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EXPLANATORY NOTES FOR THE 1:30 000 OLARY REGOLITH-LANDFORM MAP OF WHITE DAM

I. C. Lau

CRC LEME OPEN FILE REPORT 241

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The regolith and landforms of the White Dam area were mapped at 1:30 000 scale. This was undertaken to gain an understanding of the geomorphology of the landscape, and the regolith materials in the region. A second reason for mapping the regolith-landforms in the region was to link the surficial materials with the remotely sensed data, in particular the hyperspectral imagery.

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ABSTRACT

The following notes are an accompaniment for the White Dam 1:30 000 Regolith-Landform map produced as part of the principal authors thesis for a doctorate of philosophy, at The University of Adelaide in 2004. The area of the map is constrained by five hyperspectral swaths, which total an area of 250 $km^{2.}$ The White Dam region is of significant interest as it hosts a number of sites of Cu-Au mineralisation in an area that contains both regolith- and bedrock-dominated terrains. The regolith-landform map contains 1474 polygons and 30 individual regolith-landform units (RLUs). The notes provide an expanded explanation of the RLUs and are accompanied by descriptions of the nature of the regolith materials, landforms and vegetation types and communities that exist in the White Dam area. The regolith-landforms were interpreted using remotely sensed data, including Landsat, ASTER, HyMap, gamma-ray spectroscopy and digital orthoimagery. Ground observations and measurements were performed to validate the RLU in three field trips in 2001-2003.

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1. INTRODUCTION

This report summarises the processes and techniques used to create the White Dam 1:30 000 regolith-landform map and provides details on the regolith landform units (RLUs) described in the map legend. The map was produced as part of a larger project investigating the use of remote sensing technology, specifically airborne hyperspectral data, in regolith dominated terrains in South Australia. This work was performed as part of the authors PhD which was completed in 2004 at the University of Adelaide.

The White Dam regolith-landform map is situated over the White Dam Cu-Au-Mo deposit which is located at the western edge of the Willyama inliers in the Olary Domain of the Curnamona Province. The area covers the BULLOO NORTH, BULLOO SOUTH MINGARY NORTH and MINGARY SOUTH 1:25 000 map sheets and OLARY SI54-2 1:250 000 map sheet.

The regolith-landforms were interpreted using remotely sensed data, including Landsat, ASTER, HyMap, gamma-ray spectroscopy and digital orthoimagery. Ground observations and measurements were performed to validate the RLUs. The creation of the map was performed using both on-screen digitisation and line features, derived from printed imagery, drawn on clear film. The final map product was produced in a digital format for use with GIS software.

Background

Regolith covering the Curnamona Province has long been considered a major impediment to minerals exploration. However, recent research into what was previously considered a monotonous and featureless blanket covering the bedrock has created a greater understanding of regolith-landforms and processes. Regolith materials have increasingly been effectively used within exploration programs for targeting geochemical anomalies (e.g. McGeough & Anderson 1998; Lintern & Sheard 1999; McQueen *et al.* 1999; Lawie 2001). As a result there is an increased demand from the minerals exploration industry for information on the characteristics of the regolith, as well as the application of this knowledge to assist land management and landscape research.

There are few published accounts of the regolith and landscape of the western Curnamona Province in South Australia (Callen 1990; Forbes 1991; Gibson & Wilford 1996; Gibson 1999; Skwarnecki *et al.* 2001; Crooks 2002). This document demonstrates the application of a variety of remote sensing data sets to efficiently characterise and map the regolith-landforms of the White Dam area. This study has benefited greatly from the relatively recent acquisition of remote sensing data by PIRSA, largely as a part of its involvement with the Broken Hill Exploration Initiative (BHEI) and CRC LEME (Szpunar & Reif 2001).

2. NATURE AND ORIGIN OF REGOLITH AND LANDSCAPE IN THE WHITE DAM REGION

Previous Regional Regolith Studies in the Curnamona Province

Previous regolith-landform mapping of the area had been published at 1:500 000 scale (Gibson & Wilford 1996), which provided a very broad and general representation of the area. Mapped polygons were relatively large and contained considerable internal heterogeneity, restricting the use of the map for the provision of a regional overview rather than comprehensive field applications. More detailed mapping at 1:100 000 (Lawie 2001; Skwarnecki *et al.* 2001) and 1:25 000 (Crooks 2002) had been carried out to the north, west and south but did not extend onto this study area. The mapping schemes used were dissimilar, and used different systems of classification to suit the targeted user.

In the eastern portion of the Curnamona Province there has been a number of 1:25 000 map sheets completed of the Broken Hill and Tibooburra regions, as well as a 1:100 000 regolith-landform map of the area around Broken Hill (Hill 2000). The system of regolith mapping was based on the RTMAP (Regolith Terrain Mapping) database (Pain *et al.* 1991; Pain *et al.* 2001) of the Australian Geological Survey Organisation/Geoscience Australia (AGSO/GA), which involved the description of features of the materials at the surface and the landform setting. This was the system used for the mapping of the White Dam region. Detailed regolith-landform mapping (1:2 000) was performed by Brown & Hill (2003) over the White Dam Prospect and surrounding area.

Landscape and Climate

The landscape of the region is part of the bedrock-dominated Olary Ranges and the flanking regolith-dominated lowlands, associated with the Lake Eyre and Murray Basins. The study area contains the major regional drainage divide between the Murray Basin (Murray-Darling catchment) to the south, and the Lake Eyre Basin (Lake Frome catchment) to the north. The northerly draining system includes Bulloo Creek and other tributaries of the Mingary Creek system, which eventually terminate in the lowlands of the Strzelecki Desert and only in exceptional circumstances may reach Lake Frome. The far southwest of the area includes the headwaters of the southerly flowing Olary Creek, which eventually flows onto the lowlands of the northwestern Murray Basin.

The region has an arid climate with a mean annual rainfall of 200 mm and 2500 mm evaporation (Forbes 1991; Bureau of Meteorology 2004). Average summer temperatures have a maximum of 32.0°C and a winter minimum of 5.6°C in July.

Vegetation

The vegetation of the area consisted of chenopod shrubland dominated by *Atriplex vesicaria* (bladder saltbush), Sclerolaena spp. (copper-burrs) and Maireana sp. (e.g. *M. pyramidata* and *M. sedifolia* - bluebushes). Minor open woodland with a chenopod understorey includes tree species Casuarina pauper (belah), *Alectrylon oleofolius* (rosewood), and *Acacia aneura* (mulga). River red gum (*Eucalyptus camaldulensis*) occurs along the larger ephemeral watercourses in the region (Hill & Hill 2003). Tree cover has markedly declined in the post-settlement period (since the late 1800s) due to a combination of reasons, which include the use of timber in construction, firewood and clearance for grazing (Jenson 2001).

Land Use

The region has predominantly been managed for pastoral grazing since the 1860s. This has altered the vegetation cover and composition as well as changed some of the landforms. These features are obvious at paddock boundaries where different management practices have been operational. The area is presently managed with the stations of 'Tikalina', 'Bulloo Creek' and 'Bindarah'.

Regolith Profiles of the Olary Domain

A typical regolith profile from the alluvial plains of Olary Domain consists of fresh bedrock overlain by slightly weathered saprock, which displays parent rock textures and mineralogy, as shown in Figure 1. Saprock comprises core-stones of fresh parent rock enclosed by slightly weathered material. The size of the core stones becomes smaller with increased weathering.

Saprolite materials are generally pallid to pale in colour, where leaching has removed portions of the primary materials. The mineralogy is often dominated by quartz and kaolinite, with goethite the main ferruginous mineral. Above the pallid material there is typically a mottled zone with red-rimmed ferruginous mottles. In some locations, the top of the saprolite is indurated by a fragmented hardpan of regolith carbonate. Where a hardpan does not exist, the top of the saprolite generally grades into a clay-rich layer with abundant mottles of powdery or nodular regolith carbonate, and then into transported material. In soil horizon nomenclature, the clay-rich pedolith materials formed in situ and the underlying saprolite are classed as C horizons. The lower yellow-brown horizons containing abundant carbonate were defined as Bcs by Chartres (1981).

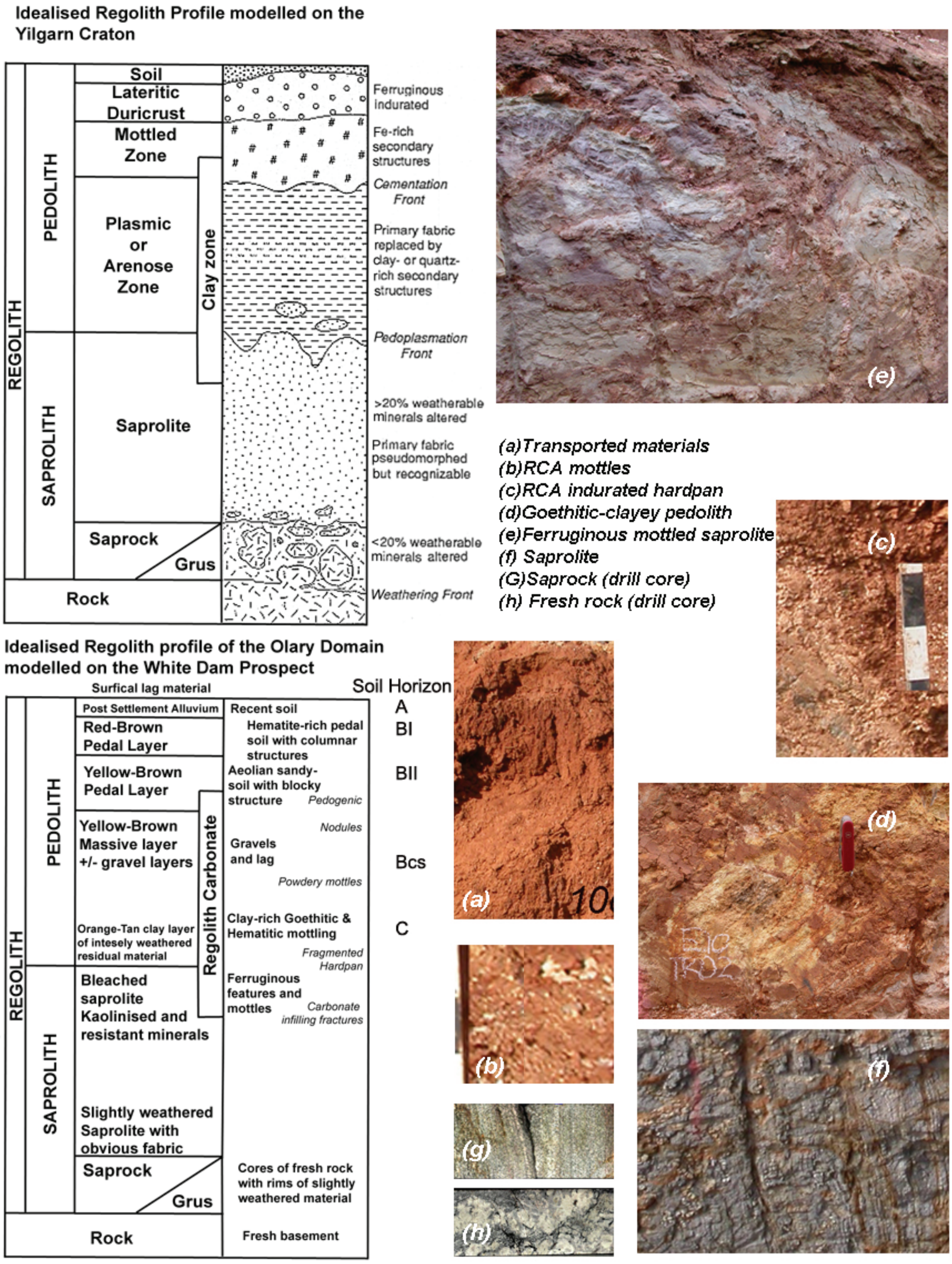

Figure 1 Comparison of the idealised Yilgarn regolith profile with field observations of regolith profiles from the Olary Domain (idealised regolith profile from Robertson & Butt 1997, soil horizon nomenclature from Chartres 1981).

The boundary between the transported and in situ pedolith is often difficult to determine through visual techniques. However, spectral analysis using shortwave infrared instruments has been successfully used to delineate regolith horizons (Lawie 1996; Dawson 2003; Lau *et al.* 2003).

Above the regolith carbonate mottles there are generally massive yellow- to red-brown horizons, locally containing gravel lags. The upper section of the massive yellow-brown material grades into a blocky-structured material, which is typically overlain by a deep red-brown layer with columnar 'pedal' structures and in many cases contains abundant rootlets. The deep red-brown pedal layer is thought to be the pre-pastoralism palaeo-surface. Equivalent soil horizons to the yellow-brown and the red-brown materials were classified by Chartres (1981), as BII and BI horizons, respectively,

The overlying layer of massive to faintly laminated light red-brown material (A horizon) consists of alluvial and aeolian material deposited through the process of shallow overland sheet-wash and aeolian input. These materials have been deposited since European settlement and are termed Post-Settlement Alluvium (PSA).

Chartres (1981) found that the mid-soil horizons (BI BII) in the Fowlers Gap region consisted of aeolian and transported material, while the lower horizons (Bcs and C) consisted of in situ weathering products and some aeolian material. Salts, calcium carbonate and gypsum in the soils originated from transported aeolian clayey pellets. The A horizon (upper most layer) consisted of clays and stone material that originated from the weathering of material up-slope, which was transported and deposited along with aeolian material.

The Effect of European Settlement on the Landscape

The influences of European settlement of the Curnamona region have caused major changes in the landscape over the last 150 years. Grazing practices, the introduction of domestic and feral herbivores and land clearing have accelerated rates of erosion by sheetwash, rilling, gulling and aeolian deflation (Fanning 1999). This has resulted in channel enlargement and knickpoint retreat as well as the destabilising of riparian areas and disruption to infrastructure, for example, fences (Pickard 1994), roads (Fanning 1996), and sites of cultural and environmental significance (Hill, S.M., 2003 *pers. comm.*). Deposition of the material stripped from the land surface occurs along contemporary ephemeral creek systems.

Nomenclature and Description of Regolith Horizons in the Curnamona Province

Alluvial sediments

The main landform assemblages associated with alluvial sediments include channels, alluvial and depositional plains, swamps, outwash fans, and drainage depressions (Hill *et al.* 1994). Larger streams mostly originate in bedrock-dominated uplands and flow towards flanking regolith-dominated terrains where they typically terminate as braided alluvial swamps, sheetflood fans and lacustrine depressions. Recent alluvium covers plains and valley floors associated with present day ephemeral drainage networks.

Throughout the Olary Domain, ephemeral channels adjacent to overland flow-dominated plains are now eroding into older alluvial sediments. Channels also occur in shallow valleys that are incising into areas of exposed bedrock and colluvial slopes. Distal to these regolith-landform are fans of alluvial or colluvial material that flank the hills and slopes of high relief.

Overbank deposits form adjacent to major drainage channels, where alluvial processes have deposited sediments on the flanking depositional plains. This typically occurs in the lower portions of the watercourse, where channel depths are lower in magnitude than in the upper regions where arroyos form. During large rainfall events the water in the channels may break the banks, flowing over the landscape and depositing material in sheetflood processes. The texture of overbank deposits range from mud to sandy material which merge laterally with the colluvial and sheetflow deposits. The shrub-like tree, Eremophila sp., commonly occurs at the margins of the deposits, marking the extent of the water's digression from the channels.

Thickness of the alluvial and colluvial cover in the southern Olary Domain is typically only 2-3 m in areas where there are some exposures of the saprolite. In regolith-dominated depositional and alluvial plains, the thickness of cover is usually much greater.

The northern parts of the Olary Domain generally have a thicker package of alluvial and colluvial material (Lawie 2001), with observations of up to 80m of transported materials logged in drill holes from the Benagerie Ridge area (Tan *et al.* 1998; Busutill & Law 2003).

Aeolian sediments

Well-sorted sand and clay pellet deposits occur over a wide range of bedrock and other materials in the Olary Domain. Holocene climatic conditions were typified by a greater temperature gradient between Australia and Antarctica than seen today. This caused strong westerly winds across vast arid regions of southern portions of the continent. The dry, cool glacial conditions and low-stand sea levels were complemented with reduced vegetation cover and consequently increased erosion by wind and fluvial processes. The deposition of aeolian material was suggested to be associated with a period of aridity in the late-Quaternary, around 17000-15000 BP (Bowler *et al.* 1976). Aeolian transported materials consist predominantly of clay pellets (described as ‘Parna’ by Butler 1956), similar to those described by Bowler (1973) and Dare-Edwards (1984), which were derived from a desiccated lacustrine source. Lake Frome is a possible source, as it is northwest of the study area and in the path of the prevailing winds (Thomson 1980).

