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OPEN FILE REPORT SERIES

REGOLITH-LANDFORM CHARACTERISTICS, EVOLUTION AND IMPLICATIONS FOR EXPLORATION OVER THE BUCKLEY RIVER-LADY LORETTA REGION, MT ISA

J.R. Wilford

CRC LEME OPEN FILE REPORT 132

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(CSIRO Exploration and Mining Report 407R/CRC LEME Report 47R, 1997.
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CRC LEME is an unincorporated joint venture between CSIRO-Exploration & Mining, and Land & Water, The Australian National University, Curtin University of Technology, University of Adelaide, University of Canberra, Geoscience Australia, Bureau of Rural Sciences, Primary Industries and Resources SA, NSW Department of Mineral Resources-Geological Survey and Minerals Council of Australia.
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CSIRO/CRC LEME/AMIRA PROJECT P417
GEOCHEMICAL EXPLORATION IN REGOLITH-DOMINATED TERRAIN, NORTH QUEENSLAND 1994-1997

In 1994, CSIRO commenced a multi-client research project in regolith geology and geochemistry in North Queensland, supported by 11 mining companies, through the Australian Mineral Industries Research Association Limited (AMIRA). This research project, "Geochemical Exploration in Regolith-Dominated Terrain, North Queensland" had the aim of substantially improving geochemical methods of exploring for base metals and gold deposits under cover or obscured by deep weathering in selected areas within (a) the Mt Isa region and (b) the Charters Towers - North Drummond Basin region.

In July 1995, this project was incorporated into the research programs of CRC LEME, which provided an expanded staffing, not only from CSIRO but also from the Australian Geological Survey Organisation, University of Queensland and the Queensland Department of Minerals and Energy. The project, operated from nodes in Perth, Brisbane, Canberra and Sydney, was led by Dr R.R. Anand. It was commenced on 1st April 1994 and concluded in December 1997. The project involved regional mapping (three areas), district scale mapping (seven areas), local scale mapping (six areas), geochemical dispersion studies (fifteen sites) and geochronological studies (eleven sites). It carried the experience gained from the Yilgarn (see CRC LEME Open File Reports 1-75 and 86-112) across the continent and expanded upon it.

Although the confidentiality period of Project P417 expired in mid 2000, the reports have not been released previously. CRC LEME acknowledges the Australian Mineral Industries Research Association and CSIRO Division of Exploration and Mining for authority to publish these reports. It is intended that publication of the reports will be a substantial additional factor in transferring technology to aid the Australian mineral industry.

This report (CRC LEME Open File Report 132) is a second impression (second printing) of CSIRO, Division of Exploration and Mining Restricted Report 407R, first issued in 1997, which formed part of the CSIRO/AMIRA Project P417.

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:
Wilford, J.R.
Regolith-landform characteristic, evolution and implications for exploration over the Buckley River - Lady Loretta Region, Mt Isa.
ISBN 0 643 06807 4
1. Regolith - Queensland 2. Geochemistry 3. Landforms - Queensland
I. Title
CRC LEME Open File Report 132.
ISSN 1329-4768

PREFACE

The P417 Project (Geochemical Exploration in Regolith-Dominated terrain of North Queensland) involves regolith studies of gold and base metal provinces of the Mt Isa Inlier and Charters Towers-northern Drummond Basin. The principle objective of the project is to substantially improve methods of exploration for base metals and gold in bedrock masked by deep weathering or beneath cover. The research includes geochemical dispersion studies, regolith mapping, regolith characterisation, dating of profiles and investigation of regolith evolution. This report documents regolith mapping from the Buckley River-Lady Loretta region which is one of several district-scale investigations over the Western Succession of the Mt Isa Inlier. Buckley River-Lady Loretta area was chosen for substantial study in the project because it is an example of some of the important problems of exploring regolith-dominated terrain in the Western Succession. The area is characterised by regolith developed on Proterozoic, Cambrian and Mesozoic rocks.

The report documents the methodology used to compile regolith maps and describes the types and distribution of regolith over the Buckley River-Lady Loretta area, approximately 40 km north north-west of Mt Isa. The origin of different regolith materials is discussed together with a summary of landscape evolution and implication of mineral exploration. The processing and enhancement of Landsat TM imagery using principle components and band ratios for separating weathered materials at the surface over the region is also discussed. An interpretative Landsat TM image highlighting Fe oxides, clays and silica materials is provided. Regolith materials are described within a landform framework and are broadly divided into three categories - duricrusts, saprolites and sediments. These categories are further subdivided based on the major lithologies being weathered, including Proterozoic bedrock, Cambrian and Mesozoic sediments. Characteristics of representative weathering profiles are discussed.

An attempt has been made to generate a regolith 'fact map' (compiled at 1:25,000) which as far as possible is descriptively based with little or no genetic bias. The 'fact map' forms the basis of three derivative maps which highlight particular themes and interpretative models. The derivative maps have been generated from a comprehensive GIS dataset over the Buckley River-Lady Loretta area which include; field-site descriptions, regolith and landform polygons and descriptions, processed Landsat TM imagery, landform features (e.g., palaeochannels), regolith geochemistry, images (scanned photos) and profile diagrams. One of these derivative maps is a geochemical sampling map (compiled at 1:25,000) which can be used as a tool for interpreting and planning geochemical surveys.

R.R Anand
Project Leader

I.D.M. Robertson
Deputy Project Leader

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1. SUMMARY

A Regolith-landform map and a series of thematic maps based on fieldwork, 1:25 000 colour air photography, enhanced Landsat TM imagery and airborne radiometrics have been produced over the Buckley River-Lady Loretta region (92 x 35 km) approximately 40 km north-northwest of Mt Isa. The maps show the distribution of regolith and landform types, relationships between regolith materials and Landsat TM imagery, associations between known mineral deposits, regolith materials and landform features such as palaeo channels and erosional scarps. In addition, a geochemical sampling strategy map has been generated which can be used as an aid in the interpretation of surface geochemistry and drill-hole samples.

