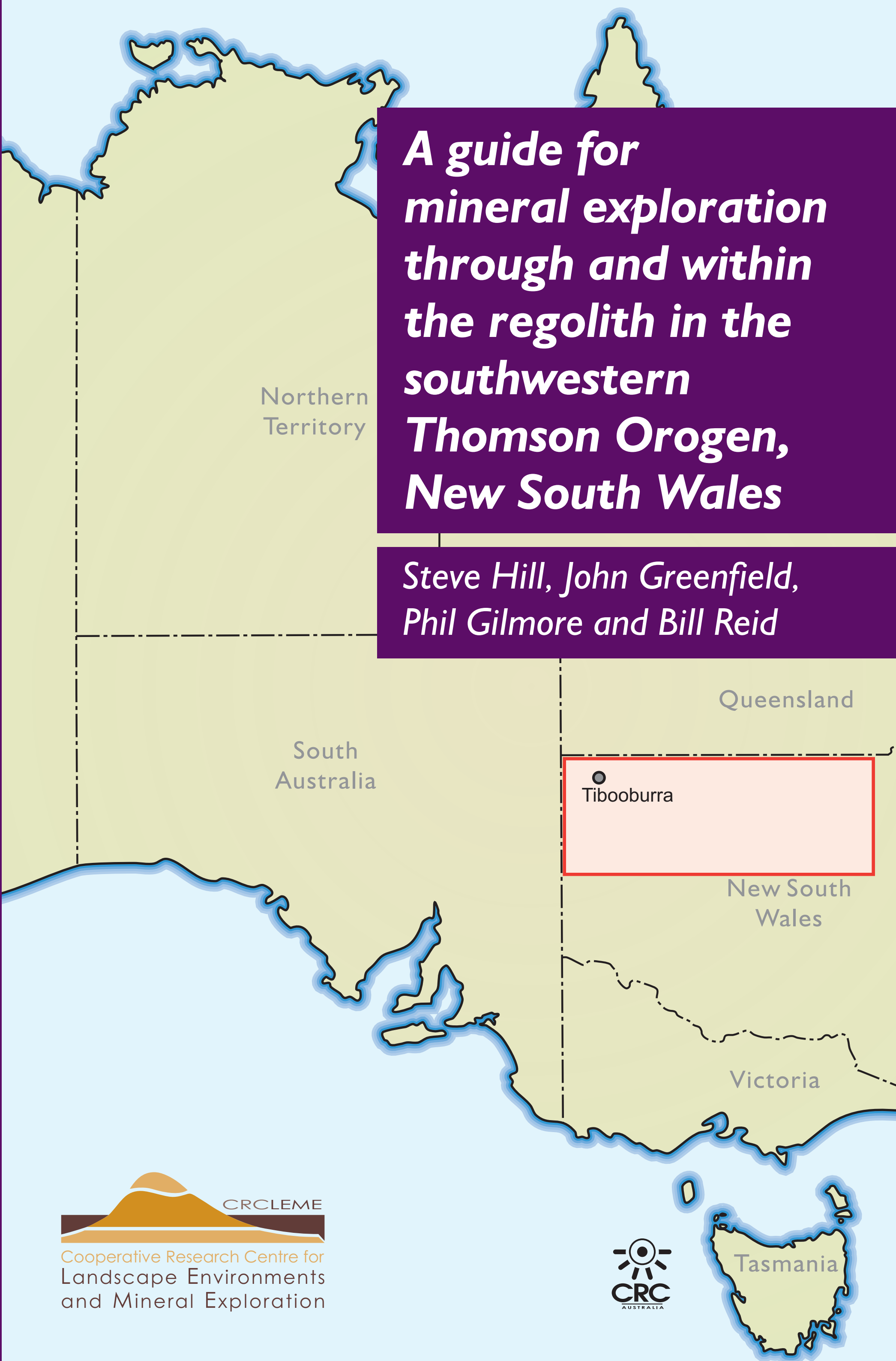
A guide for mineral exploration through and within the regolith in the southwestern Thomson Orogen, New South Wales

Steve Hill, John Greenfield, Phil Gilmore and Bill Reid



CRCLEME
Cooperative Research Centre for Landscape Environments and Mineral Exploration
CRC Australia

A GUIDE FOR MINERAL EXPLORATION THROUGH AND WITHIN THE REGOLITH IN THE SOUTHWESTERN THOMSON OROGEN, NEW SOUTH WALES

SM Hill, JE Greenfield, PG Gilmore and WJ Reid

Reference:

Hill, SM, Greenfield, JE, Gilmore, PG and Reid, WJ, 2008. Guide for mineral exploration through and within the regolith in the southwestern Thomson Orogen, New South Wales.

1. Regolith. 2. Mineral exploration. 3. Geomorphology. 4. Geochemistry.

ISBN 978-0-9806030-3-3

Publisher: CRC LEME c/o CSIRO Exploration and Mining, P.O. Box 1130, Bentley WA 6102

Editors: David Garnett, Gerry Govett and Lisa Worrall

Copy editor: Peter Storer, Peter Storer Editorial Services

Cover, graphic design and illustrations: Angelo Vartesi and Travis Naughton, CSIRO Visual Resources Unit, Perth.

Printer: Printezy.com, 128 Canning Highway South Perth WA 6151

Electronic copies of this publication in PDF format can be downloaded from the CRC LEME website http://crcleme.org.au

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1. INTRODUCTION

1.1 Purpose of the Guide

This Guide is designed to assist mineral explorers working in the regolith-dominated terrains of the southwestern Thomson Orogen in far northwestern NSW–in particular the Tibooburra–Milparinka area (*Figures 1A and 1B*). Although it is hoped that information presented in this Guide may also be applicable across the Thomson Orogen and adjoining regions, it should be noted that the focus on the Tibooburra–Milparinka area of far northwestern NSW reflects:

- the concentration of geological and regolith studies and mapping within this area
- the area's known mineralisation
- that the remainder of the Thomson Orogen region is relatively unknown.

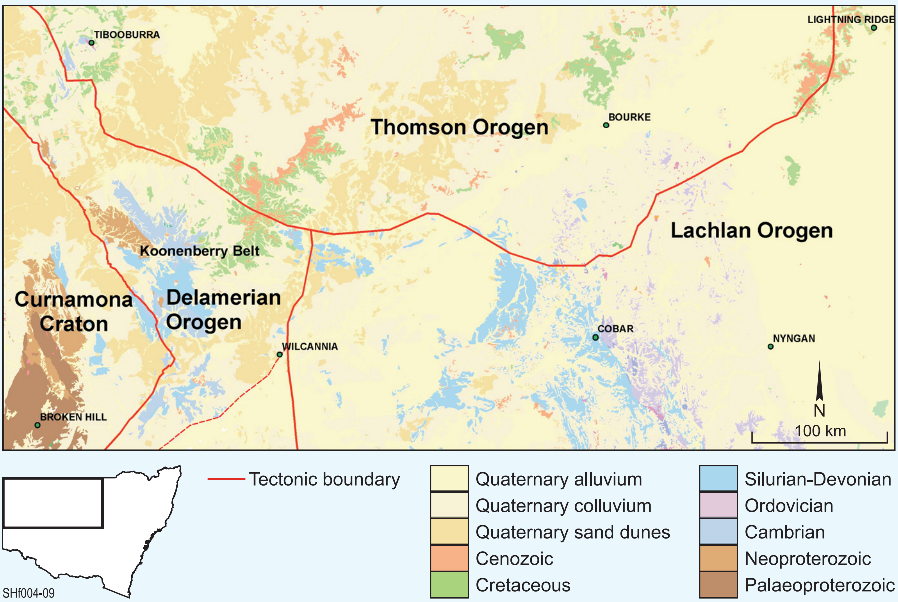


Figure 1A: Location of the Thomson Orogen region in northwestern New South Wales.

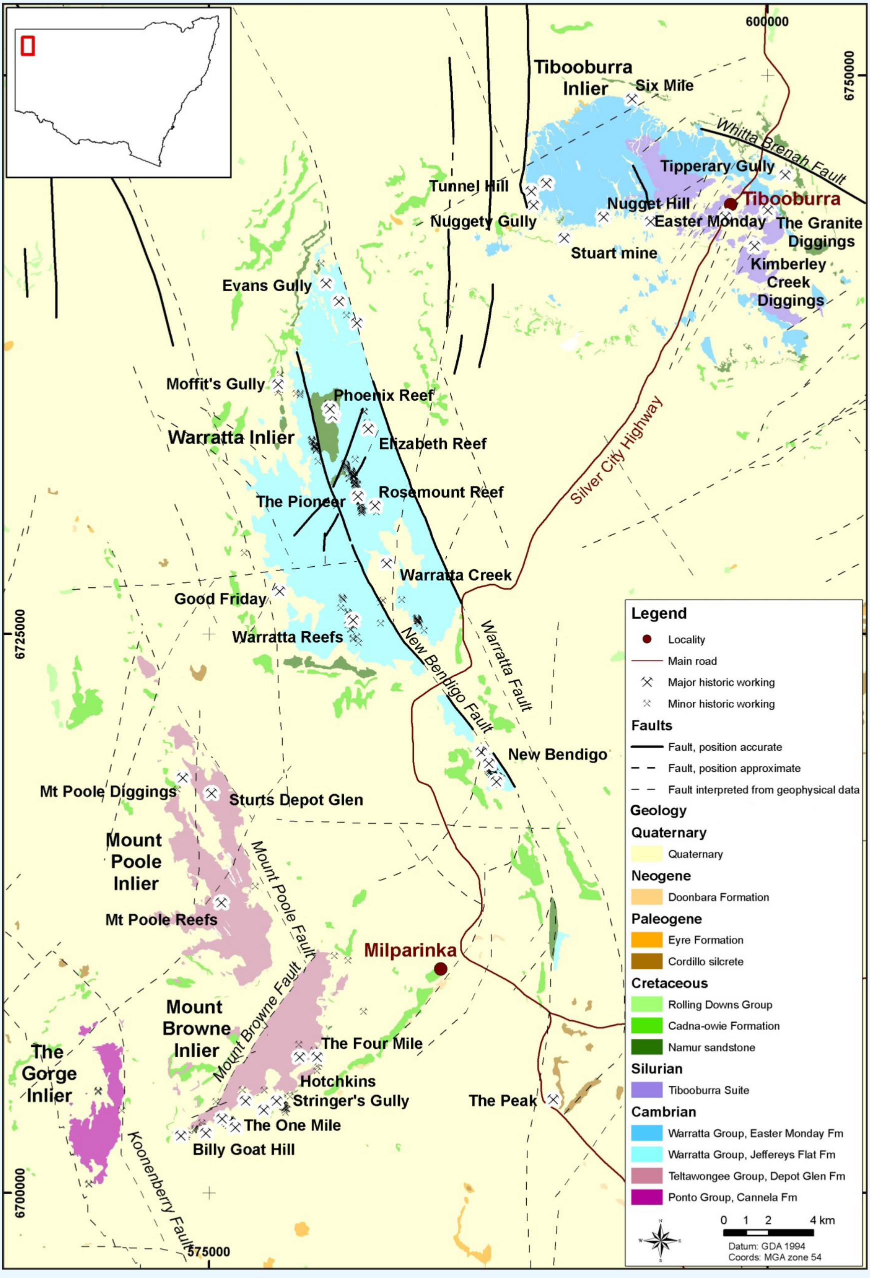


Figure 1B: Location of the Tibooburra–Milparinka area, which is the main area considered in this Guide. Geological information derived from NSW DPI 1:100 000 geological maps.

The Guide provides an introduction to the regolith and landscape history of the region, together with advice on strategies and methods that can assist with exploration for mineral deposits within and through the regolith. The information presented here is based on current knowledge and known best practice, but does not provide a guarantee of exploration success. Much of the data and knowledge presented here have been developed as a result of research and mapping programs in the region between 2001 and 2007 conducted by the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME) and close core participant collaboration between the University of Adelaide and the New South Wales Department of Primary Industries (NSW DPI) geological mapping program.

1.2 Exploration context and challenges

The regolith–and in particular the transported regolith (sediments)–provides the greatest mineral exploration challenge in this region. Bedrock exposure accounts for less than 1% of the landscape, with the remainder of the region having sedimentary basin cover. Within the deepest parts of the sedimentary basins, the sediment thickness may exceed hundreds of metres (*Figure 2*). Sediment thicknesses may decrease to less than 1 metre within the bedrock inliers, but even here the thin cover of sediments is typically extensively transported, thereby obscuring the underlying bedrock. In the few places where bedrock is exposed, it is typically highly weathered: making it difficult to determine the nature of the underlying fresh rock. Mineral exploration approaches for this region, therefore, need to be able to penetrate the weathered and sedimentary materials of the regolith or to be able to effectively explore within it, or across the top of it.

The Tibooburra–Milparinka area provides field exposures of a wide range of regolith materials and associated landforms that are closely related to several major periods of sedimentary basin evolution since at least the Mesozoic. The sediments associated with these basins have covered the prospective bedrock as well as re-distributing and re-accumulating geochemical signatures derived from the weathered, eroded and buried bedrock. In some cases, this re-distribution and re-accumulation has formed historic mineral

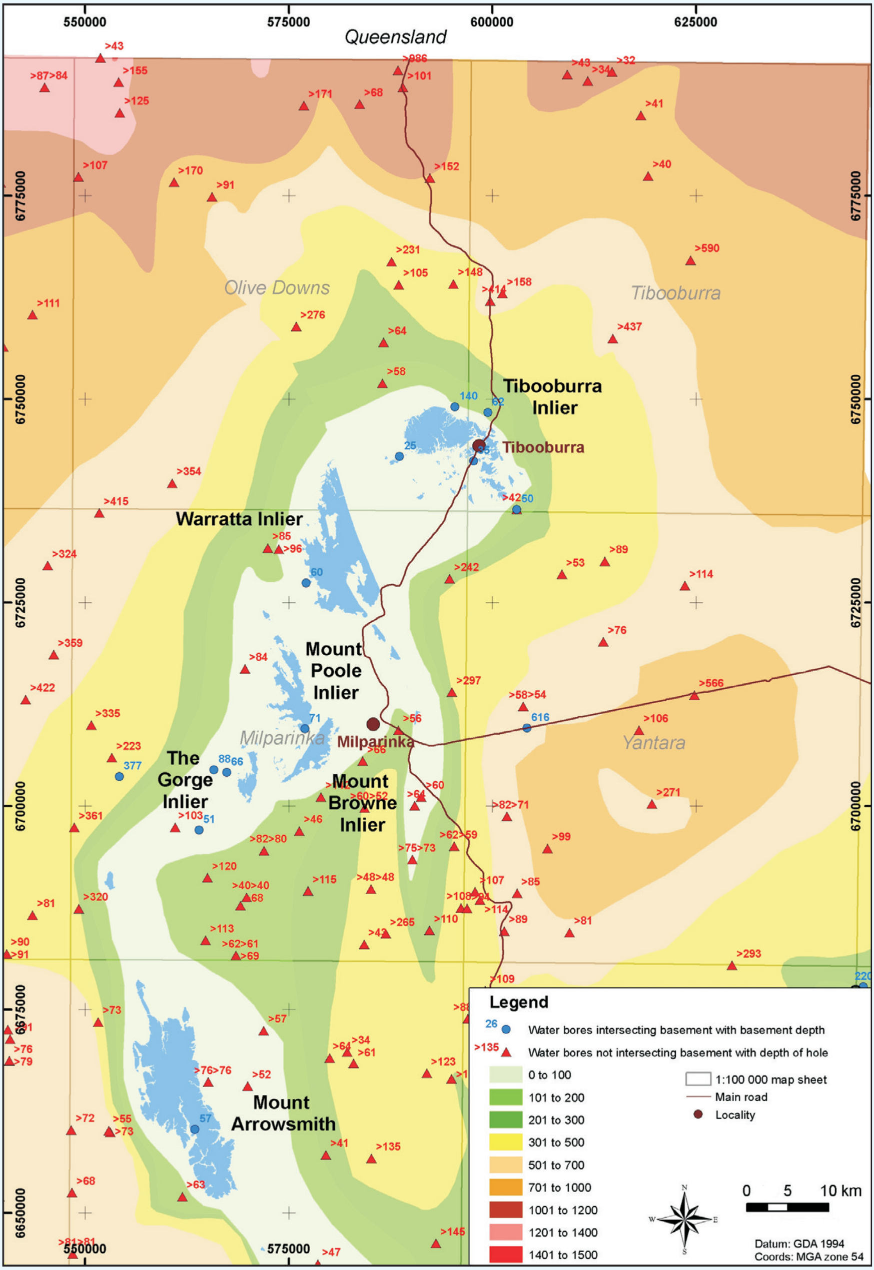


Figure 2: NSW DPI interpretive image of the depth to the base of the Mesozoic sequence in the Tibooburra–Milparinka area. This image is based on a compilation of previous drilling results (mostly water bores) and field checking.

deposits in their own right (e.g. sedimentary Au placers flanking many of the bedrock inliers, such as near Mount Browne and Tibooburra), while in others geochemical anomalies have formed that can be potentially traced to bedrock sources. In many other places, however, the sedimentary cover may appear to obscure any signature from the underlying bedrock, but even here further examination may be more revealing (*Figure 3*). Understanding of the sedimentary basin framework and its links to long-term landscape evolution and the development of regolith materials is therefore an essential foundation for mineral exploration programs in this region.

Figure 3: Less than 1% of the Thomson Orogen region in NSW contains bedrock exposure. A large part of it looks like this scene near Mount Poole. Upon close inspection, and with an 'eye for the landscape', the angular quartz component of this surface lag suggests that bedrock may not be that far below the surface (GDA: 574561 mE / 6706532 mN).

It is surprising that although the Tibooburra–Milparinka contains numerous Au placers within the Mesozoic and Quaternary sediments, the primary sources for these have not been identified. In effect, these placers constitute a large regional Au anomaly within the regolith. Although the bedrock is highly prospective for Au mineralisation, primary vein Au occurrences are limited to restricted parts of the Warratta and New Bendigo inliers. It is incredible that there has been so little effective exploration dedicated to the search for the source of the widespread, and locally rich, placer Au in the area. This is partly the result of the remoteness of the region, but is more particularly due to the challenge posed by the extensive sedimentary basin cover across most of the region and the lack of effective exploration models and approaches for these settings.

Some highlights and key themes outlined in this guide that address these mineral exploration challenges include:

- a simplified outline and recognition of the significance of the Mesozoic and Cenozoic basin stratigraphy and palaeo-landscape interpretations for mineral exploration
- Mesozoic palaeo-landscape reconstructions that further constrain the provenance of Mesozoic-hosted placer Au in the Tibooburra–Milparinka area
- definition of several key palaeodrainage systems involved in geochemical dispersion and accumulation within the landscape–in particular the Mesozoic palaeodrainage system dispersing and accumulating Au
- the important tectonic controls and influences on regolith and landscape evolution
- recent breakthroughs in developing the potential applications of plant biogeochemistry for mineral exploration under cover.

2. THE EXPLORATION ENVIRONMENT

Understanding an exploration region's setting helps to define the context, approaches and constraints on mineral exploration programs. The main geological and environmental attributes of the region are outlined in this chapter.

2.1 Climate

The region presently experiences a semi-arid to arid climate. Daily temperatures in summer are frequently over 30º C, and in winter may fall as low as –6º C. The annual rainfall is about 230 mm at Tibooburra, with a high degree of yearly variability and a slight summer-dominated seasonality. Aridity and summer-rainfall dominance generally increases towards the northwest of the region. Wind directions tend to be variable, although they slightly prevail from the southwest with the passage of high-pressure systems across central Australia.

2.2 Vegetation

There are four broad vegetation types in the region (*Figure 4*): each with close geobotanical associations with regolith-landform settings:

- Mulga woodlands on sandplains and in dunefield swales. These include mulga (*Acacia aneura*) and bastard mulga (*Acacia stowardii*) trees, with sandhill wattle (*Acacia ligulata*) shrubs and a rich diversity of ephemeral herbs. White cypress pine (*Callitris glaucophylla*)-dominated woodlands, or isolated individuals, extend across some aeolian dunes and sandplains.
- Chenopod shrublands on sheetflow plains and rises. These have a co-dominance of saltbush (*Atriplex spp.*) and bluebush (*Maireana spp.*) with copper-burrs (*Sclerolaena spp.*). The most widespread and abundant shrubs include bladder saltbush (*Atriplex vesicaria*), cotton bush (*Maireana aphylla*), black bluebush (*Maireana pyramidata*) and pearl bluebush (*Maireana sedifolia*). Open woodlands with chenopod understorey typically include trees of black oak (*Casuarina pauper*), rosewood (*Alectryon oleifolius*) and mulga (*Acacia aneura*), and shrubs

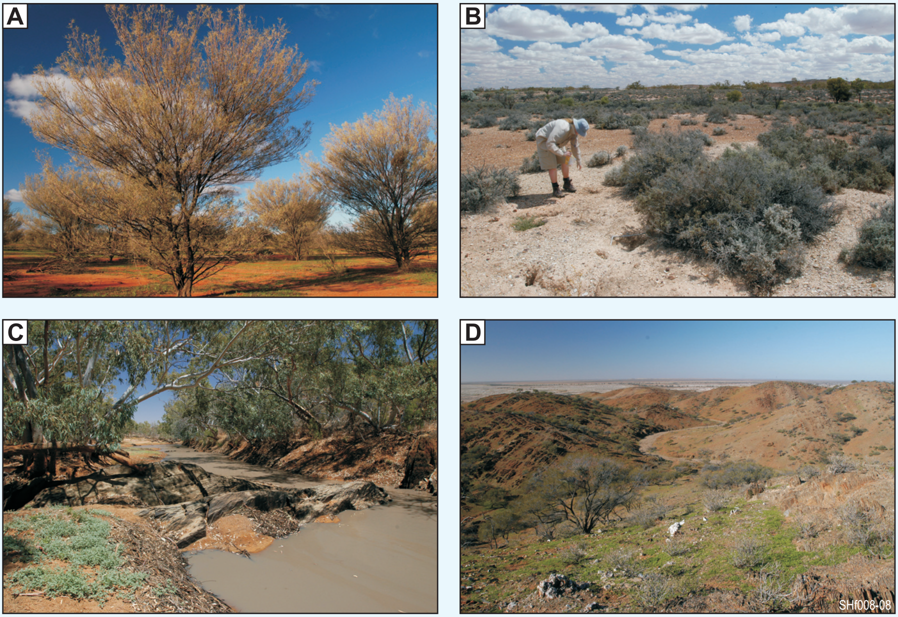


Figure 4: Representative photographs of the major vegetation communities of the Tibooburra–Milparinka area. (A) mulga woodland on sandplain, Tibooburra Common (GDA: 601716 mE / 6742431 mN). (B) chenopod shrubland on sheetflow plain southern Warratta Inlier (GDA: 583068 mE / 6727748 mN). (C) riparian woodland along Perseverance Creek at Depot Glen (GDA: 575895 mE / 6718017 mN). (D) open woodland with mulga and bastard mulga trees and emu bush shrubs on erosional hills near Mount Browne (GDA: 579235 mE 6707842 mN).

of cabbage-tree wattle (*Acacia cana*). Chenopod shrublands also colonise the margins of saline lakes, where samphires (*Halosarcia spp.*) tend to prevail.

- Riparian woodlands. Major channels and their banks are typically colonised by river red gum (*Eucalyptus camaldulensis*) grading downstream to depressions and floodplains dominated by black box (*Eucalyptus largiflorens*) in the south and coolibah (*Eucalyptus coolabah*) in the north. Gidgee (*Acacia cambagei*) and beefwood (*Grevillea striata*) become more prevalent along alluvial systems towards the north. Smaller channels may be colonised by prickly wattle (*Acacia victoriae*) and western boobialla (*Myoporum montanum*).
- Open mixed woodlands on erosional hills and rises of weathered

bedrock. These are dominated by mulga (*Acacia aneura*) and whitewood (*Atalaya hemiglauca*) trees, with desert bloodwood (*Corymbia tumescens*) mostly colonising areas of the Tibooburra Granodiorite and its flanking contact aureole. Shrubs are mixed and variable, but typically include saltbushes (*Atriplex spp.*), bluebushes (*Maireana spp.*), dead finish (*Acacia tetragonophylla*), hopbushes (*Dodonaea spp.*), cassias (e.g. *Senna artemisioides*), emu bushes (*Eremophila spp.*) and velvet potato-bush (*Solanum ellipticum*).

Since the late 1800s, the vegetation cover has been greatly modified by increased herbivore grazing, caused by the introduction of rabbits, sheep, cattle and goats–together with increased kangaroo populations–as well as localised tree clearance for fuel and construction (Kenny 1936; Beadle 1948; Fanning 1999; Lord 1999).

Despite local variations, these four broad vegetation types dominate the region. Further details and subdivisions can be found in Keith (2004), Beadle (1948), Eldridge (1988), and Pickard and Norris (1994). As discussed later, their recognition has important implications for using biogeochemical sampling programs.

2.3 Topography and landforms

The Tibooburra–Milparinka region generally consists of undulating broad plains between 60 and 200 metres above sea-level. The main topographic uplands are included within the Grey Range, which includes Mount Shannon (332 m), the Warratta Hills (295 m), Mount Browne (274 m) and the Whittabrenah Hills near Tibooburra (~250 m). There are five broad landscape settings in the region (*Figure 5*):

- hills and rises consisting of either: (a) weathered bedrock or (b) weathered Mesozoic and Cenozoic sediments
- sheetflow plains and rises, typically with extensive surface lag
- dunefields and sandplains, particularly associated with the Strzelecki Desert in the west, but extending across low-lying interfluves in the east
- alluvial systems, associated with major ephemeral streams

- lakes and playa systems, such as those associated with terminations of many alluvial systems.

Accounts of the landscape further east in the Thomson Orogen region can be found in Thoms *et al.* (2004).

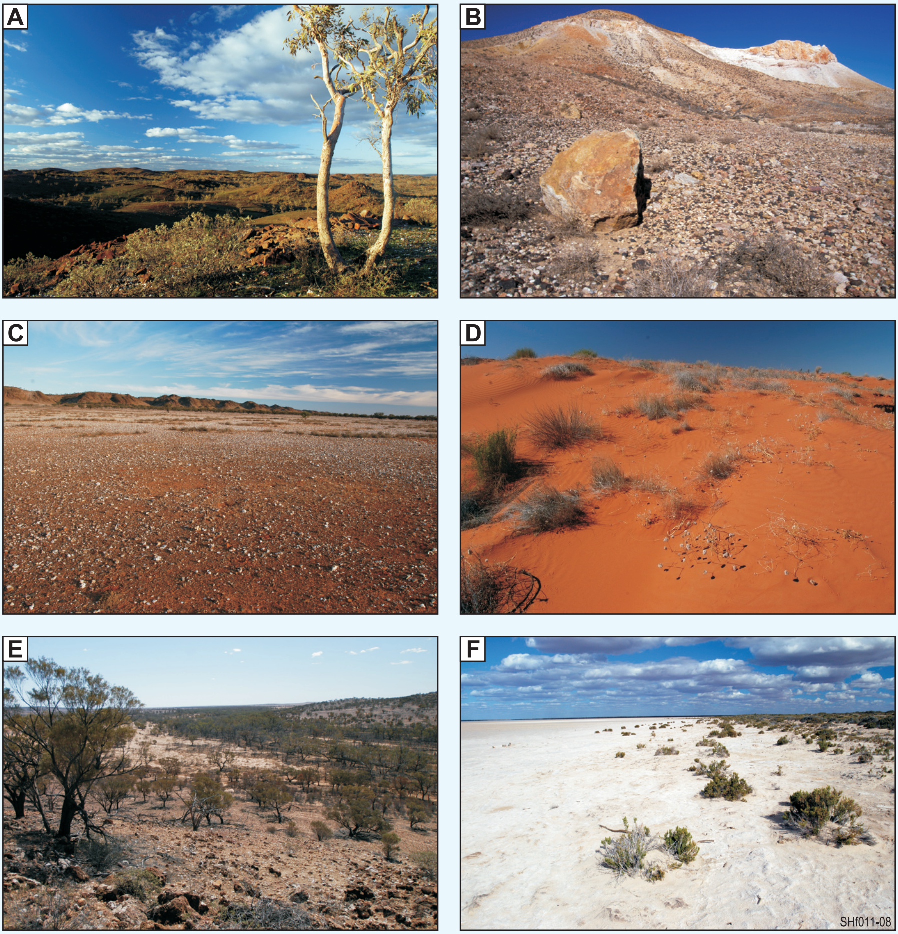


Figure 5: The main landscape settings for the region. (A) hills and rises consisting of weathered metasediments and granodiorite west of Tibooburra township (GDA: 594608 mE / 6744441 mN). (B) hills and rises consisting of weathered Mesozoic and Cenozoic sediments, Mount Stuart (GDA: 596891 mE / 6723207 mN). (C) sheetflow plains and rises northwest of the Mount Browne Inlier. (D) dunes and sandplains near Cameron Corner (GDA: 509232 mE / 6791874 mN). (E) alluvial systems, such as at Mount Wood Gorge (GDA: 621029 mE / 6754301 mN). (F) lakes and playa systems, such as the playa at Salt Lake (GDA: 607050 mE / 6666725 mE).

2.4 Hydrology

The Tibooburra–Milparinka area contains two main active drainage basins:

- The Lake Eyre Basin in the west, with drainage mostly flowing towards the Lake Frome depocentre, but typically terminating within the Strzelecki Desert dunefields. Local drainage systems, such as Lake Wallace Creek, Yandama Creek, Stewarts Camp Creek and Fromes Creek, are included in this drainage basin.
- The Bulloo–Bancannia Basin in the central north of the region, including the Bullo Overflow system that originates in southwestern Queensland, and local streams such as Yancannia Creek, Berawinnia Creek, Evelyn Creek, Warratta Creek, Thomsons Creek and Twelve Mile Creek. Local depocentres include fresh- and saltwater lakes such as Bancannia Lake, Nuchea Lake, Cobham Lake, Salt Lake and Caryapundy Swamp.