The aeolian deposits contain a moderate textural contrast, with a shallow, light brown to red-brown loamy A horizon, which abruptly overlie a medium blocky red clay-loam to clayey B horizon. The transported clay pellets are accompanied by rounded silt-sized calcium carbonate nodules, which are extensive in the BII horizon. This carbonate may have been dissolved and re-precipitated in the Bcs horizon as a hardpan overlying the saprolite. The source of the carbonate may also have originated from rainwater.

Regolith Carbonate Accumulations

Regolith carbonate accumulations (RCA) had previously been thought to predominantly occur in semi-arid to arid regions of the world (Milne 1992), where the limited supply of water had reduced the effective removal of carbonate minerals in solution. This simplistic view is challenged by the presence of regolith carbonate in the southern regions of South Australia and western Victoria. The increasingly arid climatic conditions of the late Cainozoic, coupled with decreasing rainfall and high evaporation rates permitted widespread regolith carbonate formation in the central and southern portions of Australia. This was aided by the influx of aeolian derived carbonate material from the coastal regions to the southwest. Pedogenic (vadose) RCA are thought to occur where winter rainfall contains high concentrations of Ca and Mg. These elements concentrate in the soil through evaporation and precipitate as carbonates.

Regolith carbonate accumulations develop as a variety of morphologies, such as nodular, boulder, massive sheets of tabular material, duricrusts, encrustations of saprolite, friable powders, mottles and fine pedogenic coatings. Regolith carbonate is distinct from limestone and other carbonate accumulations in that their formation occurs in terrestrial settings. The RCA predominantly have a calcite-rich mineralogy but can also consist of dolomite, or more rarely, aragonite. Other materials such as quartz, feldspar, muscovite, zircon, smectites and gypsum also make up a minor portion of the mineralogy in many cases (Hill & Foster 1998; McQueen *et al.* 1999). Weathered bedrock that is rich in Ca (such as amphibolites) have been found to have a predisposition for RCA to form in the overlying pedolith and the formation of an indurated hardpan of regolith carbonate over the saprolite (Anand *et al.* 1997).

In the Curnamona region, RCA occur as hardpans, pisoliths, nodules, mottles and pedogenic layers or horizons throughout the landscape (Figure 2). They develop in aeolian/alluvial sediments, soils, weathering profiles or directly capping bedrock. The thickest and most laterally extensive accumulations mostly occur within broad valley systems containing alluvial and aeolian regolith materials (Hill 2000).

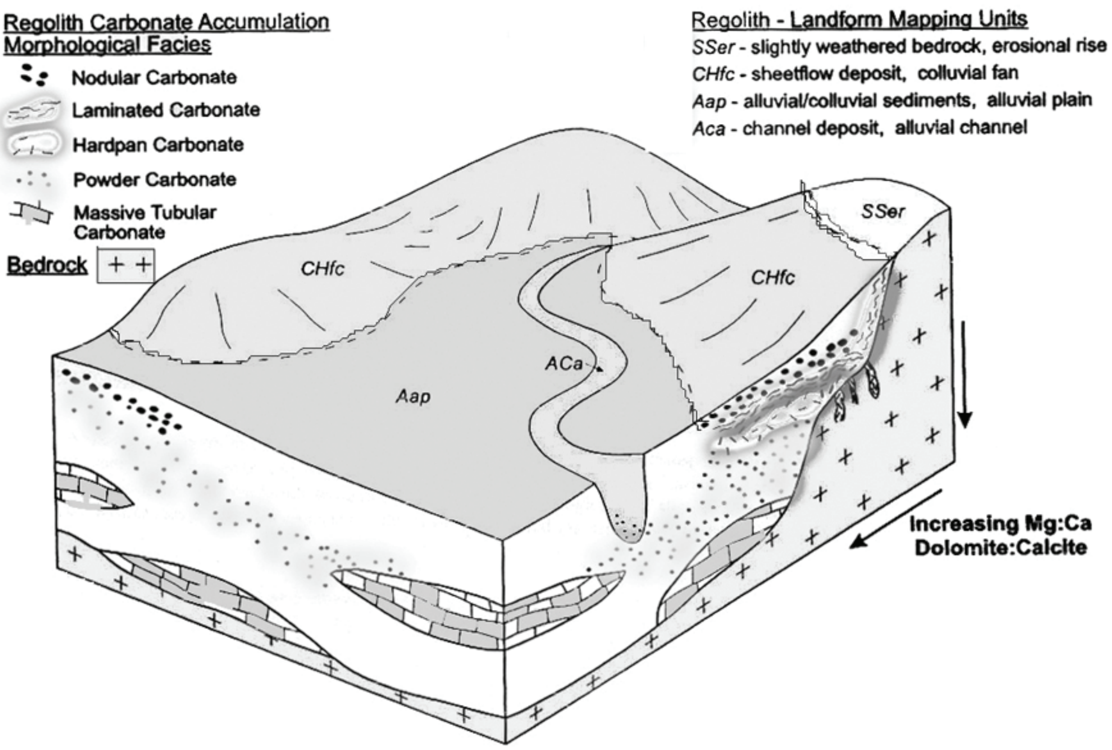

Figure 2 Morphologies of Regolith Carbonate Accumulations in the Curnamona Province, demonstrate variations through the profile and over lateral distances. This can be closely linked to the regolith materials and the landform setting. Regolith-landforms can be used to predict the presence of RCA (adapted from McQueen *et al.* 1999).

Colluvial sediments

Colluvial sediments in the Olary Domain include rock falls, creep, slides, debris flows and sheetwash. Sediments transported and deposited by shallow overland flow (including sheetwash) are extremely widespread across the Curnamona Province, typically extending from the upper slopes of rises down towards the axes of adjacent valley systems where they contribute to alluvial sediments (Hill 2000). Colluvial deposits occur along valley margins and adjacent to bedrock exposures and can be associated with alluvial fans.

Areas of prominent quartz or ferruginous lag occur on low relief plains flanking rises where shallow overland flow (sheetflow) processes dominate. The quartz material originates from sub-cropping bedrock and quartz veins, which have been exposed by erosion. On the lowermost portion of slopes the process of overland flow may converge and form rills approximately parallel to slope. These gradually merge with the drainage depressions and depositional plains, where the slope is too small to facilitate overland flow.

Most sheetwash deposits are contained within broad low relief fans and lobes that mantle slopes. Sheetflow occurs on soils with relatively low infiltration rates (Butt 1992). Many have a prominent 'contour band' or 'tiger-bush' surface pattern (as shown in Figure 3 and Figure 4, where surface lags conform to form bands perpendicular to the slope direction of alternating sparsely vegetated pebbly bands and more densely vegetated bands of silty sand (Brown & Dunkerley 1996; Dunkerley & Brown 1999; Wakelin-King 1999).

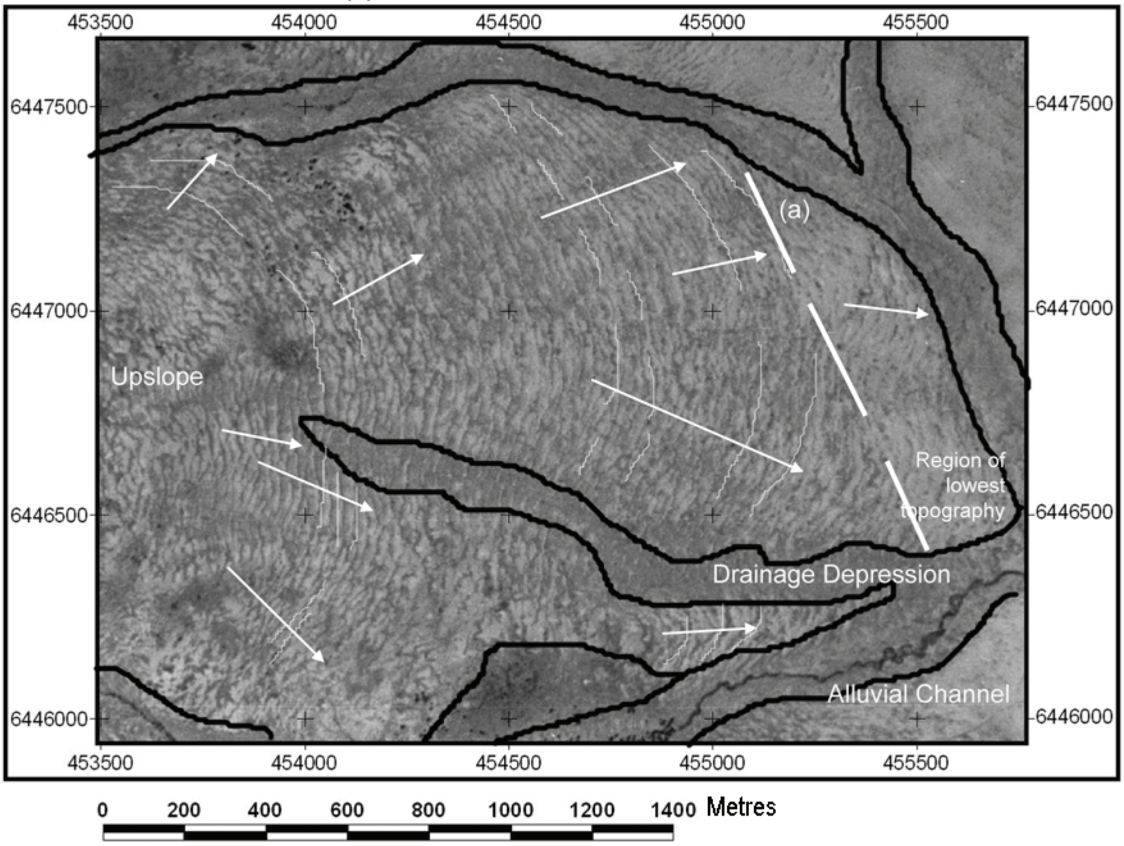

Figure 3 Example of banded vegetation on an ortho-photograph of the White Dam alluvial plain. Sheetflow occurs from the topographically elevated region in the west, downslope to the east. Note the reduction of the clarity of the vegetation bands to the east of the fence line (a) due to increased grazing levels

Linear vegetation banding occurs on sheetflow-dominated, low-relief plains where the substrate supports vegetation growth and infiltration rates are low (Chappell *et al.* 1999; Wakelin-King 1999). There have been many differing theories on the mechanics of how banded vegetation is formed. The shape and morphology of the vegetated bands has been associated with the slope gradient and annual rainfall (Valentin *et al.* 1999).

Ludwig *et al.* (1999) suggested that collections of material on the surface acted as a trap for sediment and organic material, which increased the potential of germination of seedlings that were captured (Figure 4). The colonising plants, usually chenopods such as *Atriplex sp*. or *Maireana sp.*, increase the permeability of the soil through the penetration of roots and the production of organic acids. The areas of increased permeability are contrasted by the interband regions, where a soil crust or surface lag material promotes shallow overland flow. The water is shed from these regions to the vegetated bands where it penetrates soil, providing moisture for the plants.

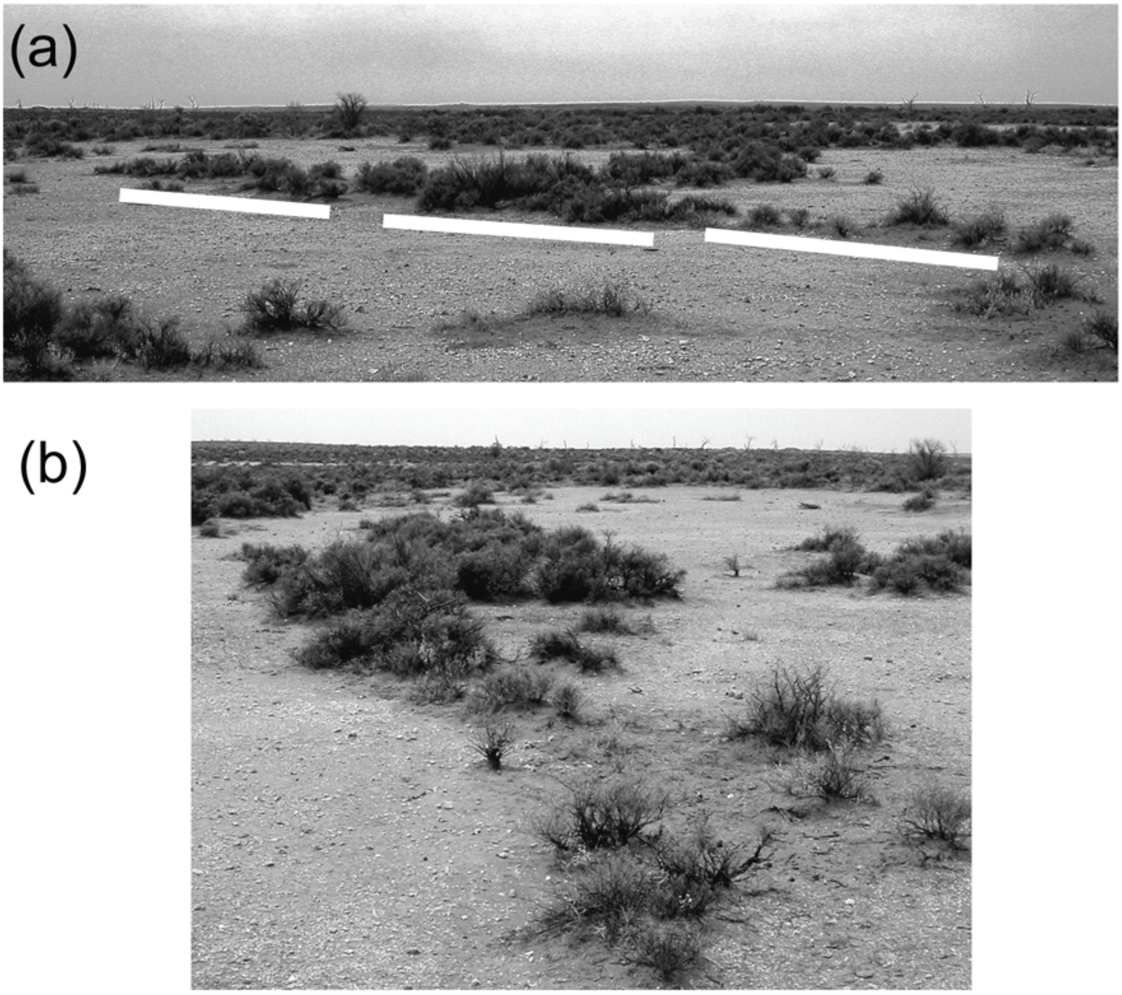

Figure 4 Example of banded vegetation from the White Dam alluvial plain, in the Olary Domain. The upper photograph (a) shows the vegetation band looking upslope. The total length is approximately 30 m long by 3 m at the widest portion. (b) A view along the contour band, showing the accumulation of vegetation litter and the increased surface roughness within the grove. The microtopography is not evident from the photographs, demonstrating the subtleness of the landform. The groves at this location were dominated by *Maireana pyramidata.*

The microtopography of the linear banded region consists of a series of shallow hollows (<0.1 m) in the interbanded regions and slightly elevated vegetated regions arranged in alternating parallel strands. The explanation for the topographically elevated regions has been suggested to be due to the trapping of eroded and aeolian materials by the chenopods and plant litter. Dunkerley & Brown (1999) found that the surface roughness increased downslope through the interband region and reached a maximum in the vegetated banded region. They concluded that the surface runoff was hindered by these properties and that the banded vegetated landscape represented a stable configuration.

Vegetation banding has been predominantly described as occurring parallel to topographic contours although this is not always the case (Dunkerley & Brown 2002). Oblique vegetation banding, with an orientation of 45-70º to topographic contours, has been shown to occur in regions of western New South Wales.

Vegetation and its Use as a Surrogate for Regolith-Landforms

The vegetation of the Olary region is dominated by chenopod scrublands, mostly consisting of bladder saltbush (*Atriplex vesicaria*) and copper-burrs (*Sclerolaena spp*.) across plains and rises. Mulga (*Acacia aneura*) and belah (*Casuarina pauper*) open woodlands occur, with a chenopod understorey, across the rises and hills of the region. The larger ephemeral creeks are lined by riparian woodlands of river red gum (*Eucalyptus camaldulensis*). A summary of the vegetation types of the region is show in Table 1.

Figure 5 displays a toposequence of the vegetation types and their associated regolith-landform units for an idealised landform cross section, based on observations from the Curnamona Province. A typical profile consists of Rock Sida (*Sida petrophila*) mulga on the topographically elevated saprolite rises with bluebushes on the calcareous slopes. The fringes of the saprolite-dominated terrains are marked by the presence of western rosewoods. Bladder saltbush typically occurs on the lower slopes of the rises and low plains. The alluvial regions are characterised by the presence of larger shrubs and trees, such as river red gums and prickly wattles.

