CRCLEME
Cooperative Research Centre for
Landscape Evolution & Mineral Exploration

OPEN FILE REPORT SERIES

WONNAMINTA REGOLITH-LANDFORMS

D.L. Gibson

CRC LEME OPEN FILE REPORT 114

November 2001

WONNAMINTA
REGOLITH-LANDFORMS

D.L. Gibson

CRC LEME OPEN FILE REPORT 114

November 2001

CRC LEME is an unincorporated joint venture between The Australian National University, University of Canberra, Australian Geological Survey Organisation and CSIRO Exploration and Mining
Headquarters: CRC LEME c/o CSIRO Exploration and Mining, PO Box 1130 Bentley, Western Australia, 6102

Copies of this publication can be obtained from:
The Publication Officer, c/- CRC LEME, CSIRO Exploration and Mining, P.O. Box 1130, Bentley, WA 6102, Australia. Information on other publications in this series may be obtained from the above or from http://leme.anu.edu.au/
Cataloguing-in-Publication:
Gibson, D.L.
Wonnaminta Regolith-landforms
ISBN 0 643 06772 8
1. Regolith - New South Wales, 2. Geochemistry. 3. Landforms - New South Wales
I. Title
CRC LEME Open File Report 114.
ISSN 1329-4768

Addresses and affiliations of authors

David Gibson
Cooperative Research Centre for Landscape
Evolution and Mineral Exploration
c/- Geoscience Australia
PO Box 378
Canberra, ACT, 2601
Australia

PREFACE AND EXECUTIVE SUMMARY

The Wonnaminta regolith-landform mapping project was carried out to provide regolith information over part of the Koonenberry Belt, a little-explored area of late Proterozoic to mid-Palaeozoic rocks in western NSW over which there has been only minimal investigation of regolith prior to this study. The area was chosen firstly as Staff of the NSW Department of Mineral Resources were carrying out detailed bedrock mapping in the area, and a regolith-landform map would complement their work. Secondly, the area is bordered by sediments of the Mesozoic Eromanga Basin, and provides an area where the regolith expression of the interaction between basement rocks and basin sediments could be studied.

This report and the accompanying map provide information on the regolith, landforms, aspects of Mesozoic to Recent history, and potential geochemical sampling media of the area, gathered and deduced during and after a short field-mapping exercise.

Scattered rises of Mesozoic and possibly younger sediments are present as outliers over much of the area. The intervening low relief areas, formed mostly on highly weathered bedrock, are interpreted to have been eroded a maximum of a few tens of metres below the original Mesozoic unconformity. A stony surface mantle characterises these low relief areas; part of this mantle is derived from silica- or iron oxide-cemented sediments that are no longer preserved *in situ*. This has important implications for traditional "lag" geochemical sampling.

Resistant Devonian sandstone forms two ranges in the area. At least one, and probably both were present as topographic highs in part of the Mesozoic, subsequently covered with Mesozoic sediment, and then exhumed by preferential erosion of the sediment to produce the contemporary landform. This implies very slow erosion of upland areas of these more resistant rocks, and highlights the importance of exhumation of landforms in the landscape evolution of the area.

David Gibson

CONTENTS

LIST OF FIGURES

ABSTRACT

The Wonnaminta regolith-landform map is a product of the first attempt at 1:100 000 scale regolith mapping within the Koonenberry Belt, an inlier of dipping late Precambrian to Devonian basement rocks northeast of Broken Hill in far western NSW. The map and this report have been produced to show the range and distribution of regolith materials present in an area where basement rocks are overlain by the remnants of a veneer of Mesozoic Eromanga Basin sediments, and to document known aspects of regolith and landform history of the area. Relief is generally low, apart from ranges and plateaux of Devonian sandstone and several steep low hills of Eromanga Basin sediments. Most pre-Devonian basement rocks and the Mesozoic sediments have been deeply weathered. Outcrop of pre-Devonian rocks over much of the area is limited to saprolite exposed in watercourses incised into erosional plains and rises, which are dominated by a stony mantle over desert loam soils. This mantle is considered to be colluvial rather than residual lag, as it includes fragments that have not originated from the underlying rocks (eg cemented fragments of now-removed sediment), and in some areas has clearly been transported. Some of the basin sediment has been silcreted, resulting in local cappings of *in situ* silcrete and extensive areas of a mantle of silcrete fragments over both sediment and basement saprolite. Cementation of sediments is by iron compounds is also locally important. Aeolian deposits dominate the southern part of the area.

Relatively resistant Devonian sandstones make up two areas of high relief within the area, the Turkaro Range and Koonenberry Mountain. Analysis of these landforms and their relationships with the adjacent sediments suggests that at least the former, and probably both features were present in the Mesozoic, buried beneath Jurassic to Cretaceous sediments, and exhumed by differential erosion after lowering of relative base levels in the area by regional post-sedimentation warping. It is also interpreted that bedrock has been eroded to a maximum of a few tens of metres below the Mesozoic landsurface over most of the area.

Few metallic mineral occurrences have been recognised in the area. Possible geochemical sampling media for future exploration include surface stony materials, soil, stream sediments, regolith carbonate, ferruginous saprolite, rock chips, and silcrete. Ferruginous surface fragments are locally common, comprising one or more of the following: ferruginised basement saprolith, fragments of quartz-iron oxide veins from basement rocks, ferruginous silcrete, iron-cemented sediment, and magnetic "buckshot" gravels. The last are interpreted to probably be derived from the weathering of both Mesozoic and basement materials. The variety of surface ferruginous material present implies that sampling of undifferentiated surface ferruginous material may lead to erroneous geochemical results. Soil and stream sediments are likely to have an aeolian component that will dilute any bedrock geochemical signal. Silcrete has most probably formed exclusively in cover sediment, and is thus not presently considered to be a useful sampling medium for basement mineralisation. Regolith carbonate is present in many soils in the area. There has been no investigation of this as a potential gold exploration sampling medium. It is possible that the basal Mesozoic sediments could be used as palaeo-stream sediment samples. However, there are few exposures of cross-bedded sandstone that could be used to determine Mesozoic palaeocurrent directions, so this technique might only give a general indication of mineralisation.

1. INTRODUCTION

1.1 Location and geology

The Wonnaminta 1:100 000 sheet area covers part of the northern Koonenberry Belt, between 30°30' and 31°00' S and 142°00' and 142°30' E in northwestern NSW (Fig 1). All grid references in this report and the accompanying map use the WGS 84 grid as a surrogate for GDA 94. These have a displacement of about 214 m in a NNE direction from the AGD 66 grid. The ground footprint of the map is thus slightly NNE from that of maps of the sheet area produced using the AGD 66 datum.

The homesteads of Marrapina, Koonawarra, Kara, Nundora, Nuntherungie, and Wonnaminta pastoral leases are the only centres of permanent habitation. Access to the area is via formed earth roads connecting the Silver City Highway with the opal-mining centre of White Cliffs to the southeast. Reasonable access through much of the area is afforded by station tracks. However, vehicular travel away from tracks is in many places made difficult by numerous incised gullies, dense saltbush (threat of tyre puncture), or loose aeolian sand. Many soils in lower relief areas quickly become soft during rain, making even main road access difficult. The dry beds of some creeks are trafficable by 4WD vehicles. All homesteads are connected to the telephone network via a radphone tower on the southwest peak of the 'Three Hills' between Wonnaminta and Kara homesteads, and a remote area 240 V power grid.

The area consists mostly of erosional plains and rises on variably weathered steeply dipping late Precambrian to early Palaeozoic basement rocks (mostly low-grade metasediments with some metavolcanics), with some low hills and hills of resistant less deformed Devonian quartzose sandstone (Fig 1). The bedrock geology of the area is described by Mills (1992), with updates provided in papers from Broken Hill Exploration Initiative Meetings (eg Mills & Hicks, 2000). A preliminary 1:250 000 scale basement map was published by Mills (1997). Areas of Mesozoic sediments in the far NW and NE of the area are part of the main Eromanga Basin (Brunker, 1967), and there are many scattered outliers of similar sediment in small silcrete-capped mesas and larger stony rises and low plateaux scattered across the area. Mesozoic plant fossils have been collected in some larger exposures of sediment at the 'Three Hills' between Wonnaminta and Kara homesteads, roughly in the centre of the sheet area (Brunker, 1967). In this report it is assumed, but by no means proven, that all sediment outliers in the area are Mesozoic. A veneer of aeolian sand dominates the low relief southern part of the area, masking underlying geology. A well-formed intermittent drainage system with associated alluvium is present over most of the area. After heavy rain, water flows via this system to local depocentres in sandplains north and west of the area.

1.2 Climate and vegetation

Climate is hot and arid, with much of the highly variable rainfall falling during summer and winter storms. Bell (1972) gives a detailed account of climate of the area, and Macdonald (2000) presents a review of climate at Fowlers Gap Field Station, about 30 km to the west-southwest. Vegetation consists mainly of saltbush and bluebush with grasses, forbs and copperburrs in the erosional plains and rises, with some mulga *(Acacia aneura)* and other small trees. White cypress pine (*Callitris columellaris)* and belah (*Casuarina cristata*) are common in areas of aeolian sand. More rugged areas of Devonian sandstone are characterised by mulga and grasses, with white cypress pine on Koonenberry Mountain. River gums (*Eucalyptus camaldulensis*) are present along larger drainage lines. Natural vegetation has been significantly affected by grazing by introduced domestic animals and rabbits (Bailey, 1972). All of the area is used for low intensity grazing on pastoral leases. Details of vegetation are provided by Milthorpe (1972a,b) and Walker (1991).

1.3 Previous work

Previous work relevant to regolith studies in the area include the Cobham Lake 1:250 000 geological sheet and explanatory notes (Brunker & O'Connell, 1967; Brunker, 1967), and the Cobham Lake

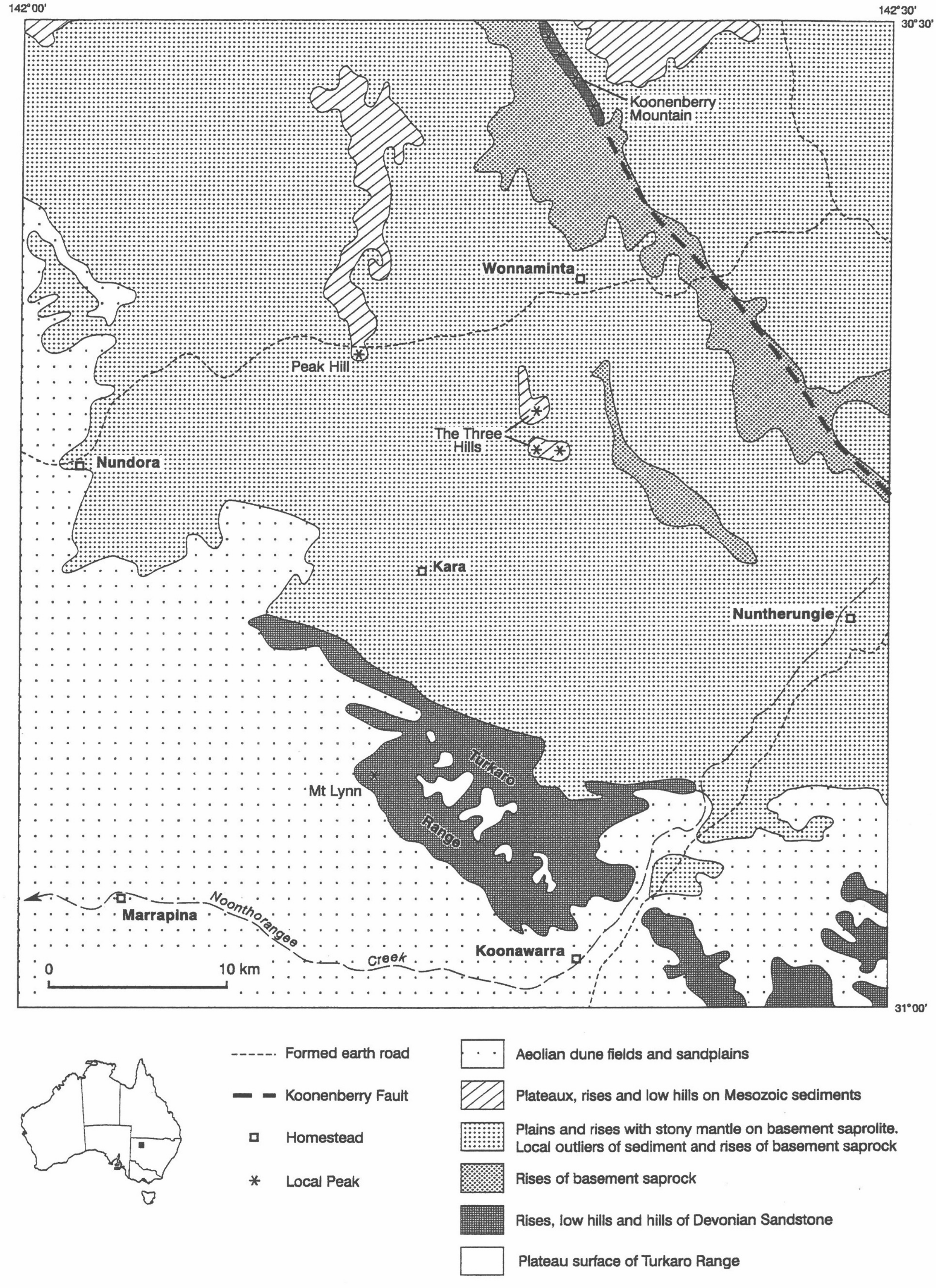


Figure 1. Locality and major regolith divisions of the Wonnaminta 1:100 000 sheet area

1:250 000 Land Systems Series Sheet and Explanatory Notes on the Land Systems of Western NSW (Soil Conservation Service of NSW, 1980; Walker, 1991), which partly used data from an earlier land system study (Corbett *et al.*, 1972; Mabbutt, 1972; Corbett, 1972). The area forms part of the Broken Hill 1:500 000 regional regolith landform map (Gibson & Wilford, 1996; updated by Gibson, 1999 and Gibson & Wilford, 1999), which was based on collation of existing information and photointerpretation with minimal field checking. Neef (1998) presents ideas on the Mesozoic to Recent landscape history of the area. Early results of this survey are given by Gibson (2000a).

1.4 Work objectives

The objective of this study was to produce a first pass 1:100 000 regolith-landform map and investigate aspects of landform history in an area where the interaction between regolith associated with basin sediments and underlying basement could be studied, as part of the CRCLEME Basins Program. A secondary objective was to produce a map which would complement a 1:100 000 solid bedrock geology map of the sheet area being produced by staff of the NSW Department of Mineral Resources based in Broken Hill (K. Mills and M. Hicks) as part of a detailed survey of the Koonenberry Belt. Samples were not taken for laboratory analysis. However, it is considered that the map and report will help future detailed investigations of regolith in the area by providing a spatial framework for regolith components.

1.5 Study methods

The mapping was based on airphoto interpretation with ground checking to provide information on regolith components. Regolith-landform mapping units and their associated regolith components were identified after about 8 days field work and initial photointerpretation. Polygon boundaries, drawn on overlays to 1:50 000 colour aerial photos after detailed photointerpretation, were compiled onto drafting film over 1:50 000 paper prints of the topographic base which was prepared by a consultant especially for the bedrock mapping. The polygons were then scanned, vectorised and warped to give a true spatial coverage. Detailed integration of data from gamma ray spectrometric surveys and satellite imagery was not attempted due to time constraints and the need for further field checking of various responses. However, there is general agreement between the remotely sensed data and the polygons presented on the map. For example most blue-green areas on the gamma ray spectrometric image (K, U and Th as red, green and blue) on the map (i.e. relatively high thorium and uranium, and low potassium) correspond to mapped polygons of the unit *SPer3*, which is characterised by a dominantly ferruginous stony mantle. Details of all mapping units are recorded in the AGSO regolith database.

2. DESCRIPTION OF REGOLITH MATERIALS

Information provided on regolith is mostly from the author's observations, combined with data from the Cobham Lake land systems 1:250 000 sheet (Soil Conservation Service of NSW, 1980) and explanatory notes (Walker, 1991). Further detailed information on regolith materials is included in section 3 on regolith-landform mapping units.