The maps reveal a complex history of landscape evolution. A combination of a long weathering history and variable degrees of stripping has resulted in a landscape of highly variable regolith. Rocks exposed at the surface reflect weathering processes which operated from the Jurassic to the present day. Regolith consists of duricrusts (5% map sheet area) which may reflect both local and transported derivations, saprolite (67% map sheet area, includes bedrock) and sediments (28% map sheet area).

Duricrusts and saprolite

Duricrusts typically cap deeply weathered zoned profiles which include ferruginous, mottled and bleached saprolite at depth. These highly weathered materials are associated with relict parts of the landscape including palaeoplains, plateaux and mesas.

Three types of ferruginous duricrust are recognised including; massive, fragmental, nodular and slabby duricrust. Ferruginous duricrusts are commonly associated with Fe-rich lithologies (e.g., shales, basalt and dolomitic siltstones). Siliceous materials include massive microcrystalline silcrete, silicified sands and gravels and siliceous saprolite (typically cementing the mottled and bleached zones). Silcretes are associated with palaeolows in the landscape (e.g., river channels) and with siliceous bedrock lithologies (e.g., siltstones) Veneers of sheet wash gravels, residual sand and clay overlying mottled saprolite are common in areas of relatively low relief (rises, erosional plains and pediments). Lithosols lying directly on bedrock or saprock occur on steeper slopes are most common over the higher relief and geomorphologically active eastern half of the study area.

Sediments

Alluvial gravel, sand and clay are associated with river channels, terraces and alluvial plains. Colluvial sands, gravels, clays and lags form sheet flow and footslope deposits. Extensive blankets of sheet flow deposits occur over the central western part of the study area where they overlie deeply weathered saprolite. Major rivers at the southern end of the map sheet are superimposed over the predominantly north-south structure of the underlying Proterozoic rocks. In places these rivers have been captured and their flow redirected to the north. Silica or Fe commonly cements alluvium to form 'creek rock' or alluvial hardpan along river floors. Small areas of colluvium occur as coarse footslope deposits below steeper hill slopes.

Implications for exploration:

Some regolith-landforms should be assessed carefully when interpreting surface and drill hole geochemistry, these include:

1) Exhumed landscapes which have largely removed Cambrian sediments exposing ferruginous and mottled Proterozoic bedrock. In many places not all the Cambrian has been completely removed leaving behind pockets or veneers of Cambrian sediments in the form of cherty breccia or gravel lags. These patches of Cambrian can give false geochemical anomalies.

2) Regolith developed on Mesozoic and Cambrian lithologies are unlikely to directly relate to mineralisation at depth. Re-worked Proterozoic bedrock and metals precipitated from groundwaters in the Mesozoic sediments may give false anomalies.

3) Bedrock below palaeoplains are commonly deeply weathered and leached. Metal concentration within these highly weathered zones are typically low.

4) Massive, fragmental and nodular duricrusts and ferruginous saprolite have developed largely *in situ*. These materials can be sampled to detect mineralisation at depth.

5) Slabby iron duricrusts are thought to be largely formed from lateral movement of iron and as a result may give false anomalies. Nevertheless, they can be used to give broad geochemical indicators.

6) Mottling and Fe granules derived from the mottles in silcretes and silicified saprolite may be useful sampling media in highly siliceous terrains.

2. INTRODUCTION

2.1 Background

This report documents results from the Buckley River-Lady Loretta district which is one of several district-scale investigations over the Western Succession of the Mt Isa Inlier and complements regional synthesis studies of the Mt Isa Region by Anand *et al.* (1996).

The term regolith used in this report describes all weathered and/or transported material above fresh bedrock. Merrill (1897) defined regolith as the whole range of unconsolidated material that mantles the earth's surface. Although unconsolidated is used in the original definition of the regolith, indurated materials such as duricrusts and other materials formed by secondary enrichment and dehydration are now included in the definition. The word itself comes from the Greek rhegos = blanket and lithos = stone. Regolith therefore is the blanket over the rock. The regolith is seen as a barrier to mineral exploration. Understanding the nature and distribution of regolith materials in a landscape, in relation to underlying geology and mineralisation has proven critical in any comprehensive exploration program when exploring in deeply weathered or covered terrains.

Exploration problems in the Mt Isa region include:

- recognising transported and *in-situ* ferruginous and siliceous materials;
- separating sedimentary cover from weathered Proterozoic bedrock;
- understanding the complex geochemical signatures arising from multiple profiles;
- correctly interpreting element concentrations in the weathered Mosozoic and Cambrian sediments overlying mineralised Proterozoic bedrock; and
- distinguishing gossans from Fe duricrusts and other ferruginous materials in the landscape.

2.2 Objective

The objective of this study is to develop an understanding of how the landscape and regolith have evolved with the aim of substantially improving geochemical exploration methods for base metals and gold. Specific objectives are to:

1) establish spatial relationships between landforms, regolith and lithology by detailed regolith-landform mapping;

2) determine mineralogical and geochemical characteristics of selected regolith types;

3) develop effective exploration strategies in different regolith-landform settings;

4) develop an understanding of weathering processes; and

5) evolution of regolith- landforms.

