend(s) in the Cu data for Windabout samples. The data also indicate substantially lower Cu contents and moderately lower Co contents for the Windabout samples. This may be a result of the deeper depth to, type and tenor of mineralization between the two deposits.

In another set of experiments, soil from a 2 km traverse (A-A′) across mineralization at the relatively undisturbed Windabout Prospect was sampled (Figure A 87, Figure A 88) at 100 m intervals and taken from 0-0.1 m and 0.1-0.2 m (Carragher, 1999). Samples were analysed for up to 50 elements. Results indicate that mineralization was not detected in any element (including Co and Cu) in any digest (total, nitric acid, ammonium acetate, EDTA, MMI A or MMI B) for either soil fraction (<180 µm, >180 µm) or bulk soil.

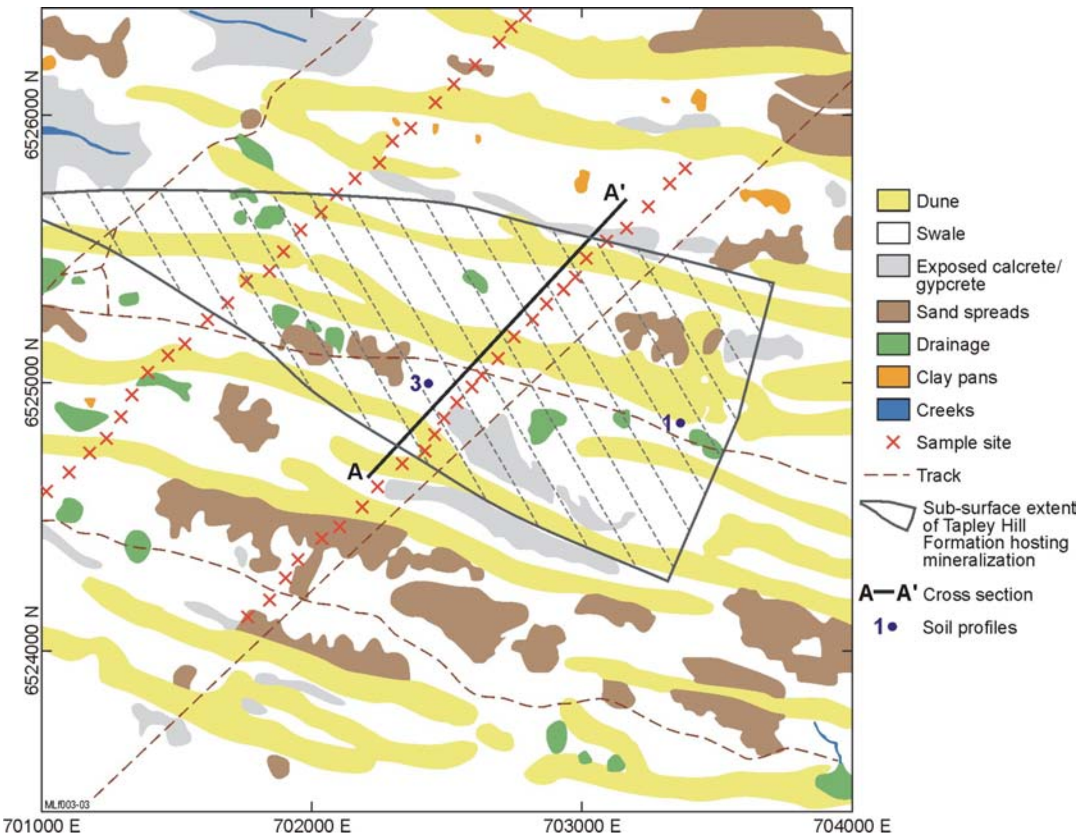


Figure A 87: Windabout Prospect showing sampling traverses, mineralization and regolith. See Figure A 85 for location. (After Carragher, 1999).

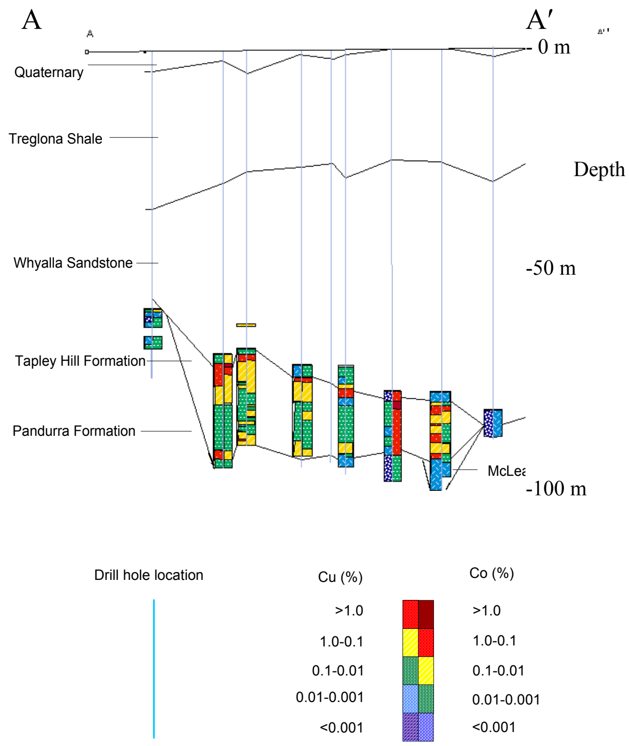


Figure A 88: Section (A-A′) across sampled traverse showing stratigraphy and Cu-Co mineralization in 1m drill intervals. Section location is shown in Figure A 87. (From Carragher, 1999).