2.1 Transported regolith

2.1.1 Alluvial sediments

Alluvium is present along modern watercourses. The sediment consists mainly of red-brown fine clayey sand to sandy clay with gravel beds. Exposed sections of more than 2 m of alluvium are rare. Channels are typically incised, with a bed load of sand and gravel with minor silt, generally forming a reticulated network. Some trees growing in or beside the channels have much of their root system exposed, suggesting that the channels have migrated or incised rapidly. The top layer of alluvium exposed in some gully banks is silty with poor soil structure, and may postdate introduction of stock to the area (post-settlement alluvium). If this is the case, many gullies may have developed since this time. However, Wakelin-King (2000) has studied Fowler's Creek to the west of the area and found that similar deposits range in up to >5ka. Small rounded magnetic ferruginous fragments (most likely containing maghemite) make up some of the gravel clasts in alluvium along Noonthorangie Creek, resulting in small amplitude short wavelength magnetic anomalies in regional airborne magnetic data.

2.1.2 Aeolian sediments

Aeolian dunefields (both longitudinal and irregular dunes are present) in the southwest of the map area extend westward to modern depocentres in the central part of the Bancannia Trough (various unnamed swamps, and Bancannia Lake - see Soil Conservation Service of NSW, 1980; Gibson & Wilford, 1999). These and the adjacent alluvial plains have been a source for sand that has been blown into the area mostly by westerly to southwesterly winds. Original sources of the sand are probably both the northern parts of the Broken Hill Block to the west of the Trough, and the local area. In many areas of the dunefield there appears to be only a veneer of aeolian sand, overlying weathered bedrock or Mesozoic sediments; no thickness data are available.

Sandsheets in the southeast of the area have probably originated from the aeolian transport of sand derived from Devonian sandstone in the area. Crescent-shaped lunettes adjoin two larger claypans in the far west of the area. Thin veneers of aeolian sand are also locally present over erosional areas in the northwest of the area. Source-bordering dunes are present along some creeks. The sand grains in aeolian deposits are generally stained red with iron oxides.

2.1.3 Colluvial sediments

Coalescing colluvial fans and colluvial footslopes are present around hills of Devonian sandstone. The colluvium present ranges from boulders that have fallen from precipitous slopes, to sandy sheetwash sediment. The sediment has at least locally been cemented by regolith carbonate, which also occurs as a layer over the underlying saprock. The lower slopes of Koonenberry Mountain are characterised by boulder scree deposits that have been locally topographically inverted (see description of unit *SSeh1* below).

A stony mantle of silcrete fragments is associated with areas of Mesozoic sediment, and is also present on the plateau surfaces of the Turkaro Range. The fragments are dislocated downslope from their *in situ* source (which in some cases has actually been totally removed by erosion), and thus the mantle is considered to be colluvial, with transport probably by a combination of gravity, sheetwash and biological processes. The mantle of silcrete fragments on the Turkaro Range is unrelated to the underlying Devonian sandstone. Similarly, the stony mantle of mostly basement-derived material that covers most of the lower relief erosional areas over basement rocks is likely to be colluvial. Dispersion of fragments of resistant basement-sourced material away from outcrops is clearly visible, with watercourses locally marking the junction between mantles with different clast types.

The extent of the dispersion of surface fragments may be quite large. K. Mills (Geological Survey of NSW, pers. comm. 2001) has noted that in the area southeast of Koonenberry Mountain, shales of the Watties Bore Formation (Kayrunnera Group), which occur northeast of the Koonenberry Fault do not host milky quartz veins, whereas the Ponto Beds which form higher country to the southwest are extensively veined. However, a stony mantle of angular milky quartz fragments characterises plains and rises on the Watties Bore Formation. It is interpreted that this mantle has been derived from areas of Ponto Beds southwest of the fault, and represents sheetwash deposits derived either directly from the higher areas, or possibly from dispersion of now-eroded topographically inverted alluvial deposits derived from the west.

It is not certain whether the stony mantle as seen today is an entirely natural phenomenon, or has been accentuated relatively recently by soil loss due to aeolian winnowing following the introduction of grazing animals and rabbits, which had a marked effect on natural vegetation (Bailey, 1972). Early stocking rates were as high as 32 sheep per 100 ha around 1894, about three times higher than modern stock levels (Milthorpe, 1972b).

Components of the mantle include fragments of milky quartz and quartz-iron oxide veins, resistant bedrock (mostly quartzite), ferruginised saprolite (both basement and sediment), silcreted sediment (most probably all Mesozoic) which is ferruginous in part, rounded clasts exhumed from Mesozoic conglomerates, and small rounded magnetic ferruginous fragments. Proportions of these components vary with location.

Fine sheetwash sediments are present in swales in dunefields, and in lower parts of low relief erosional landscapes.

2.1.4 Lacustrine sediments

Lacustrine sediments are present in claypans mostly in the dunefields in the southwest of the area. Fine sediment predominates.

2.1.5 Soils

Soils form a mobile layer over sediment or saprolith. Details of soils are included in the descriptions of individual map units; Corbett (1972) and Walker (1991) give more information. There is a major distinction between stony lithosols present in areas of higher relief over saprock, and desert loams and clay soils over more weathered material. The loams are generally calcareous and gypseous, and there is partitioning of microtopography, soil and vegetation into zones roughly parallel to topographic contours (tiger stripe or contour banding – see section 3.2.1 below).

2.1.6 Hardpan

Many scree slopes below local ridges with silcrete outcrop or lag have a partly cemented hardpan developed in colluvial material. Erosion appears to have proceeded rapidly where the hardpan is breached, giving rise to smooth scree slopes punctuated with erosional scars. Composition or origin of the cement in the hardpan is not known.

2.2 *In situ* regolith

In situ regolith consists of saprolith and residual materials. Saprolith (weathered rock) is a product of isovolumetric weathering, and is subdivided into saprolite (more than 20% of labile minerals weathered) and saprock. Residual materials include collapsed or disrupted saprolite and residual lag. The stony mantle across much of the area of basement rocks is considered to have moved laterally by sheetwash (see above), or to have originated as part of the eroded former Mesozoic sediment cover, and is thus not classed as residual lag. The weathered Mesozoic sediments are treated as saprolite rather than regolith sediment, as they are part of an eroded basin sequence. The weathered sediments have been locally cemented by silica to form silcrete, and both weathered sediment and basement saprolite have been locally cemented by iron oxides.

2.2.1 Saprolite

Various rock types have differing susceptibility to weathering. Most older basement rocks, particularly more feldspathic rocks, have been highly weathered, and are mechanically weak, leading to erosion to produce low relief landforms. Depths of weathering are not known. Mesozoic sediments where not cemented by iron oxides or silica are generally highly weathered and mechanically weak. In an area in the far northwest of the sheet, the Mesozoic saprolite is mottled. No evidence has been found for a specific period of deep weathering in the area. Erosion of saprolite, which is in many cases mechanically very weak, has been slowed by the generally low stream gradients over the area (a product of drainage graded to relatively high base levels in local drainage sumps), and stony mantles which protect the underlying materials from wind ablation and sheetwash erosion.

2.2.2 *Cemented saprolite*

Silcrete

Silcrete is common across the area. Most silcrete in the area results from cementation by silica of material with rounded quartz granules or pebbles (which are not a component of the basement rocks). This indicates that they have formed in sediment rather than basement-derived saprolite. No definite silcreted saprolite of basement rock has been recognised by the author in the area; however silcreted basement saprolite has been described in the Xmas Tank area 7 km to the east of the map area beneath silcreted sediment (Gibson & Wilford, 1999a,b). The host sediment for silcrete in the sheet area varies from mudstone to boulder conglomerate. It is assumed, but by no means certain, that Mesozoic sediments form the host for all silcrete in the area. Some silcrete occurs as recognisable pods or lenses within or at the base of the Mesozoic sediments. However, silcrete is now preserved mainly as a surface layer of loose clasts, even on pinnacles and mesas that appear from a distance to have a solid capping. The *in situ* silcrete is not necessarily confined to one horizon or level, as might be expected if it formed at a low relief palaeo-landsurface, such as the 'Cordillo surface' of Wopfner *et al.* (1974), as is suggested by Neef (1998) and Neef *et al.* (1995) for the Koonenberry and Fowlers Gap areas. For example, loose boulders of silcreted sediment are present on the crest of the most northern of the 'Three Hills' (i.e. the original *in situ* silcrete must have occurred at a higher elevation) (fig 18), but silcreted sediment also crops out on low mounds near the base of the hill, around 40 m below and less than 1 km distant from the crest. This and other exposures of *in situ* silcrete on slopes below plateau surfaces that have a mantle of loose silcrete clasts strongly suggests that the silcrete formed at various levels within the sediment during or after weathering, but prior to the shaping of the contemporary land surface. It is probable that preferential erosion has been an important factor in the development of landscape, with both silcrete outcrop and areas with a dense mantle of silcrete fragments protecting mechanically weak materials below from erosion. The actual mechanism of formation of the silcrete by the cementing of host sediment, its depth beneath the surface at the time of silcreting, and the timing of cementation remains unclear. Some silcretes in the area display vertical columnar structures. Thiry & Milnes (1991) describe similar rocks in the Stuart Creek opal field in South Australia as 'pedogenic silcrete' and massive silcrete as 'groundwater silcrete'.

Ferruginised saprolite

Saprolite of both Mesozoic and basement rocks has been locally ferruginised to form hard, iron rich rocks. Ferruginisation has generally occurred along specific beds in the Mesozoic sediments. Similar ferruginised sediments from the Fowlers Gap area to the southwest contain up to 70% Fe_2O_3 (Hill & Gibson, 1998). Iron oxides have precipitated both along joints and as irregular zones within basement saprolite. K. Mills (Geological Survey of NSW, pers comm 2000) has observed irregular zones of ferruginisation at the unconformable contact between Mesozoic sediments and basement saprolite in the Williams Peak area, east of the map area.

2.2.3 *Saprock*

More resistant older basement rocks such as quartzite, and siliceous rocks of the Ponto Beds (generally forming a band to the southwest of the Koonenberry Fault) are little-weathered, and classed as saprock. Quartzose Devonian sandstones are generally also only slightly weathered, with ferruginous staining and a hardened surface patina developed in many areas. Quartz and to a lesser extent quartz/iron oxide veins are extremely resistant to chemical weathering. However, they are brittle, and physically break down to fragments of mostly less than 10 cm.

2.2.4 *Residual clay*

Some rises, especially in the vicinity of Kara homestead, have a cap of silcreted sediment (either *in situ* or as loose fragments) overlying gypseous, bleached, powdery clay. Gypsum is present as both powdery masses and coarse bladed crystals. The clay is probably residual to saprolite of either basement shale or Mesozoic mudstone. Some exposures of basement saprolite grade into similar gypseous clay lacking the bedrock fabric that is present in the saprolite; this residual material most probably results from disruption of original rock fabric by gypsum growth.

2.3 Precipitated regolith

This includes precipitated silica, iron oxides, salts and carbonates. The first two are present as cement in cemented saprolite (section 2.2.2 above).

2.3.1 Gypsum

Gypsum is common in soils, and is also locally present in saprolite of both basement rocks and Mesozoic sediment. Both powdery gypsum and coarse crystals to 10 cm are present. Gypsum growth has sufficiently disrupted some saprolite to form residual gypseous clay (see above). The origin of sulphur in gypsum is unclear. Basement units and fresh Mesozoic mudstone are pyritic, and would release sulphur when weathered. Sulphur might also be introduced to the area in salts in dust and rain. Study of sulphur isotopes might indicate the primary sources for the sulphur.

2.3.2 Regolith carbonate

Most soils in the area contain regolith carbonate, with concentrations up to 50% in soils over calcareous shales (Corbett, 1972). The carbonate is largely powdery, but is also present as a solid horizon over saprock in some areas of Devonian sandstone. In some areas, carbonate occurs in soils over calcium deficient quartzose rocks (eg Devonian sandstone), and thus the calcium cannot have originated from the underlying bedrock. It may have been introduced to the area via salts in rain and dust, and redistributed through biologic activity, solution and physical transport of eroded carbonate in modern sediments.

3. REGOLITH-LANDFORM MAPPING UNITS

Data provided below on regolith and landform are mostly from the author's observations, combined with soil and vegetation information from the Cobham Lake land systems 1:250 000 sheet (Soil Conservation Service of NSW, 1980) and Walker (1991). Mapping units are grouped into those dominated by depositional or erosional regolith, with subgroups within each of these groups. As regolith is in many cases layered, and as there is lateral variation of regolith within landscapes, each mapping unit has a variety of associated regolith types. Mapping units have been differentiated on the basis of both major and minor components of regolith present, landform, and airphoto texture. Letter symbols for map units are made up of upper case letters that delineate the major regolith type present, and lower case letters which correspond to the dominant landform present. A digit attached to the symbol allows several similar units with minor differences in regolith to be distinguished. Letter symbols used are:

Regolith

A alluvial sediments	L lacustrine sediments
IS aeolian sand	SP saprolite
C colluvial sediments	SS saprock

Landforms

ap alluvial plain	ep erosional plain (0-9 m local relief)
ud dunefield	er erosional rise (9-30 m relief)
ub source-bordering dune	el low hill (30-90 m relief)
us aeolian sand sheet	eh hill (90-300m relief)
uu lunette	
fc colluvial fan	
pp playa plain (claypans)	

3.1 Units dominated by transported regolith

3.1.1 Alluvial sediments

Aap1: undifferentiated alluvium

Mappable areas of alluvial sediments comprise this unit. The sediments are present in zones along modern watercourses in backplains, levees and channels (Fig 2). Minor aeolian sand is also present within *Aap1* in localised small source-bordering dunes. Regolith carbonate concentrations are also locally present. Saprolith is locally exposed beneath alluvium in some gullies. This unit is equivalent to the Fowlers land system of Walker (1991). Soils are red-brown texture contrast soils, brown clays and red earths. Vegetation includes black bluebush and Mitchell grass on backplains, bladder saltbush on levees, with short grasses and copperburrs after floods or rain, and river red gums along channels.

Unmapped small areas of alluvial sediments are also present as a minor component of the regolith in most map units throughout the area.

Figure 2. Alluvial channel with exposure of dipping saprolite beneath alluvium (unit *Aap1*). The top (lighter coloured) layer of alluvium in the channel bank has poor soil structure and was probably deposited prior to incision of the channel, possibly after introduction of grazing animals to the area. Note exposed roots of the older tree (*Eucalyptus camaldulensis*) in channel, indicating channel deepening or migration. 54J 622855 E 6586657 N

3.1.2 Aeolian sediments

ISer1: locally derived aeolian sand sheets on erosional rises

This unit is characterised by a veneer of sand over Devonian sandstone in erosional rises and plains in the southeast of the area, and is broadly equivalent to the Tekum Land System of Walker (1991). This is described as being dominantly a sandplain, with footslopes and low rises of sandstone with relief to 15 m, extensively overlain by Quaternary sand. The sand is most probably derived by weathering and erosion of the underlying sandstone, but is subject to severe windsheeting and drift. Thus in this study the sand is classed as aeolian, but differs from unit *ISud1* (below) as the sand has a local source, and is generally not organised into dunes. A winnowed stony lag of sandstone fragments is locally present. Soils consist of sandy red earths and calcareous loamy soils. There is little organised drainage. Vegetation consists of scattered mulga and other shrubs, with speargrass, copperburrs, and other grasses and forbs.

ISub1: source-bordering dunes

Source-bordering dunes of mappable size identified during photointerpretation make up this unit. The mapped dunes have not been field checked, but most probably consist of sand blown from adjacent creek beds, similar to small unmapped areas of source-bordering aeolian sand within unit *Aap1* that were observed during field checking.

ISud1: dunefields

Most of the aeolian sand in the area has been mapped as unit *ISud1*, which encompasses reticulate, irregular and longitudinal dunes with intervening interdune flats and small unmapped claypans (fig 3). There is a general east to northeast trend in dune crests. This unit is equivalent to the Nucha (irregular to longitudinal dunes) and Marrapina (reticulate dunes) land systems of Walker (1991). Aeolian sand is present in dunes up to 6 m high. Small claypans with clayey sediment are locally common, and interdune flats and swales locally have surface fragments of regolith carbonate nodules and rarer clasts of sandstone with carbonate coating. Minor alluvium is present along creeks originating in erosional areas to the north and east, and terminal floodout zones from these. Depth to underlying saprolith is unknown, but most likely variable. Red sands and sandy earth soils are present on dunes, red earths, calcareous sandy loams and loamy sand texture contrast soils on flats, and brown clays in pans. Vegetation consists of mulga and other shrubs, belah, white cypress pine, and grasses and forbs. Black box (*Eucalyptus largiflorens*) locally fringes claypans.