3. BUCKLEY RIVER-LADY LORETTA STUDY AREA AND REGIONAL SETTING

3.1 Location

The Buckley River-Lady Loretta regolith-landform map area is located approximately 40 km north-northwest from Mt Isa and covers part of the Kennedy Gap (6757) and Mammoth Mines (6758) 1:100 000 map sheet areas (Figure 1). The Map covers an area of approximately 92 X35 km eastwest and lies between the AMG coordinates of - 291000E;7837000N (top left); 326000E:7745000N (bottom right).

3.2 Climate and vegetation

The area has a semi-arid, monsoonal climate with distinct wet and dry seasons. Most of the rainfall (approximately 500 mm) occurs in the summer months between January and March. Summer rainfall is unpredictable and droughts are common. Mean maximum and minimum temperatures range from approximately 35° and 25° C in December with corresponding winter temperatures some 10 to 15 degrees cooler. Vegetation over the area consists largely of spinifex(*Triodia pungens*), acacia shrubs and scattered low eucalyptus trees. Mesozoic sediments are typically densely covered by *Acacia Shirleyi* (Lancewood). Several species show strong associations to soils with high Cu concentration including Polycarpaea glabra, Eriachne mucronata and Tephrosia sp. are associated with mineralization at Lady Loretta and Drifter. Detailed account of the vegetation types in the area is given by Perry and Christian (1954).

3.3 Previous investigations

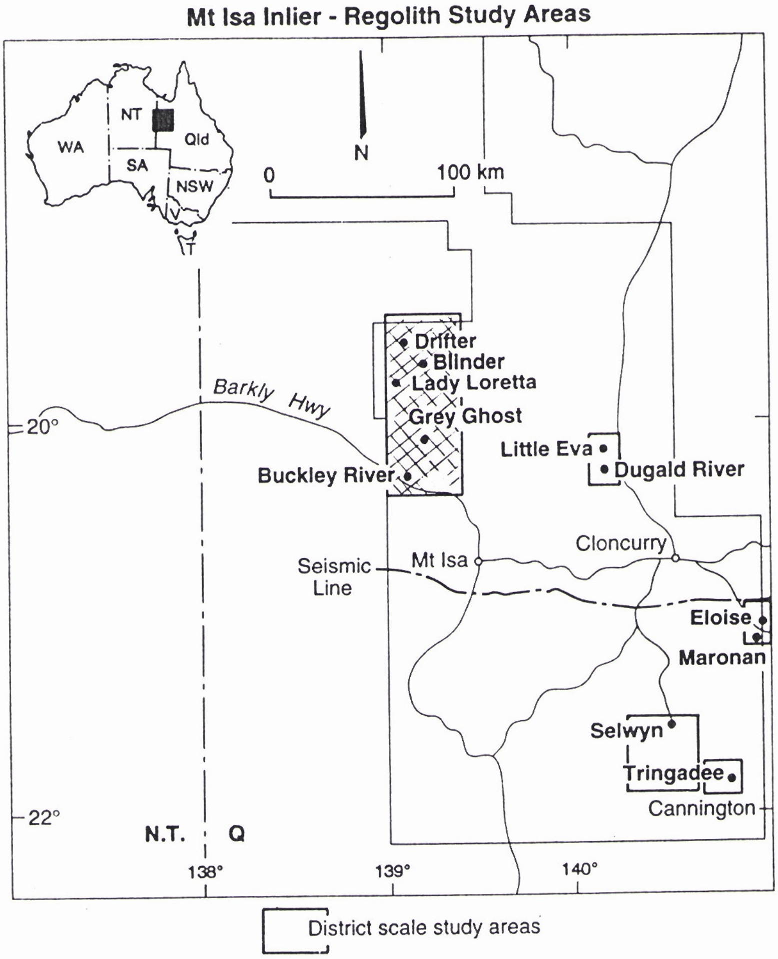
Previous detailed information on regolith and landscape evolution in the area is sparse. Aspects of the geomorphology and physiology of the area and surrounding areas has been described by Doutch (1976) and Smart *et al.* (1980) in regional studies of the Carpentaria and Karumba basins. Stewart (1954) has described the geomorphology of the Barkly region which includes the western margin of the study area. Twidale (1964) describes the geomophology of the Leichhardt-Gilbert area. More recently, regolith-landform characteristics and weathering history of the Mt Isa Inlier has been described by Anand *et al.* (1996).

The geology of the area has been described by De Keyser (1958), Carter *et al.*, (1961), Cavaney (1975), Opik *et al.* (1973). More recently Wilson *et al.* (1979) and Hutton and Wilson, (1985) have mapped the geology for the Kennedy Gap and Mammoth Mines 1: 100 000 sheets. De Keyser and Cook (1973) have described the geology of the middle Cambrian phosphorites and associated sediments.

3.4 Physiography

Regolith-landform mapping is used to separate the Buckley River-Lady Loretta region into 9 major landform types. These landforms include colluvial plains and minor footslopes, alluvial plains and floodplains, pediments and erosional plains, rises, low hills, hills, bevelled hills, escarpments and plateaux. The distribution of major landforms and their percentage cover over the area is shown in Figures 2 and 3.