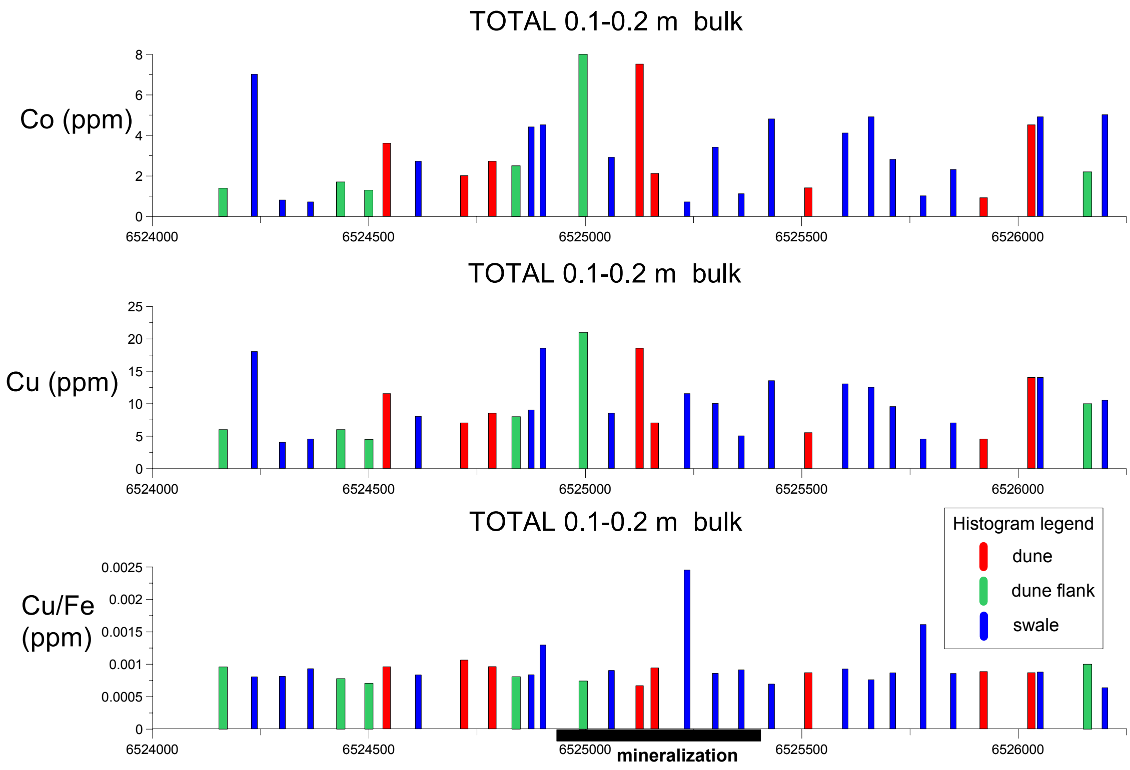


Figure A 89: Selected geochemical data from the Windabout traverse. (From Carragher, 1999).

A.14.6 Conclusions

Two styles of Cu and associated Co mineralization were investigated at Cattle Grid and Windabout. At Cattle Grid concentrations of Cu and Co in the upper regolith were higher than those at Windabout and may reflect the style of mineralization and/or the depth of transported overburden; further investigations are required to test whether the buried mineralization can be detected near the surface. At Windabout, data suggest that buried mineralization cannot be detected either by conventional or partial extraction geochemistry. Copper, Co and other elements appear to be related to the distribution of Fe and Mn occurring as oxides.

A.15 ADELAIDE HILLS LEAD-SILVER MINES (BAKER, 1999)

A.15.1 Introduction

Lead-silver mineralization was discovered at Glen Osmond (South Australia) in 1840 following land surveys for agriculture in the late 1830s (Brown, 1908). Mining began in the early 1840s, making them the oldest metal mines in Australia. Some thirty lodes of sulphide mineralization were recognized but only six were mined. The deposits were discovered by recognition of secondary carbonates, sulphates and halides at the surface (Brown, 1908).

Precipitation falls mostly in the winter (Schwerdtfeger, 1976). Vegetation has been highly modified by human activities but remnant bush consists of *Eucalyptus microcarpa* and *E. leucoxylon* woodland.

The study area is located 10-15 km south-east of Adelaide GPO at Glen Osmond in the Adelaide Hills (Mt Lofty Ranges). The aim of the study was to investigate geochemical dispersion from old workings and distinguish them from other anthropogenic sources of contamination.

A.15.2 Geological setting

Sedimentary rocks (Burra Group) of Neoproterozoic age dominate the western side of the Mount Lofty Ranges (Forbes *et al*., 1981; Forbes and Preiss, 1987; Preiss *et al*., 1993; Preiss and Cowley, 1999). This Group is well exposed in the study area and unconformably overlie Palaeoproterozoic basement schists and gneisses. Of specific interest within the Burra Group is the Glen Osmond Slate, which hosts the Pb-Ag mineralization that has been exposed by mining and erosion. It is a laminated and fine sandy siltstone with small-scale cross-bedding evident in fine, sandy bands (Preiss, 1987).

The study area is restricted to the elevated blocks of the Adelaide Hills in the Mt Osmond area and a portion of the Adelaide Plains west of the Hills. This area, and the Mount Lofty Ranges as a whole, is a morphological result of faults orientated northeast to north that began to form in the early Tertiary and have remained active to the present. Post-Pliocene uplift was focused on the western edge of the Mount Lofty Ranges resulting in active erosion outstripping *in situ* weathering (Tokarev *et al*., 1998). The result has been a graben-horst system of ranges and the flanking St. Vincent and Murray Basins to the west and east, respectively (Sprigg, 1945; 1946).

A.15.3 Mineralization

The Glen Osmond Mines are located along the Eden Fault Scarp with mineralization in narrow veins striking predominantly east-west, perpendicular to the strike of the fault (Coates, 1983). Galena and cerussite occur in a matrix of clay, Fe oxide, calcite, barite and quartz (Brown, 1908). The lodes containing this mineralization vary in width from 0.3 to 1.2 metres. Within them, solid veins or shoots of ore up to 50 metres in length and half a metre wide were mined. About 2500 tonnes of hand picked ore averaging 70 per cent lead and 20 oz of silver per tonne were produced (Brown, 1908).

A.15.4 Regolith

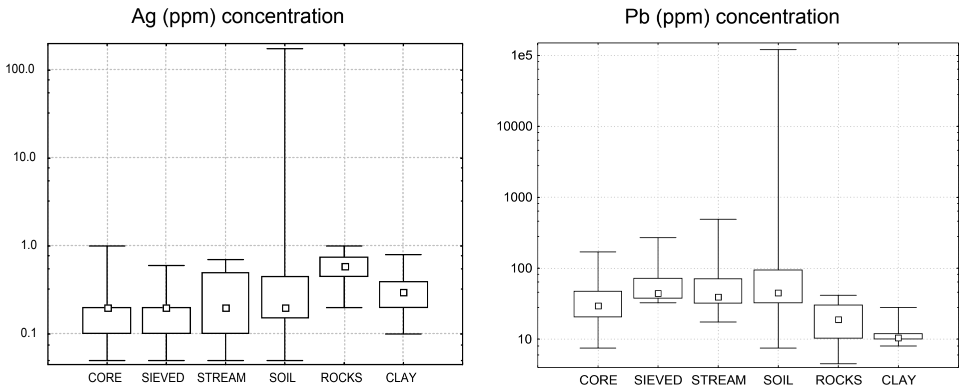
The regolith study area is divided into two units: *in situ* and transported. The Pb-Ag mines outcrop in hilly terrain (200 to 300 m relief) primarily consisting of slightly to moderately weathered bedrock (including saprock) overlain by thin colluvium-alluvium and soil. Drainage from the Adelaide Hills is to the north-west onto a gently sloping outwash plain (Adelaide Plains) consisting of thick (>100 m) Quaternary colluvium and alluvium overlain by soil, impregnated with calcrete to varying degrees.