Plant Type	Common name	Genus and species name	Regolith-Landform association
Tree	Mulga	*Acacia aneura*	Well drained substrates, saprolite exposures, low hills and aeolian sand plains
Tree	Belah	*Casuarina pauper*	Occurs in a variety of RLU, associated with hardpan RCA
Tree	Belah	*Casuarina cristate*	Larger, less emaciated appearance than pauper
Tree	White Cyprus Pine	*Callitris columellaris*	Aeolian material, saprolite exposures and colluvial slopes, commonly harvested for timber
Tree	River Red Gum	*Eucalyptus camaldulensis*	Forms ribbon strands along riparian fringes of large ephemeral creeks
Tree	Western Rosewood	*Alectryon oleifolius*	Associated with Belah on RCA soils and fringing saprolite dominated terrains
Tree	Prickly Wattle	*Acacia victoriae*	Associated with alluvial landforms
Shrub	Bladder Saltbush	*Atriplex vesicaria*	Widely distributed perennial with shallow root system, abundant in alluvial and depositional settings forming monospecific plains
Shrub	Pop Saltbush	*Atriplex holocarpa*	Adjacent to alluvial channels and creeks
Shrub	Thorny Saltbush	*Rhagodia spinescens*	Found in alluvial plains and creeks
Shrub	Black Bluebush	*Maireana pyramidata*	Commonly occurs on friable substrates. Deep rooted and long living (100+ years). Deeply weathered saprolite and low sloping alluvial valleys
Shrub	Pearl Bluebush	*Maireana sedifolia*	Commonly occurs on friable substrates containing RCA within 60 cm depth from the surface (Cunningham *et al.* 1992)
Shrub	Rock Sida	*Sida petrophila*	Predominantly occurs where saprolite is present/subcropping on erosional rises and drainage depressions
Shrub	Emu Bush	*Eremophila sp.*	Colonises various regolith-landforms
Shrub	Hop Bush	*Dodonaea sp.*	Sandy and clay-rich soils on alluvial plains

Table 1 Summary of the common vegetation of the Curnamona Province (after Hill 2000; Hill & Hill 2003).

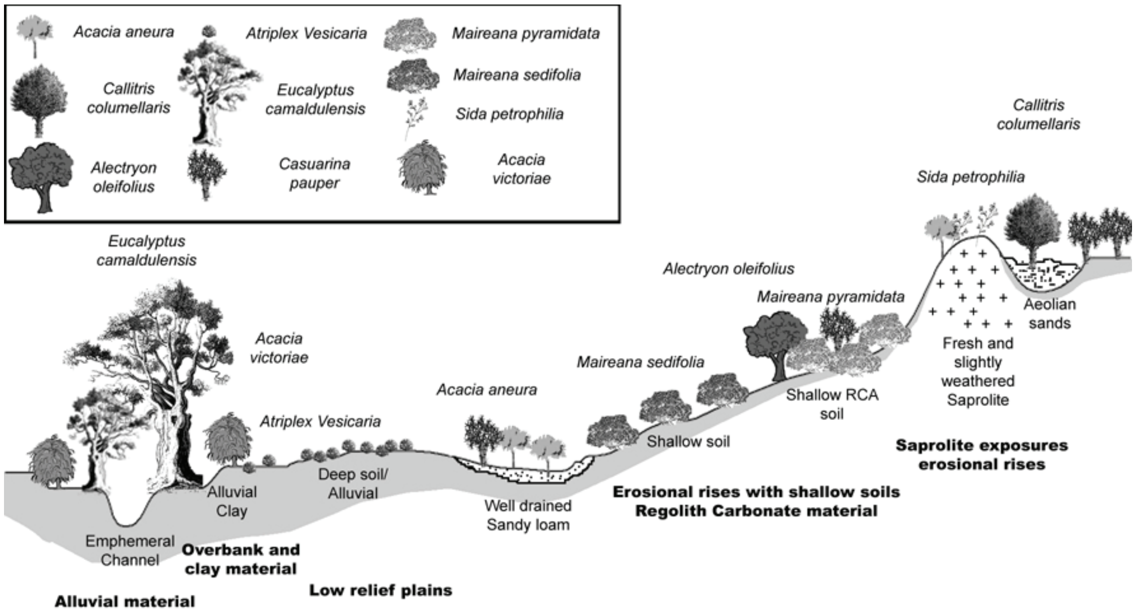

Figure 5 Generalised vegetation toposequence for the White Dam area, showing variation of vegetation species with differing regolith materials and position in the landscape. Once the vegetation associations of different regolith-landforms have been established, they can be used as surrogates in the regolith-landform mapping process (adapted from Hill 2000).

Vegetation cover has markedly declined since the pastoralism of the region due to the use of the timber for fences, firewood and drought fodder and the consumption of shrubs by feral and domestic herbivores (Jenson 2001). A detailed nomenclature of plant species of the eastern central region of Australia can be found in Cunningham *et al.* (1992), and Hill (2000) and Hill & Hill (2003) give a summary for the Curnamona Province.

Geomorphology and Location of the Area of study

Topography and Regional Drainage Systems

The area of this study is constrained by the coverage of the hyperspectral dataset. The dataset consists of a rectangular area, approximately 10 km wide by 25 km long, extending in a northeasterly direction (Figure **7**). The highest elevation occurs at MacDonald Hill (373 m), in the southwestern portion of the study area, which is part of the MacDonald Ranges. The topographic relief decreases to the north and south to an average elevation of 200 m above sea level (Figure **6**).

The regional drainage features consist of ephemeral creeks, which are subject to flooding after irregular, low frequency, high-magnitude rainfall events. The main drainage feature in area is Cutana Creek, which is joined by Bulloo Creek from the northwest and continues to the east into Mingary Creek, which travels in a northerly orientation out onto the Mundi Mundi Plain. To the South of the MacDonald Ranges the Wiawera Creek travels southeast onto the plains of the Murray Basin (Figure **7**).

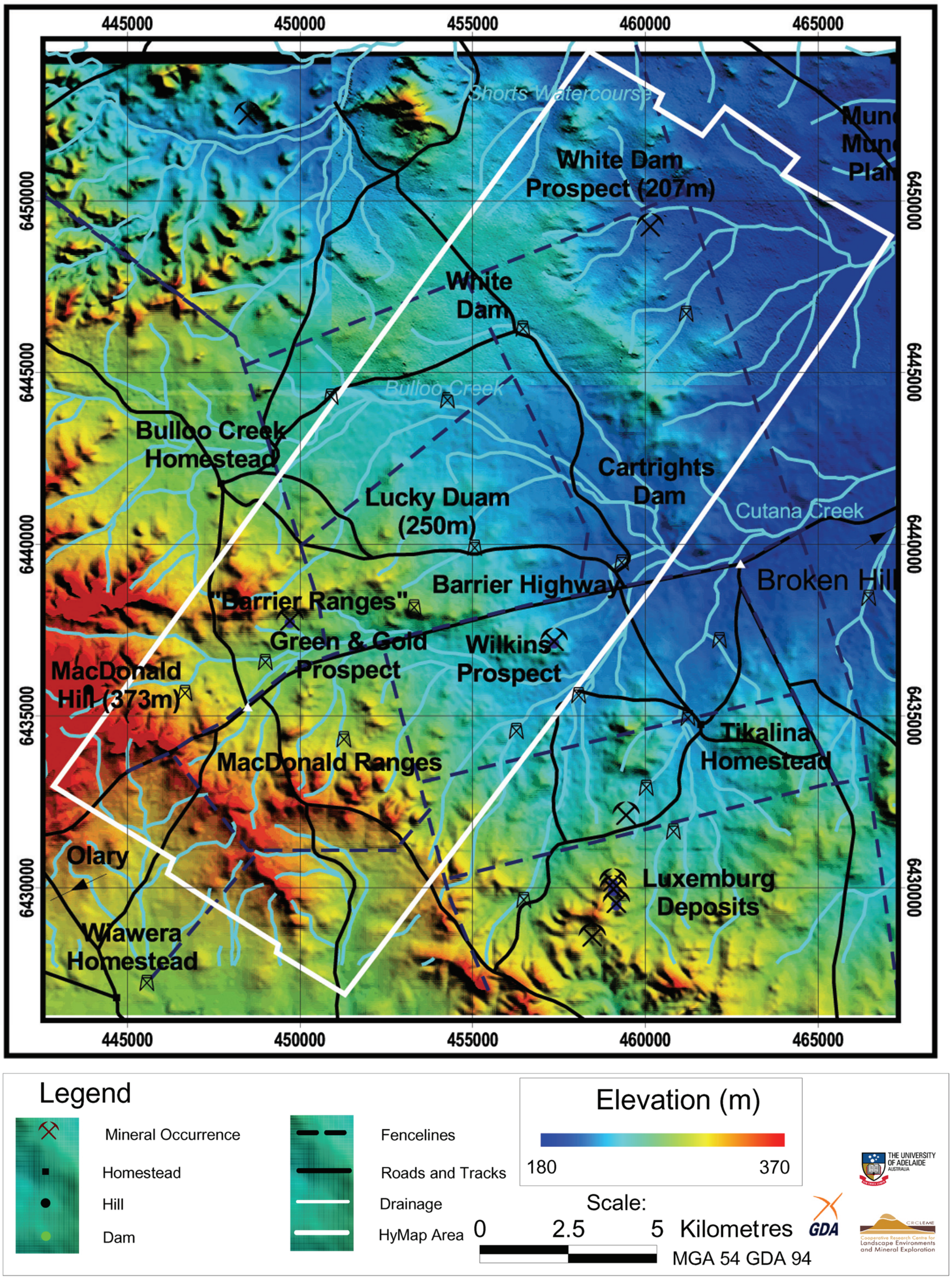

Figure 6 Digital elevation model of the study area generated from PIRSA supplied data. The original elevation data was derived photogrammetrically and used to ortho-rectify the aerial photography in the production of ortho-photographic images. The northwestern corner of the data was not covered by the original dataset and was filled with MIMEX geophysical survey elevation data of higher resolution. The mosaiced portion has a slightly higher overall elevation and produces a slight discontinuity where the overlap occurs.

Detailed Overview of the Field Area

The southern area consists of Adelaidean metasediments that make up the southern facing slopes of the MacDonald Ranges and the northern margin of the Murray Basin. The MacDonald Ranges define the position of the drainage divide that separates the Lake Frome Basin to the north and the Murray Basin to the south (as shown in Figure **7** and interpreted from the DEM, Figure 6). The MacDonald Ranges also define the regional contact between the Adelaidean and Willyama Supergroup rocks, which occur to the south and north of the boundary respectively. To the south of the MacDonald Ranges an expanse of 'badlands'-style topography exists, where extensive erosion has caused gulling on the southern rises. As the slope angle decreases the landscape becomes dominated by alluvial landforms which surround small rises of exposed Adelaidean basement. Surface lags and alluvial channels dominate the landscape.

To the north of the MacDonald Ranges the slightly weathered Willyama saprolite exposures form northward trending small hills and rises that are separated by channels and erosional depressions, which drain into the east flowing Cutana Creek. With increasing distance from the MacDonald Ranges the rises display lower topographic relief and the exposures of basement become less distinct. The landforms around the Cutana Creek region are dominated by transported regolith materials and vegetation, with exposures of saprolite isolated to the regions of higher topography.

The Wilkins Cu-Au prospect occurs in the central-eastern region of the study area, between the northeast orientated Barrier Highway and Cutana Creek. The area contains exposures of sheared and highly deformed Willyama Supergroup basement rocks, which are related to the east-west oriented ranges north of the Barrier Highway.

To the northeast of MacDonald Hill a graded road, leading north to Bulloo Creek Station intersects the large east-flowing channel, which drains from the exposed rocks of the Kalabity Inlier. To the south of the creek is a pair of quarries, immediately adjacent to the Bulloo Creek road, which are used for the road material around the Bulloo Creek station. The region contains abundant subcrop of Willyama Supergroup rocks, with a thin cover of alluvial and colluvial material. The rocks to the north of Cutana Creek are highly altered, with abundant muscovite. These Willyama Supergroup rocks are part of one of the shear zones that dissect the region in a generally east-west orientation.

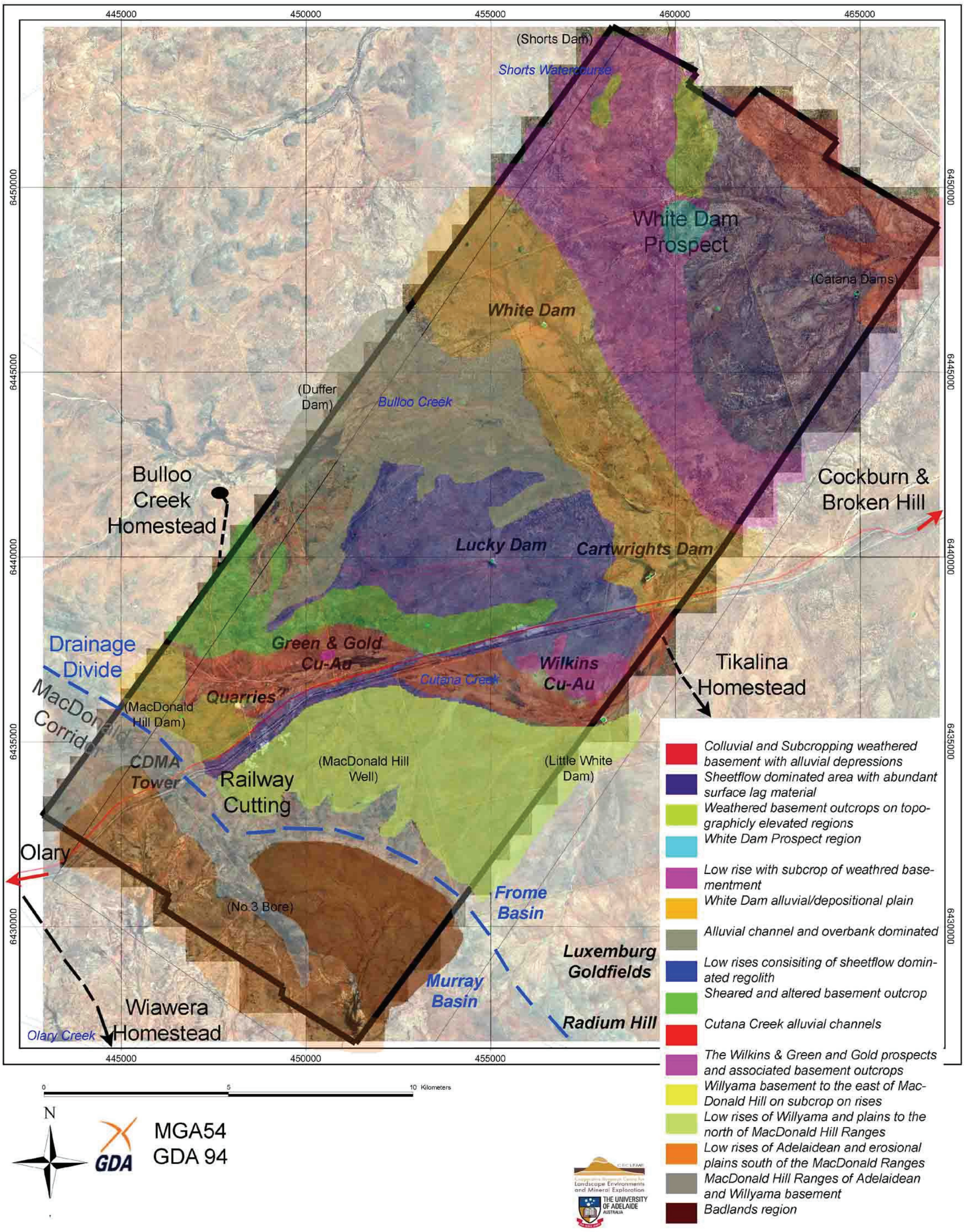

Figure 7 Map showing the main features of the region of investigation discussed in the text.

Cutana Creek flows to the east-southeast with a ridge of exposed Willyama Supergroup derived saprolite trending approximately parallel to the drainage. This linear belt of outcrop (termed in this study as the 'Barrier Ranges" due to the proximity of the highway), appears to be the easterly succession of the rocks that occur in the Wilkins region. This feature marks an important geomorphic feature in the region as it separates two catchments and indicates the approximate boundary between the outcrop and regolith-dominated terrains. The Green and Gold Cu-Au prospect is situated on a flood plain which is located south of the Barrier Ranges and east of Bulloo Creek Road. This prospect occurs at the transition between the low rise to the north and the alluvial plain containing Cutana Creek.

The region to the north of the Barrier Ranges is dominated by alluvial systems with small, isolated occurrences of exposed basement inliers. The region drains to the east and joins the southeast trending floodplain (termed the White Dam Alluvial Plain), which contains the reservoir 'White Dam'. The alluvial plain consists of a stretch of area with minimal chenopod colonisation, intersected by tree-lined ephemeral channels and closed woodlands of *Acacia aneura*. The northern regions of the plain are blanketed by a layer of PSA and have isolated banded vegetation occurrences. The alluvial cover is thinner in the southern regions where weathered subcrop has been exposed as inliers.

