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REGOLITH CHARACTERISATION AS AN AID TO MINERAL EXPLORATION IN THE WUDINNA NORTH AREA, CENTRAL GAWLER PROVINCE, SOUTH AUSTRALIA

VOLUME I

M.J. Sheard

CRC LEME OPEN FILE REPORT 232 /
PIRSA MINERAL RESOURCES REPORT BOOK RB 2007/14

July 2007

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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 Primary Industries and Minerals Council of Australia, established and supported under the Australian Government's Cooperative Research Centres Program.

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

This report presents outcomes of a CRC LEME research project involving the Department of Primary Industries and Resources, Adelaide, South Australia (PIRSA) that commenced in mid 2004 and continued until mid 2006. There were no confidentiality agreements entered into regarding any aspects of this research project or covering any primary data and images or derived data and images obtained during the execution of this project. All contents, data and samples associated with this report are open file items. All reference materials (regolith samples, thin and polished sections) have been retained by PIRSA at their Drill Core Storage Facility, 23 Conyngham St, Glenside, South Australia, 5065. Those materials can be viewed without restriction by prior arrangements with the Drill Core Storage Facility Manager [ph: (08) 8379 9574 ; Fax: (08) 8338 1925].

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Reference:
Sheard, M.J., 2007. Regolith Characterisation as an Aid to Mineral Exploration in the Wudinna North area, Central Gawler Province, South Australia. *CRC LEME Open File Report 232. PIRSA Report Book 2007/14*, Volume 1 98 pages.

Keywords
1. Regolith – South Australia. 2. Basement Weathering – South Australia. 3. Landforms – South Australia. 4. Covered Terrain – South Australia. 5. Gold – South Australia. 6. Wudinna – South Australia. 7. Gawler Ranges National Park – South Australia. 8. Pinkawillinie Conservation Park – South Australia.

ISSN: 1329-4768
ISBN: 1 921039 81 7

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Published by: CRC LEME, c/o CSIRO Exploration and Mining, PO Box 1130, Bentley, western Australia 6102

PREFACE AND EXECUTIVE SUMMARY

The Central Gawler Gold Province of South Australia's Gawler Province (nee Craton), is a recently defined gold mineral province where the drilling of gold-in-calcrete anomalies encountered similar deposit styles – hence the suggestion that they may be linked. Over 90% of the Central Gawler Province crystalline basement is under cover by some or all of the following: thick Gawler Range Volcanics (also a potential host for Au) and/or these regolith regimes – palaeochannel sediments, aeolian dune fields, and deeply weathered bedrock. Basement geology and structure are outlined from geophysical interpretation but locating mineralization beneath regolith cover has proven to be challenging. Misleading results are commonly due to false geochemical lows, displaced anomalies, or a poor understanding of regolith landform evolution and/or poor choices of the appropriate regolith sample media. Investigations described in this report focus on regolith landform units in an area ~20 km north of Wudinna, and complement company exploration drilling programs targeting gold mineralization in bedrock, in particular at Barns and Baggy Green gold prospects.

Objectives

- Map out regolith landforms, develop a landscape evolution model and a series of diagrammatic landscape regolith profiles covering *in situ* crystalline basement (protolith) and cover sequences (weathered *in situ* crystalline basement plus transported materials).
- Evaluate the use of surface and shallow regolith materials as a means to outline areas of shallow *in situ* bedrock where soil and calcrete geochemical techniques are likely to be more successful in locating subsurface Au and base metal mineralization.

Adopted approach

- Regolith mapping to characterise and highlight Relict *in situ* crystalline basement (protolith to pedolith), indicate thickness of transported cover where possible and define all regolith landforms.
- Develop a regolith landscape evolution model using available historic information and field observations.

Results

- There is significantly more exposure of surficial and thinly covered weathered *in situ* basement in this area than was previously mapped or recognised (previously <8%, now increased to ~35%).
- Shallow transported cover (<5-10 m) over basement may contain geochemical components of the underlying rocks that can be used to identify their lithotypes in appropriate sample media. These areas are expected to also show anomalous elements related to hosted mineralization – especially where this extends into the weathered zone. Biotic transportation of elements such as Au, Ag, Cu and As, through the regolith has been demonstrated in this area by recent CRC LEME research.
- *In situ* weathered basement profiles in the Study Area generally display some erosive loss or truncation, and those retaining pisolitic Fe-rich pedolith are relatively rare and thin (<1-3m). More commonly a collapsed megamottled horizon forms a red to dark brown Fe-rich pedolith capping (<1-1.5 m) on megamottled pallid saprolite. That horizon is variably indurated, it commonly displays crack and void in-fill material of mixed character – transported and *in situ* sourced. Within or below the collapsed megamottled horizon, an arenose zone of collapsed quartz grit (<1-3 m) may also be present, forming a basal pedolith component. The underlying saprolite (<50m) is readily identified by its highly weathered upper pallid sub-zone and darker lower sub-zone, both retain remnant or pseudomorphed rock textures and foliation. Good exposures occur in erosional terranes – especially along retreating escarpments within Gawler Ranges National and Pinkawillinie Conservation Parks.
- Debris flow deposits emanating from the flanks of Mt Sturt highlands were recognised in exposed sections marginal to playas. Similarly there are significant linear lowlands now under aeolian and lacustrine sediment cover, where thick riverine sediments infill broad and numerous palaeovalleys. Both terranes would form substantial modifiers to any geochemical interpretation that may be made on surface sample assays from those areas. Detailed regolith mapping, terrain analysis and drilling were critical to recognition of these generally hidden features. Importantly, additional buried debris flows and palaeochannel sediments are expected to occur in this region.
- Results of the landscape evolution study, especially with respect to contemporary and palaeo-dispersion mechanisms, indicate that an understanding of landscape position and local landforms are both crucial when selecting appropriate geochemical sample media and for interpreting their trace element assay values.

Key Recommendation

Regolith landform mapping, in combination with landscape evolution modelling of contemporary and palaeo-dispersion mechanisms, are key components to a better understanding of areas where deep weathering and thin to moderately thick transported cover combine to obscure potentially mineralized protolith (crystalline basement). Those key determinants are essential to any surface geochemistry interpretive confidence in what is taken to be truly anomalous *vs* what is actually falsely anomalous.

M.J. Sheard, July 2007

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Regolith Characterisation as an Aid to Exploration in the Wudinna north area, Central Gawler Province, South Australia.

M.J. Sheard

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ABSTRACT

Over much of the Gawler Province (nee Gawler Craton) deep weathering profiles and extensive transported cover combine to hide crystalline basement (protolith) from conventional surface exploration methods. Recently recognised, the Central Gawler Gold Province lies within South Australia's Gawler Province. Previous conventional geological mapping attests to a dearth of protolith outcrop south of the Gawler Ranges highlands (northern Eyre Peninsula). Regolith landform mapping had never been tried or assessed for a large part of Central Gawler Gold Province, especially where demonstrated gold-in-calcrete anomalism occurs. To properly assess whether regolith characterisation, mapping and landscape evolution modelling could assist mineral exploration, a regolith landform Study Area was chosen ~20 km north of Wudinna and ~100 km WNW of Kimba. The Study Area covers ~445 km^2 and has corner grid coordinates of 528000-551447 E and 6358000-6377000 N (GDA 94, Zone 53 I). This area includes parts of Gawler Ranges National Park and Pinkawillinie Conservation Park; it also encompasses Barns and Baggy Green gold prospects.

Regolith profile recognition utilised methods and models established within CRC LEME. A modified RED Scheme (developed by CSIRO Exploration & Mining) was used for regolith mapping, in combination with geomorphology for landform description, and pedology for soil recognition. The aim being to highlight areas of *in situ* crystalline basement (protolith to pedolith) and thinly covered equivalents. Two adjoining 1:20,000 scale regolith landform map sheets resulted, where a Landscape Evolution Block Model with 12 Diagrammatic Regolith Profiles are key components. Forty six regolith landforms were identified, they include: 14 Relict + 9 Erosional + 20 Depositional and 3 Duricrusts. Regolith landform mapping increased the area of protolith derived regolith from <8% to ~35% and therefore has increased surface mineral prospectivity by a similar four fold factor.

Aeolian sand plain—dune systems form the major surficial transported cover. Sand cover is relatively thin (<1 to ~15 m) but forms a significant barrier to conventional surface exploration methods. Yaninee-Narlaby Palaeochannel complex and Corrobinnie Depression (Narlaby Palaeochannel) are buried fluvial valleys where sediment thickness may exceed 30 m. Areas of fluvial deposition have been partially defined by this study and exploration drilling. Inverted topography, forming small mesas, reveals bog-iron overprinted palaeochannel sediment, evidence for swampy reducing conditions where acid groundwater input was once a significant factor in Fe-Mn mobility. These bog-iron capped mesas are also evidence for erosional landscape lowering of the area by 10-15 m since the late Palaeogene and illustrate significant profile truncation.

Mapping and petrography show that a previously widespread but thin Fe-rich pisolithic horizon (<1 m) developed on a deeply weathered profile has been substantially minimised by erosion. Most of the remaining Fe-pisolith bearing horizon (pedolith) occurs as scattered *in* situ remnants or forms lag accumulations in the transported cover. More commonly, a collapsed Fe-megamottle horizon (1-1.5 m) forms the regional duricrust as a conspicuous variably indurated pedolith. The collapsed Fe-megamottle horizon can display void and crack in fill of mixed transported and *in situ* character. Within or below that a arenose zone (lowest pedolith) of collapsed quartz grit (<1-3 m) may occur, where clays and other fines are absent to rare. Eroding escarpments provide windows onto the underlying saprolite (commonly megamottled, and pallid in the upper two thirds; thickness <50m). Saprock and protolith are restricted to a few small cropouts, of which two are named (Poondana Rocks and Little Pinbong Rockhole). Contacts between Tunkillia Suite and Hiltaba Suite lithotypes are not exposed and their similar petrophysical subsurface boundaries are quite difficult to define even from detailed aeromagnetic properties and gravity data.

Significant duricrusts include: gypcrete, calcrete, ferricrete and silcrete. Field and petrographic evidence from silcrete outcrop support the timing of megamottling in saprolite and palaeochannel sediment as both being prior to silicification. Silcrete typically caps collapsed arenose zones and may contain appreciable colluvium but may also extend into alluvium. Calcrete has been used by mineral explorers as a convenient geochemical sampling medium and forms massive sheets, accreted nodule aggregates, nodules, thin plates and earthy overprints within soils and substrates. No superior

geochemical sampling medium to calcrete was identified but more use of the Fe-pedolith for such work may provide finer detail in areas of relict terrane. Gypcrete is abundant, especially around playas and associated lunettes, and gypsum can be a significant dilutant in surface geochemical samples.

PIMA infrared analysis of playa muds identified alunite at 9 locations in the western half of the Study Area (possibly derived from acid groundwater). Those in the NW quadrant this may relate to weathering of protolith hosted sulphides. Gypsum is a common evaporite mineral in most playa sediments. Kaolinite in exposed saprolite has a higher crystallinity index than kaolinite in playa sediments. Palaeochannel clays are commonly montmorillonitic and the (older) Orange Longitudinal Dunes (map symbol De-4) also have clayey cores containing montmorillonite.

Gold-in-calcrete geochemistry overlaid on the regolith map demonstrates that most Au anomalism is associated with exposed or very thinly covered *in situ* weathered basement. However, there is one significant Au anomaly developed over a palaeochannel tributary, where exploration drilling has confirmed Au in high ppb to low ppm concentrations within the channel sediment. Gold grains can be panned from palaeochannel sand and gravel samples from those drillholes. The bedrock sources of this sediment hosted Au remains elusive.

Reliable interpretations of surface geochemical signatures are not possible without an adequate comprehension of the regolith profile, its degree of profile loss by erosion, and whether or not any remnant mineral signatures are laterally displaced via erosion or mass wasting (debris flows) or sheet flow alluvial dispersion. Identification of host provenance is essential for interpreting the significance of trace element data. Confidence in the <u>trueness</u> of surface geochemistry is significantly improved when any anomalism is known to be either: *in situ*, displaced, diluted, or missing through profile erosion. Results of the landscape evolution study, especially with respect to contemporary and palaeo-dispersion mechanisms, indicate that both an understanding of landscape position and landforms are crucial when selecting appropriate geochemical sample media and for interpreting their trace element assay values.

Key Recommendation

Regolith landform mapping, in combination with landscape evolution modelling, are additional key components to a better understanding of areas where deep weathering and thin to moderately thick transported cover combine to obscure potentially mineralized protolith. Those key determinants are essential to surface geochemistry interpretive confidence in what is <u>truly</u> <u>anomalous</u> *vs* what is <u>falsely anomalous</u> regarding sample trace elements.

Acknowledgements

The author wishes to acknowledge the assistance received from the following: South Australian Government – through PIRSA-Geological Survey for significant funding over two years; C. Nixon (DEH District Ranger) & B. Waining (DEH Environmental Geoscientist) for permitting access to Gawler Ranges National Park and Pinkawillinie Conservation Park – thereby allowing mapping to occur; Adelaide Resources Ltd and C. Drown (Exploration Manager) for access to drillhole data + drill samples + surficial geochemical data covering the ‘Barns’ and ‘Baggy Green’ gold prospects + local geology interpretations; G. Gouthas (PIRSA Geological Survey) and M.J. Lintern (CSIRO Exploration & Mining) for field assistance and in-field technical—scientific advice; P. Waring and J.B. Ragless for airphoto acquisition and enlargement printing—annotating; P. Trethaway, L. Simmons, JA. Cronk, R. Beinoravicius and S. Rossi for compiling the digital Regolith Landform Maps from airphoto line work plus diagrammatic sketches and compiling the pdf, jpeg, digital ArcReader map versions; S. Rossi for the data CD-ROM preparation; PIRSA Publication Drafting for some of the location plans and diagrammatic sketches; Pontifex & Associates (Adelaide) for preparation of rock and regolith thin-sections plus polished block mounts and several photomicrographs of portions of those blocks; foram identification by L. Stoian, PIRSA Geological Survey—Biostratigraphy; J.L. Keeling (PIRSA Geological Survey & CRC LEME) for PIMA analysis and interpretation; J.L. Keeling, L. Worrall and C. Pain (latter two – Geoscience Australia & CRC LEME) provided valuable peer review comment on an advanced draft of this report and map; and to S. Game and A. Vartesi (CRC LEME, Perth, W.A.) for arranging final document jackets, CD labels, assembly and distribution. All these contributions are noted with appreciation.

Key regolith landforms from the Wudinna north area.

Plate 1: Little Pinbong Rockhole, deformed protolith, Tunkillia Suite orthogneiss. In the background dune sand obscures an underlying *in situ* lateritic profile.

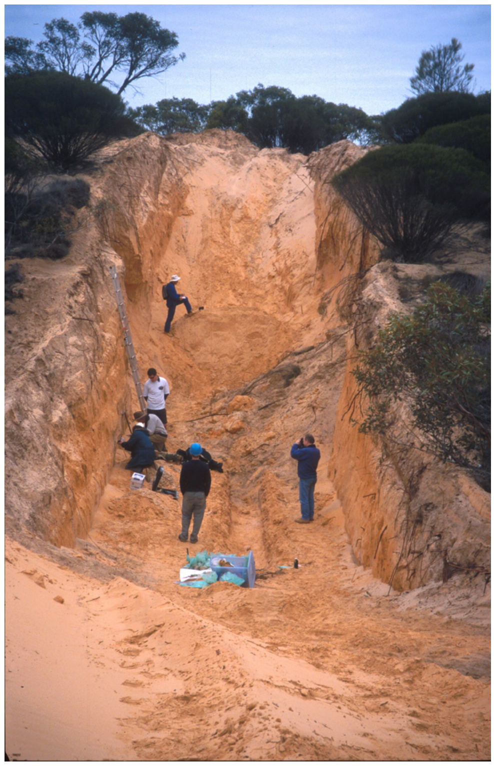


Plate 2: Sampling dune trench sand for dating, geochemistry & stratigraphy, Barns gold prospect, April 2004.

Plate 3: An eroding escarpment of weathered *in situ* basement (Tunkillia Suite orthogneiss) 2.6 km E of Little Pinbong Rockhole. The dark red-brown Fe-rich capping is a collapsed megamottle horizon (lower pedolith; note its irregular base) which contrasts strongly with the underlying leached (pallid) saprolite. In the foreground are weakly Fe-stained quartz veins (pale orange). Thin sand plain covers this *in situ* weathered profile and generally obscures it from direct observation away from uncovered residual landforms or eroding terrain in many parts of this district.

Introduction

Background

Transported cover and deeply weathered crystalline basement together form a major exploration impediment over much of the Gawler Province and especially over the northern Eyre Peninsula. Therefore finding ways to make exploration more efficient would further encourage exploration investment and improve the chances of mineral discovery. South Australia's Government sponsored Targeted Exploration Initiative (TEiSA) during the late 1990's to 2000's through PIRSA has encouraged exploration in the Gawler Province. More recently the SA Government's "PACE Initiative" has carried forward the earlier government-sponsored exploration initiatives. However, the ubiquitous transported cover and deeply weathered materials over much of SA, conceal large areas of prospective crystalline basement. Regolith research on Eyre Peninsula by PIRSA Minerals and Energy Resources Group has since 2003 been done mostly through the Cooperative Research Centre for Landscape Environment and Mineral Exploration (CRC LEME), including the regolith study of the Wudinna north area reported here. **Note**, the name Gawler Craton has been superseded by Gawler Province to avoid boundary + tectonic + age restrictions implied by using "Craton" (Cowley, 2006).

Regional geological mapping at 1:250,000 scale (YARDEA sheet) was carried out by the South Australian Geological Survey in the late 1970's to 1980's (Blissett *et al*., 1988a). Explanatory Notes for YARDEA were later published by PIRSA (Parker and Flint, 2006). Additional geological detail is available o the Cacuppa and Minnipa 1:100,000 sheets (Blissett *et al*., 1988b, c) and from the PIRSA SA_Geology digital database. Previous mapping records few exposures of crystalline basement south of the Gawler Ranges, where dominantly aeolian cover obscures the bedrock.

Since the 1980's, substantial parts of the region have been set aside as natural history conserving parks, they include: Gawler Ranges National Park and Pinkawillinie Conservation Park (Figures 1, 2). Access for scientific research requires notification and permission from the Department of Water, Land and Biodiversity Conservation – National Parks and Wildlife Service SA. The natural history of the region is described in Twidale *et al*. (1985).

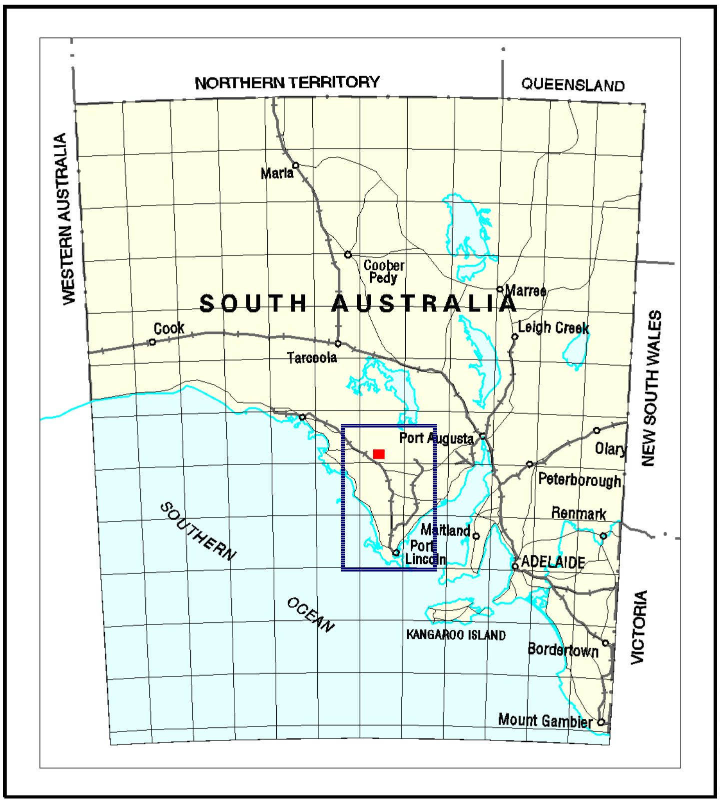
Recent accounts of the crystalline basement for northern Eyre Peninsula and the Wudinna district are given in Drexel *et al*. (1993), Schwarz, *et al*. (2002), Drown (2002, 2003), Fairclough and Schwarz (2003) and Ferris and Schwarz (2004). Descriptions of the regional transported cover sediments are provided in Drexel and Preiss (1995).

Crystalline basement in the Wudinna area includes the following broad lithic-terranes: high metamorphic grade polydeformed Archaean Sleaford Complex (dominates the eastern part of the district but does not crop out within the area mapped for this project), and Palaeoproterozoic Tunkillia Suite orthogneiss (granite-granodiorite, occurs in the central part), while less deformed Mesoproterozoic Hiltaba Suite granite and Gawler Range Volcanics dominate the western and northern areas respectively. Hiltaba Suite plutons intrude the Tunkillia Suite but contacts are not exposed in the mapped area. Meta-dolerite dykes and quartz vein stockworks of uncertain age also intrude or cross-cut the crystalline basement rocks.

Many of the few prominent granite outcrops in the district are named, although a some remain un-named and a number have Native—cultural or tourist significance. Only two of the named sites appear within the Study, they are: Poondana Rock (nee "Brazil Rock") a large whaleback inselberg pair of Hiltaba Suite granite rises (Plates 9 to 11); and Little Pinbong Rockhole (Plate 1), an exhumed weathering front orthogneiss surface with small water-holding depressions. A number of smaller un-named sites of either Tunkillia Suite or Hiltaba Suite granitoids occur; these typically form low outcrop, just protruding the cover sequence, but may include granite tors and remnant core-stone boulder lag.

Previously recognised and named transported cover materials, with their geo-map symbols in brackets, include: Quaternary – Moornaba Sand (Qhem; Plate 2), Pooraka Fm (Qpap); ?reworked Bridgewater Fm. or ?Wiabuna Fm. equivalent (Qpew); Bakara and/or Ripon Calcrete (Qpca) [the latter two names are now obsolete] (Blissett *et al*., 1988a ; Parker and Flint, 2006).

LOCALITY



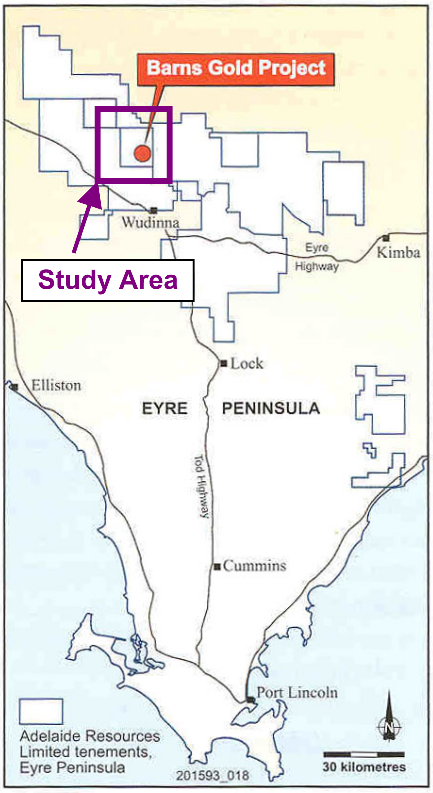


Figure 1: State Map (left) with key geographic features and the Study Area marked by a small red square. Inset (right map) is of Eyre Peninsula, showing local towns, main roads, exploration tenements, Barns Au prospect and the Study Area.

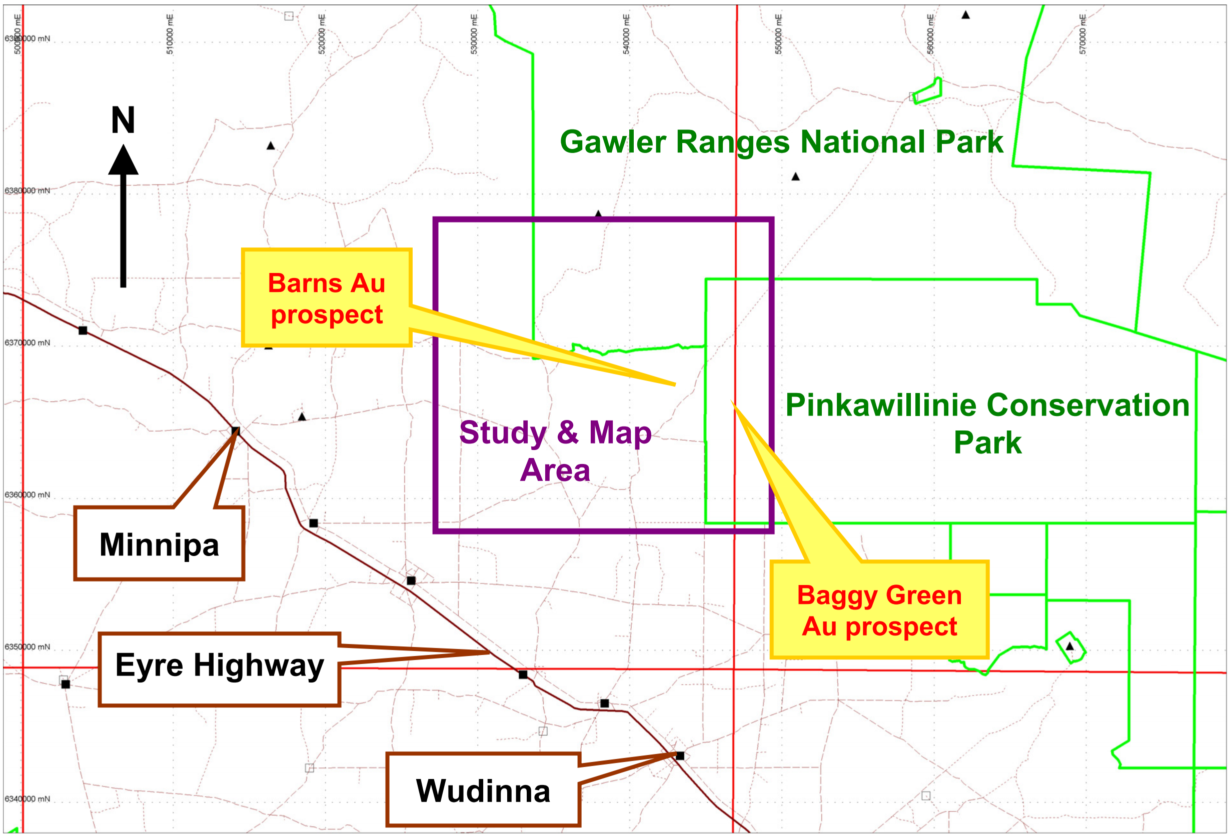


Figure 2: Principal boundaries and towns. Regional Parks (green boundary) cover ~40% of the Study Area (purple boundary; 19 x 23.45 km).

Figure 3: Extract from YARDEA 1:250 000 geological sheet covering the Study Area (outlined). Mapped crystalline basement exposure is <8%, new regolith mapping has increased that area to ~35%.

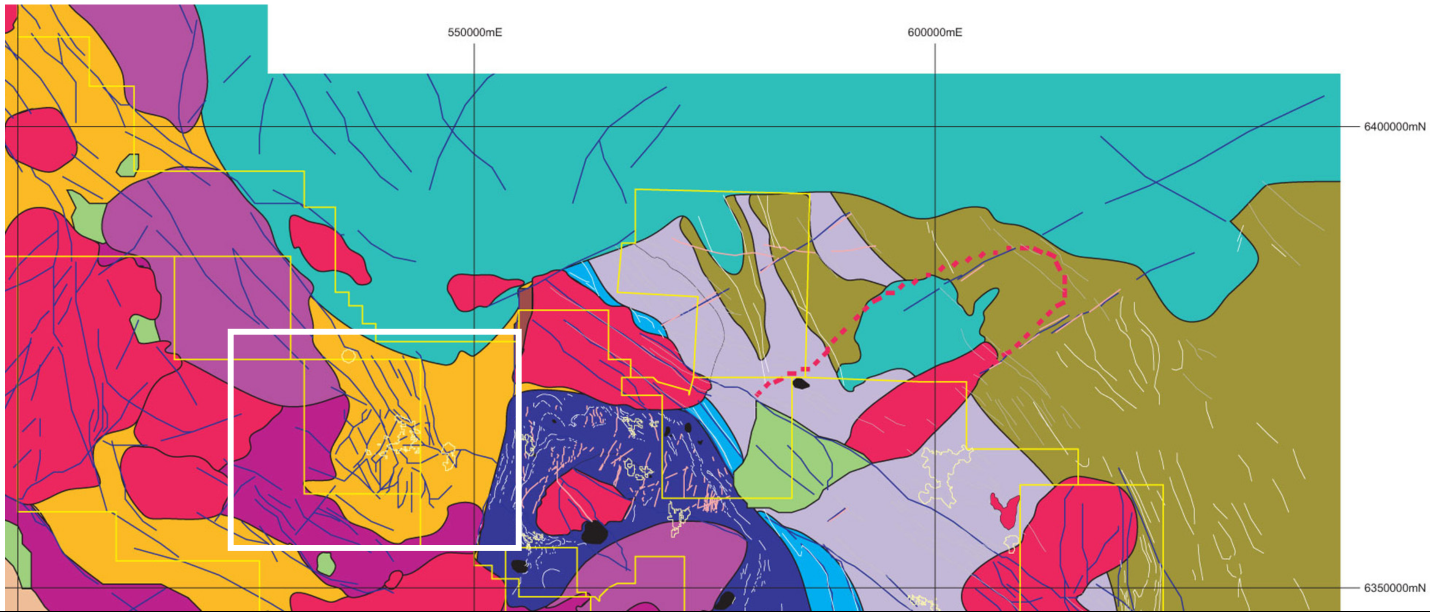
Other previously recognised but un-named transported cover items include the following: Palaeogene to Neogene [Tertiary] – Garford Fm. equivalent (Tig); "terrazzo" style silcrete (Tsi_1, Tsi_2, TmQ_{Si1}); ferruginous cementation in the Garford Fm. equivalent (T_{fe}); and cavernous, rubbly ferruginous laterite (TmQ_{fe3}). For the Quaternary – saline and gypsiferous playa lake deposits (Ql_1); aeolian quartz sand dunes + sand spreads (Qhe_2); aeolian gypsiferous sand dunes fringing playa lakes (Qhe_4); brownish sand spreads around playa lakes (Qhe_5); thin reddish brown loamy sand containing Bakara Calcrete nodules (Qpr_4) (Blissett *et al*., 1988a; Parker and Flint, 2006)

Numerous ephemeral playas occur in the Study Area, including one covering ~13 km^2 but only two relatively small playas have been formally named, they are: Hidden Lake and Agars Lake. Overall the area has a dearth of formally named geographic features.

Exploration for base and precious metals in the Wudinna district was unknown until the gold-in-calcrete methodology, as used in Western Australia, was brought into South Australia by Dominion Mining N/L in the early 1990's, resulting in the discoveries of the Challenger Gold Deposit (Christie Domain), the Tunkillia Prospect (Harris Domain) and numerous other gold-anomalous—mineralized areas across the Gawler Province (Lintern and Butt, 1993; Lintern, 1997; Edgecombe, 1997; Drown, 2002, 2003; Lintern, 2004a).

In 1998, Newcrest Mining Ltd defined a broad gold-in-calcrete anomaly on their tenement (Exploration Licence 2845) ~25 km north of Wudinna (later named "Barns prospect"; Figures 2-6,) with a peak Au value at 31 ppb. This anomaly had surface dimensions of 4.5 x 1.5 km and in late 1999, Adelaide Resources Ltd acquired the tenement after confirming Newcrest's earlier calcrete results. By 2002 Adelaide Resources Ltd had drill tested the Barns prospect Au anomaly and associated mineralization, demonstrating significant Au intersections over an area ~700 x 700 m (Figures 5, 6, depth range 31-158 m; intersections of 2-35.5 m but typically 8-16 m; Au grades ranged between 1-67.6 g/t where 1.5-4 g/t were more common; Drown, 2002, 2003). The Barns prospect mineralization is blind, in that it does not crop out, and through most of the saprolite there is little or no detectable Au. However, some residual or hydromorphic Au signature is retained within the surficial saprolite-hosted calcrete and soil. Subsequent work by Lintern (2004b) has demonstrated a probable biogenic role in the accumulation of Au within calcrete in this area.

Sampling and drilling by Adelaide Resources Ltd delineated additional Au mineralization at their White Tank prospect in 2003 (1 km south of Barns prospect). In collaboration with Newmont Gold, Adelaide Resources located more gold-in-calcrete anomalies that were drill tested during 2004 for mineralization at a new prospect – Baggy Green (~5 km east of Barns prospect). Moreover, they had similar finds further east at their Belmont zone and Red Rag prospects. This and earlier work has indicated that an area ~65 x 20 km hosts clustered gold anomalism north and east of Wudinna (Adelaide Resources Ltd, 2003, 2004). One very small ferruginous outcrop within highly weathered Tunkillia Suite orthogneiss, NW corner of the larger central northern playa, has assayed ~1 ppm Au (pers. comm., C. Drown, Adelaide Resources Limited, March 2006).



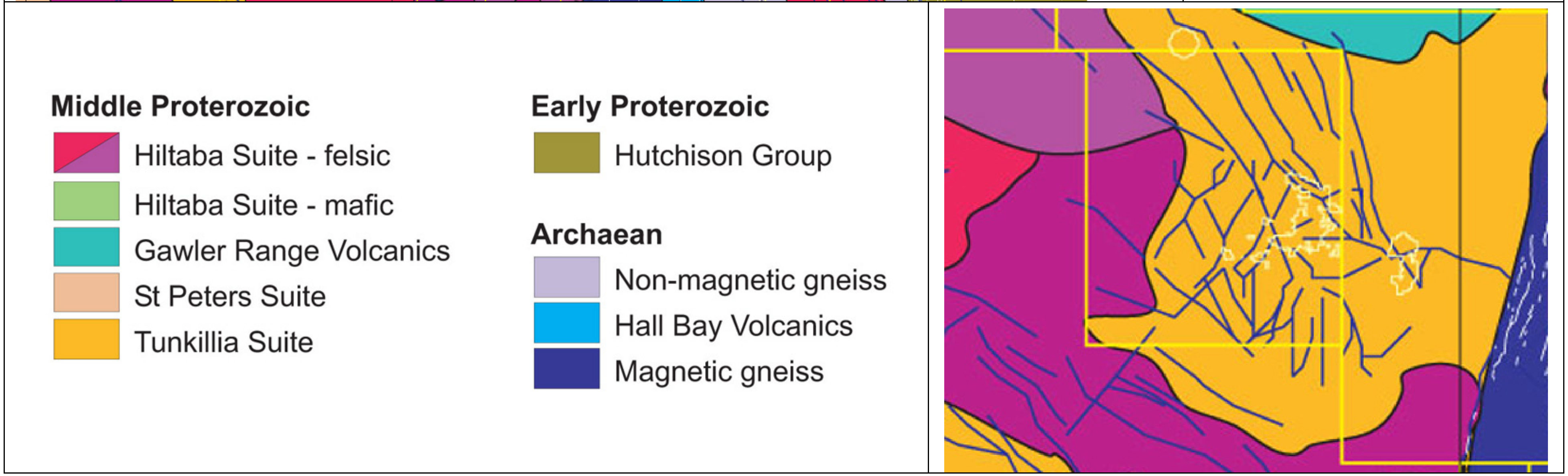


Figure 4: Interpreted basement geology for the Wudinna region. Interpretation based upon geophysical data, exploration drilling and outcrop evidence. A white box on LHS map indicates the enlargement (lower RH image) covering the Study Area (scale ~19 x 23 km). Petrophysical similarities between the Tunkillia and Hiltaba Suites granitoids leads to some uncertainties regarding subsurface common boundaries.

Both images are extracted from the original map-image provided by Adelaide Resources Ltd.

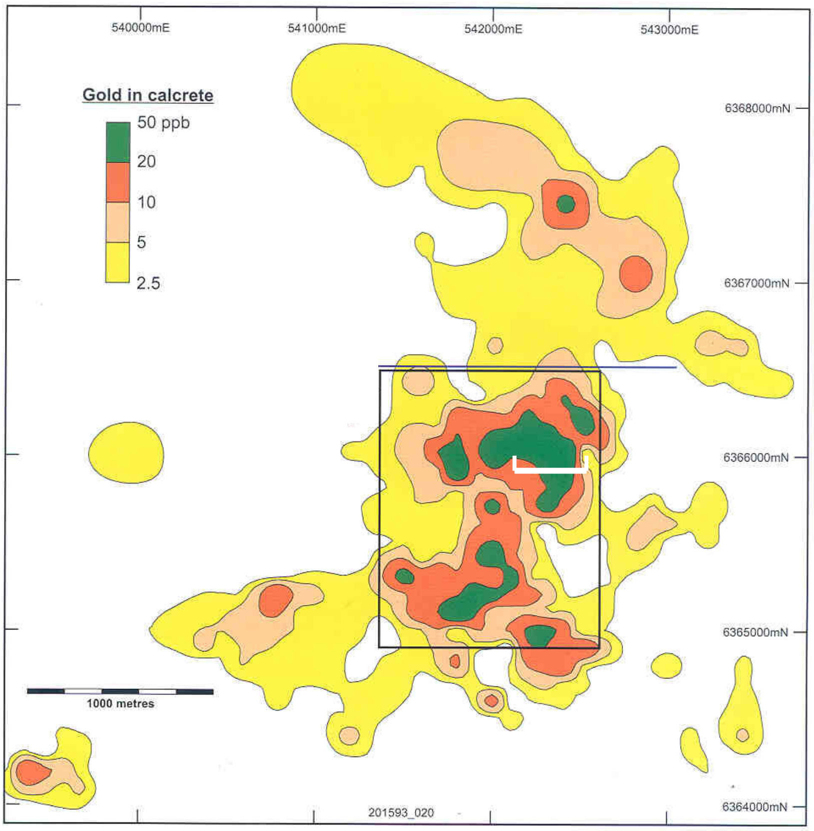


Figure 5: Barns Au Prospect, Au-in-calcrete anomaly pattern (after Drown, 2003).

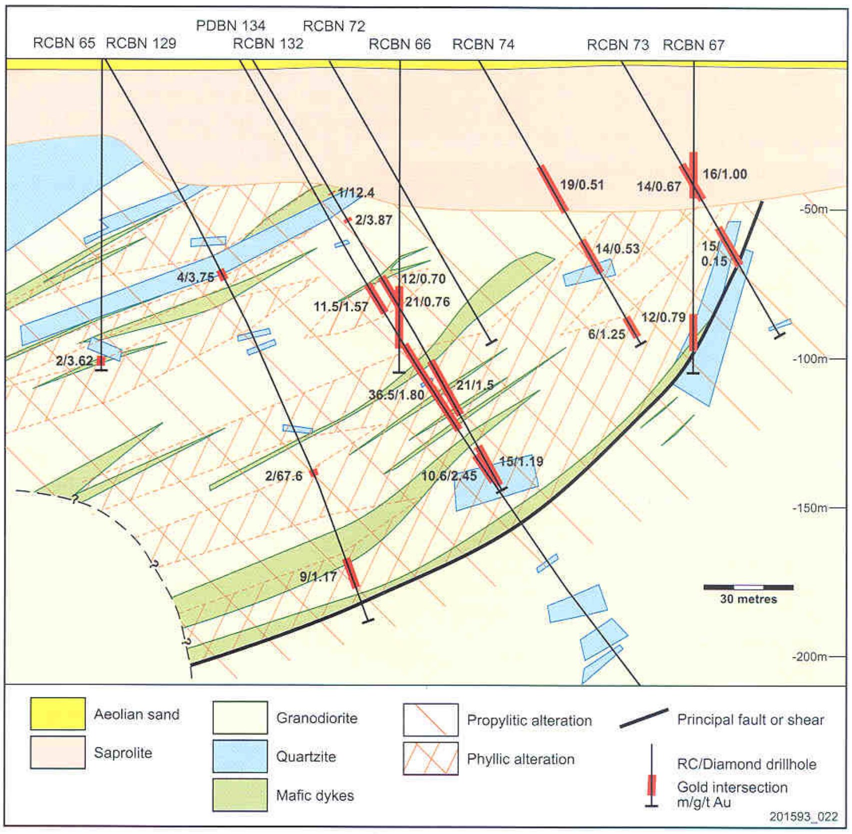


Figure 6: Barns Au Prospect, E-W cross-section along white-line in Figure 5 above. Drillhole Au intersections are marked in red (Drown, 2003).