(A)



(B)

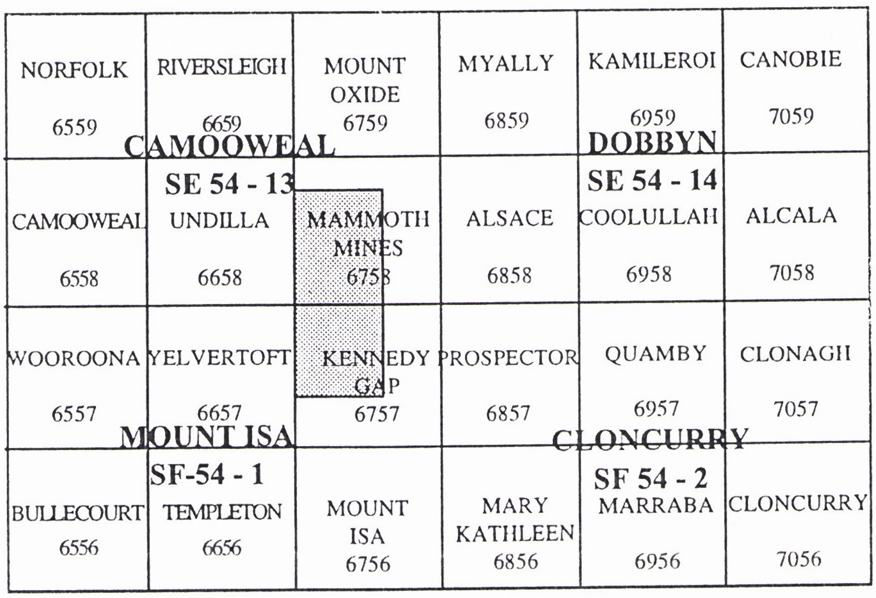


Figure 1. A - location map of the Buckley River-Lady Loretta study area (in hashed lines) and other study areas of the P417 project. B - index map of adjoining 1:100 000 map sheets.

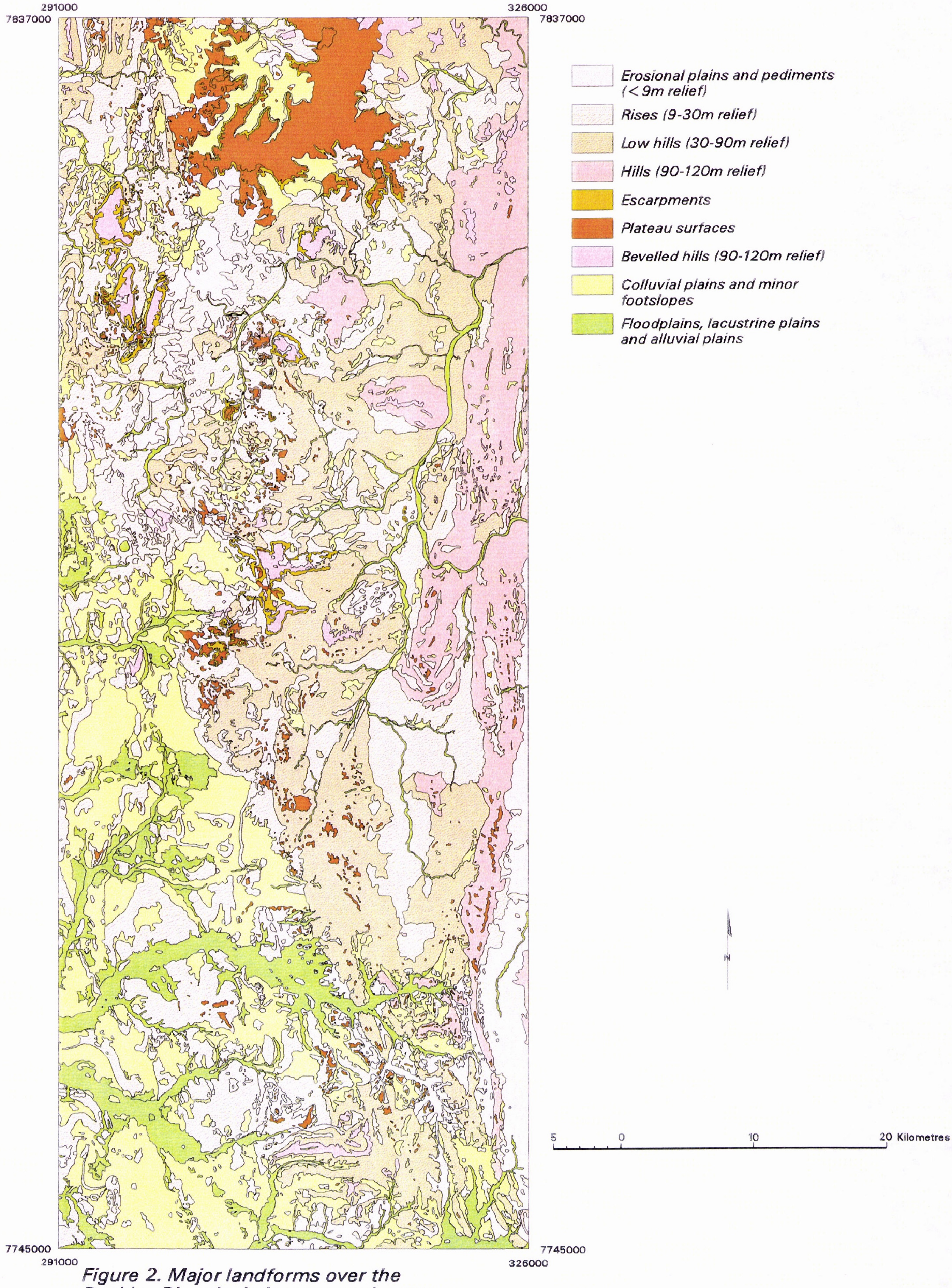


Figure 2. Major landforms over the Buckley River-Lady Loretta study area.