In the southern region of the White Dam Alluvial Plain, the drainage features from the north-northeast, northwest and west converge to form a large meandering channel, which flows east and joins the Mingary Creek system. Cartwrights Dam, which is the largest water body in the study area, is located in the region of the intersection. The creeks merge and follow a sinuous (meandering) path to the east-southeast and before joining the Mingary Creek system, which flows northward onto the Mundi Mundi Plain.

The White Dam Alluvial Plain is bound to the east by an elevated north-northwest trending region, which marks the approximate location of a major fault. To the east of the region the landscape is dominated by low hills and eroded plains, which are blanketed by lag material. In the northern-most portion of the area there are a series of low hills that have exposures of Willyama Supergroup bedrock at the crests.

The White Dam Cu-Au prospect is in the central-northern portion of the study area, under a blanket of alluvial and colluvial cover. An ephemeral creek system, flowing in an easterly direction, occurs to the immediate north of the prospect. Scattered exposures of slightly to moderately weathered saprolite to the north, south and west, occur in the region of the White Dam prospect.

Figure 8, Figure 9, Figure 11 and Figure 10 demonstrate the range of regolith-landforms present in the White Dam region. A distinction is made between the various regolith-landform units by their associated regolith-landform mapping codes, as defined by Pain *et al.* 1991.

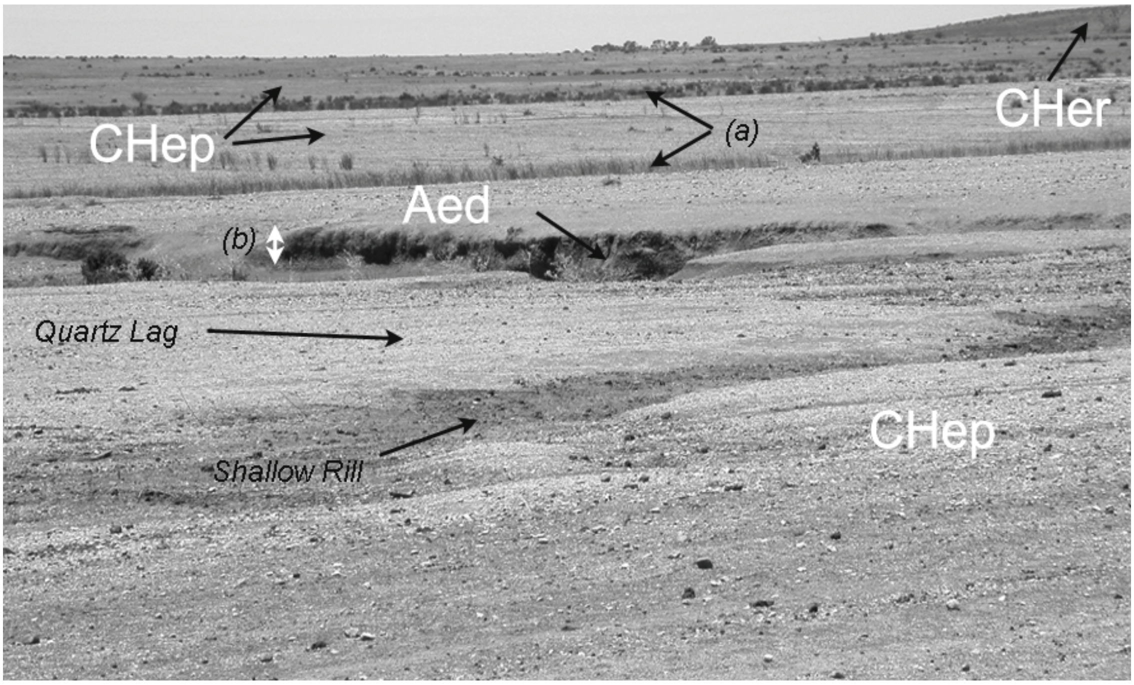

Figure 8 View across a topographically low lying area, towards an elevated rise (background) that is dominated by colluvial-sheetflow processes (CHer). Abundant quartz material occurs on the surface of the depositional plain (CHep)-foreground and middle distance), which is dissected by recent channelling (Aed). Note (a) the vegetation banks have been planted by landowners in attempt to reduce erosion by limiting overland flow. In the foreground a shallow rill, contained a lesser abundance of quartz lag, can be seen starting to develop. Behind this feature is an erosional channel, which is down-cutting through the PSA (b) and underlying palaeosoil.

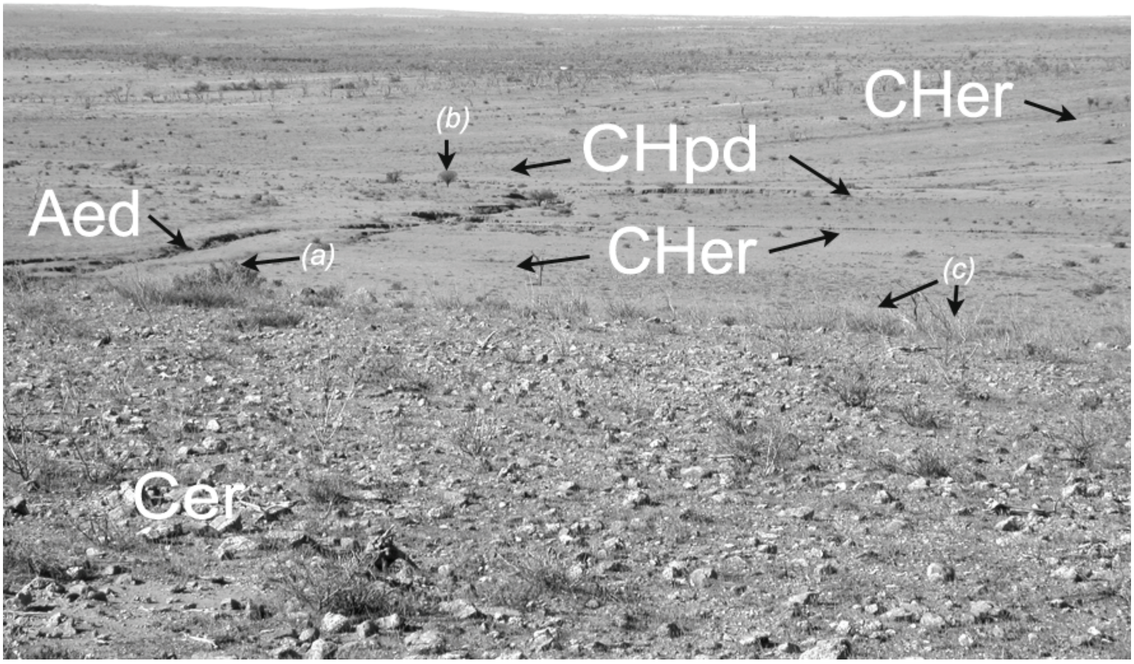

Figure 9 View from a topographically elevated position across colluvial-dominated landscape. The material in the foreground consists of colluvial ‘float’, derived from underlying basement subcrop. The cobble-sized clasts occur on an erosional rise (Cer), which has a decreasing slope angle and in the middle distance, sheetwash material become the dominant surface material (CHer). In the far middle distance the landform has less relief, forming a depositional region (CHpd) which is flanked by a CHer in the far distance. Materials shedding off of the erosional rises are transported by sheet-wash mechanisms downslope to the CHpd, where they accumulate. An erosional depression (Aed) parallel to slope originates on the rise (Cer) and terminates in the region of lowest relief (CHpd). A variety of vegetation types occur in the region and, although sparse, can aid the interpretation of the regolith-landforms. (a) A bluebush chenopod (*Maireana sp.)* occurs at the limit of the colluvial cobbles, making the approximate boundary of the two regolith-landform units. On the depositional plain (b) a *Dodonaea sp*. occurs on the clayey soils. On the colluvial slopes (c) various low grasses and forbs colonise between the cobbles.

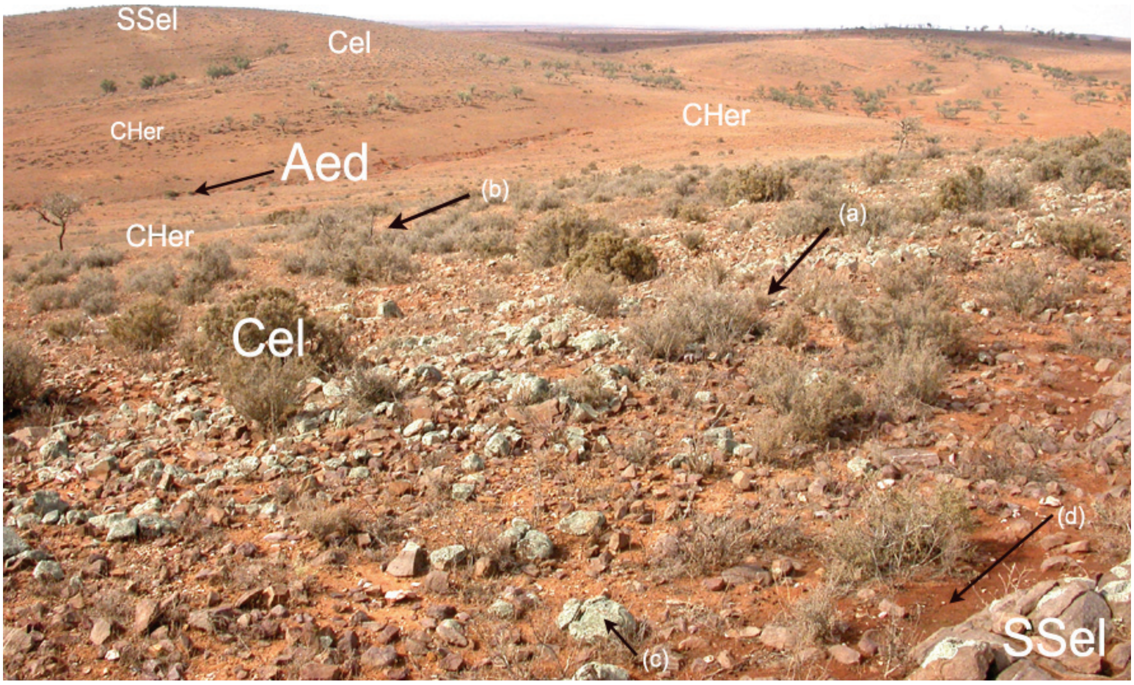

Figure 10 An erosional depression (Aed) occurs between two low hills that have exposures of saprolite at the crests (SSel). A regolith toposequence occurs downslope of colluvial material (Cel), which is flanked by sheetwash deposits on the lower slopes (CHer). Variations in the vegetation communities highlight the change in landforms and regolith materials. (a) *Atriplex vesicaria* occurs on the colluvial materials, whereas (b) *Maireana sp.* occurs on the lower portion of the slope. In the middle distance a shoulder between the two low hills is mantled by quartzose sheetflow materials. In the foreground (c) cryptograms can be seen covering a larger portion of the exposed surface of the (a) colluvial cobbles (light green colouration). (d) The soil immediately adjacent to the bedrock exposures displays a dark-red colour, which contrasts the yellow-brown material partially covering the downslope float and sheetwash.

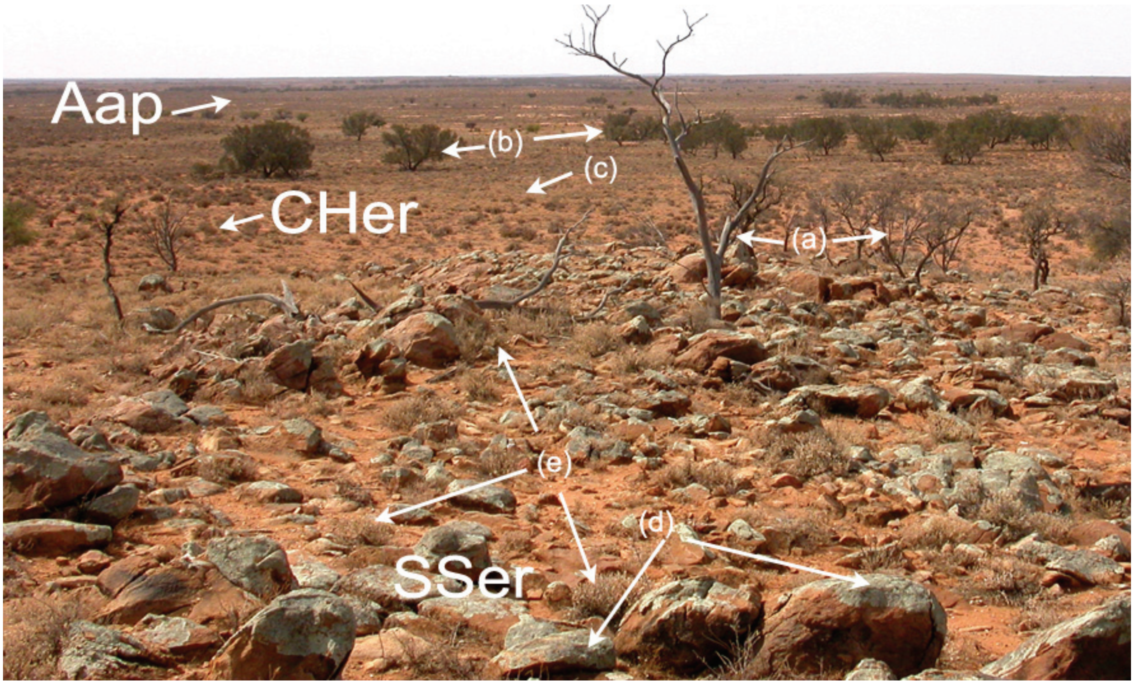

Figure 11 View from a low rise of exposed Willyama bedrock colonised by (a) emaciated *Acacia aneura* and (e) low grasses between the rocks, which are (d) coated by a cryptogram cover (green lichen). The downslope materials consists of sheetflood sediments of red-brown quartzose sands and lithic gravels (CHer) colonised by (c) *Atriplex vesicaria*. The region further downslope is colonised by (b) *Alectryon oleifolius* (western rosewood), which typically occurs in regions containing near-surface regolith carbonate accumulations. In the far distance is an alluvial plain (Aap) in the lowest portion of the local area.

3. INTERPRETATION OF REGOLITH-LANDFORMS USING REMOTELY SENSED DATA

The digital data examined for their usefulness when applied to regolith-landform mapping, consisted of multispectral, hyperspectral, geophysical and topographical imagery. Relatively low-cost Landsat and ASTER space-borne satellite data were compared to ortho-rectified photography and hyperspectral imagery for pattern recognition. Each dataset were used to add a different component of information to the final product. For example, geophysical datasets, such as radiometrics, were utilised for their ability to reveal information on the surface materials when differentiation was inconclusive with the other imagery. Digital elevation models were found to be useful for adding landform and geomorphic information to the mapped regolith units, enabling areas of low topographic relief and rises to be differentiated.

Air-photographs were used as the initial source of information, as they displayed features in high-resolution and with natural colour red-green-blue (RGB) true colour composites (TCCs). Additional data were used to accentuate and characterise discrete features that were not identifiable on the air-photographs. Satellite imagery allowed a greater area to be covered, making it useful for regional studies, and possessed higher spectral resolution (a larger portion of the EM spectrum) than air-photographs. This allowed the Landsat and ASTER data to resolve a wider range of targets on spectral properties and composition of materials than air-photographs, which relied on colour, tone and texture to resolve small features. However, the space-borne imagery was not able to identify gradual boundaries of smaller RLUs. Figure 12 demonstrates the inadequacies of spatial low-resolution imagery for detailed mapping.

Mapping for this exercise was performed on transparent film over 1:30 000 scale printed images. The film was drum scanned, digitised and imported into a GIS (Pashley, B. 2004 pers. comm.). Onscreen mapping of the digital datasets using a GIS package (ArcView version 3.3) was used for polygon classification and final map creation. Once the information had been digitised, a small number of units were further sub-divided into different regolith-landforms on the basis of field notes and information from the integrated datasets.

Ortho-Imagery

The highest resolution dataset consisted of 1.25 m resolution ortho-rectified colour air-photographs (supplied by PIRSA and acquired by KEVRON Pty Ltd, 1997). This was used as a base image for regolith-landform identification, field navigation and geo-registration of the other datasets. A contrast stretch enhancement was performed on the digital data to enhance subtle variations between the regolith-landform features. Figure 13 is an example of the enhancing effects of contrast stretching ortho-imagery.

The high spatial resolution enabled the presentation of small features, such as individual trees and rock exposures, to be identified from the contrasting red-brown soil (Figure 12). The variations between the surficial materials were generally subtle, with many units consisting of similar materials (for example, red-brown soil and chenopod shrublands) in different proportions.