Barns plus Baggy Green prospects, including Weednanna prospect to the east, along with the mid 1990's more northerly discoveries of Nuckulla Hill plus the Tunkillia gold prospects, which together with historic Tarcoola and Glenloth Goldfields; describe a new Proterozoic gold arc called the "Central Gawler Gold Province" (Budd, 2002; Ferris and Schwarz, 2003; Adelaide Resources Ltd 2003; Drown, 2003). A metadata catalogue—directory of information and data resources for Central Gawler Gold Province has been assembled by Thomas (2004).

The regolith study reported herein aimed at: – "*assisting development of technically efficient procedures for mineral exploration through a comprehensive understanding of regolith and landscape evolution, and their influence on the surface expression of concealed mineralization*".

Location and Landforms

The Study Area centroid lies ~25 km north of Wudinna, ~25 km east of Minnipa, ~37 km NNW of Kyancutta and ~100 km WNW of Kimba on northern Eyre Peninsula (Figures 1-3, 7). Two adjoining map sheets at 1:20,000 scale were produced covering an area of ~445 km^2 (19 x 23.45 km) within the following grid coordinates (GDA 94, Zone 53 I, 528000 to 551447 mE and 6358000 to 6377000 mN).

Relief for most of this area is generally subdued (locally <15 m) but regionally can be more varied (max ~200 m) where the highest points are on the flanks of Mt Sturt (~300 m AHD and just N of Map A northern edge). Large ephemeral playas form depositional lows at ~100 m AHD, and the largest of these (northern) has its floor ~30-45 m below the surrounding terrain. Overall the regional terrain slopes gently southwards from the Gawler Range highlands (N of mapped area). This terrain expresses a marked landform grain composed of abundant longitudinal dunes with associated sand plain, punctuated occasionally by granite inselbergs (whaleback or dome and tor outcrop) or saprolith and associated—derived soils. In the north, the Gawler Ranges form an elevated highland landform where the abrupt rise imposes an orographic variance to wind directions and rainfall. Dune patterns near this elevation change are complex, typically anastomosing or serpentine in plan view, and possibly taller in stature than dunes further south. An ~EW oriented landscape low forms a subtle valley complex through Pinkawillinie Conservation Park (map area's SE quadrant) and is likely to be part of the more extensive NW-SE oriented Corrobinnie Depression (occupied by the Narlaby Palaeochannel or associated tributary). That depression encloses an area where anastomosing festoon dunes and associated sand plain patterns are distinctly different from those on surrounding terrains. Moreover, the buried Yaninee Palaeochannel produces a similar valley-like depression in the mapped area's SW quadrant with salinas, claypan playas and associated lunettes occupying the lowest portions. Regolith profiles are accessible via moderate erosional incisions in deeply weathered basement, or in road cuttings and borrow pits, and through exploration drillhole samples in a few mineralized areas.

Access and climate

Access is from the sealed Eyre Highway and a variety of both sealed or unsealed roads, farm and State Park tracks. Vehicle access to some areas of the Parks is not possible and those areas were reached on foot. Drill data are limited to areas where exploration tenement holders have permission to drill and sample, and exclude areas subject to Aboriginal heritage or of cultural significance.

This region is semi-arid mallee–heathland with a relatively dry hot Temperate climate (Stern *et al*., 2000) where cereal and livestock farming occupy most of the cleared freehold land (Figure 7). Annual rainfall ranges between ~320-340 mm with an annual evaporation rate estimated to be 2250 mm. In some years there is significantly less rainfall and more evaporation (Bureau of Meteorology, 2004). Summers are generally hot and dry while the winters are typically cool. Rainfall occurs mostly between April-October (Schwerdtfeger, 1985; Griffin and McCaskill, 1986).

Native vegetation

Native vegetation is well preserved within the Gawler Ranges National Park and Pinkawillinie Conservation Park (Figure 7); genera are aridity and moderately salt tolerant. Most of the areas outside the Parks have been largely cleared for agriculture, exceptions being tall steep-sided dunes, saline playas and rocky areas or sites prone to seasonal heavy equipment bogging. Remnant native vegetation is also retained along many road verges and some Crown or District Council Reserves. A complete botanic inventory of all genera or species for the mapped area was beyond the scope of the project.

However, the more notable vegetation types are set out below and have been cross checked against Rutsche and Lay (2003) and Lange and Lang (1985).

Figure 7: Satellite image covering the Study Area (outlined). Scene was captured during winter when this semi-arid fringe area receives most of its annual rainfall. A large unnamed ephemeral salina-playa dominates the scene at top centre, and a large ephemeral playa complex occupies the SW corner, both areas in this scene have pans containing some water (blue-grey patches). The Quaternary dune pattern (trending ~WNW-ESE) is most evident within cleared farm paddocks, although the larger dunes can still be seen through remnant natural open woodland vegetation. Native vegetation remains mostly undisturbed within the Pinkawillinie Conservation Park and Gawler Ranges National Park boundaries. Image courtesy: *Google Earth 2006 / TerraMetrics 2006*.

Substantially this is—was a district of sclerophyll open woodland and heathland, where trees are dominated by mallee (multi-stemmed) eucalypt scrub to 5 m and rarely 6-7 m stature (principally *Eucalyptus incrassata* subspecies *incrassata*, *E. socialis, E. oleosa, E. dumosa* and *E. gracilis*. Plates 4-6). Where interdune corridors occur, larger stature eucalypts remain within some road verge reserves but larger stature trees become more numerous on the flanks of Mt Sturt (*Eucalyptus foecunda* and *E. flocktoniae*). Some playa fringes have well established groves of paperbark trees to 4 m (*Melaleuca glomerata*). These can have trunks >40 cm diameter and tolerate very salty soil conditions. Common shrubs to <3 m in stature are dominated by broom bush *Melaleuca uncinata* but at least two other similar growth habit *Melaleuca* ssp. were noted. A number of *Acacia* ssp. were observed in both sandy and clayey soils but due to a lack of available flowers at the time of mapping, none were identified to species level. Rarer shrubs of 1-3 m stature include *Beyeria leschenaltii* (turpentine bush), *Eremophila alternifolia* (emu bush), *Santalum acuminatum* (quandong), *Dodonaea angustissima* and *D. lobulata* (hop bush), the Proteacea – *Hakea francisiana* and *Grevillea hueglii* + *G. nematophylla* were also observed. Sandy and well drained rock scree to skeletal soils are commonly vegetated by clumps of spinifex (*Triodia irritans* and *T. scariosa*) while sand plain and more clayey areas have a diverse native to exotic grass cover that typically includes various introduced weed species – now invading the uncleared Reserves and Parks. Playa fringing sandy terraces to marshland areas support a wide variety of both phreatophytic and/or halophytic shrubs, forbs and creepers (including bluebush *Maireana sedifolia*, *M. pyramidata*, and saltbush *Atriplex stipitate*, *A. vesicaria*). The bright purple flowering fleshy leaved ground covering 'pigface' creepers (*Disphyma crassifolium* and *Carpobrotus modestus*) can be common along playa fringe terraces.

Plate 4: Pinkawillinie Conservation Park vegetation, dominated by mallee scrub (*Eucalyptus* spp.) with many understory shrubs and forbs. This view is westwards from the Baggy Green gold prospect area. Sand dune undulations are apparent. The orange sandy ground has been exposed, centre view, by temporary exploration access track construction. April 2005.	
Plate 5: Pinkawillinie Conservation Park flora; the foreground is dominated by broom bush *Melaleuca uncinata* growing where a patch of ferruginous gravel derived from an underlying collapsed megamottle horizon (pedolith) has been exposed by deflation. Near the Baggy Green gold prospect centroid. In the background where sand plain and thin dunes occur are taller mallee trees and scrub (*Eucalyptus* spp.). View is southwards. April 2005.	
Plate 6: Open mallee woodland covering an island of gently undulating Orange Sand plain enclosed by cleared agricultural land, north of Agars Lake. This area is dominated by a N-S string of small playas where both gypsum and halite encrust clayey floors. Aeolian sands are invading those playa floors in several places. Soils here are sodic and have potential to become locally salinised. Tree clustering may reflect locations of less saline soil. Sept. 2004.	

Work Program

The mapping style and methodology developed and used by the author during CRC LEME's *Harris Greenstone Belt Regolith Studies* (Sheard and Robertson, 2003, 2004) was to be utilised and expanded upon for this new mapping study. The area to be selected needed to have proven Au-in-calcrete anomalism and associated drilled Au-mineral intersections. In addition, it should not have previously been mapped by regolith methods. Unrelated field inspections by the author during 2002 and 2003 had demonstrated that the area most suitable for regolith landform mapping included the Barns and Baggy Green gold prospects. Work commenced in 2004 and continued to late 2006.

Preliminary site access requirements, data searches and acquisition of suitable aerial photography began in the first half of 2004. Portions of the Gawler Ranges National Park and Pinkawillinie Conservation

Park together occupy ~40% of the selected Study Area (preserving crucial interpretive outcrop sites, soils and natural biodiversity). Entry permission for mapping purposes to those Parks was given by the District Ranger and Regional Environmental Officer. Access clearance to active exploration tenements held by Adelaide Resources Ltd was sought and granted by August 2004. Mapping commenced in September 2004 and aimed to: establish regolith assemblages, determine depths of cover, describe regolith components and landforms, establish reference regolith profiles and to assemble evidence for understanding and modelling of the landscape evolution for this area.

Follow-up work in conjunction with M.J. Lintern (CSIRO Exploration & Mining, Perth) was undertaken in April 2005. Laboratory studies of samples and office based map compilation followed. There has been no similar comprehensive regolith mapping study over this part of Eyre Peninsula. Recent investigations within this area include: an Honours project over a single ~1 km long transect for regolith influences on biochemical signatures (Mayo and Hill, 2005), a PhD biogeochemical research project on vegetated dune sand above mineralized substrate at the Barns Au prospect (Lintern, 2004b and 2005), and regolith geophysics near mineralized basement over the SE corner of the Study Area (Joseph *et al*., 2005).

Methods

Mapping and Sampling

Regolith boundaries were mapped in the field directly onto nine 1:15 000 scale colour air photograph hard copy enlargements, derived from original digital colour air photography (1:42,670; surveys 5863 & 5864 flown 19/09/2000). The air photographs and Regolith Landform Map cover part of the YARDEA 1:250,000 topographic map, spanning portions of Yaninee (5932-2) and Wudinna (6032-3) 1:50,000 topographic maps.

Mapping and gathering of surface information was from traverses on foot and by vehicle; locations were obtained by hand-held GPS (all coordinates quoted herein are in the GDA94 format). Surface sampling, excavation of soil profiles by shovel or trowel-spatula, use of drill chip logging, surface photography and air photograph interpretation, together augmented this work. No sampling occurred at sites of cultural or tourist significance. Colour standards of Munsell (1975) plus Kelly and Judd (1976) provided useful references and guidance for sample descriptions in the field and laboratory contexts. Geological mapping principles were used within a regolith and geomorphic landform context. Regolith polygons, sample points and item tags were marked on the airphoto enlargements in the field. The area mapped covers a wide variety of regolith materials, including weathered granites, associated basement, soils and various transported cover materials. Depth information has been included from exploration company drillhole data, District Council borrow pits and natural exposures. Regolith cross-section construction involving substantial vertical exaggeration followed the principles set out by Rod (1974). A detailed explanation of the map sheets is given below under Regolith Landform Map Explanatory Notes. The final maps were compiled in Adelaide by PIRSA's Spatial Information Branch (Sheard, 2007 in Volume 2, Appendix 6).

Sample treatment and analysis

Photography and Microscopy

Sample examination under magnification in the field employed standard hand lenses (10x + 15x), and in the laboratory a binocular microscope was used (16x, 25x, 40x, 63x & 100x). Selected samples were sawn and sent to Pontifex & Associates (Adelaide) for thin-section and impregnated polished block preparation. Subsequent petrographic observations and descriptions were performed by the author using an in-house Zeiss 'Jenapol' petrological microscope.

Photography in the field and laboratory involved a standard 35 mm camera with zoom lens, using 100 and 200 ASA colour slide film. Selected frames were then scanned with a Nikon LS-2000 slide scanner to produce high resolution digital images. Chiptray photography involved laying selected chiptrays on a purpose-built jig (max of 5 drillholes and <80 m of sampling per image) and the jig angled to facilitate maximum natural daylight illumination. Rock slab photography involved lightly oiling the sample's cut surface, then with an added scale bar, each was scanned at high resolution using a colour digital paper–image scanner.

Photomicrographs of selected thin-sections were taken using a microscope attached digital camera and magnification settings to suit the selected objects. Photomicrographs of opaque clasts within one polished block mount were made by Pontifex & Associates. A petrographic reflected light microscope with attached camera were employed for this work and the images scanned to digital files.

Geochemical analysis

Geochemical sampling and analysis was not included in the scope of this project. However, calcrete assay geochemical data obtained by Adelaide Resources Ltd (current tenement holders of this area) were provided to the author for use with this study. Additional data discussed herein covering the Barns Au prospect are drawn from the work of Lintern (2004a, b) plus Lintern and Rhodes (2005). Plots of selected assay data are given in Volume 2, Appendix 2, from the complete data set provided on the Report CD-ROM. Descriptions and interpretations appear in the Geochemistry & Interpretation section of this report.

PIMA infrared spectral analysis

Selected sub-samples from various sediments and *in situ* weathered materials were air dried and powdered in a mortar and pestle prior to analysis by Portable Infra-red Mineral Analyser (PIMA). Samples still containing too much moisture for interpretable PIMA spectra, were then oven dried to remove excess moisture. Clay and other mineral species present were determined by a visual inspection of individual spectral absorption curve features and comparison with the Ausspec International "The Spectral Geologist" (TSG) mineral library spectra. Reference was made also to data contained within Pontual *et al*.(1997). All primary spectral curves and data are located in Volume 2, Appendix 3. Selected spectral plots and descriptions appear in the PIMA Analysis section.

Regolith in Profile

Regolith terminology used herein follows that of Eggleton (2001), Robertson and Butt (1997), Robertson *et al*. (1996) and Butt and Zeegers (1992), refer to Figure 8. Regolith landforms encountered in the Wudinna north area encompass a wide range of weathered *in situ* items, numerous sediments and noteworthy soils. Full section regolith profile exposures are not abundant but the application of regolith architectural associations to limited exposures and/or partly eroded profile segments has provided additional useful information. Road-track cuttings, roadside borrow pits and quarries, natural erosional escarpments, exposures via biological activity (burrows, tree-throws, *etc*.), and exploration drilling have aided the four dimensional interpretation and modelling. An account of the numerous regolith materials follows, where the oldest are described first and the youngest last.

Relict Class

The term relict, as used herein and on the accompanying maps (Sheard, 2007 in Volume 2, Appendix 6), follows that used by Sheard and Robertson (2003, 2004) and means "*remnant (residual) basement (fresh or weathered) lying within a broader area of younger, transported cover or erosional terrain*". A major portion of basement outcrop and subcrop in the Study Area is deeply weathered (*in situ* residuum), some has been partially to significantly eroded, some has been buried by later sedimentary activity, or that in current outcrop may be actively eroding today. Most if not all of the outcropping relatively fresh crystalline basement has been exhumed from below the weathering front by Late Cainozoic landscape sculpturing processes.

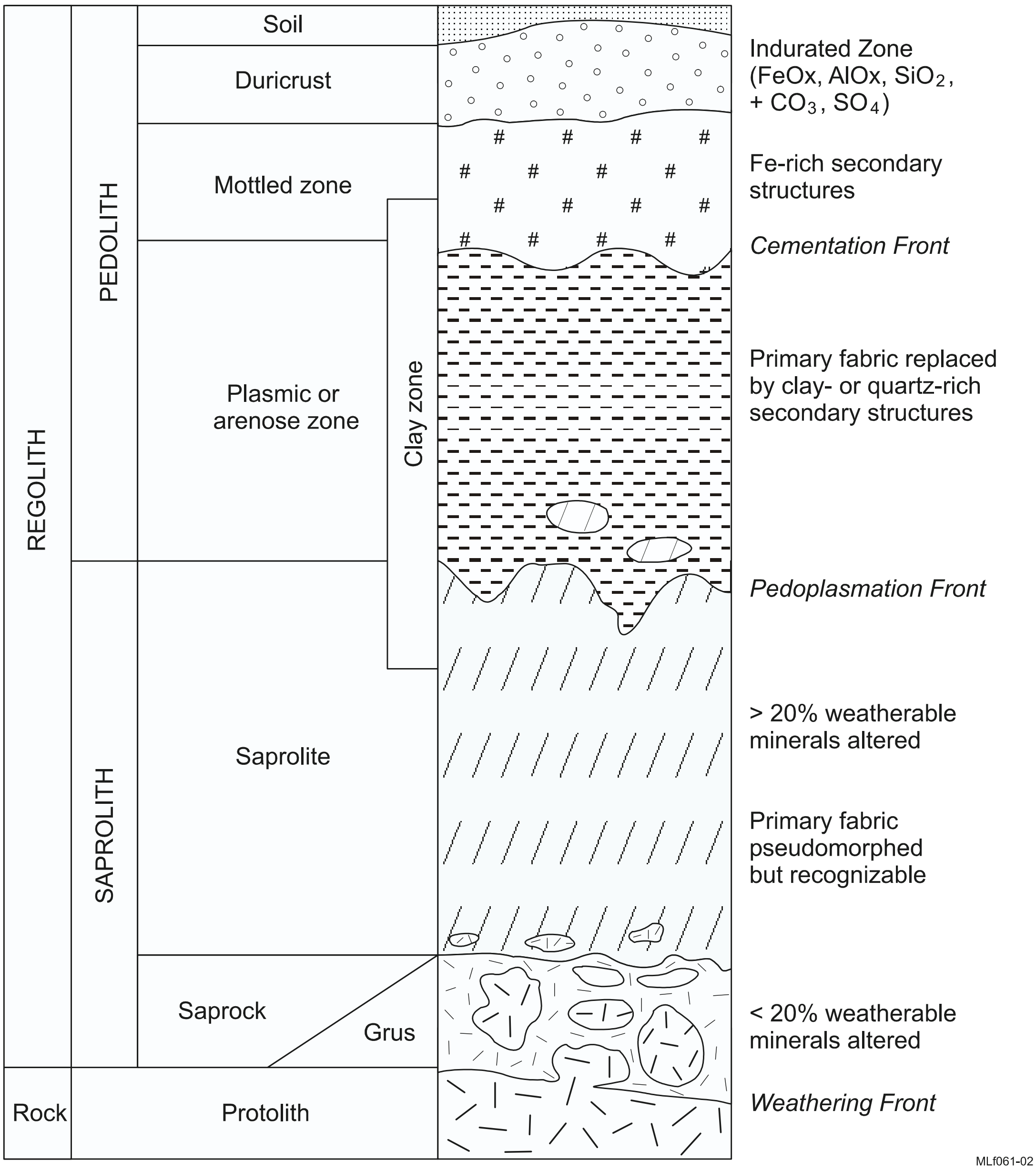
Protolith

Protolith is a general term for parent material from which the regolith is formed (Butt and Zeegers, 1992; Eggleton, 2001). Protolith therefore includes crystalline basement and sediments; but as a regolith term used herein (and by Sheard and Robertson, 2003 & 2004), **protolith** is applied only to the parent crystalline basement.

Regolith deriving from protolith is said to have formed *in situ* even where some vertical profile collapse may have occurred but where lateral movement has been minimal. By definition protolith can contain up to 5% of weatherable minerals altered by weathering processes, and is commonly referred to as 'fresh rock' or 'bedrock' or 'basement' (Robertson and Butt, 1997, Anand and de Broekert, 2005).

Sleaford Complex

The oldest rocks known to occur in this area is the undifferentiated Archaean Sleaford Complex metasediments, meta-intrusives and metavolcanics, – all highly deformed and of granulite facies metamorphic grade (refer to: Daly and Fanning, 1993; Schwarz, 2003: Fanning *et al*., 2007). However, these rocks do not crop out within the mapped Study Area, nor on the enclosing two 1:100,000 map sheet areas. A subsurface indication for these rocks in the far SE corner of the Study Area is inferred from the regional aeromagnetic data, where a subdued magnetic signature exhibits a multiply parallel banded sequence. Calcrete trace element assays for As and Ni also indicate the presence of this metasediment at depth (see later sections). Recent work by Joseph *et al*. (2005) using ground electromagnetic profiling has confirmed a subsurface contact with younger intrusive Tunkillia Suite (orthogneiss). Direct evidence for the subsurface weathering depth and regolith zones expressed by this sequence in the Study Area is limited. Drown (2003) reports on RAB drilling intersections near the western boundary of the Sleaford Complex, which revealed lithotypes similar to those described for the Hall Bay Volcanics by Teale *et al*. (2002) from a linear north-south belt further south on Eyre Peninsula.



(Adapted from: CRC LEME - Atlas of Weathered Rocks 1997, Open File Report 1; CSIRO Division of Exploration Geoscience, Report 390, 1st Revision.)

Figure 8: Generalised Regolith Terminology after Robertson and Butt (1997) modified slightly to better represent South Australian regolith.

Tunkillia Suite

Most of the protolith—saprolith outcrop and subcrop in this area consists of Tunkillia Suite foliated granitoid forming gneissic small whaleback and dome inselberg to low tor landforms in the eastern half of the Study Area (landform symbol: **RgP2**). Ferris and Schwarz (2004) provide a regional definition for this Suite. Tunkillia Suite granite to granodiorite (orthogneiss), exposed at Little Pinbong Rockhole and also near the large playa (SE end) consists of highly deformed medium- to coarse-grained, pinkish-grey orthogneiss. Primary mineralogy consists of plagioclase, K-feldspar phenocrysts, quartz and biotite, with accessory apatite, allanite, magnetite and zircon. Deformation has produced fine-grained dark grey banding within parts of the gneiss, where remnant phenocrysts-porphyroblasts are rare. This rock is commonly cross-cut by folded quartz veins or stockworks and by less folded pegmatite and aplite veins (Plates 1, 7 & 8). Tunkillia Suite orthogneiss, as protolith, has exposure resulting from erosive processes stripping away overlying and surrounding pedolith and saprolith, leaving protolith as whaleback, tor and low dome landforms. Tunkillia Suite contains the quartz-sulphide vein-hosted gold at Barns and Baggy Green gold prospects (Drown, 2003).

Primary age, determined by U/Pb zircon dating of the granodiorite at Little Pinbong Rockhole has yielded a $^{207}Pb/^{206}Pb$ magmatic age of 1,669±13 Ma (Palaeoproterozoic; Fanning *et al*., 2007).

Hiltaba Suite

Occurring dominantly in the western half of the Study Area, Hiltaba Suite granite protolith—saprock forms scattered minor outcrop and subcrop as: whaleback to dome inselberg, tor and low platform landforms (landform symbol: **RgP1** and Plates 9-11). Hiltaba Suite granites are anorogenic, they intrude Tunkillia Suite orthogneiss as large batholithic plutons that are typically massive to occasionally weakly foliated. This granite locally is pink to pinkish grey (regionally it can be redder), medium- to coarse-grained, and has the following mineral assemblage: K-feldspar, quartz, biotite, ± hornblende, ± plagioclase, and with accessory minute haematite grains, apatite, and zircon (Plate 12; Parker and Flint, 2006). Cross-cutting quartz veins and minor pegmatite or aplite veins may be observed at some localities. Hiltaba Suite granite, as protolith, has exposure resulting from erosive processes stripping away overlying and surrounding pedolith and saprolith, leaving protolith as whaleback, tor and low dome landforms.

Primary age, determined by U/Pb zircon dating at numerous localities across the Gawler Province has yielded a general emplacement time of ~1,590±10 Ma (Mesoproterozoic; Fanning *et al*., 2007).

Gawler Range Volcanics (felsic volcanics and dykes)

Outcropping only in the far central northern part of the Study Area, Gawler Range Volcanics occur as porphyritic dacite (landform symbol: **RvP1**) to form the peaks of Mt Sturt. There flows ± volcanic breccias present as protolith to saprock. Lithologically it is a highly porphyritic dacite, of a dark greyish brown, and where mechanically eroding there can be a surficial fragmentary gibber-lag or talus of the parent lithotype.

Gawler Range Volcanic equivalents, as undifferentiated intrusive felsic dykes (landform symbol: **RvP2**) occur in Tunkillia Suite granitoids (deeply weathered) exposed at the SE corner of the large northern playa. Most are weathered to pallid saprolite (see Saprolite section) but one large dyke appears relatively unweathered (Plate 13) however, under high magnification this rock has much of its original vitric matrix (glass) highly altered to sericite ± kaolinite (see Petrography section). Dominantly aphanitic to mildly porphyritic, of rhyodacite composition, these rocks are dark greyish brown (fresh) to greyish or pallid when highly weathered, and may present with a surficial fragmentary gibber-lag apron of parent lithotype.

Gawler Range Volcanics have a U/Pb zircon age range of 1,591±3 Ma to 1,592±3 Ma (Mesoproterozoic; Fairclough and Schwarz, 2003). Fanning *et al*. (2007) report weighted mean ages ranging from 1,604±12 Ma to 1,583±12 Ma for felsic dykes and a porphyry, southern Central Gawler Province.

Quartz Veins

Quartz veins as significant blows, dykes and stockworks occur within both Tunkillia Suite and more rarely within Hiltaba Suite granitoids (landform symbol: **RqP-**). Quartz usually does not weather, rather the veins persist but collapse or dislocate when the host rock weathers, therefore the veins are considered herein as being protolith only. All appear to be of the siliceous hydrothermal fracture infill type. Typically they are white to pale grey but may be surficially stained pink, orange or brown by FeOx–FeOH minerals within a weathering profile (Plate 3). Veins may stand well proud of weathering or eroding host rock, and the host outcrop is usually surrounded by a surface apron of quartz scree-talus. Several generations of veins are apparent, where some are parallel to foliation while others cross-cut it, some being folded and some not. Vein widths range from <1 mm up to ~3 m, and can be a few metres to >50 m long. Stockworks were observed in several locations (especially in outcrop along the Paney Road north of Little Pinbong Rockhole) and some have a multi-branched 'antler' form.

Age, coeval with granite emplacement-crystallisation and during regional tectonic–deformational activity.

Saprock

Saprock is rock in an early state of weathering, where 5-20% of the weatherable minerals are altered. In the Study Area saprock, as outcrop, is a very minor component and tends to occur as a narrow rind or halo-zone rimming protolithic outcrop and subcrop. However, within thicker *in situ* regolith profiles (>50 m) this zone may make up an horizon <1-~18 m thick (commonly ~2-10 m) near the weathering front (*c.f.* Regolith Profile Sections A-B + C-D on the Regolith Landforms Map A in Volume 2, Appendix 6).

Captions to Plates on the following page.

Plate 7: Tunkillia Suite granodiorite outcrop at Little Pinbong Rockhole, displaying intense foliation, folded bands and cross-cutting pegmatite veining. Hammer scale is 300 mm long.	**Plate 8**: Tunkillia Suite granodiorite at a more extensive tor and dome outcrop near the large northern playa. Intense foliation, folded bands and cross-cutting pegmatite veins are apparent. Hammer scale is 300 mm long.
Plate 9: Poondana Rocks, an exhumed whaleback inselberg of Hiltaba Suite granite, here surrounded by wheat fields. View is towards the east, this elongated exposure is ~270 m long and ~150 m wide.	
Plate 10: Poondana Rocks viewed end on, to demonstrate the elongated dome pair, view is southwards. The saddle area exposes remnant saprock to saprolite and accumulated aeolian soil.	**Plate 11**: Poondana Rocks, east side displaying rillen on the steeper face. Foreground comprises a well vegetated lee side sand dune implying a dominant wind direction from the WSW.
Plate 12: Slab section through Hiltaba Suite granite. Essentially undeformed, K-feldspar-plagioclase-quartz-biotite-hornblende. Sample R977107 from small low bench-like outcrop N of Poondana Rocks.	**Plate 13**: Slab section through banded rhyodacite of the GRV intrusive felsic dykes exposed on the SE shores to the large northern playa (sample R977106).

Plate 7

Plate 8

Plate 9

Plate 10

Plate 11

Plate 12

Plate 13

Saprolite

Saprolite is rock in an advanced state of weathering, where >20% of weatherable minerals are altered and where rock competence is low enough to break easily with a single hammer blow. It typically retains relict primary texture and metamorphic fabric because the weathering alteration is essentially isovolumetric (Eggleton, 2001). In the author's experience a great deal of saprolite in South Australia typically has a pallid or highly leached upper portion (Plate 3). In the Wudinna north area this pallid portion can be seen at numerous retreating escarpments in eroding terrain where weathered basement is being actively exposed. Within un-eroded *in situ* weathered profiles this leached portion may make up an interval ~12-~60 m thick (commonly >15-~35 m) where the pallid portion typically consists of two thirds to three quarters of the entire saprolite (*c.f.* Regolith Profile Sections A-B + C-D on the Regolith Landforms Maps in Volume 2, Appendix 6). There are a number of distinct saprolites recognised in the Study Area, they are listed below in a similar order to their respective protolith parent material, although no chronologic weathering order is implied.

Highly weathered foliated granite (landform symbol: **RgS2**; *c.f.* RgP2 & RgS1): saprolite retains remnant primary texture and foliation, the upper portions are typically Fe-megamottled and/or are stained dark red, red, orange or yellow-brown (Plate 3). Incipient silicification may occur at the top as a form of outcrop case hardening or where more completely developed it can form a massive silcrete cap (see Duricrust section). Mineralogy is generally: coarse-grained quartz grit + kaolinite ± FeOx ± folded white to greyish quartz veins and stockworks. Weathered Tunkillia Suite orthogneiss.

Weathered mafics (landform symbol: **RbS1**): occurs in isolated very small outcrop around the large northern playa and consists mostly of dark green to green-grey to dark brown and near black dolerite ± basalt. Remnant amphiboles and plagioclase can sometimes be observed along with the more obvious hydrothermal alteration minerals: chlorite ± epidote ± actinolite. Weathering products include: smectite ± kaolinite ± goethite. Banding–layering may be present and a remnant foliation is occasionally exhibited. Variably ferruginous near upper surfaces where thin massive to mammillary goethitic caps have developed at some localities (dark brown to yellowish brown).

Highly weathered granite (landform symbol: **RgS1**; *c.f.* RgP1 & RgS2) material retains remnant primary texture and a weak foliation, the upper portions are typically reddish to orange and yellow-brown Fe-mottled and/or stained. This material is rare in outcrop but is known from subcrop in excavations and drillhole intersections. Incipient silicification or a calcrete hardpan may occur at the top surface as a case-hardening feature. A pale hued medium- to coarse-grained material dominated by quartz + kaolinite ± FeOx ± white to grey quartz veins. Weathered Hiltaba Suite granite.

Gawler Range Volcanics, felsic dykes (undifferentiated; landform symbol: **RvP2**). This item has been described above under Protolith, however, most of these dykes are exposed in the saprolite zone where they are weathered equally to their host granitoid (Plate 14). Dominantly aphanitic, these dykes present as a quartz + kaolinite ± FeOx saprolite, typically they are <1 m thick and <100 m long. Some 'snake-head' dyke terminations are displayed in the eroding outcrop platform at the big northern playa (SE corner; Plate 15). Megamottling and Fe-staining are typically less than within the weathered host granitoid. Weathering time frame is Mesozoic to Cainozoic with a Quaternary exhumation time.

Megamottles

According to Eggleton (2001) mottles are segregations of a subdominant colour that is different from the surrounding dominant material's colour. In regolith, mottles can have sharp, distinct or diffuse boundaries. They typically range in size from 10-100 mm, but may reach several metres in size—whereupon the term megamottle is used. Megamottles are generally >200 mm across and in the Study Area commonly consist of haematite-rich and goethite-rich segregations displaying strong colours (Plates 16-22).

In the 'Lateritic Profile' model of Robertson and Butt (1997) and Eggleton (2001) a 'mottled zone' is commonly developed within the pedolith where pedogenic processes overprint all pre-existing textures and replace metamorphic foliation with a pedogenic fabric. Anand (2005) and Anand and Paine (2002) demonstrate that some mottling can also develop within saprolite. In such cases, weathering has been near iso-volumetric and therefore those megamottles commonly exhibit little to no loss of primary rock texture or metamorphic foliation (see later Petrography section).

Megamottles appear to be widespread over the Gawler Province, and those horizons are commonly expressed within the upper highly leached portions of saprolite or are part of the pedolith. Arguments have been put forward by a number of regolith scientists that extensive megamottling implies a long-term saturation of the weathering profile via an overlying active fluvial channel, swamp, lake or even by marine incursion. But the regional extent of saprolite hosted megamottling across the Gawler Province seems to defy many of the more localising models, while the dearth of marine sediments (remnant or otherwise) in the Wudinna north area may also preclude a marine incursion mechanism too. Therefore this phenomenon in South Australia remains enigmatic and requires more research to adequately explain.

In the Wudinna north area megamottles seem to be restricted to weathered Tunkillia Suite orthogneiss. However, surficial exposures of saprolitic Hiltaba Suite granite are very limited by comparison, and so megamottling within Hiltaba Granite derived saprolite cannot be precluded. Outside of the Study Area, megamottled saprolitic Hiltaba Suite rocks have been observed by Parker and Flint (2006). Conventional mottling of saprolitic Hiltaba Suite was rarely observed and, where exposed, seems never very pronounced, although, recognisable mottling is more common in the pedolith zone. Within un-eroded *in situ* profiles megamottles may form a colourful horizon ranging over ~2-~10 m thick (commonly 2-5 m) within the upper saprolite. Post development, well cemented or indurated megamottles can coalesce via profile collapse to form a collapsed megamottle horizon or capping (see below). Silicified megamottle horizons within highly weathered Tunkillia Suite rocks were observed in this area, these can form colourful silcrete (see Duricrusts section). That relationship implies mottling occurred prior to the massive silicification phase or phases that yielded extensively developed silcretes recognised elsewhere in South Australia. Those have had timings established (based on basinal stratigraphy and K-Ar dating evidence elsewhere) as occurring during the Palaeogene and early Neogene (Benbow *et al*., 1995b, Thiry and Milnes, 1991).

Pedolith

Arenose and Plasmic zones (horizons) were encountered during the field studies but are not represented as discrete entities on the Regolith Landform Maps because they are generally quite thin and tend to present only in vertical outcrop. Arenose and/or plasmic horizons occur above the Pedoplasmation Front (Figure 8), above saprolite and, when present, they form the basal pedolith. Both zones are not possible to recognise from drill cuttings and so could not be portrayed on the Regolith Landform Map cross-sections.

Arenose Zone, this is a grit (sand) dominant horizon with a grain supported (or nearly so) pedogenic fabric. All or most fines have been removed, probably by low pH solutions, leaving a collapsed profile with no primary fabric or texture remaining (Robertson and Butt, 1997). At several locations this zone has later been selectively silicified to a dense silcrete (see samples R977102, 103, 117 in Petrography section). Thickness range is <0.1 to <1 m.

Plasmic Zone, forms a massive clay or silty clay horizon, where mesoscopically there appears to be only a homogeneous plasmic fabric, and this is developed over rocks poor in quartz. These horizons have been created by solution and authigenesis reactions on weathering minerals, and by various mechanical processes affecting the resultant clays (shrinkage, swelling and settling; Robertson and Butt, 1997). Rarely observed in the Study Area because most crystalline basement protolith has abundant quartz grains, however, some of the finer grained bands within Tunkillia Suite orthogneiss have yielded intermittent plasmic horizons. Thickness range is <0.2 to <1 m.

Collapsed megamottle horizon (landform symbol: **RgQm**; *c.f.* RgS2 & RgQd): this distinctive pedolith horizon consists of Fe-rich megamottles that have been collapse merged through clay and fines removal around them during pedogenic and deflationary processes, which may have also involved low pH groundwater and/or aeolian mechanisms (see Landscape Evolution section). The fines-removal process leaves the more indurated Fe-rich megamottles, as ‘blocks’, coalesced with abundant residual quartz grit plus colluvium and alluvium derived and incorporated from the surface (*c.f.* Anand, 2005). Outcrop evidence suggests that a megamottle profile collapse of 25% to >60% is needed to achieve such a thick Fe-rich horizon (1-1.5 m). Incorporated exotic quartz clasts include: rounded to subangular sand-sized grains to granules and occasional gravel to pebbles; these have worked their way further into the profile from the original pedogenic surface by as much as 1-5 m via cavities left between megamottle blocks and by normal surface cracking (developed during seasonal aridity). The resultant collapsed megamottle horizon forms a very distinctive Fe-rich pedolith (Fe-duricrust) over much of the

Study Area's eastern half. It typically forms a distinctive surface armouring to a residual landscape, this can lead to escarpment development where erosion penetrates, then undercuts that armouring (Plates 3, 23-26; see Landscape Evolution section).

Thickness range is<0.5-1.5 m, where it can have an irregular basal contact with any arenose or plasmic zones or with any remaining un-collapsed megamottled saprolite. Mostly it is dark red to dark red-brown to brown but occasionally it is yellow-brown, and these hues tend to mimic the underlying saprolite megamottle colours. Haematite + quartz ± goethite ± minor kaolinite are the typical mineral assemblages represented. Collapsed or disrupted Fe-stained quartz vein remnants may also be present.

Silicification of collapsed megamottles was not observed and so it is possible for that collapse–deflationary process to post date the major silcrete episodes of early Palaeogene and mid Neogene (see Duricrusts section).

	
Plate 14: Megamottled upper saprolite developed in Tunkillia Suite orthogneiss where a felsic GRV dyke has intruded (centre frame, weathered dyke width <0.5 m). Dykes are less mottled than their host gneiss. SE corner, large N playa.	**Plate 15**: As per Plate 14, displaying snake-head termination to a greyish dyke. Megamottle pattern is seen in plan section. SE corner, large N playa, GPS: 0541753E, 6371408N. Notebook scale is 130 mm wide.

Captions to plates on the following page.

Plate 16: Red megamottles developed in leached saprolite at an erosional site E of the Paney Road. Hammer scale is 300 mm long.	**Plate 17**: Red megamottle highlighting thin white quartz veining in an otherwise near white kaolinite-rich saprolite. Site E of the Paney Road. Hammer scale is 300 mm long.
Plate 18: Maroon megamottle in near white kaolinite-rich saprolite, in plan section exhibiting embayment features. Eroding platform, SE corner large N playa. Pen scale is 140 mm long.	**Plate 19**: Dark red-brown megamottles and Fe-staining highlighting fracture-vein features. Site E of the Paney Road. Pen scale is 140 mm long.
Plate 20: 3D exposure of megamottled upper saprolite. View is west, megamottles up to 400 mm across. Eroding platform, SE corner large N playa.	**Plate 21**: Yellowish and reddish megamottles together in leached saprolite. Eroding platform, SE corner large N playa. Hammer scale is 300 mm long.

Plate 16

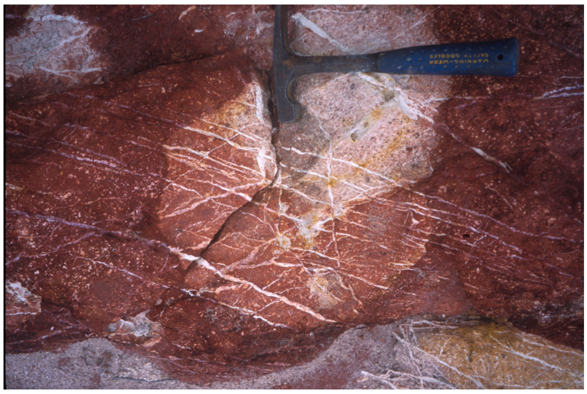


Plate 17

Plate 18

Plate 19

Plate 20

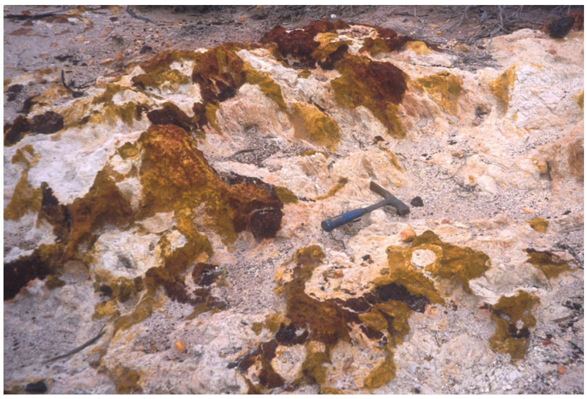


Plate 21

Captions to plates on the following page.