Figure 3. Longitudinal sand dune with White Cypress Pine trees (*Callitris columellaris*). Unit *ISud1*. 54J 602651 E 6576023 N

ISus1: small aeolian sand sheets

Small areas of aeolian sand present as thin sheets on saprolite plains have been mapped in the northwest of the area (fig 4). The sand appears to have buried the stony mantle that is present in adjoining areas. Belah is locally present, as well as grasses and forbs.

Figure 4. Small, thin aeolian sand sheet overlying saprolite with stony mantle (in foreground) (unit *ISus1*). Note scattered Belah (*Casuarina cristata*) trees. 54J 602489 E 6617105 N

ISuu1: lunettes

Two crescent-shaped lunettes adjoining claypans in the far west of the area have been mapped through photointerpretation. Walker (1991) states that lunettes in the general area (one of the components of his Cobham land system) have brown compact clayey sand soils, with calcareous sandy loams on scalded (eroded) surfaces.

3.1.3 Colluvial sediments

Cfc1: colluvial fans and footslopes

Coalescing colluvial fans and colluvial footslopes mostly adjacent to low hills of Devonian sandstone form this unit. It is equivalent to the footslope component of the Kara Hills land system of Walker (1991). The colluvium includes boulders fallen from precipitous slopes, creep deposits and sandy sheetwash sediment. The sediment has at least locally been cemented by regolith carbonate, which also occurs as a layer over the underlying saprock (Figure 5). Soils range from lithosols to massive yellowish red calcareous loamy sands. Vegetation includes mulga, white cypress pine, and grasses and forbs. At Koonenberry Mountain, the areas of colluvial sediments have been included within the saprolith-dominated polygons *SSeh1* and *SSer1* in the area as they are too small to show individually at map scale.

Figure 5. Regolith carbonate hardpan developed over saprock in a small gully on a colluvial slope at the margin of the Turkaro Range. Unit *Cfc1*. 54J 613496 E 6590679 N

3.1.4 Lacustrine sediments

Lpp1: claypans

Lacustrine sediments are present in claypans mostly in dunefields in the southwest of the area. Only the larger claypans have been mapped. These form part of the Cobham land System of Walker (1991). Fine sediment predominates, with brown crusty or cracking clay soils. Vegetation includes canegrass, copperburrs, grasses and forbs. Smaller claypans are included within unit *ISud1*.

3.2 Units dominated by *in situ* regolith

3.2.1 Saprolite

Erosional plains and rises eroded mostly on basement saprolite dominate much of the area. These are characterised by a stony mantle over residual to colluvial soil, with very little outcrop of the underlying saprolite. The stony mantle is the most striking feature of these units; however as this is only one clast thick, and apparently overlies soil on saprolite over most of their extent, they are classed as being saprolite-dominated. Stones and vegetation are mostly arranged in a 'contour pattern' stepped landscape arrangement consisting of stony risers with red desert loam soils and stone free vegetated steps with self-mulching red clays. This arrangement of stone and vegetation shows on airphotos as banding parallel to topographic contours, and hence the term contour or 'tiger stripe' (originally 'brousse tigree'; White 1970) banding is commonly used. Soils are generally calcareous and locally gypseous. The following information is summarised from the work of Mabbutt (1972, 1977), and B. Macdonald and co-workers (Macdonald 2000; Macdonald & Melville 1999, 2000; Macdonald *et al.*, 1999) who have carried out detailed work on soils at Fowlers Gap Arid Zone Research Station, 30 km southwest of the area. Zonation into vegetated and non-vegetated 'steps' and 'risers' is common in arid grassland and woodland areas throughout the world. Patterning develops on slopes that are too gentle for the development and maintenance of organised stream flow, and represents a system in dynamic equilibrium. Microtopography of the slope redistributes runoff through sheet flow, concentrating it in vegetated arcs. Bare areas are generally on sloping surfaces (run-off zones), while the vegetated run-on areas occupy flatter or depressed areas. Run on areas receive water, nutrients, salts and sediment. Sheet flow is generated in the bare areas as the soil has a sealed surface layer with absence of biotic activity. The adjoining vegetated arcs impede water leaving the bare areas. Most or all of the water is absorbed in the vegetated areas, due to the presence of macropores, burrows, and spaces between soil aggregates stabilised by organic matter. Soils of the bare and vegetated areas have different properties, due to the presence/absence of plants, and differential water absorption. In particular, soils of the runoff areas are more saline, generally by an order of magnitude (B. Macdonald, University of NSW pers comm, 2001). In the general Broken Hill area, the run-off areas are generally stony, whilst the vegetated areas are stone free.

The stone mantle mostly consists of resistant material originally derived during basement saprolith erosion and winnowing, and is considered to be mostly colluvial rather than residual (section 2.1.3). It is made up primarily of angular fragments derived from quartz (fig 6) and quartz/iron (fig 7) veins. Locally, fragments of resistant saprock (mostly quartzite, fig 8) and ferruginised basement saprolite are dominant. Resistant fragments derived from overlying sediments (fragments of silcreted and/or ferruginised sediment, and more rarely, rounded pebbles exhumed from conglomerates) are locally mixed with the basement-derived material. In some areas this sediment-derived material has clearly been dispersed from nearby outliers, but it also is present in areas with no preserved *in situ* sediment. In this situation it is interpreted to represent the last dispersed vestige of eroded cover sediment, preserved through winnowing of finer sediment and underlying basement-sourced material. This implies either that land surface lowering by erosion has not proceeded far past the unconformity between basement and sediment, or that individual clasts in the mantle may have a long residence time in terms of the rate of surface lowering. Small rounded magnetic ferruginous fragments most likely containing maghemite are locally common components of the mantle.

The stone mantle protects the underlying soil and saprolite from erosion, giving rise to a smooth undulating landscape. Small areas where the mantle has been breached are characterised by steeper slopes and rapid erosion of mechanically weak materials.

Figure 6. Quartz vein outcrop, with a stony mantle of dispersed angular milky quartz fragments. Unit *SPer1*. 54J 599075 E 6620465 N

Figure 7. Outcrop of quartz-iron oxide vein with a stony mantle of dispersed angular vein quartz and ferruginous fragments. Unit *SPer1*. 54J 598500 E 6621642 N

Figure 8. Slightly weathered quartzite with small quartz veins, with thin stony lithosol and a stony mantle of fragments of quartzite and milky quartz. Small area of saprock in unit *SPer1*. 54J 627637 E 6590282 N

SPep1-4, SPer1-3: basement saprolite plains and rises

Mapping units dominated by basement saprolite are subdivided on the basis of local relief (erosional plains or rises), whether or not general basement bedding/structural trends are apparent on airphotos, nature of underlying rocks (basement or Mesozoic), and in some cases stone type in the surface mantle where there is an obvious dominant component. This may be iron- (ferruginised sediment or saprolite, fragments of quartz/iron veins, or small magnetic fragments) or silica-rich (vein quartz, silcrete, quartzite fragments), or mixed. Mapping of areas of local surface stone type was not found to be generally possible in the time available as there is marked local variability in many areas, and readily available remote sensing methods (eg manipulation of frequency bands in satellite data) do not generally distinguish between iron oxide or silica of different origins, as are present in the area. However, areas with a highly ferruginous mantle were recognised on aerial photographs, and have been mapped separately.

Units *SPep1* and *SPep2* (fig 9) are mapped in areas with an undifferentiated stony mantle on erosional plains primarily on basement saprolite with minor saprock, respectively with or without general basement structural trends visible on airphotos. The basement trends visible in areas of *SPep1* probably reflect variable underlying lithology or degree of weathering. Similarly, *SPer1* and *SPer2* form a complementary pair of units (with and without structural trends) with undifferentiated surface stony mantle in areas of slightly higher local relief. Units *SPep3* and *SPer3* are mapped where a ferruginous surface stony mantle is dominant over large areas (dense brown response on colour airphotos) (fig 10). These units are characterised by a blue-green radio-spectrometric response (ternary colour plot, see insert on the map), indicating low potassium with some thorium and uranium. It is possible that surface fragments in these units are dispersing widely. Fragments of both ferruginised basement saprolite and sediment are present. Basement outcrop in all these units is limited mostly to saprolite exposures in gullies, and rarer saprock exposures on local crests. *In situ* quartz and quartz/iron oxide veins are locally exposed as low outcrops. Gypseous, possible residual clay is locally present.

Figure 9. Erosional plain with mixed stony mantle of angular quartz, and silcreted and ferruginised sediment (*SPep2*), punctuated by rises with outcrop and mantle of silcreted probable Mesozoic sediments in the background (*SPer5*). Lines of vegetation mark creek beds with associated *Aap1*. 54J 622855 E 6586657 N

Figure 10. Highly weathered gypseous shale saprolite, with ferruginous veins probably developed by iron oxide precipitation along fractures. The stony mantle above this outcrop is composed mostly of ferruginous fragments. The saprolite is mechanically extremely weak, and in places completely disrupted by growth of gypsum. Unit *SPer3*. 54J 608858 E 6615877 N

Small, discreet areas with a mixed ferruginous mantle (both ferruginised sediment and basement lithologies) over basement saprolite, clearly visible as small brown patches on colour airphotos, are mapped as unit *SPep4* (figs 11, 12). The ferruginous material in these areas is most likely to have a local source. It is possible that both basement and cover sediment were locally ferruginised at the unconformity, and that erosion has since removed all *in situ* sediment and the immediately underlying basement saprolite, leaving surface fragments of ferruginised sediment and saprolite over a small area.

SPep5, SPer4, SPer5: saprolite of Mesozoic sediments

About 50 m of Mesozoic sediment with plant fossils suggesting a Jurassic age are exposed at the 'Three Hills' between Wonnaminta and Kara homesteads (Brunker, 1967). The sediments are mostly well-bedded, cross-bedded sandstone and conglomerate with ripples preserved on some bedding planes, but with mudstone dominant in the top third of the section. These sediments form the basal part of the Eromanga Basin in the area, and the exposures at the 'Three Hills' are amongst the best in the general area. Clasts in conglomerates are mostly rounded milky quartz, up to 20 cm, but angular milky quartz clasts are locally common. In the vicinity of the Turkaro Range and possibly Koonenberry Mountain (see below), clasts of Devonian sandstone are also present in interpreted Mesozoic sediments. Well-rounded granules of milky quartz are in many places scattered through the sandstone, and locally concentrated to form granule conglomerate. The unconformity with the underlying basement rocks is exposed in a gutter beside the track to the radphone tower on the highest (most southwestern) of the 'Three Hills', only a few metres above the surrounding stony plain. Most of the sediment is bleached and poorly to moderately cemented, but some sandstone beds have been cemented by iron oxides, especially near the crest of the northern and southeastern hills, and *in situ* silcreted mudstone is present at the top of the southwestern hill. Other good exposures of Mesozoic sediments within the sheet area are limited, and confined mostly to small breakaways in the northwest

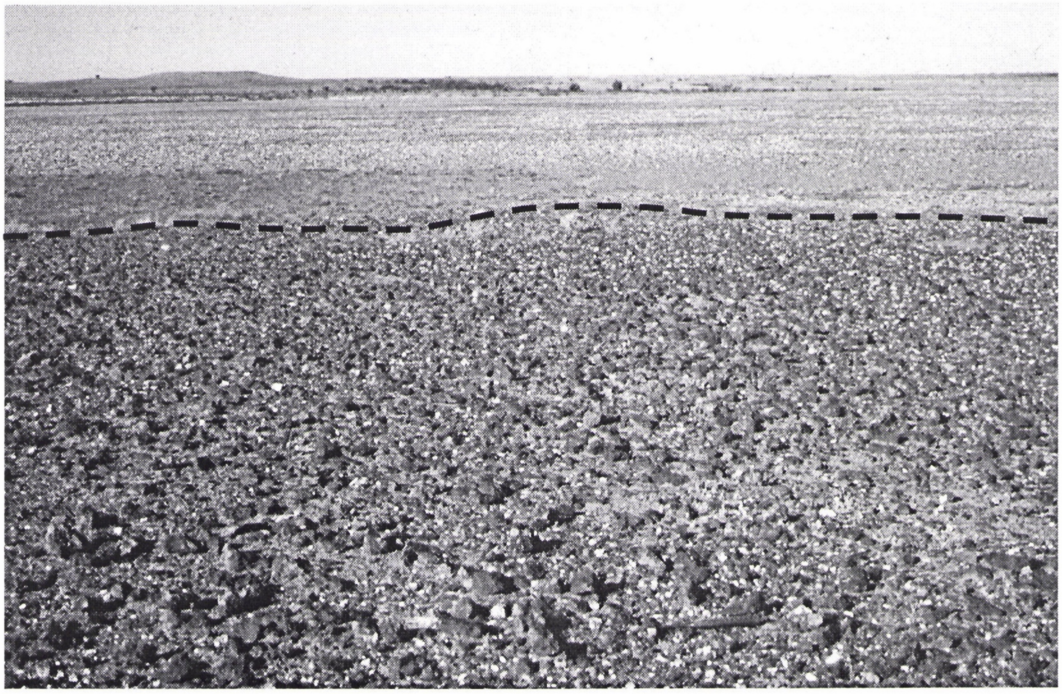


Figure 11. Stony mantle of fragments of ferruginised sediment, with minor angular milky quartz and ferruginised saprolite, over shaley basement saprolite (*SPep4*). There is a sharp contact with an area with angular vein quartz stone mantle (*SPep2*) at a minor watercourse (dashed black line). Rise with silcrete outcrop and scree (unit *SPer4*) in the background. Detail of the ferruginous mantle is shown in figure 12. 54J 603962 E 6616549 N

Figure 12. Outcrop of ferruginised (at hammer head) and bleached (below end of handle) cleaved basement shale saprolite with a stony mantle mainly of ferruginised sediment (probably originally Mesozoic), with some angular milky quartz and fragments of ferruginised shale saprolite. The landscape at this site is shown in figure 11. Unit *SPep4*. 54J 603962 E 6616549 N

in map unit *SPer4* (see below). The predominantly well-rounded quartz clasts in the sediments contrast with the angular quartz fragments derived directly from veins in basement rocks.

It is assumed that all sediments (including silcreted sediment, see below) preserved in rises, low plateaux and tablelands across the area are Mesozoic. Neef (1998) has suggested that the Palaeogene Eyre Formation (Wopfner *et al.*, 1974) was deposited across some of the area. Gibson (2000b) has shown that in the Fowlers Gap area 30 km to the west of the area, rocks mapped as Eyre Formation by Neef *et al.* (1996) are Mesozoic, as they contain Jurassic to Early Cretaceous plant micro- and macrofossils. The author has encountered no firm evidence in the Wonnaminta area for the existence of Tertiary sediments, though silcreted boulder conglomerate adjacent to parts of the Turkaro range could possibly be post Mesozoic (see section 4.1 below).

Unit *SPep5* is confined to the far northwest of the area, and is characterised by a dense mantle of fragments of ferruginised sediment overlying mottled highly weathered Mesozoic mudstone. The mantle appears to have originated as more resistant parts of ferruginous mottles that have been exhumed. Relief is low, and Mesozoic saprolite crops out only on slopes near local watercourses.

Units *SPer4* and *SPer5* are mapped over the remaining areas of Mesozoic and possible younger sediments; the latter unit is depicted where aeolian sand forms a discontinuous thin layer at the surface (figs 13). The polygons generally extend onto adjacent areas of underlying basement saprolite where a dense mantle of fragments of silcreted sediment directly overlies basement saprolite. Surface fragments are typically of silcreted and less commonly ferruginised sediment, with some rounded pebbles exhumed from the sediment. Some of the silcrete fragments are also ferruginous. Silcreted sediment locally crops out (fig 14), and there is generally rare outcrop of ferruginised or bleached sediment (fig 15). Landform generally comprises rises to low plateaux, with steeper slopes associated with outcrops; however, the 'Three Hills' (actually low hills as local relief is about 60 m) are included in *SPer4* (fig 16). Here, about 50 m of sediment containing Mesozoic plant fossils and trace fossils (Brunker, 1967) are present, and there is good outcrop of both bleached and ferruginised sediments (figs 17 & 18).