A.15.5 Regolith expression

Four groups of regolith materials were sampled: soils, rock chips, stream sediments and core of transported clays. Silver concentrations are generally low (<1 ppm) compared with Pb, which are generally in the range of 10 to 100 ppm (Figure A 90).

Soil samples were taken from across mineralization and indicate downslope dispersion of metal away from the lode. Maximum Pb concentration was 240 ppm; Ag concentrations were at or below detection. Concentrations of Pb rapidly decrease less than 100 m away from mineralization (Figure A 91).

Soil samples were taken from a shallow pit and at a set depth away from a major road on the Adelaide Plains. Lead concentrations peaked at 1050 ppm close to the road (1 m) but returned to background concentrations (<50 ppm) less than 20 m from it.



Rocks –Rock samples. n=16
Core -Regolith drill core samples. n=62
Sieved -Fine sediment fraction. n=36
Stream -Bulk stream sediment. n=36
Soil -Soil samples. n=40

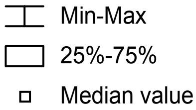


Figure A 90: Concentrations of elements in regolith materials from study area. Scales are logarithmic. (From Baker, 1999).

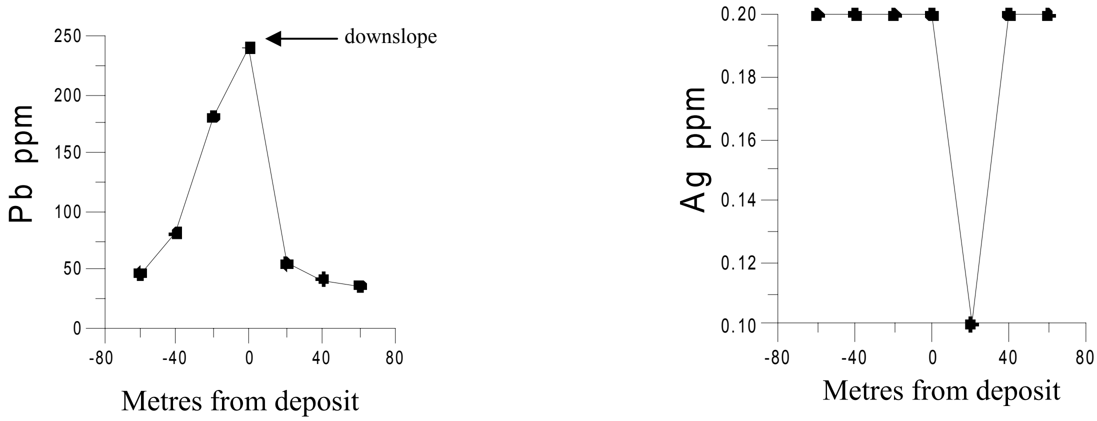


Figure A 91: Lead and Ag concentrations in soil across Pb-Ag mineralization. Location “0” directly over deposit. X axis distance units in metres. (From Baker, 1999).

a) b)

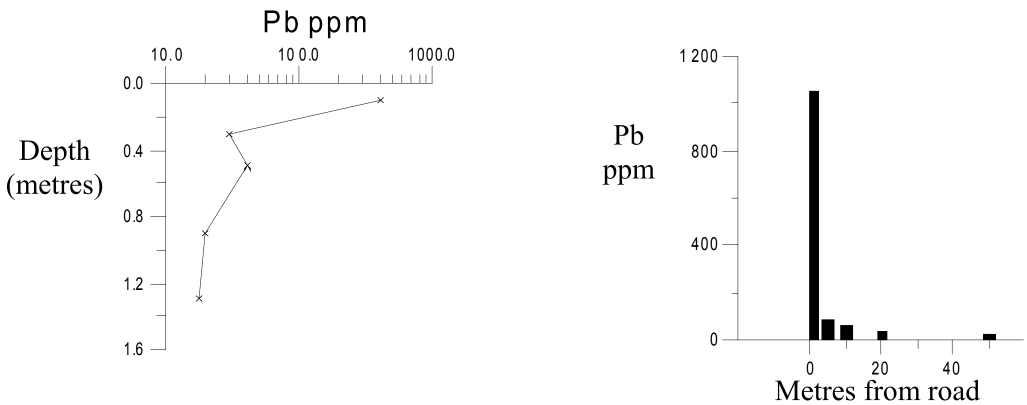


Figure A 92: Distribution of Pb in soil near main road: a) soil profile; b) distance from road location “0” in metres.

The Pb isotopic signature (^{207}Pb, ^{204}Pb, ^{206}Pb and ^{204}Pb) of ten selected samples (including galena from an outcrop) indicate a varying contribution of Pb ranging from anthropogenic to mineralized outcrop. The anthropogenic sources are mainly attributable to Missouri or Mt Isa Pb signatures that are probably related to organic Pb compounds used in petrol. The proportion of anthropogenic versus local mineralization was calculated using ternary diagrams (and, allowing for radiogenic decay of Th). It was concluded that:

1) channel and core samples from the transported regolith unit (Adelaide Plains) have high anthropogenic Pb content;
2) overbank samples have lower anthropogenic Pb than channel samples
3) samples collected within 20 m of a major road are dominated by anthropogenic Pb.

A.15.6 Conclusions

Geochemical dispersion from Pb-Ag mineral deposits in the Adelaide Hills is relatively locally confined and not readily detected from background concentrations in the adjacent Adelaide Plains. Isotopic signatures of geochemical samples can fingerprint the Pb signature and apportion contributions due to anthropogenic sources (contamination) and mineralization. Most Pb from the Adelaide Plains samples from this study is of anthropogenic origin.

A.16 OLARY SILVER MINE (SKWARNECKI *ET AL.*, 2001)

A.16.1 Geological setting

The Olary Silver Mine is located on the western side of the Olary-Bimbowrie road, about 5 km NNW of Olary. The main shaft extends to 33.5 m depth; a surface sample in its vicinity assayed 105 ppm Ag (Brown, 1908). It occurs on the western contact of a laterally discontinuous, massive to poorly banded, siliceous hematite-magnetite ironstone that is pyritic at depth (Flint, 1977). Country rocks are predominantly quartzofeldspathic gneisses with porphyroblastic muscovite and have been intruded by pegmatite bodies.

A.16.2 Regolith

The topography around the Olary Silver Mine is subdued, apart from the low ridge formed by the main outcrop of the ironstone. Along the orientation traverse, the soils are skeletal, sandy and small outcrops are common. There appears to be little or no deep weathering and the terrain is all *in situ* (erosional regime). The area away from the traverse was not investigated, but thin transported overburden is thought to be present. No carbonate was recognized in the soils.