Groundwater in the region is mostly associated with the following settings:

- Artesian water within basin sediments–in particular the Jurassic to early Cretaceous terrestrial and terrestrial-marine transition sands and gravels of the Eromanga Basin (e.g. aquifers within the Algebuckina Sandstone and Cadna-owie Formation and confined by the overlying Bulldog Shale). Recharge occurs at exposed aquifer units, such as along inlier margins, but also at the greater basin margins beyond this region.
- Shallow aquifers within alluvial sediments of contemporary alluvial systems, typically occurring at the sediment–bedrock interface, but can be within the sandy and gravely sediments within thicker sediment accumulations.
- Fractured rock aquifers, particularly along fault and fracture zones within bedrock inliers and parts of the Mesozoic sedimentary basin sediments.

2.5 Geology and mineralisation

2.5.1 Thomson Orogen

The Thomson Orogen is one of the most poorly understood major orogenic belts in Australia. It covers a vast area: mostly throughout south-central Queensland, but extends into northwestern NSW (*Figure 1*). Named by Kirkegaard (1974) after the Thomson River in central Queensland, it is part of the greater Tasmanides of eastern Australia. Geochronology and seismic data suggest the Thomson Orogen in Queensland has undergone a different history to the Lachlan Orogen (Draper 2006). Neoproterozoic to Middle Cambrian sedimentation and around 500 Ma deformation recognised in the Thomson Orogen is more akin to the Delamerian Orogeny recognised in the Koonenberry and Adelaide fold belts. A felsic magmatic/volcanic event at around 470 Ma that is not recognised in the Lachlan Orogen (Crawford *et al.* 2007)–as well as an abrupt change in structural grain and crustal thickness at the contact between the orogens (represented by the Olepoloko Fault)–suggests some differences in their early Palaeozoic histories (Draper 2006). However, in the Bourke area on the southeastern margin of the Thomson Orogen, similarities have been noted with the Lachlan Orogen. Calc-alkaline andesitic volcanics have been correlated with the Ordovician Macquarie Arc in the Lachlan Orogen (Burton *et al.* 2008). The Thomson and Lachlan orogens also share a similar post-Middle Devonian history, with deformed orogenic rocks unconformably overlain by epicratonic Late Devonian infrabasins.

The Tibooburra–Milparinka area

The Mount Poole, Mount Browne, Warratta and Tibooburra inliers in the Tibooburra–Milparinka area mostly consist of strongly cleaved, greenschist facies phyllites intruded by monzo-dioritic dykes, sills and stocks.

The Mount Browne and Mount Poole inliers contain the Depot Glen Formation: a turbidite sequence metamorphosed from low greenschist up to mid-greenschist facies (along the eastern margin of the Mount Poole Inlier). Felsic tuff in the formation has been dated at 504.5 ± 2.6 Ma (Black 2006). It has been strongly deformed and metamorphosed during the Delamerian

Orogeny (~505–498 Ma). The Warratta and Tibooburra inliers contain the Jeffreys Flat and Easter Monday formations, respectively. Tuffaceous mudstones in the Easter Monday Formation have been dated by sensitive high-resolution ion microprobe (SHRIMP) U–Pb at 497.2 ± 2.6 Ma (Black 2006). Provenance appears broadly similar among the inliers, with sub-arkosic to lithic compositions and detritus suggesting mixed continental sources including acid volcanics and sandy immature sediments, in addition to a more distal plutonic/metamorphic terrain (Stevens and Etheridge 1989). The continental provenance and shallow marine setting of the Late Cambrian sedimentary rocks suggest deposition on a continental platform or shelf. This sedimentation closely followed the Delamerian Orogeny, and the source of the detritus may have been from the Delamerian highlands to the west (Scheibner and Basden, 1998).

The main deformation event recognised in the Warratta and Tibooburra inliers is characterised by strong penetrative cleavage, concertina-style folding and steep reverse faulting. Reverse faults parallel to quartz vein networks occur on the eastern limb of some anticlines. This deformation event was contemporaneous with the Benambran Orogeny in the Lachlan Orogen (Greenfield and Reid, 2006).

The final ductile deformation event recognised in the area occurred in the Benambran, and resulted in refolding of earlier folds, quartz vein networks and cleavage. The event is characterised by kink-banding and mesoscopic F2 chevronic folding in discrete domains. Minor tension quartz-calcite veins have injected along kink bands and as minor en-echelon arrays in monzodiorite sills/dykes, but limited rock-chip assays suggest they are not auriferous.

Preceding and/or contemporaneous with this final ductile deformation event, I-type monzo-dioritic intrusions were emplaced within most inliers across the Tibooburra–Milparinka area, and have been dated by SHRIMP U–Pb to between ~428 and 420 Ma (Black 2006; 2007). Post-tectonic monzo-granites and related dykes/sills intruded across all of the Tibooburra–Milparinka inliers. The I-type geochemistry suggests melting of an ensimatic source, which, along with alkaline mafic enclaves and a strong gravity high, provides an indication of a possible mafic igneous lower crust underlying the Tibooburra area (Greenfield and Reid 2006).

2.5.2 Late Palaeozoic

Although there is little direct evidence for Permian glaciation within the Thomson Orogen, it is likely to have been an important aspect of the geological and landscape history. During these times, the region was at very high latitudes and the global climate was cold, resulting in much of southern Australia (which, at that time, was part of Gondwana) being covered by a continental ice sheet. The transport of boulders composed of bedrock types from beyond the region has been attributed to glacial activity at this time (Flint *et al.* 1980), and glacial and fluvio-glacial deposits may have provided an important component of the sediments subsequently reworked within the landscape. Interpreted periglacial sedimentary rocks of the Yanna Tank Formation have been recorded in the southern Koonenberry Belt on the Bunda 1:100 000 sheet and represent the closest direct evidence of deposits associated with Permian glaciation.

Diatremes have been widely recorded from the region, and examples from the Kayrunnera area west of White Cliffs have been radiometrically dated from the Permian (Gleadow and Edwards, 1978). These form distinctive 'bulls-eye' positive and negative magnetic anomalies within regional airborne magnetics datasets, and have been of interest to previous diamond exploration programs. Some examples have been excavated by costeans near Kayrunnera in the central Koonenberry Belt (Mills 2002), and others south of Tibooburra have been targeted for drilling based on their geophysical expressions (Brewster 1989a, b; Nelson 1990).

2.5.3 Mesozoic: Eromanga Basin

The Eromanga Basin is the largest and most central of the basins that comprise the Great Artesian Basin, and covers approximately one-fifth of the Australian continent (*Figure 6*). The Mesozoic evolution of the Eromanga Basin has been responsible for extensive deposition of sediments in the region and therefore accounts for a large part of the transported cover and constrains large components of the dispersion and formation of mineralisation signatures within the regolith.

The biggest challenge to understanding of the Mesozoic sediments in this region has been the development of a robust stratigraphic framework (e.g. problems expressed in Stevens, 1988). A large number of schemes have been used by different workers at different times and for different State Geological Surveys. Some stratigraphic frameworks are mostly developed from drilling in the deepest parts of the basins (e.g. associated with petroleum exploration), whereas others are largely reliant upon exposures in field sections nearer the basin margins. Detailed outlines of the Eromanga Basin stratigraphy can be found in Wopfner (1969), Moore and Pitt (1982), Hawke and Bourke (1984), Moore (1986), Kreig *et al.* (1995), and Packham *et al.* (2001).

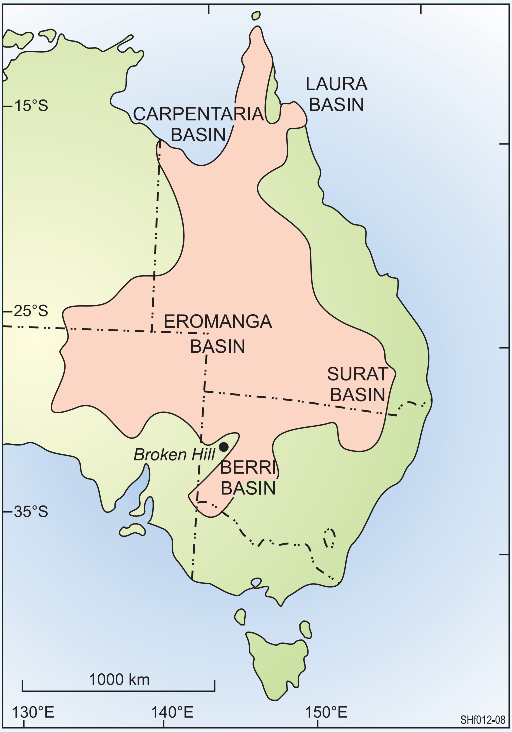


Figure 6: Location and extent of the Eromanga Basin.

The deposits in this part of the Eromanga Basin broadly reflect terrestrial sedimentation followed by marine incursion and then a return to terrestrial conditions. As a result, the sediments conform to four main groupings:

- Early Jurassic to Early Cretaceous terrestrial sediments: dominantly moderate- to high-energy, cross-bedded fluvial sandstone and conglomerate (e.g. Algebuckina Sandstone and equivalent sandstone-mudstone successions) (*Figure 7*)
- Early Cretaceous terrestrial to marine transition sediments: sandstones-

siltstones and some conglomerate (e.g. Cadna-owie Formation) (*Figure 8*)

- Early Cretaceous marine sediments: grey fossiliferous mudstone–siltstones with regressive marine sandstones (e.g. Maree Subgroup, and more specifically the Bulldog Shale and equivalent sediments) (*Figure 9*)
- Late Cretaceous terrestrial sediments: mostly low-energy, fine grained, flood-plain and lacustrine sandstone, siltstone and coal-swamp deposits (e.g. Winton Formation).

A locally used stratigraphic framework is outlined in Morton (1982) and, more recently, in some of the NSW DPI mapping program; however, a more basin-wide and simplified approach based on field exposures is adopted here. Locally defined units such as the Gum Vale Beds or Gum Vale Formation (McMinn 1981b; Morton 1982) are for the most part a mixture of the Algebuckina Sandstone and Cadna-owie Formation, along with numerous previous incorrect correlations with the Tertiary Eyre Formation. More recent interpretations by the NSW DPI of the Namur Sandstone flanking many of the inliers are here broadly grouped within the Algebuckina Sandstone and equivalent units. The same has been done for other Jurassic–Early Cretaceous terrestrial units such as the Poolowanna Formation, Hutton Sandstone, Birkhead Formation, Adori Sandstone, Westbourne Formation and Murta Formation, which are mostly known from petroleum drilling in the deepest parts of the basin. The locally defined Whittabrenah Shale (Morton 1982) is equivalent to the Bulldog Shale of the Maree Subgroup.

The outcrop patterns of these sediments are generally concentrically arranged around margins of the bedrock inliers in the Tibooburra–Milparinka area. The Early Jurassic to Early Cretaceous terrestrial sediments (e.g. Algebuckina Sandstone and equivalent sediments) tend to overlie or immediately flank the inliers, where they form a distinctive rounded, quartz-dominated surface lag across exhumed parts of the inliers and flanking the inlier margins. Excellent exposures occur at Quarry Hill (*Figure 7*) and Tunnel Hill on the Tibooburra Inlier, and along the Warratta and New Bendigo fault-line escarpments south of the Warratta Inlier. These sediments represent erosion and reworking of

Figure 7: Algebuckina Sandstone equivalent fluvial sediments overlying weathered granodiorite of the Tibooburra Inlier at Quarry Hill (GDA: 599451 mE 6742336 mN). Note the extensive surface lag of rounded white quartz, which approximates the exhumed unconformity surface between the Mesozoic sediments and the weathered granite. The fine-grained sandstone in the upper parts of this section may be equivalent to the Cadna-owie Formation, and represent a lateral expression of a Mesozoic marine transgression.

the weathered bedrock and therefore are the most important host of placer Au occurrences flanking bedrock inliers in the Tibooburra–Milparinka area. These are overlain and flanked by the terrestrial-to-marine transition sediments and, in turn, by the marine sequences. The lower parts of the terrestrial-to-marine transition sediments (e.g. Cadna-owie Formation and equivalent sediments) have a similar landscape expression to the underlying Algebuckina Sandstone-equivalent sediments, which in the past has made field mapping distinctions difficult. Some of the best exposures occur in creek gullies near Black Stump Dam west of the Tibooburra Inlier (*Figure 8*). The marine sediments (e.g. Bulldog Shale and equivalent sediments) typically form the low-relief, sparsely vegetated, sheetwash plains extending between many of the inliers and across the flanking plains. Notable exposures occur along North Warratta Creek northwest of the Silver City Highway and along

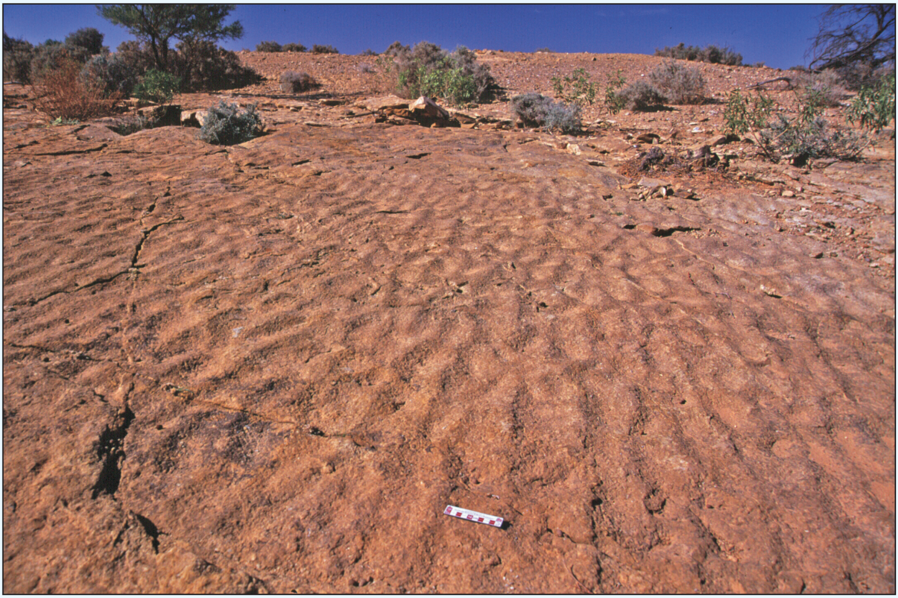


Figure 8: Inter-tidal ripples in Cadna-owie Formation equivalent sedimentary units near Black Stump Dam (GDA: 583022 mE / 6743835 mN). Scale bar is in centimetres

creeks incising the Warratta Faultline escarpment south of the New Bendigo Inlier (*Figure 9*). The upper terrestrial sedimentation phase is not clearly represented in the area, with reports of occurrences restricted to the outer margins of the tectonic domes, underlying silicified Cenozoic sediments of the Eyre Formation. Further work is needed to confirm interpretations of the Winton Formation exposures in the region. The lack of extensive Late Cretaceous to earliest Cenozoic sediments (i.e. following the Winton Formation, but preceding the Eyre Formation of the Lake Eyre Basin) has been attributed to a time of extensive weathering, with minimal erosion and sedimentation.

The Mesozoic sediments have been extensively folded and faulted in the region. This is most apparent along the New Bendigo, Warratta (*Figure 10*) and Mount Browne faults, where the sediments have experienced reverse faulting and folding including local overturning along faults. The location of bedrock inliers along the Warratta and New Bendigo faults is largely

Figure 9: Gully section of Bulldog Shale equivalent sediments near the Warratta Faultline escarpment southeast of the New Bendigo Inlier (GDA: 589874 mE / 6718942 mN). Scale bar is in centimetres.

Figure 10: Overturned Mesozoic sedimentary sequence along Warratta Fault, east of New Bendigo Inlier (GDA: 590414 mE / 6718646 mN).

controlled by the axes of anticlines within some of these folds, which expose bedrock and older sedimentary units. There are also numerous faults and fractures throughout the areas of Mesozoic sediments (e.g. Davey and Hill, 2005).

Many of the regolith, landscape evolution and mineral exploration attributes and implications of these sediments are further discussed in Chapters 3 and 4 of this Guide.

2.5.4 Cenozoic: Lake Eyre Basin and Bulloo–Bancannia Basin

For the most part, Cenozoic sedimentary basins are superimposed across the Mesozoic Eromanga Basin. The two main Cenozoic sedimentary basins in the area are the Lake Eyre Basin (Callabonna Sub-basin) in the west and the Bulloo–Bancannia Basin in the east. The contemporary and palaeodrainage divide between these basins approximates the Grey Range in the area, and continues northwards into western Queensland and southwards to the Barrier Range (*Figure 11*). The palaeodrainage divide is less well defined, and it is possible that outflow from the Lake Eyre Basin extended across this area and into the Bulloo–Bancannia Basin during the early Cenozoic. Both of these basins appear to have similar sedimentary fill and, because of the greater amount of study conducted on the Lake Eyre Basin (e.g. Callen *et al.*, 1995;

Figure 11: Regional regolith-landform map of western NSW showing contemporary drainage divides (from Hill 2005).

Aeolian Sediments
- Sands and minor silts: dunefields and sandplains
- Sands, silts and clays: lunettes

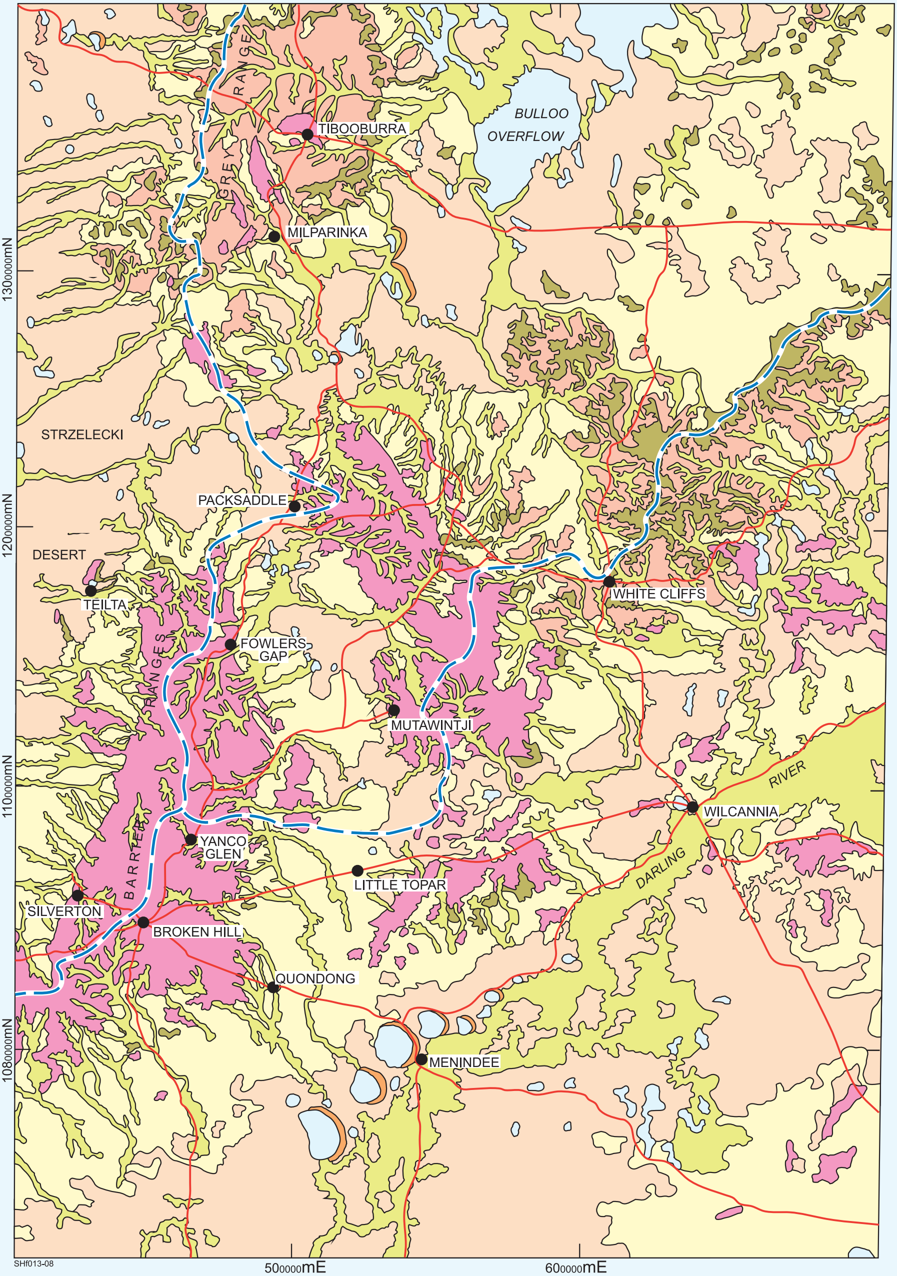
Alluvial Sediments
- Contemporary drainage sediments: channels, swamps, plains, fans, drainage depressions
- Silicified palaeodrainage sediments: erosional rises and plains

Colluvial Sediments
- Sheetflow and other shallow overland flow gravels, sands, silts and clays: fans, plains, rises

Lacustrine Sediments
- Silts and clays in playas and freshwater lakes and swamps

Weathered Bedrock
- Kaolinitic, smectitic, ferruginised and silicified weathered conglomerates, sandstones, siltstones and claystones (from the Mesozoic Eromanga Basin): erosional hills, rises and plains
- Slightly to moderately weathered bedrock: erosional mountains, hills, rises and plains

- Regional drainage divides
- Main road
- Town or locality


BULLOO
OVERFLOW
TIBOOBURRA
MILPARINKA
GREY RANGE
STRZELECKI
DESERT
PACKSADDLE
TEILTA
WHITE CLIFFS
FOWLERS GAP
BARRIER RANGES
MUTAWINTJI
WILCANNIA
RIVER
DARLING
YANCO GLEN
LITTLE TOPAR
SILVERTON
BROKEN HILL
QUONDONG
MENINDEE
1300000mN
1200000mN
1100000mN
1080000mN
500000mE
600000mE
SHf013-08

Alley, 1998), the stratigraphy outlined here conforms to that basin. The Cenozoic sediments of the Bulloo–Bancannia Basin have received very little previous description (only briefly outlined in Hill 2005).

Cenozoic basin sediments are mostly related to periods of fluvial, lacustrine and some aeolian sedimentation continuing to the present day. Weathering and induration development are also closely associated with the evolution of this basin fill, and are discussed separately in Chapter 4. Much of the Cenozoic basin sediments occur in low-lying settings with subdued topography and limited exposure, except for around the margins of the tectonic domes and along fault-line escarpments in the Tibooburra–Milparinka area. There are three main phases in the sedimentary records of these basins:

- Late Palaeocene to Middle Eocene: dominantly fluvial sandstone, carbonaceous clastics and quartzose conglomerates (e.g. Eyre Formation and equivalent sediments) (*Figure 12*)
- Oligocene to Pliocene: lacustrine and fluvial sand, silt and clay (e.g. Namba Formation and equivalents)
- Pliocene to Quaternary: fluvial, colluvial, lacustrine and aeolian sands, gravels and clays (such as deposited within the contemporary landscape).

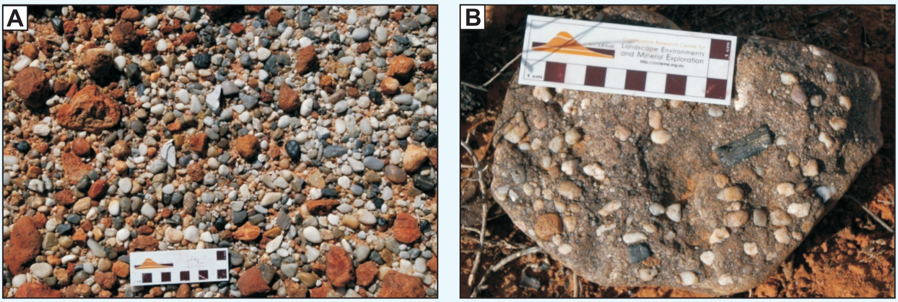


Figure 12: Eyre Formation sediments. (A) Rounded quartzose pebbles are a distinctive lithological characteristic of the lower parts of this unit, such as this example from the Eyre Formation type section near Innamincka.
(B) an example of silicified quartzose pebbles from near the New Bendigo Inlier (GDA: 589775 mE / 6718147 mN).

The Palaeocene to Middle Eocene fluvial sediments are eastern extensions of the Eyre Formation (Wopfner *et al.*, 1974) in the Lake Eyre Basin. Equivalent sediments are present in the Bulloo–Bancannia Basin. Both are confined to either discrete palaeovalley fill, mostly along the axes of synclines near the Warratta and New Bendigo Inliers, or broad sediment sheets exposed in escarpments along the uplifted margins of the Tibooburra Dome. Oligocene to Pliocene Namba Formation sediments are very limited in their exposure in the region and have mostly been identified after palynological analysis of drill samples (e.g. McMinn 1981b). Poorly consolidated ferruginous gravels overlying and flanking silicified Eyre Formation on the eastern margins of the Tibooburra Dome, such as immediately west of Mount Wood homestead, may also be equivalent to outwash associated with the Doonbarra Formation or Namba Formation (*Figure 13*). The Pliocene to Quaternary sediments provide widespread cover and sections are best exposed in gully walls. These sediments are discussed further in Chapter 3.

Figure 13: Doonbarra Formation equivalent sediments west of Mount Wood Homestead. Note the abundant sub-rounded maghemite clasts (GDA: 618406 mE / 6718147 mN).

2.5.5 Mineralisation

The Au-endowed Late Cambrian inliers exposed in the Tibooburra–Milparinka area suggest that there is potential for orogenic Au mineralisation in the region. Limited drilling has revealed quartz veining in altered metasediments throughout the NSW Thomson Orogen, including sulphide mineralisation associated with quartz veining in deformed phyllites in the area covered by the Urisino 1:250 000 sheet. The presence of basalts (with ocean island chemistry) and serpentinites in the project area (Louth Volcanics) suggest that the orogen has the potential to host arc- and ocean crust-related Au and base metal deposits. Gold–base metal deposits around Mount Dijou, south of Bourke, and Sn deposits associated with the Triassic Doradilla Granite, are also within the interpreted Thomson Orogen boundary.

Early speculation about the presence of Au in far western NSW was mostly derived from the South Australian Government, which was keen to establish an Au-field close to South Australia. In 1858, a prospecting party led by Capt. J Crawford, and sponsored by the South Australian Government, travelled through the Barrier Range and as far north as Depot Glen. Although unsuccessful, the noted abundance of quartz veins in the region maintained speculation. In October 1880, a prospector, Arthur C. Ashwin–with the assistance of local station employee, John Thompson–found Au near Mount Poole station (McQueen 2007). This was followed in February 1881 by the discovery of a payable Au-field at Mount Browne by James Evans and three other prospectors (McQueen 2007). On April 15, 1881 (Good Friday) Au was found on the southwestern margin of the Warratta Inlier (hence the 'Good Friday' diggings) and 3 days later was discovered west of the present location of Tibooburra ('Easter Monday' diggings). Prospecting then extended westwards towards Nuggety Gully. Most of the earliest discoveries were from surface 'specking' within alluvial settings, but then included dry blowing and panning. The search also extended into the flanking older sedimentary cover, especially due to the search for 'deep leads'. This included attempts to sink deep shafts at sites such as Billygoat Hill, The Four Mile, The One Mile and Tunnel Hill, which were mostly terminated because of low grades, hard cements or flooding.

Early mining accounts collectively refer to the Au-diggings in the region as the 'Albert Goldfield' (Brown 1881; Pittman 1895a, b; McQueen 2007). Early prospecting was challenged by the remoteness, supply shortages, unreliable Au transport, a hot dry climate and, for most of the time, a shortage of water for mining and domestic purposes–although periodic flooding also caused problems. The population was also ravaged by sickness, including dysentery, scurvy and typhoid (locally known as 'Mount Browne fever'). By 1890, most of the Au extraction had concluded.

Irregular records of historical Au production from the 'Albert Goldfields' was 25,179 oz for 1881–7 and 18,890 oz for Tibooburra between 1887 and 1933 (Kenny 1934). A total of 1870 kg Au is estimated to have been obtained from the region since 1881, with highly variable grades (Barnes 1975).

Gold mineralisation and historical mining as part of the Albert Goldfield in the Tibooburra–Milparinka area is mainly associated with three settings (*Figure 14*):

- turbidite-hosted orogenic Au (e.g. Warratta Inlier and western margin of the New Bendigo Inlier)
- Mesozoic palaeo-placers (e.g. Tunnel Hill and Billy Goat Hill) (*Figure 15*)
- placers associated with contemporary drainage systems (e.g. Nuggety Gully, Easter Monday, The Granites, German Gully, Good Friday and Four Mile) (*Figure 16*).

From a historical mining perspective, the sedimentary Au mineralisation yielded the most Au, and continues to be worked by prospectors. The primary source for much of this Au has not been identified, with the only notable primary Au sources restricted to Au-bearing veins in the Warratta Inlier (*Figure 17*) and margins of the New Bendigo Inlier.