Figure 13. Outcrop of silcreted Mesozoic sediment with a veneer of aeolian sand. Unit *SPer5*. 54J 599016 E 6616560 N

Figure 14. Outcrop of silcreted Mesozoic pebbly sandstone with scattered milky quartz clasts, and talus of silcrete fragments (*SPer4*). Adjoining plains are *SPep2*. 54J 600580 E 6618294 N

Figure 15. Low knoll with jumbled boulders of silcrete formed in sediment with rounded quartz granules and some pebbles, over outcropping horizontally bedded highly weathered bleached siltstone with rounded quartz granules and pebbles (at hammer), most probably Mesozoic. Unit *SPer4*. 54J 599784 E 6621629 N

Figure 16. Southwestern peak of the 'Three Hills' between Wonnaminta and Kara homesteads (*SPer4*), rising about 60 m from the surrounding plain (unit *SPer1*) which has a mantle of fragments of angular milky quartz and silcreted sediment. White scars mark outcrops of bleached Mesozoic sandstone, bounded by partly cemented colluvial slopes with scree mostly of silcrete fragments. Silcrete formed in Mesozoic mudstone is present at the crest of the hill. The base of the Mesozoic sequence is exposed in a gutter beside the track to the communications tower on the peak, only metres above the surrounding plain surface. This implies that the modern plain surface is cut only metres below the pre-sedimentation Mesozoic land surface. Crest of peak is approx 54J 624000 E 6601000 N

Figure 17. Bleached cross-bedded Mesozoic sandstone exposed on the northern peak of the 'Three Hills' between Wonnaminta and Kara homesteads. Unit *SPer4*. Approx 54J 624500 E 6603000 N

Figure 18. Ferruginised Mesozoic sandstone at the crest of the northern peak of the 'Three Hills'. Loose boulders of silcrete are present on the summit surface, implying that an original silcreted sediment body above the modern summit has been winnowed, leaving larger fragments as a discontinuous mantle. Unit *SPer4*. Southeastern hill is in the distance. Approx 54J 624500 E 6603000 N

There is no outcrop beneath silcrete on many of the small silcrete-capped rises; however some, especially in the vicinity of Kara homestead, have outcrop of bleached gypseous puffy clay beneath outcrop or lag of silcrete. This is most probably residual clay representing disrupted (due to the growth of gypsum crystals) or collapsed saprolite of basement shale or Mesozoic mudstone. Some low rises of *SPer4* adjacent to the Turkaro Range have outcrop of silcreted conglomerate with rounded quartz pebbles and clasts of Devonian sandstone ranging from pebbles to boulders up to several metres in size (figs 19 & 20). This unusual rock is further discussed below in section 4.1.

Many scree slopes below crests with silcrete outcrop or lag have a partly cemented hardpan developed in colluvial material. Erosion of the underlying saprolite or residual clay appears to have proceeded rapidly where the hardpan is breached, giving rise to smooth scree slopes punctuated with erosional scars. In rare cases, for example at Peak Hill (fig 21), old scree slopes are interpreted to have been separated from the main hill by later erosion (fig 22).

Figure 19. Silcreted conglomerate at the margin of the Turkaro Range with clasts of vein quartz (white; eg right of hammer handle) and Devonian sandstone (dark) in a light coloured matrix. Unit *SPer4*. 54J 614466 E 6584125 N

Figure 20. Silcreted sediment forming a rise about 500 m from the margin of the Turkaro Range (to left of photo). Large area of dark rock in foreground is a single clast of Devonian sandstone >2 m long within the sediment. There is a similar rise with silcreted sediment in the background. Unit *SPer4*. 54J 614466 E 6584125 N

Figure 21. 'Peak Hill' (*SPer4*), a rise adjacent to the Nundora-Wonnaminta road. A low ridge with silcrete scree forms an almost complete ring that surrounds the central peak. The top half of the peak is composed of highly weathered Mesozoic sediments, overlying shaly basement saprolite. Loose clasts of silcreted sediment form a protective mantle at the top of the 'hill'. Peak is at approx 54J 614700 E 6606800 N

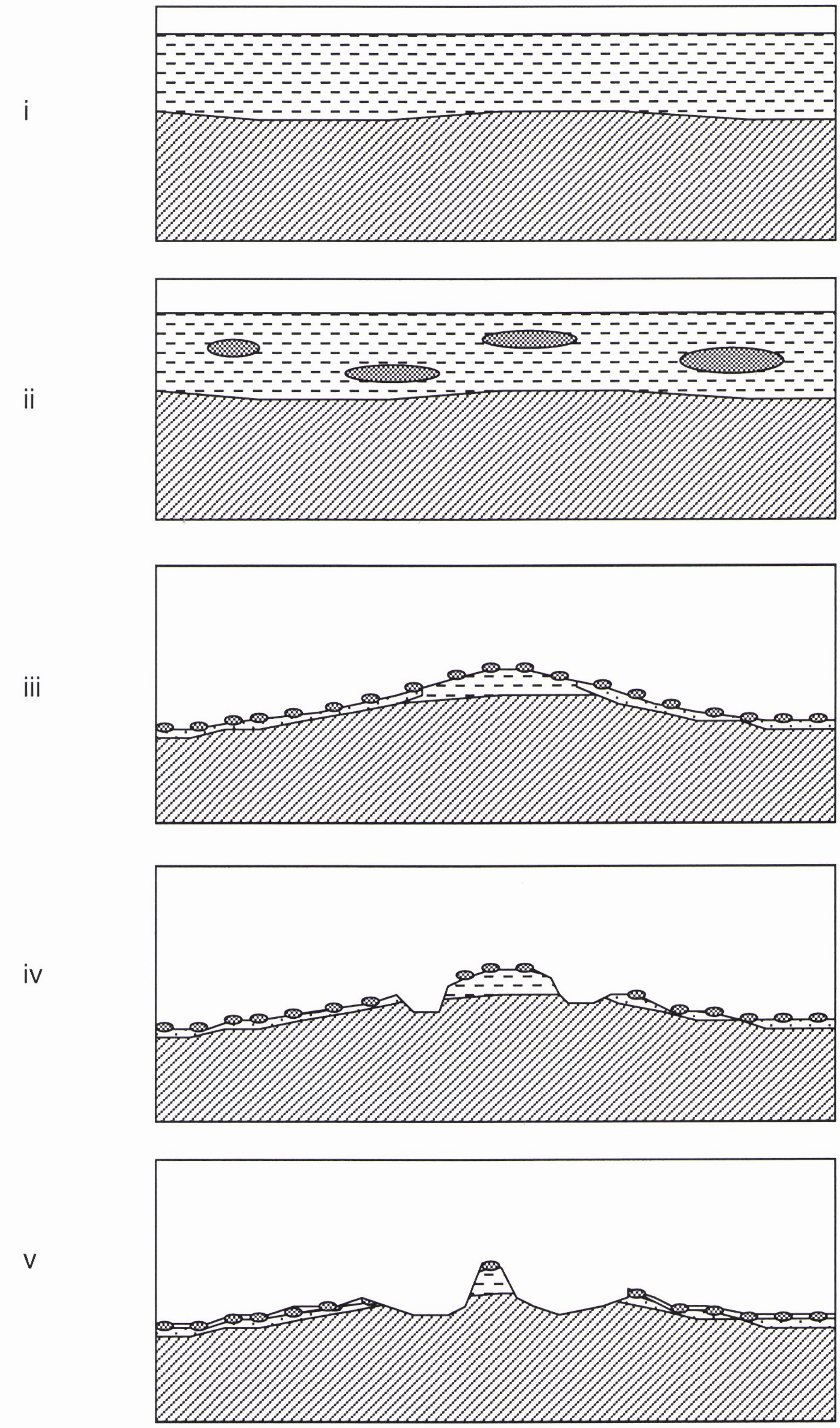


Figure 22. Cartoons of possible sequence of events in the formation of 'Peak Hill'. i. Deposition of Mesozoic sediments over basement rocks. ii. Partial silcreting of Mesozoic sediments, and weathering of sediments and basement rocks (not necessarily concurrent). iii. Erosion to form a broad rise with mantle of silcrete fragments derived from winnowed silcreted sediments. Mantle is partly cemented to form a protective hardpan. iv. Hardpan is breached on upper slopes, and underlying highly weathered sediment and basement saprolite is eroded. Crest of rise and lower slopes are protected from erosion by a mantle of silcrete blocks. v. Further erosion reduces rise to a sharp peak with loose silcrete blocks at crest; original lower slopes are preserved by the hardpan.

SPer6: unknown saprolite type

Two low ridge-tops with a dense partly ferruginous stony mantle that includes small ferruginous magnetic fragments are mapped as unit *SPer6.* An area of *SPer3* that has a ferruginous stony mantle that appears to be at least in part dispersing from the ridge-top surrounds the more northwesterly polygon. This northwestern area of *SPer6* adjoins an area of Mesozoic sediment (*SPer4*) at similar elevation, but no outcrops were observed on the ridge flanks. Thus it is uncertain whether the lag overlies weathered sediment or basement. The more southeasterly ridge has some low outcrops of basement shale and quartzite, but silcreted and ferruginous sediments also crop out. The ferruginous sediment contains small magnetic ferruginous clasts, quartz granules and rare silcrete clasts to 5 cm; it must thus postdate the formation of silcrete. The surface stony mantle on the southeastern ridge includes various fragments of ferruginous material (including small rounded magnetic clasts), silcreted sediment, quartzite (some clasts have attached silcrete matrix, indicating that they have been reworked from silcreted sediment), both angular and well-rounded quartz pebbles, and rounded clasts of ferruginous Devonian sandstone (figs 23, 24). The nearest area of Devonian sandstone is about 10 km distant, thus these clasts must have been moved by a dispersion system that has since been topographically inverted. A 1.5 m hand auger hole on the southeastern ridge intersected gypseous clayey sand with rare pebbles, before bottoming on a larger clast. Gypseous clay soil is present in the northwestern polygon of this unit.

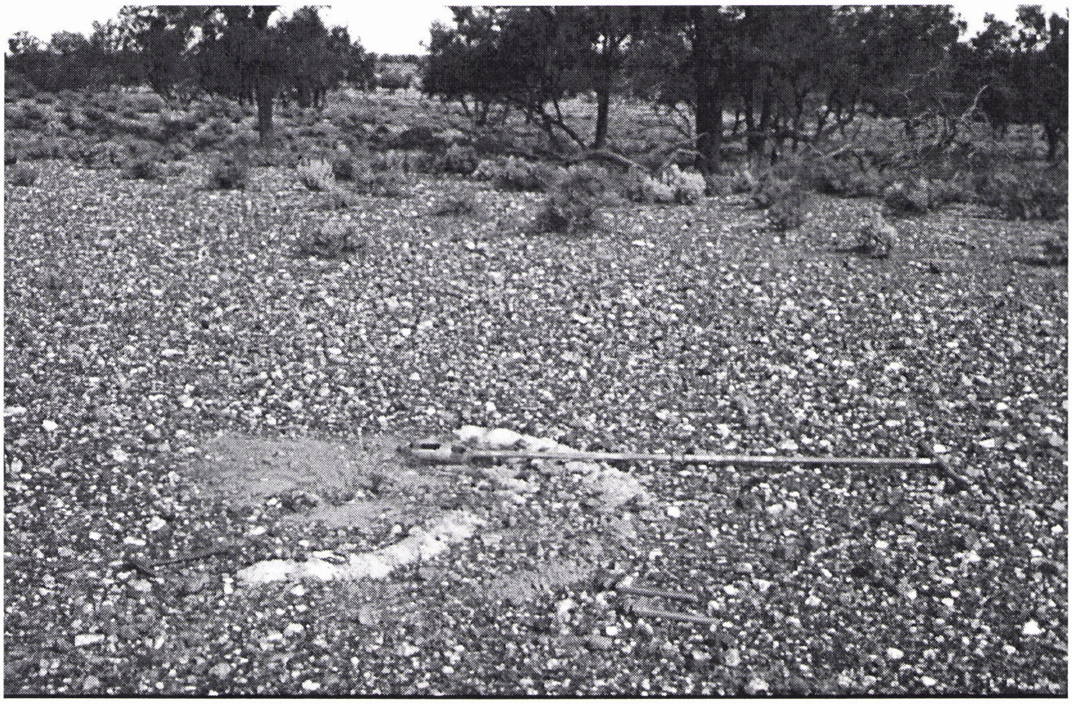


Figure 23. Mixed stony mantle including clasts of silcreted and ferruginised sediment, fragments of quartzite and angular milky quartz, rounded clasts of Devonian sandstone, small rounded ferruginous magnetic clasts, and rare rounded milky quartz pebbles at the crest of the 'Noonthorangee Range', a low local watershed. Soil in a 1.5 m auger hole is clayey sand with some pebbles, and coarse gypsum crystals below 1.2 m. The hole bottomed on a large stone or bedrock. Unit *SPer6*. 54J 631698 E 6590309 N

Figure 24. Detail of stone mantle at auger hole in figure 23, with clasts of silcrete (large clasts, bottom centre), quartzite (with quartz veins, eg below pen magnet), rounded (eg small clast bottom left) and angular quartz clasts, and dark ferruginous fragments; the smaller ferruginous fragments are rounded and magnetic. Unit *SPer6*. 54J 631698 E 6590309 N

The origin of surface magnetic ferruginous fragments in the area is unclear. A considerable amount of magnetic material has been transported to Noonthorangee Creek, where it makes up an important component of the alluvium. In general terms, magnetic iron-oxide fragments are locally common at the surface in drier areas of SE Australia where ferruginous or mottled weathered fine-grained rock or sediment is being eroded. Non-magnetic iron oxides and oxy-hydroxides can be transformed to maghemite at temperatures of a few hundred degrees, such as can be generated during fires, in the presence of organic matter (I. Robertson, CRC LEME, pers comm 2001; Schwertmann *et al.*, 1995). Alternatively, it is possible there may be a biological control on mineral transformation. The source iron compounds can potentially form in both weathered basement and younger sedimentary rocks. The presence of maghemite at a level close to the Mesozoic unconformity suggests that at least some of it has originated through weathering of the Mesozoic sediments, as well as possibly from the immediately underlying basement saprolite.

3.2.2 Saprock

SSel1, SSeh1: saprock low hills and hills

Units *SSeh1* and *SSel1* are mapped over areas primarily of Devonian sandstone. The former is represented by one polygon in the north, Koonenberry Mountain, which is technically a hill as local relief is less than 300 m. This is made up mostly of resistant Devonian sandstone preserved within a local bifurcation of the Koonenberry Fault. It is a single steep ridge with many slopes exceeding 45^{o} and extensive outcrop (fig 25). Lower slopes are eroded onto the surrounding older rocks, and are included in the unit *SSer1* (see below). *In situ* regolith consists of slightly weathered rock, with iron oxide staining and some formation of surface patina. Pockets of thin stony soil and boulder scree overlie this. The scree becomes thicker and is more common near the base of slopes. There has been some topographic inversion of scree deposits on lower slopes. Trails of scree that were once gully-filling now form interfluves between modern gullies eroded into shaley bedrock (fig 26). Vegetation is characterised by white cypress pine and mulga, with shrubs and grasses growing in pockets of stony soil between outcrop and boulders.