Plate 22: Reddish megamottles and ghosts thereof, where some have leached cores. Site E of the Paney Road. Hammer scale is 300 mm long.	**Plate 23**: Collapsed megamottle horizon capping megamottled saprolite. Eroding escarpment-shore line, SE corner of large N playa. Hammer scale is 300 mm long. (*c.f.* Plate 22)
Plate 24: Close-up of the breccia-like collapsed megamottle horizon in Plate 23. Material also contains significant hard bars (arrowed) where iron mineral re-cementation has occurred. Hammer scale 300 mm.	**Plate 25**: Collapsed megamottle horizon capping pallid saprolite. A solution pipe has developed into the saprolite (RHS) allowing FeOx-rich breccia to infill from above. Erosional site 2.6 km E of Little Pinbong Rockhole. Hammer scale 300 mm.
Plate 26: A detached megamottle from the collapsed megamottle horizon. The haematitic-quartz grit material is vuggy where less cemented portions have eroded out. Sample, from ~3 km NE of Little Pinbong Rockhole. (sample R977116).	

Plate 22

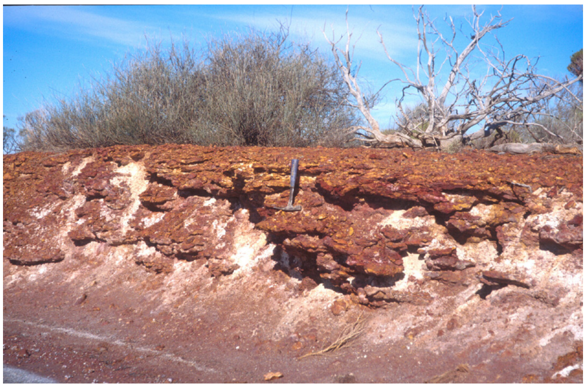


Plate 23

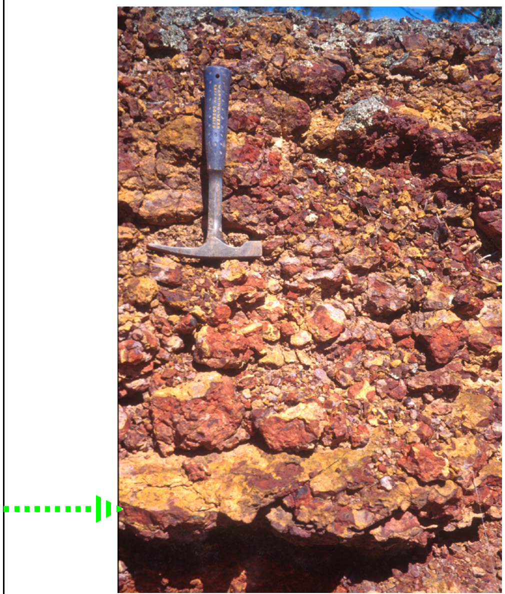


Plate 24

Plate 25

Plate 26

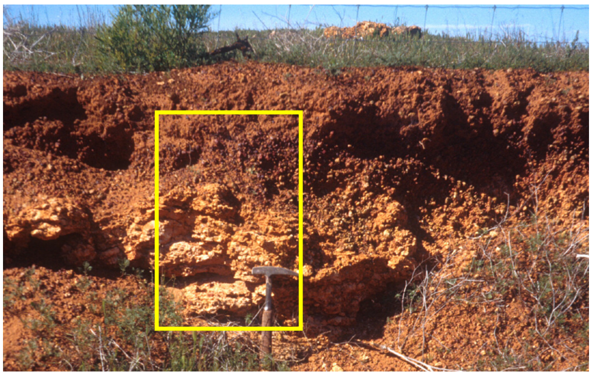


Plate 27: Ferruginous pedolith profile developed in extremely weathered Tunkillia Suite. Exposed in road-side borrow pit on a rise ~350 m S of Little Pinbong Rockhole. Yellow box outlines close-up of Plate 28. Hammer length 300 mm.

Plate 28: Close-up of Fe-fragment-rich profile in adjacent Plate 27. An eroding red-brown earthy grit soil (RgQe) + Fe-pisoliths occurs in profile upper 175 mm. Pale lower zone is a calcrete overprint (B_{Ca} horizon) developed within the Fe-rich gravelly collapsed megamottle lag horizon. Hammer length 300 mm.

Plate 29 (opposite): Brownish earthy grit (RgQg), pit exposure 660 m N of Poondana Rocks, extremely weathered Hiltaba Suite granite. Upper ~0.5 m is intensely calcrete overprinted, while the uncemented extensively weathered gruss below is weakly bound by clay-silt fines but remains quite porous. Nearer the protolith outcrop calcrete is absent from this same profile. White bar at base is 180 mm long.

Pisolitic Fe-pedolith (landform symbol: **RgQd**) highly weathered granite (*c.f.* RgQm): this landform is seen only on the eastern side of the Study Area. It forms an Fe-rich pisolitic horizon, ~0.3-1.0 m thick, capping the *in situ* weathered substrate. Pisolitic Fe-pedolith is dark red-brown to brown to dark brown or sometimes yellow-brown (Plates 27, 28). The haematitic-goethitic pisoliths (<1-8 mm diam.) formed *in situ* have well developed cutans, and this profile may contain Fe-stained relict vein quartz fragments. All primary texture and metamorphic foliation have been destroyed by pedogenic overprinting – forming a newer pisolith fabric. Where exposed or near surface, the top or an interval within may be calcreted, commonly incorporating numerous Fe-pisoliths (see Duricrust section). Observed only within extremely weathered Tunkillia Suite orthogneiss. This Fe-rich horizon may have an associated soil developed within its top 10-760 mm and that typically has a strong reddish colour. Eroding outcrop areas of this Fe-pedolith are locally referred to as 'red-ground'. Evidence for thin horizons of densely cemented haematitic-goethitic pisoliths was seen in fragmentary form only (see Petrography section) but these hint at long-term landscape stability during their formation (see Landscape Evolution section). Because this is an *in situ* developed pedolith horizon it may carry anomalous residual signatures to base and/or precious metals if the associated subsurface protolith has been mineralized.

This residual material may have been in-part or completely stripped in places by erosive processes, these are continuing to expose and erode this horizon. A commonly associated soil is RgQe (see below). Poorly to selectively vegetated, mostly by low stands of *Melaleuca* sp. (Plate 5).

Soils

There are four soils of note recognised within the Study Area. These have developed within *in situ* weathered materials and together cover a significant percentage of the uncleared and cleared land. All are pedolith components but for ease of recognition, and as distinct landscape elements, they are treated here under their own Soils section. Textural descriptions (*i.e.* sandy clay) follow those of Northcote (1979, pp. 26-28) but classification into a more formally recognised soil type has not been attempted here because there are many differing and/or conflicting classifications used in Australia and such designations are unnecessary for this study. Furthermore, some soil terminology used herein also derives from Eggleton (2001, pp. 39-44, 110-112).

Reddish earthy grit (landform symbol **RgQe**) pedolith horizon (*c.f.* RgS2 & RgQg): an Fe-stained earthy grit-sand, derived mostly from highly weathered granite (gruss), developed exclusively around Tunkillia Suite granite outcrop and subcrop. Red-brown to strong orange-red, with mineral components: quartz + haematite + clay (<15%). This soil is commonly ~2.0-<4 m thick and has an earthy pedogenic fabric formed *in situ*. However, this soil may also have a variable aeolian sand input (<15%) as it is commonly over-run by spaced longitudinal dunes or related sand plain. Nodular to earthy calcrete may be present as a noticeable B_{Ca} horizon. Where undisturbed this soil can be well vegetated by various tree, shrub and grass species.

Brownish earthy grit (landform symbol: **RgQg**) pedolith horizon (*c.f.* RgS1 & RgQm): an Fe-stained earthy grit-rich horizon developed exclusively around Hiltaba Suite protolith outcrop-subcrop. Typically reddish brown to strong yellow-brown, it contains quartz + kaolinite + haematite ± goethite and is ~1.0->2.0 m thick. Formed *in situ* within extremely weathered granite-derived gruss, this soil presents surficially as a dark orange loamy to sandy light textured soil (Plate 29). Fragmentary remnant vein quartz may be present at some sites. The near surface top may contain variably massive to earthy (B_{Ca} horizon). Where undisturbed this soil can be well vegetated by various tree, shrub and grass species.

Red-brown sandy clay (landform symbol: **RgQh**) pedolith horizon (*c.f.* RgQg): a clay-rich soil developed into saprolitic Hiltaba Suite granite. Dominantly red-brown gritty clay plus minor redder variants (Table 1). Mineralogy includes: clay + quartz + FeOx (clay <35%) and it is typically <2.0 m thick. Formed *in situ*, this soil has a pedogenic fabric displaying obvious peds, it usually has added aeolian sand (<15%) derived from the spaced longitudinal dunes that commonly cross its surface. Nodular to platy calcrete is usually present as a distinct B_{Ca} horizon. Where undisturbed this soil is well vegetated by various tree, shrub and grass species.

Reddish Loam (landform symbol: **R-Q1**) pedolith horizon: a deep red-brown to orange light sandy clay loam (15-20% clay) to clay loam (30-35% clay) a pedogenically active zone of >0.5-~1.5 m thickness. Developed mainly within transported substrate but may also overlie or be partly developed within a deeply weathered *in situ* substrate. Calcrete is usually present as nodules to platy or earthy forms (B_{Ca} horizon). This soil occurs in the western half of the mapped area on gently undulating and sloping plains, it may be extensively cultivated where cleared. Reddish Loam also occurs west of the Barns Au prospect where it overlies and partially incorporates palaeochannel sediments, but it may also have a significant aeolian sand component. Where undisturbed this soil can be well vegetated by various tree, shrub and grass species.

Depositional Class

This class of regolith includes lacustrine, paludal, alluvial-fluvial, colluvial and aeolian materials. By far the most dominant in the mapped area are the aeolian component and the largely buried palaeochannel sediments. Next in importance is the lacustrine, with minor paludal, colluvial and Holocene fluvial components. These materials together form a cover to the cratonic basement sequence and therefore can impede surface based exploration. An understanding of the distribution and thickness of these landforms is essential to surface geochemical anomaly interpretation and choice of sites for follow up testing by drilling.

Lacustrine-Paludal

Under the Quaternary climatic regime for this area, lakes and swamps were and are typically ephemeral depocentres and sites of significant deflationary activity. Although, during the Palaeogene-Neogene there were intervals where climate was much wetter, supporting long-term surface water ponding and deposition primarily in lacustrine-paludal environments (Benbow *et al*., 1995a). Minor localised stream flow, moderate localised sheet flow and significant aeolian processes operate within each ephemeral water ponding catchment area. During arid times, desiccation of depocentre floors leads to aeolian deflation through wind stripping of clays, silts and evaporitic minerals (halite, gypsum, etc). Stripped materials include silt to sand-sized particles, termed parna, and gypsum. Their removal leads to localised deposition on the lee side of the source depocentre, forming a lunette (crescent-shaped wide and low-angle curved dune). However, a significant quantity of the depocentre's floor fines (particularly the clay fraction) is commonly lost to that catchment by dust dispersal, resulting in long lasting topographic depressions with only relatively thin lacustrine sedimentary sequences preserved. In a few instances the losses have far exceed the sediment input, yielding ever deepening and widening landscape depressions (see Landscape Evolution Section). The following descriptions are ordered according to relative age, presumed oldest first to presumed youngest last.

An account of the regional salt lakes, their hydro-chemistry and biota is given by Williams (1985) but none of the playas within in that paper occur within the Wudinna north Study Area. However, many of the same principles will apply regarding playa-lake hydro-chemistry, biota and lacustrine development.

Bog-iron

A palaeo-swamp deposit, the Bog-iron (landform symbol: **Dl-4**) outcrop represents a very minor surficial component in the mapped area but it does indicate a significantly different climatic regime to that of the Quaternary, did once operate there – possibly a much wetter time (higher rainfall and less evaporation). Outcrop comprises massive black FeOx (± MnOx) cemented sand that forms a capping of <1.0-~1.5 m thick. It either directly overlies saprolite (RgS2) or caps thin yellowish to brownish sand and feldspathic grit of possible fluvial-colluvial origin. That sand inturn unconformably overlies the collapsed megamottle pedolith horizon (RgQm). These sediments have been equated with Garford Fm. (Palaeogene to Neogene) by Blissett (1988). Bog-iron minerals are chemically precipitated during sediment deposition or at least immediately coeval with the final sand bed deposition. It is clear though that deposition changed from fluvial to paludal in order to allow for bog-iron mineral deposition to occur (FeOx + MnOx + FeOH, primarily as very fine-grained haematite ± goethite ± limonite) possibly initially precipitating on organic fines in the sediment.

Outcrop exhibits irregular blocky jointing near retreating escarpments (Plate 30). Two small areas of Dl-4 occur as landforms involving inverted palaeotopography, where retreating escarpments now form playa fringing mesa-butte exposures, E of the Paney Track, north of the Gawler Ranges National Park southern gate-grid. The Bog-Iron outcrop is vegetated by trees, shrubs and grasses only where it is aeolian sand covered.

Playas and palaeo-playas

A number of palaeo-claypan deposits were recognised (landform symbol: **Dl-5**; *c.f.* Dl-1). These appear to result from playa burial by abundant sand ingress during active dune building episodes and/or by changing hydrography where either further water ingress is prevented or the playa is sediment infilled beyond its capacity to hold additional water – leading to playa extinction. The biggest area of palaeo-claypan occurs within the large SW playa complex, but all deposits are located within the western half of the mapped area. Some deposits are leached of organics and so present as pallid laminated clays. Others are highly gypsiferous or can contain brightly coloured laminated clays.

Palaeo-claypan deposits consist of: pallid to medium grey to yellowish gypsiferous clay ± silt ± minor sand, and are variably coherent to weakly lithified by evaporitic salts. Deposits may have darker hued organic-rich lamellae but these are rare by comparison with active playa deposits. Dl-5 materials are commonly exposed through deflation or fluvial sheet wash exhumation, a process that is especially significant within the large SW playa complex. Palaeo-claypans may retain remnant lunette associations that are actively eroding to form 'bad-lands' landforms. The large SW playa complex occupies a distinct ~EW trending landscape depression that is coincident with an extension or anabranch to the Yaninee–Narlaby Palaeochannel complex and this aspect is consistent with similar persistent elongated landscape lows mapped elsewhere on the Gawler Province (Benbow *et al*., 1995c;

Hou *et al*., 2000; Hou, 2004; Sheard and Robertson, 2004). Palaeo-claypans are generally poorly to non vegetated.

Active playa floors (landform symbol: **Dl-1**), ephemeral playas of various sizes are relatively common across the Study Area (>60) but only two are formally named (Plates 31-33). Playas occur in landscape lows where internal drainage dominates and a discernable flat-lying depocentre has formed. Their floors consist of grey to dark grey to dark brown to red-brown to pink and red muds that include clay and silt ± minor sand. A number of playa muds were found to be extremely sticky when moist while others will easily soil ones fingers during manual texturing but are not really sticky. PIMA mineral spectral analysis has not adequately resolved this conundrum, however, clay grain size may be the real cause, ultra fine-grained clays are known to be highly cohesive and are typically very plastic (*c.f.* Sheard and Bowman, 1996).

Most playa muds were found to be moist just below the surface and soft to weakly coherent but occasionally, where very clayey, they are quite coherent. Organic-rich lamellae, bands and dark horizons are common but in some playas there has been significant bioturbation of the upper ~300 mm, where partial to full disruption of bedding is observed (Plates 34-37). Some playa floors have thin white halite crusts, but both Agars Lake and Hidden Lake have thicker halite crusts (30-60 mm) where white hopper-faced crystals to 12 mm diameter are common, some even persist undissolved when the lakes hold significant water bodies (Plates 31, 38). Gypsum crystal mats, individual crystals (<2->30 mm long) and crystal V-twins to 35 mm were observed growing in some playa muds at depths of 100-150 mm (Plate 39). Within the agriculturally cleared lands, playa muds commonly exhibited thin near surface charcoal-rich sandy to silty layers (Plates 35-37; ? land-clearing fire evidence). Playas in this area can have bright red mud where haematite-rich run-off waters exit nearby ferruginous outcrop such as the collapsed megamottle horizon (RgQm; Plate 40). Active playas are unvegetated.

Modern playa shores and terraces (landform symbol: **Dl-2**). These surround most playas but their widths and shapes vary considerably. Playa shores and terraces consist of ephemeral flood reworked aeolian sand ± fluvial sand to minor gravel and lag cobbles ± lake shore strand-line gravel ± gypsum crystal fragments ± halite ± organic flotsam, and all are usually uncemented. The materials can stand higher than playa shorelines to form terraces of low hummocky terrain – particularly near minor fluvial debouchments. Typically these materials are pale yellow to pale brown or pale neutral hued, may be bright red near Fe-rich outcrop. This landform is generally unvegetated to poorly covered by halophytic forbs and club-rushes or sedges.

Marshlands

Marshland areas (landform symbol: **Dl-3**) commonly fringe zones to ephemeral playas or places where seasonal waterlogging occurs (Plates 40, 41, 55), others have formed where significant deflation is producing incipient rain run-off concentrating depressions. Sediment-soil is mostly sandy to silty or occasionally loamy. This landform may be near level to mildly meso-scale hummocky and some examples are gently sloping (<5^{o}). Soils can be saline to hypersaline and/or gypseous, many are probably quite alkaline (pH >8.6). These areas are vegetated by tussocky grasses ± club rushes ± saltbush ± samphire ± succulent creepers.

Fluvial Landforms

This form of deposition has been relatively rare in this area for a long time – possibly reflecting the long-term Quaternary aridity. However, during the Early to Middle Cainozoic large river systems did flow over this area, carving moderate valleys into the deeply weathered terrain. Mapping has indicated two distinct landforms, one is fossil and usually buried by later aeolian and/or paludal sediment (palaeochannel sediment), while the other remains active within current creek lines (Fluvial sediment).

Palaeochannels

Palaeochannels and associated sediment do occur in the mapped area but are usually only observed from drillhole samples. The Bog-iron deposit (Dl-4) is developed within presumed Garford Fm. sands, they are of palaeochannel origin, but because landform Dl-4 has such an intense paludal chemical overprint in outcrop-subcrop, that subset has been more fully discussed in the Playa-paludal section above. The major subsurface palaeochannel deposits are not tagged with a distinct landform symbol on the Regolith Landform Maps but they appear on the two cross-sections as undifferentiated fluvial sediment.

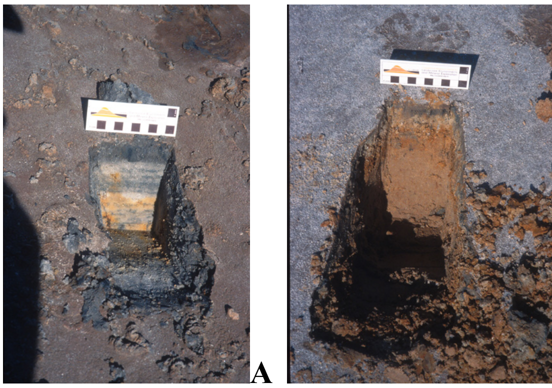
Plate 30: Outcropping blocky bog-iron horizon within Garford Fm sand and grit beds atop a small mesa. Now presenting as inverted landform through erosion. East side of Paney Road (GPS: 546549E, 6369965N).

Plate 31: View ~N after heavy late winter rains in 2004, from SE corner of the large unnamed northern playa towards Mt Sturt. White shoreline halite encrusting is evident just above the waterline. September 2004.

Plate 32: View SW after heavy late winter rains from N side of Agars Lake. The pale near shore band is coarsely crystalline halite in briny water. Orange longitudinal dunes are invading this playa from the W and are being wave eroded on their flanks and E ends. September 2004.

Plate 33: Small playa being invaded by an orange linear dune, making a horse-shoe-shaped playa, view ~W. Gypsum and halite encrust a dark grey muddy floor, with fringing paperbark *Melaleuca* sp. extending out into the mud (LHS). SW playa complex area. April 2005.

Plate 34: An excavated block of playa floor mud, laminated and multicoloured. Thin halite encrusts an organic-rich top lamella. NW map corner, large 'L-shaped' playa, central S shore.



A **B**

Plate 35: Two small excavations in adjacent playas. Both sites are from the large SW playa complex. **Site A**, has a charcoal-rich upper sandy clay on orange Fe-mottled clayey sand.

Site B, has charcoal + an organics-rich top on a gypsum crystal twin-rich sandy layer over a uniformly coloured silty sand–silty clay.

Captions to Plates on the following page.

Plate 36: Two small excavations in separate playa floors. Both sites are from the large SW playa complex. **Site A**, is a strongly bioturbated organics-rich clayey silt. **Site B**, a charcoal + organics-rich mud (silty clay + minor sand) with weakly developed yellow-brown mottles.	**Plate 37**: Charcoal and clay-rich layer overlying laminated brown organics-bearing sand on pale brownish silty clay. Playa N of Agars Lake. Pen scale is 135 mm long.
Plate 38: Tepee structures within halite crust (20 mm thick), large L-shaped northern playa. April 2005. Spatula scale is 230 mm long.	**Plate 39**: Gypsum, flat crystals, V-twins and penetration types, collected from playa muds at two localities, depth range 100-150 mm. In one mud floor the gypsum crystals formed an interlocked horizon. Bar scale is 93 mm long.
Plate 40: Playa floor red mud containing Fe-rich in-wash sediment from eroding higher escarpment surrounds of collapsed megamottled horizon. Note the vegetation surrounding the playa floor is dominated by saltbush and black bluebush. View is E, site ~2 km E of Little Pinbong Rockhole.	

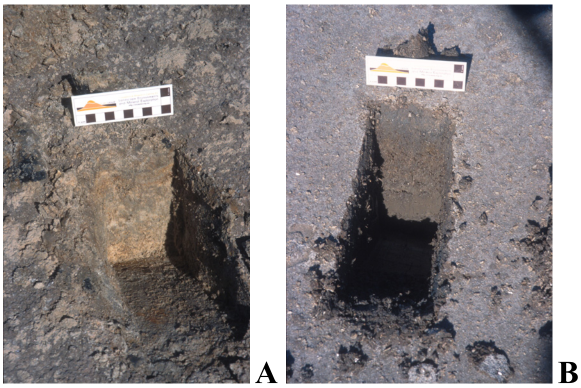


Plate 36

Plate 37

Plate 38

Plate 39

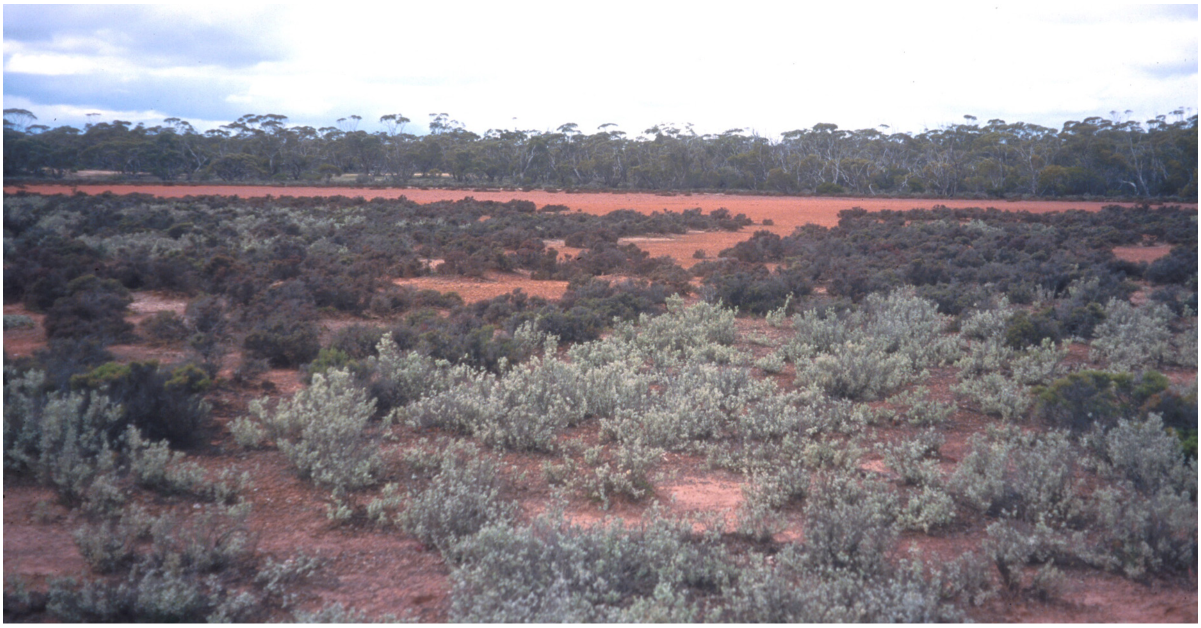


Plate 40

Plate 41: Marshland (incipient playa) area just S of Baggy Green Au prospect, within Pinkawillinie Conservation Park. View towards NW, marshland is ~100 m wide & ~350 m long here (<¼ of full area). For landscape position see also Plate 55.

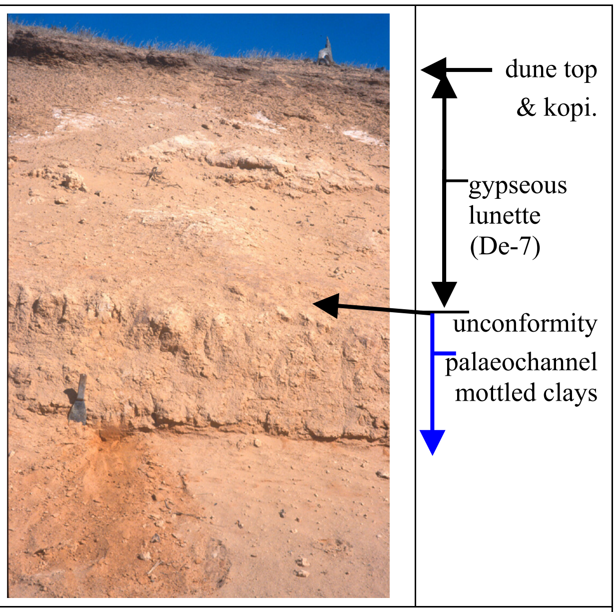


Plate 42: Eroding palaeochannel clay overlain by gypseous lunette (*c.f.* Plate 43). Exposure at E end of sand island, SW playa complex (GPS: 530592E, 6361253N). Spatula scale is 230 mm long.

Plate 43: Eroding red to brownish mottled palaeochannel greenish clay, exposed in small spade dug pit at E end of sand island within a central playa, SW playa complex. Immediately below the clay is an indurated sand bed that is nearly too hard to excavate with a G-pick or crowbar. Spatula scale is 230 mm long.

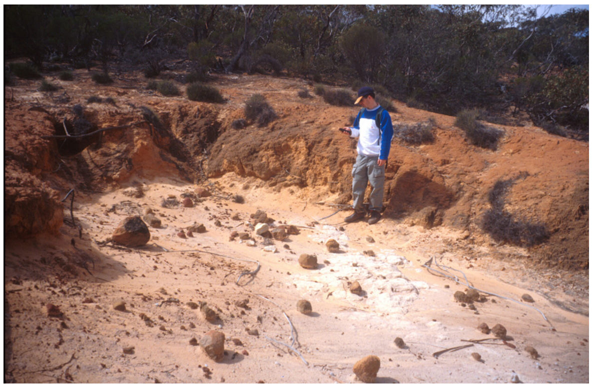


Plate 44: Eroding edge of debris flow deposit near NW shores of large northern playa. Erosion has released numerous angular boulders of unweathered Mt Sturt porphyry that now rest upon pallid saprolitic Tunkillia Suite. The debris flow deposit is overlain by playa fringing dunes and sand plain to depths of 1-5 m.

There is one location inside the large SW playa complex where red mottled greenish clays and indurated sand beds were observed in limited outcrop to subcrop (Plates 42, 43). Those clays are massive and contain <3% sand (fine- to medium-grained), while the underlying sand beds contain angular to rounded, medium- to coarse-grained quartz, and intergrain voids may be partially lined or cemented by clay or evaporitic minerals. Other resistate mineral grains and lithics are rare to absent. Induration of those beds ranges from low to medium – where locally a moderate degree of rock competence can be developed in some layers.

Primarily covered by younger gypseous dunes ± kopi ± playa sediment or aeolian sand, there are however, some scant surface indicators of the palaeochannel sediments, these occur as dispersed gravel lag, composed of indurated red mottle remnants released from eroding mottled clays. Manual excavation revealed the vertical extent to be <2 m from below a cryptic unconformity surface to where more sandy beds are now buried under modern playa muds. The red mottled greenish clay is ~1.80 m thick and >0.20 m of indurated sand underlies that clay. A true thickness for this palaeochannel sediment remains uncertain here because there are no nearby drillhole sections or logs available. Parker and Flint (2006) have described similar greenish clays and sands from palaeochannels elsewhere on the YARDEA map sheet. The above mentioned site is too small for presentation as a distinct polygon on the Regolith Landforms Map B but its location is at the eastern end of a small dune-island within a medium sized playa (GPS: 530592E, 6361253N).

The surrounding playa complex occupies a distinct ~EW trending landscape depression where its terrain aspect is coincident with an extension to or an anabranch of the Yaninee—Narlaby Palaeochannel system. A feature that is consistent with similar persistent elongated landscape depressions mapped elsewhere on the Gawler Province (Benbow *et al*., 1995c; Hou *et al*., 2000; Hou, 2004; Sheard and Robertson, 2004; Parker and Flint, 2006). Sediments at this site most resemble clays and sands from the middle to upper Garford Fm. which does occupy the Yaninee—Narlaby Palaeochannel further to the west and east according to Parker and Flint (2006), Benbow *et al*. (1995c), and Binks and Hooper (1984).

Additional palaeochannel deposits in this area are associated with the Corrobinnie Depression (Narlaby Palaeochannel) and related landscape lows (SE map quadrant) as suggested by Twidale and Campbell (1985) and demonstrated further to the west by Benbow *et al*. (1995c) plus Binks and Hooper (1984). These fluvial sediments have been identified also in recent exploration drilling just north and east of Little Pinbong Rockhole plus north, west and east of Barns Au prospect (pers. comm. C. Drown, Adelaide Resources Ltd, March 2006). Drill samples provided by Adelaide Resources Ltd have enabled the author to construct two ~4 km long cross-sections (Regolith Landform Map – Regolith Profile Sections A-B and C-D) through the Barns and Baggy Green Au prospects. Both display palaeochannel intersections where poorly to well sorted sands (containing some beds of strongly or brightly coloured quartz sand) plus pale hued clay beds, together reach thicknesses of <10->30 m. Examples from the drilled profile sections (Regolith Landform Map) are displayed in Plates 45-47 while the logs and chiptray photos to several others are available in Volume 2, Appendix 1. The larger palaeochannels have deeply incised the *in situ* weathered regolith to yield truncated profiles, where all pedolith and even substantial portions of the upper saprolite are eroded away. Near the palaeochannel centres, the unconformity may be marked by a basal gravel-rich bed or a course-grained lithic to quartz clasted colluvium (<1-~2 m thick, with well rounded clasts 3->20 mm diam.).

It is worth noting that anomalous gold was detected in calcrete overlying the buried palaeochannel north of Barns Au prospect (see x-section A-B) and gold grains have been panned from drill cuttings sampling this palaeochannel segment plus another north of the Baggy Green prospect (pers. comm. C. Drown, Adelaide Resources Ltd, June 2006). Sources for this sediment hosted gold (± ?chemically remobilised Au) have not been located so far, and will require further work on the complex local channel architecture plus flow directions to better establish potential drill targets.

Ephemeral Creeks

Ephemeral creeks, channel confined alluvium (landform symbol: **Da-1**). Materials occur within current creek lines and are usually loose but may be variably cemented by pedogenic carbonate (calcrete) and/or gypcrete. Sediment is sandy, gravelly to pebbly and may have rare cobbles but the alluvium does not display much silt. Only one defined creek line (~2.4 km long) was mapped out for this area. Channel confined surface water flow is exceedingly rare over this landscape and confirms a high subsurface porosity that is capable of absorbing most rainfall and potential run-off – even during intense storms. Minor stream gutters do occur, typically draining into playas and clay pans but they rarely exceed 300 m in length and tend to have flume dimensions of 1-2 m wide by <0.5 m deep. Landform can be variably tree lined by *Eucalyptus* sp, *Acacia* sp. and by various shrub species.

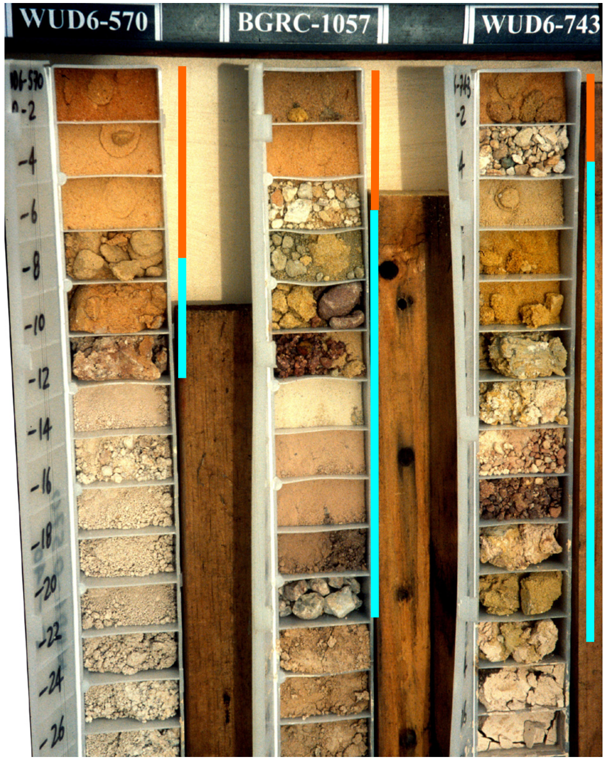


Plate 45: Drilled palaeochannel sediment at Baggy Green Au prospect (N-NE end). Orange bars indicate aeolian sand, blue bars indicate palaeochannel sand ± clay. A basal quartz gravel occurs at 20-22 m in drillhole BGRC-1057. Sampling interval = 2 m.

Plate 46: Drilled palaeochannel sediment at Barns Au prospect (western edge). Orange bars indicate aeolian sand, blue bars indicate palaeochannel sand ± clay. Fluvial sediments extend to 32 m (vertical depth) in drillhole RCBN-317. Sampling interval = 2 m.

Plate 47: Drilled palaeochannel sediment at Barns Au prospect (northern extension, within Corrobinnie Depression). Orange bars indicate aeolian sand, blue bars indicate palaeochannel sand ± clay. Sampling interval = 2 m.

Colluvial Landforms

There are three mappable landforms on the flanks of or deriving from the Mt Sturt highland. All are dominated by colluvium, *i.e.* moved into their current resting places primarily by gravity assisted processes but the piedmont slope deposits also have a sub-dominant fluvial-sheet flow component. Each landform overlies older terrain and thereby obscures that in a physical and geochemical sense from surface sampling techniques.

Debris Flows

Debris flow (landform symbol: **Dcdf**): a gravity assisted mass wasting colluvium of loosened slide materials derived from steep slopes. Grain sizes are clay to boulders (of Mt Sturt porphyry) in a matrix supported framework. All the materials are derived from Mt Sturt in one or more mass wasting flow-slide events. The matrix is a red-brown clay-silt-sand mixture where larger lithic clasts are angular to rounded and unweathered. Where exposed distally from Mt Sturt the landform is <1->4 m thick. It appears to cover an area of several square kilometres, leading back to the lower slopes of Mt Sturt and crops out through erosional sites near the large N playa where it overlies pallid saprolite (Plate 44). Debris flows may mask off from surface sampling techniques some or all of the underlying regolith geochemical signature. The aeolian sediments overlying debris flows are well vegetated by Mallee *Eucalyptus* sp., *Melaleuca* sp., *Acacia* sp. and many shrub types. Where cropping out, due to erosion and hypersaline conditions, debris flow materials are non vegetated.

Piedmont slope deposits

Piedmont slope deposit (landform symbol: **Dcps**): crops out on the southern flanks of Mt Sturt and is dominantly a colluvial landform where long-term mass wasting and alluvial fan material have deposited on moderate to semi-steep slopes. Minor slope-wash and localised fluvial activity have also contributed sediment. Materials are orange to red-brown sandy clay with variably abundant clasts of Mt Sturt porphyry. Clasts range from medium-grained gravel to occasional small boulders, and are mostly matrix supported but occasionally are clast supported. Nodular calcrete is present in $B_{\mathbf{Ca}}$ horizons. This landform has been previously assigned to Pooraka Fm. equivalent but it is not typical of that formation where originally defined on the Adelaide Plains, nor to equivalents mapped elsewhere (Sheard and Bowman, 1996). Piedmont slope materials may mask off from surface sampling techniques some or all of the underlying regolith geochemical signature. This landform is well vegetated by Mallee *Eucalyptus* sp., *Melaleuca* sp., *Acacia* sp., many shrubs and especially grasses.

Talus

Talus (landform symbol: **Dcta**): a gravity assisted, mechanically moved deposit of loosened rock from precipitous slopes around Mt Sturt. Clast sizes range from gravel to boulders and large blocks with little or no fines, and occurs as a brownish clast-supported framework. Deposits can have significant slopes <15 to <25^{o}. This material forms a geomechanically unstable narrow wedge around part of the porphyry outcrop and it is mostly poorly vegetated by a few shrubs and trees.

Aeolian Landforms

Ten aeolian landforms have been recognised within the mapped area, and a stratigraphic order (with relative ages) can be established for many of these. However, it is likely that more dune forming episodes could be chronometrically defined by additional luminescent dating of siliceous sand profiles. Landform differentiation herein is based upon stratigraphic evidence, morphology, landscape position, grain mineralogy-morphology, profile colour and pedogenic indicators (soils, palaeosols, cements, sesquioxide segregations). Predominantly aeolian grains are quartz sand to coarse silt but significant gypsum-rich and clay-rich particulates also abound in some landforms (lunettes, kopi). Sand and silt sources include locally eroded quartz-rich rocks plus resistate mineral grains derived from exposed and weathered protolith; as well as exposed sandy sediments. Clay in the form of parna and dispersed fines within the aeolian landforms can be derived by deflation from local playas—clay pans, eroding pedolith—saprolith and eroding sediment. Sand and fines are also derived well away from the mapped area, as demonstrated by the larger longitudinal dune systems linking as an easterly extension or outlier to the large Great Victoria Desert.

Most of the playas have associated lunettes composed of deflated lacustrine sediment blown to the lee side as parna, silt and seed gypsum to form crescent-shaped dunes. Deeply weathered protolith has also contributed clays and quartz grit to this process (see Landscape Evolution section).

Significant and sudden elevation variance in the landscape has induced perturbations in regional and local dune—sand plain patterns – especially near the Gawler Ranges, around some large granite inselberg whalebacks and surrounding the deeper playa depressions. The resultant distinctive landform patterns have been mapped out as separate landforms even though many may have similar depositional time frames to other more easily defined aeolian deposits. Until appropriate dating is applied in a systematic way to the whole dune–sand plain package in this area, the full aeolian history will remain partially conjectural.

Orange longitudinal dunes and associated sand plain

Stratigraphically the oldest aeolian sand system is the orange longitudinal dunes (landform symbol: **De-4**) and associated orange sand plain (landform symbol: **De-3**). However, these may involve two or more distinct deposition cycles because some of those dunes and sand plain are quite deeply red-hued indicating a possible antiquity that stratigraphy alone is unable to refine further.

Generally these dunes stand <2.5-~7 m above the surrounding plain and occur in isolation or in minor dunefields but are commonly broader, are more widely spaced and usually stand lower than those of De-2. Most De-4 dunes have an orientation of ~110 to ~120^{o} (ESE) and may be forked. They can be over-run by younger paler sands (De-1 & De-2), thereby preserving any un-eroded palaeosols in De-4 (*i.e*. brownish FeOH segregation-bearing horizons, <0.5 m thick, and palaeo calcrete). Commonly De-4 dunes are truncated or modified by later erosion and in many cases only present as partial dunes or dune cores. In cross-section these dunes are weakly asymmetric where the southern side is slightly steeper. Their overall morphology suggests that two wind directions (from ~NW and ~SW) dominated aeolian grain transport during dune development. Sand is highly siliceous, coloured dark orange-yellow to medium orange-yellow to orange-brown, is fine- to medium-grained and uniformly sorted, it is typically loose to moderately bound by pedogenic carbonate and can contain indurated carbonate rhizomorphs at depth (Plates 48-50, 53, 54; Table 1).