Turbidite-hosted Orogenic Au

The timing, alteration and structural controls of turbidite-hosted orogenic Au in the Warratta Inlier compare favourably with turbidite-hosted orogenic Au deposits as defined by Bierlein *et al.* (1998), and to the world-class deposits of the Bendigo Zone of the Victorian Goldfields (Greenfield and

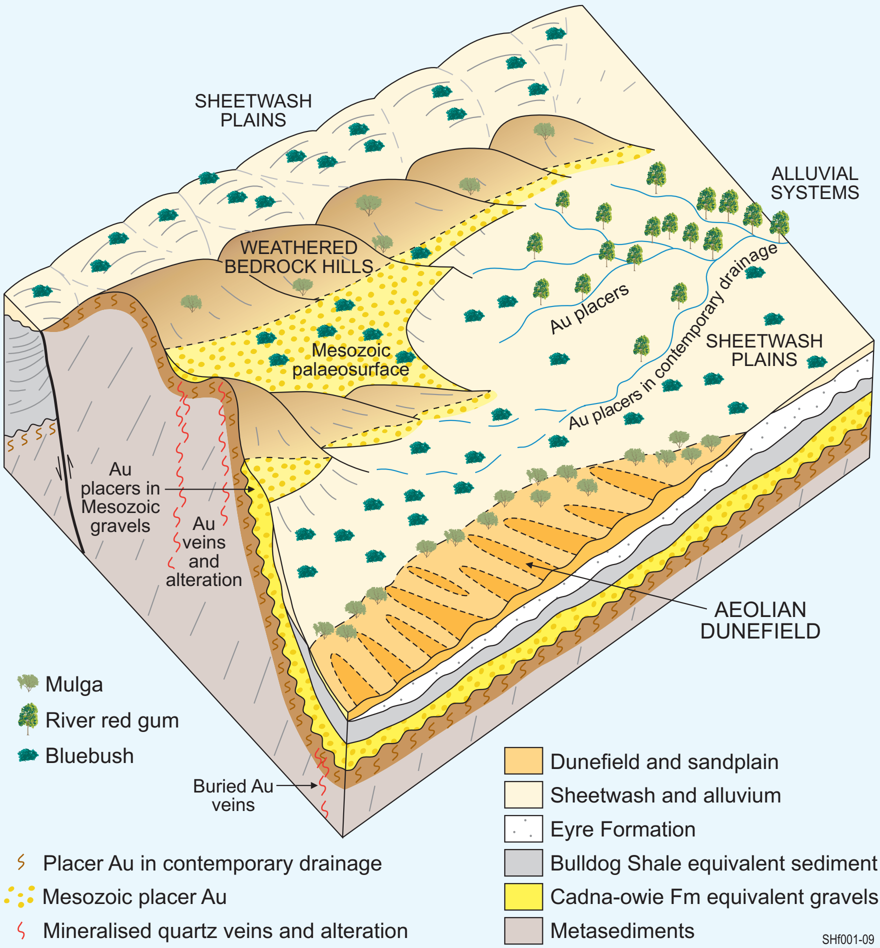


Figure 14: Diagrammatic representation of settings for Au mineralisation in the Tibooburra–Milparinka area.

Reid, 2006). Gold is associated with syn-deformational quartz veins, which were injected parallel to cleavage formed in the Late Ordovician–Silurian Benambran Orogeny (Greenfield and Reid, 2006). Gold mineralisation is mainly related to the second (of three) generations of veins: predominantly containing quartz, albite and carbonate, with variable amounts of pyrite, arsenopyrite, chalcopyrite, galena, pyrrhotite and native Au (Thalhammer 1992). These quartz veins are hosted by the Jeffreys Flat Formation of the Warratta Group: a 2-km thick turbidite sequence with pyritic siltstone and minor conglomerate and limestone (Greenfield and Reid 2006).

Greenfield and Reid (2006) described an association of mineralisation with two alteration zones: firstly, narrow phengite–chlorite–pyrite–carbonate halos around quartz veins and, secondly. carbonate–sericite 'bleached' zones extending kilometres along strike. Whole-rock K–Ar dates from quartz-vein alteration halos in the host phyllite are 441 ± 5 Ma, 438 ± 3 Ma and 424 ± 4 Ma (Thalhammer 1992). Dextral transpressional deformation in the Late Benambran Orogeny resulted in further quartz veining and chevron folds (Greenfield and Reid 2006).

The majority of production in the Warratta Inlier was from the Pioneer Mine, which yielded 66 oz Au from 77 tons of ore in 1884 and 30 oz Au from 40 tons of ore in 1886 (Kenny 1934). Gold-bearing veins were also worked at the Phoenix, New Bendigo, Warratta, Rosemount and Elizabeth prospects, but only minor, or no, Au-bearing veins were recorded from other inliers in the region.

Despite average grades of up to 25 g/t Au (Kenny 1934), the Pioneer–Phoenix area was not drilled until 2006 when exploration results confirmed the down-dip continuation of mineralisation, including 4 metres @ 4.39 g/t from the 88 metre hole TP003 (Mortimer 2007).

Further potential for orogenic Au exists in turbidite sequences to the east of the Koonenberry Fault in units that were strongly deformed by the Benambran Orogeny, underneath Mesozoic and Quaternary cover (Gilmore *et al.* 2007).

Mesozoic Palaeo-placer deposits

The basal gravels of the Mesozoic sediments (Algebuckina Sandstone and equivalent units) in the region were widely targeted. Notable examples include Tunnel Hill on the western margins of the Tibooburra Inlier (*Figure 16*) and most of the historical workings on the southern and eastern margins of the Mount Browne Inlier. Gold typically occurs as detrital nuggets as 'flaky' or 'foil-like' morphologies (*Figure 17*) and angular quartz clasts with Au (Marston 1984; Chamberlain 2001; Gibbons and Hill, 2005). The basal 0.6 metres of Mesozoic conglomerate at Tunnel Hill assayed at 11 g/t over a length of 4.6 metres (Kenny 1934).

Figure 15: Fluvial Mesozoic sediments (Algebuckina Sandstone equivalent) overlying weathered Easter Monday Formation metasediments at Tunnel Hill (GDA: 589521 mE / 6745048 mN). The Au-rich gravels at this unconformity were reworked by gullies associated with the contemporary alluvial system and re-accumulated in placer deposits down-slope (such as Nuggety Gully). The basal Mesozoic gravels here were historically mined, and included construction of a tunnel into the hillside along the unconformity surface (GDA: 589440 mE / 6744840 mN).

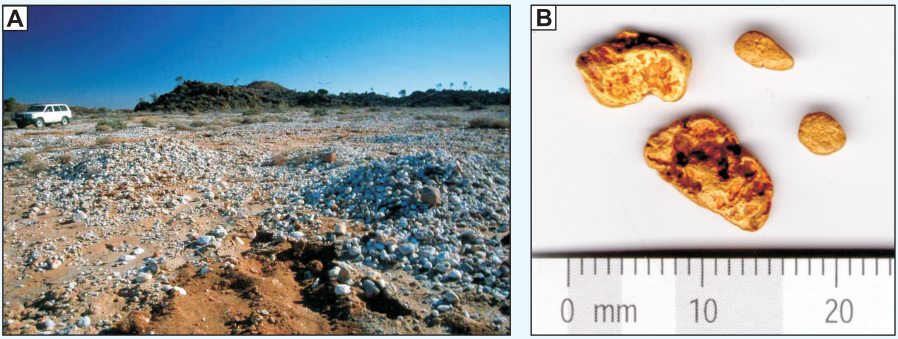


Figure 16: Gold workings within contemporary alluvial systems. (A) The Granites alluvial diggings near Tibooburra (GDA: 598440 mE / 6744395 mN). (B) Au nuggets from The Granites diggings.

Typically, the basal Mesozoic sediments have a shallow dip away from the inliers (Brown *et al.* 2006) and were derived by erosion of emergent bedrock and distributed by high-energy fluvial-to-marginal marine processes (Hill *et al.* 2005). Based on palaeo-current indicators (e.g. cross-bedding), a provenance to the west and northwest of the Tibooburra and Mount Browne Inliers is suggested, and parts of many of the inliers were emergent during the Mesozoic causing interruptions to flow and sediment (including Au) deposition.

Placers associated with contemporary drainage systems

Gold associated with contemporary alluvial systems is mostly located where the drainage channels and depressions have eroded and reworked the basal Mesozoic sediments and underlying bedrock. For example, in the western margins of the Tibooburra Inlier, the workings at Nuggety Gully (*Figure 16*) represent Au reworked from basal Mesozoic sediments from sites such as the adjacent Tunnel Hill mineralisation. These are the most widespread of the Au occurrences exploited by early miners. Grades of 0.5 g/t have reported as typical in the base of contemporary alluvial channels (Marston 1984). The headwaters of many of the contemporary drainage systems with Au placers are within hills and rises of the bedrock inliers: leading many early prospectors to search for an Au-rich bedrock provenance. This exploration approach, however, does not fully appreciate the importance of the Mesozoic fluvial systems for transporting and depositing Au that has since been reworked by the contemporary drainage systems. Therefore the Au source areas would have been better traced using a Mesozoic palaeodrainage reconstruction (such as now provided in this Guide) rather than focusing on contemporary systems.

Other minerals

Drilling diatremes in the area was attempted by CRA Exploration in 1988 in the northeast-orientated Cobham Kink Zone, to the southeast of Tibooburra–Milparinka. The exploration model was to target Tennant Creek-style Au mineralisation (Nelson 1990). Drilling of the total magnetic intensity (TMI) anomaly, approximately 7 kilometres southeast of Tibooburra intersected a

Late Permian–Early Triassic mafic, alkali-basaltic, volcanic breccia (Nelson 1990). This diatreme was the only one successfully tested and numerous other 'bulls-eye' magnetic anomalies remain untested in the area. No diamond potential or analyses of the diatreme TMI have been reported (Gilmore *et al.* 2007).

Opal occurrences are not widely recorded from the Tibooburra–Milparinka region, despite some anecdotal accounts. Non-precious opal has been reported from within the silcreted Mesozoic and Cenozoic sediments of the region (Wopfner 1978), and is frequently observed in fracture-fillings veins within the Mesozoic sediments, particularly associated with silicified wood samples. Parts of the weathered Mesozoic marine sediments (equivalent to the Maree Sub-group, but locally described as from the Doncaster Member of the Rolling Downs Group) host economic opals in the White Cliffs area (Burton and Mason 1998) and, despite the widespread distribution of weathered sediments equivalent to this unit in the Tibooburra–Milparinka area, no economic opals have been recorded.

Figure 17: Pioneer Mine and battery area photograph, Warratta Inlier (GDA: 582790 mE / 6729842 mE).

3. REGOLITH MATERIALS

The regolith can be informally defined as 'everything between fresh rock and fresh air'. Formally, it includes the entire unconsolidated or secondarily re-cemented cover, which overlies more coherent bedrock, that has been formed by weathering, pedogenesis (soil formation), erosion, transport and/or deposition (Eggleton 2001).

Regolith materials can be broadly subdivided into either *in situ* or transported materials (*Figure 18*). *In situ* regolith is still in its original place and includes weathered bedrock that has not undergone physical transport. In field descriptions, it may be sub-divided based on its weathering grade (slightly to highly weathered bedrock) or broadly referred to as saprolith, which may then be divided into saprock (< 20% of weatherable minerals altered) or saprolite (> 20% weatherable minerals altered). Transported regolith includes both exotic (sediments) and redistributed (pedolith) materials where the primary fabric is destroyed. The distinction between *in situ* and

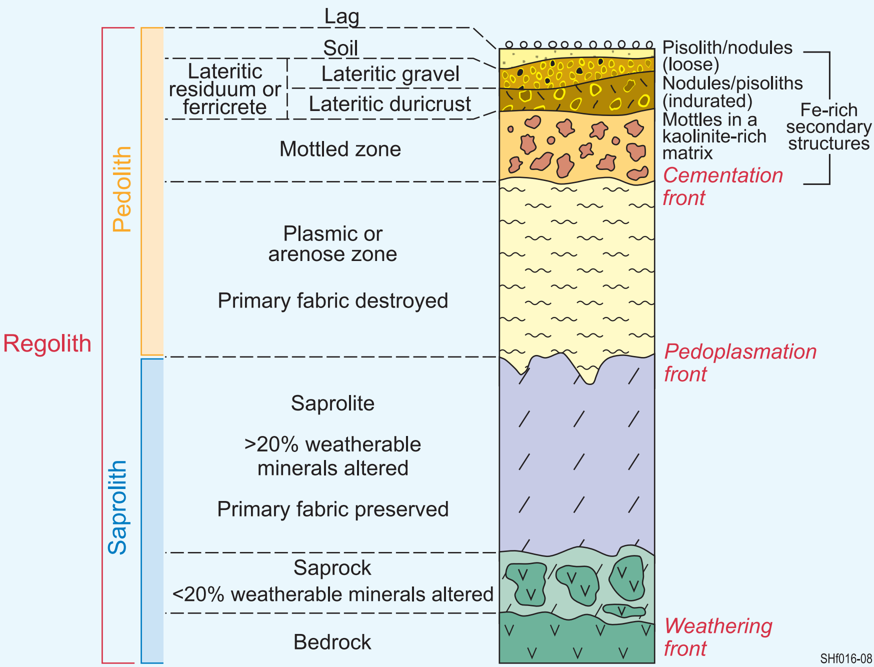


Figure 18: Standard terminology and zones for regolith profiles (Eggleton 2001).

transported regolith is of critical importance to mineral explorers, because it allows more confident identification of possible sources of regolith materials: either from underlying or distant source rocks. This is particularly important when trying to explain the origin of surface geochemical anomalies that may be linked to mineralisation.

Although a relatively simple concept, the distinction between *in situ* or transported regolith can be problematic and debatable: particularly where overprinting related to subsequent weathering, pedogenesis and induration can obscure some of the distinguishing features. The interpretation of the weathered Mesozoic and Cenozoic sediments as either transported regolith or weathered bedrock has also been problematic (e.g. Hill 2002). In most cases, the sediments have undergone some degree of *in situ* weathering and induration, but they are grouped here as transported regolith in order to maintain their significance as sediments within the regolith and landscape evolution framework, and because they have not undergone sufficient diagenesis to warrant consideration as bedrock. The following overview of regolith materials considers *in situ* and transported regolith types and then the more complicated overprinting relating to soils (pedogenesis) and induration.

3.1 *In situ* regolith

Some helpful indicators of the exposure or subcrop of *in situ* regolith within areas of sedimentary cover for this region include:

- preservation of primary bedrock fabrics, textures and structures, such as quartz veins, cleavage planes, inter-locking mineral grains (or secondary mineral pseudomorphs)
- responses characteristic of exposed bedrock in remotely sensed data continuing into areas otherwise mapped as having sedimentary cover (e.g. radiometric data is particularly useful in this regard, but interpretation may be complicated by dispersion away from outcrops)
- surface lags containing an increase in angular quartz vein clasts
- widespread landscape expression of basal sedimentary basin units

(e.g. Algebuckina Sandstone and equivalent sediments) flanking outcrop or providing patchy cover to subcrop. In particular, basal sediments with large boulders of locally derived bedrock clasts

- neotectonic setting corresponding to the axes of anticlines and/or the up-thrown side of fault scarps, where bedrock has been brought closer to the surface
- colonisation by plants typically associated with bedrock exposures, such as mulga (*Acacia aneura*), whitewood (*Atalaya hemiglauca*), bloodwood (*Corymbia tumescens*) and, rock sida (*Sida petrofila*).

All of these approaches have been effective in the discovery of previously unmapped bedrock exposures in the Tibooburra–Milparinka area. In many areas flanking bedrock inliers, the sedimentary cover thickness has been shown to be less than 10 m, rather than the hundreds of metres that had been estimated previously.

3.1.1 Weathered bedrock

Exposed and near-surface occurrences of bedrock have all been weathered to some degree. Weathered bedrock material can be simply subdivided in the field based on its degree of weathering as follows:

- slightly weathered bedrock (fresh rock–saprock): typically with weak red-brown ferruginous surface staining, primary minerals very prominent and tight, but slightly opened, joint and fracture sets. It tends to require a hammer to break in the field (kicking results in more damage to the foot than to the rock!).
- moderately weathered bedrock (saprock–saprolite): typically friable, variably ferruginised and kaolinitic, but still with some prominent primary minerals. It tends to break easily when struck with a hammer and falls apart when kicked, but cannot be broken by hand.
- highly weathered bedrock (saprolite), typically highly friable and highly quartzose and/or kaolinitic. It is easily broken by hand.

Slightly weathered bedrock is widespread across the bedrock inliers of the region: typically forming erosional hills, rises and plains. The most prominent examples occur as erosional rises topped with rounded tors of granite and granodiorite near Tibooburra, and as large exposures of quartz veins, such as within the Warratta, Mount Poole and Mount Browne inliers (*Figure 19A*). Parts of the metamorphic aureole surrounding the Tibooburra Granodiorite consist of slightly weathered bedrock forming prominent rises.

Moderately weathered bedrock is the most abundant grade of weathered bedrock exposed in the region, where it forms erosional hills, rises and plains within the inliers. It displays variable degrees of ferruginisation, with slightly more-ferruginised exposures typically associated with sites either immediately underlying the former extent of Mesozoic sediments or defining pre-Mesozoic upland surfaces (such as in the Warratta Inlier) (*Figure 19B*). The less-ferruginised exposures tend to be closely related to areas of more recent erosion within the bedrock inliers. This largely accounts for some of the variations in remote sensing pattern, colour and tone within the bedrock inliers.

Exposures of highly weathered bedrock are restricted across the region, mainly because it is easily eroded and is not cohesive enough to form prominent exposures. The best examples are typically underlying sections of transported regolith, such as below the Mesozoic sediments at Quarry Hill, Sugarloaf Hill, along the northern margins of the Tibooburra Inlier, and at Billygoat Hill at the southern end of the Mount Browne Inlier. The first two examples are derived from weathering of granodiorite, whereas the others are from weathering of metasediments. Discontinuous exposures of highly weathered metasediments underlie the sheetflow and alluvial sediments within the Warratta Creek valley between the Silver City Highway and northwards to near the Warratta Battery (*Figure 19C*). These occurrences correspond to a structurally controlled valley system that was previously covered with Mesozoic sediments. A similar zone of kaolinised highly weathered bedrock has been uncovered within mine shafts at the northeastern end of the New Bendigo Inlier, and accounts for the local name for this area of 'White Elephant'.

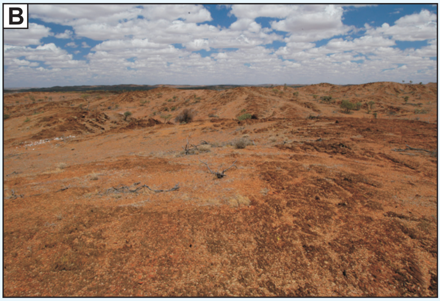


Figure 19: Examples of different grades of weathered bedrock from the Warratta Inlier.
(A) slightly weathered metasediments with quartz veins (GDA: 579972 mE / 6723691 mN).
(B) moderately weathered metasediments (GDA: 581217 mE / 6725272 mN).
(C) highly weathered metasediments (GDA: 582987 mE / 6728130 mN).

3.2 Transported regolith

Assorted marine, alluvial, colluvial, aeolian and lacustrine sediments are abundant across the region– particularly within low-lying settings, flanking hills and rises of bedrock inliers–although some of the older sediments may now occupy elevated or buried settings.

3.2.1 Marine sediments

These are mostly associated with the Early Cretaceous Bulldog Shale and partly with the Cadna-owie Formation of the Eromanga Basin. Lithological descriptions of these sediments are given in Chapter 2.

The main occurrences are subsurface, such as hundreds of metres thickness of Cadna-owie Formation and Bulldog Shale-equivalent sediments within the Bulloo Embayment of the Eromanga Basin, underlying the Bulloo Overflow east of Tibooburra. Sediment thickness also increases to the north and west towards the Frome Embayment and the Cooper Region of the Eromanga Basin. The best surface exposures of these sediments occur within the banks of incised creeks at the lowest points between the bedrock inliers, such as along North Warratta Creek between the Warratta and Tibooburra inliers, and along Mokely Creek northwest of the Warratta and Tibooburra inliers. These sediments are in faulted contact and are locally deformed along the faulted inlier margins, such as along the Mount Browne Fault, Warratta Fault and the faults defining the northeastern margin of the Tibooburra Inlier. The sections exposed along the Warratta Fault near the New Bendigo (*Figure 20*) and Warratta South inliers are particularly extensive and include the type section of the Gum Vale Beds (Morton 1982), which is a locally named sediment package equivalent to the Cadna-owie Formation and Algebuckina Sandstone.

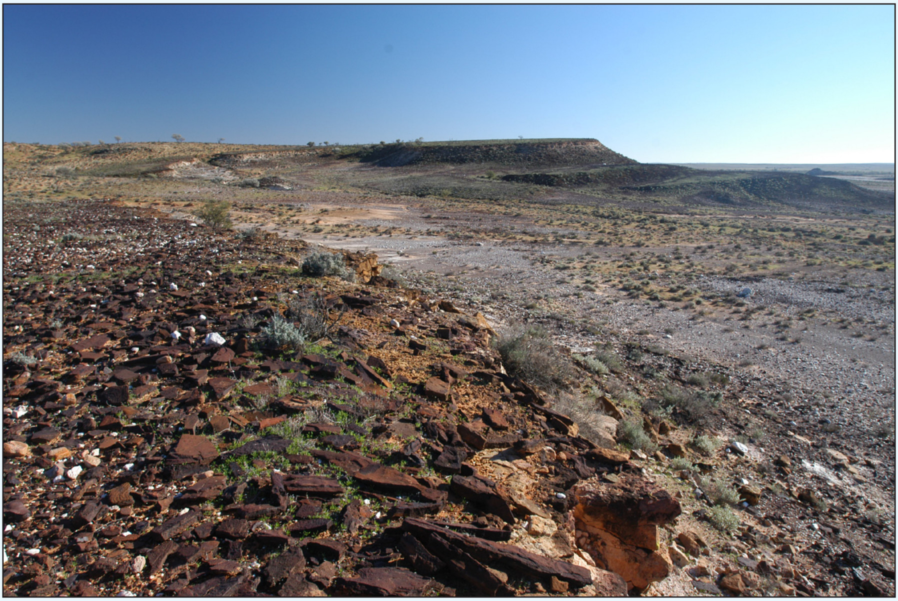


Figure 20: Mesozoic sediments exposed along the Warrata Fault-line escarpment looking north (GDA: 588883 mE / 6719621 mN). Note that sediments have been faulted and tilted towards the west, while the rise in the foreground and the prominent rise in the background represent the E–W trending axes of anticlines from an earlier generation of deformation. The embayment in the middle distance corresponds to the axis of a syncline, between the two anticlines.

These sediments are typically highly weathered to kaolin, with induration from silica, calcite, gypsum and Fe oxides. The co-existence of gypsum and ferruginous induration in weathered Bulldog Shale exposures is largely due to the pyritic, organic-rich nature of these sediments when they are fresh. Oxidation of the pyrite (Fe-sulphide) would have produced sulphates (e.g. gypsum) and Fe oxides (e.g. hematite and goethite in the ferruginous induration). The sulphide oxidation and Fe ferrolysis would have been responsible for the production of highly acidic weathering solutions and profiles, and would largely account for the Al leaching and relative accumulation of silica required for silcrete development in these sediments. The distinctive white escarpments of the breakaways' in the Olive Downs, Mount Wood Hills and Mount Stuart-Camels Hump areas are mostly composed of these weathered sediments, with a capping of silicified Tertiary Eyre Formation. Calcite induration is more common (but not diagnostic) in parts of weathered Cadna-owie Formation, and is largely due to dissolution of diagenic calcite cements in these sediments as well as contributions from dust and rainfall (Gibbons and Hill, 2005; Dart *et al.*, 2007).

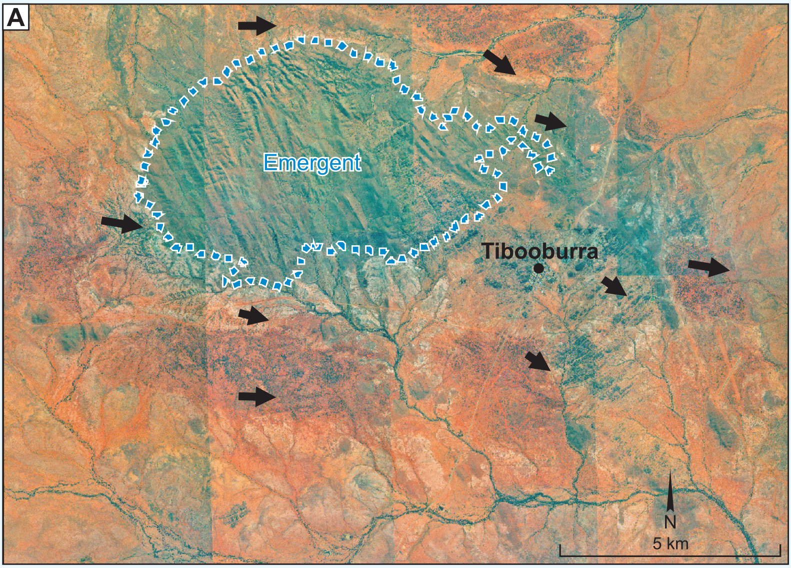
3.2.2 Alluvial sediments and palaeodrainage

There are three main types of alluvial sediments identified in the region:

- Mesozoic fluvial sediments associated with the Algebuckina Sandstone and equivalent sediments
- early Cenozoic sediments equivalent to the Eyre Formation in the Lake Eyre Basin and un-named equivalent sediments in the Bulloo–Bancannia Basin
- alluvial sediments associated with contemporary drainage systems.

The distinction between these systems is enormously important for mineral explorers because they have different relationships with primary, bedrock-hosted mineralisation and therefore have different potential as hosts for Au-placers and different implications for tracking the provenance of Au-bearing sediments.

The Mesozoic palaeodrainage is part of a large braided river system associated with the Algebuckina Sandstone and equivalent sediments. Measurement of palaeo-current indicators, such as tabular and trough cross-bedding, show a general west to east palaeo-flow towards the Bulloo Embayment east of Tibooburra (*Figure 21*). Parts of the bedrock inliers



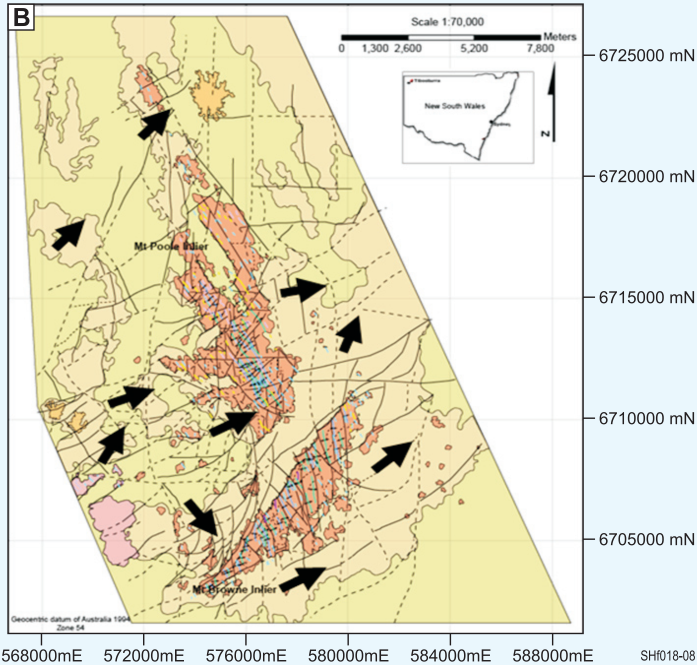


Figure 21: Palaeo-flow directions measured (mostly from cross-bedding) in the fluvial Mesozoic sediments. (A) Tibooburra Inlier. (B) Mount Poole and Mount Browne Inliers (Davey 2005).

acted as local impediments and constrictions to palaeo-flow and therefore formed important sediment traps for placer Au deposition. The landscape at this time was highly weathered, which is reflected in the quartz and kaolin mineralogy of these palaeosediments, and perhaps also included reworking of remnants of Permian fluvio-glacial outwash sediments. Localised bedrock exposures also contributed shale and granite pebbles and boulders to parts of these sediments. This palaeodrainage reconstruction is one of the key components to understanding placer Au entrapment and towards constraining the provenance of Au contributions to the placers.

The early Cenozoic Eyre Formation and equivalent sediments are more confined to sandy meandering palaeochannels near the bedrock inliers, but are part of larger alluvial sand sheets further away from the bedrock inliers. They consist largely of eroded and reworked Mesozoic marine sediments that covered much of the landscape immediately prior to the Cenozoic. The few bedrock exposures were likely to have been highly weathered: accounting for the lack of lithic detritus and dominance of quartz and kaolin minerals in these sediments. This has important implications for mineral exploration, and explains why samples of the Eyre Formation palaeosediments in this region tend to be Au-poor in comparison with the underlying Mesozoic alluvial sediments and the contemporary alluvial systems flowing across the inlier margins. Limited palaeo-current measurements from the region suggest that the Tibooburra–Milparinka area featured a palaeodrainage divide between the Lake Eyre Basin to the west and the Bulloo–Bancannia Basin to the east. West-to-east trending palaeovalley systems occupied the axes of synclinal troughs between the New Bendigo Inliers (*Figure 22*). These sediments have since been reverse faulted along NW–SE trending structures, such as the Warratta Fault and New Bendigo Fault, and have been tilted around the outer margins of the Tibooburra Dome.

Sediments associated with contemporary alluvial systems contain a mixture of red-brown and white quartzose sands, kaolinitic clays and lithic fragments. Stream sediments derived from the bedrock inliers are dominated by lithic fragments, whereas streams within the sedimentary basin areas typically contain the greatest diversity of clast types, because of the reworking of older sediments. The Au-bearing alluvial sediments within contemporary drainage systems are typically reworked basal Mesozoic alluvial sediments, and therefore the Au has experienced several episodes of alluvial transport and re-deposition.

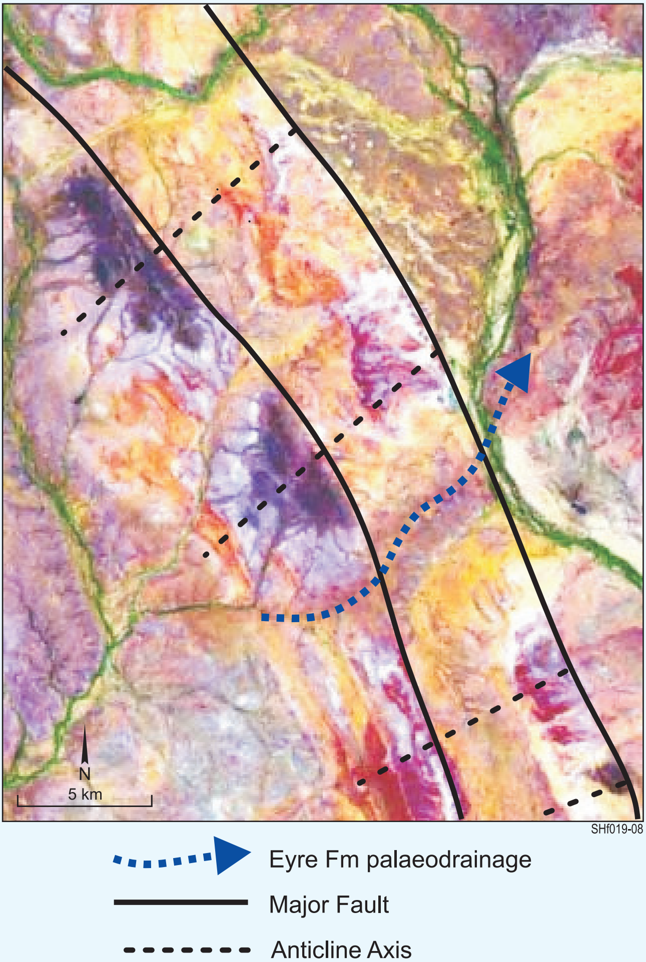


Figure 22: Annotated Landsat bands 741 image showing Eyre Formation palaeodrainage, overlying Bulldog Shale equivalent sediments preserved within syncline axis, south of the New Bendigo Inlier. Palaeo-flow was northeastwards along the syncline axis, and has been offset by NW-SE trending reverse faults.