Unit boundaries for regions dominated by sheetflow processes were often gradational, with variable abundances of vegetation or the mixing of communities across regolith-landform units. The transitional nature of these features made exact location of the RLU boundaries difficult and somewhat subjective in nature. This may have caused some boundaries to be displaced when comparing to field occurrences, but were often adequate for 1:30 000 scale mapping.

Feature Extraction Techniques and Results

The ortho-photography was displayed as a RGB true colour image, which resulted in a contrast of red-brown, pale orange-tan, blue-green grey, dark green-black and white tones. The red-brown regions were typically PSA, a red-brown alluvium/colluvium/aeolian material deposited on low sloping rises or depositional plains. The red colour was related to the topsoil (A) horizon that blanketed much of the lower topographic regions.

Red brown coloured areas were found to occur immediately adjacent to the blue-greenish grey regions and were often divided by the sinuous pale-orange tan and or dark-black regions, attributed to alluvial channels and alluvial depositional plains. Large areas of dark linear features along watercourses and near channels, were mapped arid swamps (Aaw1). These consisted of thickly vegetated areas of woodland, with an understorey of chenopods. Blue-greenish grey regions, which commonly occurred as inliers, were mapped as exposures of basement outcrop of the Willyama Supergroup and Neoproterozoic aged metasediments. The lithostratigraphies each showed characteristic patterns, with further differentiation of units able to be performed using an integration of remotely sensed datasets, although beyond the significance or purpose of regolith-landform mapping.

White patches, occurring as small circular features, were often found to highlight rabbit warrens (Figure 13). These bare patches of pale yellow-brown coloured soil were commonly excavated in soft friable substrates, such as where RCAs occurred. The burrowing consequently brought regolith carbonate material to the surface, where it contrasted the surrounding red-brown soils. Rabbit warrens were also observed along the contact of the Adelaidean and Willyama lithologies in the southeastern portion of the MacDonald Ranges. The excavation occurred in soils containing hardpan regolith carbonates, which had formed over the hydromorphic barrier. This region was colonised by trees of Casuarina pauper, which were visible in the high-resolution ortho-imagery, and the Landsat ETM+ panchromatic imagery (Figure 14b).

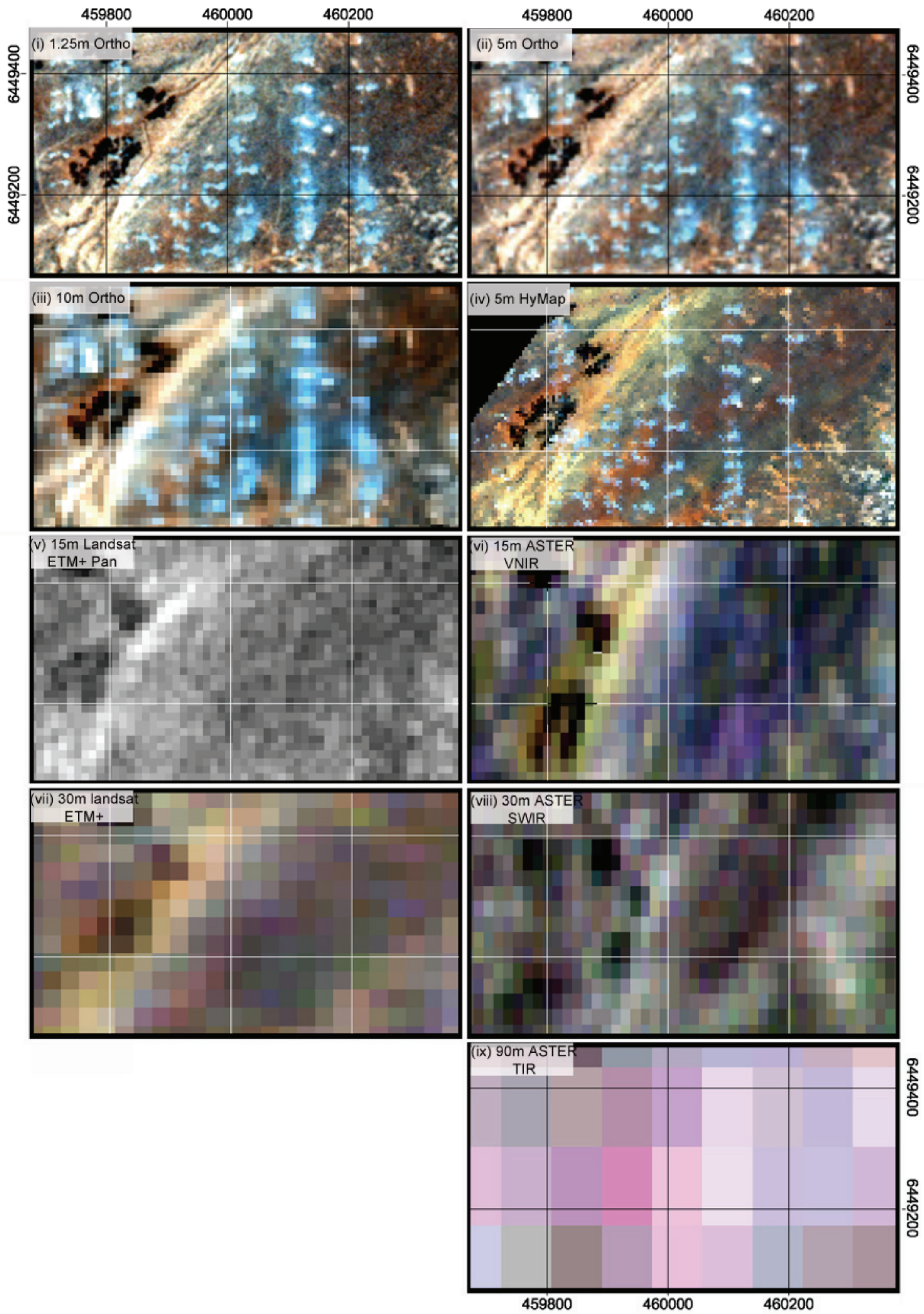

Figure 12 Comparison of the spatial resolution of various remote sensing datasets over the White Dam Prospect. The group of black pixels on the western edge of the area represents a group of trees in an alluvial channel. The trees are still visible in the 30 m Landsat and ASTER data, although it is difficult to distinguish RLU boundaries at this scale. Note the mis-registration of the ASTER VNIR and SWIR data. . Ortho-photography data was resampled from the original (i) 1.25 m resolution with (ii) 5 and (iii) 10 m, for comparison to (iv) 5 m HyMap imagery and the low-resolution space-borne data (v-ix). The low-resolution data

consist of (v) panchromatic band of Landsat ETM+ (15 m), (vi) ASTER VNIR, (vii) Landsat ETM+ TCC, (viii) ASTER SWIR (30 m) and (ix) ASTER TIR data.

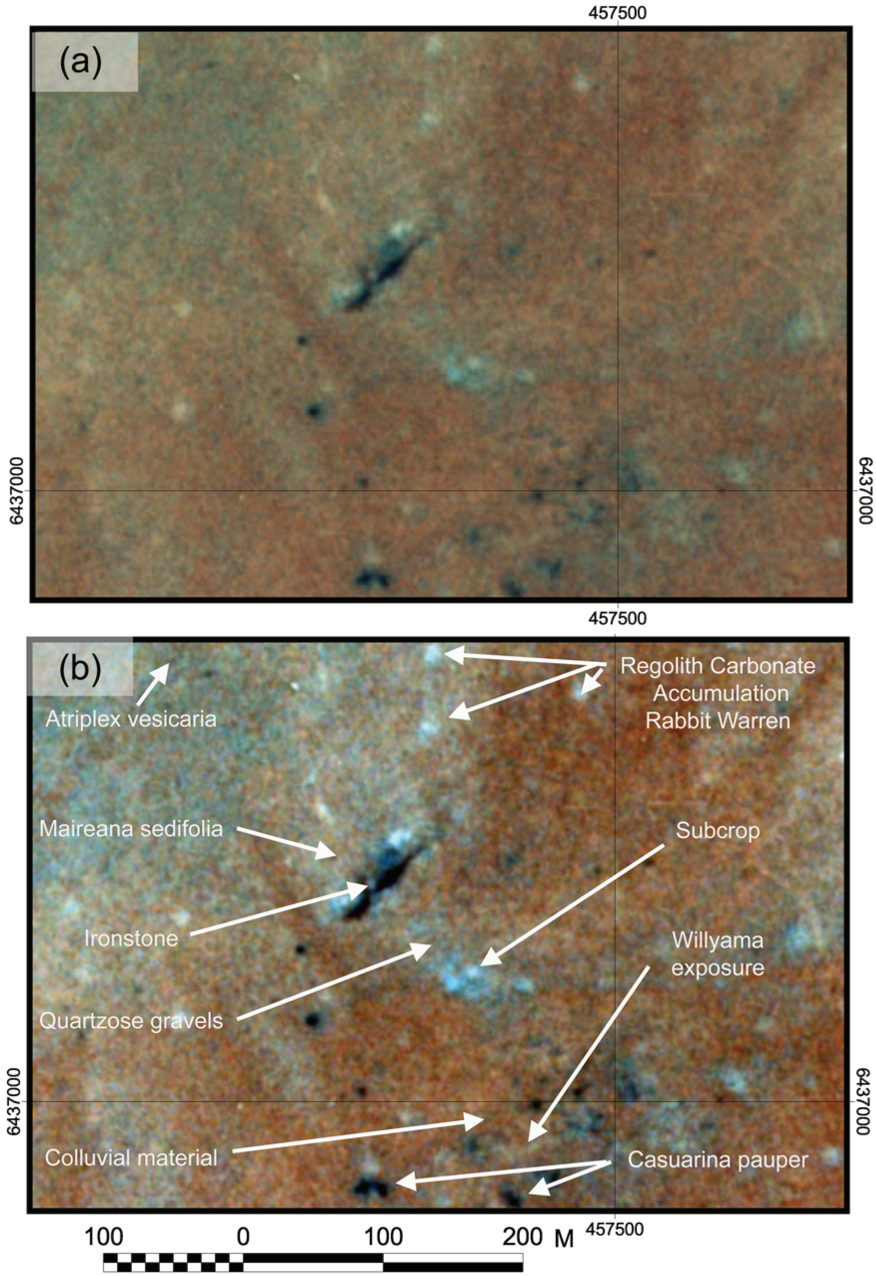

Figure 13 Contrast stretched (a) and un-enhanced (b) ortho-photography of the Wilkins Cu-Au Prospect. The topography of the area increases to the south, with the Willyama saprolite exposed on a low hill at the bottom of the images. The enhanced image allows for better discrimination of regolith features, especially the change in vegetation communities with different landforms.

Colonising vegetation affected the ortho-image by darkening the hues of RLUs in the TCC imagery, or darkening the tone in the greyscale-displayed imagery. Dense vegetation occurrences caused an increase in the darkness of pixels. Although often considered a hindrance to geologists, vegetation has been shown as a useful RL mapping surrogate. Hill & Foster (1999) demonstrated the use of arid vegetation as an indicator for underlying regolith materials; for example, the use of bluebush (Mariana sp.) as a proxy for regolith carbonate accumulations within the substrate.

The position of RLU in regolith toposequences can be identified by vegetation surrogates. Field observations noted a change in the vegetation communities across a profile from a topographically elevated to low lying region in the landscape. At the Wilkins Cu-Au Prospect, Mariana sp. was found on topographically elevated sheetflow dominated slopes, whereas areas of lower relief to the north were colonised by Atriplex vesicaria (Figure 13). Changes in vegetation types have been attributed to different substrate materials and thickness of cover.

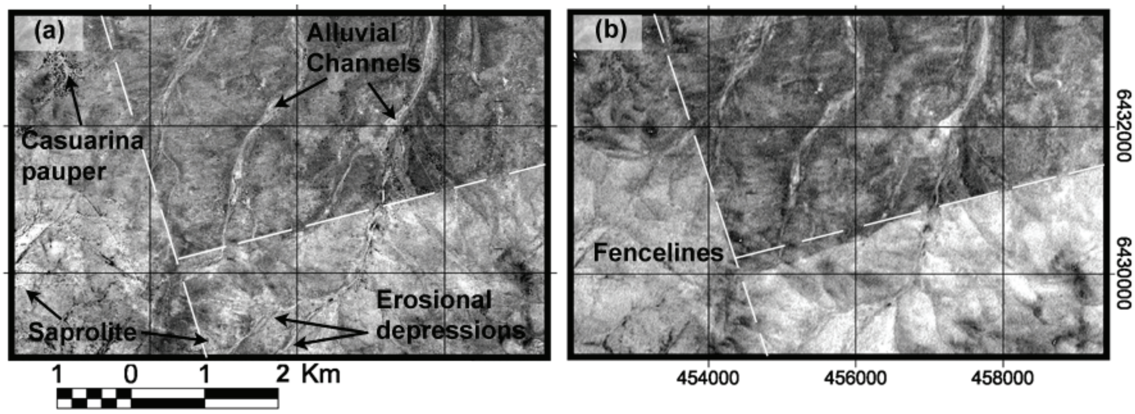

Figure 14 Differential vegetation abundances on neighbouring paddocks in ortho-imagery (1.25 m) (a) and Landsat ETM+ Panchromatic (15 m) data (b), making the identification of unit boundaries across these regions difficult. The ability of the datasets to resolve spatial features is similar at this scale.

The patches of lighter material were identified as predominantly milky quartz lag, where it formed stippled or banded patterns. In these regions overland sheetwash was the dominant method of surface transport. Sheetflow deposits commonly occurred on slopes immediately adjacent to bedrock or in association with alluvial channels. The fan or elongated triangular shaped occurrences commonly possess linear contour banding, associated with vegetation growth perpendicular to the slope (Dunkerley & Brown 1999; Wakelin-King 1999). Not all areas of banded vegetation contained prominent quartzose and lithic gravels. Regions where soil crusts and minor lags occurred had a red-brown colour to the interband regions.

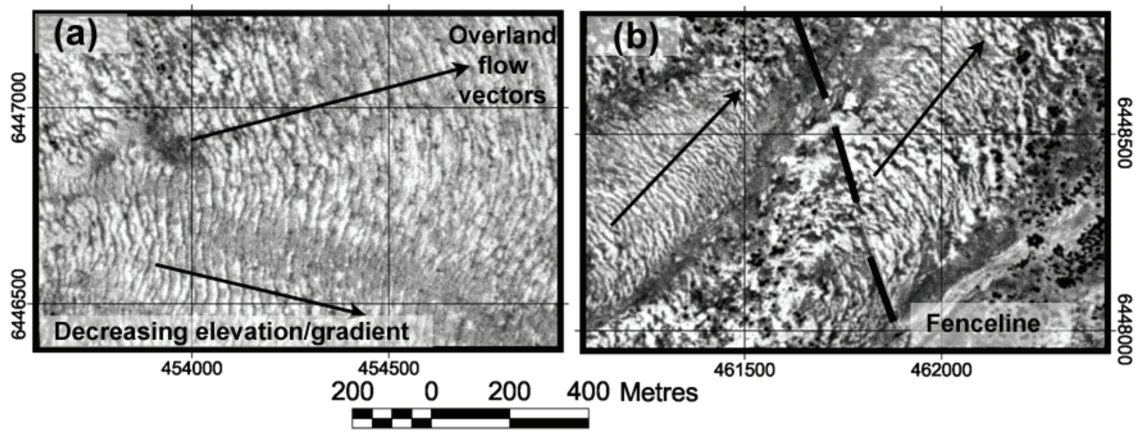

Figure 15 Examples of linear vegetation banding from the ortho-imagery of the White Dam area. The distance between the bands was found to increase downslope (a) and the degree of cohesiveness the banding decreases as flow vectors become less constrained by the gradient. The fenceline in image on the right (b) has influenced the process of overland flow, causing differences in the patterning either side of this feature. The central sheetwash fan displayed a greater abundance of quartzose surface gravels than the fan immediately to the northwest. The two fans are flanked by alluvial depressions that carry shed material along the direction of decreasing slope (northeast).

The high-resolution of the ortho-imagery was useful for the identification of cultural and man-made features. Objects such as dams, fence lines, tracks, buildings and quarries were easily distinguished from natural features. These features were not always obvious in the lower resolution data, except were extensive disturbances to the surrounding area through human activity had occurred.