The associated but more aerially extensive orange sand plain (De-3) is generally ~0.3-~2.0 m thick and tends to mantle any palaeo-surface undulations, the sand plain therefore forms a low relief undulating surface. This landform is commonly overlain by the paler dunes and sand plain of De-2 and De-1.

Previous geological mapping has included these landforms within 'Moornaba Sand'. A precise age is not available but Late Pleistocene would fit the stratigraphic evidence.

Typically these dunes and sand plain are well vegetated where uncleared for agriculture. Native vegetation vestiges remain along taller dune crests, and within Parks, Reserves, or surviving road verge plant corridors. Dominant vegetation communities include: several mallee tree species *Eucalyptus* sp. and broom bush *Melaleuca* sp. plus abundant spinifex and many small shrubs. Both landforms are farm cultivated south of Gawler Ranges National Park.

Yellowish longitudinal dunes and associated sand plain

Yellowish longitudinal dunes (landform symbol: **De-2**) and associated yellowish sand plain (landform symbol: **De-1**) dominate much of the landscape, creating a regionally significant landscape grain of rolling downs terrain. Stratigraphically these landforms are younger than those of De-4 and De-3,

Generally De-2 dunes stand <2->12 m above the plain, are narrower and much longer than those of De-4. Most have an orientation of ~120^{o} (ESE) and can occur in isolation but more typically they form significant dunefields (Figure 7; Plate 55). Dunes may be forked and many over-run the older aeolian landforms of De-3 and De-4. In cross-section De-2 dunes are asymmetric where the southern side is steeper; and their overall morphology implies that two wind directions dominated aeolian grain transport during dune development. This sand is highly siliceous, is generally coloured light yellowish brown to light greyish brown, is fine- to medium-grained, and is loose to weakly bound by earthy pedogenic carbonate below 1.5 m (Table 1, Plates 2, 51-53). A paler podsol has developed within these dunes to a depth of <1.0 m, this usually has an acid pH (<5.5) in contrast to the sand below where an alkaline pH occurs (>8.6). The podsol profile may contain scattered dark organic matter and abundant plant roots but no pedogenic carbonate.

The associated yellowish sand plain (De-1) extensively mantles the regional palaeo-landsurface forming low rolling undulations but it may also display minor linear dunes or dendritic dune patterns. Sand is similarly coloured to the dunes, is fine- to medium-grained and highly siliceous, is typically loose free-running at the surface but deeper is weakly bound by earthy pedogenic carbonate. Thickness ranges from ~0.3-<2.0 m, and may be thicker (<5 m) below minor dunes.

Both landforms have previously been mapped as being equivalent to Moornaba Sand, a geological formation that now seems to require redefinition.

Dating of a temporarily exposed dune profile (full depth section of ~8 m) overlying the Barns gold prospect in April 2004, and employing optically stimulated luminescence methodology, has revealed an age range of 26,300 ± 1300 yBP to 17,000 ± 1300 yBP (Lintern & Rhodes, 2005).

These landforms were generally well vegetated prior to twentieth century agricultural broad-acre land clearing for cereal cropping and stock grazing. Native vegetation vestiges remain along taller dune crests, and within Parks, Reserves, or surviving road verge plant corridors. Dominant vegetation communities include: several mallee *Eucalyptus* sp. trees and broom bush *Melaleuca* sp., there can also be abundant spinifex and many shrubs.

Complex longitudinal dunes

Complex longitudinal dunes (landform symbol: **De-2/De-4**). Dunes De-2 overly De-4 dunes: these duplex dunes were recognised at track-road cuttings and erosional sites. Major sand colour contrasts are: De-2 (Munsell 10YR 6/3 to 10YR 8/5, dry) *versus* De-4 (7.5YR 7/7 to 2.5YR 6/8, dry), refer to Table 1 and Plates 53, 54. Pedogenic carbonate induration is generally stronger and the granular texture more clayey in dunes of De-4 (>5% clay) than in dunes of De-2 (<1% clay).

Complex sand plain

Complex sand plain (landform symbol: **De-5**): is a light greyish brown to light yellowish brown, fine- to medium-grained siliceous sand, loose free-running at the surface but may be weakly bound deeper in the profile by earthy pedogenic carbonate. Thickness range is ~0.3->2.0 m and maybe >4-7 m where minor dunes also occur. This landform typically thinly mantles palaeo-land surfaces forming rolling undulations and minor anastomosing linear to dendritic to festoon and parabolic dune patterns (Plate 55, Figure 7). Its sand may be stratigraphically equivalent to aeolian landforms De-1 and De-2 but De-5 forms distinctive landform terranes in Pinkawillinie Conservation Park and Gawler Ranges National Park.

Complex sand plain within the Pinkawillinie Conservation Park occurs in two areas, one east of Little Pinbong Rockhole and the other is confined to an ~WNW trending subtle valley that may form a tributary to or an outlier of the more extensive ~NW-SE trending Corrobinnie Depression-Narlaby Palaeochannel. Twidale and Campbell (1985) demonstrate a tectonic relationship between the Corrobinnie Fault and the Corrobinnie Depression – a landscape pattern that was exploited during the Palaeogene to Neogene by northwesterly flowing rivers of the Narlaby Palaeochannel system. Late Pliocene to Pleistocene climate changes, and debouchment blockages, caused those rivers to eventually cease functioning and allowed aeolian sediments to partially infill their remnant valley systems. Dune patterns presented by Twidale and Campbell (1985) for aeolian deposits within that extensive depression display a distinctly different morphology than is evident for the surrounding aeolian terrane. Festoon and parabolic dunes abound further east in the main Corrobinnie Depression, but within the portion covered by this regolith study, dunes are dominantly of the festoon type where curvi-linear anastomosing crests make a complex topography. This distinctive dune landform presentation may be a useful tool for mapping palaeochannels in this region. Dune orientation is dominantly WNW with subordinate ~NW and minor ~SE trends, rarer parabolic dunes do occur and all have westward facing U-openings – *i.e.* open up-wind. Dune morphology differences between those within the depressions and those on surrounding plains is suggested as being due to a higher abundance of source sand within the depressions (Twidale and Campbell, 1985). They also suggest that the festoon-parabolic dune fields are older than the longitudinal dunes on surrounding plains, based on the depressions being markedly wetter and therefore offering or hosting early vegetative stability to moving sand – particularly within swales. However, stratigraphic evidence for this assertion was not encountered during this study and therefore dune profile dating by optical luminescence would be required to prove this age assertion.

Nearer the Gawler Ranges another area of similar De-5 dune terrain occurs surrounding Mt Sturt, but seems more related to highland orographic affects on aeolian sand movement than to fluvial depression infill. Sand there is also more likely to have been locally sourced from slowly eroding volcanic hills and peaks. Parabolic and festoon curvi-linear dune forms are in near equal numbers; to the SE and SW of Mt Sturt their morphology indicates a prevailing wind direction towards the SE and ESE. The co-located larger dunes of landform De-10 seem to reflect a similar dune morphology but on a grander scale. Typically the De-5 landform is well vegetated by Mallee *Eucalyptus* sp. and *Melaleuca* sp. trees, *Acacia* sp. shrubs, abundant spinifex and a diverse community of small to medium stature shrubs.

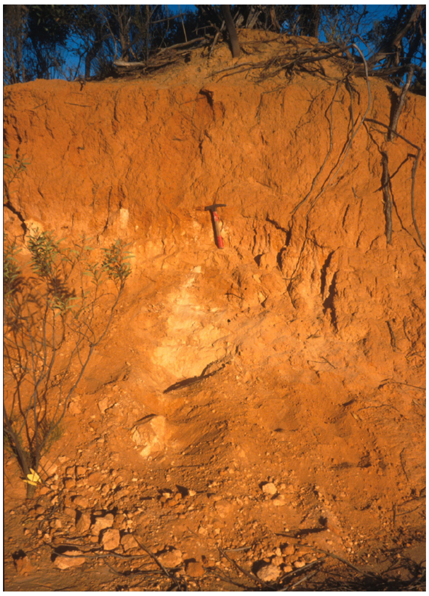
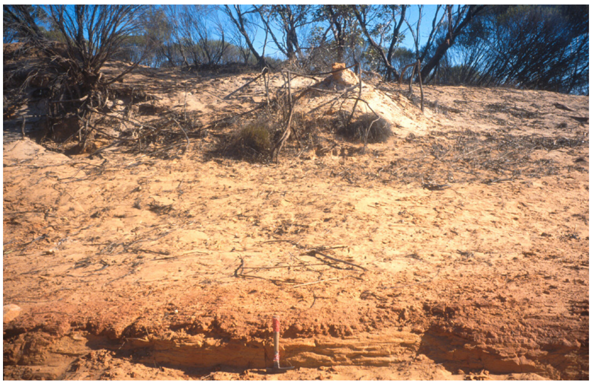
	

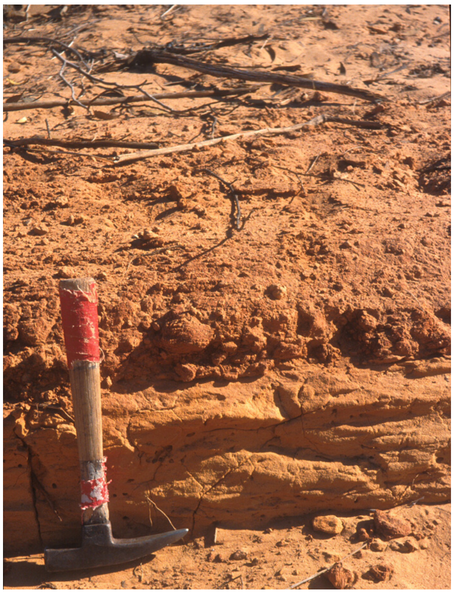
Plate 48: Roadside sand pit section through orange longitudinal dune. Significant calcrete occurs below hammer, becoming indurated and blocky near base of view. Hammer, 0.3 m long.	**Plate 49**: Road cutting in orange longitudinal dune overlain by younger yellowish dune. A palaeosol with Fe-segregations is evident at 1.5 m below dune crest. Scale hammer is 0.3 m. See also Plate 50.
Plate 50: Road cutting exposure of orange longitudinal dune remnant palaeosol below an unconformity. Fe-segregations are evident as distinct nodules and pisoliths near hammer red taped handle end. Calcrete forms paler hued earthy patches. Hammer is 0.3 m long. Close-up of section in Plate 49. (GPS: 528700E, 6364475N).	

Table 1: Sand and gritty soil colours.

Sample R number	Munsell (dry, wet)	Kelly & Judd (1976) / [1]colour (dry, wet)	Land-form tag	Sample description
1039975	10YR 6/3, 10YR 5/3	lt.gr.y.Br, gr.y.Br	De-2	Upper pale dune, podsol, at 0.30 m, Barns Au Prospect
1039976	10YR 7/5, 10YR 6/5	lt.y.Br, lt.y.Br	De-2	Upper pale dune, podsol base, at 1.00 m, Barns Au Prospect
1039977	7.5YR 7/7, 7.5YR 6/5	m.o.Y, lt.Br	De-2	Upper pale dune, at 2.15 m, Barns Au Prospect
1039978	10YR 8/5, 7.5YR 8/5	pl.o.Y, pl.o.Y	De-2	Upper pale dune, core calcrete zone, at 2.50 m, Barns Au Prospect
1039979	7.5YR 6/8 7.5YR 6/6	dk.o.Y, dk.o.Y	De-4	Lower orange dune remnant near yellowish dune edge, at 1.50 m depth, Barns Au Prospect
1039967	2.5YR 5.5/8, 2.5YR 5/6	br.O, gr.r.O	De-4	Bright-strong orange dune
1039968	10YR 8/2, 10YR 7/2	y.Gr, y.Gr	De-8	Near-shore sand island in big playa
1039969	10YR 6/4, 10YR 4.5/3.5	lt.y.Br, m.y.Br	De-8	Large sand island in big playa, crest of dune
1039970	5YR 6/5, 5YR 6/4	lt.Br, lt.Br	De-4	Orange sand at base of younger over-riding dune
1039971	7.5YR 6/4, 7.5YR 5/3	lt.Br, lt.gr.Br	De-2	Younger over-riding dune to orange sand base
1039972	7.5YR 6/6, 5YR 5.5/6	dk.o.Y, lt.Br	De-4	Orange sand dune, at 80 cm depth
1039973	7.5YR 5.5/5, 7.5YR 5/4	lt.Br, lt.Br	De-4	Orange dune core, at 140 cm depth
1039974	7.5YR 5/5, 7.5YR 4/3	lt.Br, m.Br	De-4	Orange sand below younger pale brownish dune
1039934	5YR 5/7, 2.5YR 5/7	br.O, br.O	RgQg	Brownish earthy soil (weathered gruss)
1039980	10YR 7/4, 10YR 6/4	lt.y.Br, lt.y.Br	De-2	Upper pale dune, podsol, 0.30 m depth, ~2 km W of Barns Au Prospect
1039981	10YR 6/7, 7.5YR 6.5/7	dk.o.Y,	De-2	Upper pale dune with earthy calcrete, sampled at 2.30 m depth, ~2 km W of Barns Au Prospect
1039982	7.5YR 7/7, 7.5YR 6/6	m.o.Y, dk.o.Y	De-4	Lower orange dune top, weakly cemented; at 3.00 m depth, ~2 km W of Barns Au Prospect
1039983	7.5YR 6.5/8, 5YR 6/8	m.o.Y, m.O	De-4	Lower orange dune core with calcrete rhizomorphs; at 4.50 m depth, ~2 km W of Barns Au Prospect

[1]**Colour** word abbreviations, as defined by Sheard and Bowman (1996). Modifiers: dk = dark, lt = light, m = moderate. Colours: br, Br = brown; gr, Gr = grey; o, O = orange; r, R = red; y, Y = yellow.
Note: upper case designates the dominant colour: *i.e.* lt.gr.y.Br reads as "light greyish yellowish Brown".
Sample coordinates are available from the **Sample Register** in Volume 2, Appendix 1

Lunettes

Two categories of this aeolian landform have been mapped out, they differ mainly on mineral content rather than on morphology. The gypsum lunettes are more prone to erosion by rainfall and rain run-off than are those of the silt and parna type.

Lunettes (landform symbol: **De-6**). These are usually low, crescent-shaped clayey to silty, parna-rich deposits forming low angle dunes on the E ± NE ± SE (lee) sides of clay pans and playas. Pale colours occur and are commonly associated with low density—powdery gypsum (kopi, Plate 42). Lunette materials may have darker surficial layers and can be quite clayey towards their basal zones. Most lunettes are <5 m thick but a few around the large SW playa complex maybe ~8-10 m thick. Some playas exhibit 2-3 generations of overlapping lunettes. Vegetation is dominantly grasses and some low halophytic shrubs.

Gypsum lunettes (landform symbol: **De-7**): these have a similar morphology to the lunettes of De-6 except for the percentage by volume of aeolian gypsum. These lunettes are commonly near-white to pale grey, and composed of seed gypsum crystal fragments, some may be partially clayey towards their base. Many gypsum lunettes have a crusty carapace ~10-50 mm thick, a case hardening induced by rainwater partially dissolving and later reprecipitating gypsum as a grain cementation. Thickness of the whole landform maybe >3 m and this is most common in-around the large SW playa complex. Many have erosional flanks 'badlands' (see Erosional Class section). Sparsely grass vegetated.

Playa side dunes and sand plain

Playa side dunes (landform symbol: **De-8**): these are commonly off-white to pale yellowish to pale brownish siliceous sand that is loose free running, and rarely exhibits any pedogenic carbonate but may contain appreciable powdery to well crystallised gypsum. Forms irregular to curvilinear asymmetrical dunes and the island forms may be complexly crested. Landform occurs on some playa headlands, shore proximal areas and as playa islands. Sand thickness ranges over 3->20 m. Sparsely to densely vegetated by shrubs of many genera and sometimes by trees of Mallee *Eucalyptus* sp., *Acacia* sp. and shrubby *Melaleuca* sp.

Playa periphery sand plain (landform symbol: **De-9**): typically an off-white or pale yellowish or pale brownish siliceous sand that is free running (dry) to weakly bound by gypsum, but rarely exhibits any calcrete horizons. The landform consists of near flat to slightly sloping areas of sand associated with playa side dunes of landform De-8. This sand plain occurs around shore proximal areas and islands, it may exhibit some aeolian deflation or some alluvium or some ephemeral wave action erosion near shore areas. Thickness ranges over <1-~3 m. Sparsely to well vegetated by phreatophytic to halophytic shrubs and forbs of several genera. Gnarled stands of paperbark *Melaleuca glomerata* may adorn this landform's near lake fringe terraces.

Irregular dunes

Irregular dunes (landform symbol: **De-10**): these are light yellowish brown to pale orange, fine- to medium-grained siliceous sand that is loose free-running at the surface (dry) but at depth may be weakly bound by pedogenic carbonate. Thickness ranges over ~3-<8 m. This landform fringes the Gawler Ranges high ground and extends out from it towards the S where it forms irregular dendritic to curvilinear dune patterns similar to those of landform De-5 but much larger. It is commonly associated with aeolian landforms De-5, De-1 and De-2 but forms quite distinctive landform terrane in Gawler Ranges National Park. Typically the dunes are well vegetated by Mallee *Eucalyptus* sp. trees and *Melaleuca* sp. shrubs with abundant spinifex (*Triodia* spp.) and many varieties of small shrubs.

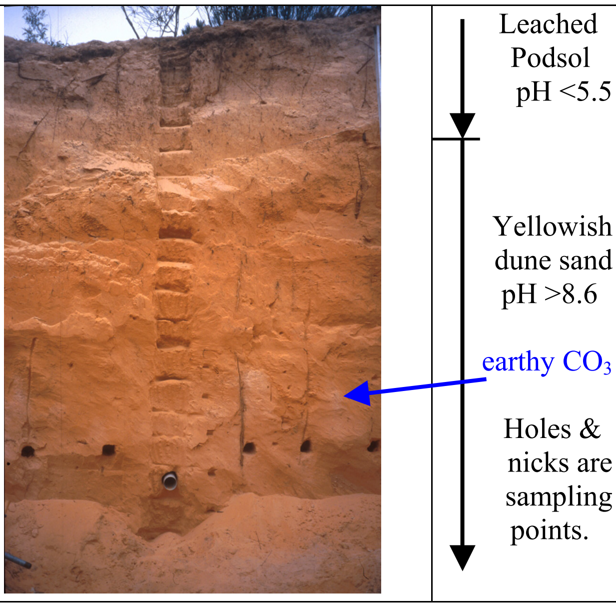


Plate 51: Yellowish longitudinal dune profile exposed in a temporary trench at Barns Au prospect; ~5 m of section is on view. Paler earthy carbonate zone has a very irregular top (see Plate 52). Dark tree roots extend well into the carbonate zone. Full view of trench is in Plate 2.

Plate 52: Earthy carbonate protuberance exposed in W wall of temporary trench at Barns Au prospect. Note the dark plant roots above the spatula scale (230 mm long) – well into the dune profile.

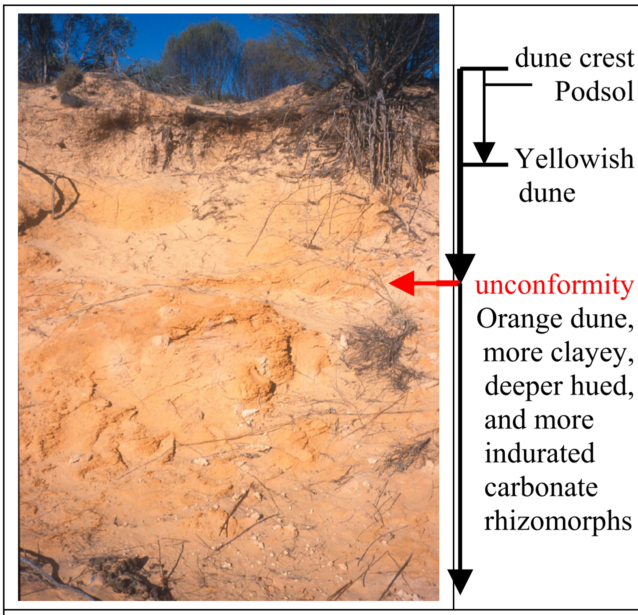


Plate 53: Yellowish longitudinal dune De-2 overlying orange longitudinal dune De-4. Exposed in old track cutting, ~2 km W of Barns Au prospect. Profile view is 4.7 m. (GPS: 539847E, 6365307N)

Plate 54: Indurated carbonate rhizomorph fragments eroded from orange longitudinal dune. Exposed in old track cutting, ~2 km W of Barns Au prospect. Hammer scale is 300 mm. (GPS: 539847E, 6365307N)

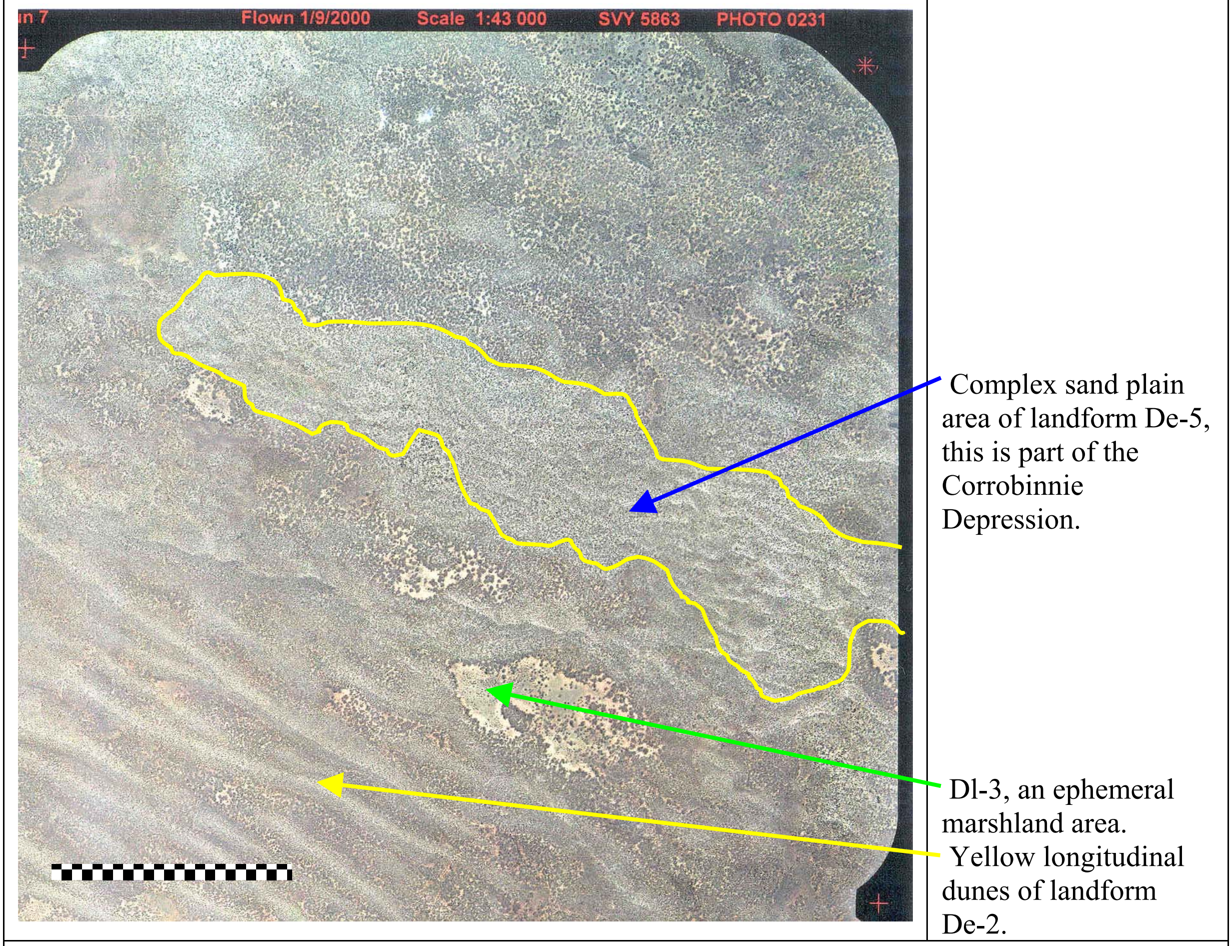


Plate 55: Part of airphoto 0231 (Svy 5863) displaying a sizable area of complex sand plain with festoon dunes (landform De-5) within Pinkawillinie Conservation Park. This overlies part of the Baggy Green Au anomaly. Compare with the bolder dune pattern of landform De-2 in this image lower third A green arrow points at the marshland displayed in Plate 41, an area of grasses and sparse trees. Chequered scale bar (lower LHS) = 1 km.

Erosional Class

Erosional Class involves the dynamic outcrop peripheries to several landforms from both Relict and Depositional terranes where significant profile transformation has occurred (or is occurring) through erosion. Those areas suffer from a number of erosive surface processes, those include : wind ± water, or water ± wind, and more rarely gravity ± water; where the removal of appreciable outcrop and subcrop material occurs, causing localised profile truncation (fully or in part). This is an important terrain-landform class because erosion can have profound affects upon any residual geochemical signatures or footprints that may have indicated the presence of nearby unweathered mineralization. It is especially important where an *in situ* weathered profile is eroded enough to expose its trace element leached collapsed pedolith horizons and/or leached upper saprolite. Erosion can dislodge and displace residuum (±remnant trace element signatures) laterally into depositional landform areas that may overly unmineralized (barren) basement terrane. Mineral explorers should make themselves aware of all currently active and palaeo-active erosional landforms or areas on their tenements prior to attempting any surface sampling for trace element assay. A failure to do this leads explorers to poorly distinguish (or not at all) between true anomalism (positive and negative) from false anomalism (positive and negative).

Eroding highly weathered protolith

There are a number of well exposed areas within the map boundary that lie in close proximity to existing public roads where eroding highly weathered protolith terrane (as saprolith ± pedolith) can be examined. Many of these sites are within Park boundaries where sampling will require authorisation, but non-destructive observations and photography are worthwhile recognition training exercises. Still other sites are much harder to approach by vehicle but an observer can do so relatively easily on foot. Those places are very instructive sites to visit and describe (*e.g.* 2.6 km E of Little Pinbong Rockhole, 547000E, 6750000N, Plate 3). Five eroding landforms adjacent to relict terranes are described below.

Eroding highly weathered foliated granite

Eroding highly weathered foliated granite (landform symbol: **EgS2**, *c.f.* RgS2) Saprolite: a pallid coarse-grained, quartz + kaolinite ± folded white to grey quartz veins. The saprolite retains relict texture and deformational foliation, its upper portions are typically Fe-megamottled and/or are Fe-stained dark red to red to orange and yellow-brown. Erosional slope terranes can be deeply incised to form 'badlands' near retreating escarpments but slopes become more gently undulating distally (Plate 3). Landform EgS2 represents highly weathered Tunkillia Suite orthogneiss. Vegetation is very sparse in badlands areas, limited to low shrubs and occasional grasses.

Eroding highly weathered granite

Eroding highly weathered granite (landform symbol: **EgS1**, *c.f.* RgS1) Saprolite: a pallid medium- to coarse-grained, quartz + kaolinite ± white to grey quartz veins. This saprolite retains relict texture and tectonic foliation, its upper portions are usually reddish to orange and yellow-brown Fe-mottled, and/or are Fe-stained. EgS1 is a rare crop out feature in this area due to the ubiquitous Pleistocene aeolian cover, however, it is exposed in a few roadside excavations. Erosion has commonly been by deflational fines loss or by alluvial sheet flow. This landform represents highly weathered Hiltaba Suite granite. Where subcropping, vegetation is either sparse woodland or of low shrubs and some grasses.

Eroding collapsed megamottle horizon

Eroding collapsed megamottle horizon (landform symbol: **EgQm**, *c.f.* RgQm & EgQd) Pedolith: a strongly coloured Fe-cemented material where megamottles have merged by partial profile collapse into a distinctive Fe-rich pedolith (terrane capping). This horizon is <0.5-1.5 m thick and commonly has an irregular base; typically the horizon is dark red to dark red-brown to brown and rarely is yellow-brown. Retreating slopes are deeply incised near escarpment edges and release dark to bright red sediment onto lower slopes via fluvial flumes or beds where sheet flow occurs. Deriving from extremely weathered Tunkillia Suite orthogneiss. Mostly unvegetated on steep slopes, or variably vegetated by low stature trees and shrubs.

Eroding pisolitic Fe-pedolith

Eroding pisolitic Fe-pedolith (landform symbol: **EgQd**, *c.f.* RgQd & EgQg): an Fe-rich pisolitic horizon <0.3-1.0 m thick, dark red-brown to brown and yellow-brown. Pisoliths on steep to moderate slopes are shed into soil by slope colluvial processes and alluvial sheet flow, leading to cutan breakage or loss. Upper parts may be calcreted and this can shed down slope as a conspicuous lag. A strong red-brown hue is imparted to any associated soils by this landform or where it is farm cultivated. Locally this landform is referred to as 'red-ground'. Deriving from extremely weathered Tunkillia Suite orthogneiss. Variably covered by stunted trees and shrubs.

Eroding brownish earthy grit

Eroding brownish earthy grit (landform symbol: **EgQg**, *c.f.* RgQg, & EgQd) Pedolith: an Fe-stained extremely weathered granite derived gruss, developed exclusively around Hiltaba Suite granite outcrop and subcrop. Reddish brown to strong yellow-brown, quartz grit ± kaolinite + haematite ± goethite, ~1.0-2.0 m thick. Where exposed or near surface, its top may be variably calcreted. On rolling downs south of Gawler Ranges National Park this landform is farm cultivated and forms dark orange loamy to sandy soils, slowly eroding via wind and slope alluvial sheet flow processes. Naturally well vegetated but poor where severely eroded.

Eroding colluvium

Two eroding colluvial landforms are described below. These are minor occurrences but their exposed profiles can provide significant information on landform internal structure and sometimes on what substrate horizons or regolith zones define the eroding colluvium base and thickness.

Eroding debris flow

Eroding debris flow (landform symbol: **Ecdf**, *c.f.* Dcdf): a gravity assisted mass wasting colluvium, loosened material from steep slopes. Ecdf landform terrane is exposed through erosion around the NW escarpment fringed margins of the large northern playa (Plate 44). Grain size ranges from clay to boulders in a matrix supported framework. Material originally derived from Mt Sturt in one or more mass wasting or flow-slide events. Matrix is a red-brown sand-silt-clay mix where larger lithic clasts or fragments are angular to rounded and unweathered. Ecdf is <1->4 m thick and where eroding it rests unconformably upon pallid saprolitic Tunkillia Suite orthogneiss. Erosion of fines is leaving a conspicuous lag consisting of pebble to boulder sized clasts on erosional surfaces. Poorly to unvegetated on erosional terrane.

Eroding piedmont slope deposits

Eroding piedmont slope deposit (landform symbol: **Ecps**, *c.f.* Dcps). Located on the southern flanks of Mt Sturt, the primary landform is dominantly a colluvial long-term mass wasting-fan deposit located on moderately steep to low angle slopes. It has an orange to red-brown sandy clay matrix with variably abundant clasts of Mt Sturt protolith (porphyry). Erosion of Dcps to form Ecps terrane is minor but will in time become significant. Any mass clearing of trees by either natural or human-made processes, will induce more significant erosional gullying because the clay matrix is of a dispersive (sodic) type that will dramatically respond to flowing water (as is evidenced where currently eroding; *c.f.* Northcote and Skene, 1972 and Northcote, 1979). There is nodular calcrete present in the soil B_{Ca} horizon but this too is highly erodable when exposed. Poorly to unvegetated where eroding.

Eroding Aeolian Landforms

There are only two eroding aeolian landforms of note, they are described below. Although of minor occurrence, the exposed profiles provide information on parent landform internal structure and grain size variation with depth.

Eroding orange sand dunes

Eroding orange sand dunes (landform symbol: **Ee-1**, *c.f.* De-4): this landform terrane occurs where the parent dune (De-4) is either deflating or being alluvially eroded by sheet wash processes. These dunes may be overlying deeply weathered basement and therefore the erosion provides a window to that substrate. Surface lags of calcrete are usually only seen where sand is well eroded. The terrain can be gently undulating to locally gullied or sculptured to form steeper slopes. Some 'badlands' terrain occurs where dune cores are clayey or are pervasively cemented by earthy calcrete. Commonly eroded areas are poorly vegetated by shrubs and grasses or are bereft of vegetation.

Eroding gypsum lunettes

Eroding gypsum lunettes (landform symbol: **Eegl**): this feature can be seen most commonly on the outward facing flanks of some gypsum lunettes (*c.f.* De-7) but can also occur to a lesser degree on the internal flanks (playa side) where internal drainage to a pan–playa is eroding back into the surrounding rises. The white to pale grey seed gypsum ± gypsum flour (kopi) ± gypcrete ± clay erodes to form minor 'badlands' terrain fringing landform De-7. This feature is more common around the large SW playa system but has also been observed to particularly affect palaeo-lunettes where new gypsum input via aeolian transport is no longer available. Where erosion occurs an indurated gypsum capping several millimetres thick is usually present and this may exhibit micro-karstic solution features like rillen, a highly pitted surface, or pot-holes and tubes. This terrane can be very treacherous to drive vehicles over because the crust is thin and may be underlain by low-density highly collapse prone kopi. Poorly grass-vegetated to bare ground.

Duricrusts

Four main duricrust types occur in the Wudinna north area, they all represent cementation overprinting of a pre-existing substrate by air-borne and water-borne salts, either locally sourced during weathering or migrated into the profile from external sources (*i.e.* calcrete and gypcrete). All duricrusts described herein have been generated within a pedolith zone, however, some now represent an exhumed or exhuming palaeo-pedolith (ferruginous and silcrete). On the accompanying Regolith Landform Maps only the ferruginous duricrusts are displayed as distinct named landform polygons (see next section) while those of gypcrete, calcrete and silcrete are indicated by overprint symbols within their host regolith material.

Ferruginous

The various ferruginous duricrusts in the Study Area form readily mappable and quite distinct regolith components, they include: Collapsed Megamottle Horizon – RgQm; Pisolitic Fe-pedolith – RgQd; and the Bog-iron Dl-4. These could have been collectively termed and mapped as "ferruginous duricrust" or 'ferricrete' but were not treated as such herein, nor on the Regolith Landform Maps. To have adopted a bulked or grouped approach to describing these very different ferruginous materials could lead to serious geochemical interpretive implications that may be quite misleading. Full accounts of the individual items are therefore provided earlier under their respective mappable names–landform tags (RgQm, RgQd, Dl-4).

Gypcrete

Gypcrete (landform symbol: **Cg**): a chalky to moderately compact to crusty gypsum ($CaSO_4 \cdot 2H_2O$) cement, typically pale grey to pale yellowish grey but may sometimes be white (Plate 56). In some areas it can form an interlocking crystalline mat of 'fish-tail' crystals, or a more indurated capping to powdery gypsum (kopi). Usually gypcrete is localised near to or within playas, or on the crests to lower flanks of gypseous lunettes. Thickness can range from <100 to ~500 mm. The low density kopi form can be treacherous terrane to cross with heavy machinery or narrow wheeled vehicles. Typically gypcrete is non vegetated.

Plate 56: White crusty gypsum invading orange longitudinal dune sand from an overlying greyish gypseous lunette landform. Agars Lake, NW corner. Hammer scale is 300 mm long.

Calcrete

Calcrete (pedogenic carbonate) or regolith carbonate accumulations (landform symbol: **Cc**): can form a significant duricrust that may consist of laminated sheets or massive zones to nodular aggregates (Plates 29, 58). These may form natural surficial exposures in erosional terrain around some playas and minor alluvial channels, or calcrete can be observed in artificial exposures (road cuts, borrow pits, cultivated land and where very recent deflation now operates). Opportunistic exposures occur at fallen tree 'throws' (Plate 57) and where animal burrows penetrate this material. Usually very pallid to pale yellowish, and more rarely pink or orange to reddish; calcrete naturally occurs at depths of 200-550 mm within a soil B_{Ca} horizon, although surface outcrop and lag may present where an area is eroding. Calcrete developed on or within landforms RgQd or RgQm commonly exhibits incorporated Fe-rich fragments and pisoliths (Plates 27, 28, 58-61). In more porous host materials, like sand dunes, calcrete rarely forms a duricrust but may still be present in appreciable quantities as thick earthy zones (>2-3 m, Plates 51, 52) or more rarely forms distinct rhizomorphs that once did or still do encase plant roots (Plates 54, 62).

Any particular calcrete horizon may involve one or many episodes of carbonate dust input, as well as, multiple pedogenic modifications and biotic reworking. These horizons are always younger than their host substrate–landform. There is strong isotopic evidence for all calcrete developed in southern Australia having been derived from a marine source, and transported inland as dust and aerosols (Sr^{87}/Sr^{86} & $\delta C^{13}{}_{PDB}$; Lintern *et al*., 2006). The same isotopic data indicate terrigenous modification by plants and soil biota. Additional physical evidence for calcrete containing aeolian carbonate dust, derived from a marine source is the presence of silt sized marine microfossils (forams, shell & Bryozoan fragments; see Petrography section) and reported from elsewhere in South Australia (Phillips and Milnes, 1988; Phillips, 1988).

Calcrete has become a popular geochemical sample medium for gold exploration in areas of regolith cover in southern Australia since the middle 1990's (Au-in-calcrete methodology) and is usually sampled for that purpose at or within its upper profile (top ~200 mm) by spade excavation and either G-pick or crowbar hammering, or more rarely by auger drill sampling (Lintern and Butt, 1993; Edgecombe, 1997; Lintern, 1997; McQueen *et al*., 1999).

Typically calcrete is non vegetated where exposed by deflation or fluvial erosion but can have abundant Bluebush (*Maireana sedifolia*) inhabiting areas where calcrete is thinly soil clad.

Silcrete

Silcrete (landform symbol: **Cs**): is dominantly a siliceous cementation of pre-existing host lithotypes and in this area is only of the pedogenic type. Groundwater silcrete is not known to occur within this area. Typically silcrete is greyish to yellowish but may even be orange, red to red-brown or intensely brown, where megamottles or a ferruginous host have been silica overprinted. Silcrete is generally very hard and splintery but if only incipiently developed it may be a far less competent rock type. Accessory minerals and lithic inclusions present in varying amounts, these can include: fine-grained anatase ± relict zircons ± opaque heavy minerals ± entrapped quartz vein fragments and remnant quartz grit ± colluvial and/or alluvial quartz (the latter two components apply only to silicified sediments). Silcrete sometimes displays internal banding parallel to the original pedogenic surface. Locally its thickness ranges from ~0.1 to ~0.5 m ± an underlying incipiently silicified zone of up to ~0.4 m thick (Plates 63, 64). Mostly developed within the quartz grit-rich arenaceous zone of highly weathered felsic lithotypes and possibly within some of the older sedimentary deposits (Neogene and older). Areas where silcreted megamottles were observed include: within the escarpment-fringed small playas ~2.6 km E of Little Pinbong Rockhole (GPS: 546846E, 6367920N), exposed in a borrow pit ~250 m S of Little Pinbong Rockhole (GPS: 543997E, 6366745N), and as blocky float (<300 mm diam.) along the eastern shores to the large northern playa (GPS: 542196E, 6371540N) (Plates 64-67).

Previous geological mapping by Blissett *et al*. (1988a, b) indicated silcrete outcrop was more widely distributed than has proven to be the case, while some outcrop was not recognised by them. Silcrete exposures depicted on the accompanying regolith maps are relatively rare, but silcrete does have a much wider subsurface distribution, as has been demonstrated by mineral exploration drilling. It is also likely to be much more thickly developed within palaeochannel granular sediments where it may also encompass laterally interdigitating groundwater silcrete.

Plate 57: A fallen tree 'root-throw' exposure of calcrete, Pinkawillinie Conservation Park near S boundary with Waters Rd and E of Bartley Rd.