3.2.3 Colluvial sediments (including sheetflow)

Colluvial sediments in the region are derived from rockfall, creep, slides, debris flow and sheetwash. Colluvial sediments mostly consist of locally derived lithic, quartzose and indurated regolith pebbles with red-brown quartzose sands.

Sheetflow sediments are the most widespread colluvial sediment type in the region: typically extending from the upper slopes of rises down towards the axes of adjacent valley systems where they typically converge into channels and grade into alluvial systems. Most sheetflow deposits are contained within broad, low-relief fans and lobes that mantle slopes over distances of tens of metres to tens of kilometres. In many cases they exhibit a distinctive 'contour band' or 'tiger stripe' surface lag arrangement: clearly seen in high-resolution surficial remotely sensed data (*Figure 23*). This consists of bands transverse to slope of sparsely vegetated pebbly surface lag alternating with more densely vegetated bands of silty sand (Dunkerley and Brown 1995; Wakelin-King 1999).

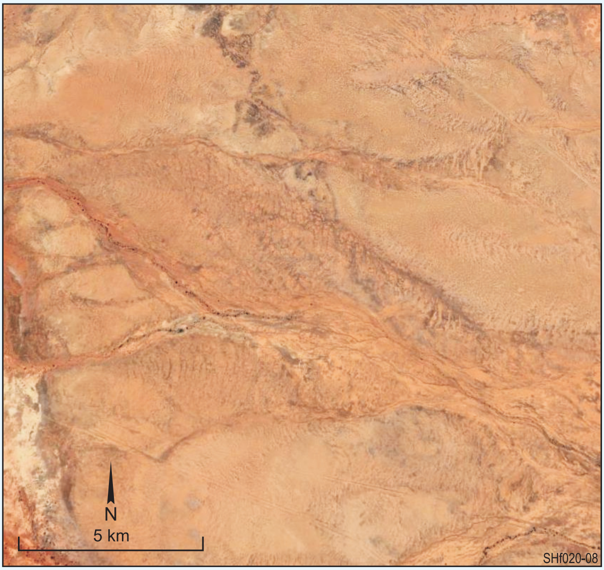


Figure 23: Colour ortho-photo showing contour banding derived from sheetflow, approximately 6 km east of Tibooburra.

Creep is a process occurring on most slopes, and is clearly demonstrated in surface exposures and excavations into weathered pelitic schists, where steeply dipping cleavage planes are 'bent' or disrupted near and at the surface as they move down-slope.

Rock falls contribute to the development of talus deposits at the foot of steep slopes, particularly adjacent to prominent exposures of slightly weathered bedrock, such as near Mount Browne (*Figure 24*), as well as along escarpments of silicified regolith, such as at Olive Downs. Land and rock slides and flows have been particularly prevalent along escarpments composed of highly weathered Mesozoic and Tertiary sediments, such as east of Olive Downs. The uncohesive weathered substrates on steep slopes, when lubricated and loaded with water either from groundwater or large rainfall events, can become unstable and slide. Because the slides may contain cohesive large 'blocks' of sediment, they can pose a challenge to sedimentary and stratigraphic reconstructions at these sites.

Figure 24: Colluvial rock-fall talus near the summit of Mount Browne (GDA: 578351 mE / 6708025 mN). Note strong structural control from cleavage planes.

An unusual landscape feature of the region is where many of the hills and rises capped by silicified sediment have been detached from their former talus-mantled slopes. In these cases, the talus mantle is ‘armoured’ by clasts of silicified sediment, whereas the intersection between the talus slope and the rise or hillcrest is less protected and tends to be incised at a greater rate than the rise or hill crest and the talus slopes. Mount Wood, northeast of Tibooburra, provides a good example of this landform assemblage.

3.2.4 Aeolian sediments

Sparse vegetation cover combined with a dry land surface and strong winds have contributed to the extensive development of wind-blown sediments in the region. These aeolian deposits form extensive landforms in their own right, and most surficial regolith materials have an aeolian component. Aeolian materials are mostly composed of fine sand and silt, including sand-sized ‘pellets’ of clay minerals, quartz, minor Fe oxides and calcite (Chartres 1982, 1983; Hallsworth *et al.* 1982). These sediments typically have a red to red-brown colour, and tend to be lighter coloured (and in some cases white) close to alluvial channel and lake sources.

The grain size of aeolian material varies within the region, which is an important consideration if it is to be avoided or discarded from sieved fractions of soil and stream sediment in geochemical samples. Close to streams and lakes receiving stream discharge, the aeolian materials tend to be coarser grained, with saltated aeolian clasts up to one millimetre in diameter (coarse sand), and many of the finer fractions are winnowed or washed away. Across dunefields and within sandplains, sands typically range between 60 and 200 µm. Finer grained aeolian contributions from suspended dust particles may be less than 60 µm. Lunettes and other clay-rich aeolian deposits typically contain sand-sized clay pellets that may disaggregate upon wet sieving to form dispersive clays. The key to identifying aeolian-size fractions from within surficial geochemical samples is therefore orientation studies and the subsequent identification of well-sorted, typically spherical and well rounded clasts, some of which may not have mineralogical or chemical affiliations with the underlying substrate.

Landforms in the region dominated by aeolian sediments include longitudinal linear dunes, sand plains and lunettes. Localised aeolian deposits flanking ephemeral stream channels mostly consist of pale red-brown quartzose sands with minor micaceous and lithic clasts. These can form source-bordering dune ridges–sub-parallel to channel margins and up to 3 metres high–derived from aeolian mobilisation of desiccated channel sediments. Linear dunefields, consisting of parallel to sub-parallel, low, WSW–ENE- trending, elongate sand ridges up to 10 metres high are best developed in low lying areas such as the Strzelecki Desert in the west of the region (Wasson 1983a; 1983b; Stevens 1991a), and across much of the Bulloo–Bancannia in the east. Sandplains and irregular, hummocky dunes are also typically developed on the margins of alluvial channel systems and lacustrine depressions, and may represent the alluvial reworking and subdued remnants of dunefields. Lunettes (smooth, crescent-shaped dunes transverse to prevailing wind direction) occur on the eastern shores of most ephemeral lakes in the region (*Figure 25*). The composition of these is mostly white-grey to light red-yellow, gypsum and quartz sand. Lunettes have formed from the downwind, wave-driven build-up of sandy lake sediments when the lakes are full, as well as from deflation of lake sediments when the lakes are dry.

3.2.5 Lacustrine sediments

Lacustrine sediments are deposited from transport by waves and by solution and suspension in lakes. Lacustrine basins are in low-lying parts of the region, particularly at the terminal or overflow parts of alluvial systems. Water in the basins is ephemeral. Lacustrine sediments mostly include clays and silts, including clay minerals, quartz, salts (including halite and gypsum) and organic material.

Many of the sedimentary depocentres and the margins of contemporary lacustrine depressions contain concentrically arranged ridges that represent shorelines from previously larger lakes (*Figure 25*). Drainage systems also mostly become distributary systems at these points, representing lower stream gradients across the palaeo-lake floors, and possibly also remnants of palaeo-lake deltas. The age of these lakes is not known with certainty. They underlie the aeolian dune systems of the region. Similar enlarged lake systems have been described from inland parts of South Australia associated with:

- Quaternary enlarged lakes, particularly preceding glacial maxima, when cooler climates supported lower evaporation rates
- Late Oligocene to Early Pliocene, Namba Formation lacustrine conditions, which have some palynological support from the region (e.g. McMinn 1981a).

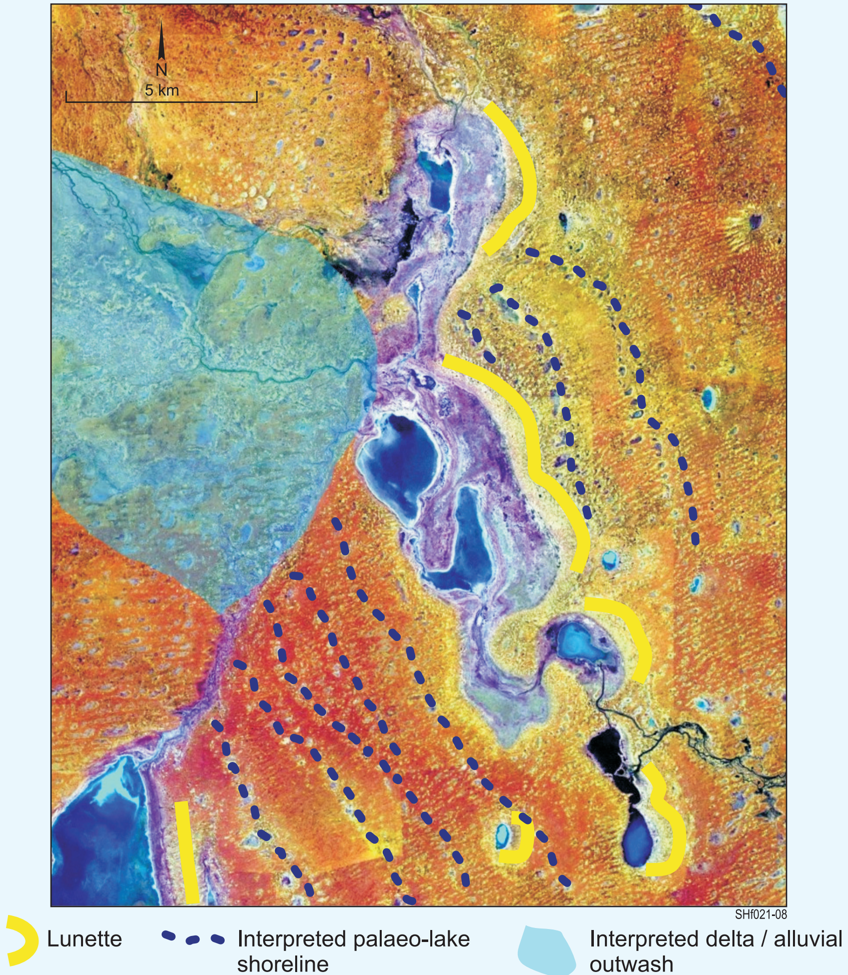


Figure 25: False colour satellite image of lunettes near Yantarra Lake, southeast of Tibooburra. Note also the annotations indicating large arcuate palaeo-lake shorelines.

3.3 Soils–pedogenic overprinting

Soils are part of the regolith and, for most geochemical exploration programs, they provide the most widely accessible sampling medium. Soil is the unconsolidated mixture of organic and inorganic matter on or near the surface of the Earth that has been subjected to and influenced by genetic and environmental factors such as climate, macro- and micro-organisms and topography (Eggleton 2001). As such, soil differs from the material from which it is derived in many physical, chemical, biological and morphological properties, and characteristics. Most especially. there is a destruction of the fabric of the parent material and the formation of new fabrics (the pedolith) from which soils may develop. Soil profiles typically have several horizons–such as upper A-horizons and underlying B-horizons–although undifferentiated soils can occur (e.g. in rapidly deposited or young sediments, or shallow soils on bedrock). Some layering may also relate to sedimentary deposition, which is commonly mistaken for soil horizons in this region.

Major soil types of the region, defined according to the Australian Soil Classification (Isbell 2002), are:

- ***Red sodosols***, with sodic, clay-rich and, in some cases, calcic B-horizons,–previously called desert loams. These are widespread across sheetflow plains and rises, particularly flanking alluvial plains and within drainage depressions.
- ***Red kandosols***–previously known as red earths. These have low texture contrast horizons. They mostly occur within alluvial plains and as heavy sandy loams associated with aeolian dunefields and sand plains.
- ***Calcarosols*** are highly calcareous soils–previously called solonised brown soils. They are typically powdery, but can contain carbonate hardpans and hard nodules. They are mostly developed from the weathering of Mesozoic sediments with calcareous cements (e.g. parts of the Algebuckina Sandstone and Cadna-owie Formation), but can also conform to localised occurrences outlined further in section 3.4.1.
- ***Rudosols*** and ***tenosols*** have negligible to weak pedological organisation. They typically occur as clastic-rich thin soils in upland settings overlying weathered bedrock or silicified regolith (previously

called lithosols), or as finer textured soils within young and rapidly deposited sediments, such as post-settlement alluvium (PSA) and dune sands (previously called siliceous sands).

- ***Vertosols*** are clay-rich and have seasonal shrink-swell cracking and gilgai, they were previously known as grey or black earths. They are widespread across ephemeral alluvial swamps and weathered Mesozoic marine shales (e.g. Bulldog Shale).
- ***Hydrosols*** are seasonally wet soils, previously called saline solodised solonetz soils. They are mostly localised to saline playas, where they can be referred to as hypersalic hydrosols.

Characteristic and predictable sequences of soils typically occur across the landscape. In this region, this partly reflects differences in soil-forming processes within different landscape settings, as well as different exposure, deposition and erosion of regolith parent materials. Upland settings typically have thin clastic rudosols, where the rates of soil erosion tend to exceed rates of soil formation. The erosion of uplands (predominantly by sheetflow and gullying) provides detritus for sedimentation in lower landscape settings. Mid-slope settings tend to have closely balanced rates of soil erosion and deposition, and therefore tend to function as sediment-transit zones within the landscape. Valley and drainage depression settings host the accumulation of laterally derived sediments and solutes. This is expressed as the near-surface precipitation of carbonates, gypsum and halite. Sodic (and even magnesium) salts accumulating at depth can make this part of the profile highly dispersive, leading to the physical and chemical removal of subsurface material and the formation of soil tunnels and collapse. This is typically expressed at the land surface by the development of surface depressions, locally called 'crab-holes' (because they can host yabbies or other crustaceans). These depressions should not be confused with gilgai, which are depressions and rises formed from the shrink–swell behaviour of clays.

Soil lags or surface lags refer to the coarse particles that are typically gravel size that extend across the land surface. Some lags are thought to have formed as residual accumulations from the removal (winnowing) of finer or less-dense material (McQueen 2008). This may account for some lags;

however, in most cases, the soils that underlie well developed surface lags contain very few (if any) large gravel clasts, suggesting other mechanisms for lag formation (*Figure 26*). One possibility is that profiles can be modified by forces developed during the shrink–swelling of clays and salt crystallisation, leading to the migration of coarse gravel clasts either upwards to the surface, or in some cases to a horizon within the profile to form a stone-line. Surface erosion of fine particles may expose these stone-lines at the land surface. Another process that is significant in the development of surface lags is the spread and rearrangement of lag clasts by the activity of sheetflow across the land surface. This accounts for the surface banding in many of these lags (see section 3.2.3 for further details) and the graded fining of lag clasts down-slope.

3.4 Indurated regolith

Indurated regolith is weathered material that is hardened or cemented. Broadly, indurated regolith includes materials hardened by pedogenic processes near the land surface, as well as those hardened by groundwater processes extending into the subsurface. The term 'duricrust' refers to similar materials, but this term implies development only at the land surface, rather than also including subsurface induration due to groundwater processes. Indurated regoliths are described and sub-divided based on the chemical or mineral composition of the indurating material, followed by description of the induration morphology or host material. These regolith types are some of the most prominent and distinctive in the region's landscape, and can potentially preserve expressions of palaeo-landscapes and palaeo-environmental conditions. They may host trace metals that are important in geochemical mineral exploration approaches.

3.4.1 Regolith carbonates

Regolith carbonates include calcrete, dolocrete and magnecrete, respectively–reflecting the dominance of calcite, dolomite and magnesite carbonate minerals (Hill *et al.* 1999; McQueen *et al.* 1999. Unfortunately, in some cases, regolith carbonates have been incorrectly referred to as 'calcrete', irrespective of dominant carbonate mineralogy and the degree of indurated

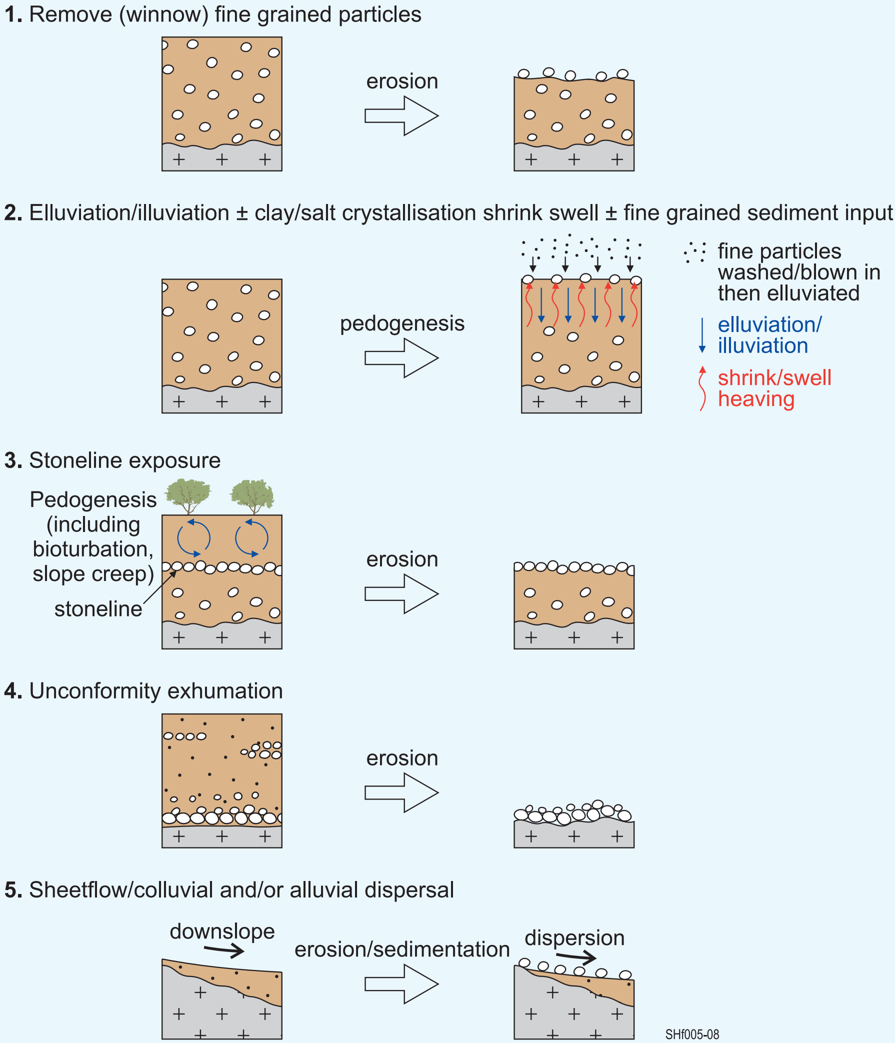


Figure 26: Models for pebbly surface lag evolution.

hardening. Although they are widespread across the region, they are not locally abundant: making them best suited to regional geochemical sampling programs, rather than the local surveys used in other parts of southern arid Australia. The main types and settings in the region are (Gibbons and Hill 2005):

- hardpans covering saprock in drainage depressions (*Figure 27A*). These result from the evaporation of carbonate-rich waters ponding at the hydromorphic boundary at the saprock-sediment interface

- powder and hardpan carbonate overlying weathered Mesozoic sandstones with calcareous cements
- powder and hardpan carbonate along faults and joints *(Figure 27A*), representing local groundwater discharge and through-flow sites
- hardpans and powder carbonates associated with weathered bedrock alteration zones associated with mineralisation.

Studies of the chemical sources of Ca and Sr in regolith carbonates in the area using Sr-isotopes (assuming that Sr and Ca behave similarly and have a common source) indicate major rainfall and dust chemical additions (Dart *et al.* 2007), although inputs from diagenetic calcite cements in Mesozoic sediments, and carbonate alteration zones within metasediments, are likely to have been important local contributors.

3.4.2 Ferruginised regolith

Ferruginised regolith includes materials previously called ferricrete or laterite. The usage of the term 'laterite' has been problematic and is not recommended. It has been loosely used to refer to a wide range of materials including soft, clayey weathered materials, or highly Fe-oxide-indurated materials, or conceptual weathering profiles with regular upwards arrangement of 'pallid', mottled and indurated horizons. For some people, it also has connotations of the former existence of regionally extensive palaeo-plains and, for others, an automatic expression of tropical palaeoclimates, both of which cannot necessarily be asserted. Although ferricrete has less genetic and controversial connotations, its restriction to hard, Fe-oxide cemented materials does not include soft, partially indurated materials, such as within subsurface mottled zones. The more generally descriptive adjective 'ferruginised' is therefore recommended, followed by a descriptive term for the regolith host materials or preceded by a descriptive morphological term if the regolith host material cannot be easily defined.

Ferruginised regolith is widespread in the region, but is mostly exposed on the margins of bedrock inliers and the escarpments of 'breakaways' within

Figure 27: Regolith carbonates in the Tibooburra–Milparinka area. (A) typical exposure as laminated hardpan coating on weathered bedrock interface within drainage depression (GDA: 6725000 mE / 580000 mE).
(B) powder carbonate within fractures within weathered granodiorite (GDA: 597883 mE / 6744067 mN).

Mesozoic sediments. This includes:

- ***ferruginised saprolite***–where primary bedrock fabrics (e.g. quartz veins and cleavage) are preserved. It may be exposed as mottles and liesegang banding in saprolite (*Figure 28A*) but it is mostly expressed in the landscape as ferruginous surface lag derived from the near-surface occurrence of mottled saprolite
- ***ferruginous sediment***–typically with mottled or massive ferruginisation, particularly within the weathered Mesozoic marine sediment sequences
- ***nodular ferruginisations***–consisting of detrital ferruginous clasts within a ferruginous sediment matrix, mostly occupying low-lying landscape settings (*Figure 28B*)
- ***slabby ferruginisations***–typically forming along groundwater discharge points or within faults and fractures.

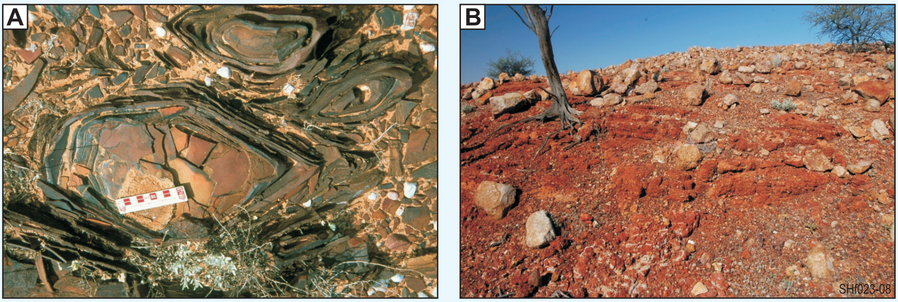


Figure 28: Ferruginised regolith photographs. (A) liesegang ferruginisation of weathered Easter Monday Formation (GDA: 600684 mE / 6743838 mE). (B) detrital ferruginisation (note bedding) overlain by boulders of silicified sediment, near Mount Wood homestead (GDA: 618406 mE / 6738703 mN).

Ferruginous regolith mostly consists of goethite and hematite, plus primary minerals, such as quartz, derived from the regolith host material. Different types of ferruginised regolith and associated weathering zones have developed in specific landscape settings (*Figure 29*) and regolith hosts in response to local environmental conditions (Bourman *et al.* 1987; Hill *et al.* 1996). Many of the ferruginous zones within weathering profiles are laterally discontinuous and may occur at multiple depths within single vertical profiles: largely reflecting changes in parent material composition and the

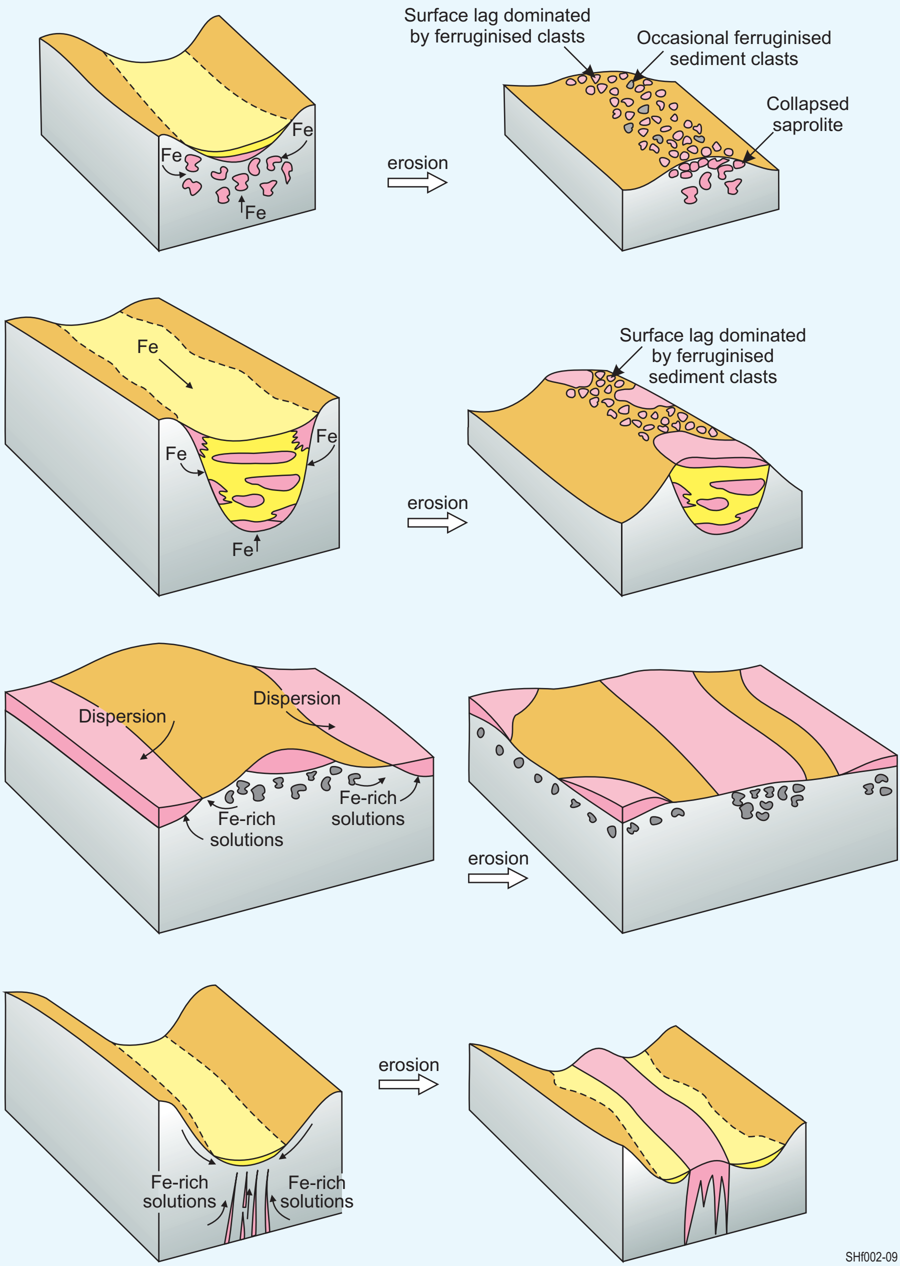


Figure 29: Models for the evolution of ferruginous regolith types in the Tibooburra–Milparinka area.

porosity and permeability of the regolith host. This is inconsistent with the claims of previous workers who suggested that there had been widespread cyclic planation associated with extensive 'laterite' profiles.

3.4.3 Silicified regolith

Regolith that has been indurated by silica is one of the most prominent and abundant rock types in the region. Silicified regolith is most prominent on rises and low hills composed of Mesozoic and early Cenozoic sediments. It forms a major component of surface lags on sheetflow fans, where it may be described as 'gibber'. The main silicified regolith morphologies exposed in the region are:

- ***silicified sediments***, including a wide range of morphologies formed as a result of pedogenic and groundwater silicification processes
- silicified, red-brown hardpans (e.g. Chartres, 1985)
- ***silicified saprolite***, where weathered bedrock fabrics, such as quartz veins and inter-locking crystals, are preserved.

The most prevalent silica-indurating mineral in the silicified sediments and the silicified saprolite is micro-crystalline quartz, although opaline silica, with minor chalcedonic silica, may also be present (Wopfner 1978; Alexandre *et al.* 2004). Micro-crystalline anatase and hematite may also be present. The red-brown hardpans are mainly indurated by opaline silica, and dehydrated clays and halide salts can also contribute (Chartres 1982).

Silicified sediment is the most abundant silicification type in the region. This includes tabular, massive forms that preserve the original sedimentary fabric and structures. They formed in association with silica-rich groundwaters, within subsurface aquifers. The best examples can be seen around the outer margins of the Tibooburra Dome, such as near Olive Downs. More complex silicification morphologies also include botryoidal and ropy (also referred to as 'glerpy' by Taylor and Ruxton 1987) (*Figure 30A*), columnar and nodular silicification (*Figure 30B*), that are best related to silicification due to pedogenic processes at or near palaeo-landsurfaces. Silicified pipe structures up to 2 metres tall and 1 metre wide occur within some profiles and as free-standing exposures (Watts 1978; Hill 2000) (Figure 30C). There has been some speculation that these structures might be petrified trees, but it is more likely that they are silicified dissolution pipes within weathered sediments.