HyMap Imagery

HyMap data consisted of 128 bands from 0.4 µm to 2.5 µm wavelengths with 20 nm spectral resolution. The spatial resolution of HyMap imagery is dependant on the acquisition flight height, with a typical survey consisting of 5 x 5 m pixels, with a 2.5 km wide by 25 km long swath. Techniques adapted from multispectral processing, such as D-correlation stretches of diagnostic wavelength regions (Figure 16) and three colour composites using Minimum Noise Fraction bands, can be used to produce images designed to highlight differences in the adjacent materials (Figure 17) The primarily benefit of hyperspectral data is the large range of narrow spectral bands that allow the discrimination of individual absorption features. Such spectral resolution allows the creation of RGB and ratio composite images that specifically target diagnostic mineral absorptions. The higher spectral and spatial resolution of HyMap over satellite-borne data allows for further discrimination of materials within major groups such as Fe-oxides, vegetation, clays, and to a minor degree, carbonates.

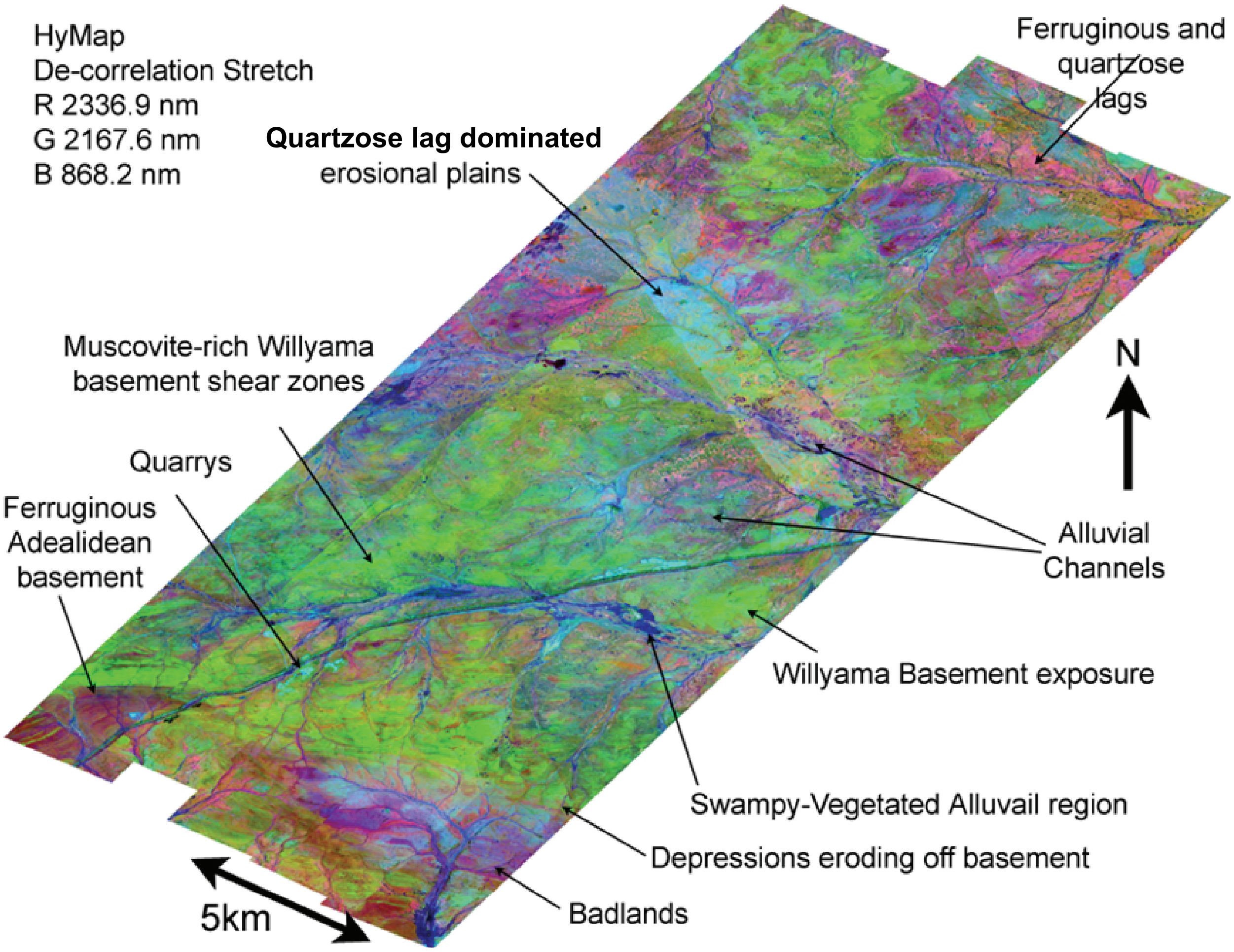

Figure 16 Perspective view of a decorrelation stretched HyMap image of bands 2336.9 nm, 2167.9 nm and 868.2 nm RGB of the whole five swaths. Basement exposures and areas of shallow depth to bedrock are bright green, due to high Al-OH absorptions, whereas ferruginous and vegetated areas are blue.

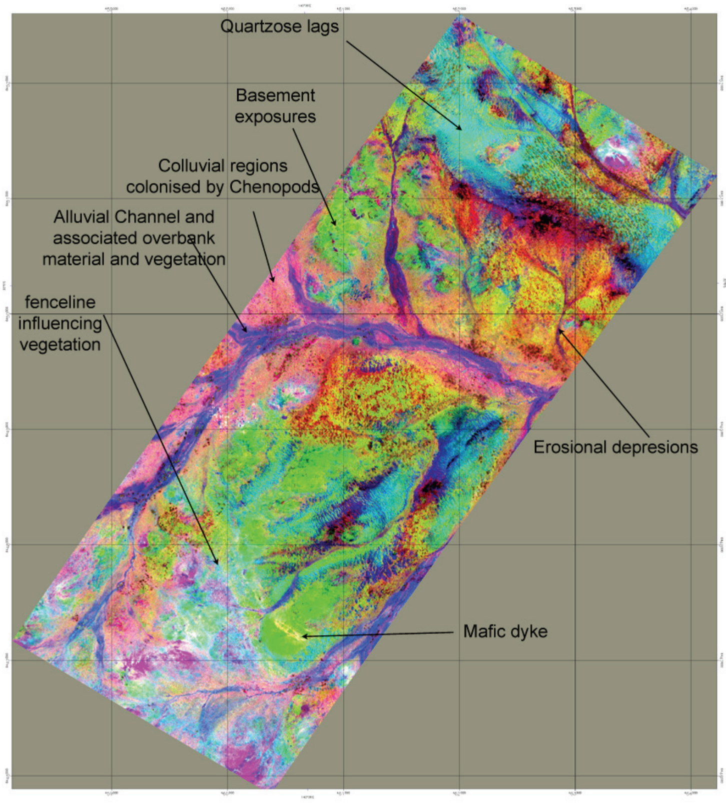

Figure 17 Regolith-landform mapping using MNF 123 RGB over the White Dam Prospect.

Feature Extraction Techniques and Results

Simulated TCCs can be constructed from the HyMap data to match the ortho-imagery, by using bands with similar centres to the RGB colours. HyMap TCC of the White Dam area was found to display a larger contrast between materials than the enhanced ortho-imagery, as shown in Figure 12. This was attributed to the narrower bandwidths of the HyMap channels. Although the HyMap imagery displayed a lower spatial resolution than the ortho-imagery, the TCC images were found to be equally useful for mapping RLUs at the scale of 1:25 000.

One of the simplest methods for displaying hyperspectral data is as RGB D-correlation stretched colour composites selected from diagnostic band areas for Fe-oxides, clays and vegetation. The resultant image highlighted areas of vegetation in blue, outcrop as green and Fe-rich areas, regolith materials as pink-red hues. D-correlation stretching can be performed on the orthoimagery to produce similar contrasting images as the HyMap D-stretched data. Principal Component and Minimum Noise Fraction composite images can also be used for pattern mapping and RLU discrimination. Further processing, involving the examination of characteristic mineral absorptions and the bands that correspond to them, can provide a more specific analysis.

Hyperspectral Remote Sensing and Mineral Mapping of the Regolith

This research showed that the mineralogy of surficial materials can be determined from remotely sensed spectral methods, aided by proximal ground control measurements. Pre-processing and atmospheric correction of airborne hyperspectral imagery played an important role in the effectiveness of the information extraction processes. Selective atmospheric correction methods enhanced the overall spectral response of the scene, improving the ability to identify mixed endmembers. The development of semi-automated software for the application of a similar technique to the modified-radiative transfer/empirical line calibration technique performed in this study would greatly enhance the quality and interpretability of the HyMap imagery over less focussed atmospheric correction methods, such as HyCorr or ACORN.

Interpretations of the Remotely Sensed Data

Mineralogical interpretations of the regolith from the remote hyperspectral data divided the White Dam area into alluvial regolith-dominated, *in situ* regolith-dominated and bedrock-dominated terrains. Alluvial regions were characterised by large abundances of vegetation and soils with a hematite-rich mineralogy. Highly weathered areas of *in situ* material consisted of goethite and various forms of kaolinite, whereas the bedrock-dominated regions displayed white mica/muscovite mineralogy. Areas flanking bedrock exposures commonly consisted of shallow muscovite-rich soils containing regolith carbonate associations, with both materials able to be mapped by the HyMap data using the above mentioned techniques.

A majority of the slightly weathered bedrock exposures in the MacDonald Ranges, derived predominantly from Adelaidean metasediments, did not have an obvious spectral signature in the VNIR-SWIR region. Detection of these exposures by remotely sensed imagery was only seen where the rocks had been altered or weathering products occurred. Bedrock that displayed poorly defined spectral features was discriminated from shadow and vegetation through the use of modified traditional hyperspectral mineral mapping techniques.

Landsat

A scene of Landsat TM (Thematic Mapper) consists of an image with a coverage of 185 x 185 km. Six broad-bands, with 30 m resolution, cover the visible to shortwave infrared region with one low resolution (60 m) thermal band and a panchromatic band with 15 m resolution. The addition of a panchromatic band allows the other bands to be pan-sharpened to increase the resolving ability of the datasets. This feature is only available with Landsat ETM+ data.

The characteristics of Landsat TM (and ETM+) data are favourable for the mapping of regolith materials on scales less than 1:25 000. Landsat TM band spacing and pixel size generate measurements of the integration of rock, soil and vegetation features for a surficial area of 90 m^2. The extraction of information on these materials can be used as surrogates for features of regolith-landform maps. Spectrally homogeneous areas within Landsat TM imagery has been shown to correspond to RLU and used for description and the mapping of boundaries in regolith-dominated terrains (Wilford *et al.* 2001).

Feature Extraction Techniques and Results

The Landsat bands that were used for the data from the White Dam area were selected to target the diagnostic absorptions and reflections of the common materials and minerals. This was performed through the selection of three-band colour-composites. The TCC used bands 3-2-1 as RGB and produced images with similar colour tones as the ortho-image, although with a much lower resolution, as shown in Figure 12. This image demonstrates the regional nature of the Landsat TM imagery.

The false colour composite (FCC) of Landsat Thematic Mapper Band (TM) 7, TM4, TM1, as well as the ratio composites of TM5/TM4, TM4/TM3, TM5/TM7 and DPCA2 (principal component 2), TM5/TM4, TM7+ TM1 (RGB) were found to be the most useful combinations for highlighting differences in regolith-landforms. Landsat TM imagery displayed a greater amount of information on the compositional variability of RLUs than the ortho-imagery. Integration of the two datasets was found useful for differentiation and classification of polygons mapped on feature recognition with the higher spatial resolution imagery.

Radiometrics

Airborne gamma-ray surveys involve the detection of gamma emissions from specific radio-nuclei related to the decay of potassium (K), thorium (Th) and uranium (U) isotopes. Measured gamma-radiation has been related to the primary mineralogy and geochemistry of bedrock materials. Weathering of basement exposures by physical and chemical processes causes the release and redistribution of the radio-elements. The distribution of these isotopes enables the interpretation of some of the geochemical properties of the regolith materials, such as K, Th and U contents. The abundance and distribution of K, Th and U in the regolith has been documented by Scott & Yang (1997) and Wilford *et al.* (1997).

The resolution of radiometric data is closely dependant on the line spacing of the aerial gamma ray survey. Gridding can be performed to reduce the pixel size but may not improve the resolving ability of the data. Detailed information on the acquisition and processing of airborne gamma-ray surveys is discussed by Minty (1997) and Minty *et al.* (1997).

Feature Extraction Techniques and Results

Radiometric datasets were used in this study to identify areas of bedrock exposure. Regions of moderate radiometric response were tentatively interpreted as areas of shallow subcrop or colluvial material dispersed downslope of exposed basement. Previous studies in the Curnamona Province have suggested isolated uranium highs in transported regolith regions are the product of regolith carbonates originating from U-rich ground waters (Hill 2000). Similar features were seen in the White Dam gamma-ray data, in areas of low K and Th radio-element response. Field mapping identified these regions as transported regimes, with variable distribution and abundances of RCAs. It is still unclear if the carbonate was the source of the elevated U response in the radiometrics or the feature was related to noise.

Regions of slightly weathered saprolite, corresponding to the Wiperaminga Subgroup and granites displayed an elevated K abundance, as did the sheared lithologies of the Barrier Ranges. These rocks, which typically occurred as topographically elevated exposures, had a large quantity of white-mica minerals (predominantly muscovite) and were associated with pegmatite bodies. The elevated K was related to these materials. Flanking these exposures the materials displayed halos of decreasing K abundance, which were attributed to colluvial and sheetwash transported materials, which have been transported downslope.

In the northeastern regions the radiometrics had elevated Th responses. The lithologies of this region were mapped as calc-silicates of the Ethiudna Subgroup (Forbes 1991; Chubb 1999). The surface lags in the northeastern part of the study area were typified by ferruginous material (Crooks, pers comm., 2003), which was to the abundant magnetite in the calc-silicates. Another possible source of the ferruginous lag from remanent material generated from the sulphidic Bimba Formation, which has yet to be mapped in the White Dam region. The process of Th and U scavenging by Fe-oxides and clays has been related to elevated Th and U in gamma-ray spectrometry surveys (Dickson *et al.* 1996; Wilford *et al.* 1997).
The alluvial channels flanking the bedrock-dominated regions (the MacDonald Corridor and the ranges fringing the Barrier Highway) displayed elevated Th responses. Vegetation was typically found to be absent in these channels, which consisted of mostly lithic fragments with minor abundances of heavy mineral sands. It is unsure if the elevated responses were due to the opaque minerals or the lithic materials, which were predominantly feldspars and quartz, with minor muscovite.

Digital Elevation Model
Digital elevation models can be created from various sources of information. Each method has an impact on the resolution and accuracy of the data. Some common sources of DEMs include;

- Information from active sensors, such as radar (Shuttle Radar Topography Mission);
- Differential GPS measurements;
- Satellite data, such as processed Level 3 ASTER data or SPOT-PAN;
- The simultaneous acquisition with geophysical surveys, using instruments such as laser altimeters;
- The Australian Land Information Group (AUSLIG) 9 second DEM.

Mapping scale of the study area dictates the minimum DEM resolution required. Regional investigations would require a coarse resolution dataset, such as the AUSLIG 9 second DEM (which has a resolution of only approximately 250 m), whereas prospect scale mapping projects may be able to use ASTER data (~15 m resolution). Higher resolution DEMs are especially useful where the topographic variation is discreet. These high resolution datasets can be vertically exaggerated to accentuate subtle changes in elevation, which subsequently can be interpreted as variations corresponding to different regolith-landform units. For this study the DEM consisted of 25 m resampled information extracted from the ortho-imagery and a high-resolution dataset from an airborne geophysical survey of the White Dam Prospect.

Feature Extraction

The DEM was used to delineate landform and geomorphological features, through the creation of three-dimensional perspective views of the enhanced datasets draped over an exaggerated elevation surface. The identified landform features were then used along with the surface information derived from the other remotely sensed datasets to compile the regolith-landform map.

Fieldwork and Ground Survey

Three periods of fieldwork, each lasting a week, were conducted to validate and ground-truth the interpretations from the imagery. The initial period of fieldwork, following the preliminary image interpretations, consisted of transects of all the accessible station tracks to gain an overview of the area. The second field trip involved the recording of site descriptions and the collection of samples of different regolith materials for laboratory spectral analysis, to compare with the HyMap responses. The final stage of fieldwork consisted of a detailed collection of samples from costeans at the White Dam Prospect and transects from the Wilkins, Green & Gold and Luxemburg regions.

4. NOTES ON THE REGOLITH LANDFORM UNITS ON THE WHITE DAM 1:30 000 REGOLITH LANDFORM MAP

Mapping scheme

The mapping scheme used here has been adapted from the AGSO/GA Regolith-Landform Unit program, commonly referred to by the name of the database, RTMAP. The mapped units represent surficial areas of similar landform and regolith characteristics that can be identified at the scale the mapping was performed (Pain *et al.* 1991). The units described in regolith-landform mapping are typical associations of materials and areas of similar attributes and do not necessarily represent 'pure' or 'uniform' regolith materials and landforms. The 'purity' of RLUs are scale dependant and vary with map size (Wilford *et al.* 2001).