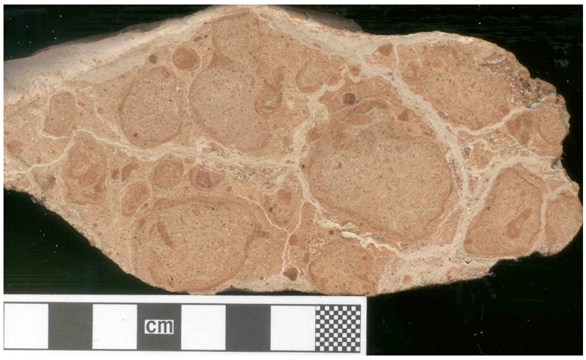


Plate 58: Complex calcrete in slab section, displaying re-cementation of nodules and pisoliths. This calcrete occurs as sheet and boulders in the mapped area's central parts. (Sample R977119). *C.f.* Plates 81-88.

Plate 59: Calcreted Fe-fragment-rich pedolith in roadside borrow pit ~350 m south of Little Pinbong Rockhole. (See also Plates 27, 28).

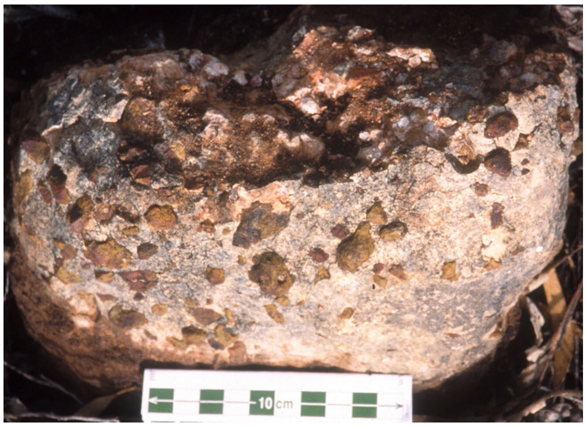


Plate 60: Calcrete lag boulder encapsulating Fe-rich fragments, released from the subcropping collapsed megamottle horizon. Baggy Green Au prospect.

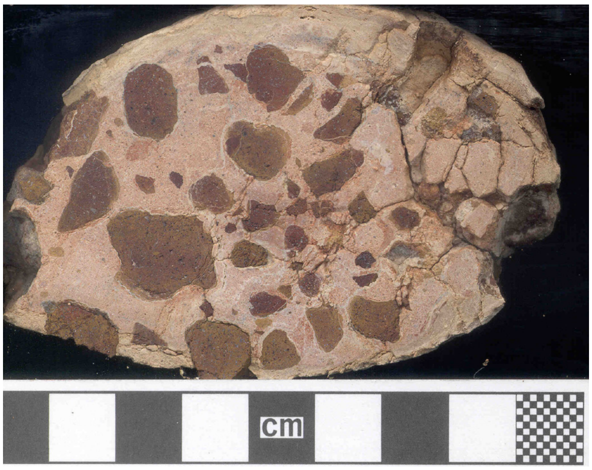
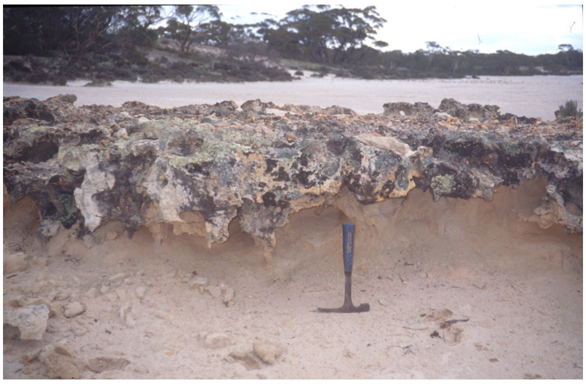


Plate 61: Slab section through a calcrete lag cobble revealing the entrapped ferruginous fragments derived from the underlying collapsed megamottle horizon. Baggy Green Au prospect. Sample R977111. *C.f.* Plate 80.

Plate 62: A fragile and porous calcrete rhizomorph fragment from the yellowish longitudinal dune profile exposed by a temporary dozer trench at Barns Au prospect. Pen scale is 135 mm long.

	
Plate 63: Silcrete cap developed in an arenose zone (pedolith), on saprolitic Tunkillia Suite orthogneiss. Here silcrete armours an eroding low rise. (GPS: 537914E, 6375018N). Hammer scale 300 mm.	**Plate 64**: Silcreted arenose zone (pedolith) on saprolitic Tunkillia Suite orthogneiss; an eroding playa platform. Silcrete is 300-450 mm thick with an irregular top and bottom. (GPS: 537614E, 6375592N). Hammer length 300 mm.

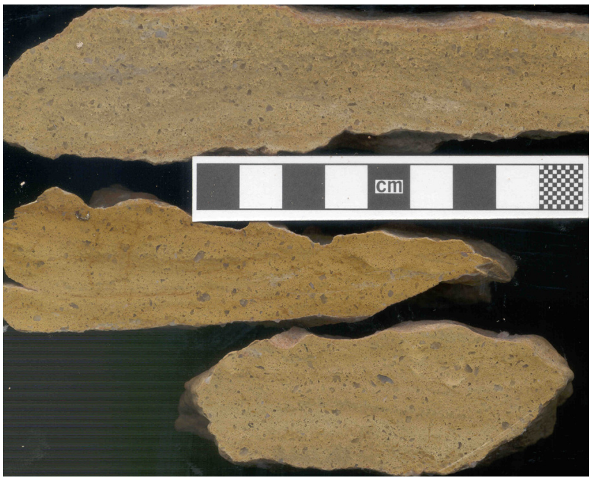



Plate 65: Slabs of silcreted colluvium and arenose pedolith collected from the outcrop depicted in Plate 64. (Samples R977102 to 977104).	**Plate 66**: Slabs through ferruginous silcrete developed within megamottled fluvial sediment ~2.6 km E of Little Pinbong Rockhole. Samples R977108 to 977110).
Plate 67: Slab section through a silcreted megamottle developed within saprolitic Tunkillia Suite orthogneiss exposed in a roadside borrow pit ~200 m S of Little Pinbong Rockhole. (Sample R977120).	

Evidence from elsewhere in South Australia indicates there have been at least three major episodes of silcrete development, which affected landscape surfaces in the Late Cretaceous, early Palaeogene and mid to late Neogene times based upon host rock ages and basinal stratigraphy (Sheard and Callen, 2000; Lintern and Sheard, 1999; Mason and Mason, 1998). On cratonic areas this series of silicification episodes have commonly overprinted each other to form one complex massive silcrete horizon. The occurrence of massively silcreted megamottle zones indicate that silicification post dates the megamottling, and also that erosion had exposed those megamottle zones to near-surface pedogenic modifications – suggesting a significant antiquity for megamottling in this area.

Typically silcrete is non vegetated unless highly fractured, whereupon some shrubs and grasses may inhabit the fractures. Silcrete may also host ubiquitous lichen patches on long exposed surfaces.

PIMA infrared spectra analysis

PIMA Analysis of 38 samples included those from playa sediments (majority), palaeochannel clay (2), dune sand with fines (2), soil (1) and saprolite (4). Some of the playa muds are so black that they don't reflect back enough infrared signal for reliable mineral identification. Sample locations are marked on Figure 9.

During field work the author noticed that after light rains some playa clays were very sticky under foot, and when manually textured, those clays were highly plastic to plastic (samples R1039937, 1039941, 1039942, 1039945, 1039946, 1039948-1039951, 1039957). While in adjacent playas similar clays by appearance were neither particularly sticky nor plastic (samples R1039936, 1039938-1039940, 1039963, 1039944, 1039947, 1039952-1039956, 1039958-1039964). This feature indicated a possibility that different clays may be included and therefore, either a variety of source materials could be involved, or a variety of depositional-diagenetic processes were operating across this landscape. In order to test that hypothesis selected samples were collected for PIMA spectral analysis. Some potential source materials were also sub-sampled to ascertain their clay mineral species assemblages. PIMA spectra, sample data and indicated mineralogy are provided in Volume 2, Appendix 3.

Playa sediments have PIMA spectral indicators for the following minerals in varying degrees of abundance: gypsum (± ?anhydrite), halloysite, kaolinite, illite, K-alunite + Na-alunite, ?palygorskite and muscovite. Halite and quartz grains are also present but do not reflect infrared absorption features recognised by the PIMA sensor. Most of the indicated mineral species were expected and do appear in some or many of the playa muds but K-alunite (potassium aluminium sulphate; samples R1039937, 1039941, 1039942, 1039945, 1039947, 1039956, 1039958, 1039964) occurred at eight quite separate playas (all in the western half of the area) but Na-alunite was only indicated from one site (also in the western area; sample R1039944). Alunite may indicate that acid groundwater has or is emanating from oxidising buried palaeochannel sediments containing diagenetic sulphides (as exhibited by sample R1039966) or that oxidising sulphides hosted by deeper protolith are releasing acidic waters into low lying areas.

The sticky character of some playa floor clays when wet may be due to the presence of halloysite and illite, but PIMA spectral evidence for this is not clear or is contradictory regarding any confidence from such a small sample population. However, clay particle size could be the more likely candidate where ultra fine clays typically display high cohesion and high plasticity (*c.f.* Cainozoic clay analyses reported by Sheard and Bowman, 1996). The presence of muscovite in one sample from near the large L-shaped NW playa may indicate a nearby saprolith source. Two small crop outs of Hiltaba Suite saprolith do occur N of that playa. Palaeo-playa sediments (samples R1049962-1049964) appear to be no different to their modern day equivalents, although once again the number of samples was quite low by comparison (3 *vs* 30).

Palaeochannel clays are PIMA spectra dominated by smectite (montmorillonite) + halloysite and K-alunite (samples R1039965, 1039966). Sample R1039966 also indicated the presence of K-alunite, suggesting acid groundwaters or the oxidising of diagenetic sulphides within the fluvial sediments may be the source for such secondary mineralization. The greenish colours (gleyed) and high plasticity commonly displayed by those materials is consistent with abundant smectite content (*c.f.* Cainozoic clay analyses reported by Sheard and Bowman, 1996).

Orange longitudinal dune cores (clayey sand) have montmorillonite and gypsum indicated (samples R1039972, 1039973). Montmorillonite was unexpected as a binding agent, rather than the more commonly observed kaolinite or illite (in dunes elsewhere), those clays are more abundant in exposed eroding saprolite than is smectite. Exposed palaeochannel sediments may therefore be a prime candidate source for that smectite, possibly transported by wind as parna, then dispersed and illuviated well into the dune interiors by meteoric water seepage.

Sub-soil within highly weathered gruss (brownish earthy grit of landform RgQg) derived from Hiltaba Suite granite has PIMA spectral indications for halloysite and montmorillonite (sample R1039934).

More samples would need to be analysed to allow comment regarding any difference in weathering products between Hiltaba Suite granite and Tunkillia Suite orthogneiss.

Saprolitic materials (pallid) derived by weathering Tunkillia Suite orthogneiss have PIMA spectral indications for kaolinite (both well and poorly crystalline) plus halloysite (samples R1039929-1039931, 1039934, 1039935). A sample of saprolite taken from saprolitic Tunkillia Suite orthogneiss reflected good absorption spectra for well crystallised kaolinite (sample R1039930). Similarly for one of the megamottled saprolite samples excavated from below the Barns prospect dune (sample R1039931). Micas, gypsum and alunite were not indicated in any of these pallid saprolites.

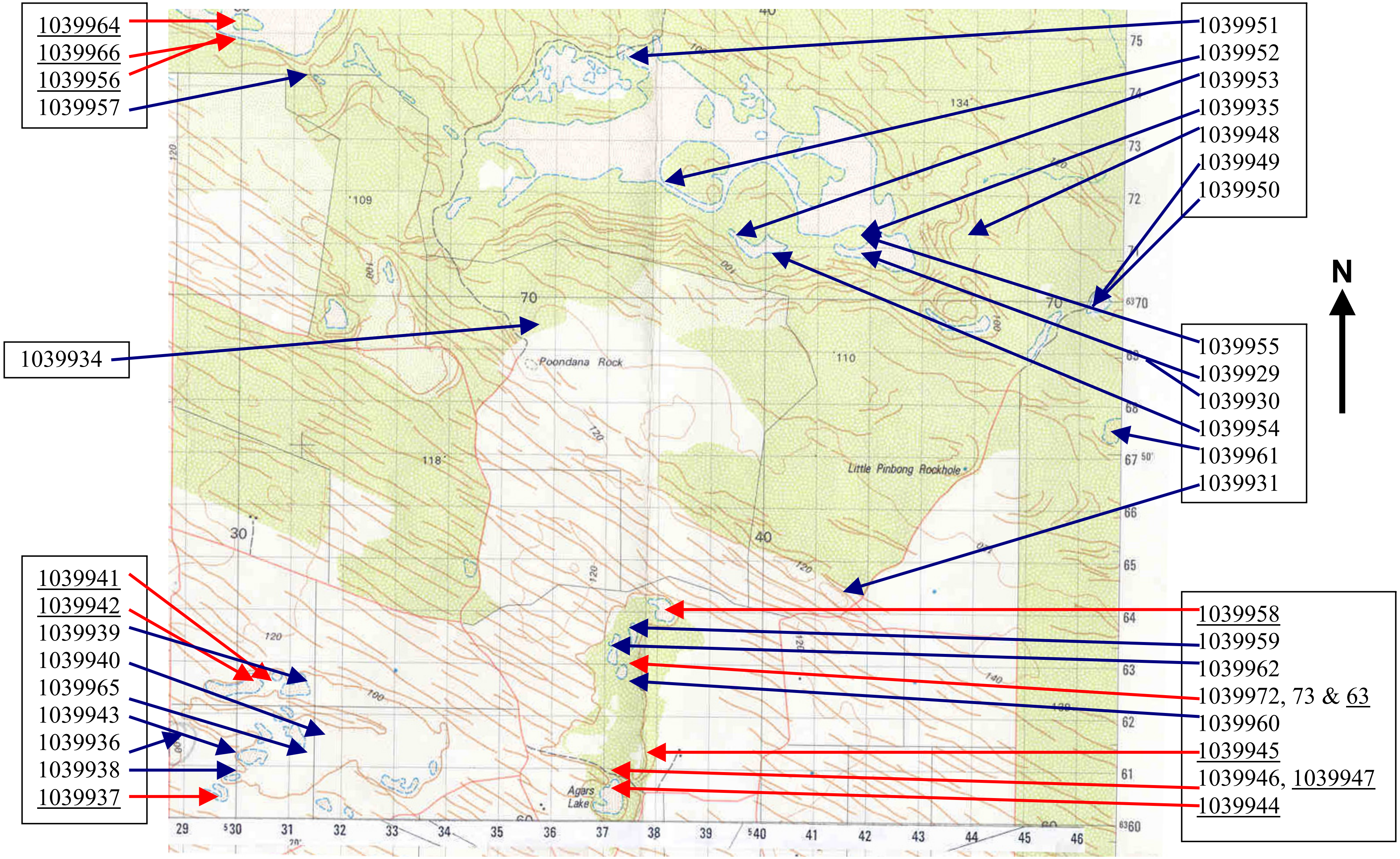


Figure 9: Extract from the Minnipa 1:100,000 topographic sheet, samples collected for PIMA mineral analysis have approximate locations indicated by the arrows and sample R-number. Those with underlined numbers + red arrows are sites where alunite was indicated by PIMA spectra. Grid squares = 1 km.

Petrography

Standard thin-sections and large format thin-sections (50x75 mm) were prepared for 22 regolith samples. In addition, two epoxy resin mounted blocks for samples of loose granule-fragments were polished to permit examination of the opaque components by reflected light microscopy. Full petrographic descriptions are provided in Table A4-1 (Volume 2, Appendix 4). The following paragraphs are a synopsis derived from those descriptions but with photomicrograph plates added where appropriate.

Sedimentary Regolith

Six samples exhibited robust alluvial-fluvial grain characteristics under moderate magnification (R977100, 977101, 977108 to 977110 & 977115). Palaeochannel sands with well rounded quartz grains and a high sediment maturity are represented by samples R977100 and 977101 (Plates 68, 69), but sample 977115 (Plates 70, 71) also contains near source gravelly to pebbly angular colluvium – suggesting it formed very close to the river bank-cliff area. All three samples have been strongly overprinted at a later time by black dense FeOx-MnOx cements, under a strongly reducing paludal environment yielding Bog-iron rock.

Samples R977108 to 977110 represent fluvial sediment where most grains display a high sedimentary maturity (long transport history, Plates 66, 72-74). However, sample R977108 also contains appreciable colluvium suggesting a depositional site where less mature sediment was washing in (a river bank proximal area). All three samples have been overprinted by later silica and titaniferous cement to form silcrete (see next section).

Duricrusts

A number of duricrust materials were examined in thin-section, the ferruginous varieties are discussed under the *In situ Regolith* heading below.

Silcrete

Silicification of regolith was observed in both sedimentary and *in situ* weathered regolith (pedolith, megamottled saprolite and pallid saprolite). Silicification to massive silcrete was the most commonly observed form but incipient silicification yielding a more indurated regolith was noted occurring below the main duricrust at some locations. The sedimentary cases have been described above (samples: R977100, 977101, 977108 to 977110 & 977115). It is worth comparing them with the *in situ* weathered regolith varieties described below.

Samples R977102-977104, 977117, 977120 are all silicified *in situ* weathered regolith (Plates 65, 67, 75-79). Dominating those are silcreted collapsed arenose zones (lower pedolith) composed chiefly of angular quartz grit ± minor amounts of colluvial subrounded to rounded quartz. Embayed quartz grain edges suggest grain etching by acid fluids – possibly the very same fluids that carried in amorphous silica–titaniferous cements (QAZ). Rock textures range from dominantly grain supported to less common matrix supported. All or most fines were probably removed by pedogenesis during zone collapse and the remaining interstitial clays were replaced by QAZ cement. Sample R977104 is less well cemented and represents the incipient form of silicification sometimes observed to underlie massive silcrete.

Sample R977120 (Plates 67, 78, 79) exhibits a silcreted megamottle complex, developed within pallid saprolitic orthogneiss, where the QAZ cement has replaced most intergrain clays and/or sericite without textural disruption (isovolumetric), forming a matrix supported texture. A delicate web-like internal structure is well preserved within the Fe-megamottle. Samples R977108, 977110 and 977117 also display silcreted megamottling. These relatively uncommon examples of regolith multi-overprinting, within both sediment and saprolite, provide confirmation to a sequential order for these processes, *i.e.* megamottling must have preceded silcreting in this area.

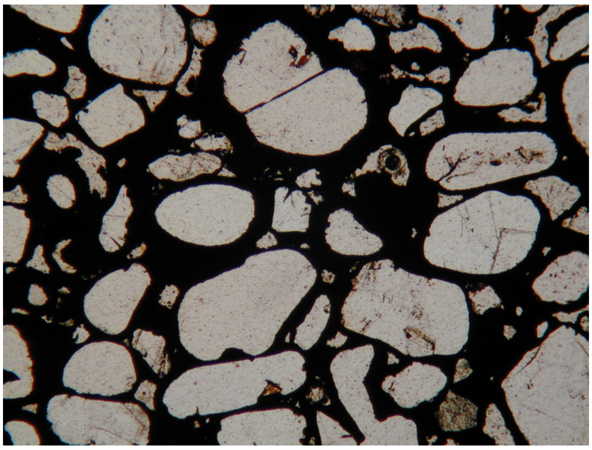


Plate 68: Bog-Iron cemented fluvial sediment in plane polarised light. Note quartz grain rounding, opaque FeOx cement, some grains have embayed etch pits, irregular pale brown grains are secondary silica. Sample R977100. Image width = 1.5 mm.

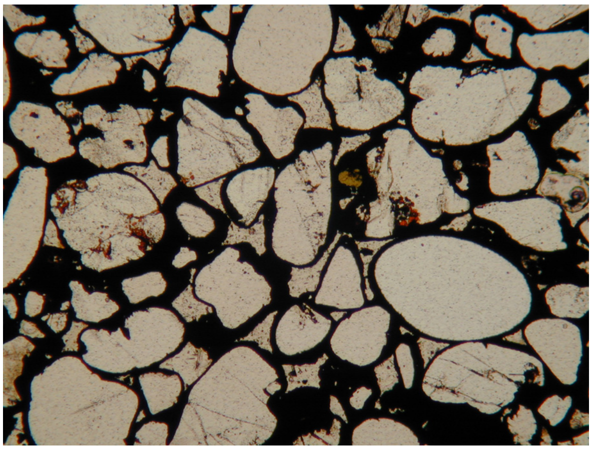


Plate 69: Bog-Iron cemented fluvial sediment under plane polarised light. Note quartz grain rounding and angularity, opaque FeOx cement, some grains have embayed etch pits, irregular pale brown grains are secondary silica. Sample R977101. Image width = 1.5 mm.

Plate 70: Bog-Iron cemented colluvium (slab) with angular saprolite + vein quartz clasts. Cement resembles that of the overlying fluvial sediment overprinted Bog-iron landform (landform symbol Dl-4). Sample R977115.

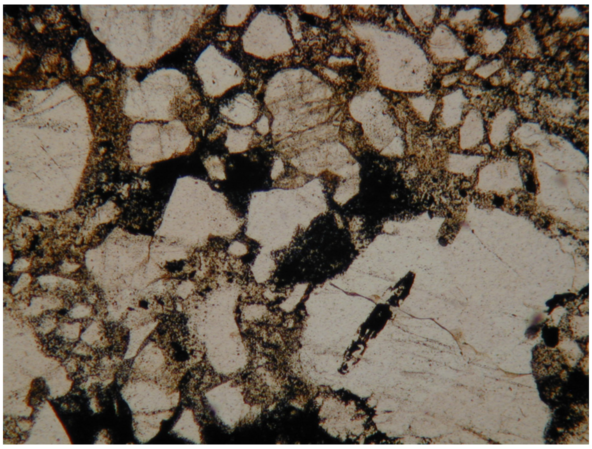


Plate 71: Bog-Iron cemented colluvium in plane polarised light. Note angular quartz grains, opaque FeOx cement, an edge of a large yellow-brown saprolite clast (*c.f.* Plate 70) occupies top RHS. Sample R977115. Image width = 0.8 mm.

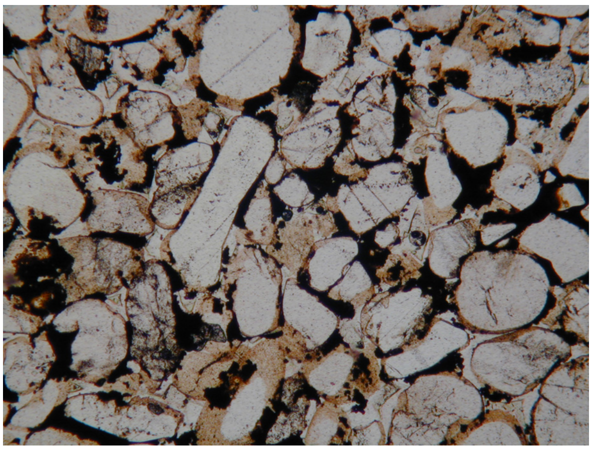


Plate 72: Silcreted sediment: alluvium + colluvium, in plane polarised light. QAZ cement is opaque and brownish with ragged edges. Sample R977108. Image width = 1.5 mm.

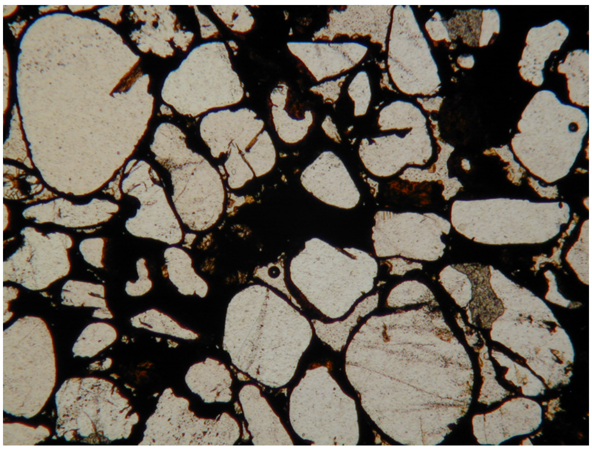


Plate 73: Silcreted fluvial sediment in plane polarised light. Well rounded-subrounded grains. QAZ cement: opaque to browns and ragged edges. Sample R977109. Image width = 1.5 mm.

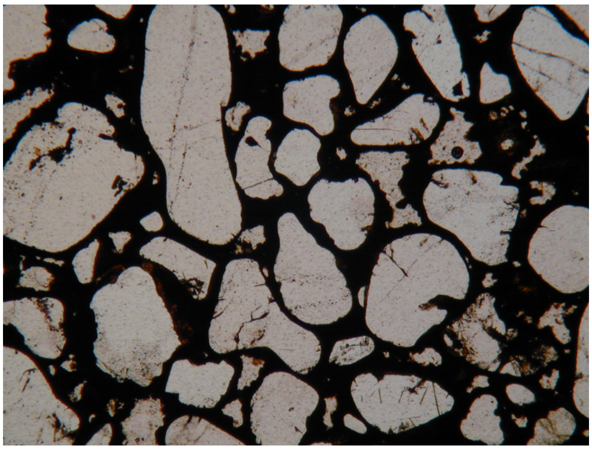


Plate 74: Silcreted fluvial sediment in plane polarised light. Quartz grains: subrounded-well rounded. QAZ cement is opaque + dark brown. Sample R977110. Image width = 1.5 mm.

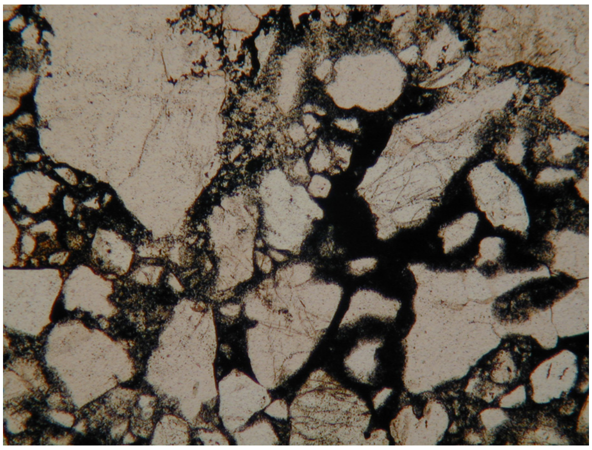


Plate 75: Silcreted collapsed arenose zone grit in plane polarised light. Angular quartz grains. QAZ cement: opaque + brownish, ragged edges. Sample R977102. Image width = 1.5 mm.

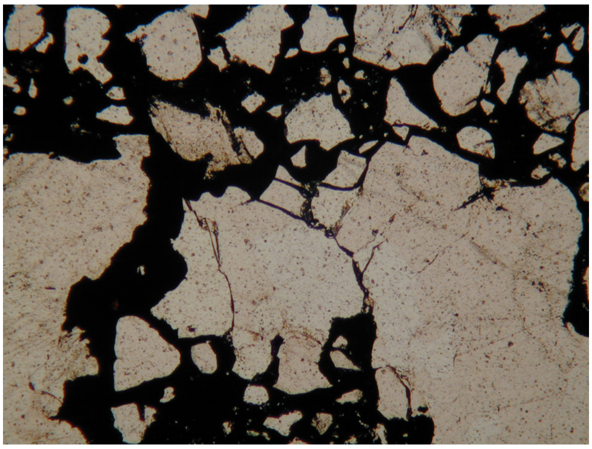


Plate 76: Silcreted collapsed arenose zone grit in plane polarised light. Jig-saw-fit angular quartz grains in a matrix supported texture. QAZ cement: opaque + dark brown. Sample R977103. Image width = 1.5 mm.

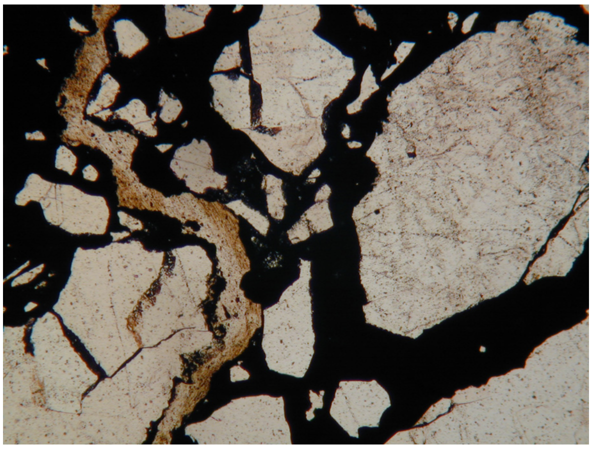


Plate 77: Silcreted collapsed megamottled arenose zone grit in plane polarised light. Jig-saw-fit angular quartz grains in matrix supported texture. QAZ cement: opaque + dark brown. Sample R977117. Image width = 1.5 mm.

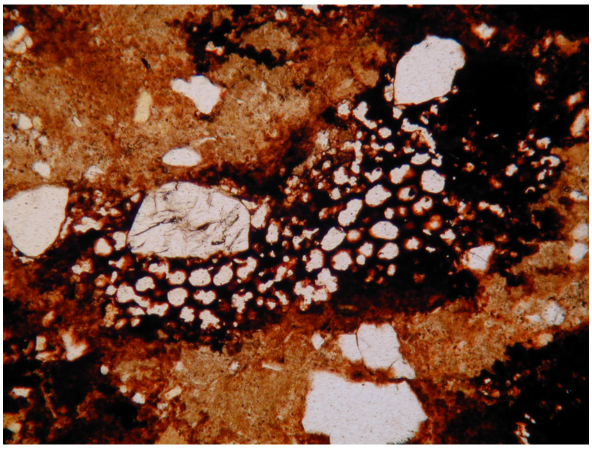


Plate 78: Silcreted megamottled saprolite in plane polarised light. Small angular quartz grains outline relict gneissic foliation. QAZ & FeOx cements are mostly opaque. QAZ cement + relict sericite + kaolinite are stained red-brown. Sample R977120. Image width = 1.5 mm.

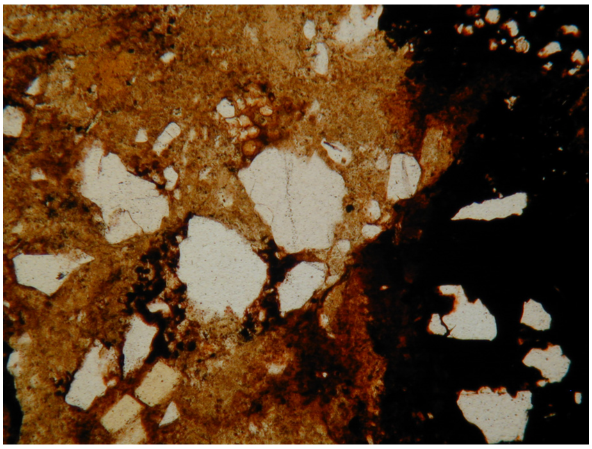


Plate 79: Silcreted megamottled saprolite in plane polarised light. Megamottle edge is captured right of centre. QAZ + FeOx cements are both opaque and variably stained red-brown (*c.f.* Plate 78). Sample R977120. Image width = 1.5 mm.

Calcrete

Two samples of calcrete were examined in thin-section, samples R977111 and 977119. Calcrete R977111 (Plates 60, 61, 80) is from an off-white carbonate boulder enclosing cm sized brown Fe-rich fragments derived from an underlying *in situ* ferruginous host (calcrete overlies part of Baggy Green Au prospect). This calcareous duricrust overprints a colluvial lithosol where wind + water-borne sand has been incorporated prior to pedogenic carbonate cementation into a $B_{\mathbf{Ca}}$ hardpan horizon (rubbly to sheet calcrete). An input of exotic dust from a distal coastal area is indicated by the presence of numerous identifiable foram and shell fragment microfossils. These present as: distinct discs (~0.2-0.5 mm) with coiled tube tests + many internal chambers, or as globular-lobate chambered tests, or as lattice-like or mesh-like forms. All are carbonate and most have a thin dark carbonate rind. *Lepidocyclina* sp. was identified, this was a benthic type (water depth of ~400 m) of marine foram of Lower to Middle Miocene age. *Globigerina* sp. was also identified, this was a pelagic type of marine foram known from sediments of Lower Miocene age (both forms are exotic components, wind blown in from the coast). Foram identification by L. Stoian, PIRSA Geological Survey—Biostratigraphy. Later deflation has exhumed and broken up this calcareous hardpan to form scattered surface calcrete float.

Sample R977119 is more typical of the ubiquitous calcrete of this area (Plates 58, 81-88). This is a complex nodule–pisolith agglomerate, pale cream to pink, that formed a partly exhumed block and sheet outcrop in a cleared cereal growing paddock. Calcrete here displays multiphase carbonate precipitation where pedogenic pisoliths are incorporated into larger nodules, and they have been later incorporated into a single aggregate to further merge into laterally extensive sheet calcrete. Different quartz grain morphology between pisoliths and nodules is very obvious under magnification and suggests nodule formation at several sites – possibly on sloping terrain – a notion supported by nodule cutan breakage. The whole rock suggests a migration of pisoliths and nodules down slope prior to final cementation into a single pedogenic duricrust. During carbonate cementation some lithic fragments were replaced by cryptocrystalline carbonate, preserving precursor mineral textures and partial metamorphic fabrics. Nearly a dozen relict foram tests and minute shell fragments were observed (~0.2-0.5 mm or smaller) as distinct discs with coiled tube + many internal chambers, or as globular-lobate forms, or as lattice-like forms, or fragments displaying parallel growth rings. All are carbonate and many have dark thin carbonate rinds. Fragments of *Lepidocyclina* sp. were identified, this was a benthic type (water depth of ~400 m) of marine foram known in sediments of Lower to Middle Miocene age. *Globigerina* sp. was also identified, this was a pelagic type of marine foram known from sediments of Lower Miocene age (both forms are exotic components, windblown in from the coast). Foram identification by L. Stoian, PIRSA Geological Survey—Biostratigraphy. These indicate an input of exotic dust from a distal coastal area.

Both samples have indicators for externally sourced carbonate (presence of marine microfossils). Externally sourced carbonate is a common component of calcretes throughout southern Australia (Butt, 1992; Phillips and Milnes, 1988, Phillips, 1988; Lintern *et al*., 2006). Both samples also exhibit minor surface karst indicating the dynamic nature of calcrete in regolith within this environment.

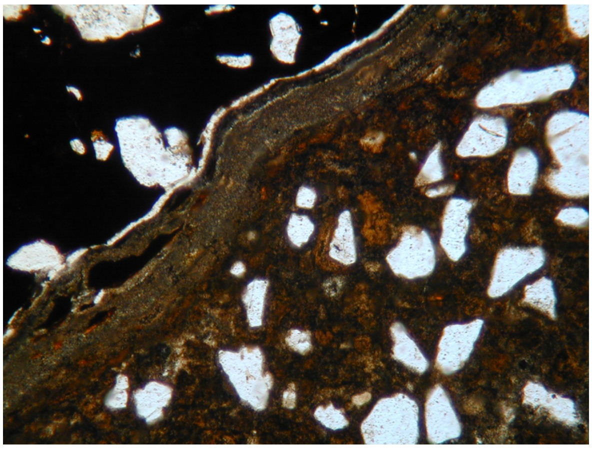


Plate 80: Calcrete enclosing ferruginous lag in plane polarised light. Lag clast (top LH corner) is laminar carbonate rinded. Aeolian quartz grains are trapped within the structureless calcrete. Sample R977111.
Image width = 1.5 mm.

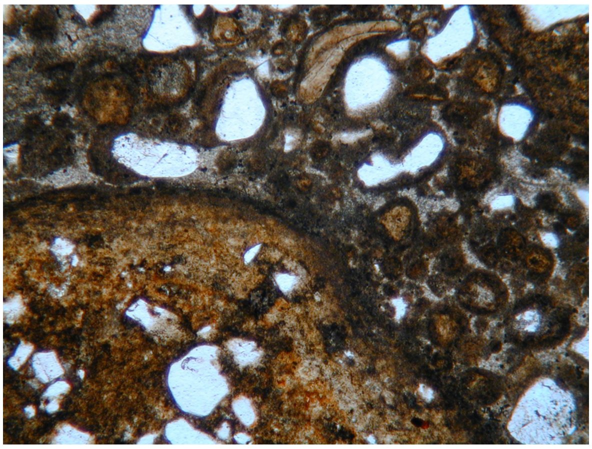


Plate 81: Calcrete nodule-pisolith aggregate in plane polarised light. Banded rind to pisolith (bottom LH corner). Entrapped quartz grain shape inside and outside the pisolith indicate differing sand sources involved. Sample R977119. Image width = 1.5 mm.

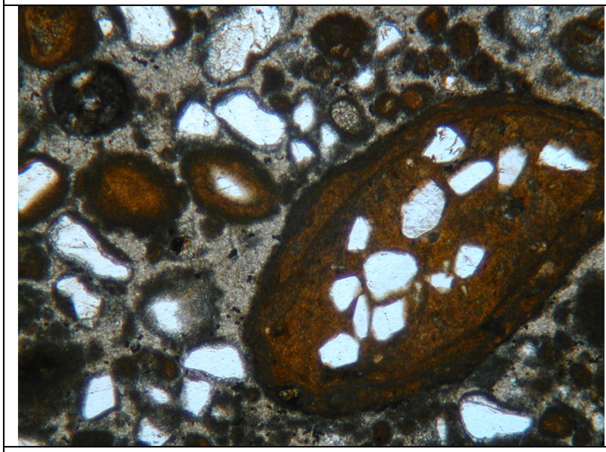


Plate 82: Calcrete pisolith aggregate in plane polarised light. Banded rinds to pisolith (centre right). Entrapped quartz grain shape inside and outside the pisoliths indicate differing sand-silt sources involved. Sample R977119. Image width = 1.5 mm.

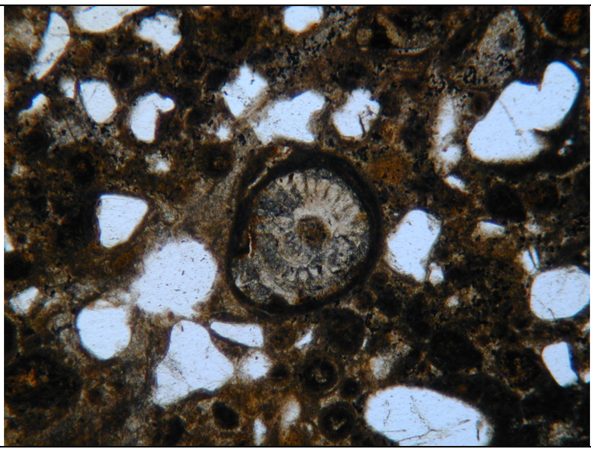


Plate 83: Calcrete sample R977119 in plane polarised light. Centre, a coiled and chambered marine foram test ?*Globigerina* sp. (Lower Miocene, planktonic type) a reworked exotic aeolian clast in a Quaternary duricrust. See enlargement in Plate 84. Image width = 1.5 mm.

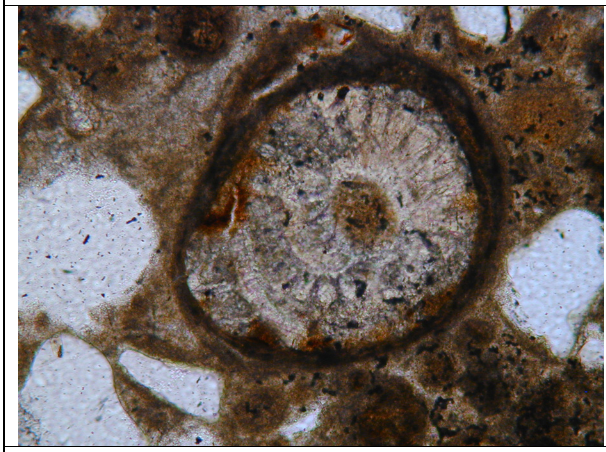


Plate 84: Calcrete sample R977119 in plane polarised light. Enlargement of Plate 83, the foram is rimmed by dark carbonate and is quite well preserved. Image width = 0.8 mm.

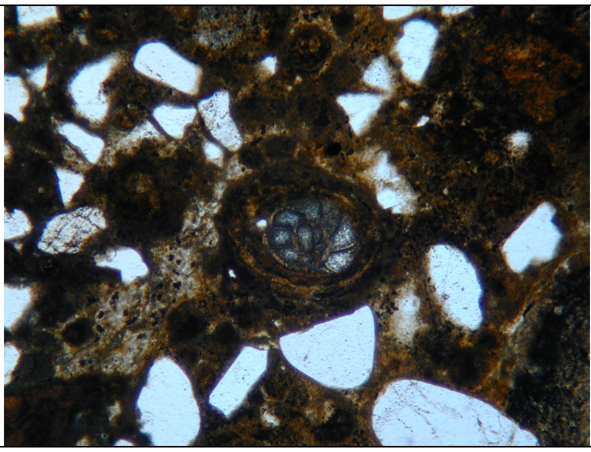


Plate 85: Calcrete sample R977119 in plane polarised light. Centre, a marine foram test ?*Globigerina* sp. (L Miocene, planktonic type) an aeolian reworked exotic clast in Quaternary duricrust. See Plate 86. Image = 1.5 mm wide.