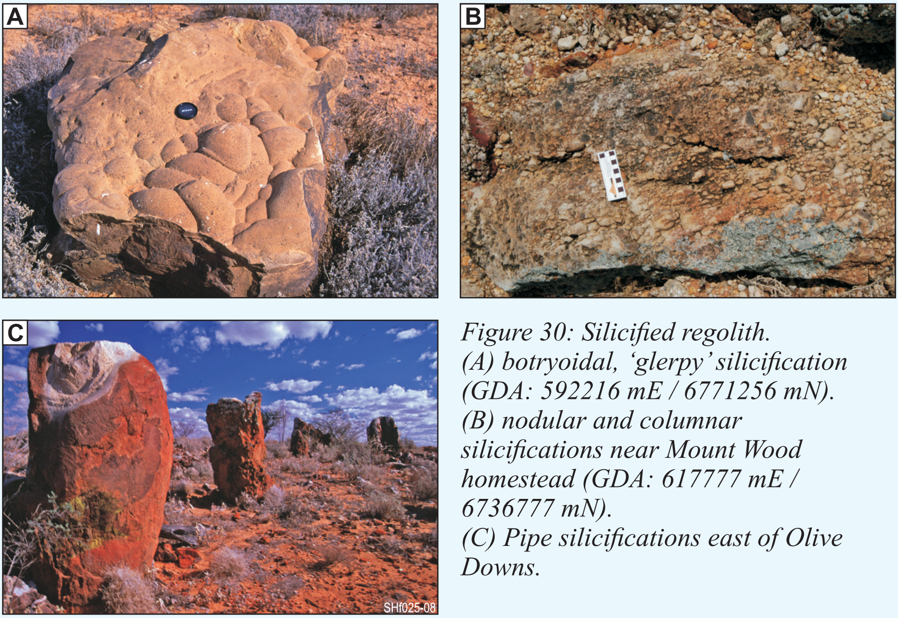


Figure 30: Silicified regolith.
(A) botryoidal, 'glerpy' silicification (GDA: 592216 mE / 6771256 mN).
(B) nodular and columnar silicifications near Mount Wood homestead (GDA: 617777 mE / 6736777 mN).
(C) Pipe silicifications east of Olive Downs.

3.4.4 Gypseous regolith

Gypsum is a widespread and abundant component of the regolith in the region. This includes disseminated crystals, polycrystalline aggregates, large transparent sheets and fibrous selenite veins (*Figure 31*). It is most prominent in low lying areas, but is not exclusive to these settings, particularly on hills and rises composed of weathered Mesozoic marine sediments. The gypsum typically coexists with ferruginous and kaolinitic regolith, suggesting that much of it is derived from weathering of sulphides within pyritic sediments; however, meteoric sources are also likely to be significant.

3.4.5 Salt efflorescences

White salt efflorescences are well developed in sites of groundwater discharge and evaporation, such as along drainage systems and within lacustrine depressions. Halite is a major component of this efflorescence, but in some cases it may also include gypsum. The distribution of salt efflorescence is largely hydromorphically controlled–especially by the degree of leaching, which is controlled by regolith permeability, rainfall and evaporation. In some places, dead river red gums and samphire forbs further highlight these sites, particularly if the expression of the efflorescence is seasonal.

Figure 31: Gypseous regolith. Selenite veins within oxidised Mesozoic sediments, Rainbow Rocks (GDA: 618095 mE / 6769684 mN). The scale bar is in centimetres.

4. LANDSCAPE HISTORY

4.1 Controls on landscape evolution

The development of the landscape and the associated regolith materials provides an important context and framework for mineral exploration programs in regolith-dominated landscapes. The chemical and physical properties of the contemporary landscape and the attributes of its regolith are the result of a combination of environmental factors and events that have taken place within the landscape history of the region. For example, the dispersion and deposition of Au placers in the Tibooburra–Milparinka area have been influenced and modified by landscape processes and events that have operated since at least the Mesozoic. Understanding these processes will markedly increase the chances of exploration success. The landscape is the result of a seemingly complex array of processes and controls. The main factors that have controlled the landscape and regolith development of the region are:

- bedrock structure and lithology
- tectonics
- palaeoclimate
- eustacy
- anthropogenic influences.

4.1.1 Bedrock structure and lithology

Variations in bedrock can exert a major influence on the evolution of regolith and landscape. The cohesiveness and strength of rock is a fundamental control on variations in resistance to erosion and weathering. This may be influenced by structures and fracturing, the degree of cementation and the hardness of individual minerals. As might be expected, hard and cohesive rocks tend to form more-prominent landscape features, such as hills, whereas soft and less cohesive rocks tend to form less-prominent landscape features, such as valleys and plains. Notable examples of these influences from the region include the prominent ridges and hills corresponding to the hard contact metamorphic aureole surrounding the relatively less-resistant parts of the Tibooburra Granodiorite. Jointing controls on tor and relief development within areas of the Tibooburra Granodiorite represent a localised structural control on weathering and erosion (*Figure 32*).

Weathering susceptibility and the type of secondary products will also vary for different bedrock types. Different primary minerals have different resistances to both physical and chemical weathering and so produce different weathering products that may then be eroded and contribute to sediment. Granitic rocks, such as the Tibooburra Granodiorite, tend to develop weathering profiles where the feldspars are transformed to clay minerals, particularly kaolin, whereas mica minerals tend to weather to clay minerals and, in some cases, Fe oxides. This leaves quartz, which is more resistant to chemical weathering, to be liberated as quartz sand, which would then be available to form a major component of sedimentary units such as the Mesozoic Algebuckina Sandstone and the early Cenozoic Eyre Formation.

Figure 32: Jointing control on tor development near Hidden Valley, Tibooburra Inlier (GDA: 599234 mE / 6741733 mN).

Metasediments, such as the Easter Monday Formation, Depot Glen Formation and Jeffreys Flat Formation (Greenfield and Reid 2006), tend to be more easily weathered and eroded when they are in the form of highly cleaved siltstones and phyllites–yielding fine-grained clays–whereas sandstones and quartzites tend to be harder and more resistant to weathering and instead contribute more boulders and pebbles to sediments. Quartz veins are particularly resistant to weathering and erosion and, when eroded, contribute white vein quartz fragments into sediments. If the quartz veins are Au-bearing, then fragments of Au veins may be associated with these sediments, such as occurred within the Mesozoic fluvial sediments equivalent to the Algebuckina Sandstone.

4.1.2 Tectonics

The Tibooburra–Milparinka area shows extensive evidence of tectonic imprint on the regolith and landscape evolution (*Figures 33, 34*). The most obvious of these is the expression of linear fault-line escarpments, which define the margins of many of the bedrock inliers (*Figure 34A*). Tectonism has therefore controlled the exposure of weathered bedrock, but has also influenced the exposure of Mesozoic and Cenozoic sediments and subsequently the nature and depth of sedimentary cover. During the landscape history, it has also created topographic relief that has been important for driving erosion and sediment production as well as creating accommodation space within basins for sediment accumulation.

Tectonics has also had a major impact on the development and re-arrangement of drainage networks. For example, during the Mesozoic, the Mount Browne Inlier had a very subdued landscape expression and for the large part Mesozoic palaeodrainage flowed from west to east across the inlier (the subdued relief and palaeodrainage flow across the Mount Browne Inlier created an effective trap for detrital Au at this time). Subsequent uplift along the Mount Browne Fault has transformed this drainage and now streams are diverted to the north and south of the inlier before proceeding to the southeast. Stream terraces cut into weathered bedrock (referred to as strath terraces) (*Figure 34B*) and prominent steep sections of drainage profiles (knick-points) (*Figure 34C*) can be identified upstream of many of the recently active fault-lines, such

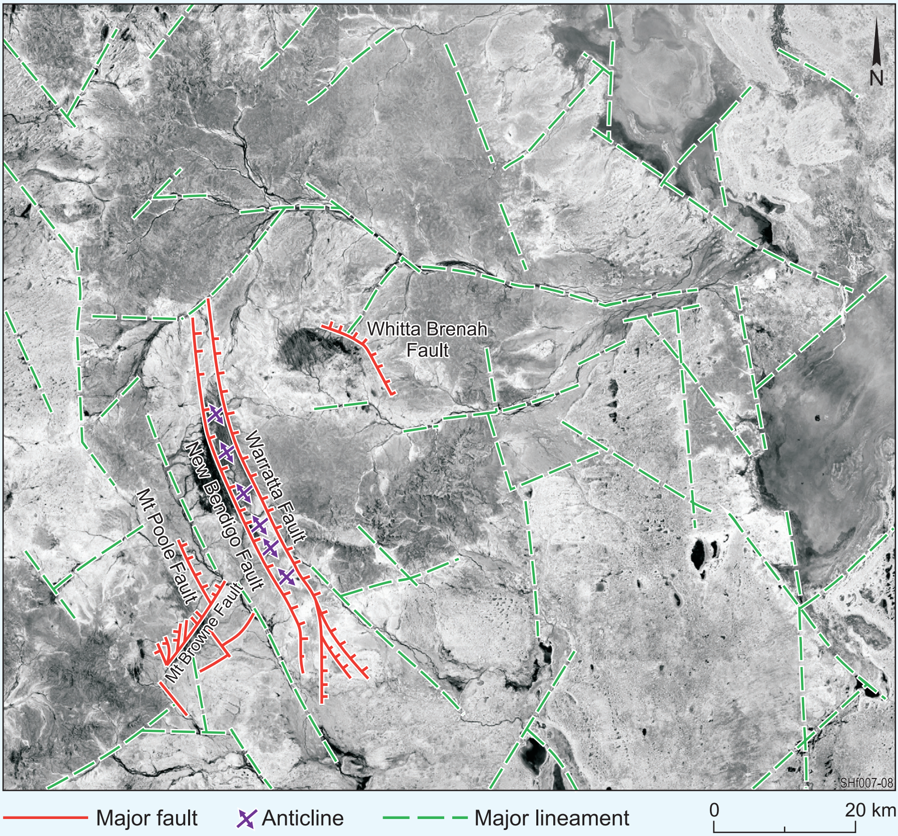


Figure 33: Morphotectonic map of active fault and fold structures in the Tibooburra–Milparinka area.

as the Warratta Fault (Anderson *et al.* 2004; Davey and Hill 2005). Another fundamental tectonic control on regolith processes has been the relative vertical movement of regolith profiles compared with stream base-level and the groundwater table. Uplift of the regolith profiles resulted in a relative drop in both stream base-level and the watertable, facilitating widespread oxidation of the regolith profile. This has probably helped to drive the oxidation of the pyritic Bulldog Shale in the region, resulting in Fe ferrolysis and acid-sulphate weathering conditions in the early Cenozoic (Hill 2000, 2005).

The Mesozoic sediments in many areas have been gently folded (limbs

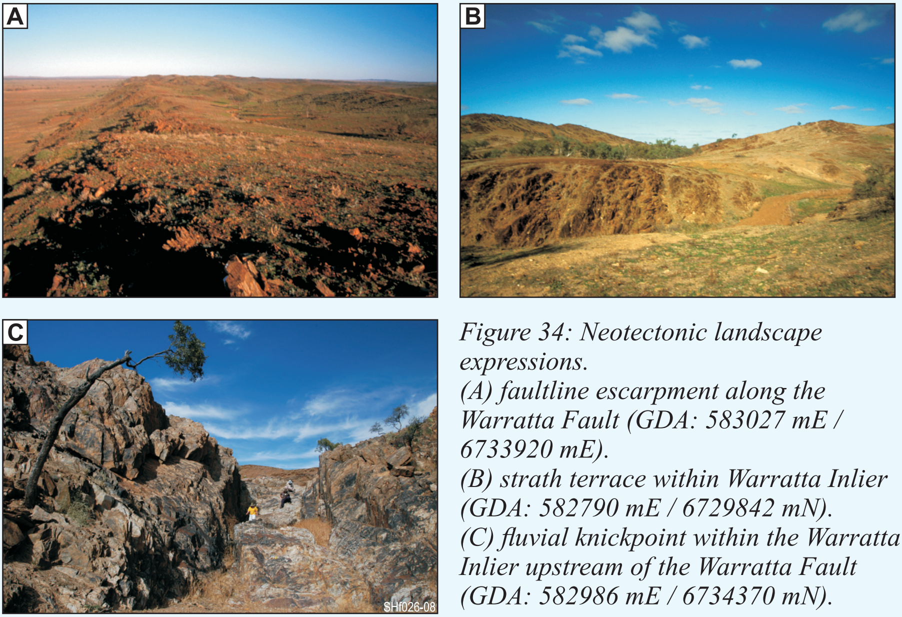


Figure 34: Neotectonic landscape expressions.
(A) faultline escarpment along the Warratta Fault (GDA: 583027 mE / 6733920 mE).
(B) strath terrace within Warratta Inlier (GDA: 582790 mE / 6729842 mN).
(C) fluvial knickpoint within the Warratta Inlier upstream of the Warratta Fault (GDA: 582986 mE / 6734370 mN).

dipping between 3 and 19º) mostly with WSW–ENE-trending fold axes, such as near the Warratta South and New Bendigo inliers (McAvaney and Hill 2006). The outcrop pattern of bedrock associated with inliers, such as the New Bendigo Inlier, Warratta South Inlier, the Warratta Inlier and recently discovered small bedrock inliers south of the New Bendigo Inlier, conforms to the axes of anticlines in these folds. The axes of synclines in these folds appear to have been exploited by Eyre Formation palaeovalleys, trending in a general west-to-east direction between bedrock inliers, such as south of the New Bendigo Inlier (McAvaney and Hill 2006). This constrains the age of this folding to between the Early Cretaceous and the Early Cenozoic.

NNW–SSE striking reverse faults are defined by prominent fault-line escarpments in the region, such as those associated with the Warratta Fault and the New Bendigo Fault. These faults have offset and tilted Mesozoic and Tertiary sediments, and locally folded and overturned Mesozoic sediments, such as along the Warratta Fault between Gum Vale Gorge and Warratta Creek. Other ENE–WSW trending faults, such as the Mount Browne Fault, have also deformed Mesozoic and Tertiary sediments, and may be a conjugate set to the ENE–WSW structures (Davey and Hill 2005). At least the NNW–SSE trending reverse faults have been interpreted as being reactivated older structures: dating back to the early Palaeozoic (Greenfield and Reid 2006). The reactivation of these structures is likely to be a result of the contemporary E–W compressive stress regime in the region (Hillis and Reynolds 2000).

4.1.3 Palaeoclimate

Palaeoclimatic reconstructions specific to the region are very limited. Some evidence, however, can be extrapolated from flanking basin areas, such as parts of the Eromanga Basin and Lake Eyre Basin in South Australia.

Climate controls the availability of water and the provision of wind and temperature that drive many regolith and landscape processes. These climatic factors also have secondary influences on attributes such as the nature and extent of vegetation cover and stream discharge and accumulation of water within lacustrine depressions. Climatic conditions have also contributed to changes in sea-levels and, therefore, many of the landscape controls discussed in section 4.1.4. The region has experienced marked climatic changes throughout its landscape history–leading to different types of impact on the regolith and landscape evolution.

One of the earliest climatic impacts on the landscape evolution was the cold climate of the Permian. At that time, Australia (then part of Gondwana) was at very high latitudes: near to the south rotational pole (Alley 1995). By the Mid-Carboniferous, the circum-global equatorial seaway had been closed. As a result, cooling occurred in Australia and as a result carbonate banks became rare, shelly faunas reduced in number and diversity, and sediment became dominantly clastic. The giant clubmoss of the Early Carboniferous disappeared, and vegetation became dominated by cold-adapted seed-bearing ferns, a few lycopods and conifers. The continental glaciation that swept across Gondwana in the Permo-Carboniferous, included a large ice sheet across southern Australia. The nearest direct evidence for Permian glacial and fluvio-glacial conditions is from the Yanna Tank Formation in the southern Koonenberry Belt. Sedimentary units in the Cooper Basin, in the

Troubridge Basin near Adelaide and under the Murray Basin in NSW and Victoria also contain evidence of Permian glaciation (Alley 1995).

The Mesozoic palaeoclimates of the region have been largely interpreted from sedimentology, spore-pollen microfossils and macrofossils. The Jurassic to Early Cretaceous terrestrial sediments, such as the Algebuckina Sandstone and equivalents, are interpreted to have been deposited in a cool, temperate, conifer-forested setting (Krieg *et al.* 1995). Fossils of conifer wood are widespread and abundant from this unit in the region, including tree trunks and logs up to 4 metres long (e.g. the display in the Tibooburra Museum). The Early Cretaceous terrestrial–marine transition sediments, such as the Cadna-owie Formation and equivalent sediments, were deposited in seasonal climates with cold periods (Frakes and Francis 1988), and a subsequent increase in more cold tolerant plants (Krieg *et al.* 1995), and possibly seasonal ice-carrying boulders. Further cooling is reflected in the Early Cretaceous marine Bulldog Shale and equivalents. Glendonite (calcite pseudomorph after the hydrous calcium carbonate mineral ikaite) nodules indicate very cold water, because the original mineral ikaite is stable only at near-freezing temperatures. Isolated transported boulders, or lonestones, of probable glacial origin are widespread (Krieg *et al.* 1995).

The Cenozoic is broadly characterised by rainforest occurrences in the early part, followed by increasing aridity towards the present day. Palynofloral evidence from the Eyre Formation indicates widespread rainforest and, along with extensive fluvial sedimentation, suggests very wet climates: warm enough to support a mixed vegetation mosaic of angiosperm-dominated rainforests to gymnosperm-dominated and mixed angiosperm–gymnosperm rainforest, and some lowland areas supporting palms–all with diverse fern and moss understorey (Benbow *et al.* 1995). Towards the later parts of Eyre Formation, sclerophyllous vegetation may have colonised the drier hinterlands, with rainforest dominating along moister valley floors. The climate became more arid from about the mid-Cenozoic onwards, which was expressed in the vegetation by a decrease in the abundance of rainforest, and an increase in sclerophyllous and grassland vegetation.

Quaternary climate changes have been an important control on the development of regolith and landforms, particularly associated with the surficial alluvial, colluvial, aeolian and lacustrine sediments (Bowler and Magee 1978; Wasson 1979). The Quaternary period covers the last 1.8 million years, and is characterised by marked global climate oscillations–particularly in temperature, rainfall and evaporation–leading to alternating:

- ***glacial episodes***, featuring the growth of continental icesheets. This resulted in marine regression– exposing the continental shelf–as well as initial lake expansion (due to reduced evaporation in cooler climates) and then desert expansion at the peak of continental drying. The vegetation cover reduced at these times, resulting in increases in aeolian and sheetflow activity. The peak of the last glacial maximum episode was approximately 20–18 ka BP.
- ***interglacial episodes***, when ocean temperatures were higher and sea-level rose as a result of thermal expansion and addition of melt-waters to the oceans. These episodes were characterised by global marine transgression submerging the continental shelf, and desert retreat. Vegetation cover and pedogenic processes are likely to have been more prevalent during these times. The last interglacial maximum was approximately 120 ka BP.

The climatic controls on regolith evolution–although potentially important–may have been over-emphasised in some previous accounts. This is perhaps best illustrated with previous interpretations for indurated regolith in the region. The development of ferruginous regolith in the region has been widely attributed to wetter and more 'tropical' conditions in the past (Stephens 1971; Langford-Smith and Watts 1978). Ferruginous materials, however, appear to have developed at many times throughout the landscape evolution of the region, and may still be forming in the present arid conditions (Hill *et al.* 1996; Hill 2000).

Silicified regolith has been attributed to both wetter conditions in the past (e.g. Alley 1998) as well as to the onset of aridity during the late Cenozoic (e.g. Langford-Smith and Watts 1978), or to a seasonal combination of both climatic extremes (e.g. Wopfner 1978). In contrast, Hill (2000) suggests that its development could be better related to acidic weathering conditions associated with ferrolysis and pyrite oxidation within Mesozoic and Cenozoic sediments. This would lead to the leaching of Al from clays, and the relative accumulation and local redistribution of silica-rich by-products to form silcretes. The oxidation of the regolith may in part be driven by climate, but would also be very much linked to tectonics, Mesozoic eustacy and sedimentary basin evolution.

Regolith carbonates have been previously interpreted as an indicator of climatic aridity because of reduced leaching of their chemical constituents. Although this is partly true, it is an oversimplification that overlooks the importance of variations in the supply of chemical constituents for their initial development. Simply attributing regolith carbonate development to climatic aridity does not account for the present distribution of regolith carbonates in this region. Thus, they are less widespread towards the more arid northwest of the region, compared with the higher rainfall areas near Broken Hill and towards the south coast of Australia. Chemical inputs associated with atmospheric contributions (rain and dust) have instead been suggested as an important control on the widespread development of regolith carbonates in the winter-rainfall dominated areas to the south. These are closer to potential marine Ca and Mg sources than are the summer-dominated rainfall areas to the north (Hill *et al.* 1999 McQueen *et al.* 1999; Hill 2000; LJ Hill 2004).

4.1.4 Eustacy

For an inland region such as this, it may be surprising that eustacy could be considered an important component of the landscape history. However, because the development of the landscape extends beyond the Mesozoic, marine transgressions within the Eromanga Basin have been significant.

The Early Cretaceous marine transgression associated with deposition of the Cadna-owie Formation and Maree Subgroup sediments constituted the region's major marine incursion (*Figure 35*). This led to sedimentation and backfilling of upland valleys. The marine sediments associated with the Maree Subgroup include the pyritic, organic-rich Bulldog Shale. Subsequent marine regressions would have resulted in stream incision, water-table lowering and the weathering of the marine sediments. Oxidation and ferrolysis of these sediments following marine regression would have led to the development of acid-sulphate weathering conditions, as is expressed by the abundance of ferruginised, gypseous weathering profiles within the Early Cretaceous marine sediments.

The marine transgressions of the Cenozoic do not appear to have extended into the region, even though some sites may have been below sea-level. Instead, large lakes are likely to have extended across low-lying parts of the landscape associated with the mid-Cenozoic Namba Formation.

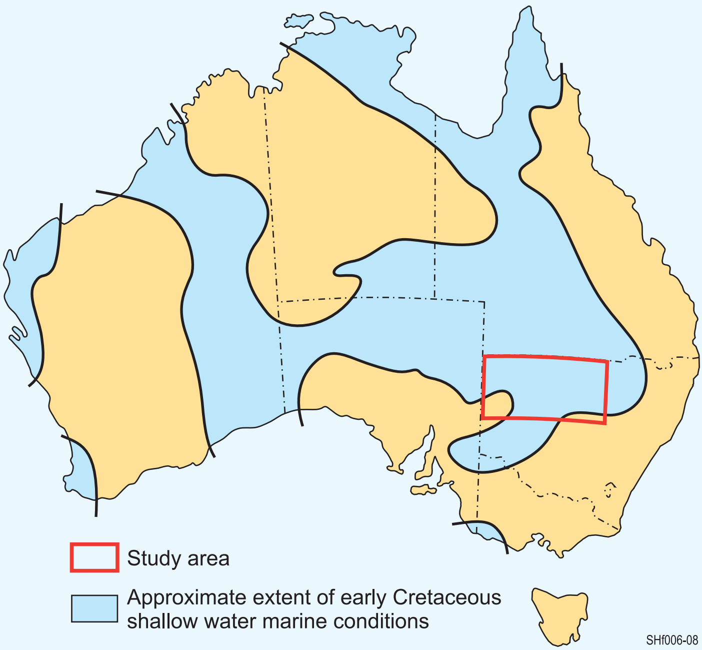


Figure 35: The extent of marine incursion during the Early Cretaceous that included parts of the Eromanga Basin.

4.1.5 Anthropogenic influences

Human settlement and activities in the region have had an influence on the regolith and landscape. Changes to parts of the landscape directly or indirectly due to human activity have influenced landscape processes controlling local erosion and sedimentation. Human-induced erosion can lead to the rapid obliteration or redistribution of soil geochemical signatures of underlying mineralisation that may have taken long periods of time to develop. The recently and rapidly deposited PSA and other sediments also may not have had sufficient time to allow for the formation of surface anomalies in the vicinity of mineralisation. An appreciation of the recent human influences on the landscape and regolith is therefore important in mineral exploration programs, particularly if sampling surficial materials (e.g. soils and stream sediments) for geochemical exploration. The potential for anthropogenic influences at geochemical exploration sample sites should therefore be noted.

Aboriginal occupation of the Tibooburra–Milparinka region appears to have included the Wongkumara group, whose homelands extended from the Cooper Creek area into far northwestern NSW. Modification of the landscape of the region by Indigenous people is difficult to determine, although their most significant impact is likely to have been localised removal of vegetation cover using fire. This would contribute to increased erosion and sedimentation, as well as trace element exchange between burnt vegetation and the regolith (either as local additions to soils or transport and contributions to sediments).

European impact on the landscape began with Captain Charles Sturt's expedition into the region. This expedition arrived in the Tibooburra–Milparinka area during January 1845. The party was halted in the region at Depot Glen near Mount Poole homestead for nearly 6 months during a severe drought, and the search for water and feed for his stock and men placed a major constraint on travel. Subsequently, from 1847 pastoral leases were taken up in western NSW, extending into northwestern NSW during the 1850s and 1860s. In 1861, the Burke and Wills expedition passed through the Bulloo Overflow area, east of Tibooburra, which they referred to as 'the mud plains'.

The discovery of Au led to increased settlement of the region during the early 1880s. By late 1882, the townships of Mount Browne, Milparinka, Tibooburra and Albert serviced the region. The township of Tibooburra was officially acknowledged in the NSW Government Gazette on January 16,

1885. It presently has a population of approximately 150: largely supporting the surrounding pastoral community, tourism and the administrative centre for Sturt National Park.

The landscape impact of European settlement has been documented by Fanning (1999). This has included significant removal of vegetation cover through grazing (by stock, but also particularly rabbits) and removal of timber, resulting in soil erosion from upland settings and sedimentation in low lying sites. Studies in western NSW by Wasson and Galloway (1986) and Fanning (1999) suggest that the average post-settlement sediment yield was up to 50 times greater than the average yield for the 3000 years preceding settlement.

4.2 Regional landscape and regolith evolution

4.2.1 Weathering, induration and palaeo-surfaces

The bedrock of the region has continued to weather during its exposure to surface and near-surface processes. The preservation potential of weathered materials (reflecting the balance between formation of weathered materials and its erosive removal) has varied in time and space. The expression of erosion or denudation within the landscape history is typically expressed by way of the sedimentary record in basin areas, although in some cases erosional unconformities and palaeo-surfaces may be important.

There have been four distinct induration and weathering events recorded in the region:

- pre-Mesozoic weathering
- late Mesozoic (pre-Palaeogene) weathering
- mid-Cenozoic weathering and induration
- Neogene to Recent weathering and induration.

Pre-Mesozoic weathering profiles and associated palaeo-surfaces have been partly exhumed from beneath Mesozoic sediments. These are best exposed along the margins of bedrock inliers, and include friable, kaolinitic weathered granodiorite on the Tibooburra Inlier near Quarry Hill and Sugarloaf Hill (see

Field Guide Appendix), and kaolinitic metasediments, particularly along the northern Tibooburra Inlier margins at Billy Goat Hill near Mount Browne, and along all but the eastern margins of the Warratta Inlier, particularly along the Warratta Creek valley. The quartzose sediments with minor lithic fragments within the basal Mesozoic sections further support interpretations of a weathered pre-Mesozoic landscape. The erosion of weathered profiles from this time is likely to have been initiated from topographic relief produced during the initiation of the Eromanga Basin in the region. Palaeo-surfaces associated with this pre-Mesozoic weathering have been most important as a source of detrital Au to fluvial sediments equivalent to the Algebuckina Sandstone. Areas of topographic relief extending above the elevation of the pre-Mesozoic unconformity (but not differentially displaced by tectonism) represent the foundation of undulating hills and rises of the Mesozoic landscape. Some of the best examples of this can be seen in the hills east of Jeffreys Flat on the Warratta Inlier, and the hills of the Tibooburra Inlier west of Tibooburra. These hills are likely to have been subdued (but locally significant) rises during the Mesozoic.

Remnants of weathering profiles associated with the Late Cretaceous 'Mornay Profile' (Idnurm and Senior 1978) are also likely to occur in the region. This inference is supported by the deposition of quartz and kaolin dominated sediments (e.g. Eyre Formation and other equivalent sediments) derived from the erosion of a highly weathered landscape that had developed before the Palaeogene. Following the marine regression in the later part of the Early Cretaceous, the pyritic marine sediments of the Bulldog Shale would have been sub-aerially exposed, thereby facilitating widespread oxidation and weathering.