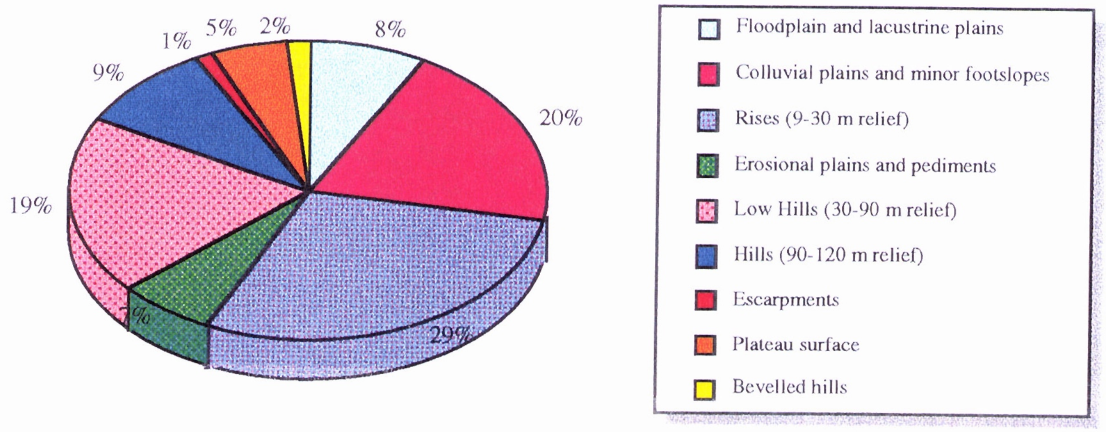


Figure 3. Pie chart showing the proportions of major landform types.

The southwest corner of the map sheet is characterised by generally low relief with extensive sheet flow colluvial plains and broad floodplains associated with Buckley River, Cattle Creek and Johnson Creek. In contrast actively eroding landforms with generally higher relief (up to 300 metres) exists in the north-northeast of the map sheet. A major erosional escarpment separates these two major physiographic regions (Figure 4) which correspond to the Barkly Tableland and Isa Uplands, of Smart *et al.* (1980).

Drainage patterns include open and closed dendritic, weakly braided and trellis. Trellis drainage reflects the prominent northsouth structural fabric of Proterozoic bedrock. Open dendritic and braided patterns are associated with low relief palaeoplains and high relief actively eroding landscapes, respectively.

The highest relief is associated with resistant ridges along the northeast edge of the map sheet. Most of the ridges have bevelled tops due mainly to post-Mesozoic planation. Plateau surfaces and bevelled hill tops have developed on Proterozoic, Cambrian and Mesozoic lithologies and are best developed in the northern part of the map sheet area.

A major divide separates rivers flowing west towards the Georgina Basin and those draining north into the Gulf of Carpentaria (Figure 4). Buckley River, Johnson Creek, Cattle Creek and Dingo Creek flow west and are tributaries of the Georgina River which eventually flows south into Lake Eyre. Thornton Creek and Gunpowder Creek flow north to the Gulf of Carpentaria. The drainage systems flow intermittently with all but the largest rivers drying out to discontinuous waterholes in the dry season.