A.16.3 Regolith expression

A.16.3.1 Rock-chip sample geochemistry

The maximum concentrations obtained from sulphidic samples for ore-associated elements from the dump were: Cu (750 ppm), Ag (1.4 ppm), As (27 ppm), Bi (15 ppm), Mo (13 ppm), Se (5 ppm), Te (2 ppm), Au (580 ppb) and Hg (0.25 ppm).

A.16.3.2 Orientation soil-lag traverse

Nine samples were collected along a traverse across strike of the mineralized horizon passing through the main shaft. The soils were sandy red brown, with locally abundant lag. Three lag types were recognized: (i) coarse- to fine-grained hematite-magnetite ironstone, mainly in the vicinity of the ironstone ridge; (ii) medium- to fine-grained quartz, along the whole traverse; (iii) medium to fine-grained pegmatite, at the southern and northern ends of the traverse.

Elements associated with mineralization (Au, Cu, S, W): Gold shows a peak about 40 m wide over the mineralized zone in all fractions (Figure A 93). Concentrations of Au are generally greatest in the <75 µm fraction (25 ppb, over a background of <10 ppb). The bulk <6 mm fraction has samples with high Au contents at the ends of the traverse; the southernmost sample appears to be unrelated to mineralization, but the northernmost sample also has slightly anomalous Au contents in other fractions.

Copper shows a peak about 40 m wide over the mineralized zone in all fractions (Figure A 93), with the best response in the <75 µm fraction (peak value 160 ppm, over a background of <80 ppm). The peak to background value of about 2 also holds for all the other fractions. Although S exhibits relatively low variance, all fractions show a peak over the mineralized zone. All fractions except 2-6 mm show a peak over the mineralized zone. The most prominent peak is in the <75 µm fraction, with a peak value of 5.5 ppm over a background of <2 ppm.

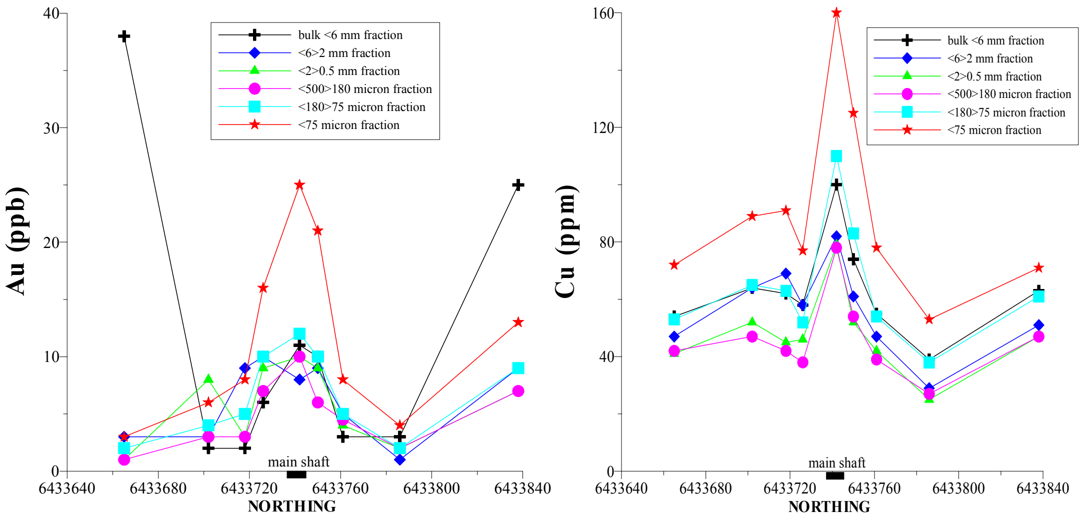


Figure A 93: Distribution of Au (ppb) and Cu in various size fractions along the orientation traverse, Olary Silver Mine. (From Skwarenecki *et al*., 2001).

A.16.4 Conclusions

Sampling of the dumps suggests that the geochemical signature of the mineralization is Ag, As, Au, Bi, Cu, Hg, Mo, Se and Te. The orientation soil survey indicated that Au and Cu are the best indicators of mineralization; S and W may also be useful pathfinders. The best responses were in the <75 µm fraction. The <6 mm fraction would be an acceptable compromise.

A.17 REGIONAL STUDIES

A.17.1 Hydrogeochemistry in the Gawler Craton (Gray et al., 2001).

Groundwater characteristics of the Gawler Craton appear similar to those of the Yilgarn Craton (Gray, 2001). Plotting pH vs. salinity (Figure A 94) indicates two significant trends:

(i) most groundwaters are pH 6.5 – 8.3, varying from fresh to hypersaline;
(ii) The saline-hypersaline groundwaters commonly vary from pH 7.5 to 3.

Thus, a significant proportion of the groundwaters within the Gawler Craton have similar abilities to mobilize Au (*i.e.*, high acidity and salinity) to those of the Kalgoorlie region of the Yilgarn Craton. In acidic conditions, Al is precipitated as alunite [$KAl_3(SO_4)_2(OH)_6$], with resultant major K and moderate SO_4 depletion (McArthur *et al*., 1989), which in the Yilgarn Craton is particularly marked in the Kalgoorlie area (Gray, 2001). A similar K-depletion is observed in the Gawler Craton (Figure A 95), again indicating the similarity of hydrogeochemical processes operating in the Yilgarn and Gawler Cratons. Insufficient groundwater data from the Gawler Craton are available to comment on Au or trace elements, but the similarity of major element chemistry to the Yilgarn indicates that these elements should behave in a similar manner.

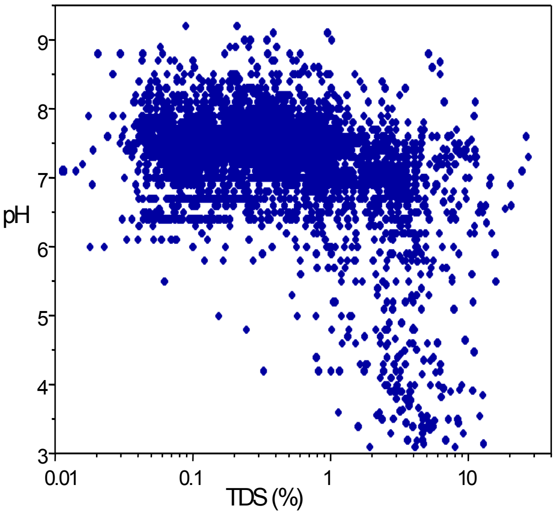


Figure A 94: pH vs. TDS for Gawler groundwaters. (Data from PIRSA).