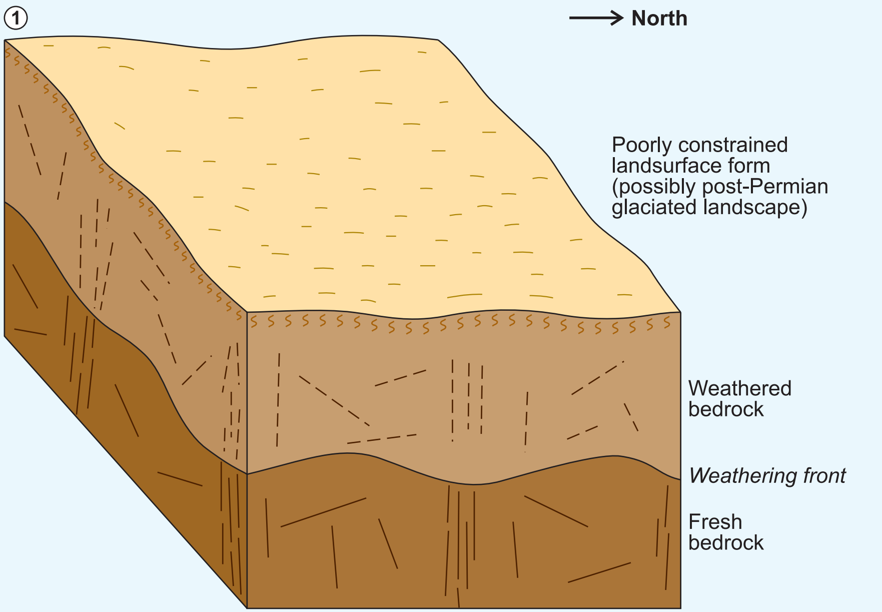
Previous interpretations of weathering and induration during the Cenozoic mostly highlight a mid-Cenozoic or late Palaeogene–Early Neogene event (e.g. Wopfner and Twidale 1967; Idnurm and Senior 1978; Callen 1983; Alley 1998). This has been associated with the development of the Late Eocene to Oligocene 'Silcrete of the Cordillo Surface' and 'Cordillo Surface' in parts of the Lake Eyre Basin (Wopfner and Twidale 1967; Alley 1998), and the Late Oligocene Canaway Profile in western Queensland

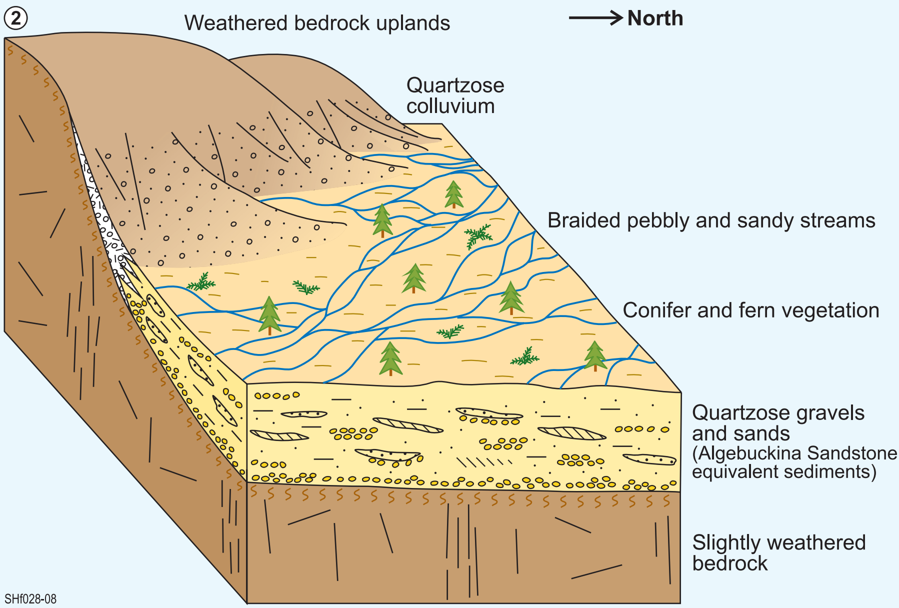
(Idnurm and Senior 1978). A silicified Eocene flora assemblage within partially topographically inverted palaeovalley sediments at Fowlers Gap (Greenwood *et al.* 1997; Hill and Roach 2003) is also consistent with Eocene silicification in at least parts of western NSW. As well as representing times of enhanced weathering and induration in the region, this also represents a time of reduced erosion following sedimentary basin filling (Hill 2000). Landscape settings hosting sediment accumulation and induration would have a relatively high preservation potential, and therefore tend to be well expressed within the landscape and stratigraphic record. The Lake Eyre Basin sediments also provide some of the few stratigraphic benchmarks used to determine the age of induration. In some circumstances, however, the presence of silicification has been used to establish an initial stratigraphic context for the sediments (e.g. Wopfner and Twidale 1967), and therefore there are dangers of developing a circular argument. Cenozoic weathering and induration events, such as Plio-Pleistocene silicification associated with gypsum development (e.g. Wopfner 1978), have also been interpreted to post-date the Namba Formation deposition (Alley 1998).

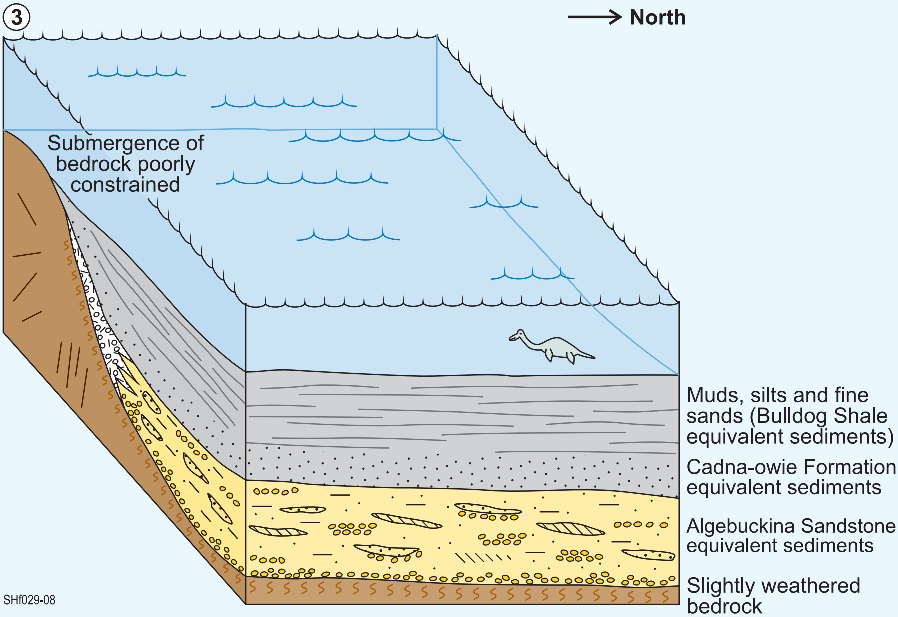
The development of regolith carbonates occurred in the later part of landscape evolution in the region. This is consistent with their development within relatively young regolith host materials (e.g. aeolian, alluvial and colluvial sediments closely related to the contemporary landscape) and also with their overprinting (such as hardpan coatings) of ancient regolith materials. Radiocarbon dating of regolith carbonate coatings on soil peds from western NSW has provided ages from approximately the last 1000 years (Fanning 1999), suggesting that development of regolith carbonate could be an ongoing process. This development is partly related to reduced leaching associated with increasing aridity during the Cenozoic, but is also related to the increased input of marine-derived dust and dissolved components in rainfall, particularly in the south of the region (Hill *et al.* 1999; Hill 2000; LJ Hill 2004; Dart *et al.* 2007).

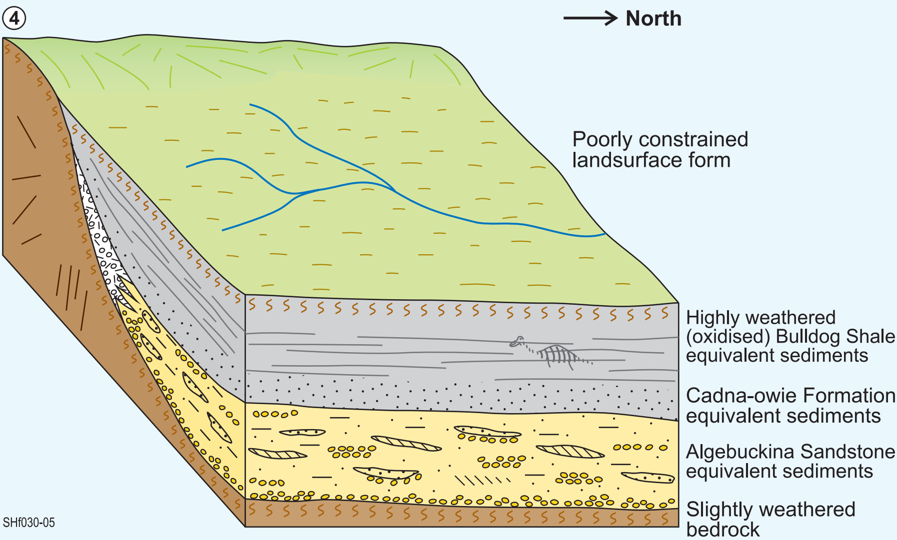
The sequence of main regolith and landscape evolution events is summarised in *Figure 36*.

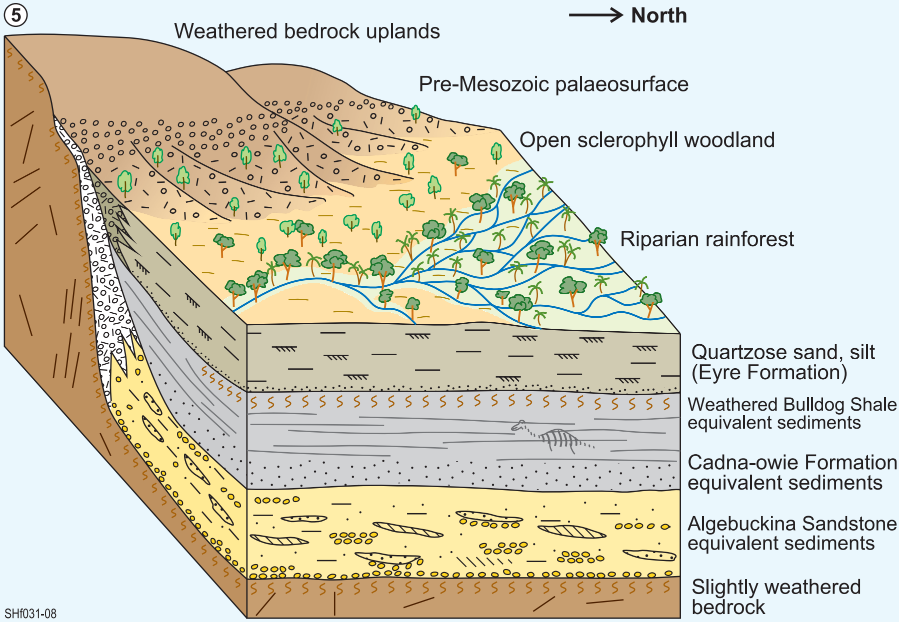
Figure 36: Diagrammatic landscape reconstruction for key time periods in the landscape history of the Tibooburra–Milparinka area.

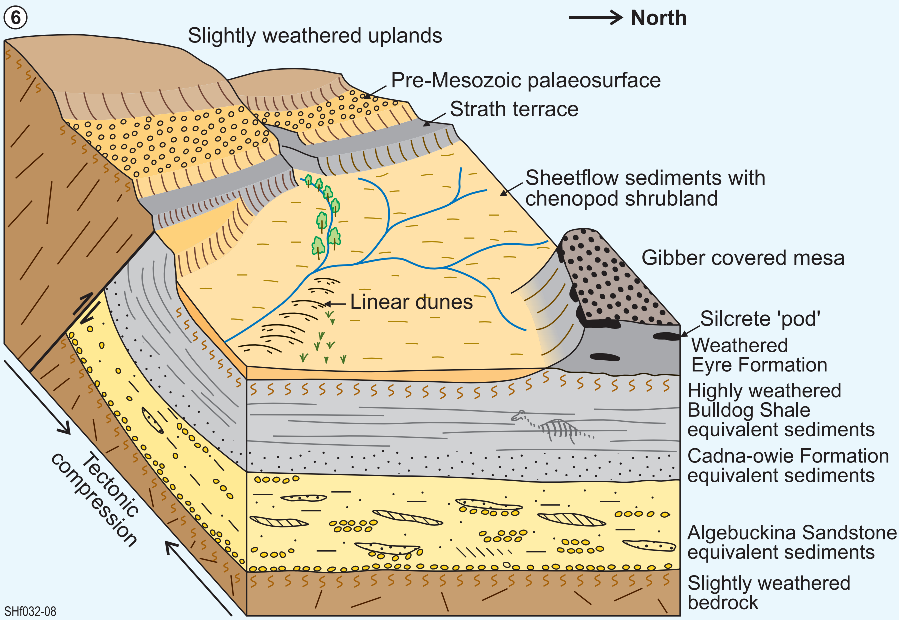





3
North
Submergence of bedrock poorly constrained
Muds, silts and fine sands (Bulldog Shale equivalent sediments)
Cadna-owie Formation equivalent sediments
Algebuckina Sandstone equivalent sediments
Slightly weathered bedrock
SHf029-08


4
North
Poorly constrained landsurface form
Highly weathered (oxidised) Bulldog Shale equivalent sediments
Cadna-owie Formation equivalent sediments
Algebuckina Sandstone equivalent sediments
Slightly weathered bedrock
SHf030-05


5
North
Weathered bedrock uplands
Pre-Mesozoic palaeosurface
Open sclerophyll woodland
Riparian rainforest
Quartzose sand, silt (Eyre Formation)
Weathered Bulldog Shale equivalent sediments
Cadna-owie Formation equivalent sediments
Algebuckina Sandstone equivalent sediments
Slightly weathered bedrock
SHf031-08


6
North
Slightly weathered uplands
Pre-Mesozoic palaeosurface
Strath terrace
Sheetflow sediments with chenopod shrubland
Gibber covered mesa
Linear dunes
Silcrete 'pod'
Weathered Eyre Formation
Highly weathered Bulldog Shale equivalent sediments
Cadna-owie Formation equivalent sediments
Algebuckina Sandstone equivalent sediments
Slightly weathered bedrock
Tectonic compression
SHf032-08

5. REGOLITH IN MINERAL EXPLORATION

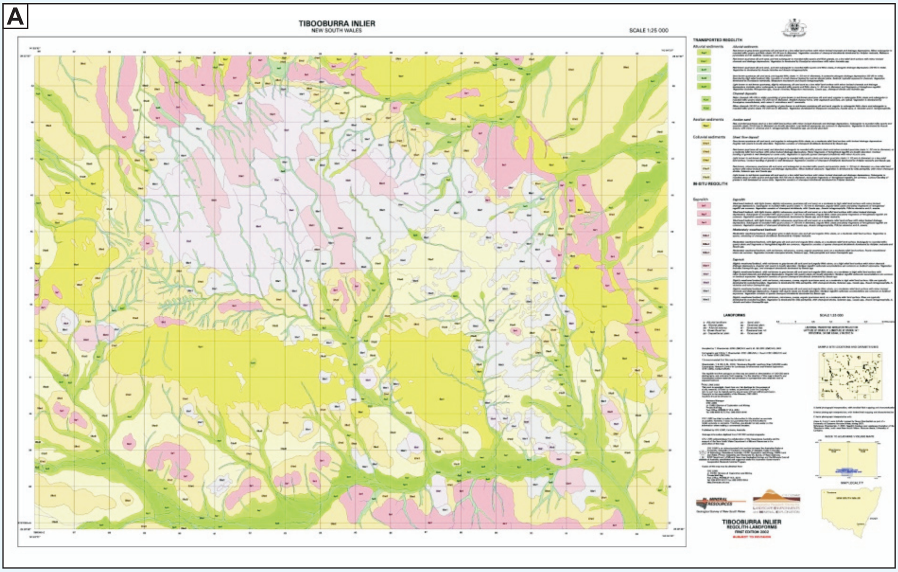
5.1 Regolith-landform mapping

Maps of the regolith materials and their characteristics provide valuable frameworks for mineral exploration programs in regolith-dominated terrains. A regolith map can be used to:

- give an account of the types of regolith materials that may cover bedrock, thereby better defining the nature of the exploration challenge
- show the distribution and abundance of the types of regolith materials available for geochemical sampling
- provide information on the framework for landscape evolution models and accounts of geochemical provenance, dispersion and accumulation over time
- provide a near-surface context when linked to other attributes such as interpretations of mineral systems, geophysics and regolith geochemistry
- provide a foundation for the production of derivative maps that highlight certain attributes of the regolith or features for special purpose applications such as mineral exploration (e.g. dispersion vectors maps and exploration strategy maps).

5.1.1 Regolith maps

Regolith maps of the Tibooburra–Milparinka area have been constructed by the NSW Geological Survey, as well as by researchers and students at the University of Adelaide (*Figures 37 and 38*). These maps mostly use a regolith-landform framework, which therefore provides not just an account of the regolith materials of an area but also the landform expression. The landform expression is important because it is not only related to the development or modification of regolith materials, but it also relates closely to contemporary landscape processes that may influence the chemical and physical dispersion and accumulation processes operating in the landscape. A simple alpha-numeric code (after Pain *et al.* 2007) is used to depict the regolith-landform units. Some of these codes may at first appear nonsensical, but after using



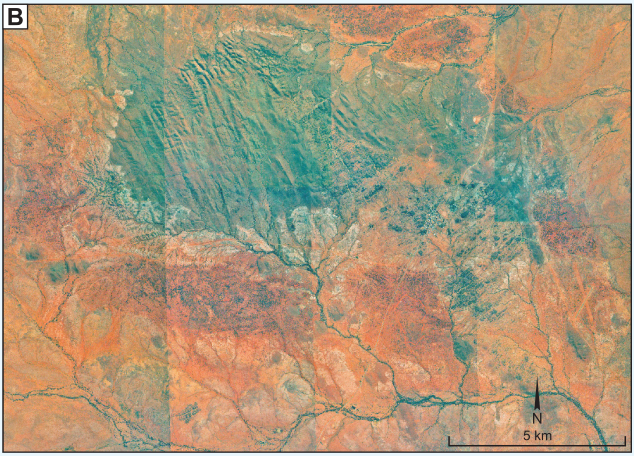


Figure 37: (A) Regolith-landform map of the Tibooburra Inlier (originally produced at 1: 25,000 by Chamberlain and Hill 2002). A full-sized version of this map is available within the appendices of this guide.
(B) colour aerial photograph mosaic of corresponding area. Although polygon labels and details may not be visible at this scale of reproduction, the general relationships between the map polygons and the aerial photograph patterns, tones and colours can be seen. For further details, see original map.

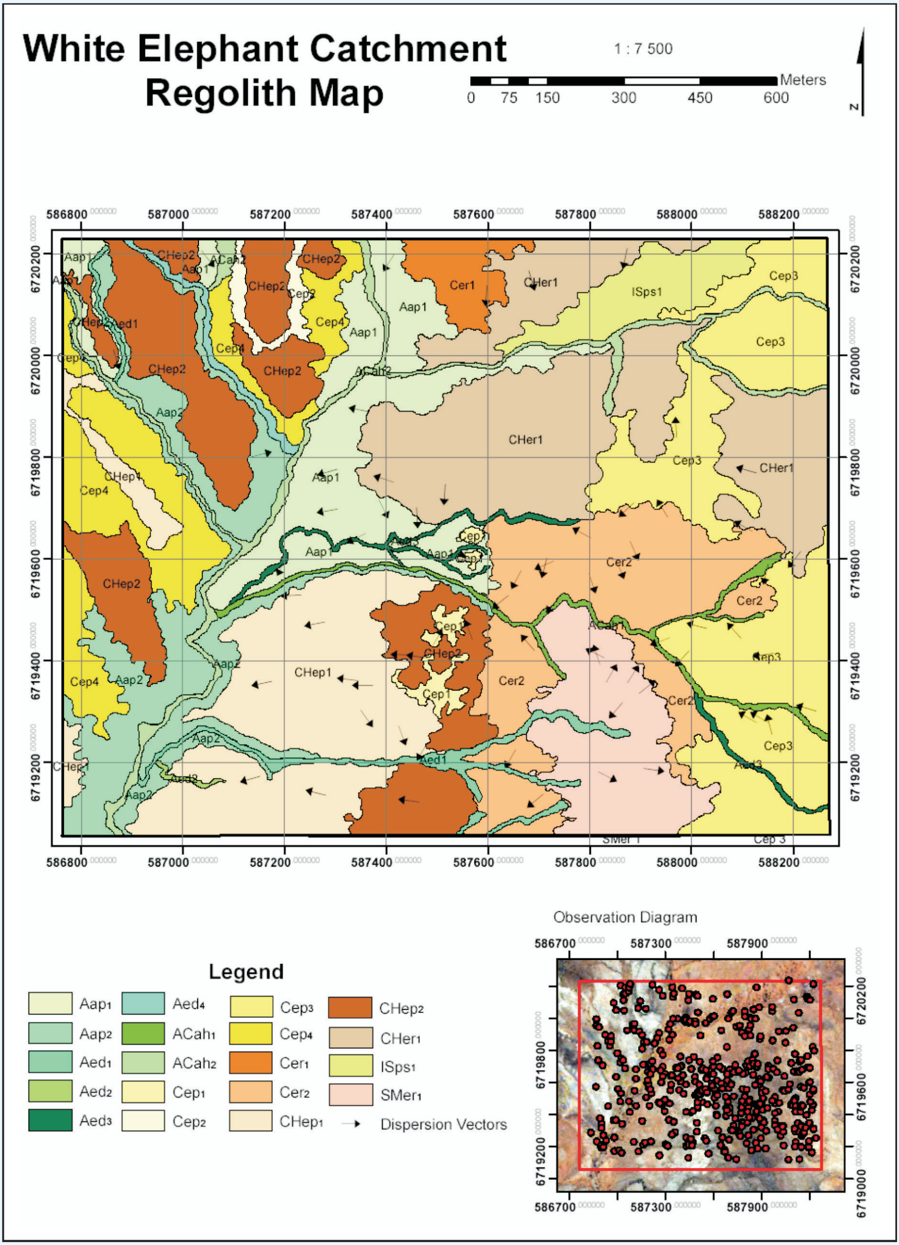
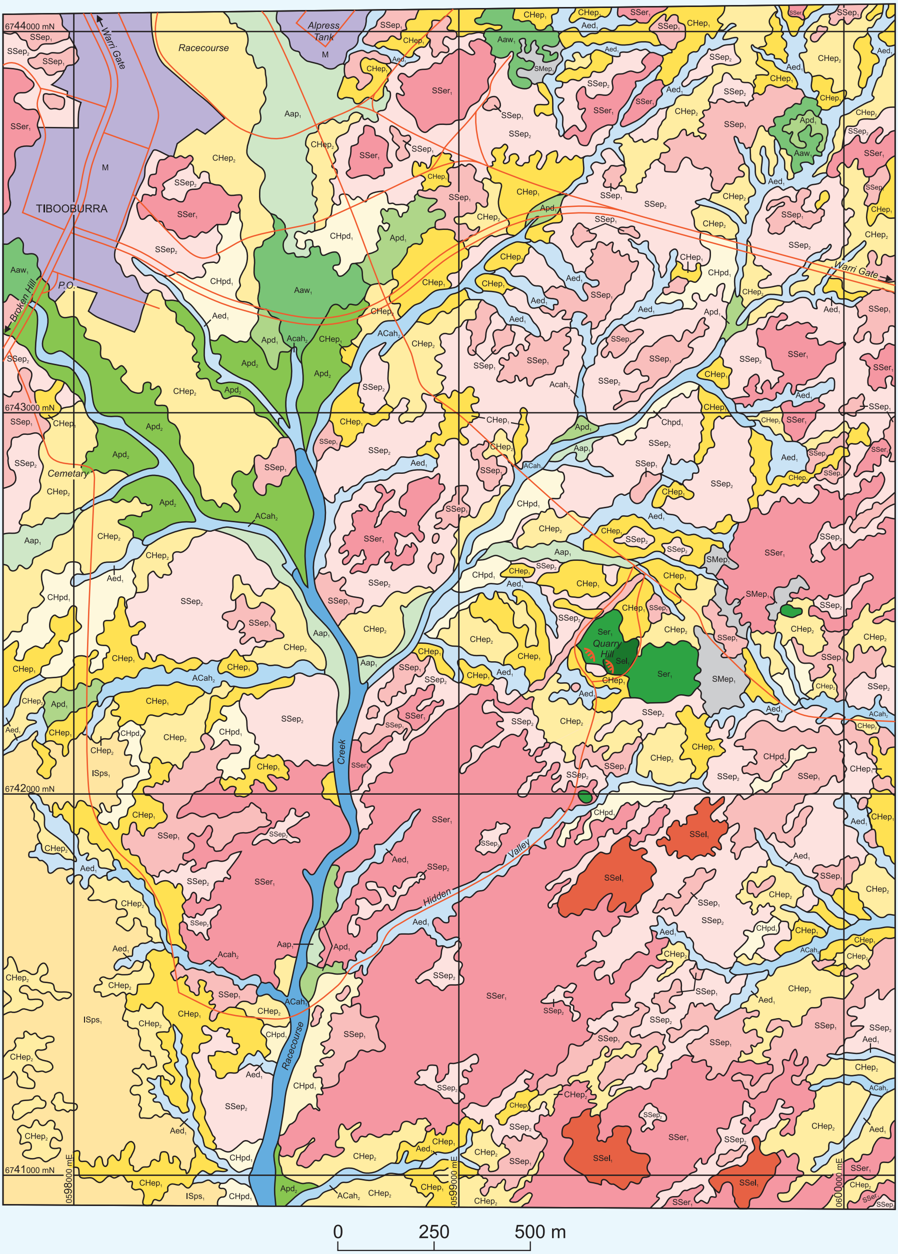


Figure 38: Detailed regolith-landform maps from the Tibooburra–Milparinka area. (A) northern New Bendigo Inlier ('White Elephant catchment') (Tucker and Hill in prep.)


TIBOOBURRA
Racecourse
Alpress Tank
Warri Gate
Warri Gate
Broken Hill
P.O.
Cemetery
Creek
Quarry Hill
Hidden Valley
Racecourse
6744000 mN
6743000 mN
6742000 mN
6741000 mN
0598000 mE
0599000 mE
0600000 mE
0 250 500 m

TRANSPORTED REGOLITH

ALLUVIAL SEDIMENTS

$ACah_1$	Alluvial channel sediments colonised by river red gum
$ACah_2$	Alluvial channel sediments colonised by prickly wattle
Aed_1	Alluvial drainage depression
Aap_1	Alluvial plain with mixed channels and depositional plains
Apd_1	Alluvial depositional plain at floodout
Apd_2	Alluvial depositional plain flanking channels
Aaw_1	Alluvial swamp

AEOLIAN SEDIMENTS

$ISps_1$	Aeolian sand plain colonised by mulga woodland

SHEETFLOW SEDIMENTS

$CHep_1$	Erosional plain with rounded quartzose gravels
$CHep_2$	Erosional plain with rounded quartzose gravels and red-brown sand
$CHpd_1$	Depositional plain with red-brown sand and lithic gravels

IN - SITU REGOLITH

SAPROLITH

Sel_1	Silicified quartzose sands and gravels in low hills
Ser_1	Silicified quartzose sands and gravels in erosional rises
$SSel_1$	Slightly weathered bedrock forming low hills (30-90m relief) with prominent tors
$SSer_1$	Slightly weathered bedrock forming erosional rises (9-30m relief) with prominent tors
$SSep_1$	Slightly weathered bedrock forming erosional rises (0-9m relief) with prominent tors
$SSep_2$	Slightly weathered bedrock forming erosional plains (0-9m relief) with shallow sediments and minor tors
$SMep_1$	Moderately weathered bedrock forming erosional plains (0-9m relief) composed of quartzose and kaolinitic saprolite with prominent corestones

Major road

Track or minor road

Quarry

M	MADE LAND Extensively disturbed (e.g. excavated) or urban land

Figure 38: Detailed regolith-landform maps from the Tibooburra–Milparinka area. (B) Quarry Hill area, Tibooburra Inlier.

them for about a day in the field they begin to make more sense. The first one or two upper case letters represent the dominant regolith materials, and the following lower case letters represent the dominant landform expression. Numbers following these letters represent the number of minor variations of these units subdivided in the mapping, and may relate to slight difference in mineralogy or vegetation assemblages of units. For example, the RLU code:

$\mathbf{SMer_1}$

corresponds to the following information:

- **SM** signifies 'moderately weathered bedrock (saprolite)'
- **er** signifies and 'erosional rise' landform
- **1**, and any other following subscript numbers, allows for subdivision based on variations in attributes within this general regolith-landform assemblage.

For the NSW DPI regolith maps, there is a strong emphasis on also signifying the regolith 'parent materials' or provenance, particularly because these maps were produced closely in conjunction with their regional geological mapping program.

Regolith maps are typically constructed from two main sources:

- remotely sensed data and ground geophysical data
- field observations

5.1.2 Remotely sensed data and ground geophysics

Remotely sensed data and ground geophysics essentially relate detectable and measurable physical characteristics to regolith materials and landforms (*Figure 39*). As such, they provide a surrogate for regolith that can be efficiently mapped across the landscape. The skill and value of this data are derived from being able to relate these surrogates to the materials being mapped. An overview of many of the geophysical and remote sensing methods in relation to regolith characterisation is given in Papp (2002).

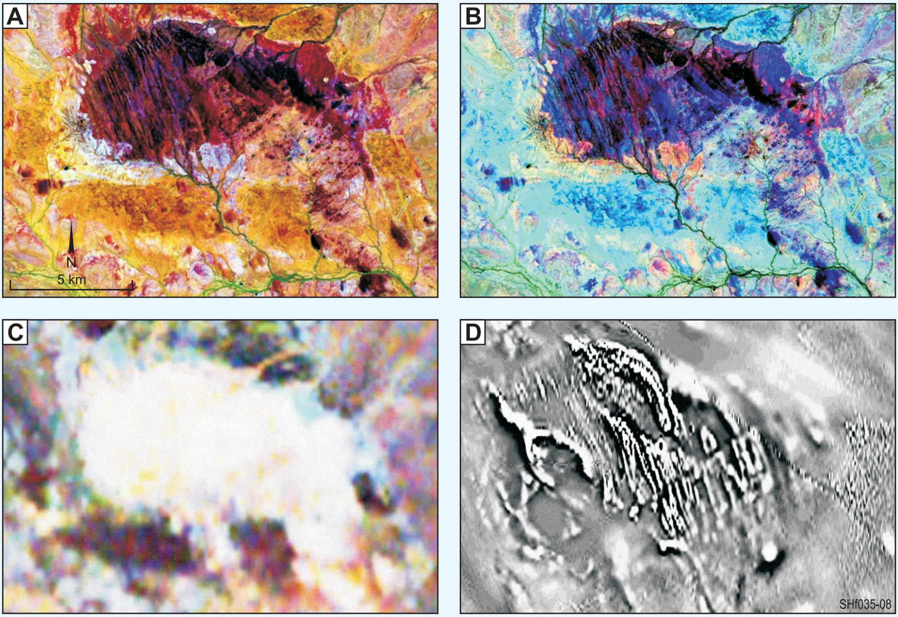


Figure 39: Remotely sensed images of the Tibooburra Inlier (see Figure 38 for corresponding regolith-landform map).
(A) Landsat7 bands-741.
(B) LandsatMS741 and PC1 Brovey transformation image.
(C) radiometrics, showing very high response within the inlier as well as along channels flowing from the inlier. Lower response (darker) is from aeolian sandsheets flanking inlier (R–G–B = K–Th–U).
(D) 1VD airborne magnetics, showing particularly maghemite-rich gravel accumulating in outwash to the east of the inlier (the Moomba gas pipeline is also a prominent NW–SE linear feature to the northeast of the inlier). See text for more detailed explanation on how these images were generated. Data from NSW DPI.