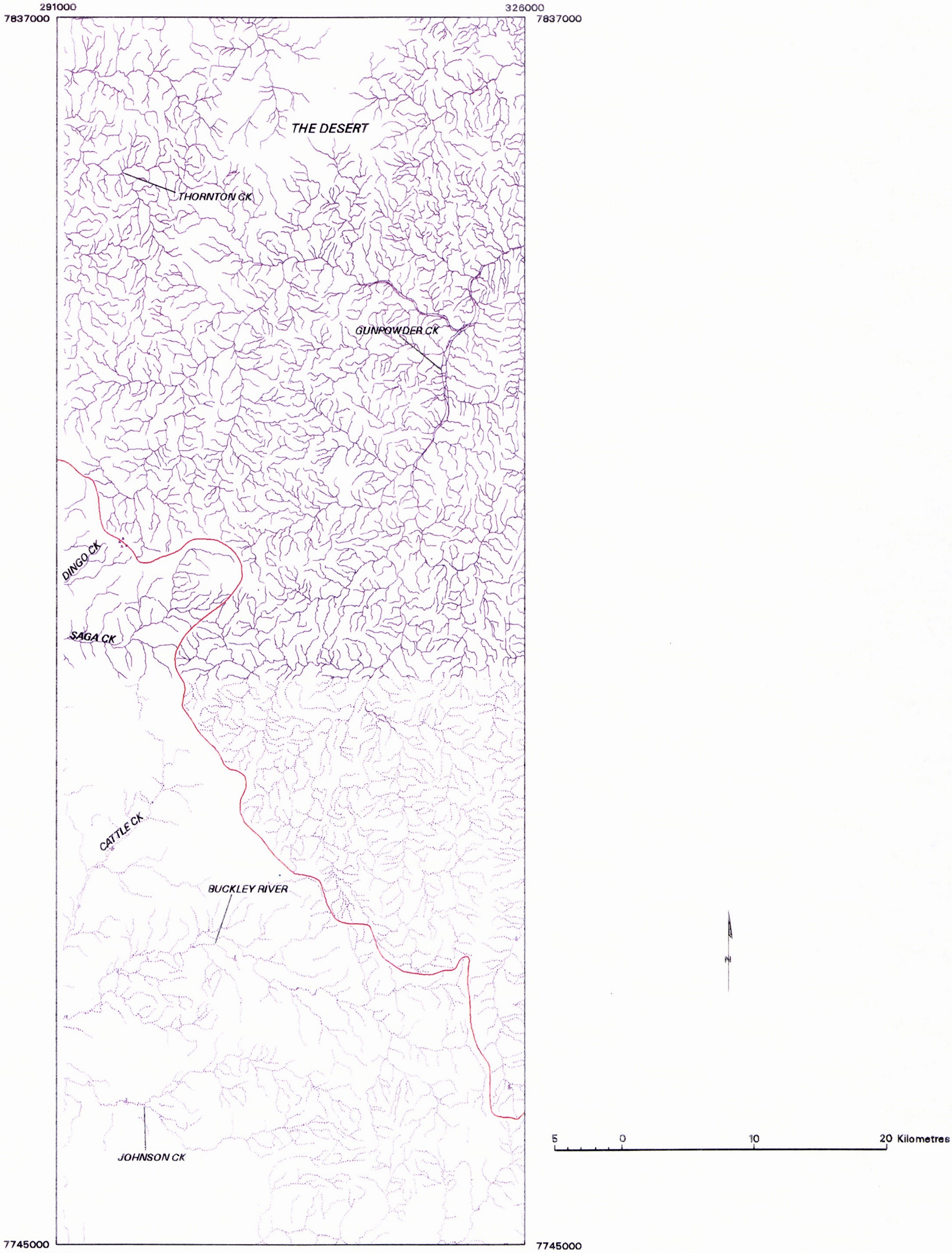


Figure 4. Major drainage divide (red), drainage patterns and major river names over the Buckley River-Lady Loretta study area.

3.5 Regional Geological setting

The bedrock geology of the Buckley River-Lady Loretta region consists of Proterozoic rocks of the Mt Isa Inlier, Middle Cambrian sediments and Mesozoic sediments. Proterozoic bedrock is the most common, Cambrian and Mesozoic sediments occurring mainly over the northern half of the map sheet (Figure 5). Proterozoic bedrock is broadly divided into the Haslingden and McNamana Groups. Rocks over the map sheet associated with the older Haslingden Group include felspathic sandstones, tuff, siltstone, quartzite and meta-basalt. The McNamana group consists of quartzite, siltstone, stromatolitic dolomite, laminated siltstone, dolomitic siltstone, orthoquartzite, shale and fine-grained sandstone (Hutton and Wilson, 1985).

The oldest rocks in the area are associated with flood basalts of the Eastern Creek Volcanics. During upper Haslingden Group time arenites and carbonates were laid down on stable shelves (Hutton and Wilson, 1985). Several periods of mild deformation, sedimentation and volcanism then occurred. Predominantly shallow water sediments were then deposited associated with the Lawn Hill Platform, the Mount Isa Orogen and a major marine transgression. The whole Proterozoic sequence then underwent major tectonism resulting in widespread deformation and uplift at approximately 1470-1490 m.y. (Hutton and Wilson, 1985). These uplifted rocks then provided the source materials for shallow marine/terrestrial Cambrian and later Mesozoic sediments. Cambrian sediments consist of siltstone, sandstone, limestone, chert, silicified shale, conglomerate, phosphorite and phosphatic siltstone. Mesozoic sediments in the northern part of the map sheet were deposited on a palaeo-slope dip of about four degrees to the north (Hutton and Wilson, 1985) and consist of sandstone, siltstone, mudstone and conglomerate.

3.6 Mineralisation

The region contains Cu, Au, Ag, Pb, Zn, U and P_2O_5. The southern end of the map sheet contains numerous Cu prospects but with insufficient tonnages or grade to support mining operation at the present time. Copper deposits include Calton Hills, King George and Lady Agnes (Wilson *et al.*, 1979). Numerous small uranium deposits occur in the Eastern Creek Volcanics which outcrop along the eastern margin of the map sheet. The most significant mineral deposits include the Gunpowder Cu deposit (which is located several Km east of the map sheet boundary) and Lady Loretta Ag, Pb and Zn deposit. The Cu at Gunpowder (Mammoth) is associated with a breccia unit and is thought to have been derived from the Eastern Creek Volcanics by hydrothermal solutions (Scott and Taylor, 1982). Mineralisation at Lady Loretta is associated with pyritic shale, siltstone, chert, sandstone and minor dolomite (Hutton and Wilson, 1985). Phosphate occurs in the middle Cambrian Beetle Creek Formation over the central northern part of the map sheet. Phosphate appears as pelletal phosphorite, collophane mudstone and as replacement phosphorite (Hutton and Wilson, 1985). The two major P_2O_5 deposits include Lady Annie and Lady Jane. These deposits are shown on the regolith-landform maps (Appendix 5).

Other prospects which lie within the area of the Buckley River-Lady Loretta regolith-landform map area and which were used as district scale study areas as part of the AMIRA P417 project, include the:

1) Python prospect (AMG:303465E:7759529N) where Cu anomalies are associated with Fe duricrusts;

2) Drifter prospect (AMG:298200E:7827700N) where anomalous Cu, Zn and Pb are associated with Cambrian sediments;

3) Blinder prospect (AMG:303875E:7821000N) where Zn and Pb anomalies occur in Cambrian sandstones; and

4) Grey Ghost prospect (AMG:310000E:777700N) where Zn and Pb are associated with pyritic Proterozoic shales. The Grey Ghost area is well dissected with deeply weathered plateau surfaces. More detailed description of these prospects is found in Anand *et al.* (1996).