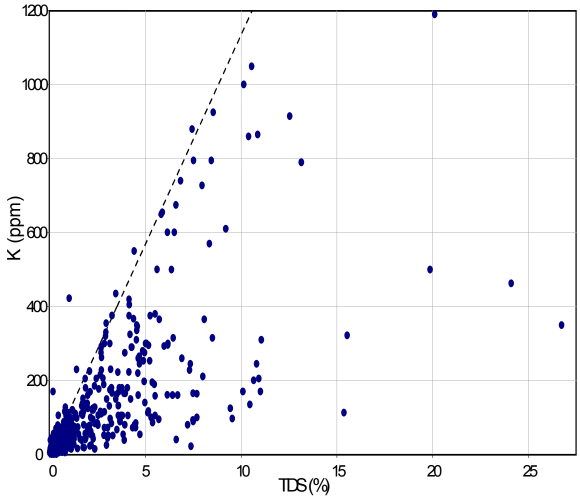


Figure A 95: Dissolved K vs. salinity for Gawler groundwaters. (Data from PIRSA).

Areas of the Gawler that are markedly more saline (Figure A 97) and acid (Figure A 98), are:

1. Along a northwest trend extending more than 200 km, approximately 100 km east of the western coast of the Eyre Peninsula.
2. West of Challenger, possibly an extension of the above trend.
3. Central-east Gawler Craton.

These areas are also highly depleted in K (Figure A 95), again indicating highly corrosive groundwaters (Section 5.3). It is predicted that these areas, like the Kalgoorlie region in the Yilgarn Carton, will have high Au solubilities and strong supergene Au mobility.

A.17.2 Dating studies using palaeomagnetism (B. Pillans, CRC LEME, written communication, 2003).

While deep weathering profiles are preserved extensively in southern South Australia, developed on a range of lithologies, little is known about their age(s) of formation. Schmidt *et al*., (1976) suggested Late Tertiary ages for weathered profiles on Kangaroo Island and in the Springfield Basin, on the basis of paleomagnetic dating. Twidale (2000) has speculated that ages may date back to the Mesozoic.

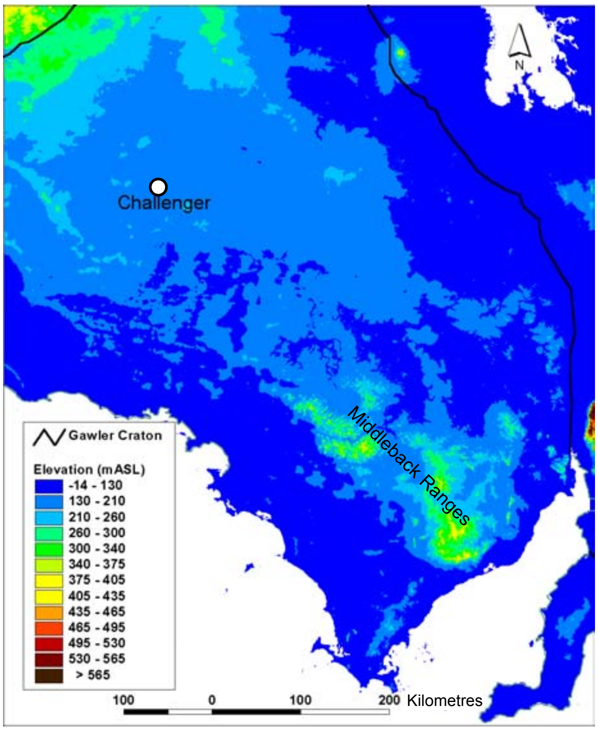


Figure A 96: Elevation of the Gawler Craton, with Challenger site shown. (Data from GA).

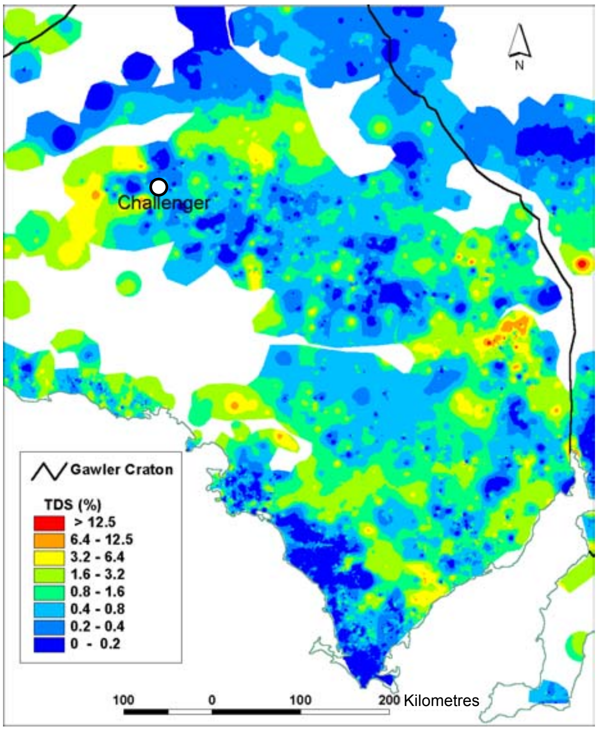


Figure A 97: Groundwater salinity in the Gawler Craton, with Challenger site shown. (Data from PIRSA).

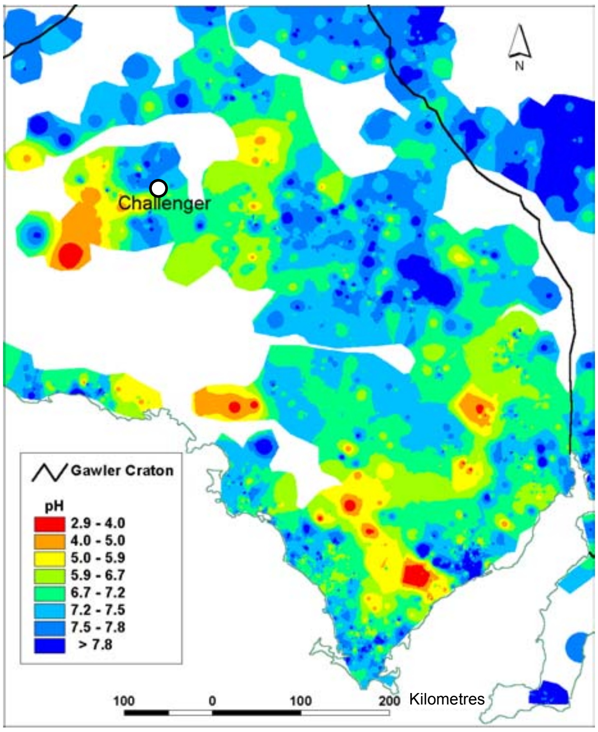


Figure A 98: Groundwater pH in the Gawler Craton, with Challenger site shown. (Data from PIRSA).