Topographic maps and digital elevation models (DEMs)

Topographic maps have for a long time been the most readily available way of representing the topography, and therefore many of the landforms, of an area. In most cases, drainage patterns are very well shown. Depending on the scale that they are being used, limitations can include the resolution of the maps: in particular the vertical dimensions or contour interval. Printed and digital topographic map data for the region at 1:250,000 and 1:100,000 scales are available from Geoscience Australia and can be ordered through their website (www.ga.gov.au). These maps are also useful because they show fence-lines, access tracks and other geographical features; however, they require regular up-dating. When using all maps–in particular topographic maps–ensure that not only is the map scale appropriate for the resolution required, but also that the map datum, projection and coordinates are compatible with other spatial datasets.

Digital elevation models (DEMs) can provide representation of an area's topography and therefore its landforms. They can be produced from existing topographic map data, although the Space Shuttle Radar Topographic Mission (SRTM) data is widely used to generate DEMs. The SRTM data are free to download from NASA: they have 90-metre cells and typically have vertical height resolution to less than 1 metre.

Aerial photographs

Until recently, vertical aerial photographs (airphotos) were the most important remotely sensed data used for making regolith-landform maps. They have been mostly ordered as contact prints, although sometimes transparencies are used. Increasingly, they are being scanned at high resolution and geo-rectified for incorporation into geographic information systems (GIS). Regions typically have coverage in black and white (especially photographs taken with the RC9 camera) or, more recently, photographs are in colour. One of their advantages has been the widespread coverage of high-resolution stereoscopic photographs (typically with 60–80% overlap in the forward direction and 30% between flight runs). The stereoscopic coverage is particularly useful in expressing landforms, and skilled interpreters can effectively use combinations of photograph colour, tone, texture, pattern and contrast to delineate changes that further relate to different regolith materials and landforms (Figure 37B). Aerial photographs for the Thomson Orogen region are available from the NSW Department of Lands, with most of the region covered by approximately 1:50,000 colour photographs. Flight runs and preview scans of photographs are available at the NSW Department of Lands website (www.lands.nsw.gov.au).

Landsat

Landsat 7 (L7) data is a multispectral dataset comprising three visible bands (resolution 15 m): one near infrared band (resolution 30 m) , one thermal band (resolution 60 m) and two short-wave infrared bands (resolution 30 m). The images are collected as continuous swaths by satellite. Images tend to provide a useful resolution at a working scale of 1:50000. Landsat has good capabilities in discriminating clays hydrated minerals (clays and micas), Fe oxides (haematite and limonite) and identification of vegetation. Further information can be found on NASA's Landsat website (landsat.gsfc.nasa.gov) and in Wilford and Creasy (2002).

Useful derivatives of Landsat data for regolith discrimination include:

- ***Landsat 7-Bands 7, 4 and 1 (commonly written as L7 741)*** presented as a red–green–blue (RGB) composite image, broadly highlight clays, Fe oxides and vegetation (*Figure 39A*). Some inferences can be made using the L7 741 image, on which inliers known not to have been eroded by post-Mesozoic incision have a strong Si signature (deep blue-black colouration). In contrast, areas that preserve a Mesozoic palaeo-surface (either exhumed from beneath the Mesozoic sediments, or not having been buried) have a strong Fe/Si signature (maroon). The extent of inlier-derived colluvium/alluvium is easiest traced by the L7 741 stretch (made 40% transparent) with the K response derived from radiometrics laid behind it. This results in inlier-derived material returning pink/purple false colour. Note, this stretch is also excellent for tracing silcrete and silcrete-derived colluvium (high Si, low K: giving a distinct blue response).
- ***Landsat 7-Principle components (PC)123***. PC is a multivariate statistical analysis in which uncorrelated linear combinations (eigenvectors) – representing similar responses in the various bands–are mapped into single bands so that each product band accounts for less variability from the original dataset.
- ***Brovey transformation***, which allows for the creation of an integrated image in RGB using several remote datasets (e.g. Landsat, radiometrics, magnetics) (*Figure 39B*).
- ***Feature-oriented principal component analysis (FPCA)***, which is a multivariate statistical analysis technique in which uncorrelated linear combinations (eigenvectors)–representing similar responses in the

various bands–are presented into single bands so that each product band accounts for less variability from the original dataset. From this, minerals such as kaolin, haematite and goethite can be highlighted.

SPOT

High resolution, stereo imaging and revisit capability are unique features of the *SPOT* (Satellite Pour l'Observation de la Terre) system. The *SPOT* satellite Earth observation system has been operational since 1986 when *SPOT 1* was launched with 10-metre panchromatic and 20-metre multi-spectral image resolution (which was withdrawn in December 1990). *SPOT 2* was launched in January 1990 and is still operational, followed by *SPOT 3* in September 1993 (which stopped functioning November 1997), *SPOT 4* in March 1998, and *SPOT 5* in May 2002. The resolution of *SPOT 5* is 2.5 to 5 metres in panchromatic mode and 10 metres in multi-spectral mode. *SPOT 5* also features a high-resolution stereoscopy (HRS) imaging instrument operating in panchromatic mode. HRS points forwards and backwards from the satellite and is therefore able to take stereo-pair images almost simultaneously. The *PLEIADES* program is intended to replace the *SPOT* satellites. It will use a constellation of smaller, more agile satellites offering an improved spatial resolution of up to 0.7 metres. Launch of the first satellite, *PLEIADES-HR-1*, is scheduled for early 2010.

The four-band multispectral data can be reprocessed using principal component analysis. By this method, principal component 1 (PC1) contains data common to all bands (particularly topographic effects and albedo effects) and can therefore be disregarded as noise. The resultant false-colour composite image (PC2 in the red channel, PC3 in green and PC4 in blue) has been particularly useful for regolith mapping in the Tibooburra–Milparinka area, especially for differentiating Cretaceous outcrop from basement (pre-Mesozoic) rocks and various cover types–*in situ* and transported.

ASTER

ASTER (the advanced space-borne thermal emission and reflection radiometer) is one of two instruments on the *NASA TERRA* satellite (the other being MODIS). ASTER senses 14 bands from the spectrum between visible near infra-red to thermal infra-red and has ground resolutions varying from 15 metres in the very near infra-red (VNIR) to 90 metres in the thermal infrared (TIR). ASTER is very useful for regolith and vegetation mapping in arid and semi-arid regions at scales as high as 1:25,000 (above which it becomes pixelated).

Airborne gamma-ray spectrometry (radiometrics)

Airborne radiometrics is a measure of the gamma-ray emittance of the top 30–50 centimetres of the Earth. This surface penetration can be useful for providing expressions through thin aeolian cover and vegetation. Emittance of the radio-isotopes of potassium (K)–together with specific daughter products from the decay of Th (equivalent Th or eTh) and U (equivalent U or eU)–are conventionally coloured red, green and blue, respectively (*Figure 39C*). It is important to be aware that U and Th are not measured directly, but that their daughter products are used as surrogates. In a closed system, this may give an accurate measure of U and Th concentrations, but many surface environments are not closed systems and either the parent U and Th, or the daughter products, can become separated, leading to disequilibrium in the decay series. This can lead to the formation of 'false' or misleading responses.

Radiometric signatures tend to relate closely to the degree of weathering, where greater weathering leads to leaching of K and Th, with the Th typically hosted in secondary Fe oxide minerals (i.e. ferruginous regolith). Bedrock typically has a strong radiometric signature, so therefore Mesozoic sediments proximal to the inliers in the study area can be differentiated by a slightly weaker combined radiometric response. Radiometrics also clearly shows the provenance of alluvial material. Inlier-derived alluvium returns a high combined radiometric response. Mesozoic sediments typically return a high-K, low eTh–eU response, probably indicating higher kaolin/illite content of transported material. Aeolian material incorporated into drainage systems invariably masks the radiometrics with a low count for eU and eTh and a moderate K response.

Magnetics

Total magnetic intensity (TMI) is a measure of the total magnetic field of the Earth, whether it be induced or remnant. First vertical derivative (or 1VD) magnetics is a Fourier function of the TMI magnetics. The 1VD is a measure of the rate of change of the Earth's magnetic field, and is useful for locating near-surface magnetic features that have high amplitudes and short wavelengths. This can be due to the maghemite content of the regolith (especially maghemite-rich detritus in palaeochannel systems). Dendritic patterns of maghemite-rich palaeodrainage channels from the later part of the Cenozoic are expressed in many parts of the area (*Figure 39D*).

Gravity

Gravity surveys show variations in the density of bedrock and regolith. Typically, regolith materials have lower density than bedrock, so thick palaeochannel fill or weathering profiles tend to be expressed as areas of lower density.

Electrical methods

Conductivity and resistivity vary for different rocks and regolith materials. Measurement of these electrical properties can therefore be used to map different regolith and rock types and attributes. Attributes such as mineralogy, water content, porosity and associated differences in salinity can influence conductivity/resistivity. Generally, sulphides and graphitic rocks are good conductors. Conductivity and resistivity have been widely used within airborne surveys to map the 3D distribution of palaeodrainage systems and, for more detailed survey, portable electromagnetic (EM) instruments, such as NanoTEM, can be used. These approaches have so far not been widely used in the Thomson Orogen region.

5.1.3 Field observations

Fieldwork associated with regolith mapping provides an opportunity to directly examine and record characteristics of the regolith and landscape not observable in remote sensing, as well as to check and test the different remote sensing expressions. The types of field observations generally include:

- regolith lithology, including colour, mineralogy, grain size, sorting and shape, fabric, pH, weathering and pedogenic features
- landform expression and landscape processes, such as erosion and deposition
- the dominant vegetation community structure (e.g. shrubland, woodland or grassland) and species
- Geographic positioning system (GPS) coordinates
- a photograph or sketch representative as well as unusual features
- sampling of materials for further analysis.

Further guidelines for some of the attributes to describe and record are given in Macdonald *et al.* (1990) and Pain *et al.* (2007).

The program of visiting field sites largely depends on:

- the time and budget of the field program
- the means of transport and its suitability for crossing the terrain
- cultural features such as availability of vehicle tracks, restrictions from fence-lines and the level of access negotiated with land-owners
- whether sample collection is also included in the program and the style of coverage required from the collection
- the heterogeneity and predictability of the regolith and landforms in the area.

Typically, a series of field traverses are used, which ideally involve as little overlap as possible and incorporate the key sites determined from preliminary interpretations of remotely sensed data. Field observation and sampling points are typically numbered along these traverses. The spacing and number of these points depends very much on the scale and objective of the mapping or sampling program.

5.2 Regolith geochemistry

The landscape typically presents a wide range of materials that can be sampled as part of a geochemical exploration program. The selection of suitable sampling media largely depends on the efficiency and availability of the material for sampling across a target area, as well as the geochemical processes of dispersion and accumulation that determine the effectiveness and characteristics of the material for exploration objectives. Given the scope for variability between the different materials in the landscape, achieving sample consistency is one of the most important aims. Ideally, the objective is to keep all variations between samples at a minimum, so that the only differences remaining are due to the underlying substrate, which may include mineralisation. This is typically not realistically achieved and therefore geochemical sampling programs need to try to account for variations within the exploration area, including landform setting, anthropogenic contributions and differences in the attributes of the materials sampled. The following includes some discussion of the more-readily available and tested geochemical (and biogeochemical) sampling media from the region.

5.2.1 Soils and stream sediments

In many areas, soils are likely to include a significant amount of exotic, transported material. This challenge must be addressed when designing a soil sampling program. The variable and low abundance of Au and many other trace metals in soils must also be considered. It is common practice to isolate a specific size fraction by sieving soil samples before chemical analysis. Soil geochemical surveys from other similar regions have targeted the finer fraction (< 120 µm), from the clay-rich B horizon, in the belief that cations present will be largely adsorbed onto clays. This will be influenced by the type of clays in the soil. For example, kaolinite and illite have very low cation-exchange capacities, whereas smectites have high cation-exchange capacities. Soils will also largely contain wind-blown, exotic components, which vary in size in different landscape settings (see Chapter 3), but are typically in the 60–80 µm size range.

Care needs to be taken when describing or targeting specific soil horizons for sampling in this region. Some of the layering within the near-surface parts of regolith profiles can be related to sedimentary deposition rather than pedogenic horizon development, even though there may be distinctive differences in colour and texture between these layers. A regionally important example of this is the PSA layer deposited across the top of most profiles that tends to be lighter brown and have a more sandy texture than underlying units, and therefore superficially resembles a soil A-horizon. Some near-surface sedimentary profiles may contain a series of truncated and buried soils (e.g. palaeosols). Conceptually, the lower-most soils (near the pedoplasmation front, where soils can be older and closer to underlying substrate), as well as more-developed soils (more pedogenically evolved allowing for better geochemical anomaly development), should contain the best geochemical expression of the underlying substrates. These different features may confuse some geochemical sampling programs; however, consistently sampling equivalent materials across the landscape is the most important objective.

Soil samples are frequently taken at a standard depth within the profile. The advantage of this approach is that it can be easily performed with minimal training, and provides some sampling consistency. This approach can be problematic when comparing samples across the landscape where differences due to landscape setting (e.g. within a catena) occur (described in Chapter 3)– resulting in different materials being sampled. For instance, a 50-centimetre sampling depth may encounter weathered bedrock on upper slopes, colluvial or aeolian material on mid-slopes, regolith carbonate on lower slopes, and alluvial sediments in valleys. This example further highlights the value of sampling within the context of a regolith-landform map to highlight and account for these differences, but also raises consideration for sampling standard materials, rather than standard depths.

Stream sediment sampling has similar problems: particularly due to differences in the ideal fraction for analysis in different fluvial settings (e.g. erosional compared with depositional). A comparative study along Racecourse Creek south of Tibooburra, found that river red gum leaf biogeochemistry provided a more reliable and representative sampling method along drainage channels (Hulme 2008).

There are presently no exploration industry reports relating to previous systematic soils sampling programs from the region, but there has been some research on the use of soils as a sampling medium. SM Hill (2004) sampled and analysed the upper and lower stratigraphic levels of soils (depositional layers, but similar in appearance to 'A' and 'B' soil horizons) in the upper eastern tributary of Dee Dee Creek. This study showed that the regolith-landform setting was the major control on soil geochemistry in this area. For instance different regolith-landform units had the following different geochemical characteristics:

- slightly weathered bedrock: locally elevated Cu (median 38 ppm); Ni (median 32 ppm); Zn (median 75 ppm); and locally low Au (median 2.8 ppb)
- alluvial regolith: highest concentration of trace metals such as Cu (median 61 ppm); Ni (median 35 ppm); Zn (median 116 ppm); and Au (median 8.1 ppb)
- colluvial regolith: low concentrations of most trace metals
- aeolian regolith: low concentrations of most trace metals.

Tucker and Hill (2006) and Tucker (2006) analysed the < 75 µm, 75–200 µm and the > 200 µm in the New Bendigo Inlier area. The medium size fraction (75–200 µm) provided the best expression of subcropping mineralisation buried by more than 1 metre of sediment. At greater sediment depths, surface geochemical expressions of underlying mineralisation was highly irregular, due to the masking effect of the exotic, transported nature of soil materials (*Figure 40*).

Surface lags have been recommended as a geochemical sampling medium in other regions (e.g. McQueen 2008). The complex origins of these have been outlined in Section 3.3 and need to be considered if they are used by mineral explorers. In particular, it is important recognise sheetflow contributions to surface lag development because these materials may have moved laterally over significant distances. Lag compositions and dispersion will also vary for different regolith-landform settings.

Fine-grained materials, including, or thought to be, equivalent to overbank deposits, have been sampled across the Thomson Orogen region in NSW (de Caritat and Lech 2007). Soil samples were taken from 99 catchment outlet sites at the surface (0–10 cm depth) and at depth (60–90 cm), and

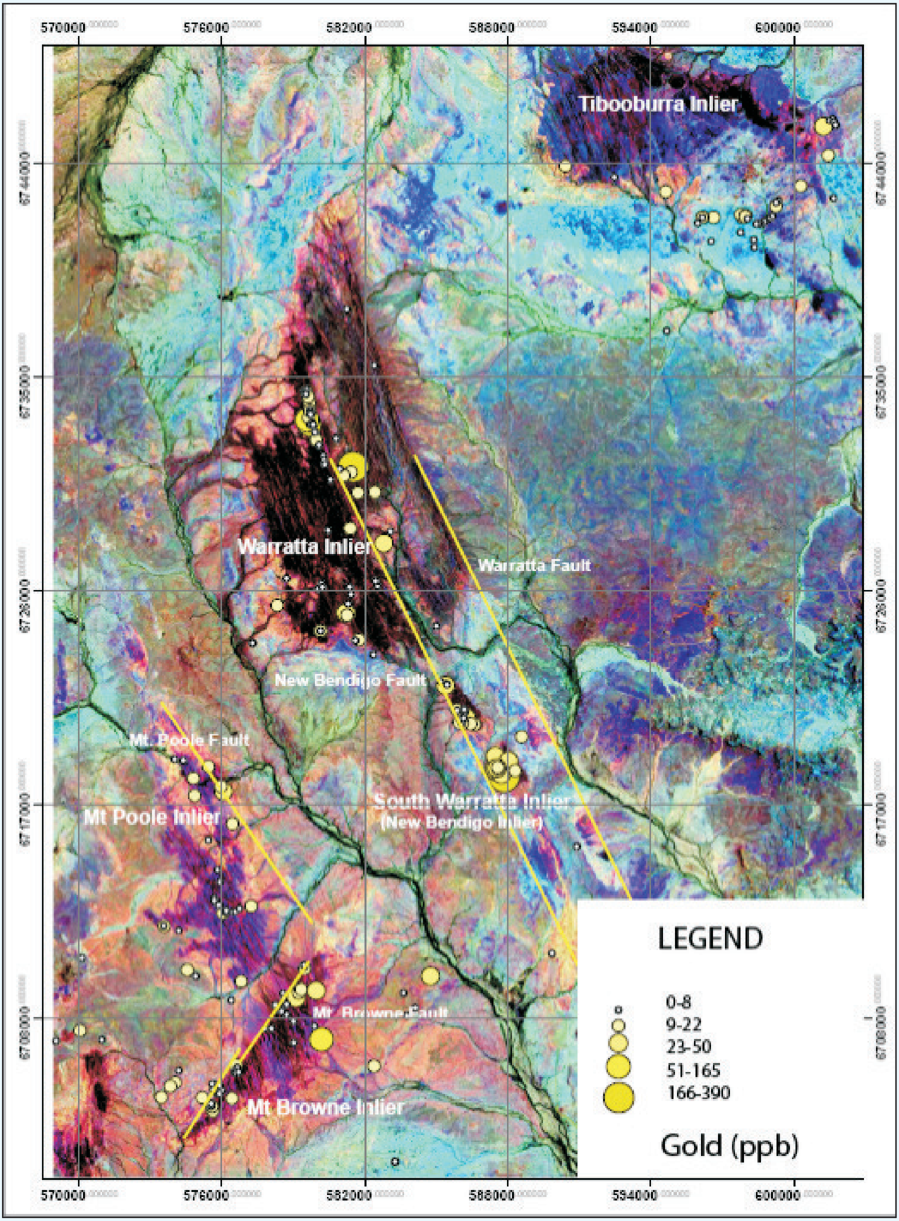


Figure 40: Gold content of regolith carbonates sampled from the Tibooburra–Milparinka area. (Gibbons and Hill 2005). Datum GDA. Background Landsat MS741 & PC1 Brovey transformation, courtesy of NSW DPI.

then both sets of samples were sieved to both < 180 µm and < 75 µm fractions. Elevated concentrations of trace metals such as Cu, Pb or Sb were interpreted as potentially reflecting areas of known mineralisation, as well as sites of unknown mineralisation that may warrant further investigation. Interpreting Au results was problematic due to sample heterogeneity (i.e. 'nugget effect'). Elements such as Cu and, to a lesser extent, Pb and Sb were predominantly higher in the samples from depth, with similar regional patterns from the < 180 µm and < 75 µm fractions. This approach may provide a geochemical baseline expression on a regional-scale–placing exploration tenements within a geochemical context–however, it is not designed for use at tenement or prospect scales with local complexity due to variable geochemical sources and dispersion pathways. Further geochemical investigation of regional anomalies may best use some of the other media as recommended in Chapter 6.

5.2.2 Regolith carbonates

Regolith carbonates are not widespread in the region, although they are abundant enough to provide a regional-scale geochemical sampling medium. The limited diversity of morphological facies, and their tendency to form at hydromorphic boundaries associated with the top of the saprolith interface, makes these materials a reasonably consistent medium for the region. The trace metal geochemical characteristics of these materials have been examined in this region, and have included analysis of more than 250 samples from the Tibooburra–Milparinka inliers and margins (Gibbons 2005; Gibbons and Hill 2005). The Au content of these materials tends to be high but variable across the region: largely reflecting the potential for detrital Au particles to be incorporated into the carbonates. In some cases, Au nuggets have been found in these materials. Gold contents are frequently tens of parts per billion, with samples taken from sites of known Au mineralisation having high Au contents of 50–390 parts per billion (*Figure 41*). The Cu contents were also high near many of the sites of known mineralisation, with values ranging from 25 to 70 parts per million near known mineralisation. From this it was concluded that regolith carbonates have the potential to provide geochemical representation of areas ranging from 10 square metres up to about 1 square kilometre (Gibbons 2005; Gibbons and Hill 2005).

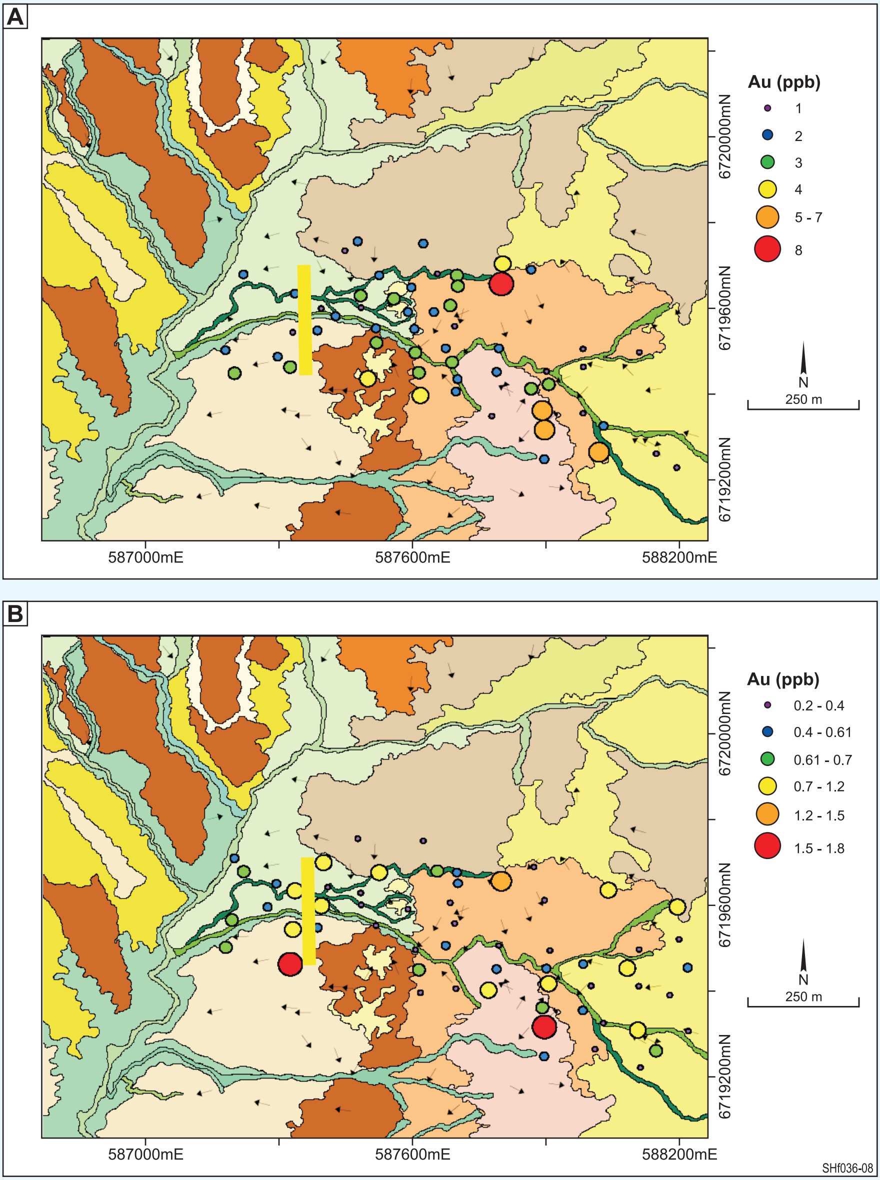


Figure 41: Gold contents from samples taken from 'White Elephant' catchment where a mineralised alteration zone (yellow line) is buried by > 5 m Mesozoic and Cenozoic sediments. (A) 75–200 µm size fraction from soils (B) black bluebush twigs. Map datum GDA.

5.2.3 Silicified sediments

Silicified regolith is widespread in the region, but its low trace metal contents (in most cases below or approaching analytical detection limits) and chemical heterogeneity make it a challenge for widespread application in mineral exploration programs. It also provides a challenge in tracing possible dispersion pathways between the sample site and the potential source of the trace metal. Even given these challenges, silicified regolith has demonstrated potential as a regional mineral exploration sampling medium. In the Broken Hill region, several studies have been able to demonstrate a link between trace element anomalies in silicified regolith and sites of known mineralisation through interpreting the assays according to trace element repositories and modelled dispersion pathways, (Hill 2000). It was found that some trace metals were hosted by different indurating cements (e.g. micro-crystalline quartz, hematite and anatase). These are likely to have been chemically dispersed in groundwaters. Other elements were associated with detrital clasts and would have been physically dispersed at the same time as the bulk of the sedimentary regolith host material.

In the area of the Tibooburra Inlier, over 20 samples of silicified, fine grained sandstone–equivalent to the Mesozoic Algebuckina Sandstone–had Au contents that ranged from below detection limit up to 7 parts per billion. Highest Au values were from the headwaters of Dee Dee Creek: near the aeolian sandsheet. These indurated sediments also typically had measurable cross-bedding that constrained the palaeo-current directions and thereby palaeo-physical dispersion vectors. Fine sandstone samples were targeted in preference to coarse-grained conglomerates, which were known to have extremely heterogeneous chemical characteristics (particularly for Au).

5.2.4 Ferruginised regolith

Relatively few ferruginised regolith samples have been analysed from the region. In other regions, they have been a useful mineral exploration sampling medium, largely because they are excellent metal hosts: particularly those containing goethitic materials, because they have a high capacity for hosting cations. If meaningful results are to be obtained from such samples, it is important to ensure that they are sufficiently similar in mineralogy, morphology and associated landscape setting that the explorer is comparing like with like. In South Australia, Bourman *et al.* (1987) have shown significant major element and mineralogical variations between different ferruginous regolith types, and these differences are likely to be very important for trace metals. Accounting for different abundances of Fe-oxide trace element hosts (perhaps by normalising analyses with respect to Fe) can be useful. Tracing the geochemical dispersion pathways of chemical constituents of these materials will also be a challenge, especially within areas of deep basin cover.

5.2.5 Biogeochemical media

Plants are a significant component of regolith and landscapes across most terrestrial settings. Their use as mineral exploration and environmental chemistry sampling media has previously gained mixed support in Australian regolith studies; however, they have numerous advantages for use due to:

- widespread cover across the landscape
- easy access to samples
- an ability to penetrate regolith (especially transported cover) thereby providing a direct chemical pathway to the underlying bedrock
- an ability to selectively extract and concentrate some elements
- an ability to integrate a chemical signature from an enlarged sampling area (potentially achieving greater site representation and reducing potential problems with heterogeneous sample media)
- minimal site disturbance and remediation costs associated with sampling
- some proven exploration success for a wide range of elements, regolith-landform settings and mineralisation styles.

In recent years, a small but important biogeochemistry research program has been undertaken in the Tibooburra–Milparinka area, largely consisting of student Honours and PhD research. The research approach has been to target trees and shrubs that are widespread across the region, or are locally significant in areas also hosting regolith geochemistry case and pilot studies (Hill 2003).

Sampling and sample preparation are outlined in the Guide Appendices. Names and botanical descriptions are after Cunningham *et al.* (1992); Kutsche and Lay (2003); and Moore (2005). Analytical suites and techniques–as well as preliminary results from the Tibooburra–Milparinka area and the Broken Hill region–are described in Hill and Hill (2003).

Biogeochemistry studies have been based on the four main regolith-vegetation settings for the region. This created a suite of recommended plant species for sampling in each of the main regolith-vegetation settings in the area, including:

- ***Mulga woodlands*** on sandplains, including characterisation of mulga (*Acacia aneura*) and bastard mulga (*Acacia stowardii*) on the Dee Dee Creek sandplain near Tibooburra (L Hill 2004; Hill and Hill 2003).
- ***Chenopod shrublands*** on sheetflow plains and rises, including characterisation of black bluebush (*Maireana pyramidata*) colonising sheetwash plains and rises overlying Mesozoic basin sediments over buried bedrock-hosted mineralisation on the New Bendigo Inlier (Tucker 2006; Tucker and Hill 2006 Tucker and Hill, in prep) (*Figure 40*, and black bluebush (*Maireana pyramidata*) and bladder saltbush (*Atriplex vesicaria*) near Tibooburra (Hill, 2004; Hill and Hill 2003).
- ***Riparian woodlands***, including river red gum (*Eucalyptus camaldulensis*) characterisation along Racecourse Creek in the south of the Tibooburra Inlier (Hulme 2008; Hulme and Hill 2003, 2004, 2005).
- ***Open mixed woodlands*** on erosional hills and rises of weathered bedrock, including characterisation of mulga (*Acacia aneura*) (Tucker 2006; Tucker and Hill 2006) and black bluebush (*Maireana pyramidata*) understorey (S.Hill 2004; Hill and Hill 2003).