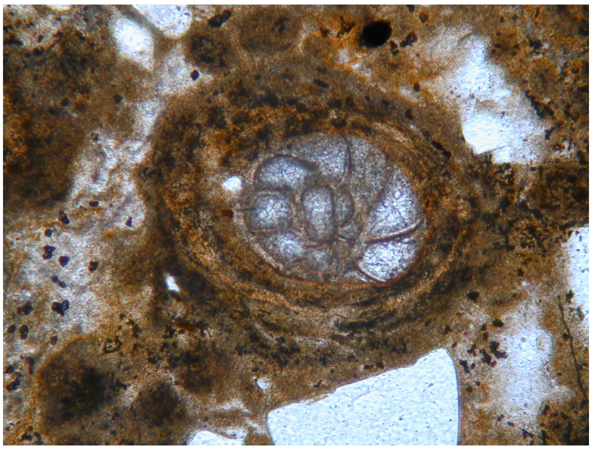
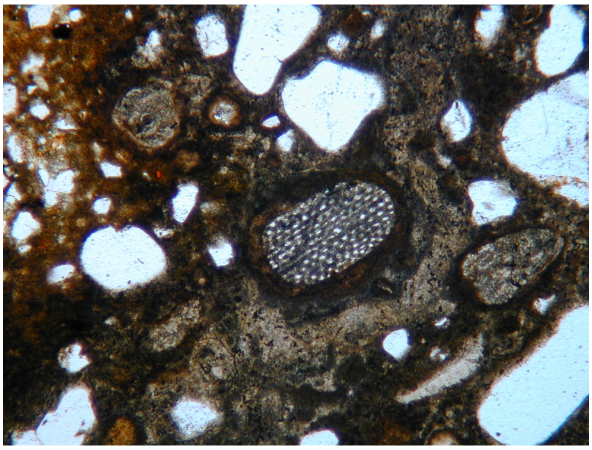
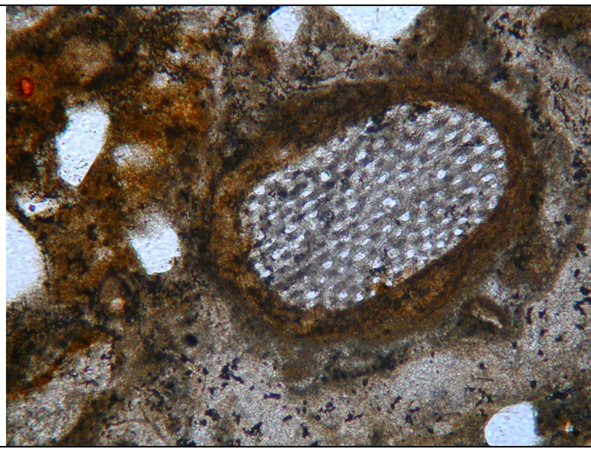
	

Plate 86: Calcrete sample R977119 in plane polarised light. Enlargement of Plate 85, the foram is thickly rimmed by a layered carbonate rind and its delicate features are remarkably well preserved. Image width = 0.8 mm.	**Plate 87:** Calcrete sample R977119 in plane polarised light. Centre, a marine foram fragment *Lepidocyclina* sp. (L-M Miocene, benthonic type) an aeolian reworked exotic clast in Quaternary duricrust. Image = 1.5 mm wide.
Plate 88: Calcrete sample R977119 in plane polarised light. Enlargement of Plate 87, this mesh-like foram fragment is rimmed by a dark carbonate rind and its delicate features are very well preserved considering the distance from source it has travelled. Image width = 0.8 mm.	

In situ Regolith

Many samples from this provenance display significantly different textures, regolith fabrics and grain morphologies to those of the Transported Regolith. These are important for landscape evolution modelling, interpreting geochemical signatures and are worth considering carefully – especially for colluvial and truncated profiles.

Pedolith

Fe-pisoliths

Sampling of an Fe-pisolith and Fe-rich clast bearing horizon was done for another purpose and was not intended to be used for microscope examination at the time. Therefore the sub-sample components are not ideal, but it did contain at least three fragments of an Fe-pisolith-rich goethite (sample R977113; Plates 27, 28, 89-94). These indicate that the sampled location is probably not far from a remnant residual highly ferruginous pisolite-rich horizon. One Fe-pisolith bearing aggregate, as a clast, contains many tiny goethitic pisoliths (<1 mm) and a few larger ones to ~4 mm, all have multiply banded rinds on complex cores and are cemented with more structureless haematite + goethite. Another reddish fragment contains sectioned tubules that are infilled with concentrically banded haematite (?fossil root channel or invertebrate burrow). Two other near black fragments contain dense goethite displaying a complex web-like fabric that typifies some bands within FeOx/FeOH-rich ‘lateritic’ cappings elsewhere in Australia (Anand, 2005; Anand *et al.*, 1993b).

This collection of sub-sampled fragments represent mixed source materials: collapsed megamottle horizon surface gravel lag + colluvial derived Fe-rich pisolith aggregates and complex band fragments thereof + soil fines. A short down slope mechanical transport history is obvious for some fragments, while others are lags derived *in situ*, the original lateritic duricrust source to some clasts is probably not far distant up slope.

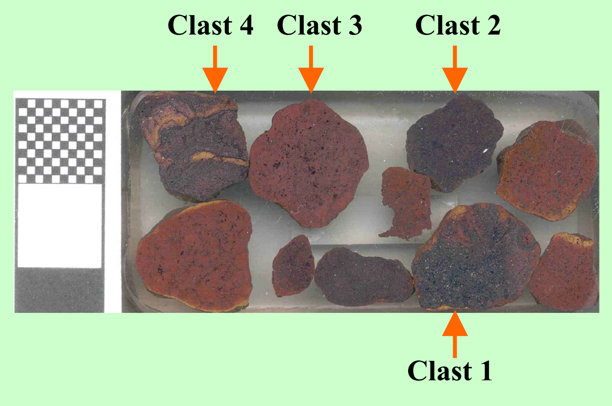


Plate 89: Polished mount of 10 ferruginous clasts from a fragmental pedolith horizon, S of Little Pinbong Rockhole. Arrows indicate to which clasts the next 5 micro-photos belong. Sample R977113. Scale bar: large squares = cm, small squares = mm.

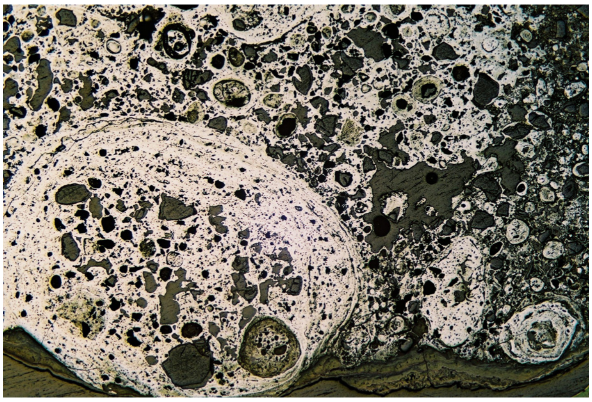


Plate 90: Clast 1 in reflected polarised light, *c.f.* Plate 89. Displays one large Fe-pisolith with banded cutan and grit-rich core + several smaller versions, all in a matrix of amorphous goethite + fine quartz grit. Pedolith, remnant clast. R977113. Plate length = 6.5 mm.

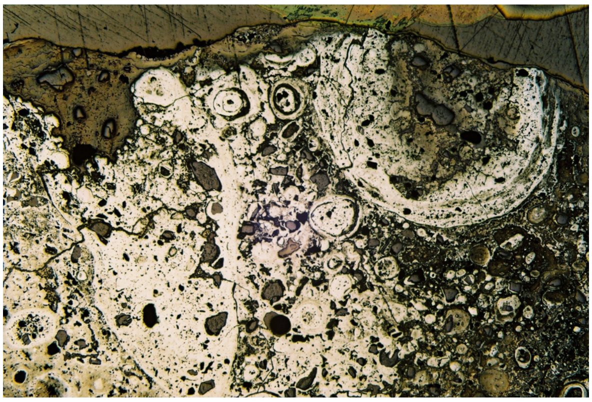


Plate 91: Clast 1 in reflected polarised light, *c.f.* Plate 89. This displays one large and many smaller Fe-pisoliths, all with cutans, + a fracture infilled by goethite. Angular quartz grit is also visible. Pedolith remnant clast. R977113. Plate length = 6.5 mm.

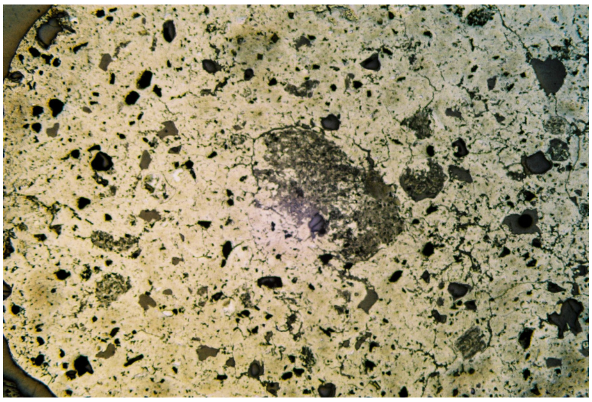


Plate 92: Clast 2 in reflected polarised light, *c.f.* Plate 89. Displays a dense less structured goethite mass containing angular quartz grit and ?ghosts of closely packed Fe-pisoliths. Pedolith, remnant clast. Sample R977113. Plate length = 6.5 mm.

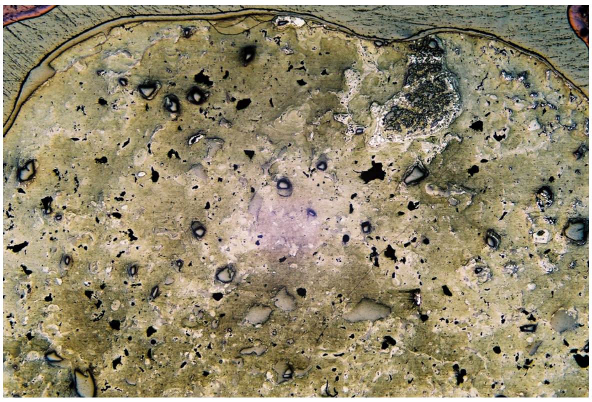


Plate 93: Clast 3 in reflected polarised light, *c.f.* Plate 89. Displays a relatively structureless haematitic mass with angular quartz grit + ghosts of relict metamorphic foliation (?saprolitic). Collapsed megamottle horizon lag fragment. R977113. Plate length = 6.5 mm.

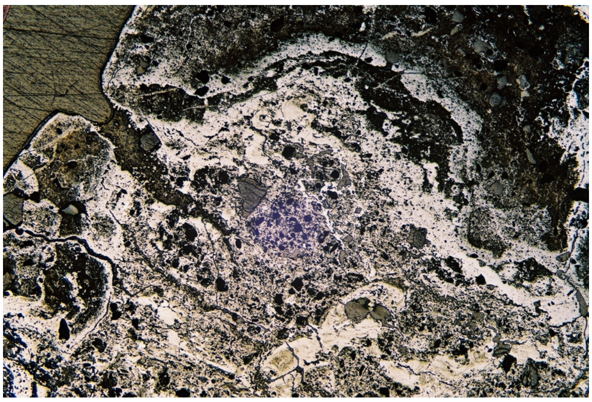


Plate 94: Clast 4 in reflected polarised light, *c.f.* Plate 89. Displays a complex internal web-like structure of goethitic filaments, fracture linings and ?ghosts of small Fe-pisoliths. Pedolith, remnant clast. Sample R977113. Plate length = 6.5 mm.

Arenose zone

Regolith of this type has been described above within the Silcrete section (samples R977102-977104, 977117) however, some arenose zones have been overprinted by other cements to form significantly different duricrust cappings and landscape features. Sample R977118 was collected from a collapsed megamottle zone ferruginous hardpan (Plate 95). It is a dense and heavy, near black haematite-rich megamottle with large cavities and vugs. Internal framework and texture is similar to the other arenose zone materials thin-sectioned, and consists of cemented angular quartz, as fine-grained silt to medium-grained grit + some subangular grit + rarer ovoid or rounded grains. Quartz grains are mixed, strained and unstrained, some contain micro mineral laths or flakes. Many quartz grains are embayed or edge etched. Rock framework is both grain + matrix supported. Matrix cement is dark reddish grey to black (haematitic), cryptocrystalline and dense. It infiltrates all grain fractures and has split multi-grain intergrowths into jig-saw-fit assemblages. This rock is a collapsed arenose zone with possibly some colluvial sediment input; it had few clay-sericite fines prior to cementation. Some grain etching by acid fluids occurred before cementation was completed.

Megamottles and collapsed forms

Megamottling has affected some pedolith horizons but is more commonly expressed, within the Study Area, in the upper saprolite. Partial profile collapse has preferentially aggregated megamottles into ferruginous pedolith horizons and these provide a variety of regolith products – especially at eroding escarpments. Samples R977109, 977110, 977117, 977118, & 977120 have already been described. Others examined in thin-section are samples R977105, 977114, 977116 (Plates 26, 96-98) plus granulated collapse lag equivalents R977112 and 977113 (Plates 89-94) described previously.

Typical megamottles in pallid saprolite display little or no disruption to the relict rock texture and metamorphic foliation, similar to those developed in arenose zones or sediment, although it is harder to detect subtle grain disruption in the latter materials. Megamottles are generally red but some brown and orange varieties were encountered. Where developed within pallid saprolite they retain much of the secondary kaolinite and illite after sericite, however, once megamottles enter a collapse horizon, where fines are being removed, then the iron percentage per mottle-block increases and becomes progressively denser (more opaque). Iron oxides also become remobilised into a new cementing agent, infilling pores, grain interstices and grain fractures – sometimes producing ‘exploded’ grains with jig-saw-fit textures. Capping many collapsed megamottle horizons are lag-gravel beds (100-500 mm thick; samples R977112 and 977113). These horizon caps can at first glance appear to be residual ferruginous pedolith (laterite), but careful examination by hand lens will reveal angular fragments that in colour and texture closely resemble underlying remnant megamottles. In some locations though, this lag bed does contain occasional to plentiful fragmentary remnant Fe-pisoliths (sample R977113), and therefore it may carry a remnant geochemical ‘ghost’.

Saprolite

A number of saprolitic materials were examined by thin-section, samples R977105, 977114 and 977120 have been described above. Although all have been overprinted by either mottling and/or silicification, their salient saprolite features remain quite strongly represented. Primary orthogneiss mineralogy, foliation and textures were best preserved in samples R977105 and 977114, while sample R977120 has more replacement of highly weathered components by later cementing agents but still retains conspicuous kaolinite + sericite (Plates 78, 79, 96, 97). A remarkable feature of these saprolites is the high degree of primary foliation, mica + sericite, and delicate structures that are preserved, in spite of on-going regolith processes. All indicate that weathering of weatherable minerals at this level, although very high, was close to isovolumetric and is not always complete throughout a particular zone or horizon.

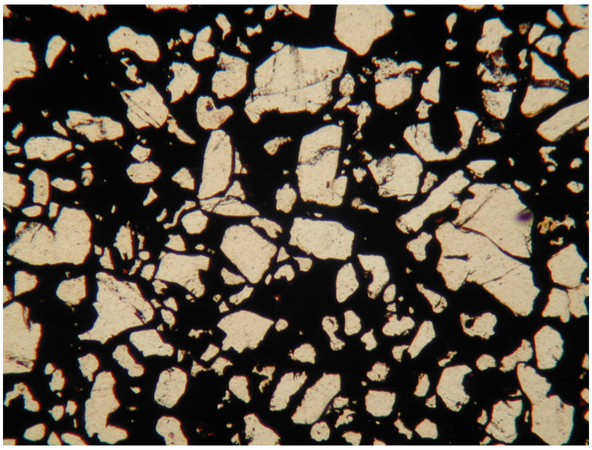


Plate 95: A densely FeOx overprinted collapsed arenose zone grit, here mostly as a matrix supported fabric. FeOx cement has totally replaced the original fine-grained matrix. Sample R977118. Image width = 1.5 mm.

Plate 96: Megamottled saprolite exhibiting well preserved gneissic foliation, now replaced by translucent illite + kaolinite + haematite. A large quartz grain appears on lower RH corner. Sample R977105. Image width = 1.5 mm.

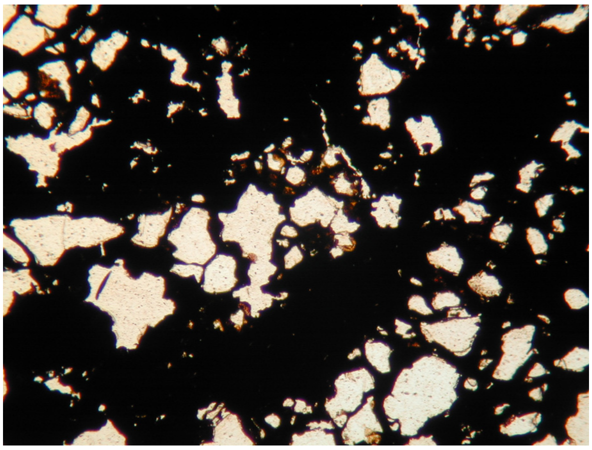


Plate 97: Megamottled saprolite exhibiting relict gneissic foliation via quartz grit chains. FeOx has replaced all sericite + kaolinite. Dominantly a matrix supported fabric. Weathering alteration and replacement have been isovolumetric. Sample R977114. Image width = 1.5 mm.

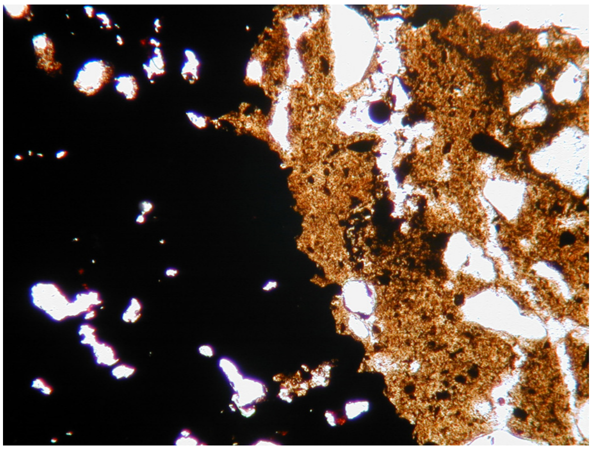


Plate 98: Megamottled saprolite, relict foliation preserved in quartz grit chains. FeOx replacement of sericite + kaolinite within black mottle, but weakly stains those minerals outside (brownish). Weathering alteration + replacement are iso-volumetric. R977116. Image 1.5 mm wide.

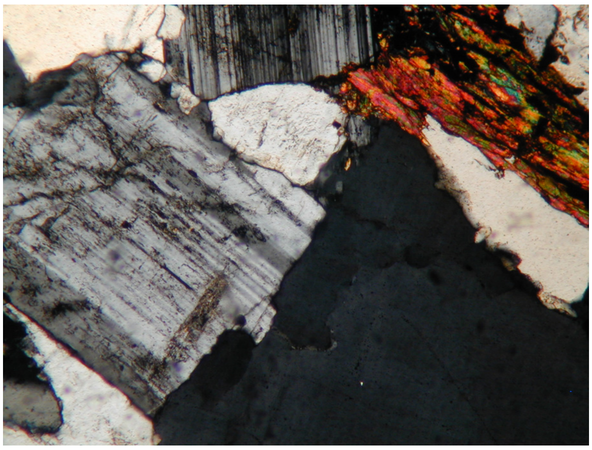


Plate 99: Hiltaba Suite granite, crossed polars. Coarse-grained microcline + plagioclase + biotite + quartz as an interlocked mass. Feldspars display minor sericite alteration. R977107. *C.f.* slab section in Plate 12. Image 1.5 mm wide.

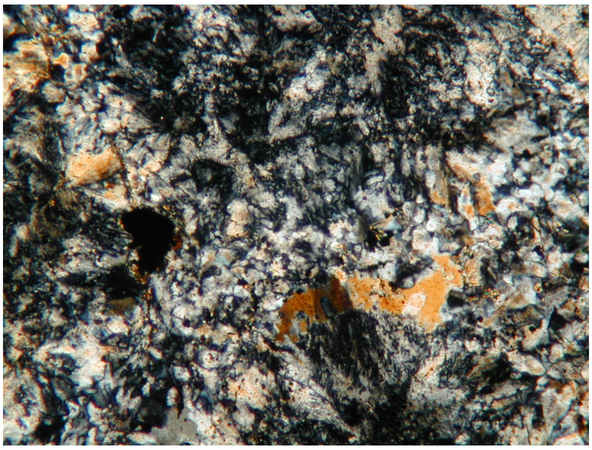


Plate 100: GRV felsic dyke, crossed polars. Pervasively altered aphanitic matrix + quartz phenocrysts (yellow), dominated by sericite after devitrified glass and feldspars. Sample R977106. *C.f.* Plate 13. Image width = 1.5 mm.

Protolith-saprock

Protolith and saprock are relatively rare at the ground surface in this area and in most cases their lithotype is obvious, where mineralogy can be easily recognised with a hand lens. No fresh samples of Tunkillia Suite orthogneiss were available due to cultural sensitivities regarding sampling from what limited outcrop sites there are. However, textures and metamorphic foliation within can be seen in the previously described weathered samples (Plates 78, 96).

Two basement rocks were examined in thin-section to determine their state of weathering-alteration (*i.e.* protolith or saprock), primary mineralogy and true lithotype. Hiltaba Suite granite (sample R977107; Plates 12, 99) has an incipiently weathered rind but a fresh sample under magnification exhibited most primary minerals as only slightly weathered-altered.

The felsic dyke rock of Gawler Range Volcanic (GRV) affinity was more surprising though (sample R977106; Plates 13, 100). In outcrop it appears as a relatively fresh rhyolite–rhyodacite, where it is hard and splintery when struck by hammer, and even retains a near vitreous lustre on freshly broken surfaces. Under thin-section examination this rock reveals itself to be strongly hydrothermally sericite altered, so that primary glass and feldspar phenocrysts are totally replaced. Only the quartz retains relict flow or mineral banding and hints at other igneous features. This alteration may explain why only tens of metres away, where other GRV related dykes are exposed by escarpment retreat within saprolitic Tunkillia Suite orthogneiss, that all present as strongly weathered pallid saprolite (kaolinite + quartz). A strong reason for this is that sericite is so easily weathered to kaolinite. Therefore the sampled dyke is a less weathered artefact of regolith development – similar to protolith and saprock corestones remaining well above the main weathering front (*i.e.* within saprolite or more rarely within pedolith).

Geochemistry & Interpretation

Resources available to this regolith study were insufficient to allow for extensive or even moderate new geochemical analyses. However, this area has been systematically calcrete sampled at a regional grid scale (1.6 km) and where appropriate, at localised infill scales (800 m, or 400 m; or <200 m over anomalism) by Adelaide Resources Ltd. They provided their near surface calcrete sample assay data to assist with this Study. Assays include the following elements and compounds: Ag, As, Au, Ca, Cu, Fe, Mg, Mn, Mo, Pb, Zn, estimated dolomite %, estimated calcite %, and estimated total CO_3%. From these data the following elements are considered to be the most interesting and are discussed below: Au, Ag, Cu, As and Ni. A spreadsheet of this open file data is available on the accompanying Data Disc CD-ROM. Element distribution and scaled values are plotted in A3 landscape format within Volume 2, Appendix 2 (Figures A2-1 to A1-5).

Gold

Gold values above 1 ppb are, in most cases, limited to areas where *in situ* regolith either crops out or subcrops below very thin transported cover (<1.0 m; *i.e.* Barns + Baggy Green Au prospects). Exceptions to this general rule for the Study Area are segments of buried palaeochannel just N of the Barns Au prospect (where cover exceeds 8 m) plus portions of the larger Narlaby Palaeochannel W of the Barns Au prospect and NE of the Baggy Green Au prospect (where in both cases cover exceeds 15 m). Gold grains have been panned out of drill cuttings (palaeochannel sand, gravel) from at least the first mentioned location (pers. comm. C. Drown, Adelaide Resources Ltd, July 2006).

Regional background Au values ranged from <0.1 to ~1 ppb (659 of the total 1657 samples; detection limit of 0.1 ppb). Gold values from calcrete developed in exposed or thinly covered *in situ* regolith typically ranged from ~1 to <30 ppb, and the 18 highest ranged from >30 to 69.5 ppb. Lower order Au values (<1.3 ppb) have also been detected in dune sand overlying the Barns prospect (Lintern, 2004b) suggesting, that with care and judicious interpretation, sampling calcrete from aeolian deposits may provide additional data on the location of buried higher order Au anomalism. The mechanism for such Au dispersal within relatively young and porous dune sand (~27,000 yBP) is biogeochemical according to Lintern and Rhodes (2005). A similar mechanism may also have been active over the placer gold, located deeper within the buried palaeochannel sediments, where immediately above surface Au anomalism has been demonstrated (see Geochemical Dispersal Models below).

Gold signatures seem to have been retained in areas where intact and remnant Fe-pedolith remain. Iron and the less abundant Mn within pedolith have probably scavenged once mobile gold during the deep weathering process, and retained it even though the upper saprolite has been entirely leached of any trace precious metal signatures. This pattern is especially obvious over the Baggy Green prospect and to a lesser degree over the Barns prospect. Release of this Au into calcrete developed on or within Fe-pedolith, through microbial and more recent pedogenic processes, is a strong possibility. Gold mobility and related biogenic influences in this area are currently the focus of a new AMIRA Project being conducted principally through CRC LEME participants in Perth, Western Australia.

There are a number of other elevated single point values where Au is in the range >5 to 30 ppb that warrant further investigation. Presently, it is impossible to adequately rank calcrete anomalies by assay value and expression within various host regolith materials because numerous additional factors are also influencing anomaly intensity and size. Those factors include: depth of source primary mineralization, thickness of cover materials, presence or absence of deep rooted vegetation, groundwater chemistry and pH (now and past), degree of residual profile loss by erosion, *etc*.

One of the anomalous highs occurs near Mt Sturt derived piedmont slope materials which over-ride upper saprolite developed in weathered Tunkillia Suite orthogneiss. Localised background values would also need to be determined, plus the degree of regolith profile preservation or truncation, in order to determine the validity of any single point assay result (*i.e*. true *vs* false).

Silver

Silver values >5 ppb (~1/3 of all samples) are, in most cases, limited to areas where *in situ* regolith either crops out or subcrops below thin transported cover (<2 m; *i.e*. Barns + Baggy Green Au prospects). Exceptions to this general rule for the Study Area are segments of buried palaeochannel just N of the Barns Au prospect plus portions of the larger Narlaby Palaeochannel W of the Barns Au prospect and NE of the Baggy Green Au prospect.

Roughly a third of samples fall within the range >6 to 30 ppb, while 17 samples fall within the highest range >31 to 153 ppb. Some of those occur near Mt Sturt protolith and its flanking piedmont slope materials, which tend to over-ride upper saprolite from weathered Tunkillia Suite orthogneiss. Other high Ag values occur randomly, external to known mineralization, and a few are associated with remnant Fe-pedolith in the defined Barns + Baggy Green Au prospects. A broader spread of the lower order Ag values (<5 ppb, 1034 samples) is apparent and this is the main difference between Ag and Au distributions for this area.

Importantly, according to Adelaide Resources Ltd, there is very little Ag in any of the primary mineralization encountered through drilling below the weathering front. Therefore silver's higher than expected concentrations within near surface calcrete is anomalous in itself. Moreover, why Ag is so surficially mobile in this generally hostile alkaline–sodic environment is not immediately clear and requires further investigation to resolve.

What may have occurred is a scavenging of any free Ag by ferruginous pedolith and/or saprolite hosted megamottles. A subsequent release of Ag within the active pedogenic zone by both mechanical and/or microbial processes, as either clast entrapments or soluble chelated electrolyte complexes (pH buffered) may have then been incorporated within the calcrete horizon through host substrate cementation plus evapotranspiration precipitation.

Copper

Copper distribution seems to mimic that of Ag but here Cu is even more widely dispersed. Copper values >5 ppm (~2/3 of all samples) are, dominantly expressed in areas where *in situ* regolith either crops out or subcrops below thin transported cover (<4 m; *i.e*. Barns + Baggy Green Au prospects). However, this is partly an artefact of the more closely spaced sampling and may prove less so if the entire area was sampled at the same density. Exceptions to these observations are segments of buried palaeochannel just N of the Barns Au prospect plus portions of the larger Narlaby Palaeochannel W of the Barns Au prospect and NE of the Baggy Green Au prospect where Cu is as pronounced in concentration as Au and Ag.

Roughly a half of all samples fall within the range >5 to 20 ppm, while 47 samples fall within the highest range of 21 to 65 ppm. Some of those occur near Mt Sturt protolith and its flanking piedmont slope materials which have over-ridden upper saprolite developed in weathered Tunkillia Suite orthogneiss. Other high Cu values occur randomly external to known mineralization and a few are enclosed within the defined Barns + Baggy Green Au prospects. A broader spread of the lower order

Cu values (<5 ppm, 512 samples) is apparent and this is the main difference between Cu and Au distributions for this area.

Why Cu seems to have been so surficially mobile in this generally hostile alkaline–sodic environment is unclear and remarkable, it requires further investigation to resolve. It may, like Au and Ag, be scavenged by Fe-pedolith and/or saprolite hosted megamottles, then subsequently released during weathering processes within the active pedogenic zone (where later calcrete developed).

Copper does seem to be linked to Au over the known Au prospects, however away from those, the distribution is more random and less clear as to a likely source.

Arsenic

Arsenic distribution pattern generally mimics those for Au, Ag and Cu. Arsenic values >2 ppm (<1/4 of all samples) are dominantly expressed in areas where *in situ* regolith either crops out or subcrops below thin transported cover (<2 m; *i.e.* Barns + Baggy Green Au prospects). However, this is partly an artefact of the more closely spaced sampling previously mentioned. Exceptions to these observation are segments of buried palaeochannel just N of the Barns Au prospect plus portions of the larger Narlaby Palaeochannel W of the Barns Au prospect and NE of the Baggy Green Au prospect where As mimics Au, Ag and Cu in distribution.

A major difference though is the outlining of Sleaford Complex paragneiss subcrop in the SE Map corner. However, the Ni distribution seems to provide a much better indicator of where that lithotype actually occurs subsurface (*c.f.* Ag, Au and Cu data).

Roughly a quarter of all samples fall within the range >2 to 20 ppm, while only 14 samples fall within the highest range of 20.1 to 45 ppm. For a commonly utilised “pathfinder element” As seems not to be very useful in this environment because it does no better at locating Au, Ag or Cu than do these elements alone.

Nickel

Low level Ni distribution generally mimics those for Au, Ag, Cu and As. Nickel values >6 ppm (>1/2 of all samples) are, dominantly expressed in areas where *in situ* regolith either crops out or subcrops below thin transported cover (<2 m; *i.e.* Barns + Baggy Green gold prospects). However, this is partly an artefact of the more closely spaced sampling rather than a real effect. Exceptions to this observation are as previously stated: segments of buried palaeochannel just N of the Barns Au prospect plus portions of the larger Narlaby Palaeochannel W of the Barns Au prospect and NE of the Baggy Green gold prospect. A major difference though is the clear outlining of Sleaford Complex paragneiss subcrop in the SE Map corner (*c.f.* As, Ag, Au & Cu data). Nickel may therefore be of use as a major intrusive boundary indicator where Archaean metasediments are presumed to subcrop in this region.

Greater than 1/3 of all samples fall within the range >6 to <10 ppm, while <1/4 fall between 11 to 15 ppm, and only 35 samples fall within the highest range of 16 to 26 ppm. Sources for Ni in this area may include firstly; mafic protolith, this occurs as dykes within the mineralized areas but those dykes do not crop out or retain an obvious presence within the leached pallid saprolite zone (refer to Figure 6). During weathering those dykes may have released trace Ni into an Fe-rich pedolith zone where it could be scavenged by FeOx and MnOx minerals. Secondly; ultramafic protolith is not known from this area, therefore such rocks are unlikely primary sources for Ni mineralization here.

Like Cu, Ni would not normally be mobile within this generally hostile alkaline–sodic environment. It is highly likely that, like Cu, Au and Ag, it is scavenged by ferruginous pedolith and/or saprolite hosted megamottles then subsequently released during weathering processes within the active pedogenic zone (hosting calcrete development).

Nickel does seem to be moderately linked to the Au + Ag + Cu anomalism over the two known Au prospects and associated palaeochannel hosted placers, however away from those sites, the distribution is dispersed and somewhat random, except for the SE corner where it highlights exceptionally well where subcropping Sleaford Complex occurs, the presence of which has been previously demonstrated by geophysics and drilling.

Geochemical Dispersion Models

Lintern (2004b) plus Lintern and Rhodes (2005) have demonstrated that the prime vertical dispersal of Au in the Barns prospect locality seems to be facilitated by trees (mainly: *Eucalyptus* sp., *Acacia* sp., *Melaleuca* sp.) these have extensive root systems seeking out deep moisture from porous regolith sources during arid seasons and extended drought. This mechanism is particularly highly developed by Mallee vegetation on dunes, where meteoric water can pond deep within the sand above its unconformity with typically more clayey substrates (pedolith or saprolith). An example of such vegetation and exposed roots is provided in Plate 2 where a deep trench was cut into the 'Barns dune' to examine its core, sample for OSL dating, expose the basal unconformity and to give access for geochemical sampling. Gold and other elements, converted into soluble forms (salts + chelates) by microbial and pedogenic processes, are thus absorbed by plant roots and pumped to the surface, then into extremity tissues (leaves, twigs and bark). There any absorbed and trace metals are eventually shed via dead tissue fall off, back into the surficial plant litter (soil A_0 + A_1 horizons) where, through microbial breakdown processes, any contained trace metals are released to be recycled back into the dune profile. Evopotranspiration then co-locates Au with Ca into pedogenic carbonate where it builds up micro-traces over time into a measurable metal content.

A set of four element dispersion models for various transported cover thickness situations were developed for the CRC LEME "*South Australian Regolith Project*", where geochemical and regolith characteristics from 16 individual regolith study sites (evaluated between 1996-2001) have been distilled into a series of practical models (Lintern, 2004a). These are re-presented herein as Figures 10 to 13 without modification. While these were developed to cover the widest spectrum of variations encountered in South Australia during those studies, all four models are very applicable to the Wudinna north suite of regolith terranes. Use of these models in conjunction with the accompanying Regolith Landform Map and a GIS multi-layered approach may further assist interpretations of geochemical dispersal and surficial trace metal anomalism in this area.

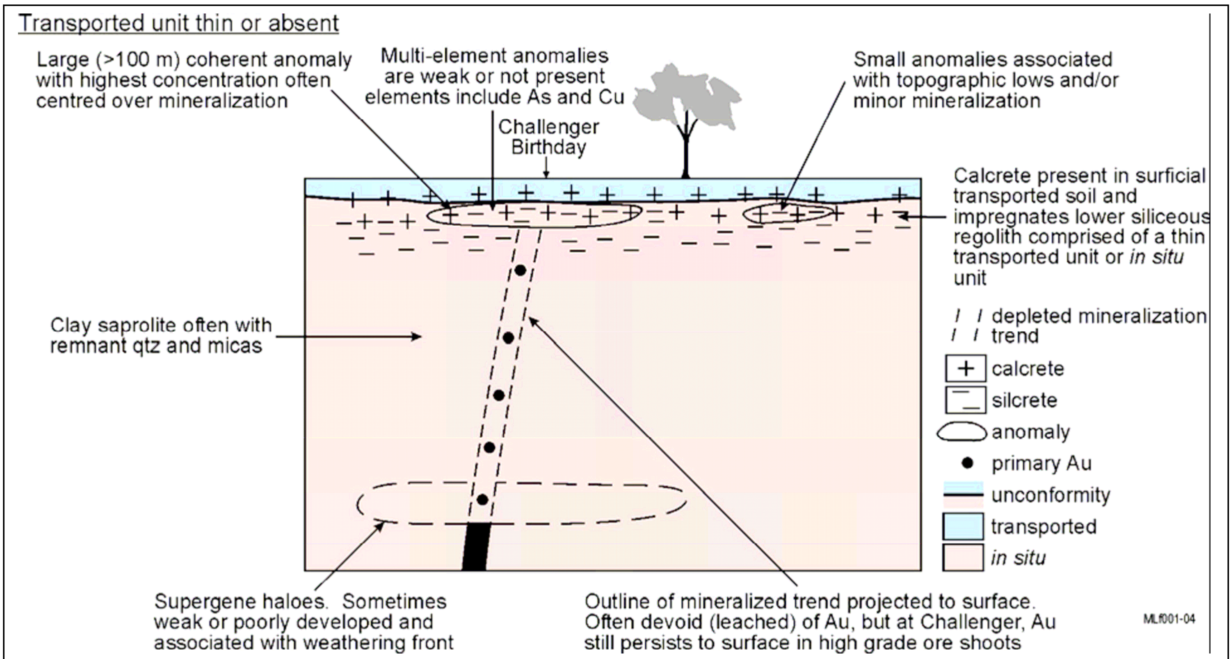


Figure 10: Geochemical dispersal Model 1, for areas of zero to thin transported cover overlying *in situ* weathered materials, as proposed by Lintern (2004a). This model is applicable to situations over the central portions of Barns and Baggy Green Au prospect where significant surface geochemical anomalism occurs.

Continued overleaf.

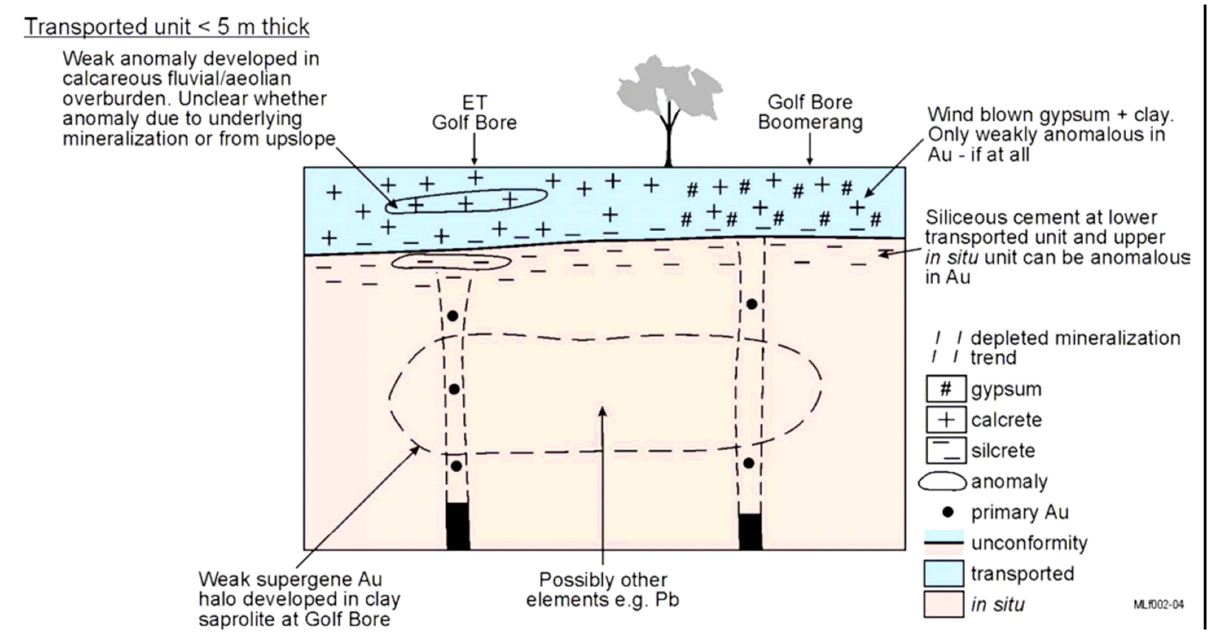


Figure 11: Geochemical dispersal Model 2, for areas of thin (<5 m) transported cover overlying *in situ* weathered materials, as proposed by Lintern (2004a). This model would be applicable to situations over the peripheral portions of Barns and Baggy Green Au prospects where some surface geochemical anomalism occurs.