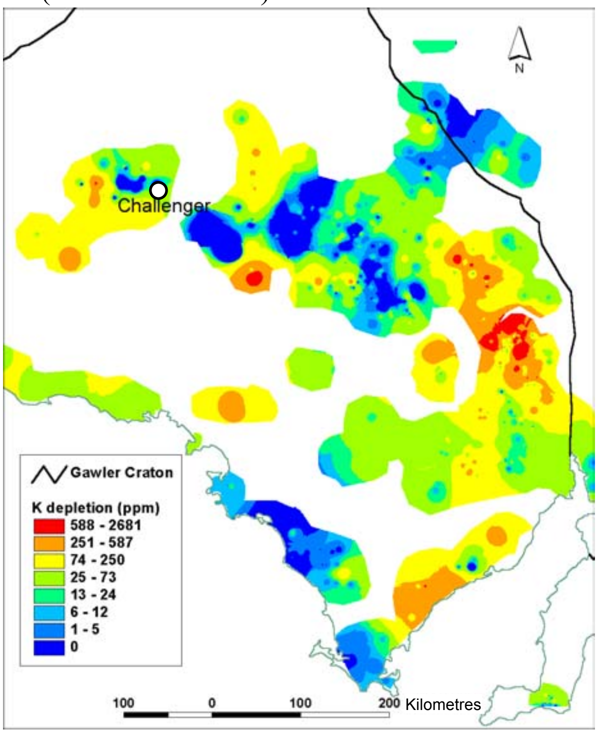


Figure A 99: Groundwater K depletion in the Gawler Craton, with Challenger site shown. (Data from PIRSA).

Weathering profiles in the Mt Lofty Ranges and at Moonta (see Section A.12) were dated, and form part of a wider paleomagnetic study by Pillans and Bourman (2001) on the ages of weathered regolith in southern South Australia.

Although only small numbers of specimens were obtained from some sites, resultant pole positions are all indicative of a late Miocene-early Pliocene age weathering event as determined by the Cenozoic Australian Apparent Polar Wander Path (Idnurm 1985, 1994). Poles determined from the Poona pit are statistically indistinguishable from those determined on samples from Moonta Bay, and results have been combined to yield a mean position.

A.17.3 Dating studies using Optically-Stimulated Luminescence (OSL) and Thermoluminescence (TL)

Both OSL and TL ages were determined for samples of quartz extracted from dune sediments at sites in, or close to, the Great Victoria Desert. The method presupposes that the luminescence clock has been reset by exposure to sunlight during deposition of the sediment. This expectation is normally fulfilled in Australian dune systems and the present determinations appear to be no exception (Huntley *et al.,* 1999).

Near Barton Siding (Barton Range), four samples were analysed by OSL: an age of 74±8 ka was found for a sample from an auger hole ~ 2 m below the dune crest; and ages of 106±8 and 184±14 ka, 1.3 m apart vertically, from the face of a borrow pit near the base of the same dune, about 10 m below the crest and just above the swale (Baril et al., 1999; Huntley *et al.,* 1999). A sample from the swale suggests that the age is probably beyond the range of OSL (250 ka) for this location (Huntley *et al.,* 1999).

Near Immarna Siding (Ooldea Range), three samples were analysed by OSL. A sample from 0.7 m below the present dune surface gave an age of 22±3 ka and two samples in the same dune, 1 m apart and some 5 m lower than the previous sample, gave ages of 192±14 and 212±15 ka. The latter site was about 2.3 m above the level of the swale (Huntley *et al.,* 1999).

At another site approximately 150 km north-west of Tarcoola, a slightly clayey calcareous sand from a swale at 70–90 cm depth was taken using an auger and a TL age of 39.2±3.6 ka was reported (M. Craig, GA, written communication, 2002).

The ages, particularly from the deeper samples at Barton and Immarna, must be regarded as unexpectedly old and indicate long-term stability of the dune field pattern, a conclusion that has been drawn by Pell *et al*. (1999) on different grounds. Establishing the age of the dunes is significant for the sampling of calcrete for anomalous Au. The dune sand has to be older than any calcrete formed in it. Since the terrain over the western Gawler Craton is unevenly covered with dunes, it is important to know whether (i) the dunes themselves have been in position long enough for the calcrete formed in them to acquire a Au signature, (ii) sampling the calcrete is likely to prove advantageous and (iii) older dunes may have higher concentrations of Ca and Au.

A.17.4 Biostratigraphic dating

A single silicified wood fragment 500 m south-east of the Challenger Gold Deposit was submitted for xylotomical analyses. The reasonably well-preserved specimen was recovered from the surface above a silicified low energy, poorly sorted, sandy, fluvial horizon infilled palaeovalley (see Section A.5, sample site GCP110). It was identified as a member of the Podocarpaceae, with a possible affinity to the genus *Phyllocladu*s (Rowett, 1997). The specimen was considered to be no older than Cretaceous, however, associated palynological and palaeobotanical data from the Eucla and Polda Basins suggests a latest Eocene - Late Miocene age.

A.17.5 Isotope studies

A.17.5.1 Introduction

Stable isotope determinations were made on a number of samples from around South Australia:

1) Strontium ($^{87}Sr/^{86}Sr$): 68 determinations were made. Strontium was used as a surrogate for Ca to understand the origins of Ca in pedogenic carbonate.
2) Carbon ($\delta^{13}C$): 95 determinations were made to investigate the C characteristics in the carbonate.
3) Sulphur ($\delta^{34}S$): 28 determinations were made to investigate the origins of S in surficial materials, principally gypsum.

Preliminary observations and interpretations of the isotope data are included in this summary.

A.17.5.2 Strontium

Strontium isotopes can potentially indicate the origin of pedogenic carbonate, whereby Sr acts as a surrogate to Ca; rocks and regolith materials have a particular ratio of Sr isotopes which can distinguish them from one another. Previous studies in Australia suggest that much of the calcrete is derived from oceanic inputs in the form of dissolved salts, aerosol and wind blown dust sourced from limestone (Quade *et al*., 1995). Similarly, the results from this study indicate a gradual increase in the proportion of heavier isotopes from ~0.7095 to 0.7125 away from the coast. This suggests an overwhelming influence of marine-derived Sr nearer the coast but a decreasing trend away from the Bight (Figure A 100, Figure A 101). The values from Challenger, located ~100 km north of the transcontinental railway line (i.e. further from Bight), are not significantly different from the other carbonates, shown on the trend in Figure A 100, similar distances from the Bight. However, the spread of data from 0.7120 to 0.7147 requires further investigation since this may indicate spot sources of Sr from the bedrock (Figure A 100). No bedrock analyses of Sr isotopes were performed but studies by Quade *et al.* (1995) indicate relatively high values of 0.823824, 1.094176, 0.832867, 0.832846 from 4 samples of gneissic and granitic bedrock from the Eyre Peninsula. Further study on the Sr isotopes from Challenger (i) of bedrock and (ii) using laser ablation MC-ICP-MS (multiple collector inductively coupled mass spectrometry) on calcrete samples would benefit this study.