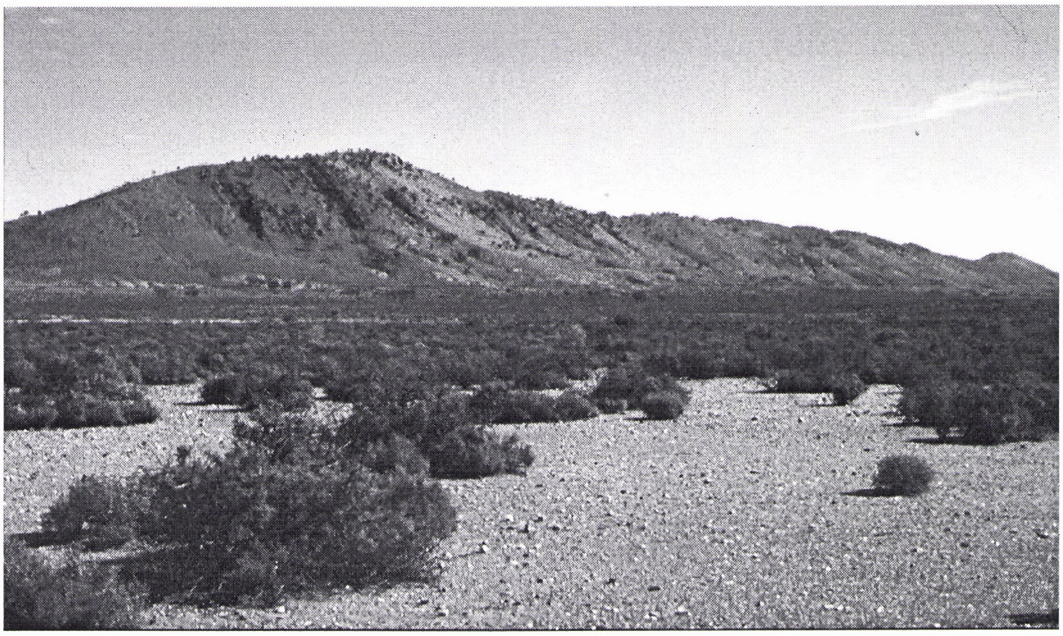


Figure 25. Southern end of the Koonenberry Mountain, from the southeast. The range is mostly slightly weathered Devonian sandstone, but highly weathered Cambrian rocks make up much of the eastern footslopes. Stony mantle in foreground is angular fragments of quartz and rock fragments (shale and sandstone). Range *SSeh1*, foreground *SPep2*. Taken from 54J 629499 E 6619267 N

Figure 26. Topographically inverted scree deposit on the lower eastern slopes of Koonenberry Mountain (*SSeh1*). The boulder scree, originally deposited in a gully, has protected the underlying highly weathered shale (outcropping in the light coloured scar in the left of the photo) from erosion, and new gullies have been eroded on either side of the scree deposit. 54J 627973 E 6619974 N

Most other areas of outcrop of Devonian sandstone are mapped as *SSel1*. Local relief is variable, mostly up to about 50 m. Outcrop is extensive on steeper slopes, but much of the area is characterised by loose surface fragments of sandstone over soil. Soils are yellow-red stony calcareous loamy sand lithosols, becoming deeper and redder in lower areas. Vegetation consists of mulga with forbs and grasses. Colluvium and aeolian sand are locally present.

SSer1, SSer2: saprock rises

Units *SSer1* and *SSer2* are characterised by resistant saprock of older basement rock types, respectively without and with a local veneer of aeolian sand. *Sser1* is approximately equivalent to the Wonnaminta land system of Walker (1991). Local relief reaches 60 m, but is predominantly less than 30 m (fig 27). The main large area of *SSer1* immediately southwest of the Koonenberry Fault has a network of closely dissected ridges with sharp crests, but other smaller areas commonly consist of individual low rounded strike ridges. Shallow loamy lithosols predominate, with some unconsolidated sands in *SSer2*. Vegetation is mostly scattered mulga and bluebush, with forbs and grasses.

Figure 27. Rises of basement saprock with ubiquitous outcrop and stony lithosols (*SSer1*). Koonenberry Mountain (*SSeh1*) is in the background. 54J 622710 E 6616847 N

SSpt1: saprock plateau

Silcrete fragments dominate a stony mantle on low relief plateau surfaces eroded on Devonian sandstone at the crest of the Turkaro Range, mapped as *SSpt1* (fig 28). The plateau surfaces are not structural, as the sandstone mostly dips shallowly to the southwest. On airphotos, the plateau surfaces do not show bedding traces of the sandstone, in contrast to the intervening incised areas. The plateaux are sparsely vegetated with herbaceous vegetation, and do not have the ubiquitous scatter of mulga typical of the adjoining more incised areas. The plateaux are characterised by a dense mantle of fragments of silcreted sediment and rarer rounded milky quartz pebbles, with fragments of Devonian sandstone (some with patches of adhering silcrete matrix) becoming more common towards the edge of the plateaux. The silcrete fragments are mostly less than 10 cm, but local concentrations of boulders may represent in situ silcrete bodies that have been only slightly disrupted by collapse of underlying material. The silcrete has formed mostly in poorly sorted sandstone with scattered rounded milky quartz granules, and less commonly in conglomerate with clasts of rounded milky quartz and rarer clasts of Devonian sandstone. The stony mantle lies on clayey sand soil, with local depressions and regolith carbonate hardpans locally exposed. Many outcrops of the Devonian sandstone through the Turkaro Range have a ferruginous appearance, due to iron oxide coatings on grains. However, some outcrops at a level just below the plateau surface display a network of fine, white vein-like features. These are not quartz veins, but narrow zones with silica cement that has filled intergranular porosity, and apparently prevented the penetration of iron oxides. Possible origins of the materials present on and around the Turkaro Range are discussed below in section 4.1.

Figure 28. Plateau surface of the Turkaro Range (*SSpt1*). The stony mantle is predominantly fragments of silcreted sediment with rounded quartz granules and pebbles, with some rarer clasts of Devonian sandstone (some with adhering silcreted sedimentary matrix) and rare rounded milky quartz pebbles. The mantle overlies calcareous soils and shallowly-dipping slightly weathered Devonian sandstone. 54J 618573 E 6585561 N

4. REGOLITH AND GEOMORPHIC HISTORY

Mesozoic sediments of the Eromanga Basin adjoin the northern Koonenberry Belt area of basement outcrop to the west, north and east, and are present as scattered outliers over the basement areas. Structure contours of the base of the Basin show that it thickens markedly within a few tens of kilometres from the edge of basement outcrop (eg Brunker, 1967; Rose, 1974; Scheibner, 1974). The author interprets that the relief on the unconformity surface is due largely to post-sedimentation warping and erosion rather than original landscape relief at the time of sedimentation, as the basal sandstone and conglomerate (Gum Vale Beds and equivalents; Rose *et al.*, 1967; Rose, 1974; Brunker, 1967) of the basin are present both in structurally high and low positions.

The presence of Mesozoic sediments has had a profound effect on the development of regolith and landscape. The sediments are a host to silcrete, one of the hardest rocks in the area, contributing to the presence of steep silcrete capped rises and low hills. Even where *in situ* silcrete is not present, erosion retarding silcrete scree covers much of the areas of sediment. Ferruginised sediment is not as widespread as silcreted sediment, but is locally common. Large outcrops, such as at the 'Three Hills' show that ferruginisation is generally confined to particular beds or groups of beds within the otherwise bleached sequence. Ferruginised sediment is probably not as resistant to weathering and erosion as silcrete, due to possible solution and movement of the cementing iron-rich compounds.

It is probable that the Mesozoic sediments originally covered all the area, perhaps with exception of the Koonenberry Range (see below). These sediments thus buried any prior landscapes of the area. However, it is probable that the gross features of the modern landscape are inherited from pre-Mesozoic forms that have been exhumed. The presence of many outliers of sediment across much of the area, at an elevation only metres or at most a few tens of metres above the surrounding saprolite plains and rises, suggests that the general low relief landsurface of the area is a slightly eroded remnant of the pre-depositional Mesozoic landsurface. In addition, evidence is presented below that the Turkaro Range and probably Koonenberry Mountain are pre-Mesozoic sedimentation landforms that have been buried and then exhumed and slightly eroded. Thus these landforms were protected from erosion (by burial) for some time.

There is some evidence that ferruginisation has taken place at the unconfomable contact between sediment and underlying saprolite (see sections 2.2.2 and 3.2.1), and various horizons within the sediments have been silcreted or ferruginised. As erosion has removed the softer surrounding weathered sediment, fragments of the cemented rocks have remained as a stony mantle. Continued erosion has in most places completely removed all *in situ* sediment, but cemented fragments from the sediment, as well as rarer clasts exhumed from conglomerates, locally remain as part of the stony mantle over basement saprolite. This implies either that land surface lowering has not proceeded far past the unconformity, or that individual clasts in the mantle may have a long residence time in terms of the rate of surface lowering. It also means that traditional geochemical sampling of ferruginous 'lag' may not be applicable in areas where there is a sediment-sourced component to the stony mantle (see section 5 below).

A complete regolith and geomorphic history for the area has not been formulated, as the timing of weathering, cementing, erosion and deposition is not well established, nor is it known whether there has been continuous regolith and landscape development, or whether there have been discrete phases. However, certain aspects of the history of various areas can be deduced from field relationships of materials and landscapes, and are discussed below.

4.1 Turkaro Range

The Turkaro Range generally consists of a partly dissected bevelled plateau surface eroded across dipping beds of Devonian sandstone, with steeper slopes down to the surrounding plains. The plateau surface is characterised by a dense stony mantle mostly of fragments of silcreted poorly-sorted sandstone and conglomerate with rounded milky quartz granules and pebbles, overlying soil on Devonian sandstone (fig 28). Rounded milky quartz pebbles, and fragments of Devonian sandstone (some with adhering matrix of silcreted poorly sorted sediment) are also present. The Devonian sandstone is well-sorted and not pebbly. Therefore it is considered that the original silcreted sediment is not related to the underlying Devonian sandstone, except that some clasts of sandstone were incorporated into the sediment. The elevation of the plateau surfaces is about 280-300 m, not much higher than the crests of the 'Three Hills', 15 kilometres away, at about 260 m. Given the similarities in dominant clast type between the Mesozoic sediment at the 'Three Hills' and the fragments of silcreted sediment preserved on the Turkaro Range, it is concluded that the stony mantle on the plateaux represents the last vestiges of a cover of Mesozoic sediment that covered the Range. It should be noted that K. Mills (Geological Survey of NSW, pers. comm., 2000) has located outcrops of post-Devonian unsilcreted sediment near Mount Lynn, with lithology similar to other exposures of Mesozoic sediments away from the range.

The plateau surface is most probably part of the pre-Mesozoic landsurface that has been exhumed, and slightly eroded. Either the range represents an area uplifted after Mesozoic sedimentation which has been stripped of sediment (a horst? – but see discussion below), or the modern range is an eroded remnant of a larger Mesozoic range that was buried, and then exhumed from beneath Mesozoic sediment. In the former case, the plateau surface may represent an exhumed uplifted part of an undulating pre-sedimentation landsurface. In the second case, the palaeo-range must have had a plateau surface, which may represent a remnant of a very old low relief landsurface that was dissected during or prior to the Mesozoic. It could be argued that the palaeo-range might not have had a plateau surface at the time of deposition, and that the plateau represents remnants of a plain eroded across sediment and Devonian rocks at some time after sedimentation when local base level was around 40 m higher than today. Subsequent lowering of base level resulted in the removal of Mesozoic sediments from around the palaeo-range, leaving a bevelled crest. However, it would be expected that all vestiges of sediment would be removed from the exposed areas of Devonian rocks during the period of planation at higher base levels.

Outcrops of silcreted sediment marginal to the range in the vicinity of Mulga Tank (5 km southwest of Kara homestead; eg at 54J 613495 6590877) and Talbots Bore (15 km northeast of Marrapina homestead; eg at 54J 614466 E 6584125 N) consist of conglomerate, with well-rounded pebbles and granules of milky quartz, and clasts of Devonian sandstone from several centimetres to several metres in size (figs 19 & 20). Two possible scenarios for the origin of this sediment follow. As the clasts in the sediment contain both local and allochthonous components, it cannot represent a product purely from the erosion of the local Devonian rocks. Firstly it may represent talus deposited at some time during the erosion of the Mesozoic sediment which is interpreted to have covered the range (fig 29a). The talus material could include sand, rounded pebbles reworked from the Mesozoic sediment, and clasts of Devonian sandstone, possibly up to large boulder size depending on palaeo-slope. No clasts of silcrete were observed in the boulder conglomerate, so in this model it is concluded that deposition of the boulder sediment predates silcreting of the eroding Mesozoic sediment. If the range is a post Mesozoic horst, the talus may have formed as faulting occurred and scarps developed. The talus and remnants of the Mesozoic sediment capping the range were subsequently silcreted, at different elevations.

Alternatively, the boulder conglomerates may be part of the Mesozoic sediment, deposited around the steep margins of the palaeo-Turkaro Range, with rounded quartz pebbles and granules introduced from outside the area, and locally-derived boulders of Devonian sandstone which fell down precipitous slopes and became incorporated into the sediment. As Mesozoic deposition progressed, the range was finally completely covered with sediment. Subsequently, but before exhumation of the range, zones of silcrete formed within the Mesozoic sediment, including some of the boulder conglomerates. Differential erosion of most of the sediment has now exhumed the range, and slope retreat has separated many of the outcrops of boulder conglomerate from the modern edge of the range by as much as 500 m. This is summarised in fig 29b.

The latter explanation is preferred. Firstly, faults have not been mapped around the range (K. Mills, pers. comm, 2000). Secondly, areas of probable Mesozoic sediment on rises between the range and Kara homestead to the north have a surface stony mantle that includes angular to rounded pebbles of Devonian sandstone, some with adhering silcreted matrix. It is interpreted that these clasts have been exhumed from the Mesozoic sediment. There must have been a local source for these clasts, as they are not lithified well enough for extended transport, and a palaeo-Turkaro Range would be consistent with such a source. Further north, for example at the 'Three Hills', sandstone pebbles have not been observed as clasts in the sediment.

A

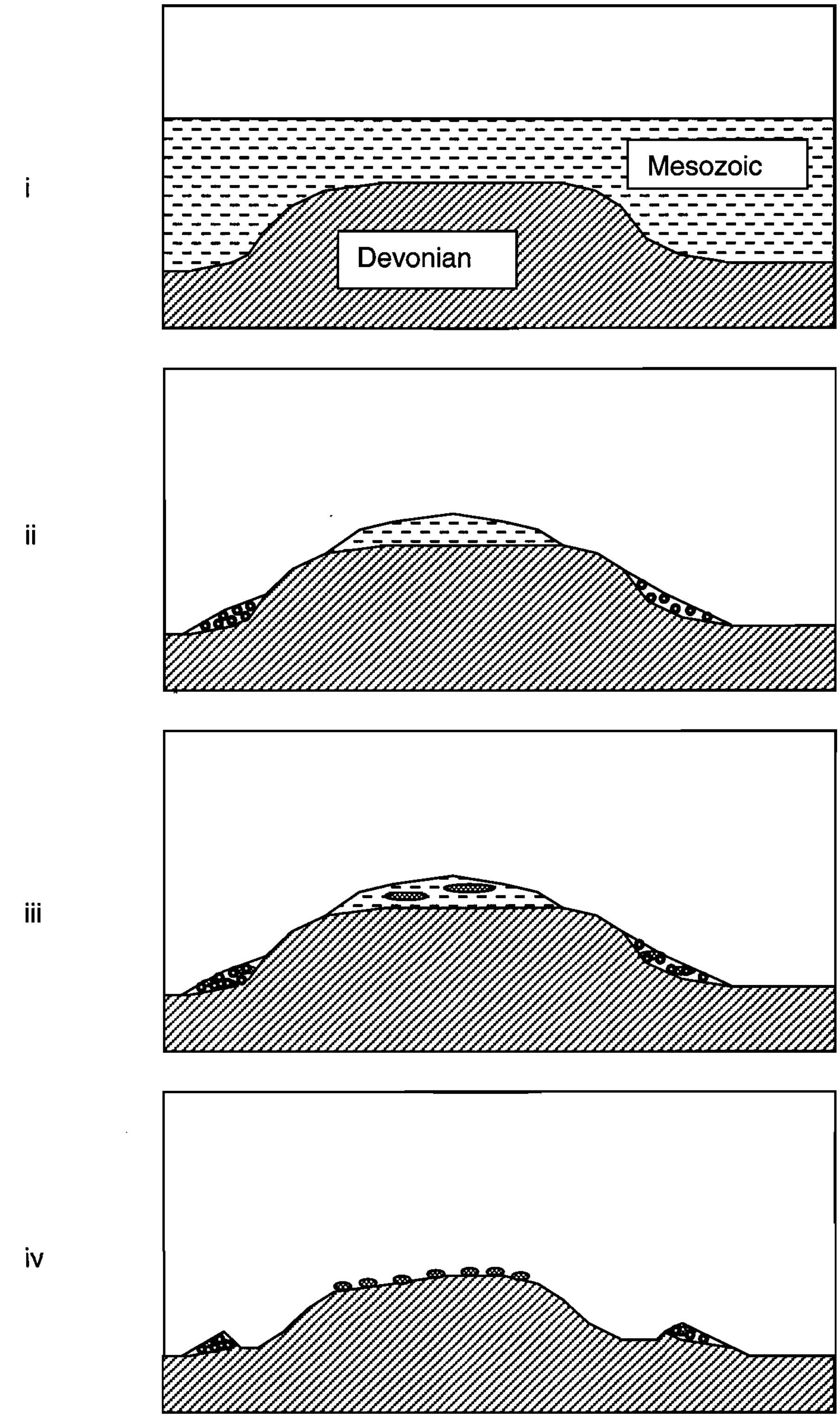


Figure 29. Cartoons of possible pathways for generation of silcreted boulder deposits at margin of, and mantle of fragments of silcreted sediment on plateau surfaces of the Turkaro Range.