RLUs are first described in the field and from remote sensing imagery, including attributes such as: lithology, landform, surface materials, minor attributes and vegetation. Polygon colours and codes on the map are used in the presentation of the RLUs. The RLU codes include three main components: the regolith materials, represented by capital letters; followed by landforms represented in lowercase letter codes; and then a modifier number, which is used to designate smaller variations between the major RLUs. Mapping codes are general classifications of the units and should be used to identify the mapped polygons and as a guide to the detailed descriptions only.

Regolith Landform Unit Descriptions

The following provides a description of some of the attributes of the RLUs interpreted for the mapping area, with a particular emphasis on its remote-sensing characteristics.

Fill

Fm1 (Fill, man made materials).

Fill consisted of areas of human activity where there had been disturbances to the regolith-landforms causing changes in the landscape or the regolith features. The construction of the Barrier Highway and railway had a significant impact on the paths of the drainage features that intersected the road Figure 18. The excavation of canals underneath the rail tracks had resulted in the creation of arid-swamps with abundant vegetation in these regions. The area flanking the road and track were heavily vegetated due to increased water runoff.

The construction of dams and channels for the collection of water had created considerable changes in the depositional environment surrounding these features. Changes included the increase of gullying and erosion in channels or the deposition of alluvial materials as overbank deposits. In the topographically low-lying regions, where significant disturbances have occurred, there was an increase in the ponding of water at the surface and a subsequent increase in presence of arid-swamps. These regions were highlighted in the imagery by an increased abundance of vegetation. Where increased erosion had occurred due to a change in the environment by human interaction, the area was often found to be bare of vegetation, which displayed a higher soil response in the multispectral imagery and a red-brown colour in the ortho-photography.

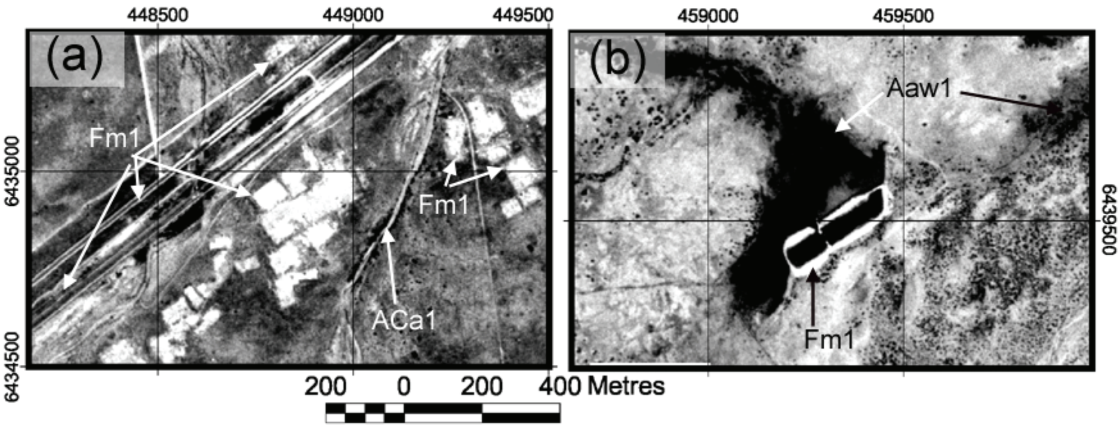

Figure 18 Ortho-imagery pictures showing the appearance of human influenced areas (Fm1) and alluvial swamps (Aaw1). The bright square areas in (a) are quarries used to construct graded dirt roads. The parallel, dark northeast trending linear features are the Barrier Highway and railway. The areas adjacent to these features influence the regolith landforms and break the continuity of units. The Aaw1 in (b) was situated around a large dam. The construction of the dam has changed the flow of minor channels in the region and created an arid-swamp.

TRANSPORTED REGOLITH

Alluvial sediments

Aaw1 & Aaw1(Alluvial swamp)

Swampy regions commonly occurred on low topographic areas where water ponded on alluvial plains, after ephemeral rainfall events (Aaw1). Vegetation was typically dense with a mixed species of chenopod shrubs and trees. The regions were highlighted in the ortho-photographs by dark green to black elongate shapes adjacent to channels and dams (Figure 18).

Swampy depressions occurred on erosional or depositional plains were subdivided from the units occurring within channels (Aaw1) and those that occurred as depressions in alluvial dominated regions (Aaw2). These depressions were characterised by rounded clay playas, which displayed a high contrast to the surrounding red-brown quartzose materials in the ortho-imagery. The vegetation communities were found to be significantly different from the chenopod scrubland, with *Eriochloa australiensis* dominating (Figure 19a).

Aed1 (Alluvial material in erosional depressions)

Aed2 (Alluvial material in erosional depressions associated with moderate topographic relief and saprolite exposures)

Vegetation within minor channels and drainage features (Aed1) were observed throughout the region adjacent to regions of sheetflow. These features occurred locally in areas that were topographically lower than the flanking regolith-landforms, which acted as conduits for water during ephemeral rainfall events. The flanking regions were sheetflow dominated on low plains or exposures of saprolite in areas of moderate relief. The formation of depressions in regions of higher topography predominantly occurred adjacent to locally exposed slightly weathered bedrock, which were associated with incising channels and the immediately flanking gully slopes (Aed2). These regions were less likely to contain significant amounts of vegetation due to the higher flow rates and lower rates of water penetration into the harder substrate (Figure 19b).

Afa1 (Alluvial material in an alluvial fan)

Floodout fans of alluvial material (Afa1) were commonly found on a variety of landforms where changes in the energy regime had occurred (Figure 19c). Typically the outwash fans occurred where a channel originating from a locally topographically elevated region encountered a channel of larger magnitude with a lower energy. Fans were also associated with abrupt changes in the slope gradient, relating to the watercourse passing through different landforms. The fans represented a change from narrow, deeply incising channels to broad plains containing meandering channels. The fans were typically densely vegetated by shrubs (e.g. *Xanthium* sp.) or were sparely vegetated and contained abundant amounts of lithic gravels.

Aap1, Aap2 (Alluvial material on an alluvial plain)

Alluvial plains were related with areas of alluvial material in low-lying landforms associated with channels and depressions (Aap). The material adjacent to the channels was dominantly alluvial in origin, with some sheetwash input and reworking. The banks of the channels were commonly vegetated by chenopod scrubland and low forbs. A distinction was made between the landforms were the banks and areas adjacent to the channels did not contain colonising vegetation and the red-brown colouration of the alluvial materials could be seen in the imagery (Aap2). Commonly the floors of the channels and depressions were vegetated, predominantly by grasses and chenopods, with minor *Acacia anuera*, as shown in Figure 19d.

Channel deposits

ACa1 (Alluvial channel in an alluvial landform)

Alluvial channels consisted of drainage features containing lithic material, predominantly quartzose, feldspathic and micaceous fragments as well as red-brown quartzose sands. The channels themselves were often bare of vegetation, as shown by Figure 19, e, & f. The banks of the ephemeral watercourses and flanking areas were often lined by chenopods and trees. Minor exposures of highly weathered saprolite occurred in areas proximal to topographically elevated regions where the channel was incising into shallow valley fill material.

Overbank deposits

AOap1, AOap2 (Alluvial overbank deposits on alluvial plains)

Areas of low relief, flanking channel systems associated with valleys that contained lithic fragments, quartz sands and abundant clays were mapped as overbank deposits. The regions have a dark brown-red colouration with lighter orange-brown rounded mottles representing the alluvial deposition of material from overflow of the adjacent channels during ephemeral flooding events. The overbank regions displayed distinct dark brown-red and yellow -brown circular features, observed as a mottled appearance in the ortho-imagery (Figure 19f).

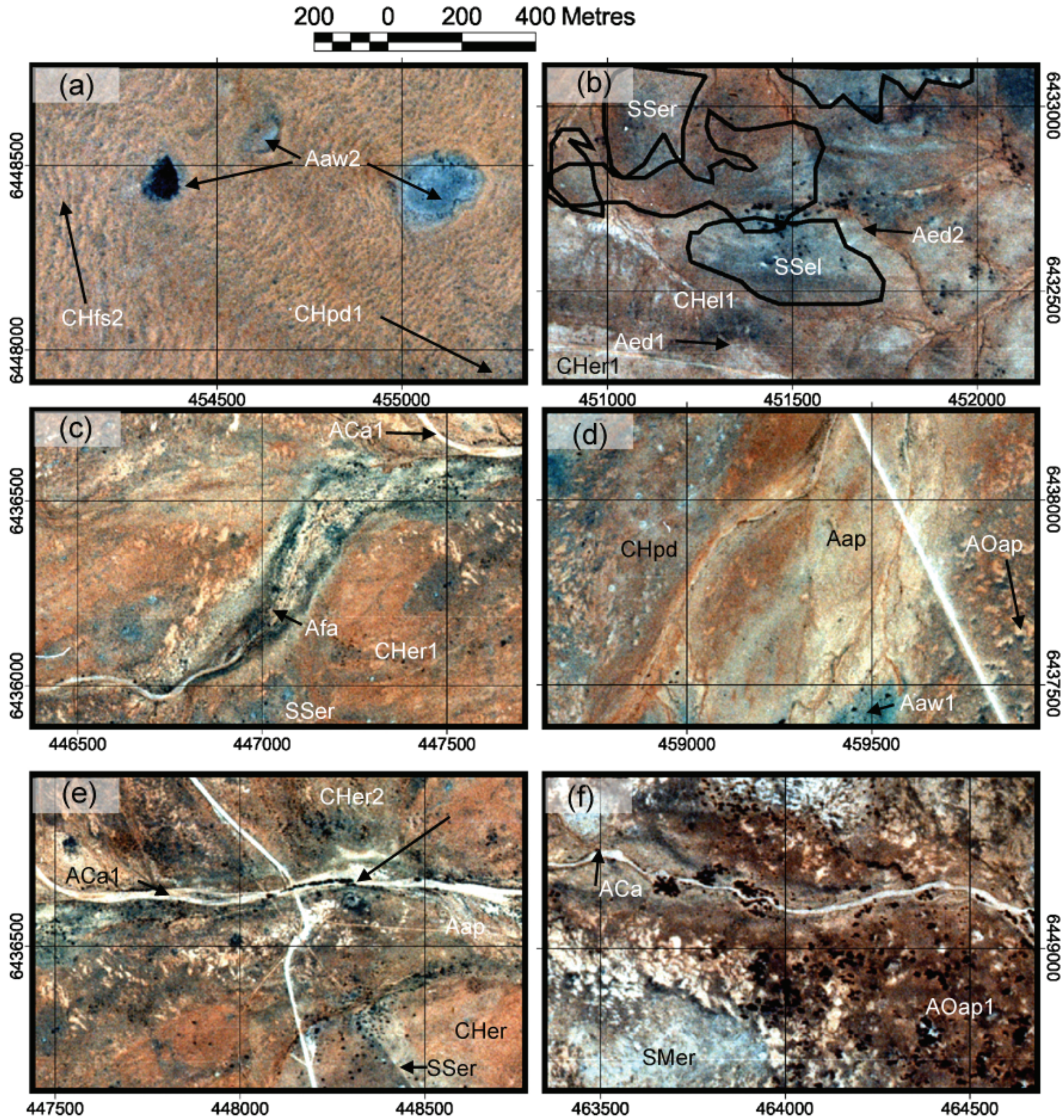

Figure 19 Orthoimagery representations of interpreted Regolith-landform units for the White Dam area. (a) Swampy depressions on an depositional plain; (b) Bedrock-dominated regions with erosional depressions; (c) Alluvial fan; (d) Alluvial plain; (e) Alluvial channel; (f) Overbank deposits and weathered saprolite

Aeolian sediments *Aeolian sand*

ISps1 (Aeolian material on aeolian sand plains)

This RLU was tentatively interpreted on the basis of the presence of clumps trees occurring in circular to oval gatherings on red-brown materials, as shown in Figure 20. The unit typically occurred on depositional plains, surrounded by sheetwash and alluvial materials. Further ground truthing and examination of the materials found on these landforms is required to legitimise the interpretation.

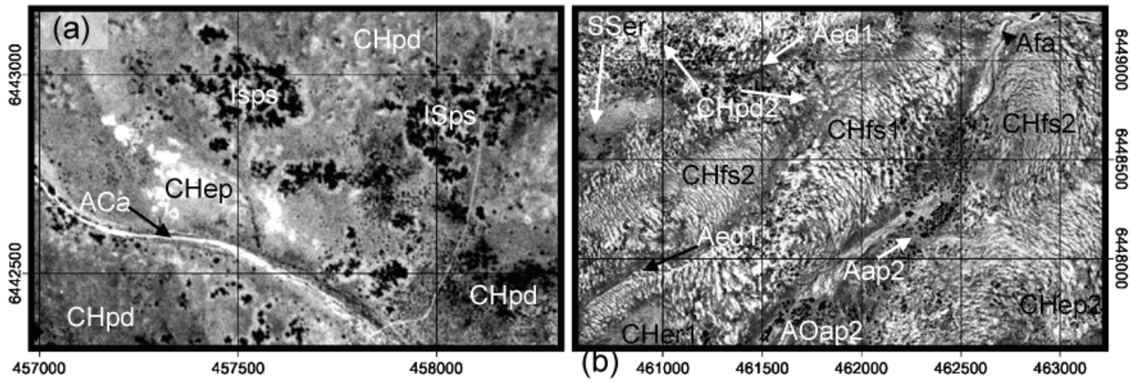

Figure 20 Orthoimagery representations of interpreted Regolith-landform units for the White Dam area. (a) Aeolian material represented by groupings of trees and (b) sheetflow dominated regions forming outwash fans.

Colluvial sediments-sheetflow deposits

These landforms occurred flanking most of the prominent bedrock and indurated regolith exposures Figure 19b. The dominant mechanism of sediment transport was by way of shallow overland-flow, with slope creep and rock fall providing a minor input.

CHfs1 (Sheet-flow material on a sheet-flood fan with abundant quartz lag)

CHfs2 (Sheet-flow material on a sheet-flood fan with abundant)

Regions characteristic of overland-flow were dominated by sheetflow, which displayed prominent vegetation contour banding were found flanking areas of low to moderate topographic relief (Figure 20b). Surface materials alternated from containing abundant quartzose lag (CHfs1) to bare soil and soil crusts with minor lag (CHfs2) (Figure 19a). The units were typically flanked by minor channels, containing linear strands of vegetation perpendicular to the contour banding. The units blended into regions of discrete vegetation banding as the slope angle decreased.

CHpd1, CHpd2, CHpd3 (Sheet-flow material on a depositional plain)

Areas where the surficial transport was dominated by overland sheetflow of colluvial materials, in low-lying topographic regions was mapped as CHpd. Surface lags and gravels were common throughout the areas mapped as this RLU. Vegetation consisted of poorly linear banded to isolated groupings of chenopods, representing the weak influence of the surface transport mechanism in their formation and orientation, in contrast to the vegetation of CHfs RLUs. Sheet wash materials derived from adjacent regions of higher relief are deposited in this RLU.

CHep1 and CHep4 (Sheet-flow material on an erosional plain)

Areas of bare soil with minor vegetation growth were found throughout the lower topographic regions, typically adjacent to mid-sections of alluvial channels (Figure 20a). The RLU was characterised by surface incision by shallow rills, perpendicular to topographic contours. Vegetation was sparse and limited to cryptograms and low forbs. CHep4 occurred in regions adjacent to saprolite exposures and areas of subcrop with a low abundance of vegetation cover. The materials at the surface were dominated by ferruginous saprolite and indurated materials. This unit displayed a distinctive dark red-brown colour in the ortho-imagery and a smooth texture.

CHep2, CHep3 (Sheet-flow material on an erosional plain)

CHep2 and CHep3 were colonised by dense vegetation clumps with varying abundances of quartzose gravels. This unit has a dark green and white mottled appearance representing the alternating quartz and vegetation coverage (Figure 20b).

CHed1 (sheet-flow material in an erosional depression) consisted of cobbles of lithic materials and quartzose gravels in elongate drainage depressions. The depressions commonly occurred adjacent to saprolite exposures in areas of moderate topographic relief. The gravels also occurred lower in the landscape, adjacent to larger alluvial channels, where gravel lags had been deposited in linear hollows parallel to slope.

CHel1 (sheet-flow material on a low hill)

Colluvial and sheetflow material, dominantly lithic materials from adjacent saprolite exposures or subcrop that occurred on topographically elevated regions and was mapped as Chel1. A thin layer of red-brown quartzose sands typically mantles the underlying saprolite and colluvial materials.