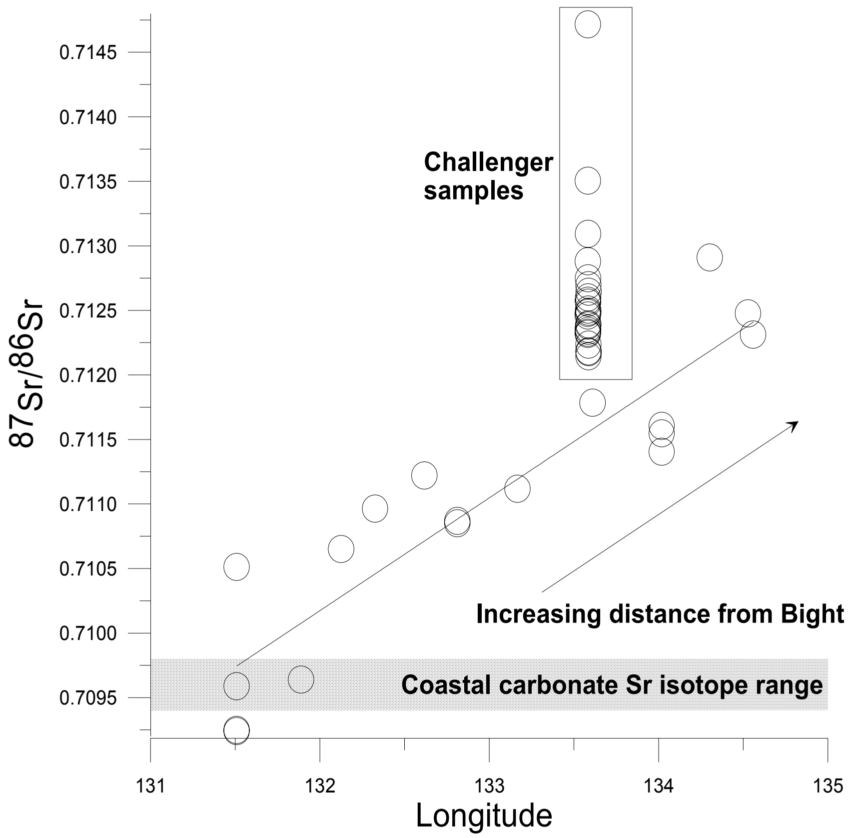


Figure A 100: Strontium isotope ratios for selected calcrete samples from the Transcontinental railway line access road and Challenger. Longitude approximately equates to distance from Great Australian Bight. The decreasing percentage of marine-derived Sr inland is reflected in the gradual increase in the heavier isotope ^{87}Sr over ^{86}Sr.

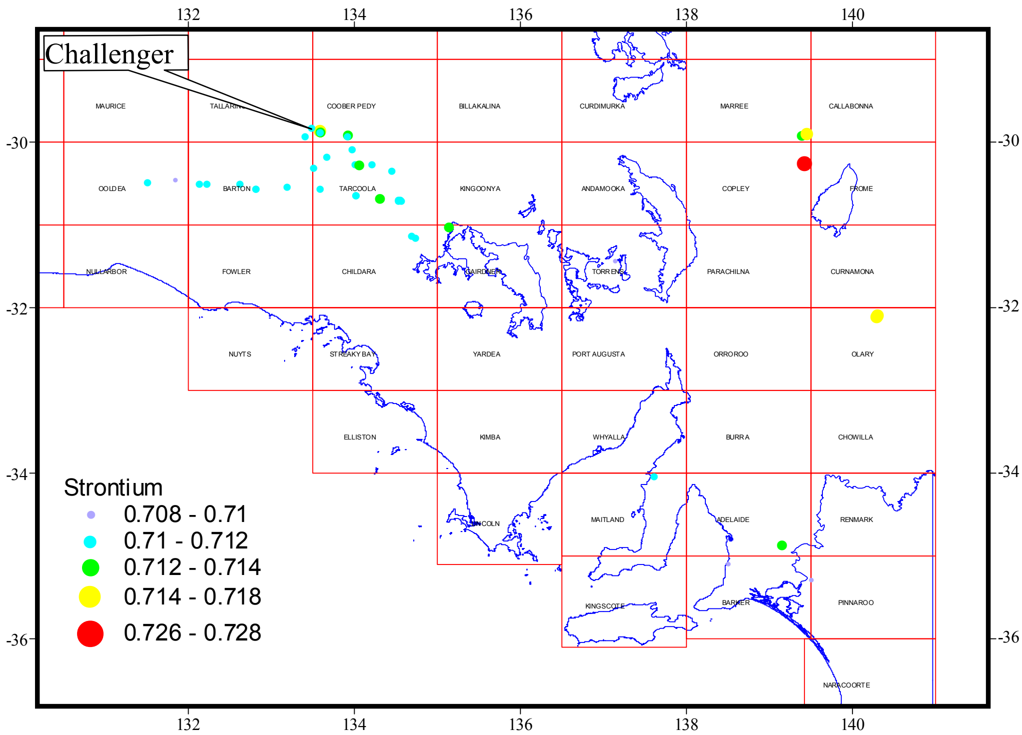


Figure A 101: Distribution of sites analysed for Sr isotopes.

A.17.5.3 Carbon

The C in calcrete may be derived from similar sources as for the (Sr) Ca, namely, oceanic inputs in the form of dissolved salts, aerosol and wind blown dust. Unlike Sr isotopes however, ^{13}C undergoes significant fractionation as a result of biological activity with different plant groups producing different fractionation responses dependant on their photosynthetic pathways. Thus calcrete C isotope values reflect the vegetation that was growing at the time of their formation, assuming there has been no solution and deposition. The main plant groups are termed C3 and C4. Typically, C4 plants grow in arid conditions, comprise grasses and shrubs, and have a distinctive $\delta^{13}C$ averaging -13 ‰. Many C3 plants grow in temperate and humid conditions, comprise trees and shrubs, and isotopically average -27 ‰. Plants produce large quantities of CO_2 when they respire and decay. In soils, where plant respiration is high, soil carbonates are ~15 ‰ enriched in ^{13}C compared with organic matter. Thus carbonates derived from pure C3 and C4 plants will have approximate $\delta^{13}C$ values of -12 and +2 respectively. However, in semi-arid soils, soil respiration rates are lower but ^{13}C can be further enriched due to mixing with atmospheric CO_2 (Quade *et al*., 1995).