Some of the attributes of biogeochemically characterised plants from the Tibooburra–Milparinka area are given in *Table 1*. Some plants, such as river red gums, lend themselves to regional as well as local-scale sampling programs. This is because their spreading, deep root-systems take up groundwater and associated trace elements that typically accumulate at the sediment–bedrock interface. At the Pinnacles in the Broken Hill region, river red gum leaves provided an expression of mineralisation buried by alluvial sediments as part of a regional 200–250-metre spaced sampling program (Barratt & Hill, 2003; S Hill 2004) and within a detailed sampling program of every tree along a creek channel (Hulme 2008). Similar regional as well as local-scale variations were found for river red gums detecting the buried geological contact between the Tibooburra Granodiorite and the surrounding metasediments along Racecourse creek, south of Tibooburra (Hulme and Hill 2005). Other species with deep penetrative root systems– such as black bluebush (*Maireana pyramidata*) on sheetwash plains overlying Mesozoic sediments (e.g as shown in *Figure 40*), and mulga (*Acacia aneura*) and bastard mulga (*Acacia stowardii*) on aeolian sandplains and dunefields–lend themselves to closer spaced sampling programs, perhaps as a pre-drilling follow-up to broadly defined regional exploration targets.

Other important considerations for biogeochemical sampling programs, mostly focus on the need for achieving sampling consistency, and include:

- Consistent species targeting, where species from the same genus have different biogeochemical mechanisms and characteristics. For example, this was shown in a comparison of the biogeochemistry of adjacent mulga and bastard mulga trees on the Dee Dee Creek sandplain (L Hill 2004), where bastard mulga (*Acacia stowardii*) samples consistently had higher Au and base metal contents than mulga (*Acacia aneura*) samples from adjacent trees.
- Consistent plant organ targeting, where different organs are found to have significantly different biogeochemical attributes from the same plant. Results have shown leaves to typically be the most consistent sampling medium and provide strongest background to anomaly contrast.
- Consistent seasonal sampling: preferably when surface soils are at their driest (this has typically been during autumn in recent years, although rainfall patterns are unpredictable in this region), if deeper penetrative chemical signatures are desired (Hulme and Hill 2004; Hulme 2008).

Table 1: Biogeochemically characterised plants from the Tibooburra-Milparinka area.

SPECIES	DESCRIPTION	DISTRIBU-TION	SAMPLING & PREPARATION	BIOGEOCHEMISTRY
Mulga *Acacia aneura* 	Small upright tree up to 14 m tall, but also forms bushy shrubs 3-5 m tall. Variety of shapes with upright branches, 'Christmas tree' shape (Acacia aneura var. conifera). Grey-green phyllodes, mostly narrow-linear, but can be broader, 3-11 cm long x 0.7-3 mm wide, with parallel veins. Yellow, cylindrical flower spikes, 8-25 mm long. Papery to woody, brown seed pods, 1-6 cm long and 0.4 – 2 cm wide. Variable intergrading and hybridising forms, including at least 10 varieties Long lived and deep-rooted	Aeolian dune swales and sandplains. Erosional hills and rises	Clean phyllodes but can resist removal from twigs. Easy to mill phyllodes.	Mulga phyllodes from 8 trees on the aeolian sandsheet in Dee Dee Creek headwaters were all below analytical detection limit (Hill, 2004). Tucker (2006) sampled over 35 mulga phyllodes from erosional rises of the New Bendigo Inlier. Au contents ranged up to 1.7ppb over mineralisation and down to detection limit (0.2ppb) away from mineralisation. Ba, Cr, Cu, Ni and Mo were also locally elevated in samples from near mineralisation.
Bastard Mulga *Acacia stowardii* 	Small spreading to upright tree up to 8 m tall, but also forms bushy shrubs 3-5 m tall. Green phyllodes, mostly narrow-linear, 3-8 cm long x 1-2 mm wide, with parallel veins. Yellow, cylindrical flower spikes, 8-25 mm long. Papery to woody, brown seed pods, 1-6 cm long and 0.4 – 2 cm wide. Long lived and deep-rooted	Aeolian dune swales and sandplains. Erosional hills and rises	Clean phyllodes but can resist removal from twigs. Easy to mill phyllodes.	Hill (2004) found Au contents up to 2 ppb in phyllodes and 5.9 ppb in twigs from 23 samples from the Dee Dee Creek sandplain, east of Tibooburra. Nickel and Zn contents tended to be higher than adjacent species. A further 150 samples were later collected and provided Au contents up to 0.5 ppb in phyllodes and 0.5 ppb in twigs (unpublished data).
Black Bluebush *Mariana pyramidata*  SHf037-08	Dark blue-green to grey, multi-branched shrub to 1.5 m tall. Leaves are alternate, succulent, linear to egg-shaped, 2-4 mm long, and covered in short hairs. Flowers are singular, occurring where the leaves join the stems, and can occur throughout the year following rain. Fruits are typically plentiful, light green, consisting of a flat tube and a wide horizontal wing, 10-15 mm wide that has a raised central section. Fruits become black when dry. Long lived.	Sheetflow plains and rises. Understorey on erosional hills and rises	Leaves easily sampled, however high moisture content can cause excessive degredation. Leaves also trap large amounts of dust. Recently small twigs have been favoured, however they need to be well broken to avoid rupturing bags and to fit mill.	23 twig and leaf samples were taken from the Dee Dee Ck sandplain (Hill, 2004), providing up to 8.1 ppb Au in twigs and 5.4 ppb in leaves. Over 100 twig samples were analysed from the New Bendigo Inlier (Tucker, 2006). Gold, Ba, Cr, Cu, Ni and Mo were locally elevated in samples from near mineralisation, even when buried by >5m. Au contents ranged from detection limit to up to 7.8ppb over subcropping mineralisation and 1.8ppb over buried mineralisation.

SPECIES	DESCRIPTION	DISTRIBU-TION	SAMPLING & PREPARATION	BIOGEOCHEMISTRY
Cabbage leaf wattle *Acacia cana* 	Shrub or small tree up to 4 m tall, with rough twisted trunk and spreading bushy canopy. Phyllodes are narrow elliptic, 50-80 x 3-5 mm, finely pointed, rigid, straight, silvery grey with fine hairs and veins. Flowers are single or small clusters, globular, golden yellow. Pods are linear, grey, slightly constricted between seeds.	Alluvial and sheetflow plains	Phyllodes are generally clean but can be difficult to remove from stems. Small spine at phyllode tip can cause discomfort, as may rancid cabbage smell of drying leaves.	52 samples of phyllodes have been collected from the Milparinka-Kayrunnera region, and analysed by INAA (Au+31). Only one sample contained detectable Se and Au, and this came from the vicinity of the Williams Peak Au-field.
River Red Gum *Eucalyptus camaldulensis* 	Large, typically single-stemmed tree up to 30 m tall with smooth white bark, with irregular red, brown, grey and yellow patches, and can have grey and rough bark at trunk base. Leaves are dull green to blue-green, 8-30 cm long and 7-20 mm wide, and drooping. Buds and fruits occur in clusters of 7-13, and buds have a rounded to slightly conical tip (beaked tip in southern and eastern forms). Flowers are white and can occur throughout most of the year. Long-lived with deep and spreading roots	Riparian woodlands along major channels	Leaves clean and easy to pick. Need to be well dried to avoid smearing in mill.	Leaf samples from 98 trees along Racecourse Creek, south of Tibooburra, were analysed by Hulme (2008). Results for Au were mostly below or close to analytical detection limit for Au, however this limit was relatively high (0.500 ppb). Several detectable values (up to 0.68 ppb Au) corresponded to where the channels intersected the sub-Mesozoic palaeosurface.
Prickly Wattle *Acacia victoriae*  SHf038-08	Tall, dense, multi-branched shrub, 2-5 m tall. Phyllodes are grey-green (can be variably glaucous), broad linear, 2-5 cm long and 3-7 mm wide, rounded at the end and may have a short, stiff point with one central vein. Globular flower heads, pake-cream to yellow, 5-6 mm wide, typically with 15-30 flowers per head. Seed pods are broad, flat, 4-7.5 cm long and 6-13 mm wide, straight, with rounded seeds. Fast growing and fairly short-lived.	Riparian woodlands and flanking alluvial plains	Although samples are easy to access, the spiny branches can make sampling uncomfortable. Sampling by closing fingers around stems and running fingers down the stem avoids most prickles, although can tear sampling gloves. Phyllodes typically clean and easy to mill.	A small unpublished data set of 13 phyllode samples from along Racecourse Creek provided below detection limit (0.500 ppb) Au results for all samples. Further, lower detction limit analysis may be required for future use of this plant.
Other plants not widely characterised in this region but with potential applications: Aeolian dunes and sandplains: white cypress pine, black oak; Sheetflow plains and rises: bladder saltbush, pearl bluebush; Riparian woodlands: beefwood, gidgee, coolabah, black box; Erosional hills and rises: whitewood				

5.2.6 Groundwater–hydrogeochemistry

Despite the regional potential, there has been no documented hydrogeochemical sampling for mineral exploration applications in the Tibooburra–Milparinka region of the Thomson Orogen. Groundwater could be sampled from existing station bores and from those encountered during exploration drilling. Ideally this medium can provide broad and regular expression of buried mineralisation. Regional hydrogeochemical surveys from adjacent parts of western NSW and South Australia have provided expressions of mineralisation.

A limitation to this exploration technique may be the availability of groundwater bores, particularly within the local scale of exploration tenements. Given the range of groundwater aquifers available in the region (section 2.4) the hydrogeological context of samples would also need to be determined for the approach to be used most successfully.

6. REGOLITH EXPLORATION STRATEGIES

The following exploration strategies are recommended based on available research and results from the region. An emphasis is given to the integration of datasets both within the regolith and landscape but also with the bedrock.

The scale of exploration has a major impact on the type of exploration strategy adopted, largely because of the different spacing, efficiency and exploration expression (or 'footprint') of different techniques. Theoretically, this allows for broad-scale targets to be refined and re-assessed at more detailed scales of exploration. The strategies presented below are grouped in scales:

- preliminary framework
- regional scale
- tenement scale
- prospect scale.

6.1 Preliminary framework

At this scale or stage of exploration, a broad overview of the potential exploration targets and previous exploration is compiled. This may include 1:250,000, or more regional, geology maps, regolith-landform maps, land systems maps (available across western NSW) and remotely sensed data.

Satellite imagery derived from Google Earth is likely to provide a useful preliminary overview at this stage and, depending on the quality and type of data available, may continue to be useful at later stages of exploration. Regional geological, mineral province and regolith-landform evolution models (e.g. Anand and deBroekert 2005) should also be considered. For the Thomson Orogen region, this would particularly include incorporation of the Mesozoic and Cenozoic stratigraphy and available palaeogeographic interpretations.

6.2 Regional scale

At this scale, widely spaced data acquisition may be required: particularly if there is little previous data available. Approaches such as the fine-grained (‘overbank’) sediment sampling from drainage outlets (e.g. de Caritat and Lech 2007) may be useful. Regional sampling of most of the Thomson Orogen region in NSW has been covered by NSW DPI, partly in association with CRC LEME data acquisition. Typically, only more-detailed follow-up sampling and data acquisition may be required for use at the tenement or prospect scales. This could include sub-dividing the exploration region into smaller ‘sub-catchments’ than the larger catchments used in the de Caritat and Lech (2007) survey. Regional-scale stream sediment surveys may also be worth considering, particularly near the basin margins where bedrock-hosted or basal Mesozoic targets could have been reworked in alluvial systems (Section 5.2.1). Opportunistic sampling of regolith carbonates (Section 5.2.2; *Figure 41*), silicified regolith (Section 5.2.3) and groundwater (Section 5.2.6) may be possible if they are available in the region.

Plant sampling programs (section 5.2.5) have some potential to be applied at regional scales, particularly for trees with broad root systems that grow along alluvial systems where they can combine chemical signatures from stream sediments or groundwater. Trees such as river red gum (*Eucalyptus camaldulensis*) have been successfully sampled at 250-metre spacing to find expression of buried mineralisation near Broken Hill (Hulme 2008), and may well lend themselves to even wider spacings for larger exploration targets with large dispersion haloes. Coolibah (*Eucalyptus coolabah*) and black box (*Eucalyptus largiflorens*) may have equivalent potential for distal and overbank parts of drainage systems, but these have not been fully tested.

It is very important that samples collected on the regional scale are placed within a regolith-landform and landscape evolution context. An example of this is shown in *Figure 42*, where the Mesozoic palaeolandscape, and in particular the palaeodrainage reconstruction, helps to account for Au accumulations flanking many of the inliers. It also broadly indicates a possible Au provenance towards the west of these inliers (e.g. to the west of the Tibooburra Inlier and to the north of the Warratta Inlier along possible extensions of mineralised bedrock systems that are known from within the inlier. Wilkinson (1889) also recognised the potential for highly prospective extensions to the south of the Pioneer mineralisation, along the Wahratta

Creek valley, where there is highly weathered bedrock under alluvium). So far, there has not been any mineral exploration sampling (e.g. biogeochemistry or groundwater) or drilling to the west of these inliers to further investigate this possible Au source.

6.3 Tenement scale

At this scale, local variations and heterogeneities in landscape can become more important in dictating the type of exploration approached used. The broad landscape settings of the Thomson Orogen region and the type of exploration media likely to be suitable include:

- alluvial settings: close spaced (250–50 metre sample spacing) river red gum (*Eucalyptus camaldulensis*) and prickly wattle (*Acacia victoriae*). Possible soil and stream sediment sampling (Section 5.2.1).
- sheetwash settings: chenopod shrubs, especially black bluebush (*Maireana pyramidata*), but also bladder saltbush (*Atriplex vesicaria*), can be usefully sampled down to approximately 25 metre spacing, provided they are growing at a density to allow for this. Soil and lag sampling may be of some use, but broad lateral dispersion pathways need to be accounted for (Sections 3.3 and 5.2.1).
- aeolian settings: mulga (*Acacia aneura*) and bastard mulga (*Acacia stowardii*) can be typically sampled down to about 50 metre spacing on many sand-plains and within dune swale corridors. Soil materials tend to be exotic (Section 3.3 and 5.2.1), but locally abundant regolith carbonates may be available for closer spaced sampling (especially with the aid of a vehicle-mounted power auger).
- Weathered bedrock hills and rises: due to the ready availability of bedrock, soils and rock chip sampling may be the most efficient and effective. Where thin transported cover provides a patchy hindrance, plant sampling techniques for mulga (*Acacia aneura*) and black bluebush (*Maireana pyramidata*) may be useful (Section 5.2.5).

Depending on the exploration budgets and objectives, some of the tenement-scale targets might be appropriately tested with ground-geophysical methods (Section 5.1.2) and drilling.

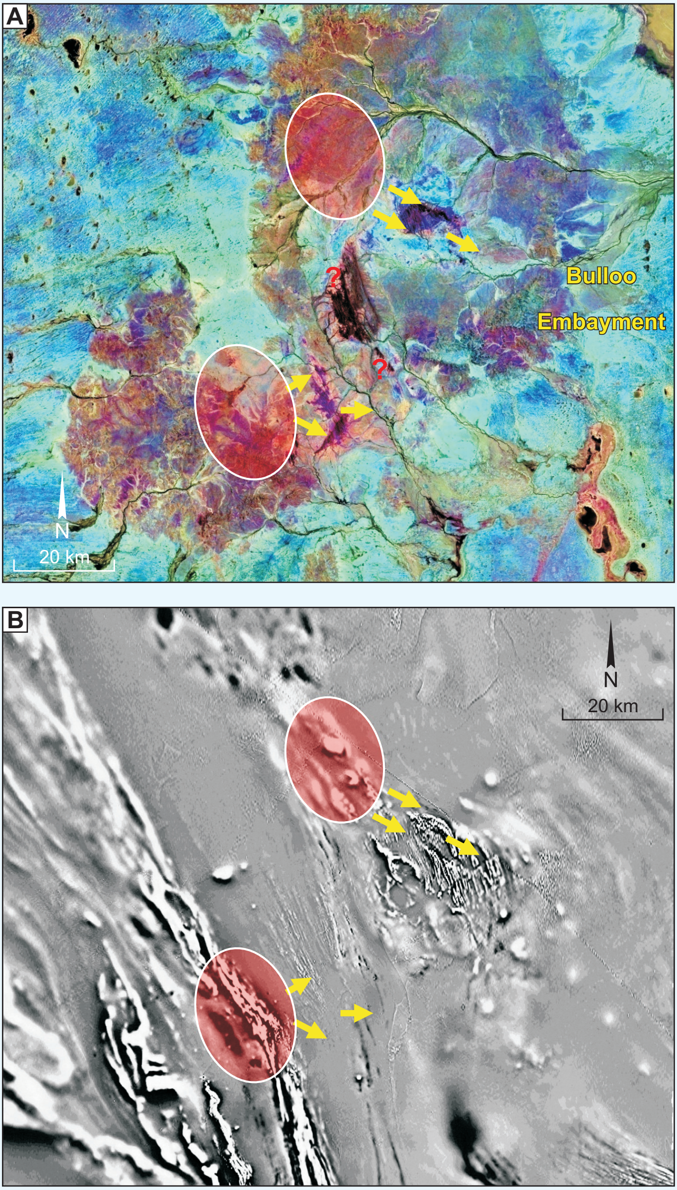


Figure 42: Regional exploration targets derived from integrated exploration research around inliers in the Tibooburra–Milparinka area.
(A) Landsat MS741, PC1 Brovey transformation image with Mesozoic palaeo-flow (yellow arrows) and possible Au provenance target areas (red ellipses).
(B) 1st Vertical Derivative airborne magnetics image of the same area showing the possible Au provenance target areas.

Local-scale refinement of regolith-landform settings and landscape evolution models is also important at this scale of exploration. Local-scale reconstructions of the Mesozoic palaeodrainage systems not only account for many of the placer Au occurrences in the area of the Tibooburra Inlier, but also suggest that others could occur near impediments to palaeo-flow, such as palaeo-ridges (*Figure 43*). Biogeochemical sampling and analysis of bastard mulga phyllodes and twigs on the leeward side of a palaeo-ridge conforming to the metamorphic aureole east of Tibooburra, contain elevated Au contents. This is consistent with the metamorphic aureole in this area forming a localised palaeo-landscape setting to 'trap' placer Au detritus.

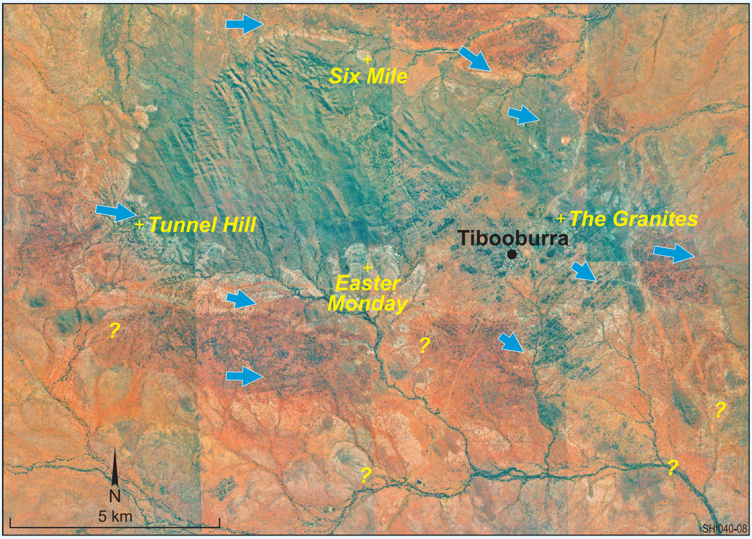


Figure 43: Local-scale exploration targets, largely derived from local-scale landscape evolution context in the area of the Tibooburra Inlier. Note how the existing basal Mesozoic hosted Au-placers are deposited immediately downstream of emergent obstructions to Mesozoic palaeo-flow (see Figure 21 for a further outline of this). Sites marked with a question mark are other possible traps that have not been tested, mostly on the leeward side of Mesozoic palaeo-flow near the contact aureole of the Tibooburra Granodiorite.

6.4 Prospect scale

Exploration at this scale should include closer spaced sampling and other approaches used at the tenement scale. For biogeochemical approaches, chenopod shrublands and many acacia groves allow for close-spaced sampling suitable at this scale. The use of drilling becomes more important at this stage, but potential inputs from drilling dust and drill spoil need to be considered if further surficial geochemical approaches are to be used in the prospect area.

ACKNOWLEDGEMENTS

The authors would like to very much thank the CRC LEME Explorer's Guide Series editors: David Garnett, Gerry Govett and Lisa Worrall. Their feedback and encouragement has been inspirational, and greatly improved the quality and coherency of this publication.

Angelo Vartesi and Travis Naughton at the Visual Resources Unit (VRU) at CSIRO, Division of Exploration and Mining, Bentley WA, are thanked for drafting many of the figures and for formatting and publishing this guide.

The research and publication of this guide has been supported by CRC LEME and NSW DPI. The NSW DPI are greatly appreciated for encouraging regolith geology research to be conducted in this region, even if this work is just the tip of the iceberg.

The residents of Tibooburra (especially staff and patrons of the Family Hotel) have been great friends and hosts during the research conducted for this guide. The landowners of the region and rangers of Sturt National Park have graciously permitted land access to many of the sites within their properties, and have shown interest and enthusiasm for reading the landscape.

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GUIDE SUMMARY AND KEY POINTS

Chapter 1–INTRODUCTION (pp. 1-6; Figures 1-3)

- Transported regolith, mostly associated with Mesozoic and Cenozoic sedimentary basins, is a major mineral exploration challenge of the region.
- Although the region is highly prospective for Au mineralisation and has potential to develop greater prospectivity for other commodities, there has been very little mineral exploration in the region.
- The Au-endowed Late Cambrian inliers exposed in the Tibooburra–Milparinka area suggest that there is potential for orogenic Au mineralisation in the region.
- Despite the widespread transported cover, the sediment depths near bedrock inliers may not be as great as previously interpreted. This provides greater hope for surficial geochemical exploration techniques, such as plant biogeochemistry, to penetrate the transported cover, such as plant biogeochemistry.
- The sedimentary basin evolution and the associated landscape history provide important contexts for mineral exploration in this region.

Chapter 2 - THE EXPLORATION ENVIRONMENT (pp. 7-30; Figures 4-17)

- The exploration environmental setting (e.g. climate, vegetation, topography and landforms, hydrology and geology) helps define the context, approaches and constraints on mineral exploration programs in the region.
- Broadly the region has an arid climate, with mostly low topographic relief and strong regolith-landform associations with vegetation communities.
- Gold mineralisation and historical mining in the Tibooburra–Milparinka area is mainly associated with three settings:
  - turbidite-hosted orogenic Au;

– Mesozoic palaeo-placers; and,
– placers associated with contemporary drainage systems.

Chapter 3 - REGOLITH MATERIALS (pp. 31-56; Figures 18-31)

- The main types of regolith materials in the region include:
  – weathered bedrock (saprolith);
  – Mesozoic marine sediments;
  – alluvial sediments associated with Mesozoic, Cenozoic and contemporary drainage systems;
  – colluvial sediments, dominated by sheetflow processes in low-relief areas;
  – aeolian sediments; and,
  – lacustrine sediments.
- Many of these regolith materials have been overprinted by induration (e.g. regolith carbonates, ferruginised regolith, silicified regolith, gypseous regolith and halite efflorescence) and pedogenic processes.

Chapter 4 - LANDSCAPE HISTORY (pp. 57-73; Figures 32-36)

- The landscape history of the region is largely a combination of processes relating to:
  – bedrock structure and lithology;
  – tectonics;
  – palaeoclimate;
  – eustacy; and,
  – anthropogenic activities.
- Bedrock structure and lithology have been a fundamental control on the landscape development, largely because of variations in weathering susceptibility of different primary mineral assemblages and the

accessibility and through-flow of weathering solutions along faults and fractures. This has also influenced the characteristics of weathering products and therefore the characteristics of weathering profiles and sediments derived from their erosion.

- Post-Mesozoic tectonic processes have a major expression in the region's landscape, particularly controlling thickness of transported cover and the erosion, deposition and weathering of bedrock and regolith materials.
- The contemporary arid climate has mostly been a feature of the landscape history since the later part of the Cenozoic. Prior to that wetter climates have characterised periods of the early Cenozoic, and colder conditions prevailed at times in the Jurassic and early Cretaceous as well as during the Permian, when there is evidence for glaciation.
- In the Early Cretaceous a marine transgression extended across much of the area, and widely deposited silts and clays with minor fine sands. These sediments effectively covered much of the bedrock in the area.
- Anthropogenic activities from both aboriginal and European settlement have had a major impact on the landscape. Introduced grazing animals (in particular rabbits) have led to reduction of vegetation cover and the localised increase in erosion and downstream sedimentation. The upper parts of many regolith profiles contain a cover of PSA related to these activities.
- The region's landscape contains remnants dating back to the Mesozoic, and possible influences from the late Palaeozoic (e.g. Permian glaciation).
- At least three major alluvial systems have been active throughout the landscape history:
- Late Jurassic - Early Cretaceous quartz-rich and minor lithic braided systems that appear to have been responsible for physical erosion and transport of Au, and its accumulation within placer deposits flanking many of the bedrock inliers. Much of this drainage appears to flow towards the Bullo Embayment depocentre to the east of Tibooburra–Milparinka;

– early Cenozoic quartz and kaolin dominated pebbly to sandy meandering and braided fluvial systems associated with the Eyre Formation; and,

– the contemporary alluvial systems that are mostly lithic dominated near inliers and quartz and kaolin dominated in basin areas. These have reworked and locally concentrated earlier vein and placer Au deposits.

Chapter 5 - REGOLITH IN MINERAL EXPLORATION (pp. 75-100; Figures 36-41)

- Regolith-landform maps provide an important initial context and framework for regolith materials within the region. They are therefore an important component of mineral exploration programs in regolith-dominated terrains.
- A range of remotely-sensed data, including geophysics, are ideal at characterising and spatially defining many regolith materials. Interpretations of these data can be later field-checked.
- Surface geochemical exploration techniques are greatly challenged by the widespread and abundant transported cover. This cover may be geochemically distinct from the underlying prospective bedrock and instead carry exotic and modified geochemical signatures.
- Soils and stream sediment are of limited value when the transported cover is greater than 1 metre thick. Regionally they may provide a broad geochemical expression, especially if carefully related to defined catchment areas.
- Regolith carbonates are widespread but not locally abundant enough to be a major local-scale exploration sampling medium. They show value as an opportunistic regional sampling medium and have provided strong geochemical expressions of areas of known Au-mineralisation in the Tibooburra–Milparinka area.
- Ferruginised and silicified regolith have not been widely tested for geochemical exploration in the region. There are a range of types of these materials that have formed in distinctly different regolith

and landscape settings. Silicified fine to medium sands associated with palaeodrainage sediments have shown potential to express Au-mineralisation and dispersion in the area of the Tibooburra Inlier.

- Plant biogeochemistry shows great potential for providing surface expressions of the geochemistry of buried substrates. The type of plant species sampled depends mostly on the regolith-landform setting for the exploration and may include:
  - mulga and bastard mulgas on shrublands on aeolian sandsheets and dune swales;
  - black bluebush and possibly bladder saltbush within chenopod shrublands on sheetflow-dominated plains and rises;
  - river red gums and possibly prickly wattle, coolibah or black box in riparian woodlands; and,
  - mulgas or possibly whitewoods within mixed open woodlands on weathered bedrock.
- Hydrogeochemistry may have potential as a regional sampling medium, particularly within the areas of artesian aquifers associated with the Eromanga Basin sediments. Samples could be taken from water bores, where available, or else from exploration drillholes if water in encountered.

Chapter 6 - REGOLITH EXPLORATION STRATEGIES (pp. 101;106 Figures 42-43)

- A range of mineral exploration strategies are recommended based on available research and results from the region. These are primarily influenced by the scale of exploration and then the regolith-landscape setting.
- At the regional scale components such as geophysical data acquisition, low-density geochemical and biogeochemical surveys and palaeogeographic reconstructions are required. Much of these data are already available through NSW DPI and in part through its association with CRC LEME.
- For tenement scale exploration the development of tightly defined

surveys and palaeogeographic reconstructions can become important. The preferred sampling media for geochemical and biogeochemical surveys will greatly depend on the regolith setting and the associated availability of different media.

- Exploration at the prospect scale can further refine techniques previously employed, such as closer spaced biogeochemical sampling. Drilling also becomes an important component of this phase of exploration.

CRC LEME EXPLORERS' GUIDE SERIES

Objective: This series is about regolith; the layer of weathered material between fresh rock and fresh air that blankets much of Australia. More specifically, it is about using regolith indicators to help identify mineral deposits in regolith-dominated terrains.

Mineral exploration is unpredictable at best. Of the thousands of prospective sites evaluated each year only a very small percentage are promising enough to justify follow-up work, and of those only a handful will yield economically viable mineral deposits. Intelligent and informed exploration – incorporating a comprehensive understanding of regolith types and processes - shortens the odds in favour of the explorer and increases the chances of success.

The **Thomson Guide** has six parts:

- Introduction and exploration challenges
- The exploration environment
- Regolith materials
- Landscape history
- Regolith in mineral exploration
- Regolith exploration strategies.

There is a guide summary and key at the back for quick reference to relevant sections, as well as a CD with extra information

The CRC LEME Explorer's Guides include:

A guide for mineral exploration through the regolith in the Cobar region, Lachlan Orogen New South Wales

A guide for mineral exploration through the regolith in the Curnamona Province, South Australia

A guide for mineral exploration through the regolith of the central Gawler Craton, South Australia

A guide for mineral exploration through and within the regolith in the southwestern Thomson Orogen, New South Wales

A guide for mineral exploration through the regolith in the Yilgarn Craton

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