A. (i) Deposition of Mesozoic sediment over palaeo-Turkaro Range. (ii) Erosion of Mesozoic sediment and exhumed Devonian sandstone, and deposition of talus which includes rounded quartz pebbles eroded from the Mesozoic, and boulders of Devonian sandstone. (iii) Talus and remnants of Mesozoic cap are partially silcreted. (iv) Further erosion removes *in situ* Mesozoic cap but leaves stony mantle of silcrete fragments and rounded quartz clasts on the plateau surface of the range, and slope retreat separates old talus deposits from the range.

B

i

ii

iii

iv

v

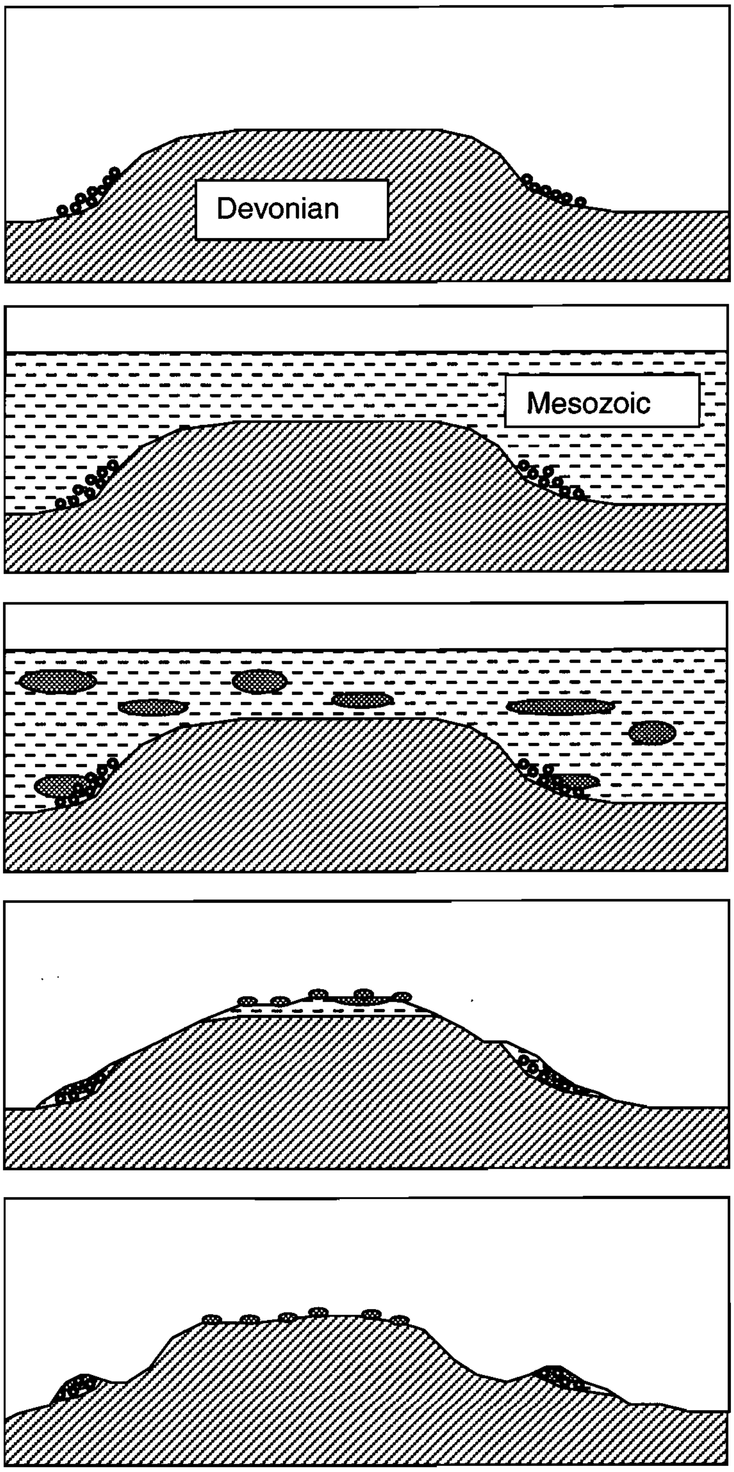


Figure 29 (continued). Cartoons of possible pathways for generation of silcreted boulder deposits at margin of, and mantle of fragments of silcreted sediment on plateau surfaces of the Turkaro Range.
B. (i) Palaeo-range is present at the onset of Mesozoic deposition, with coarse talus deposits at margins. (ii) clasts in talus deposits incorporated into Mesozoic sediment, possibly as rocky shoreline deposits during transgression by the 'Eromanga Sea'. Sedimentation continues, covering the palaeo-range with sediment. (iii) The sediment is partly silcreted, including some of the boulder conglomerates. (iv) Differential erosion removes most of the sediment, partly exhuming the range. (v) The remaining sediment on the top of the range is winnowed, leaving a stony mantle of silcrete fragments and rounded quartz clasts on the exhumed plateau surface of the range. Slope retreat separates the preserved silcreted boulder deposits from the foot of the range.

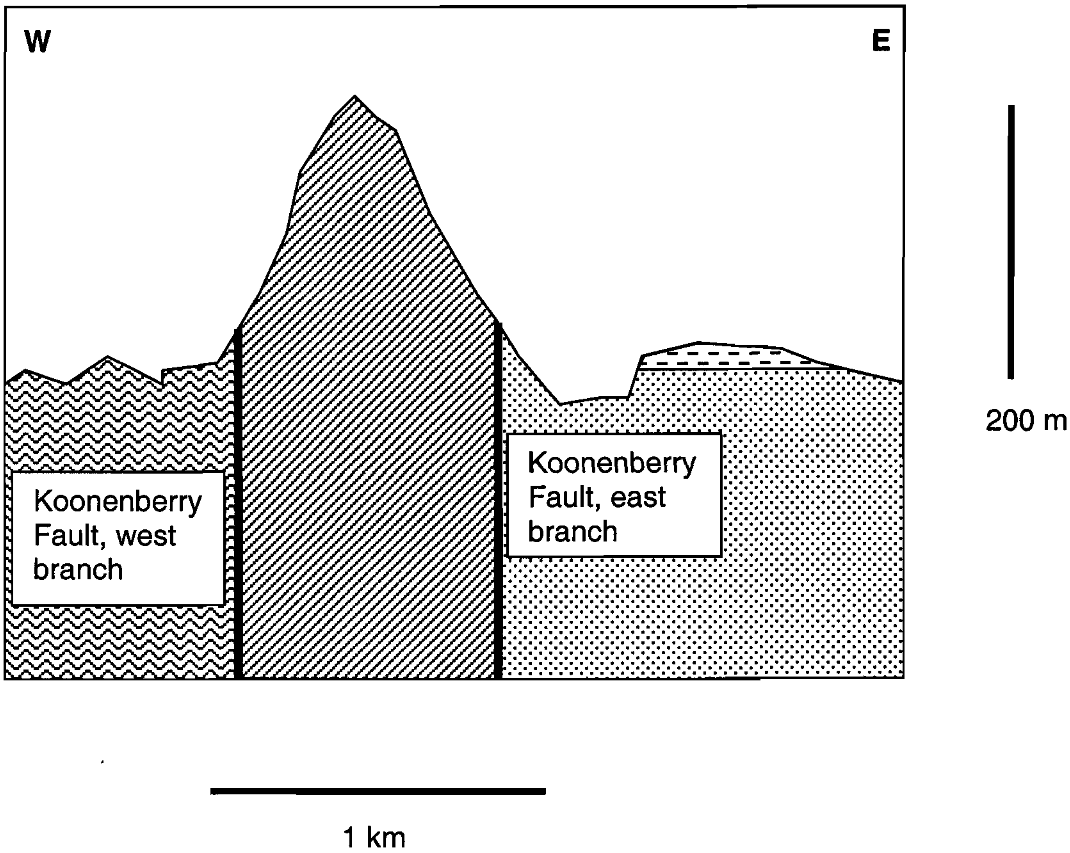
4.2 Koonenberry Mountain and the Koonenberry Fault

Koonenberry Mountain consists mainly of Devonian sandstone, preserved as a topographically inverted graben within a bifurcation of the Koonenberry Fault. The surrounding rocks are not as resistant, and the landform, a rugged single ridge about 1 km wide with a crest up to 200 m above the surrounding plains and rises, probably owes its existence to contrasting erodibility of the rocks (see below). Mesozoic sediments are preserved to within 500 m east of the eastern slopes of the Mountain, at about 200 m elevation. However, there is no direct evidence whether the Mountain was in existence during sedimentation, or whether it was formed by post-sedimentation uplift by fault movement. Mesozoic sediments have not been observed unconformably abutting the range – if they did it would confirm that a palaeo-range was present during sedimentation. Some of the low plateau surfaces sediments in these areas is limited, consisting of sandstone and conglomerate with quartz clasts, but no clasts of Devonian sandstone were observed during a brief examination of the area. Hence, the Devonian sandstone fragments at the surface might either be weathered from Mesozoic eroded on Mesozoic sediments close to the range have a surface stony mantle which includes silcrete fragments, rounded milky quartz clasts and clasts of Devonian sandstone. Outcrop of Mesozoic conglomerates (as appears to be the case on the Turkaro Range) which do not crop out, or represent Tertiary or Pleistocene dispersion of colluvium from the range on palaeo-pediments which have since been dissected to form the plateaux. If it could be shown that the Mesozoic sediments adjacent to the range contain clasts of the sandstone, it would be an indication that there was at least some relief at the time of sedimentation, to provide a local source of sediment.

The surface trace of the Koonenberry Fault on the east side of the mountain is at a higher elevation than nearby Mesozoic sediments (fig 30). The shales of the Early Palaeozoic Watties Bore Formation and Teltawongee Beds to the east of the fault are weathered and not mechanically strong. It is interpreted that they are preserved in the footslopes of the mountain as part of a relatively stable scree slope below steeper slopes of resistant Devonian sandstone. Cartoons of two possible histories of the mountain are presented in fig 31. It is apparent that under the first model (fig 31a, uplift of the mountain by faulting after Mesozoic deposition), the mechanically weak Early Palaeozoic rocks would not be expected to be present on the east flank of the mountain at a higher elevation than the Mesozoic sediments. However the second model, that the mountain was already formed by differential erosion prior to partial or complete burial by Mesozoic sediment, and was subsequently exhumed, provides a mechanism for the higher elevation of the older rocks adjacent to the eastern branch of the Koonenberry Fault. Thus this model is preferred.

The locus of the northwest-trending Koonenberry fault to the southeast of Koonenberry Mountain (fig 1) marks a change in regolith and landscape, as well as a change in bedrock type. A large area of erosional saprock rises southwest of the fault is developed on well indurated saprock of phyllite and arenite of the Ponto beds, with stony plains to the east over more weathered arenite of the Teltawongee beds. A major drainage divide occurs several kilometres to the west of and generally parallels to the fault, mostly on Ponto beds. This landscape arrangement could result either from recent movement, southwest side up, along the fault, or from contrasts in bedrock erodibility on either side of the fault without any recent fault movement. No firm evidence for either case has been found.

Basement saprock is present at elevations up to 240 m in rises west of the Koonenberry Range, whereas Mesozoic sediments are present at around 200 m east of the Range. Again, this does not necessarily signify post-sedimentation differential uplift of the western area; the pre-sedimentation land surface may have been higher to the west of the Range, due to the presence of more resistant rocks.



Mesozoic sediments, highly weathered and mechanically weak, but with resistant silcrete cap

Devonian sandstone, slightly weathered to fresh, very resistant to weathering and erosion

Ponto Beds (Cambrian to Ordovician) – slightly weathered, moderately resistant to weathering and erosion

Watties Bore Formation and Teltawongee Group (Cambrian) – highly weathered and mechanically weak

Figure 30. Sketch section across Koonenberry Mountain, showing relationship of rocks and topography. Note that eastern footslopes are underlain by mechanically weak Cambrian rocks at a higher elevation than nearby Mesozoic sediments.

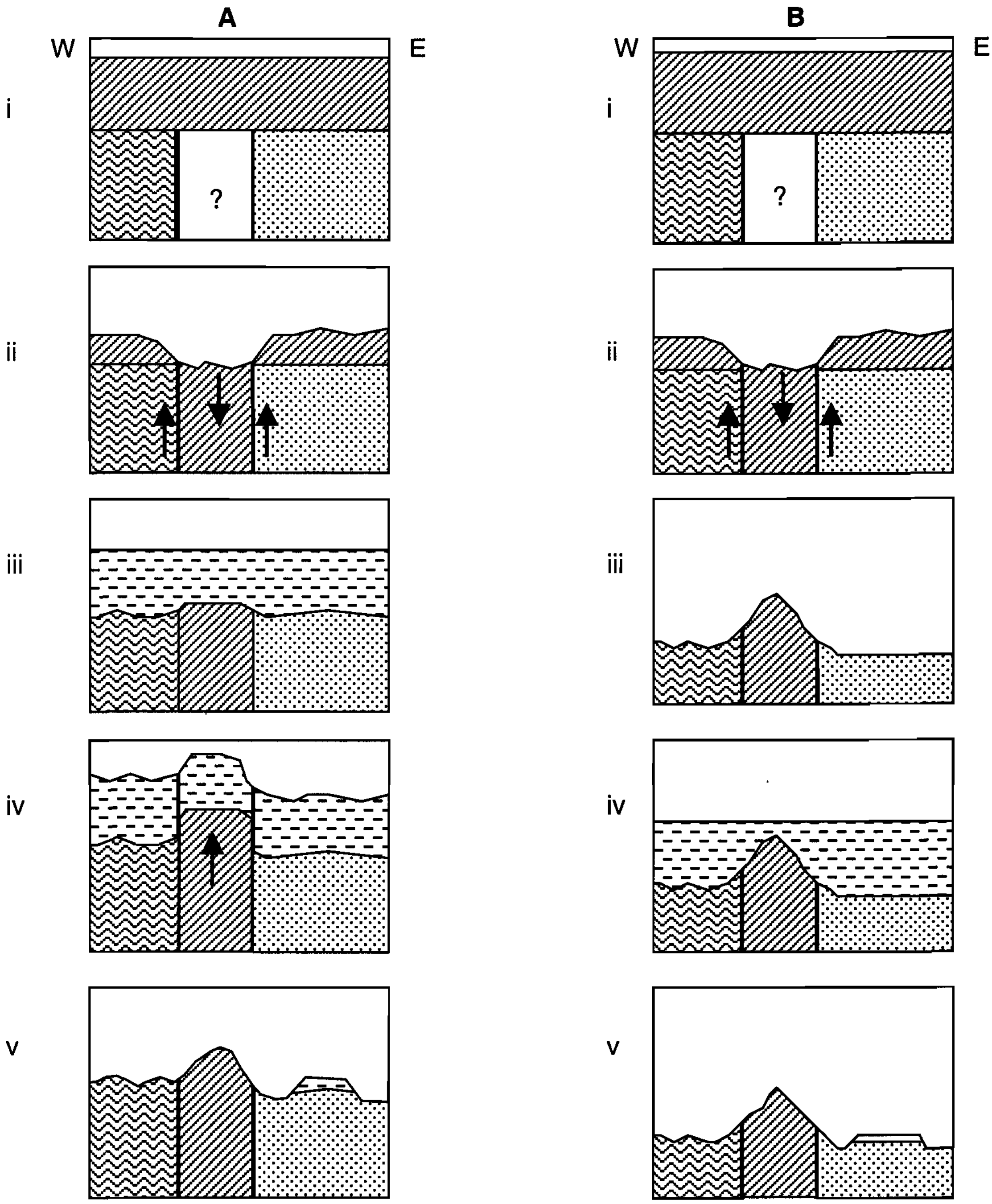


Figure 31. Cartoons of possible stages in the evolution of Koonenberry Mountain.