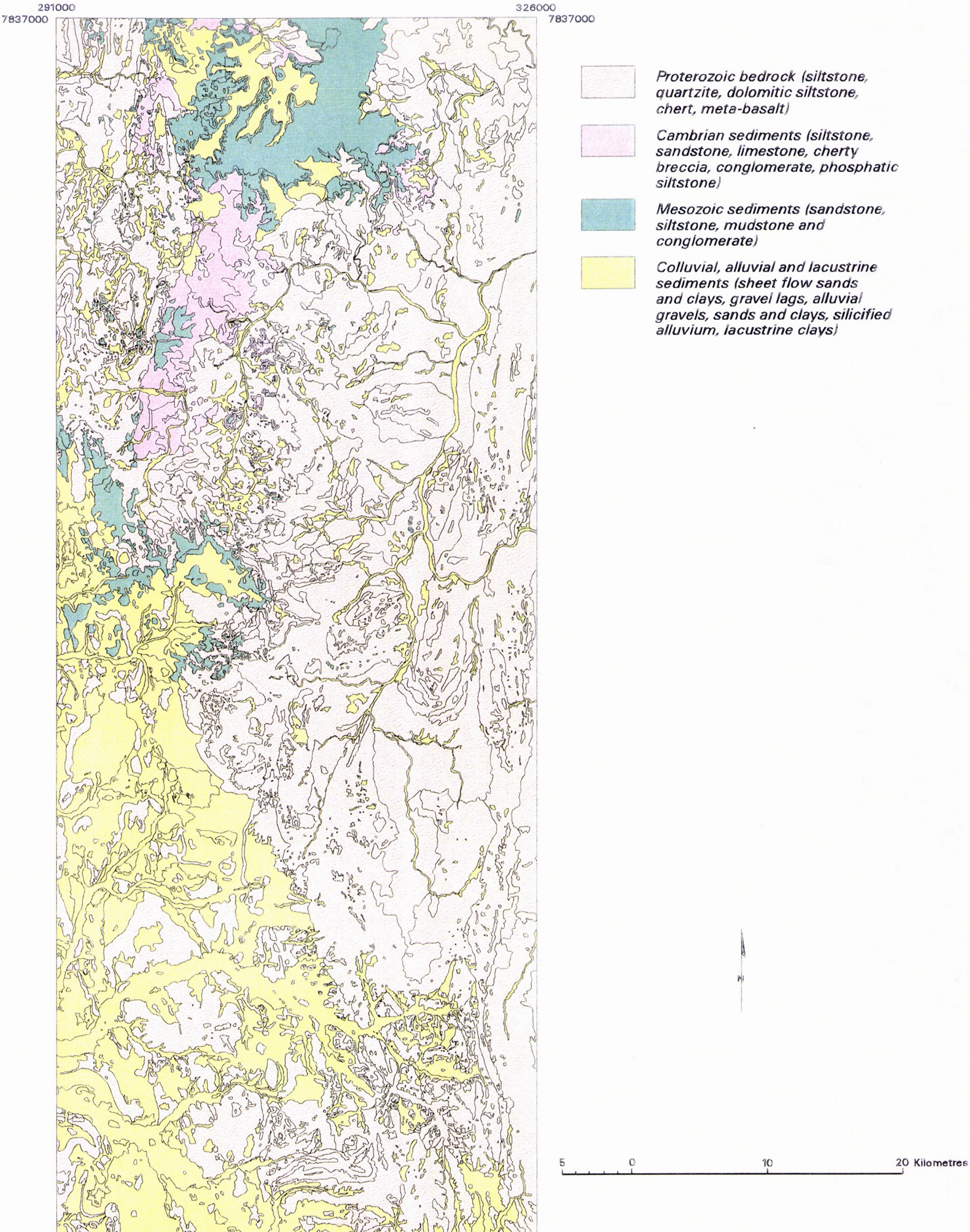


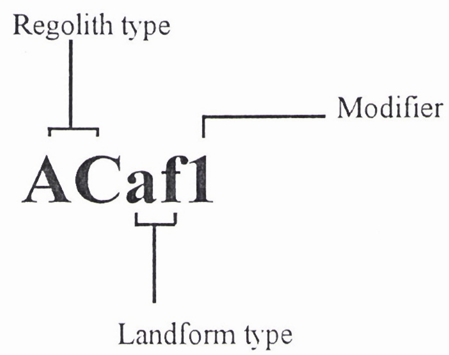
Figure 5. Simplified geological units over the Buckley River-Lady Loretta study area.

4. REGOLITH MAPPING - METHODOLOGY AND DATASETS

4.1 Regolith-Landform Units

The regolith-landform unit (RLU) is the basic mapping unit and consists of areas with similar landform and regolith characteristics that can be isolated at the scale of mapping (Pain *et al.*, 1991). Due to the variability of weathered materials both spatially and compositionally, it is often difficult to map regolith directly or, more importantly, consistently across the map sheet. Instead, mapping units are defined mainly on the basis of landform types (i.e. floodplain, mesa etc). Landforms can be used as a surrogate for mapping regolith because landforms and regolith are usually related both spatially and genetically. Relationships between landforms and regolith are then described within each RLU (see maps Appendix 5). Regolith-landform units, therefore, do not necessarily show uniform or pure regolith materials, but more typically associated and linked landform and regolith attributes. One landform type can have several different regolith types. Purity of regolith shown on the map is largely scale-dependent. With increasing mapping scale (i.e. 1:250,000 to 1:100,000) the higher the purity or uniformity of regolith is found within each RLU and the opposite relationship is true when decreasing map scale.

Regolith and landform types for each RLU are indicated on the Buckley River-Lady Loretta Map by a series of codes (see Appendix 5). Each RLU has either a three or four-letter code to describe its major regolith and landform types. The capital letters describe the regolith type and the lower case letters describe the landform type. For example, alluvial floodplain sediments deposited on a river floodplain would be expressed in the following manner;



The suffix 1 at the end of the RLU code is a modifier which allows the unit to be subdivided into one or more groups (i.e. suffix 1, 2, 3 etc). This is useful when showing subtle but nevertheless important differences within each RLU. For example alluvial sediments might be carbonate-rich and elsewhere carbonate poor. This difference can be shown on the map using the suffix 1 and 2 (i.e. ACaf1 and ACaf2).

Regolith and landform codes used on the maps (Appendix 5) are listed below.