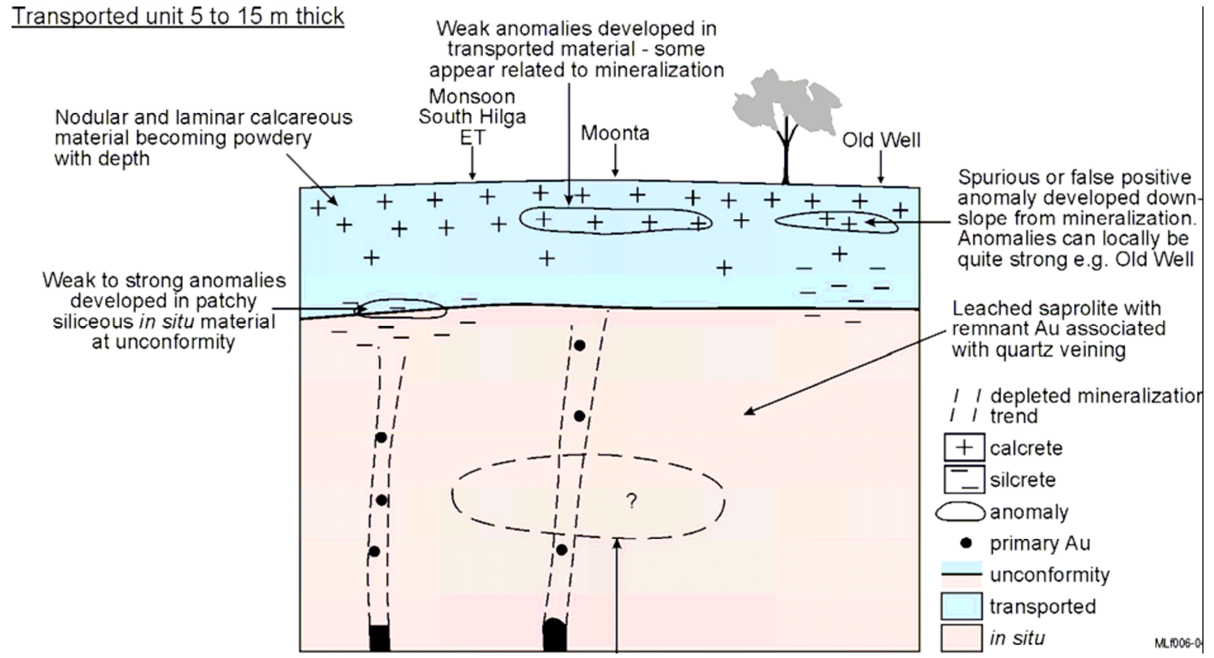


Figure 12: Geochemical dispersal Model 3, for areas of thin to moderate (5-15 m) transported cover overlying *in situ* weathered materials, as proposed by Lintern (2004a). This model would be applicable to situations over portions of the Barns and Baggy Green Au prospects where: aeolian dunes, or thin fluvial sediments, or debris flows occur and would significantly affect any surface geochemical anomalism potential.

Continued overleaf.

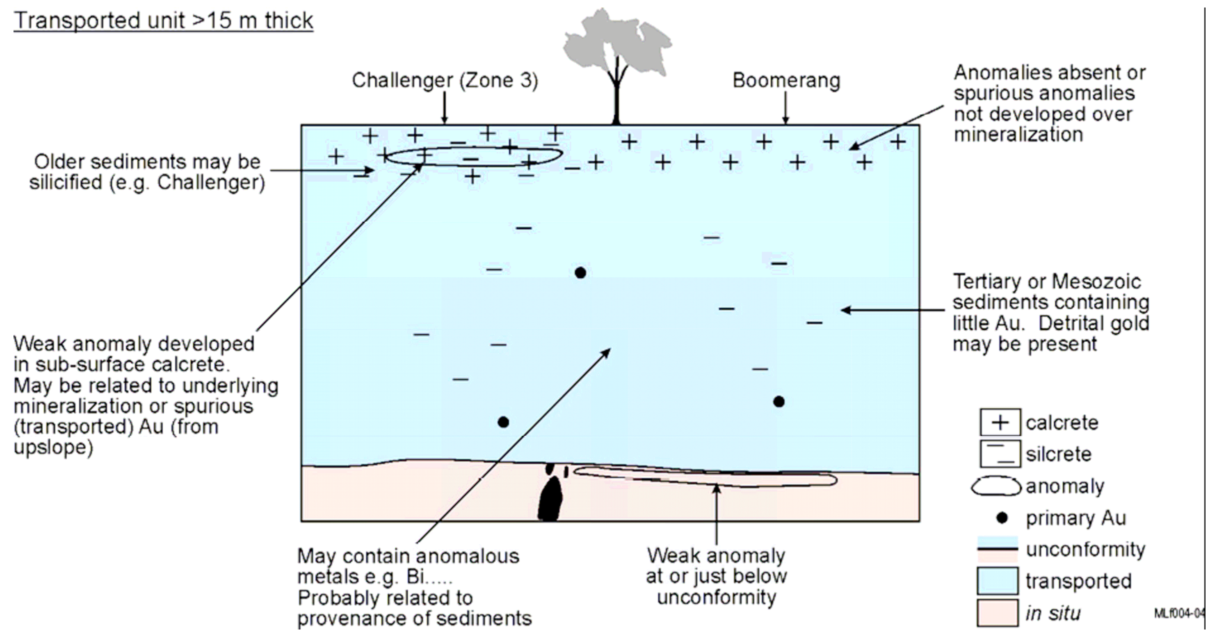


Figure 13: Geochemical dispersal Model 4, for areas of moderately thick (>15 m) transported cover overlying *in situ* weathered materials, as proposed by Lintern (2004a). This model would be applicable to situations over portions of the Barns and Baggy Green Au prospects where: tall aeolian dunes, or large lunettes and lakeside dunes, or buried fluvial channel sediments occur and significantly affect any surface geochemical anomalism. The activity of biogenic "pumping" by deep rooted trees may negate the natural blanket-blocking affect of the thick cover materials, as demonstrated by Lintern (2004b) plus Lintern and Rhodes (2005).

Regolith-Landform Maps and Explanatory Notes

Only four areas of the Gawler Province have been regolith mapped: three within the Christie Domain, Craig and Wilford (1997a, b), Wilford *et al.* (2001), Craig (2001); and one in the Harris Domain, Sheard and Robertson (2003). The first three have employed mapping databases, methods and formats promoted by Geoscience Australia (referred to by the regolith landform database acronym RTmap). The fourth map utilised the 'RED scheme' promoted by CSIRO Exploration and Mining and AMIRA (explained below). Both systems have been used widely elsewhere in the eastern and western parts of Australia. Craig (2005) has summarised those methods and their success or failings, along with how to compile regolith maps, best practice and potential pitfalls.

Outcomes from the three RTmap based regolith maps (Christie Domain) are firstly, that some important regolith landscape components were neglected or omitted – especially the 3D element; and secondly, those three maps have been poorly utilised by the exploration industry. Suggested reasons for this given by exploration company people and other users include the following:

- Transported cover on deeply weathered basement in South Australia is commonly of unknown thickness, of varied provenance, and can be quite extensive. The presence and thickness of these landforms need emphasis.
- Some outcrop patterns are hidden or disguised by the inappropriate choice of map symbols, colour schemes, overprints and landform polygon tag complexity.
- The polygon tagging is commonly cumbersome, requiring constant reference to the symbol key and/or a good memory; those therefore needs simplification.
- Depth of transported cover and/or depth to unweathered basement information is typically lacking despite abundant open file exploration drill logs and data being available since the 1980's.
- Regolith cross-sections, block models or regolith architecture relationship diagrams or benchmarks would aid understanding and interpretation but these are commonly missing on regolith maps.
- An improved understanding of regolith terminology by the intended users would improve acceptance and uptake of regolith mapping in general.

Taking those points in hand, Sheard and Robertson (2003, 2004) revisited the earlier and highly practical approach for regolith mapping, as developed by CSIRO Exploration and Mining and AMIRA for the Yilgarn Craton (Anand *et al*. 1993a, b) *i.e*. the 'RED scheme' (Relict-Erosional-Depositional). That original regolith mapping scheme, was modified for the Harris Greenstone Regolith Project in 2002, to better fit regolith presentation on the Gawler Province by incorporating aspects from other regolith mapping techniques. Reasoning for this are detailed in Sheard and Robertson (2004). Their revised RED scheme, as applied herein, is set out in Table 2. Regolith terminology follows that of Eggleton (2001), Robertson and Butt (1997), and Robertson *et al*. (1996). In addition, some of the regolith mapping methods promoted by Taylor (1997, 1999) and Taylor and Joyce (1997a, b) were also adopted.

Regolith mapping in the Wudinna north area also incorporated four noteworthy soils. Soil textural descriptions (*i.e*. sandy clay) follow those of Northcote (1979, pp. 26-28) but classification into more formally recognised soil types was not attempted (see earlier Soils section). Where appropriate some soil descriptive terms are derived from Eggleton (2001, pp. 39-44, 110-112) and soil-landscape salinity-sodicity comment draws upon Northcote and Skene (1972).

An **important difference** from the original RED scheme, is the changed use of the term **Relict**. Herein, it implies neither a residual Fe-cemented weathered rock, nor a lateritic profile. The term relict, as used on the accompanying Maps (Sheard, 2007 in Volume 2, Appendix 6), means "*remnant basement (fresh or weathered) lying within a broader area of younger, transported cover or erosional terrain*".

In exploration, it is important to distinguish basement (weathered or fresh) from transported cover. It may not be easy for new fieldworkers to make this important field distinction in the Gawler Province regolith, with consequent poor interpretation of geochemical data. The many broad scale or regional Au-in-calcrete anomaly maps covering large areas of the Gawler Province, produced in the late 1990s to 2004, are an example. Many lack provenance distinction or any data from which it could be drawn at a later stage. This has led to drilling of largely false anomalies on inliers of weathered basement with inherently higher Au backgrounds than those of surrounding transported cover with inherently lower Au backgrounds. Data from these contrasted regimes require separate analytical and interpretive treatment and the data should *never* be pooled for serious interpretation without host provenance indicators.

Regolith landform polygon tagging for this Study aimed to follow the simple notation of Sheard and Robertson (2003, 2004) so that all essential aspects of the mapped area could be adequately presented. Bold colours have been used to highlight outcropping basement, where full strength colours represent relatively unweathered rocks (protolith) while equivalent half tones represent exposed weathered and eroding equivalents (pedolith, saprolith, *etc.*). Overprint patterns are added for significant mappable duricrusts (*i.e*. calcrete, gypcrete and silcrete) while their host regolith item colour is maintained. Generally: blues depict alluvial landforms, yellows and orange hues depict aeolian landforms, and lacustrine landforms are displayed in neutral grey tones. Complex, dominantly erosional landforms are depicted in shades of green.

Landscapes can include complex regolith fractal patterns or mosaics, where distinct landforms overlap or interdigitate in detailed ways, each component with its own provenance or weathering zonal position (e.g. Dl-1 on RgS2 or De-3 on RgQm plus EgQm ± Cc ± Cs, *etc.*). It is impossible to show all details of these complex patterns at 1:20 000 scale, terranes of high complexity (in detail) are therefore represented by stacked tags (*e.g*. De-1/RgS2 or De-1 + RgQm + EgQm, *etc.*) and striped colours. Adopted bimodal and trimodal striped colours equate to those of each individual landform for that polygon but do not reflect abundance nor any regolith architectural hierarchy. Induration overprint symbols may still apply to those striped polygons in some cases. This colour scheme provides a more useful visual presentation of the overall landscape model than does previously used polygon colour protocols where the underlying landform's colour usually takes precedence (commonly adopted on geological maps; *c.f.* Taylor, 1997, 1999).

The area mapped (19 x 23.5 km) was selected to cover the widest variety of regolith materials at the chosen scale, where protolith outcrop and Au mineralization had previously been recognised via mineral exploration activity. It covers sites exposing relatively fresh to extremely weathered basement, erosional terranes and several varieties of transported cover. The Au-in-calcrete anomalism area and associated Au mineralization at Barns and Baggy Green prospects are included within the map boundaries. Topographic relief for most of this area is generally subdued (locally <15 m, regional maximum ~200 m), the highest points being on the S flanks of Mt Sturt (its summit is at ~300 m elevation). While the large ephemeral playas have depositional floors at ~100 m AHD and the larger of these playas (central northern) has its floor ~30 to 45 m below its surrounding dune-clad undulating terrain.

The *Wudinna North Regolith Landform Map, Parts A & B* (Sheard, 200; Volume 2, Appendix 6) contains 46 regolith landforms that include 14 relict, 9 erosional and 20 depositional forms plus 3 induration modifiers (duricrusts). The set of 9 erosional terranes involve 5 weathered basement lithotypes plus 2 colluvial landforms and 2 aeolian landforms. A text-only copy of the landform symbol reference is provided in Volume 2, Appendix 5 (Table A5-1) where item descriptions summarise all regolith types, zones, mineralogy, foliation, regolith fabric, granularity, landforms, likely substrates, vegetation, ages and specific dating.

Table 2: Regolith Landform Map landforms symbol notation.

Landscape Class	Brief Explanation and Notation
Relict	*In situ* fresh or weathered basement remnant as a resistive inlier within a broader area dominated by near surface younger transported cover or erosional terrain. **Landscape Class**: R = Relict. **RgQm** **specific identifier**: m = collapsed megamottle horizon, d = pisolithic Fe-pedolith, or sequential number. <u>Soils</u>: e = red earthy grit, g = brown earthy grit, h = sandy clay, or sequential number. **Regolith Zone**: P = Protolith, S = Saprolith, Q = Pedolith. **Lithotype**: v = felsic volcanic, g = granite, q = quartz vein, b = mafic volcanic/dyke.
Erosional	Terrain where erosion is the dominant landscape modifying component, can include currently eroding weathered *in situ* crystalline basement and/or transported cover deposits. **Landscape Class**: E = Erosional. **EgQm** **specific identifier**: m = collapsed megamottle horizon. <u>Sediments</u>: df = debris flow, ps = piedmont slope deposit, or sequential number. **Regolith Zone**: P = Protolith, S = Saprolith, Q = Pedolith, or sequential number. For eroding sediments no Zone is indicated. **Lithotype**: v = felsic volcanic/dyke, g = granite, b = mafic volcanic/dyke, c = colluvium, a = alluvium.
Depositional	Terrain where deposition dominates over other geomorphological processes. **Landscape Class**: D = Depositional. **Dcdf** **specific identifier**: dash & sequential number, or name abbreviation; df = debris flow, ps = piedmont slope deposit, ta = talus. **Lithotype**: a = alluvium, c = colluvium, e = aeolian, l = lacustrine/paludal.

Localised factual evidence for rock age or weathering time frames are rarely available, therefore rock ages, weathering time ranges and relative exhumation time frames (where appropriate) are drawn from the existing South Australian Geological Survey Geological Atlas Maps cited in the <u>Introduction</u> (1:100 k & 1:250 k scales). While local geomorphic relationships, local and regional regolith architecture, published or unpublished dates and the judicious use of superposition principals have all been used to establish regolith and landform precedence and relative antiquity. Detailed descriptions of the landforms are provided in this text (previous sections).

Thicknesses of transported cover are taken from mineral exploration company drilling, natural outcrop or terrain incisions and various District Council borrow pits. Two Regolith cross-sections are depicted on the *Wudinna North Regolith Landform Maps* (A–B and C–D), their construction involved vertical exaggerations of 10 times, their construction made use of dip conversion nomograms and principles set out in Rod (1974). A Regolith – Landform Relationship Model with 12 diagrammatic Regolith Profile Models are also depicted on the *Wudinna North Regolith Landform Map B*, they provide additional 3D information on subsurface regolith architecture.

Landscape Evolution

Regional landscape evolution

Palaeozoic and Mesozoic

Landscape development in this area after the last major deformation (Mesoproterozoic) has generally involved erosion, sedimentation, exhumation, deep weathering, localised landscape inversion and extensive duricrust development (Drexel and Preiss, 1995; Parker, 1995). Substantial glaciation of this part of South Australia (as part of Gondwana) took place during much of the Permian. Throughout that glaciation most if not all previous deep weathering profiles appear to have been planed off by ice, while numerous Palaeozoic sediments were either reduced in extent or thickness by the same glaciogene processes. From Late Permian forward, exposed Gawler Province rocks were once again open to weathering processes, eventually yielding thick regolith. A series of massive methane and carbon dioxide releases have been ascribed to greenhouse-induced global climate changes (warming by ~6^{o}C) with concomitant long-term global acid rain during the early Triassic and continuing intermittently into the Jurassic (Benton, 2003; Flannery, 2005). Marine rocks from those Periods indicate global anoxic ocean conditions that caused mass extinctions on scales never recorded before or since. The repeated and extended acid rain excursions may have also produced the deeply weathered highly leached (pallid) profiles that occur in many rocks and sediments exposed during those times (those regolith profiles are overlain by unweathered younger sediment in many basin onlap areas).

Rifting within Gondwana began to form two separate continental masses (Australia and Antarctica) in the Early Jurassic, due to an emerging geo-tectonic regime, which led to rift and intracratonic basin formation along the southern edge to, or on, the Australian landmass (Krieg, 1995). Late Mesozoic sediments were deposited directly upon a predominantly crystalline basement, of low relief, that had became deeply weathered during the early to middle Mesozoic. Quartz and kaolinite from those deeply weathered terrains, provided abundant source materials for late Jurassic and early Cretaceous erosion, yielding extensive and predominantly sandy sediment (Algebuckina Sandstone and Cadna Owie Fm).

During the late Jurassic to early Cretaceous, Australia was situated at about 70-60^{o}S and the climate was seasonally periglacial to glacial but was also punctuated by numerous warmer phases (Alley and Frakes, 2003; Alley and Lindsay, 1995; Sheard, 1990). Coniferous forests covered some of the landscape (Krieg, 1995, Rowett, 1997).

Early—Middle Cainozoic

On going rifting between Antarctica and Australia initiated marine transgressions into the southern basins where marine sedimentation continued into the early Neogene. These transgressions changed the existing drainage-erosion regimes and influenced climatic patterns further inland (Alley and Lindsay, 1995). As Australia gradually drifted northwards, the climate warmed and rainfall increased, promoting more rapid rock weathering and additional fluvial erosion. Significant river systems drained the Gawler Province to the west and southwest, and were dominated by sand during the Eocene but become progressively dominated by silt to clay in the Miocene (Benbow *et al*., 1995c; Hou *et al*. 2000; Hou, 2004). Significant global warming, lasting some 200,000 years, marks the beginning of the Eocene (~55 Ma), when methane–carbon dioxide clathrates in the North Sea suddenly released their gasses to the marine and air environs (Svensen *et al*., 2004; Flannery, 2005). This influx of greenhouse gasses produced abundant acid rain fall out globally, which may have caused the near-surface to mid profile regolith bleaching affecting rocks older than Eocene that were exposed or near surface then. It is clear from field observations, that coloured sesquioxides-hydroxides (+ associated trace elements) were removed and/or displaced to new locations during the early Eocene (probably by low pH ground waters), leaving behind pale to white saprolites. However, it is unclear in the Study Area (and for much of the Gawler Province) what proportion of the pallid saprolite is due only to the early-to-mid-Mesozoic bleaching and what is due only to the mid-Palaeogene bleaching. The later effects must have overprinted the earlier pallid zone, but it is likely that the later phase may have thickened the overall pallid zone. Furthermore, there are locations elsewhere in South Australia where these two regolith bleaching phases are separated by unaffected sediments that have been dated (palynology & stratigraphy), thereby providing indirect but useful weathering phase time frames.

During the late Eocene and again in the late Miocene to early Pliocene, broad-scale pedogenic silicification of the landscape developed extensive silcrete duricrusts on exposed surfaces (Benbow *et al*., 1995b). Over the Gawler Province, silcrete ranges in thickness from <1 to ~3 m, but in the Wudinna to Gawler Ranges area, silcretes are much thinner, typically 0.1-0.3 m. Pedogenic silcretes are commonly quite complex, where the landsurface has been repeatedly silica overprinted; but where continued sedimentation separates silicification episodes, silcretes are generally of a simpler form (Benbow *et al*., 1995b; Lintern and Sheard 1999; Mason and Mason, 1998; Sheard and Callen, 2000). Landscape case-hardening by silcrete has in places overprinted megamottled saprolite south of the Gawler Ranges, thereby implying megamottles predate development of the silica duricrust.

Palaeogene to Neogene vegetation for this part of the Gawler Province ranged from meso-mega-thermal angiosperm-gymnosperm mixed rainforest to meso-thermal conifer dominant rainforest (Benbow *et al*., 1995a).

Late Cainozoic

The Pliocene climate became more arid, causing major river systems traversing the Gawler Province to wane and many ceased flowing (Alley and Lindsay, 1995). By mid to late Pleistocene, strings of ephemeral playas and small clay pans marked the original fluvial traces of near totally sediment infilled palaeovalleys (Hou *et al*. 2000; Hou, 2004), and the Yaninee–Narlaby Palaeochannel complex is such an example on north western Eyre Peninsula.

Erosion during the Pliocene to Quaternary cut into the landscape, extending from less competent ground (lower) towards the generally silcrete or ferruginous armoured surfaces nearer the Gawler Ranges highlands. This process has formed small scarps standing <5 m above surrounding terrain and they commonly expose softer pallid to brightly coloured saprolith ± megamottling and ferruginous pedolith horizons.

Increasing aridity and persistent strong winds during the Pleistocene, caused extensive aeolian dune field systems to develop over much of Central and southern Australia. Siliceous sands from the Great Victoria Desert, west of Tarcoola, gradually invaded parts of northern Eyre Peninsula (Callen and Benbow, 1995). During those arid phases, and continuing today, there was a variable influx of aeolian carbonate dust, derived from extensive coastal shelf carbonate exposures (bryozoan-rich), exposed to erosion during each glacial low sea stand. Marine sourced foram microfossils have been observed in calcrete from this area and elsewhere, they are additional evidence for externally sourced carbonate in dust (0,05-0.5 mm). Isotopic data reported by Lintern *et al*. (2006) and Dart *et al*. (2007) further demonstrate a marine primary source for the calcium carbonate in Quaternary calcrete. Pedogenic modification and the actions of meteoric water have transformed those aeolian carbonates into recrystallised soil-borne forms termed calcrete (Phillips and Milnes, 1988; Lintern and Butt, 1993; Belperio, 1995; Lintern, 1997; Lintern *et al*., 2006; Dart *et al*., 2007).

Regional vegetation adapted to the increasing aridity by becoming sclerophyll dominant, sparse, tolerant of sodic high pH soils, and by becoming of moderate to low stature (Lange and Lang, 1985; Northcote and Skene, 1972). Where native vegetation has been broad-acre cleared for farming, agricultural practices generally prevented regeneration, leaving only relict vestiges along dune crests, road verges, Government Reserves and within Parks. In a few instances previously vegetation-stabilised dunes are currently reactivated, causing minor sand blow-outs and localised sand remobilisation, or are eroding by fluvial sheet wash during intense rain events.

Localised landscape evolution

After the long-term and widespread Permian glaciogene erosion of Southern Gondwana, terrain extending south of the Gawler Ranges highlands experienced relative tectonic stability and a moist climate, where deep weathering could develop without extensive erosion interrupting that process. Evidence includes: 1) a laterally extensive deeply weathered *in situ* regolith, developed within a variety of crystalline basement lithotypes, 2) those weathered *in situ* profiles have subsequently undergone localised drainage incision and minor landscape lowering through part profile collapse. Weathering of feldspars, ferromagnesian silicates, micas, and hydrothermal alteration assemblages occurred to depths of 40-60^{+} m; where new regolith mineral mixtures formed (kaolinite ± illite ± haematite ± goethite ± limonite). Igneous and metamorphic quartz mostly resisted this long-term weathering process. and is retained in regolith as quartz grit, trace gneissic banding and veins.

Basement weathering depths (from limited drilling and outcrop evidence) are relatively uniform—except where pre-existing intense fracturing or hydrothermal alteration have allowed meteoric and ground water access to deeper protolith. Saprolith has mostly retained primary (+ any hydrothermal alteration) colours near the weathering front, but further up profile, browns to reds and yellows become more dominant. Weathering has affected rock competence and it decreases with distance above the weathering front (saprock is high to medium strength, while saprolite is generally moderate to low strength). Primary rock texture and foliation have been retained in saprolite (isovolumetric mineral pseudomorphing: mineral losses = mineral gains). Profile bleaching within saprolite has yielded a very pale upper portion (1/3 to >1/2) throughout the Study Area. That bleaching process appears not to have removed or disrupted saprolitic pseudomorphed primary textures or foliation or resistate hydrothermal veins. However, strongly coloured sesquioxide ± hydroxide minerals have been either mostly or totally removed, or redistributed into mineral segregations near saprolitic top (*i.e.* megamottles ± stains).

A thin (<0.5-~2 m) arenose zone has developed above the saprolite at many sites across the Study Area. A quartz grit-rich basal component to pedolith, its presence indicates profile collapse where substantial clay removal by dissolution has occurred, leaving a structureless grain supported framework. Where silicified or otherwise intensely cemented, this geomechanically weak zone strongly resists erosion in the contemporary landscape, although, any uncemented portion tends to severely undercut along escarpments. Some escarpment exposures exhibit arenose zones below the collapsed megamottle horizon, while at other locations there is no ferruginous pedolith (either eroded or was never present). As with the collapsed megamottle horizon, an arenose zone may represent a 65% or more loss of original thickness by fines removal.

Plasmic zones (clay-rich, typically unstructured, <2 m thick) were observed either below an arenose zone or at a similar regolith architectural position. These zones can display a degree of profile collapse where the presence of jig-saw-fit dismemberment and/or rotation (high angle to low angle) of quartz veins may be present. Unlike saprolite, plasmic zones do not retain pseudomorphed original textures or foliation because pedogenesis has extended to this depth. These zones are not abundant in the Study Area and their degree of profile collapse (and associated landscape lowering) are very difficult to estimate (little or no reference points).

An *in situ* developed Fe-pisolith-rich pedolith (outcrop is of near uniform thickness) occurs as widely scattered surface to subsurface remnants within the Study Area (eastern half). Outcrop may also have associated lag aprons and/or more distally located colluvium, both containing eroded–transported Fe-pisoliths. Protolith involved with these include Tunkillia Suite orthogneiss and Sleaford Complex paragneiss (confirmed by drilling and in the latter case the As + Ni assay plots). However, outcrop mapping has not revealed whether the Fe-pisolith-rich pedolith horizon was or was not also developed over weathered Hiltaba Suite granite (western half of Study Area). Nor is there sufficient outcrop evidence to determine whether Fe-pisolith-rich pedolith horizon development is of similar form and thickness over all palaeo-landscape highs, slopes or lows in this area. What is clear though, is that erosive processes appear to have removed appreciable tracts of that horizon and lodged its granular components in surrounding colluvium-alluvium lower in the current landscape. Fe-pisolith-rich pedolith represents an end member residuum derived from extremely weathered basement, leaving only pedogenically remobilised Fe-sesquioxides and hydroxides as concentrically banded pisoliths ± amorphous cements ± variable quantities of residual quartz grit. Erosive processes are minimal during formation unless significant slopes are involved, although vertical migration processes (up and down profile of Fe-minerals and trace elements) have strongly affected such horizons. In Australia these horizons commonly retain remnant trace element signatures related to their parent protolith and/or any associated mineralization (Anand and de Broekert, 2005). Therefore these horizons may be important for geochemical sampling <u>but</u> developing an understanding of palaeo-slope involvement will be crucial to vectoring trace element anomalism back towards potential source locations. It is unclear whether enough data could be derived from detailed investigations of available outcrop in the Study Area alone to make such interpretations valid (scope for more research).

Prior to, during, and/or post development of the pedolith hosted Fe-pisoliths, a gradual collapse (in-part) of the underlying Fe-megamottled saprolite began to take place. This led to or was contemporaneous with the formation of another Fe-rich horizon in the lower pedolith. A process operated there where fines (clays + silt + other readily soluble minerals) were selectively removed – possibly by low pH groundwater (or infiltrating acid rain) leaving a residuum of less soluble materials. There abundant collapse coalesced haematite-goethite-rich megamottle blocks and resistate quartz grains ± vein quartz fragments, all together comprise a distinctive strongly coloured rubbly horizon (variably cemented, duricrust-like, ~1-2 m thick). Furthermore, where ever any overlying upper pedolith had already been eroded, thereby exposing the collapsing megamottle horizon to surface processes, then exotic angular to rounded quartz ± lithic clasts have been incorporated into this horizon (usually via surface cracks and open voids). Wind and water may have also removed more fines and soluble salts while this lower pedolith was exposed to the surface. It is possible that this horizon formed over an extensive time frame and its broad scale preservation suggests that there was no major landscape upheaval or major landscape erosion in this area during and post formation (see below). Observations in the Study Area indicate that a collapse by 65 to 80% of an affected megamottled saprolite (~5-10 m thick) would be required to yield a collapsed megamottle horizon of ~1-1.5 m thick. Although, in many cases a remnant portion of megamottled pallid saprolite persists beneath the collapsed megamottle horizon.

Limited field time and dispersed remnant outcropping profiles in hard to access Parks areas prevented a detailed terrain analysis of landscape position as an influence on the development of and final thickness to the collapsed megamottle horizon (scope for additional research). There is some undulation evident in the relict palaeo-surface of ferruginous pedolith, as revealed by exposures and drilled profiles. Examination of the Regolith Profile Sections on the accompanying Maps demonstrates some of those undulations via an interrupted but persistent subsurface intersection; intersected only by either palaeo-valleys or silcrete horizons. Drill cuttings though, do not provide adequate sample integrity for the more subtle regolith features to be observed (*i.e.* very thin horizons are poorly represented and are out of context; cementing fabrics and pedogenic fabrics are lost), therefore the Map sections provide only a rudimentary guide to those palaeo-terrains and to their palaeo-landscape interpretation.

Since development of the deeply weathered profile, erosion has gradually exposed large portions of the basement derived regolith to contemporary surface processes. These have provided observational windows onto a wide range of regolith zones and horizons in varying states of preservation. They include those with a complete pedolith profile present to those where stripping of nearly all weathered materials has left granitic whalebacks and tors. Wind erosion and fluvial stripping, along with the actions of chemically active groundwaters, have together removed fines and some soluble materials from the pedolith; and some soluble materials from saprolith. Those weathering agents have been the major palaeo-landscape modifiers. Figure 14 presents a progressive series of <u>diagrammatic</u> profiles (A to E) demonstrating how those landscape altering forces can truncate an initial fully developed weathered profile (mature profile), while retaining (through lags and remnants) hints of what previously existed there. These diagrammatic profiles may form as a toposequence exposure down slope, or occur as isolated outcrop in the contemporary landscape. Column F in Figure 14 indicates where pedogenic silicification has commonly been observed to develop in the Study Area.

Significant river systems began to incise the weathered palaeo-terrain south of the Gawler Ranges after the megamottle collapse process was well advanced—but prior to silcrete duricrust development. Evidence includes: removal of pedolith by palaeovalley incision, no obvious later pedolith development within sloping palaeovalley banks, and pedogenic silcrete horizons developed equally in palaeochannel banks and adjacent channel alluvium. The larger fluvial drainages may have been initiated by increased rainfall in the early Cainozoic and appear to have persisted until late into the Neogene (based upon stratigraphic evidence from outside the Study Area; Alley and Lindsay, 1995; Hou *et al*., 2000). However, their valleys (and hence flow directions) are aligned approximately east to west, rather than north to south as the palaeo and modern landscape slopes (Twidale and Campbell, 1985; Binks and Hooper, 1984), therefore the Gawler Ranges were not the headwaters generation area. Palaeovalleys also provided a convenient exit conduit for chemically active groundwater enriched with dissolved Fe and other trace metals leached and released down slope from ferruginous pedolith, collapsing megamottle horizons and saprolith. Those valley infill sediments may have remained active exit conduits for groundwaters since burial and therefore may be enriched with trace elements like K, V, Th and U.

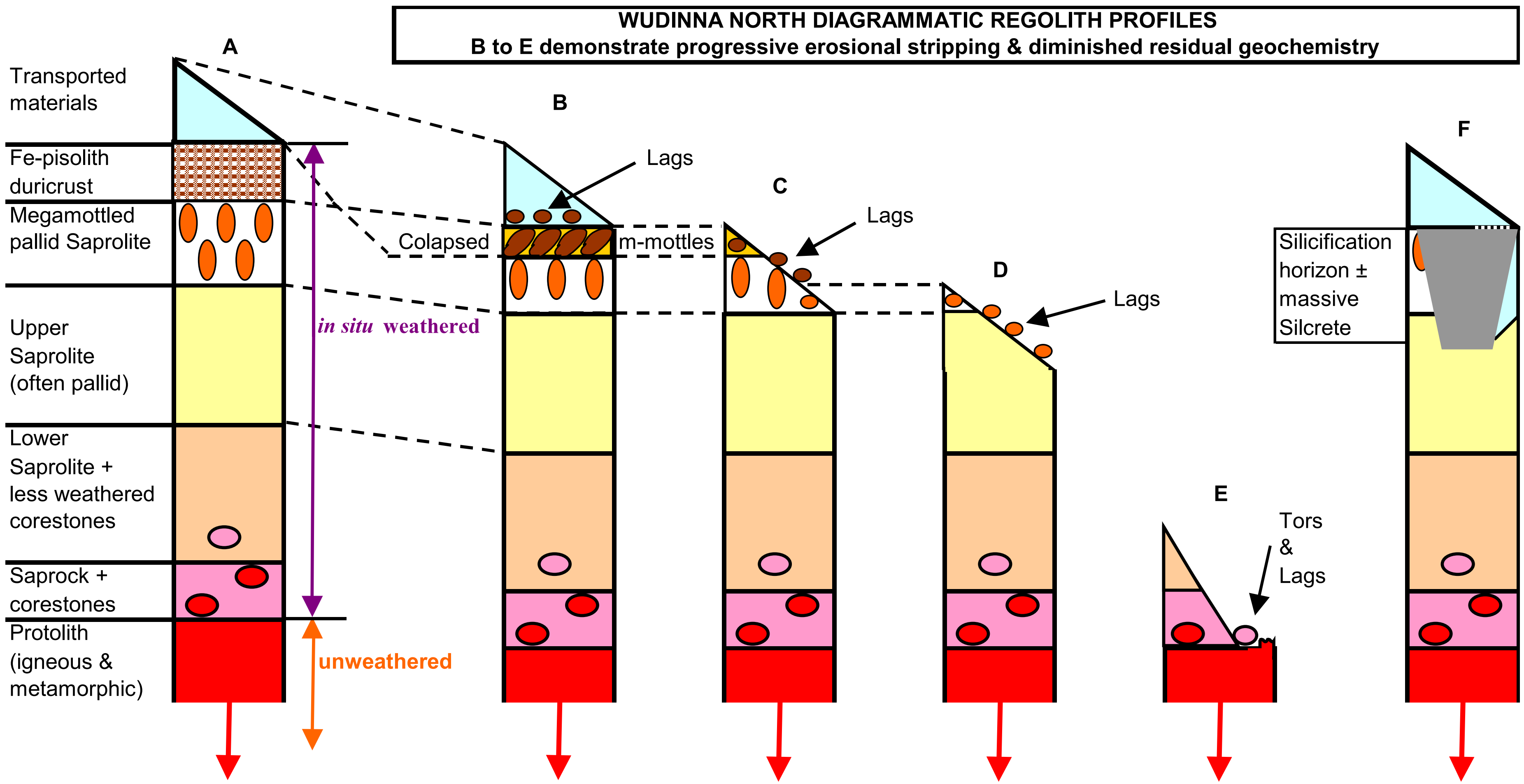


Figure 14: Diagrammatic regolith weathering profiles for the Study Area. Column A represents an un-eroded weathered *in situ* profile within Tunkillia Suite orthogneiss where a variable thickness of transported cover exists; column B represents an equivalent but partly eroded version with a collapse-truncated megamottle horizon; profiles C-E represent more highly eroded examples of profile B. Column E represents the exhumed basement protolith 'tor & whaleback' occurrences (Little Pinbong Rockhole, Poondana Rocks, *etc*.). Column F demonstrates where silicification occurs and includes Palaeogene to Neogene palaeochannel possibilities. Typically an uneroded *in situ* weathered profile in this area is 40-60 m thick ± a sedimentary cover ranging in thickness from 0->20 m. Equivalent profiles developed within Hiltaba Suite granite are similar except for an absence of intense Fe-rich pedolith horizons, there is no collapsed megamottle horizon either, and the mottled zone contains smaller and fewer mottles.

With the Quaternary onset of aridity, came valley infill, promoted by river senescence and eventual river water flow cessation. Aeolian and lacustrine sediment influxes to those palaeovalleys caused gradual burial but did not completely hide all of the remnant landscape lows. A western extension to the ~EW oriented Corrobinnie Depression (Narlaby Palaeochannel) is an example and it is discernable within the map area's SE quadrant. Another is an easterly continuance of the Yaninee–Narlaby Palaeochannel complex, as revealed by a topographic low in the SW quadrant (now occupied by an extensive playa-lunette complex). While it is also possible that the chain of playas north of and including Agars Lake mark yet another palaeovalley associated with the Narlaby Palaeochannel system.

Channel confined surface water flows in the current landscape are minimal (only one modern creek line was recognised), implying that subsurface porosity and permeability are high enough to absorb much of the excess runoff not taken up by dunes, sand plain, playas and vegetation.

A pedogenic silica duricrust developed after most megamottling had formed; this duricrust has encapsulated some or all megamottles within a particular silica cemented horizon, leaving colourful silcretes at a number of sites. Silicification has cemented alluvium, colluvium, collapsed arenose zones and parts of upper saprolite, *i.e*. any porous materials that were within an active pedogenic environment, leaving highly resistate landscape caps armouring softer underlying materials. Some pedogenic silcrete is located in palaeo-valley floor and at palaeo-toe slope landscape positions but it is also as abundant on palaeo-high ground. Therefore any influence of palaeo-hydrologic regimes on pedogenic silcrete is unclear and definite groundwater silcrete was not observed to occur. Sources for the silicifying solutions may be: from silica released by ongoing weathering; or silica released when kaolinite is dissolved by acid groundwaters and released when either saturation was exceeded, or at locations where a significant pH increase was encountered. Worrall and Clarke (2004) have proposed another mechanism involving marine regression exposing sulphide-bearing sediment that oxidises to form acid-sulphate soil conditions and these then lead to profile bleaching with Fe and Mn removed by rivers. Described earlier, another mechanism, alluded to by Benton, (2003), Svensen *et al*. (2004) and Flannery (2005), of repeated long-term acid rain associated with palaeo mega climate change scenarios, could be responsible for producing thick bleached saprolites and leaching-moving substantial amounts of Fe, Si, Ti and trace elements.

A combination of escarpment retreat via erosion, and profile burial by younger sediments, has limited currently exposed silcrete in this area; although enough remains exposed to extract a developmental history. Exploration drilling has revealed additional silcrete occurrences (see Regolith Map x-sections). Many silcrete exposures contain cryptocrystalline anatase ± other titaniferous minerals ± embayed (etched) quartz grains. The etching of normally resistive quartz implies quite aggressive fluids were involved during cementation. As to whether one or a series of silicification episodes are represented in the Study Area, it is impossible to say, although elsewhere there are at least three pedogenic silcrete forming episodes recognised (Late Cretaceous, early Palaeogene and mid to late Neogene: Sheard and Callen, 2000; Lintern and Sheard, 1999; Mason and Mason, 1998).

Evidence for contemporary landscape deflationary sculpturing was observed within the Gawler Ranges National Park and Pinkawillinie Conservation Park. A progressive set of stages leading to prolonged escarpment retreat associated with significant playa development is postulated; where internal drainage plus substantial lunettes and/or sand islands are important features (*i.e*. the large unnamed northern playa). These processes, outlined below, have been occurring during the Quaternary.