A. Post-Mesozoic horst. (i) Deposition of Devonian sandstone over faulted older basement rocks. (ii) Downfaulting to form a graben, and subsequent erosion. (iii) Further erosion, then deposition of Mesozoic sediments. (iv) Uplift of Devonian and Mesozoic between original bounding faults of the graben. (v) Erosion to form modern landform.

B. Mesozoic residual hill exhumed from beneath Mesozoic sediments. (i) Deposition of Devonian sandstone over faulted older basement rocks. (ii) Downfaulting to form a graben, and subsequent erosion. (iii) Further erosion of surrounding rocks to leave a residual hill of Devonian sandstone. (iv) Deposition of Mesozoic sediments, possibly thick enough to bury the hill. (v) Erosion of sediment and exhumation of the Mesozoic hill to produce modern landform.

Note that 'B' provides a mechanism for formation of footslopes of mechanically weak rocks to the east of the eastern Fault at a higher elevation than the Mesozoic remnant (see fig 30).

5. POSSIBLE GEOCHEMICAL EXPLORATION SAMPLE MEDIA

The relative suitability of various possible sampling media for geochemical exploration has not been rigorously assessed. However, the following notes provide information on some of the factors that should be taken into account in designing a sampling strategy, and interpreting geochemical data from the area.

5.1 Surface stony mantle

Some components of the surface stony mantle across the area are not related to the underlying basement lithologies, being derived by winnowing from the cover sequence. In particular, silcreted and ferruginised sediment, and possibly maghemite have been derived from the cover sequence, and thus may have chemistry unrelated to local bedrock. The magnetic fragments also appear to have undergone several stages of physical dispersion to lower landscape positions. Non-magnetic ferruginous material is sourced from both basement and sediment; bedrock-sourced ferruginous material, if recognisable, could be used as a sampling medium. It would be important to recognise potential dispersion patterns to help interpret the origin of anomalies. Detailed slope maps generated from digital elevation models may be of use here.

5.2 Soil

There are two distinct soil associations on basement materials: calcareous and gypseous loams and clays in low relief areas over mostly highly weathered rocks, and stony lithosols over fresher, more resistant rocks. Areas characterised by the former have been subdivided on the map depending on degree of local relief, and whether vague bedrock structural trends are visible on airphotos. Any soil sampling data should be grouped into populations based on regolith landform mapping units for statistical analysis. In addition, there is strong chemical (pH, salinity etc) partitioning of soils over small distances in areas with contour pattern (tiger stripe) gilgai (eg Macdonald *et al.*, 1999, Macdonald & Melville, 2000). Thus local soil conditions may be important in the preservation of bedrock anomalies in soil, and soil sampling may need to be carried out only within a specific part of the microtopography. Areas of aeolian sand are present in the area, thus it is possible that part of the material in the soils is aeolian derived, thus diluting any bedrock geochemical signature. Soils at Fowlers Gap to the west of the area are interpreted to include an aeolian clay component (Macdonald, 2000). Sieving or geochemical normalisation may be needed. Partial extraction techniques might be useful.

5.3 Stream sediments

Alluvial sediment in creeks is supplied by incision of gullies to erode saprolith and lower parts of soil profiles, and sheetwash that erodes soil surfaces. It is conceivable that surface soil includes a proportion of allochthonous aeolian-derived sediment (see above), thus alluvium may have a component that has not been generated from rocks within the catchment, diluting any upstream mineralisation signature. The degree of dilution may vary, causing variations in observed geochemistry. Ferruginous fragments may contain a higher metal content than the surrounding sediment. Sieving or geochemical normalisation against iron content may be needed. It is not anticipated that drainage network reorganisation has taken place since deposition of modern stream sediments, thus the chemistry of non-aeolian derived sediment should reflect that of rocks within the modern catchment boundaries.

5.4 Regolith carbonate

The chemistry of regolith carbonate and the potential of carbonate in soils as a sampling medium for gold have not been studied in the area. However, it may be important to note that regolith carbonate is abundant in areas of Devonian quartz sandstone that is most probably deficient in calcium; hence the calcium is probably allochthonous, being brought to the area by rainfall or aeolian processes. Much of the carbonate in soils over saprolite is powdery and dispersed through the soil rather than in discrete nodules or horizons. Corbett (1972) found that most soils in the general area contain carbonates, commonly up to 10%, and reaching 50% over calcareous shale. Chartres (1982) concluded that most carbonate in soils in the Fowlers Gap area to the west is of aeolian origin, but the high concentration in soils over calcareous bedrock in the Wonnaminta area suggests that it may be at least partly derived from bedrock weathering.

5.5 Silcrete

Silcrete has been suggested as a sampling medium for gold in the Gawler Craton in areas where regolith carbonate is absent (Lintern & Sheard, 1998). However, in the Wonnaminta area, virtually all silcrete has formed in transported sediment, and at this stage it appears unlikely that this could form a reliable sampling medium for basement mineralisation. However, broad trends in silcrete chemistry might reflect basement chemistry.

5.6 Rock chips

Basement rock chips could be used as a sampling medium. The degree of weathering of rock chips should be noted, and samples divided into populations depending on degree of weathering, including a population of ferruginised rocks. Normalisation of metal contents against iron content might be necessary.

5.7 Drill sampling of saprolith

Ferruginous zones within saprolite may be local concentrators of metals. Pallid saprolite may be devoid of metals even in mineralised areas. Normalisation against iron content might be necessary.

5.8 Biological sampling

Leanne Hill (CRC LEME PhD student, ANU) is studying the potential of plant matter as a sampling medium at several sites in western NSW, including a site on Kayrunnera Station, immediately east of the area (Hill *et al.*, 2000). Results of her study are not yet available, but prospective explorers in the area should consider the potential for biological sampling.

5.9 Mesozoic sediments as a palaeo-dispersal system

Detrital gold is present in small quantities in basal Eromanga Basin sediments at Williams Peak to the east of the area (Rose, 1974). Adits have been driven along the unconformity at the base of the sediments (K. Mills, Geological Survey of NSW, pers comm, 2000). It is possible that the basal sandstone/conglomerate of the sediments could be used as palaeo-stream sediment samples to indicate areas of potential bedrock gold mineralisation up palaeo-stream. However, poor outcrop, and the necessity to know palaeocurrent directions, would make interpretation of this method of sampling difficult.

6. CONCLUSIONS

Field investigations, photointerpretation and analysis of the relationships between landforms, Mesozoic sediments and regolith have provided a spatial framework of regolith materials in the Wonnaminta 1:100 000 sheet area, and provided ideas on the development of landforms. A now largely eroded cover of Mesozoic sediment across the area has contributed to the development of regolith and landform, as it contains localised resistant silcrete bodies that form local highs, and is a source of some of the resistant fragments present in stony mantles across low relief areas underlain by weathered basement rocks. The sediments buried Mesozoic landforms that have been exhumed and probably only slightly modified by later erosion. The presence of sediment-sourced surface regolith in basement areas has particular ramifications for traditional "lag" geochemical sampling as a tool for mineral exploration.

7. ACKNOWLEDGEMENTS

The owners of pastoral leases over the area are thanked for permission to enter their properties. Accommodation was provided at Wonnaminta for part of the field survey time, and the folk at Koonawarra guided the author to the plateau surface of the Turkaro Range. Kingsley Mills (NSW Department of Mineral Resources) and Steve Hill (University of Canberra, CRC LEME) provided information pertinent to this study, and have engaged the author in long debates over regolith and landforms of the area. The NSW Department of Mineral Resources lent the author 1:50 000 colour airphotos of the area and provided digital versions of the topographic base used on the map. Lindsay Highet produced a preliminary version of the map; Russell Hay brought this to final publishable state. E. Papp manipulated and rectified Landsat TM data. The study was partly funded by the NSW Department of Mineral Resources.

8. REFERENCES

Bailey, P.T., 1972. Fauna of the Fowlers Gap-Calindary areas. I. Marsupial fauna. Fowlers Gap Arid Zone Research Station, University of New South Wales, Research Series 4: 153-161.

Bell, F.C., 1972. Climate of the Fowlers Gap-Calindary area. Fowlers Gap Arid Zone Research Station, University of New South Wales, Research Series 4: 41-67.

Brunker, R.L., 1967. Cobham Lake, NSW, SH/54-11. 1:250 000 Geological Series, Explanatory Notes. Geological Survey of New South Wales, Sydney.

Brunker, R.L. & O'Connell, P., 1967. Cobham Lake 1:250 000 Geological Sheet, First Edition. Geological Survey of New South Wales, Sydney.

Chartres, C.J., 1982. Quaternary dust mantles in the Barrier range. In: Quaternary Dust mantles of China, New Zealand and Australia. Proceedings of the International Quaternary Association Loess Committee, pp. 153-159.

Corbett, J.R, 1972. Soils of the Fowlers Gap-Calindary area. Fowlers Gap Arid Zone Research Station, University of New South Wales, Research Series 4: 103-118.

Corbett, J.R., Mabbutt, J.A., Milthorpe, P.L., Ngethe, J.C., and Sullivan, M.E., 1972. Land Systems of the Fowlers Gap - Calindary area. Fowlers Gap Arid Zone Research Station, University of New South Wales, Research Series 4: 7-40.

Gibson, D.L., 1999. Explanatory notes for the Broken Hill and Curnamona Province 1:500 000 regolith landform maps. CRC LEME Open File Report, 77. CRC LEME, Perth. 59 pp.

Gibson, D.L., 2000a. Regolith, landform history and sampling strategies in the Wonnaminta area, Koonenberry Belt. In: Broken Hill Exploration Initiative, Abstracts from 2000 Annual Meeting. Australian Geological Survey Organisation, Record 2000/10, pp. 41-44.

Gibson, D.L., 2000b. Post–Early Cretaceous landform evolution along the western margin of the Bancannia Trough, western NSW. The Rangeland Journal 22: 32-43.

Gibson, D.L. and Wilford, J.R., 1996. Broken Hill Regolith Landforms, 1:500 000 map scale. CRC LEME, Perth.

Gibson, D.L. and Wilford, J.R., 1999. Broken Hill and Curnamona Province regolith landforms. Digital dataset on CD, CRC LEME, Perth.

Hill, L.J., Eggleton, R.A., de Caritat, P. and Field, J.B., 2000. Biogeochemical and geochemical dispersion and residence in landscapes of western New South Wales. In: Broken Hill Exploration Initiative, Abstracts from 2000 Annual Meeting. Australian Geological Survey Organisation, Record 2000/10: 51-52.

Hill, S.M. and Gibson, D.L., 1998. Broken Hill Exploration Initiative regolith and landscape evolution field excursion. CRCLEME Report 98, 56 pp.

Lintern, M.J. and Sheard, M.J., 1998. Silcrete – a potential new exploration sample medium: a case study from the Challenger gold deposit. MESA Journal 11: 16-20.

Mabbutt, J.A., 1972. Geomorphology of the Fowlers Gap - Calindary area. Fowlers Gap Arid Zone Research Station, University of New South Wales, Research Series 4: 81-99.

Mabbutt, J.A., 1977. Desert Landforms. ANU Press, Canberra.

Macdonald, B.C.T., 2000. University of New South Wales Fowlers Gap Arid Zone Research Station – nearly 50 years of research. The Rangeland Journal 22: 5-31.

Macdonald, B.C.T. and Melville, M.D., 1999. The impact of contour pattern furrowing on chenopod patterned ground at Fowlers Gap, western New South Wales. Journal of Arid Environment 41: 345-357.

Macdonald, B.C.T. and Melville, M.D., 2000. A comparison of the soils from two areas of sorted step chenopod patterned ground, at Fowlers Gap Field Station, western New South Wales. The Rangeland Journal 22: 72-87.

Macdonald, B.C.T, Melville, M.D. and White, I, 1999. The distribution of soluble cations within chenopod-patterned ground, Western New South Wales, Australia. Catena 37: 89-105.

Mills, K.J., 1992. Geological evolution of the Wonominta Block. Tectonophysics 214: 57-68.

Mills, K.J., 1997. Koonenberry Pre-Permian 1:250 000 geological sheet. Version 1. Geological Survey of New South Wales, Sydney.

Mills, K.J. and Hicks, M.G., 2000. Advances in mapping and understanding of the Koonenberry Belt. In: Broken Hill Exploration Initiative, Abstracts from 2000 Annual Meeting. Australian Geological Survey Organisation, Record 2000/10: 69-71

Milthorpe, P.L., 1972a. Vegetation of the Fowlers Gap-Calindary area. Fowlers Gap Arid Zone Research Station, University of New South Wales, Research Series 4: 119-134.

Milthorpe, P.L., 1972b. Pasture and pasture lands of the Fowlers Gap-Calindary area. Fowlers Gap Arid Zone Research Station, University of New South Wales, Research Series 4: 135-151.

Neef, G., 1998. Early Cretaceous-Recent landscape evolution of the Copper Mine Range and adjacent areas far west New South Wales. Journal and Proceedings of the Royal Society of New South Wales 131: 77-84.

Neef, G., Bottrill, R.S. and Ritchie, A., 1995. Phanerozoic stratigraphy and structure of the northern Barrier Ranges, western New South Wales. Australian Journal of Earth Sciences 42: 557-570.

Rose, G., 1974. White Cliffs, SH/54-12. 1:250 000 Geological Series, Explanatory Notes. Geological Survey of New South Wales, Sydney.

Rose, G., O'Connell, P. and Menzies, I.A., 1967. Milparinka, SH/54-7, 1:250 000 geological sheet. Geological Survey of New South Wales, Sydney.

Scheibner, E., 1974. Tectonic map of NSW, scale 1:100 000. Geological Survey of New South Wales, Sydney.

Schwertmann, U., Fechter, H., Taylor, R.M. and Stanjek, H., 1995. A lecture and demonstration for students on iron oxide formation. In: Churchmanm G.J., Fitzpatrick, R.W. and Eggleton, R.A. (Editors), Clays Controlling the Environment. Proceedings of the 10th International Clay Conference, CSIRO Publishing, Melbourne, pp 11-14.

Soil Conservation Service of NSW, 1980. Cobham Lake: Land systems series sheet SH 54-11. Soil Conservation Service of NSW, Sydney.

Thiry, M. and Milnes, A.R., 1991. Pedogenic and groundwater silcretes at Stuart Creek opal field, South Australia. Journal of Sedimentary Petrology 61: 111-127

Wakelin-King, G.A., 2000. Landscape history of the Fowler's Creek system. 9th Australia New Zealand Geomorphology Group Conference, Wanaka, New Zealand, Programme, Abstracts and Participants, p. 95.

Walker, P.J., 1991. Land systems of western New South Wales. Soil Conservation Service of NSW, Technical Report 25.

White, L.P., 1970. *Brousse Tigree* patterns in southern Niger. Journal of Ecology 58:549-553.

Wopfner, H. (1974), Post Eocene history and stratigraphy of northeastern South Australia. Transactions of the Royal Society of South Australia 98: 1-12.