Results indicate that there is no relationship between distance from Bight and $\delta^{13}C$ values suggesting that there is unlikely to be a marine source to the carbonate from the samples collected (Figure A 102). Moreover, the results show a distribution of values indicating input from pure C3 to C4 sources (Figure A 102). Most $\delta^{13}C$ values range from -8 to -2 with the average being -4.6. Quade et al. (1995) conclude that $\delta^{13}C$ averaging -5.3±2.2 represents a 50 % proportion of C3 and C4 contribution from plants to the carbonate (*i.e.* averaging $\delta^{13}C$ values of -12 and +2). They argue that the overwhelming CO_2 flux to the soil (including atmospheric CO_2, rainfall and dust) is primarily from respiring organisms and quote studies by Yaalon and Ganor (1975), Gile *et al.,* (1981), Pewe *et al.*, (1989), Singh and Gupta, (1977) and Quade *et al.* (1989) to support this assumption.

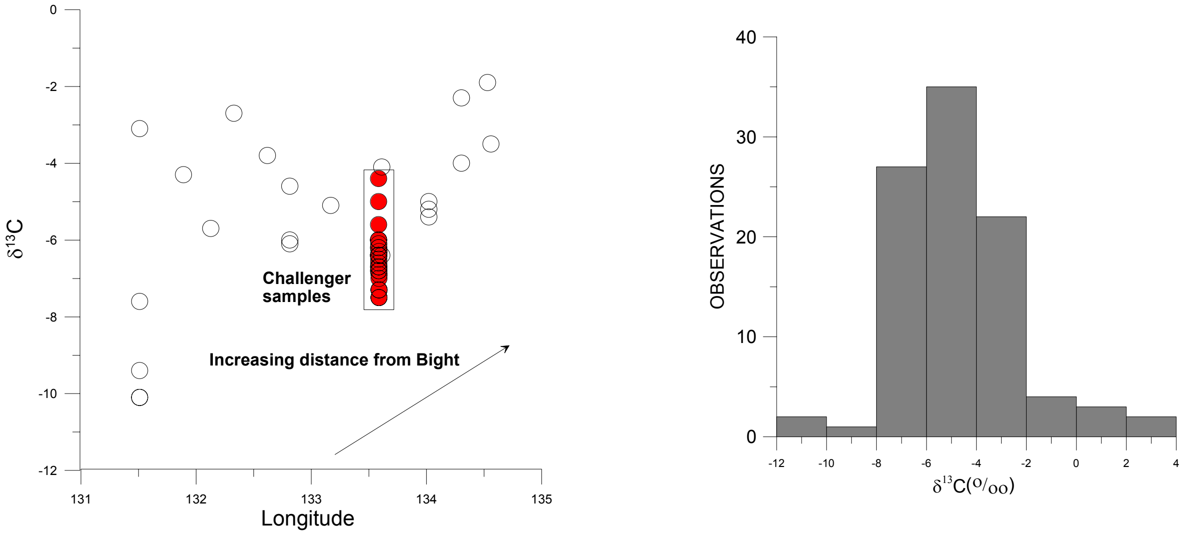


Figure A 102: Scatter plot showing poor relationship between location of calcrete sample from Bight and $\delta^{13}C$ and histogram showing spread of $\delta^{13}C$ values.

A.17.5.4 Sulphur

Sulphur isotopes were used in this study to specifically examine the origin of the gypsum found in the regolith. In some cases, gypsum appeared to be derived from local salt lakes or gypsum dunes. In other cases, however, the field relationships were less clear. At Challenger, for example, gypsum only appeared to concentrate over primary sulphides associated with mineralization.

It has been reported that there is a progressive decrease in the $\delta^{34}S$ values from near the coast to inland due to a relative decrease in the proportion of isotopically heavier S over lighter S (Chivas *et al.*, 1991). In SA, for example, the $\delta^{34}S$ value decreases from 20‰ near the coast to 14.9‰ four hundred kilometres inland at Cooper Pedy.

Preliminary results from this project indicate that most samples recorded $\delta^{34}S$ values consistent with a strong influence from a marine source (Figure A 103). Two samples with exceptionally low values were from sulphides analysed from bedrock drill cuttings.

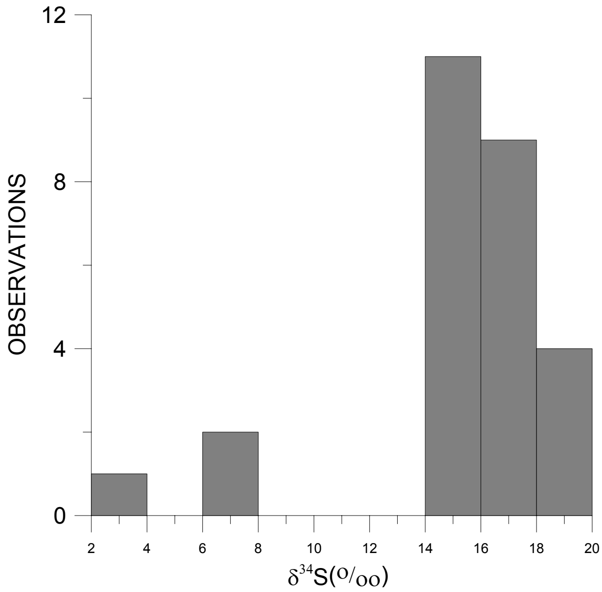


Figure A 103: Histogram showing spread of $\delta^{34}S$ values from samples collected in SA.

A.17.5.5 Conclusion.

The isotope studies have provided some important information on the origin of carbonates and gypsum in the SA regolith. The major difficulty in conducting isotope studies on calcretes is that they represent an open system with changes being potentially made to their compositions. Calcretes may dissolve and reform depending on climate and soil moisture conditions. Isotopic determinations, particularly C, reflect the current composition of the calcretes which may be comprised of a heterogenous mix of neo-formations and past un-dissolved material.

In conclusion, for calcrete, it appears that the isotope data are consistent with a marine source for the Ca and a biological origin for the C. This agrees with other studies that have been performed on calcretes from South Australia and in other parts of the world. The S isotopes suggest a marine source although the distribution of discrete accumulations of gypsum over mineralization in the regolith at Challenger Gold Deposit requires more explanation.

APPENDIX A18: DATA DISC containing PDF of report and excel file.