<u>Stage 1</u>: minor depressions in newly exposed Relict terrain begin to collect seasonal rain water, those depressions typically undergo rapid desiccation in a semi-arid environment (Figure 15). In this area, soils and upper regolith profiles contain accumulated meteoric salts – especially gypsum and halite, plus additional salts associated with dry season aeolian dust input – coming from local playas and a deflating landscape (Greene *et al*., 2006; Evans, 1998; McTainsh, 1989). Gypsum, halite and epsomite can play major roles in mechanical heave or exfoliation processes ('salt damp') causing a gradual destruction of exposed crystalline and porous rock. Where dissolving and re-precipitating within rock, such solutes generate salt crystal heave within micro-fractured, porous and granular materials. Regolith fracturing, severe grain loosening and loss of rock competence begin to take place, leading to regolith crumbling or exfoliation. This process releases new fines (clay to sand sized particles) that can easily be blown or washed free, thereby increasing the dimensions of an initially small shallow surface depression. As this process proceeds further, the depressions gradually penetrate any regolith armouring to expose softer fines-rich saprolite below (Stage 1a). Then profile undercutting can

rapidly progress, a process that promotes accelerated escarpment retreat with increasing vertical stature of escarpments (see Stage 2).

Stage 2: is evident where retreating escarpments enclose a long-lasting small to medium sized playa into which grit + clay + oxides and salts wash in during rain events, allowing wind to readily remove most fines from the exposed depocentre floors during drier times (Figure 15). These particular playas typically have a quartz grit or sand-rich floor where clays and silts are only short term residents, having a high aeolian deflation potential (e.g. the unnamed playa-escarpment complex ~2.6 km E of Little Pinbong Rockhole). Alternatively, if the retreating escarpment(s) eventually intersect with other topographic depressions then external drainage may eventuate. Thereby accelerated landscape sculpturing results through fluvial loss of crumbling-exfoliating materials, eventually leading to low stature mesa and butte terrain (common within the Gawler Ranges National Park southern area).

Stage 3: is a further development of Stage 2, where the playa-marginal escarpment fringe becomes quite extensive and may encompass playa areas in excess of 10 km^2 within landscape depressions of 10-20 m below the surrounding plains (Figure 16). A good example of this is the large unnamed northern playa, where there are associated complex lunettes, large complex side dunes and sizeable sand islands. Escarpment retreat is still active in that case, associated with ongoing aeolian removal of evaporitic salts and most fines. Therefore this feature will continue to enlarge in area and depth until hindered by impenetrable protolith or by a major climatic shift towards severe aridity. Escarpment retreat around the large unnamed northern playa also involves some escarpment benching or terracing, a feature that seems related to saprolite competency boundaries rather than specific regolith zone (or sub-zone) boundaries.

Establishing a time frame for this landscape sculpturing process is challenging: for Stage 1 to fully establish itself requires possibly many centuries to some millennia; but for Stage 3 to reach maturity may require 100,000 years or more. The fact that both longitudinal dune systems (orange and yellowish) have orientations strongly influenced by the western end of the large northern playa suggest that this depression was well established before longitudinal dune activity (possibly >80,000 to >50,000 years ago).

Quaternary glaciations over a significant portion of the Northern Hemisphere lowered sea levels globally a number of times, those colder intervals depressed global average temperature and promoted a windier more arid climate for mid to high latitude regions – particularly in Australia (Wasson *et al*., 1988; Wasson, 1989; Twidale *et al*., 2001). Significant desert dune systems arose and extended over much of the continent, but not continuously, rather in a more episodic development coincident with particular glacial and inter-glacial intervals. Luminescence dating of dune sand (particularly of quartz grains) has vastly improved the understanding of many desert dune systems ages existing today (Rhodes *et al*., 2004).

Lintern and Rhodes (2005) have established a maximum age of 26,300 ± 1300 yBP for the yellowish longitudinal dune overlying Barns Au prospect. However, there are no dates available for the stratigraphically older orange longitudinal dune and sand plain pattern, nor for any of the possibly older remnant dunes—sand plains north of Wudinna and Minnipa. Evidence from other Australian deserts suggest significant dune building episodes occurred during the following time intervals: 229-243 ka, 185-205 ka, ~167 ka, 145-155 ka, 115-135 ka, 89-99 ka, 65-68 ka, ~48 ka, ~31-35 ka and 20-27 ka (Gardner *et al*., 1987; Twidale *et al*., 2001; Lomax *et al*., 2003; Rhodes *et al*., 2004; Hesse *et al*., 2004). Furthermore, Sheard *et al*. (2006) report on the following optical luminescent ages for dunes in the Great Victoria Desert ~250 km west of Wudinna: 215 ± 15 ka, 197 ± 14 ka and 188 ± 14 ka (dune cores); 105 ± 8 ka and 71 ± 8 ka (dune mid sections); and 22 ± 3 ka (dune crest section). It is therefore reasonable to argue that dune systems in the Study Area, which are stratigraphically older than those overlying Barns prospect, will fall into one or more of the so far dated earlier dune building time intervals. Although the Barns Au prospect dune date fits within the 20-27 ka time frame mentioned above, the orange and much redder dunes immediately to the west and south could be considerably older.

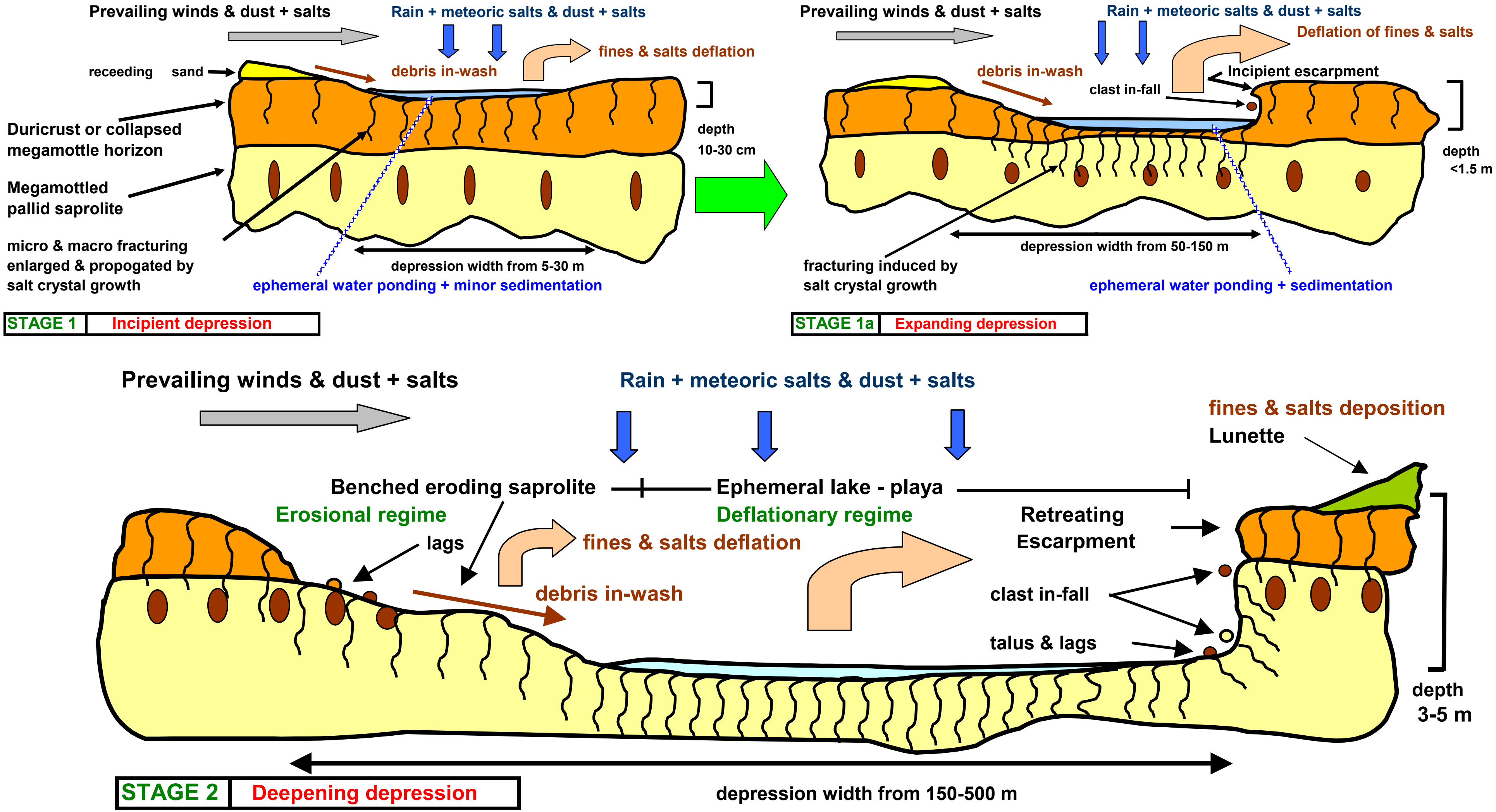


Figure 15: Diagrammatic models for localised deflationary landscape sculpturing Stages 1 and 2, all sections have significant vertical exaggerations applying. Stage 2 is a quasi-longitudinal section model.

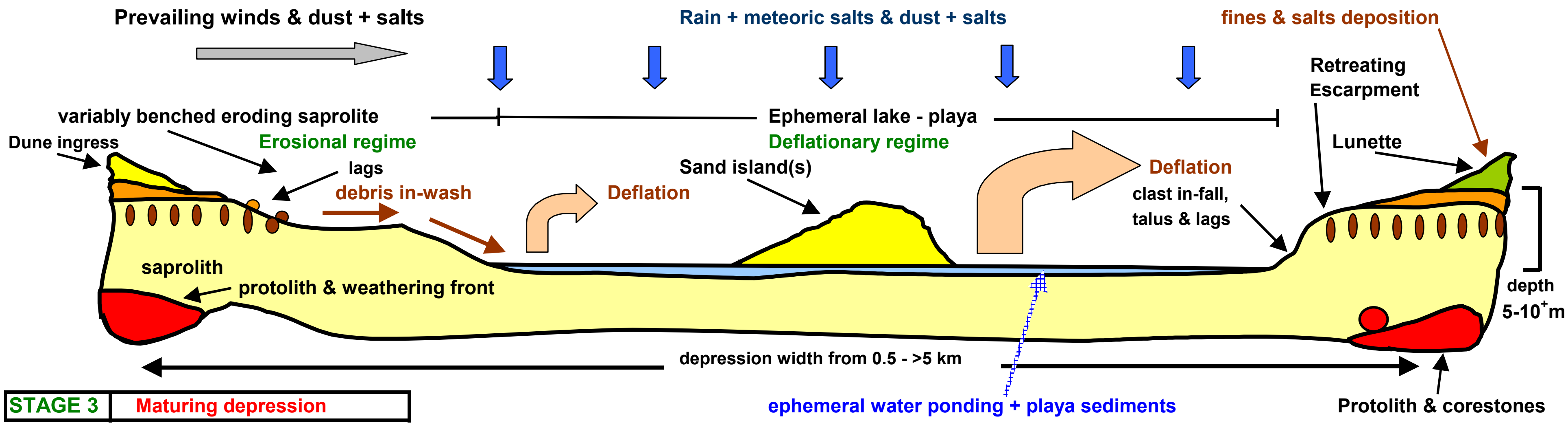


Figure 16: Diagrammatic model for localised deflationary landscape sculpturing at the mature Stages 3. Section has significant vertical exaggeration applying. This model is a quasi-longitudinal section. Regolith landforms are coloured as per Stages 1 and 2 unless otherwise labelled.

Dune building north of Wudinna reflects a dominantly SW to NW prevailing wind pattern during more arid millennia of the Quaternary. And both major longitudinal dune systems follow similar orientations, where in places yellowish dunes have built upon and/or even buried pre-existing orange dunes. The older orange dunes have more clayey cores and preserve pedogenic ferruginous segregations (granules, nodules, irregular forms to semi-indurated biscuity bands), and the palaeo-calcrete plus carbonate rhizomorphs are also more indurated. All those features suggest long-term stability for the orange longitudinal dunes (? implying they were well vegetated for extended periods), and that advanced pedogenesis operated for a lengthy time prior to the influx of yellowish dune sand.

Topography has influenced dune forms, stature and orientation. On a regional scale the Gawler Ranges highlands have induced a distinct orographic affect on dune positioning, spacing, shape and orientation – yielding irregular-serpentine dune patterns with dune long axies near orthogonal to or at substantial angles to the long axes of longitudinal dune systems further south. Significant topographic lows, like those of the Corrobinnie Depression-Narlaby Palaeochannel and buried Yaninee Palaeochannel, have perturbed prevailing winds enough to create complex sand plain with anastomosing low stature ridge patterns (festoon dunes); or through associated playa activity, have promoted complex and repeated lunette development. Conversely, on a localised scale, topographic obstacles like granite inselbergs, have associated semi-arcuate lee-side dunes (E side of Poondana Rocks).

Lacustrine loci and activity are controlled by topography, subsurface porosity and climate. All lakes are ephemeral in this region, leaving claypans, salinas and large playas during the dry seasons (Figure 7). Those developed within natural depressions (inter dune swales or corridors, *etc.*) have thicker sedimentary deposits than those developed within eroding *in situ* weathered terrain. PIMA infrared spectra indicate the presence of gypsum ± anhydrite, halloysite, kaolin and alunite. Halite and quartz are also present but do not register with the PIMA infrared sensor. Most of those mineral species were expected, and do appear in many of the playa muds, but alunite only occurred at nine quite separate playas (all in the western half of the mapped area) and may indicate acid groundwater involvement – either due to the oxidising of reduced muds within palaeochannel sediment or oxidising sulphides within weathering *in situ* protolith-saprock.

To better visualise the Wudinna north landscape features, regolith variety and relationships; a diagrammatic block model was prepared for the Regolith Landform Map accompanying this report. That model is reproduced herein as Figure 17. A series of 12 regolith profile sites are indicated upon that block model, and their respective diagrammatic landscape regolith profile models are presented in Figures 18 to 21. Each demonstrates profile complexity or simplicity along with erosional modification that may be expected or encountered at those sites. Absolute scaling is not provided because profiles can vary considerably over quite brief lateral distances. Furthermore, some vertical exaggeration to slopes, lags and dip angles has been applied to adequately render salient features. However, important profile elements and relationships have been retained and these models will be applicable at more sites than those actually indicated on Figure 17. The models demonstrate that this area has a high regolith complexity, a fact that was not fully recognised by previous geological mapping. Landscape erosion, deflationary landscape lowering, along with fluvial and aeolian sculpturing, have combined to modify, truncate or bury pre-existing relict weathering profiles. Exhumed protolith protrudes the landsurface at a number of sites (granitic tors, whaleback inselbergs, *etc.*) and is evidence for significant localised erosional losses (possibly up to ~40 m of profile).

Geomorphic and regolith forming processes remain dynamic in the Wudinna north area, these will respond to climate change and time—towards either progressing further or slowing significantly. Human impacts on regolith here are minimal so far but care will need to be exercised so as not to promote sand ‘blow-outs’ occurring through improperly managed clearing of dune crest remnant vegetation or poorly managed dune sand excavations. Furthermore, there is a significant potential for dryland salinity in this area, as evidenced by the presence of salinas and halite fringed playas (Figure 7), some demonstrating relatively recent salt scalding of normally salt tolerant shrubs and low trees marginal to those sites. Salt-induced landscape sculpturing on various scales, well demonstrates what can occur if soil and the sandy landforms are removed to expose a sodic regolith (refer to Northcote and Skene, 1972). Once any relict surficial regolith armouring has been penetrated by salt-induced heave and disintegration begun, then the landscape deflationary process will be quite difficult to manage or halt in this environment.

Regolith - Landform Relationship Model

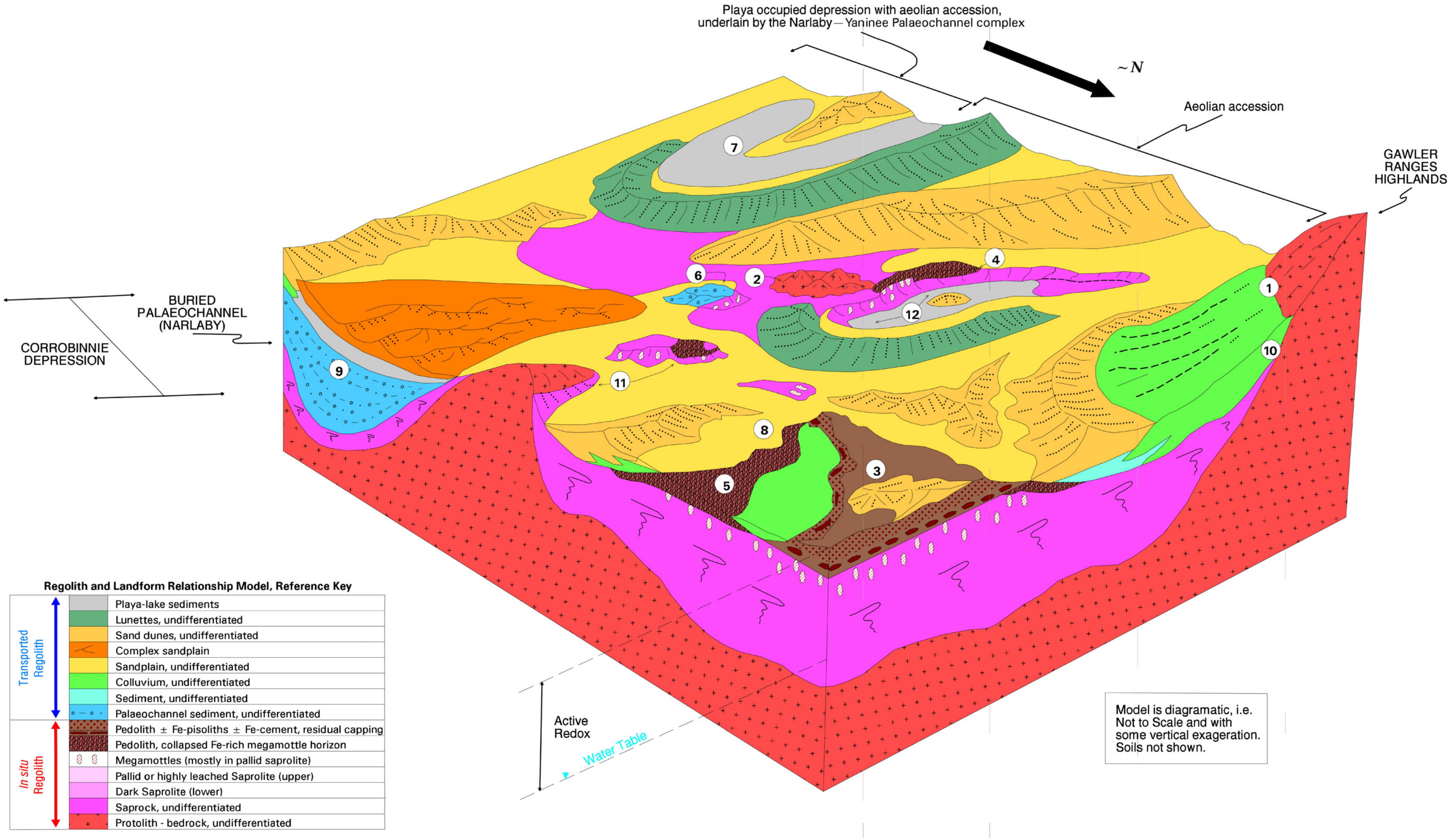
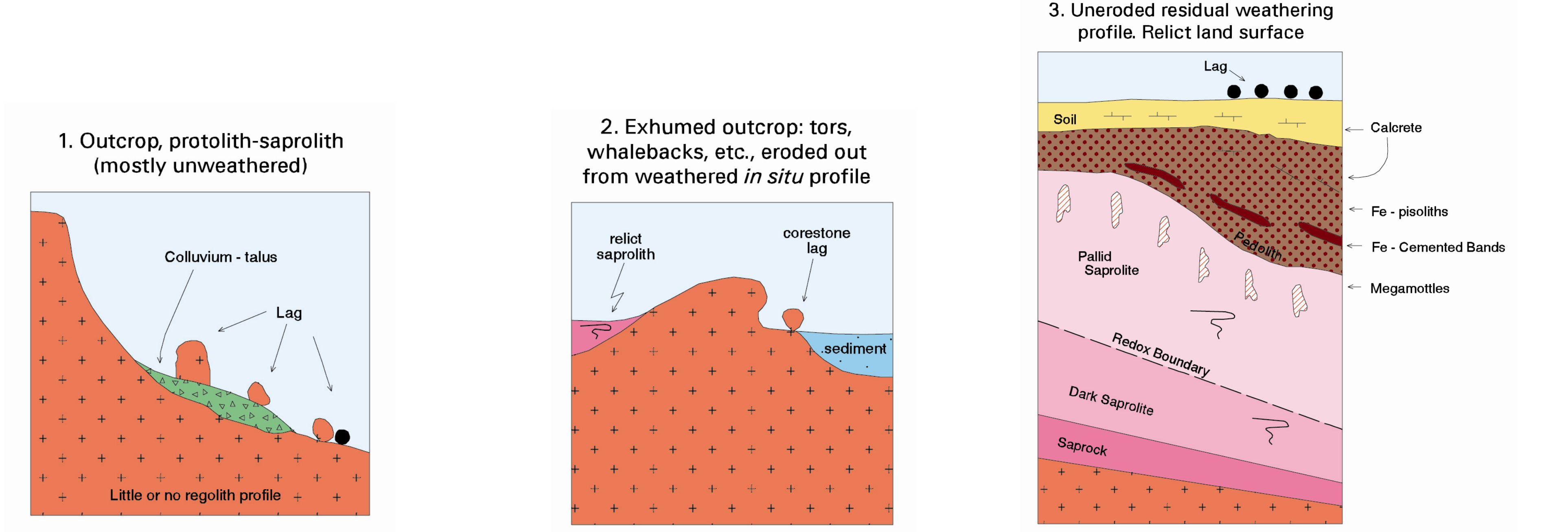


Figure 17: Regolith—Landform Relationship Model with 12 selected regolith profile sites indicated by numbered white discs. The Regolith Profile Models to each are displayed in Figures 18 to 21. Model view is towards ~SW from an elevated position.



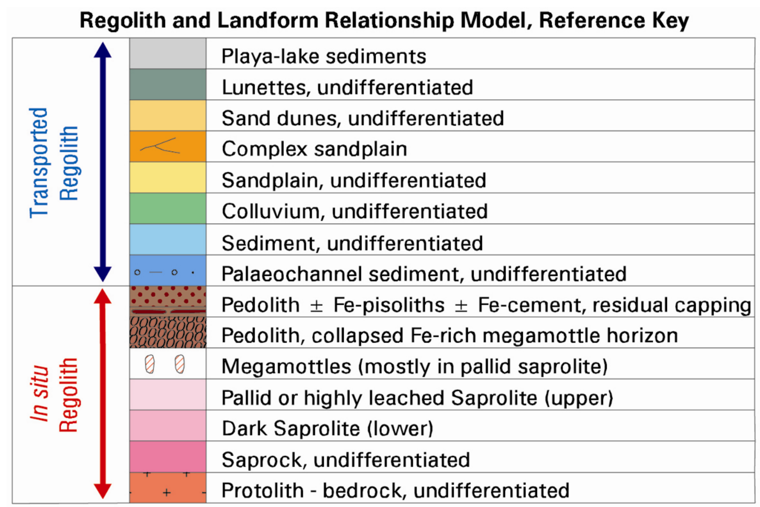
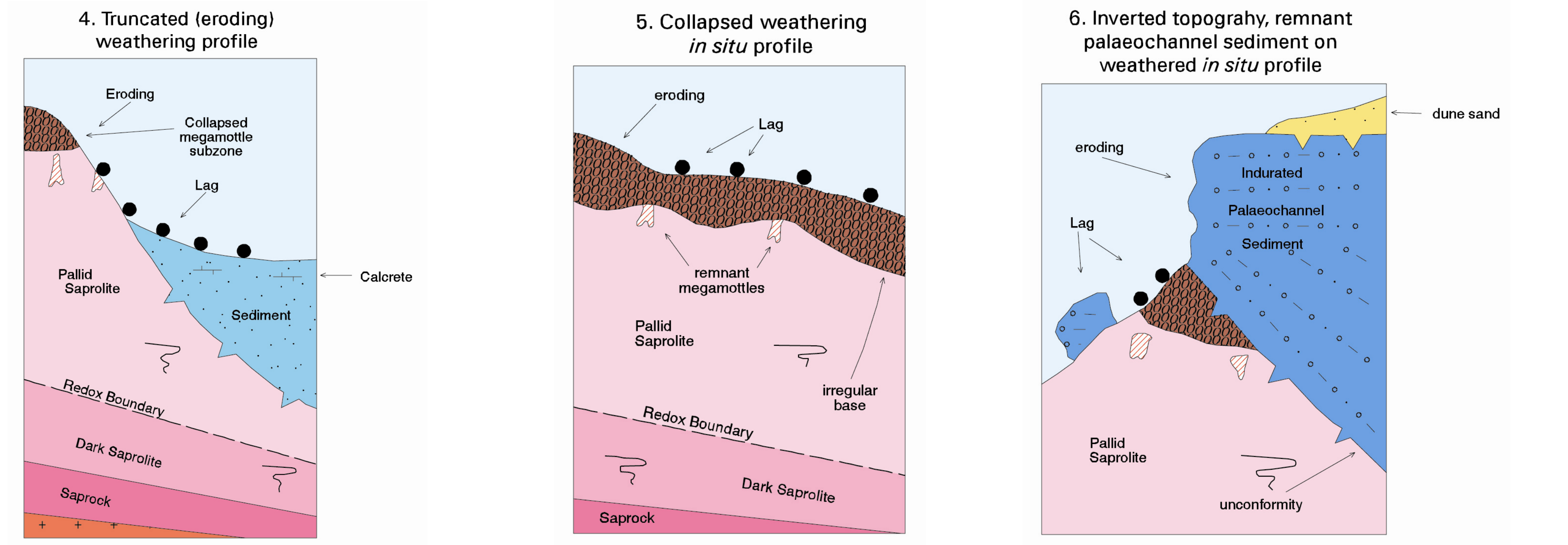


Figure 18: First three of the 12 diagrammatic Landscape Regolith Profile Models from sites indicated in Figure 17. Each demonstrates profile complexity or simplicity along with erosional modification that may be expected or encountered at those sites, *c.f.* Figures 19 to 21.



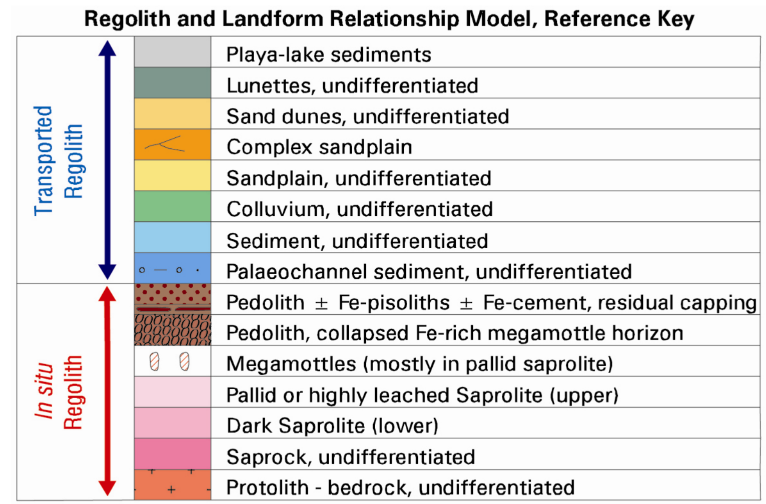
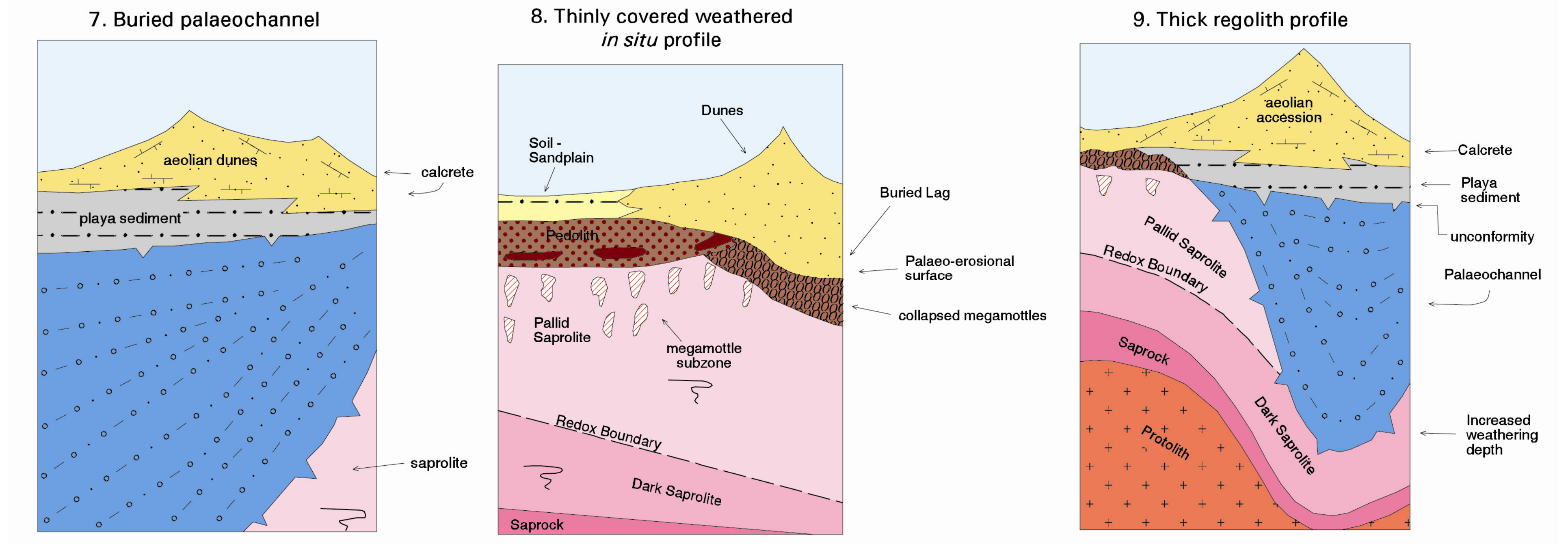


Figure 19: Second three of the 12 diagrammatic Landscape Regolith Profile Models from sites indicated in Figure 17. Each demonstrates profile complexity or simplicity along with erosional modification that may be expected or encountered at those sites, *c.f.* Figures 18, 20 & 21.



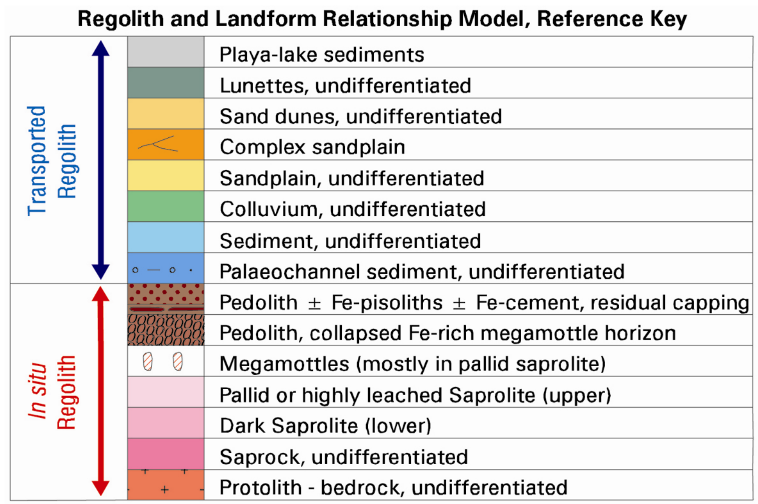
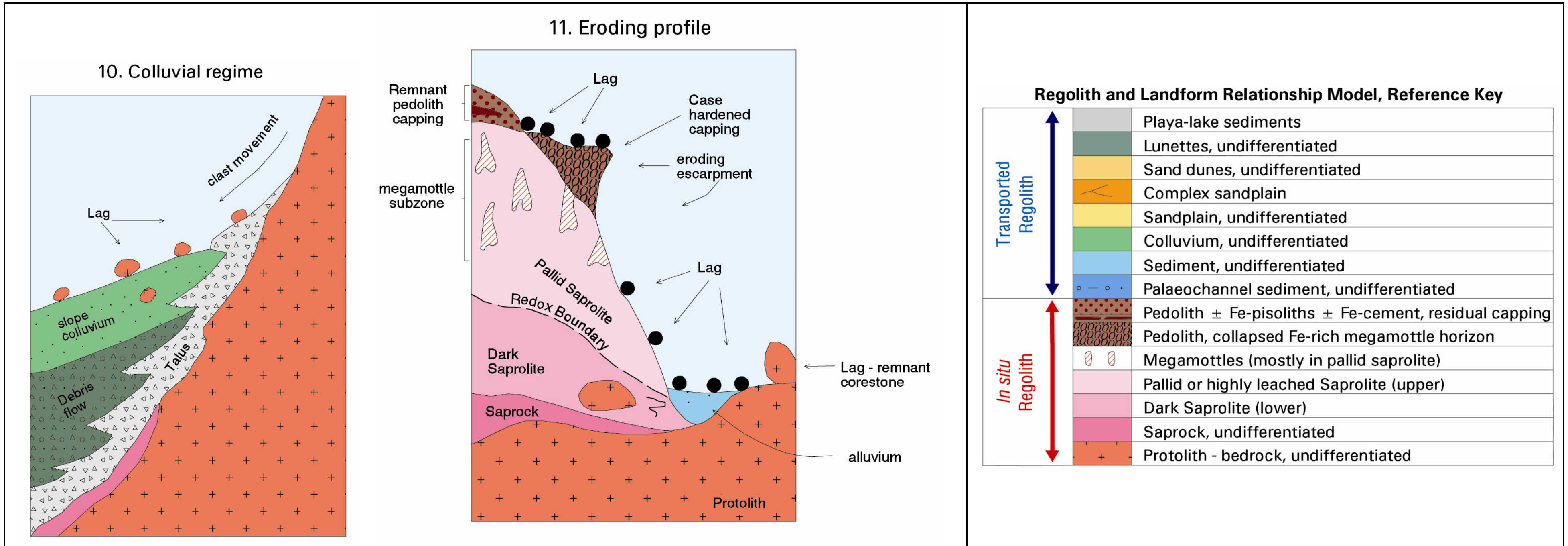


Figure 20: Third three of the 12 diagrammatic Landscape Regolith Profile Models from sites indicated in Figure 17. Each demonstrates profile complexity or simplicity along with erosional modification that may be expected or encountered at those sites, *c.f.* Figures 18, 19 & 21.



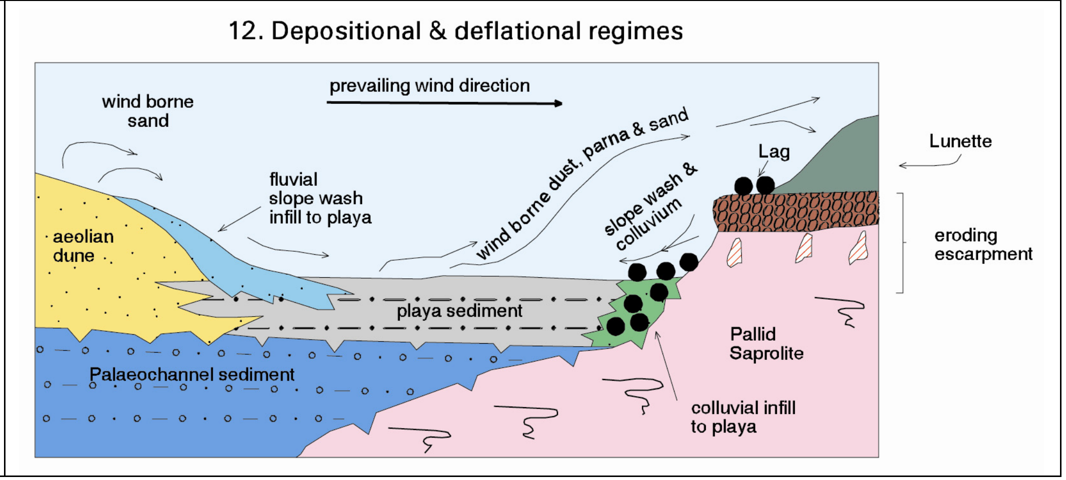


Figure 21: Last three of the 12 diagrammatic Landscape Regolith Profile Models from sites indicated in Figure 17. Each demonstrates profile complexity or simplicity along with erosional modification that may be expected or encountered at those sites, *c.f.* Figures 18 to 20.

Conclusions

- There is significantly more exposure of surficial and thinly covered weathered basement in this area than was previously mapped or recognised, (<8% increased to ~35%).
- Shallow transported cover (<5m) over buried basement may contain geochemical components of the underlying bedrock that can be used to identify basement lithotypes in appropriate sample media. These areas are expected to also show anomalous elements related to hosted mineralization – especially where this extends into the weathered zone. Biotic transportation in this area of elements such as Au, Ag, Cu and As through the regolith has been demonstrated by recently reported CRC LEME research. Regolith mapping that incorporates cover thickness is an important adjunct to interpretation of surficially derived geochemical data.
- Preservation of Fe-pisolith-bearing pedolith on weathered bedrock is rare in this area and typically is thinly developed (<1-3m) or is partially eroded. More commonly a collapsed megamottled saprolite horizon forms a red to dark brown Fe-rich capping on the *in situ* regolith profile. That capping is another pedolith horizon (<1 to 1.5 m thick) – commonly displaying crack and void in-fill of mixed transported and *in situ* character. Within or below this is a collapsed arenose zone (lowest pedolith component) consisting of quartz grit <1 to ~3 m thick. Saprolite (typically <50m thick) is readily identified by its highly weathered upper pallid sub-zone with pseudomorphed primary textures and foliation remaining. Good exposures of saprolite occur in erosional terrain – especially along retreating escarpments, within both Gawler Ranges National Park and Pinkawillinie Conservation Park.
- The presence of debris flow deposits emanating from the flanks of Mt Sturt was recognised in eroded sections marginal to playas. Similarly there are significant linear low zones, now under aeolian and lacustrine sediment cover, where riverine sediments (<10->30 m thick) occupy extensive palaeovalleys. Both would form substantial modifiers to any geochemical interpretation that may be made from surface sample assays taken from such areas. Detailed regolith mapping (where outcrop permits), terrain analysis and drill sampling were critical to recognition of these typically hidden features. However, and importantly, additional buried debris flows and palaeochannel sediments are expected to occur in this region.

Key Recommendation

Regolith landform mapping, in combination with landscape evolution modelling, are additional key components to a better understanding of areas where deep weathering and thin to moderately thick transported cover combine to obscure potentially mineralized protolith. Those key determinants are essential to surface geochemistry interpretive confidence in what is <u>truly</u> <u>anomalous</u> *vs* what is <u>falsely anomalous</u>.

Project Products

- Descriptions of weathered rock and transported cover, two adjoining Regolith Landform Map sheets containing two regolith profile-sections from selected drilled lines + a 3D Regolith Landform Relationship Model and 12 selected Regolith Profile Models.
- A landscape evolutionary history has been developed for the Wudinna north area.
- Digital data on CD-ROM including: Report pdf, mineral exploration drill collar data, assay data, PIMA spectra, + Regolith Map including two regolith profile sections + landscape-regolith relationship models.
- A GIS data package has been prepared by PIRSA Geological Survey Branch to include all Central Gawler Gold Province investigation data held by PIRSA plus all open file company data. Data and value added products contained herein will form an interactive Regolith layer to that GIS package and thereby provide comparisons with related data sets covering: geology, drilling, calcrete geochemistry, basement geochemistry, tectonics, geophysics and geochronology. PIRSA Mineral Resources Group have released an interim version of that product on DVD in June 2006, later updated versions will follow.
- Regolith surface samples and petrography samples (thin sections and polished blocks) are housed permanently for reference at the PIRSA Drill Core Storage Facility, 23 Conyngham St, Glenside, South Australia. Selected company-tenement holder sponsored drill samples may be lodged with the PIRSA Drill Core Storage Facility upon tenement surrender.

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Data CD-ROM is in a sleave on the inside of the back cover

Refer to VOLUME 2 for Appendices.

Appendix 1: Field Samples Register + Drilling Regolith Logs + Chiptray Photos.
Appendix 2: Calcrete assay data + geochemical distribution plans.
Appendix 3: PIMA: Sample minerals interpretations+ spectral data.
Appendix 4: Petrography.
Appendix 5: Wudinna North Regolith Landform Maps A & B landform symbols.
Appendix 6: Wudinna North Regolith Landform Maps A & B (1:20,000 scale, folded at rear of Volume 2). Digital versions are on the CD-ROM (Rear of this Volume).

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