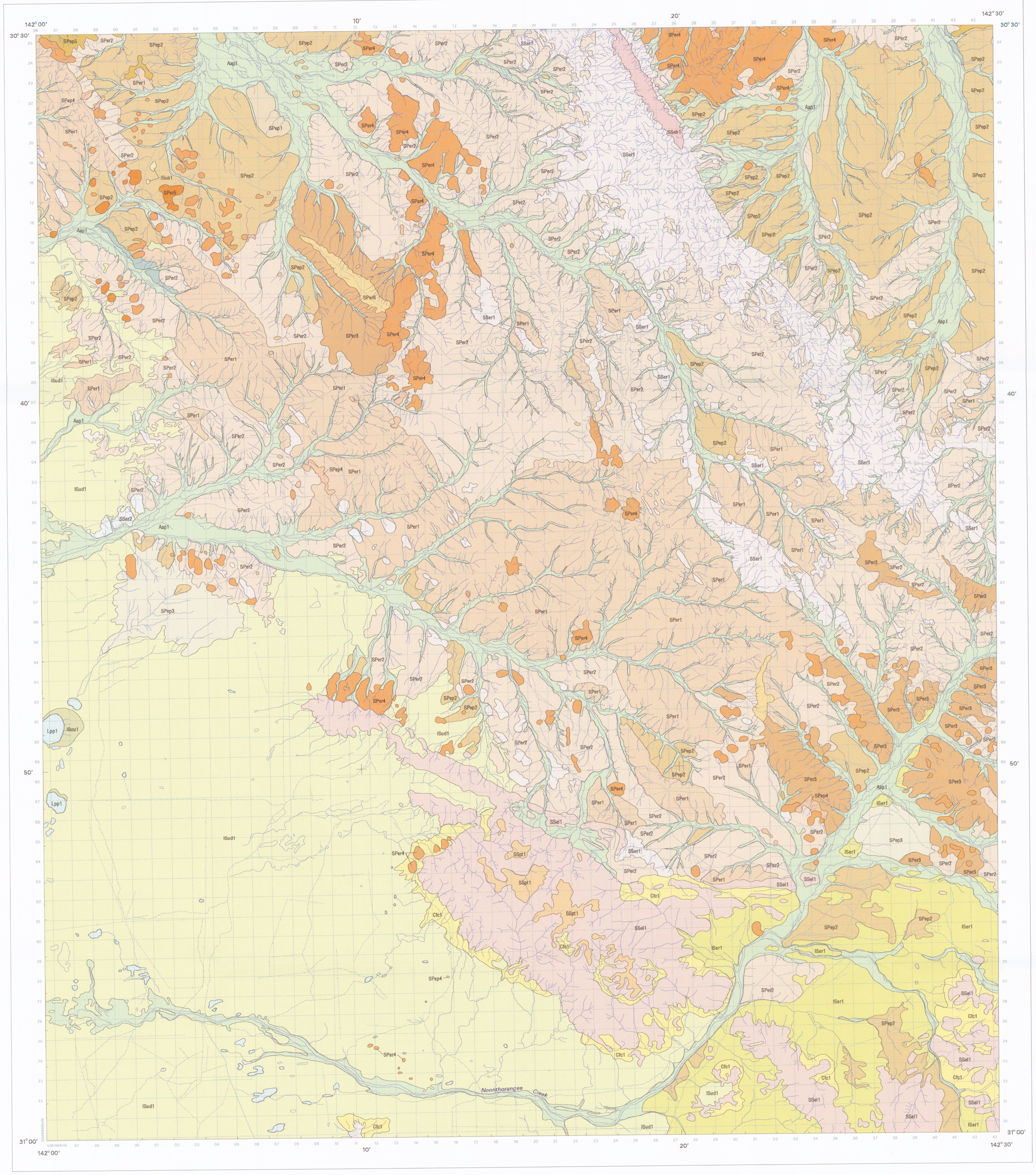
Wopfner, H., Callen, R.A. and Harris, W.K. (1974), The lower Tertiary Eyre Formation of the southwestern Great Artesian Basin. Journal of the Geological Society of Australia 21: 17-51.

WONNAMINTA

NEW SOUTH WALES

AUSTRALIA 1:100 000 REGOLITH-LANDFORM SERIES

SHEET 7336



TRANSPORTED REGOLITH

Alluvial sediments

Aap1	*Alluvial sediments* — Red brown sand, silt, clay and gravel in alluvial plains. Sand and gravel in active channel floors.

Aeolian sediments

ISer1	*Aeolian sand* — Locally derived aeolian sand forming thin sheets over Devonian sandstone, local mantle of sandstone fragments. Rises and erosional plains.
ISub1	Aeolian sand forming source bordering dunes adjacent to watercourses.
ISud1	Aeolian sand forming irregular and longitudinal dunes, local areas of stony mantle possibly over saprolith in some swales, minor fine sediment in small claypans, minor alluvium along watercourses and in terminal floodouts.
ISus1	Aeolian sand forming thin sheets in areas of stony mantle over basement saprolite.
ISuu1	Aeolian sand in lunettes on the east side of larger claypans.

Colluvial sediment

Cfc1	*Colluvial sediment* — Sandy to bouldery colluvium in coalescing colluvial fans and slopes adjacent to areas of higher relief. Regolith carbonate hardpans locally exposed.

Lacustrine sediment

Lpp1	*Lacustrine sediment* — Fine grained sediment in claypans.

IN-SITU REGOLITH

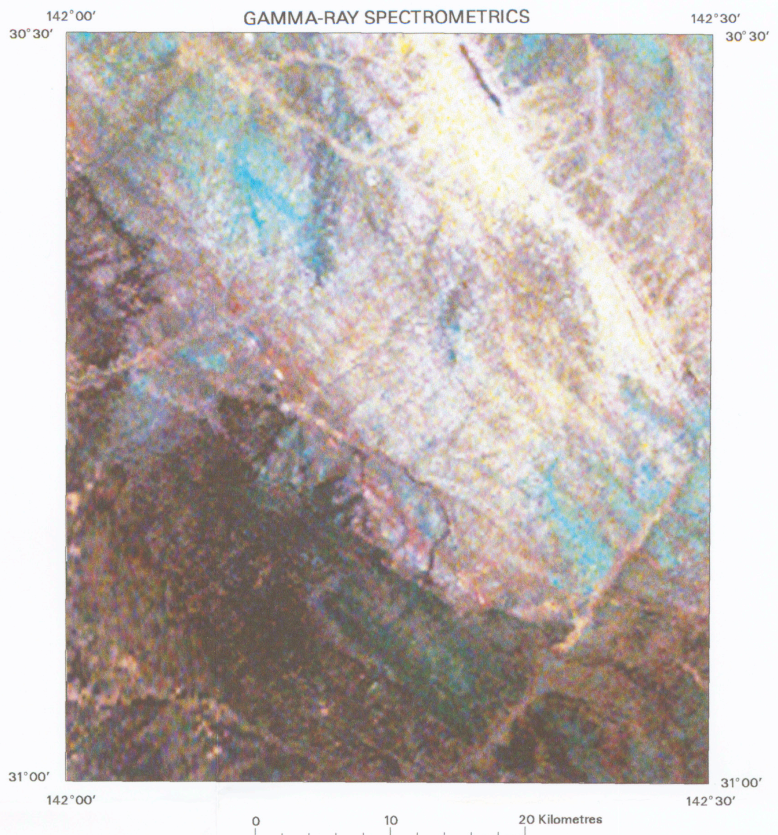
Saprolith

SPep1	*Saprolite* — Basement saprolite with mixed stony mantle. Erosional plains with contour gilgai. Bedding trends apparent on airphotos.
SPep2	Basement saprolite with mixed stony mantle. Erosional plains with contour gilgai. Bedding trends not apparent on airphotos.
SPep3	Basement saprolite with dominantly ferruginous stony mantle. Erosional plains with contour gigai. Bedding trends not apparent on airphotos.
SPep4	Basement saprolite, ferruginised in part, with dense colluvial stony mantle of fragments of ferruginised sediment and/or basement saprolite. Erosional plains.
SPep5	Mottled saprolite of Mesozoic sediments with a mantle of fragments of ferruginised sediment. Erosional plains.
SPer1	Basement saprolite and minor saprock with mixed stony mantle. Erosional rises with contour gilgai. Bedding trends apparent on airphotos.
SPer2	Basement saprolite and minor saprock with mixed stony mantle. Erosional rises with contour gilgai. Bedding trends not apparent on airphotos.
SPer3	Basement saprolite and local saprock with dominantly ferruginous stony mantle. Rises with contour gilgai. Bedding trends not apparent on airphotos.
SPer4	Weathered Mesozoic sediments (silcreted and ferruginised in part), basement saprolite and gypseous clay of unknown origin, with stony mantle of fragments of silcrete, ferruginised sediment, and clasts (mostly rounded quartz) eroded from Mesozoic conglomerate. Hardpans developed on some scree slopes. Mostly erosional rises, but includes the "Three Hills" (low hills) in the central part of the sheet area.
SPer5	Saprolite of Mesozoic sediments (silcreted in part) and basement rocks with stony mantle mostly of fragments of silcrete, and discontinuous veneer of aeolian sand. Rises.
SPer6	Saprolite (basement and/or Mesozoic) with stony mantle of ferruginous fragments (smaller fragments are magnetic), silcreted sediment, angular and rounded milky quartz, quartzite and Devonian sandstone. Local outcrop of silcrete, ferruginous sediment (with magnetic ferruginous clasts, quartz granules and silcrete clasts), and basement saprolith. Dark photopattern on broad ridges. Sandy to clayey gypseous soils.
SSeh1	*Saprock* — Slightly weathered Devonian sandstone, boulder scree. Steep rocky hills (Koonenberry Mountain).
SSel1	Slightly weathered Devonian sandstone, local colluvium and minor aeolian sand. Low hills and rises.
SSer1	Basement saprock with lithosols. Rises and low hills.
SSer2	Basement saprock with lithosols and partial veneer of aeolian sand. Rises and erosional plains.
SSpt1	Slightly weathered Devonian sandstone, with stony mantle of fragments of silcreted sediment, rounded quartz pebbles, and fragments of Devonian sandstone (some with adhering silcrete matrix), over clayey sand soil with regolith carbonate. Low relief summit surface of the Turkaro Range. Sandstone exposed at edges of unit is mostly iron stained, but also has thin white silica-cemented veins.

LANDFORMS

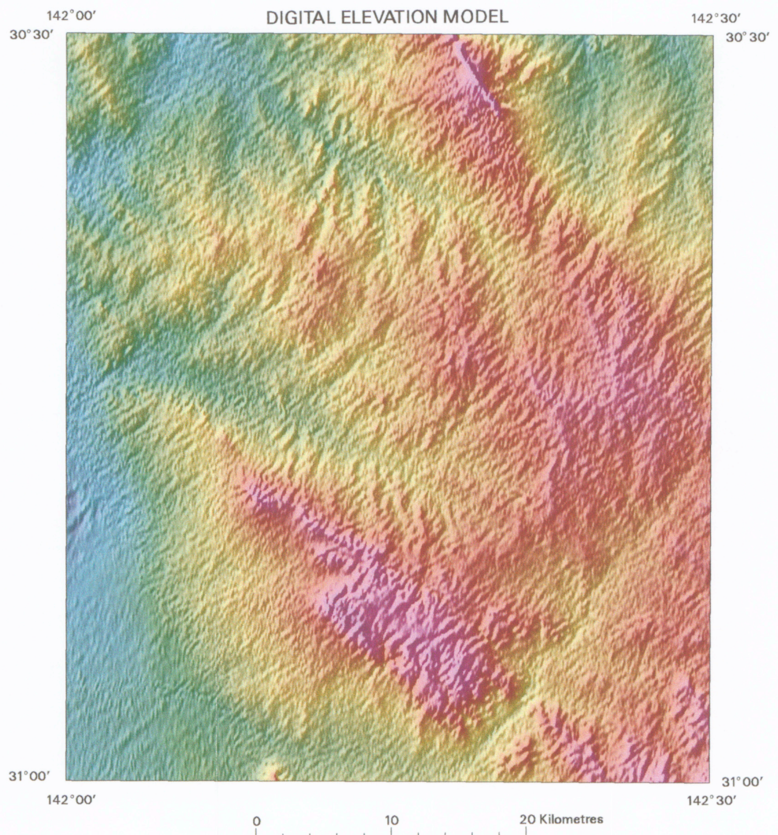
ap	Alluvial plain	pp	Playa plain	Regolith-landform unit boundary
eh	Hills	pt	Plateau	Watercourse
el	Low hills	ub	Source bordering dune	Minor road
ep	Erosional plain	ud	Aeolian dunes	Vehicle track
er	Rises	us	Aeolian sheet	Fence
fc	Colluvial fan	uu	Lunette	

GAMMA-RAY SPECTROMETRICS



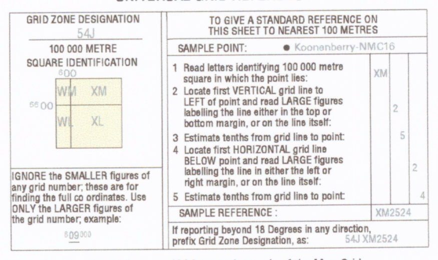
RGB image of gamma-ray spectrometrics (red: potassium, green: thorium, blue: uranium) courtesy of Department of Mineral Resources.

DIGITAL ELEVATION MODEL

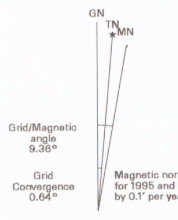


Pseudocolour image of the digital elevation model with sun angle shading from the west. Courtesy of Department of Mineral Resources.

UNIVERSAL GRID REFERENCE



Grey numbered lines are 1000 metre intervals of the Map Grid of Australia, Zone 54. Grid values are shown in full only at the southwest corner of the map

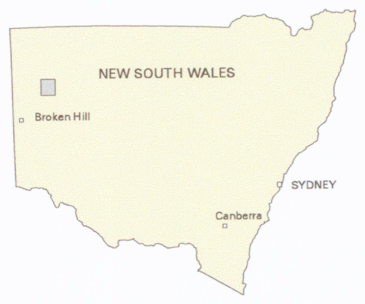


SCALE 1:100 000

0 1 2 3 4 5 6 7 8 9 10 Kilometres

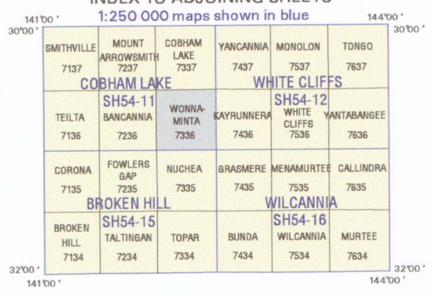
UNIVERSAL TRANSVERSE MERCATOR PROJECTION
LATITUDE OF ORIGIN: 0°. LONGITUDE OF ORIGIN: 141°
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994

MAP LOCALITY

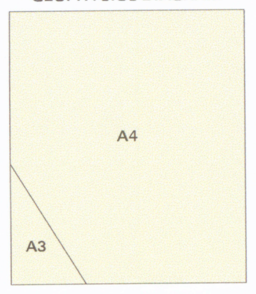


INDEX TO ADJOINING SHEETS

1:250 000 maps shown in blue



GEOPHYSICS DIAGRAM



Koonenberry area A4 is 250m line spacing 60m above ground level.
Bancannia area A3 is 400m line spacing 80m above ground level.

Compiled by D.L. Gibson (CRC LEME), 2000

Cartography by L.M. Highet (CRC LEME/AGSO - Geoscience Australia), 2000, R.J. Hay (AGSO - Geoscience Australia), 2001.

It is recommended that this map be referred to as:

D.L. Gibson 2001 - Wonnaminta Regolith-Landforms 1:100 000 scale map. Cooperative Research Centre for Landscape Evolution and Mineral Exploration, (CRC LEME) Perth/Canberra

Regolith landform polygons based on interpretation of 1:50 000 colour aerial photographs and reconnaissance field checking. Airborne gamma-ray spectrometrics is Exploration NSW data, 1994-5. Acquired for New South Wales Department of Mineral Resources by Austirex International Ltd with a 33 litre crystal pack, flown with E-W lines. Topographic information shown on this map is provided by the New South Wales Department of Mineral Resources.

This map provides a regional overview of the dominant regolith-landform associations in the Wonnaminta area.

Published by CRC LEME, Canberra, Australia.
Produced by the Information Management Branch, AGSO - Geoscience Australia, Canberra, Australia.

CRC LEME acknowledges the collaboration of the AGSO - Geoscience Australia and the NSW Department of Mineral Resources in the production of this map.

CRC LEME is an unincorporated joint venture between the Australian National University, University of Canberra, AGSO - Geoscience Australia and CSIRO Exploration and Mining, established and supported under the Australian Government's Cooperative Research Centres Program.
World Wide Web address - http://leme.anu.edu.au/

Copies of this map may be obtained from:

CRCLEME
c/- CSIRO Division of Exploration and Mining
P.O. Box 1130
BENTLEY, W.A. 6102
Tel: (08) 6436 8695 Fax: (08) 6436 8560

WONNAMINTA

REGOLITH-LANDFORMS

SHEET 7336

FIRST EDITION 2001

SUBJECT TO REVISION