CHer1 and CHer2 (Sheet-flow material on a low erosional rise)

This unit formed extensive regions in the northern and central portions of the mapping area. The sheetflow materials were associated with the low rises and gently undulating topography. The surficial regolith materials consisted of sub-angular lithic and quartzose gravels with minor red-brown quartzose sands forming patchy contour banding pattern. These regions commonly contain RCA within the substrate. The RLU is typically colonised by a sparse chenopod shrubland dominated by *Atriplex vesicaria, Maireana spp*. and *Casuarina pauper* trees.

Cep1 (Colluvial material on an erosional plain)

The colluvial material flanking saprolite exposures or basement subcrop typically had a pale grey-blue to white mottled appearance in the ortho-photography, representing the lithic and quartzose cobbles and gravel lag materials dispersing downslope. A thin layer of red-brown quartzose sands mantled this unit and were mixed with the surface lags. This RLU typically graded into sheetflow-dominated units that were colonised by dense chenopod shrublands, making the location of the boundary difficult to spot on the ortho-imagery.

Cer1 (Colluvial material on an erosional rise)

Regions of colluvial material mantling the slopes of moderate to low topographic rises, which displayed a smooth texture and a grey-blue colour in the ortho-photographs were mapped as Cer1. The material typically consisted of lithic and quartzose cobbles and gravel lags. Vegetation was typically sparse although the surface lags may be coated by cryptograms, causing the colouration seen in imagery.

IN SITU REGOLITH

Saprolith ***Moderately weathered bedrock***

SMer (Moderately weathered saprolite on low erosional rises)

The Moderately weathered bedrock materials were mostly confined to areas of relatively recent erosion, such as gullies or sheet-eroded areas. The moderately weathered material was highly friable, and easily fell apart when kicked. Most of the moderately weathered bedrock types were schists. Where the slatey cleavage has opened up, kaolin-group clays had replaced many of the primary alumino-silicates minerals, which displayed a weak ferruginous staining. Typically the saprolite is observed with a well-developed cryptogram cover, as shown in Figure 9 and Figure 11. Powdery and minor hardpan regolith carbonate accumulations were observed to occur more commonly on calcareous and dolomitic bedrock types. These lithologies typically have well developed rillen-karren and surface dissolution features (Hill & Foster 1998).

The landscape expression for this unit was typically quite subdued and mostly formed erosional rises with 9-20 m topographic relief slightly elevated rounded exposures within depressions of alluvial units. This unit is represented by pale-red to light blue mottles within red-brown areas on alluvial plains and erosional rises in the ortho-photography (Figure 19f).

Saprock ***Slightly weathered bedrock***

SSel1 (Slightly weathered saprolite on low hills)

Exposures of bedrock in areas of moderate topographic relief (20-70m) displayed a grey-blue appearance in the ortho-imagery (Figure 19b). Mantles of red-brown fine quartzose sand were typically thin. Isolated shrubs and clumps of *Acacia aneura* and *Casuarina pauper* occurred across some of the exposures.

SSer1 (Slightly weathered saprolite on erosional rises)

The regions classified by this RLU typically display shallow layer of red-brown quartzose sands partially concealing the basement exposures. The unit appeared pale-red-brown with isolated blue-grey patches in the ortho-imagery, representing exposures of saprock. These regions typically flanked exposures of saprock on the crests of rises and low hills.

5. SUMMARY OF THE REGOLITH LANDFORMS OF THE WHITE DAM AREA AND MAPPING METHODS

The White Dam area consists of both bedrock and regolith dominated regions. The central and eastern regions of the mapping area consists of low and subdued landforms, whereas the MacDonald Ranges and the area to the north of the White Dam Prospect displays moderate topographic relief. Saprolite was found to be exposed in topographically elevated areas and on erosional low relief landforms. The saprolitic material in the lower regions was found to be more highly weathered than the exposures of the MacDonald Ranges. The exposures are commonly flanked by regions dominated by sheetflow processes, containing transported materials. These regions are dissected by depressions and channels carrying the eroded material to topographically lower landforms. Deposition of the transported sediments had occurs in the regions of low topography, characterised by broad alluvial plains and swampy depressions.

Vegetation and surficial materials are useful mapping surrogates. The presence of colonies of *Maireana sedifolia* were found to be correlated with the presence of RCAs at shallow depths. These regions are commonly associated with erosional rises, where a thin substrate consisting of friable materials occurred.

Summary of Regolith-Landform Mapping at White Dam

Comparison to Previous Regolith studies in the Olary Domain

Previously constructed regolith-landform maps of the area were created using various mapping schemes and show different features when compared to the current 1:30 000 White Dam Regolith-Landform Map, prepared using the RTMAP Scheme. The small scale map (1:500 000) compiled by Dave Gibson (Gibson 1996; 1999) contained large polygons with little in the way of unit sub-division. The interpretation was performed from Landsat TM imagery with limited field mapping. Mapping performed by Li Shu (Skwarnecki 1999) at 1:100 000 scale consisted of only a small portion of the western study area of this thesis and used a scheme developed by CSIRO Division of Exploration and Mining in the Yilgarn region. Similarities existed in the polygons boundaries throughout the overlapping region but the interpretation of the regolith units were substantially different. The likeness of polygon boundaries was attributed to the overlapping area consisting of bedrock-dominated units, with much of the area composed of variably weathered exposures of saprolite.

Regolith-landform mapping had been performed to the north by David Lawie (Lawie 2001), which had centred on the characterisation of surface lag materials for their use as an exploration tool. The map produced by Lawie focussed on the morphology and mineralogy of the lag, with the other regolith materials having a secondary focus.

Detailed mapping by Aaron Brown (Brown & Hill 2003) utilized the same ortho photography as used for the 1:30 000 scale map, however, as this area was a large scale (1:2 000), the imagery was found to be at its limit and much of the mapping was performed from ground traverses. The RTMAP mapping scheme used by Brown was similar to that applied to the 1:100 000 Broken Hill Regolith-landform Map (Hill 1999) and the 1:30 000 White Dam Regolith-landform Map, which demonstrates the ability of the scheme to translate across scales.

Regolith-Landform Maps in Mineral Exploration

Research on regolith-landform mapping is of benefit to mineral resource companies for planning of exploration programs and the interpretation of results. Traditional geological maps show the type of rocks exposed at the surface but lack information on the surface processes and landforms. Regolith-landform maps provide a greater understanding of the constituents of surface materials and the movement of the regolith through the landscape.

Application of Regolith-Landform Mapping to other Landscapes

The methodology for map production employed here can be applied in other locations where suitable imagery exists. The interpretation of regolith-landforms may require some adaptation as different vegetation communities and cover types will exist throughout the world. Some local knowledge of the environment would still be required as with any mapping project.

Remote Sensing of the Regolith

Understanding of the regolith-landforms and associated materials was a critical element in the processing and interpretation of the remotely sensed data. In turn, the process of regolith-landform mapping was greatly aided by the use of remotely sensed datasets.

Regolith Mapping using Radiometrics

Radiometrics was found to be an important dataset for mapping regolith-landform features as well as identifying areas of potential alteration. The coarse resolution of the airborne gamma-ray spectroscopy data is more suited to large scale features, therefore small saprolite exposures may not be detectable. However, a large and reasonably consistent variation in the radioelement abundances of regolith-materials exists that allows a significant proportion of information to be detected from radiometric datasets. Radiometrics has the potential to play an important role in regolith-landform mapping when integrated with optical and other remotely sensed datasets.

Multispectral Remote Sensing

Multispectral sensors were useful for regional overviews and generalised interpretations of the regolith-landforms and their constituent minerals. Three-dimensional draping and band-ratio techniques were found to improve the ability of multispectral imagery to discriminate features over colour composite images of un-processed single bands. However, multispectral imagery were unable to resolve spatial features at a detail required for this project, and the limited spectral resolution was only able to identify groups of materials, such as clays, Fe-oxides and vegetation.

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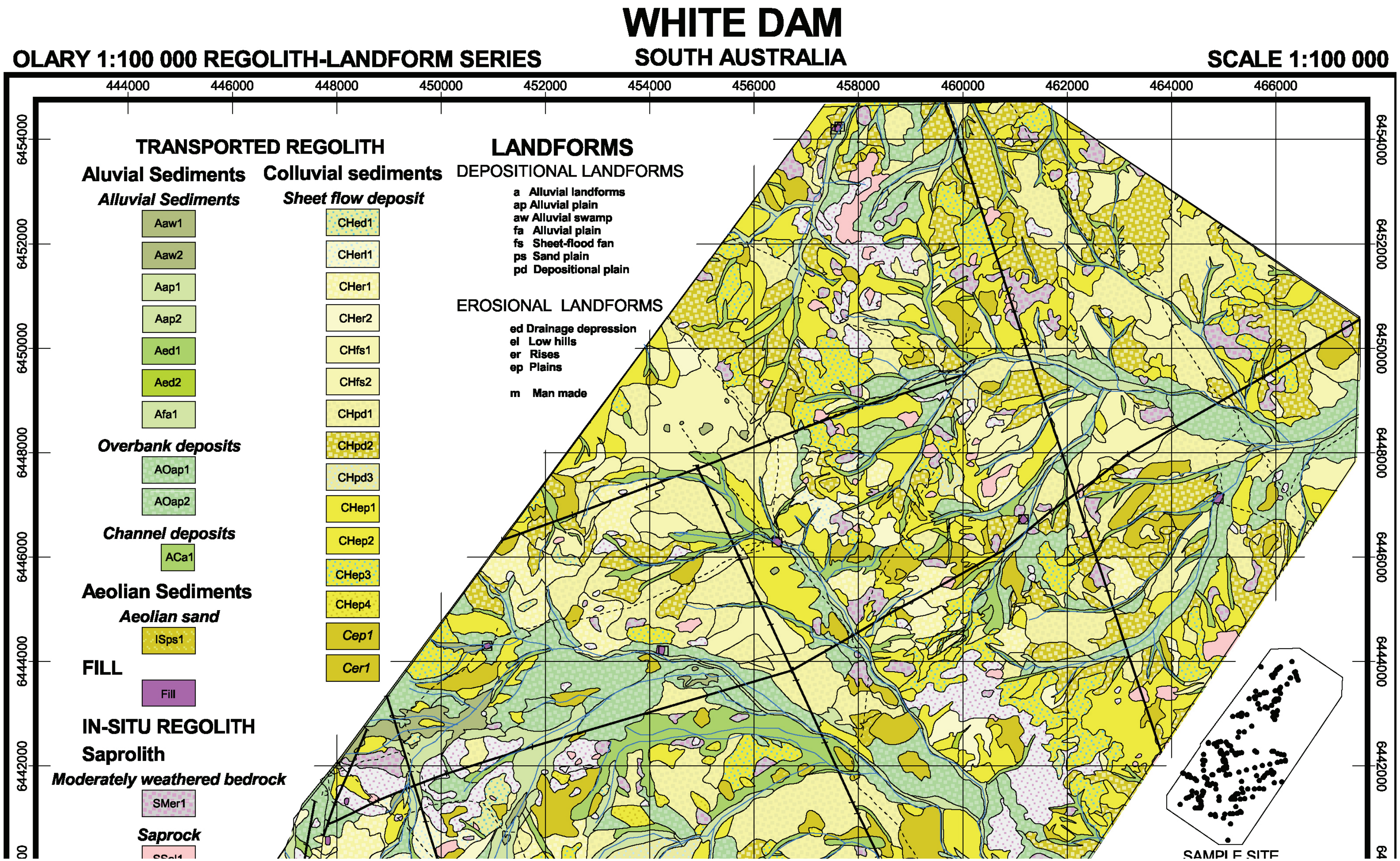
APPENDIX

DESCRIPTION OF REGOLITH MATERIALS AND SITES AROUND THE WHITE DAM REGOLITH-LANDFORM MAP AREA


WHITE DAM
SOUTH AUSTRALIA
OLARY 1:100 000 REGOLITH-LANDFORM SERIES
SCALE 1:100 000
444000
446000
448000
450000
452000
454000
456000
458000
460000
462000
464000
466000
6454000
6452000
6450000
6448000
6446000
6444000
6442000
TRANSPORTED REGOLITH
Aluvial Sediments
Alluvial Sediments
Aaw1
Aaw2
Aap1
Aap2
Aed1
Aed2
Afa1
Overbank deposits
AOap1
AOap2
Channel deposits
ACa1
Aeolian Sediments
Aeolian sand
ISps1
FILL
Fill
IN-SITU REGOLITH
Saprolith
Moderately weathered bedrock
SMer1
Saprock
Colluvial sediments
Sheet flow deposit
CHed1
CHerl1
CHer1
CHer2
CHfs1
CHfs2
CHpd1
CHpd2
CHpd3
CHep1
CHep2
CHep3
CHep4
Cep1
Cer1
LANDFORMS
DEPOSITIONAL LANDFORMS
a Alluvial landforms
ap Alluvial plain
aw Alluvial swamp
fa Alluvial plain
fs Sheet-flood fan
ps Sand plain
pd Depositional plain
EROSIONAL LANDFORMS
ed Drainage depression
el Low hills
er Rises
ep Plains
m Man made
SAMPLE SITE

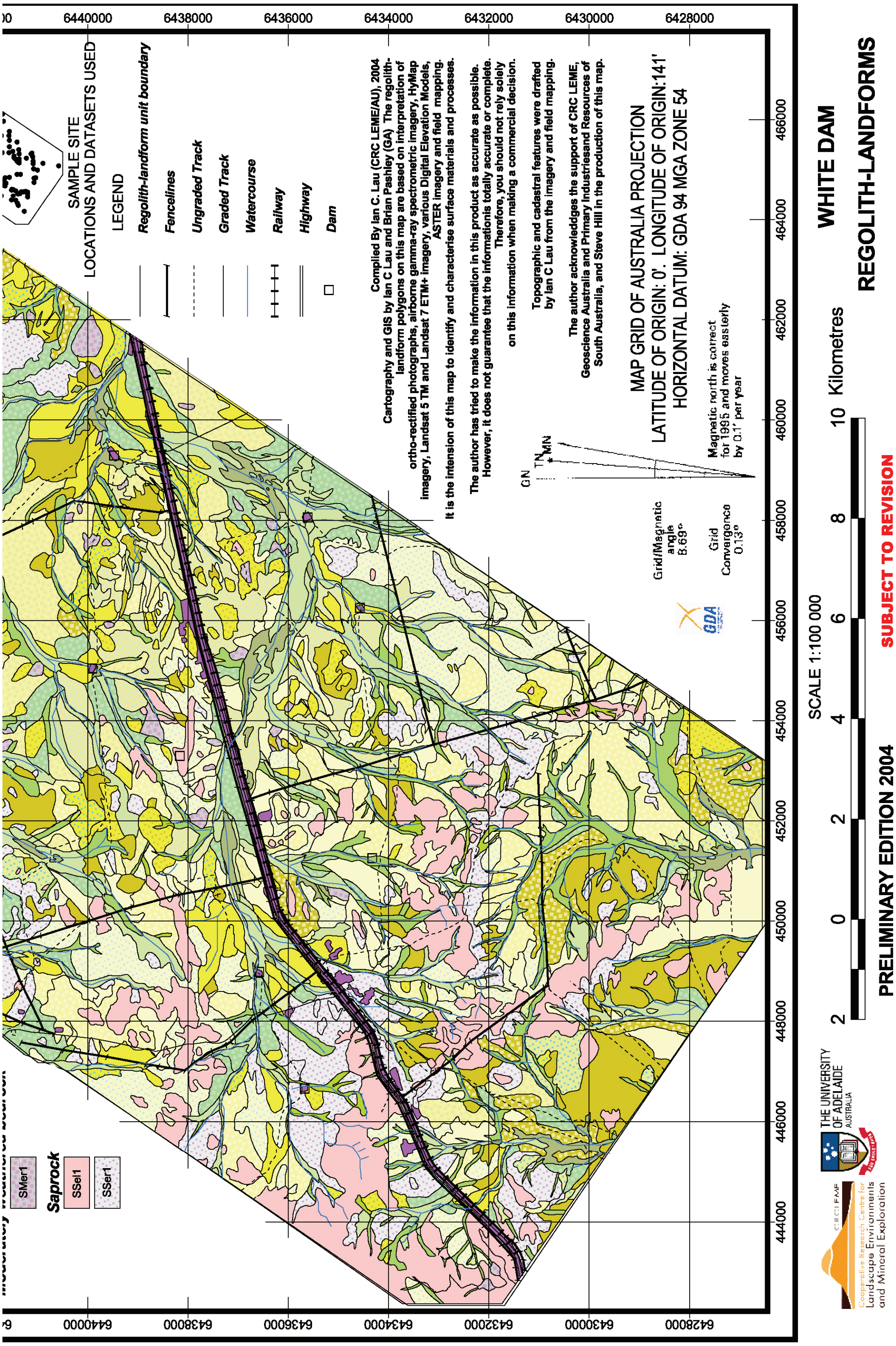


Figure 21 1:100 000 Regolith Landform Map (reduced version of the 1:30 000).