Regolith codes

DF	Ferruginous duricrust
DS	Siliceous duricrust
S	Saprolite
AC	Channel deposits
AO	Overbank deposits
AA	Alluvial terrace deposits
A	Alluvial sediments undifferentiated
CH	Sheet flow sediments
CF	Footslope deposits

Landform codes

ls	Plateau
ei	Pediments
ep	Erosional plain (<9m relief)
er	Rises (9-30m relief)
el	Low hills (30-90m relief)
eh	Hills (90-300m relief)
ee	Escarpment
af	Floodplain
ao	Floodout, overbank plain
ol	Alluvial terrace
fc	Colluvial fan
pd	Depositional plain

4.2 Data collection and map compilation

The Buckley River-Lady loretta map (Appendix 5.1) was based on approximately five weeks fieldwork with a similar amount of time for pre-fieldwork photo interpretation and image-processing. During fieldwork over 257 sites were recorded and referenced using GPS with a +/- 100 m location accuracy. The map was compiled using colour aerial photographs at a scale of 1:25 000, airborne gamma-ray imagery and Landsat Thematic Mapper imagery processed to enhance clay, iron oxides and silica (see section 5). The 1:100,000 Kennedy Gap and Mammoth Mines geological maps (Wilson *et al.*,1979; Hutton and Wilson, 1985) were used to recognise major lithological types in the region. Polygons on the map were initially drawn from landforms based on airphoto interpretation. These polygons were then in places sub-divided or modified based on the enhanced Landsat TM and airborne gamma-ray imagery. The airborne gamma-ray imagery was provided by MIM Exploration. Combinations of Landsat TM ratio bands and gamma-ray bands were used in places to delineate highly leached saprolite. The interpretation of Landsat TM for mapping regolith including various enhancement techniques are discussed below.

5. REMOTE SENSING TECHNIQUES FOR REGOLITH DISCRIMINATION

5.1 Interpretation of Landsat TM imagery for mapping regolith

Enhanced Landsat TM imagery proved to be particularly useful over the Buckley River- Lady Loretta area due to the relatively sparse vegetation cover and good outcrop exposure. The use of Landsat TM data for geological mapping is well known (Drury *et al.*, 1986, Abrams *et al.*, 1984 and Podwysocki *et al.*, 1985). However, the application of Landsat TM for regolith discrimination or, more specifically, how Landsat

TM data is used in constructing a regolith-landform map is generally less well understood. A brief summary of how Landsat TM imagery was processed, interpreted and incorporated into the Buckley River- Lady Loretta regolith map is presented here.

Spectral characteristics of common surface features including vegetation, bedrock and regolith materials in the visible and near infrared part of the electromagnetic spectrum are shown in Table 1. Landsat TM bands 1, 2, 3 and 4 show variations in Fe oxide species (hematite and goethite) and can be used to show some separation of ferruginous materials. Band 5, due to its high reflectance of soil and rock materials, is displayed as a single band grey-scale image to highlight major landform and structural features. Band 7 provides discrimination of hydroxylated silicates, aluminosilicates and carbonates. With some prior knowledge of the regolith cover a variety of band combinations and ratio bands were found to be useful for separating different weathered materials, these are:

7 + 1 for silica-rich materials (e.g., siliceous bedrock, quartz gravel lags);

5/4 for ferrous (Fe+2) iron (e.g., hematite, Fe duricrust, ferruginous saprolite);

5/7 for argillic materials - clays and carbonates;

3/4 for saprolite versus vegetation;

4/2 for ferrous (Fe+2) versus non-ferrous saprolite; and

3/1 for ferric (Fe +3) iron (e.g., goethitic saprolite and Fe duricrusts).

These band and ratio combinations can be displayed individually or as various three band false-colour combinations. However, one of the most effective enhancements for discriminating a range of different regolith materials is a technique called Directed Principle Component Analysis (DPCA) developed by Fraser and Green (1987). The DPCA is used to separate clays in the imagery by deriving principle components from ratio band 4/3 and 5/7. Ratio band 4/3 enhances vegetation and ratio 5/7 enhances a mixed response of vegetation and clay. The DPCA operating on these ratio bands is able to separate the vegetation from the clay response. The 'clay' band (derived from the second principle component) was then combined with ratio bands 5/4 and bands 7 + 1. Ratio 5/4 highlights ferruginous materials, and bands 7 + 1 highlights Si-rich materials. The final image was displayed as a three band composite image with clay in red, Fe oxides in green and silica in blue (Figure 6 and Appendix 5.3). In the three band image ferruginous saprolite, Fe duricrust and ferruginous gravel lags derived from Proterozoic and Mesozoic bedrock are typically delineated in green to yellow hues. These highly ferruginised materials tend to be best developed on fine grained argillaceous and dolomitic lithologies. Olive green hues correspond to ferruginous clays, swelling clay soils, ferruginous lags, lithosols and ferruginous saprolite (dolomitic limestone and siltstone). Silcrete, silicified saprolite and sheet flow sediments appear in blue hues. The sheet flow sediments form extensive depositional plains, erosional plains and pediments. Floodplain sediment including variable proportions of sand, clay and gravel appear in magenta. Exposed saprolite which may be partly covered by lithosols or gravel lags appears in reddish and dark green hues depending on the relative proportions of clays and Fe oxides present. Vegetation along river channels and water bodies generally appear in black or dark red.

Figure 6. Three band Landsat TM image of second principle component of 4/3 and 5/7 in red, ratio 5/4 in green and the addition of bands 7 + 1 in blue over part of the Buckley River-Lady Loretta. Regolith-landform polygon shown in yellow, palaeoslopes in red lines and palaeochannels in green lines and erosional scarps in white. Fe duricrust and ferruginous saprolite appear in yellow hues, saprolite in red, swelling clays in olive green and sheetwash colluvial sands and gravels in blue. Mineral deposits (Cu) are shown with red diamonds (the grid = 1km AMGs).

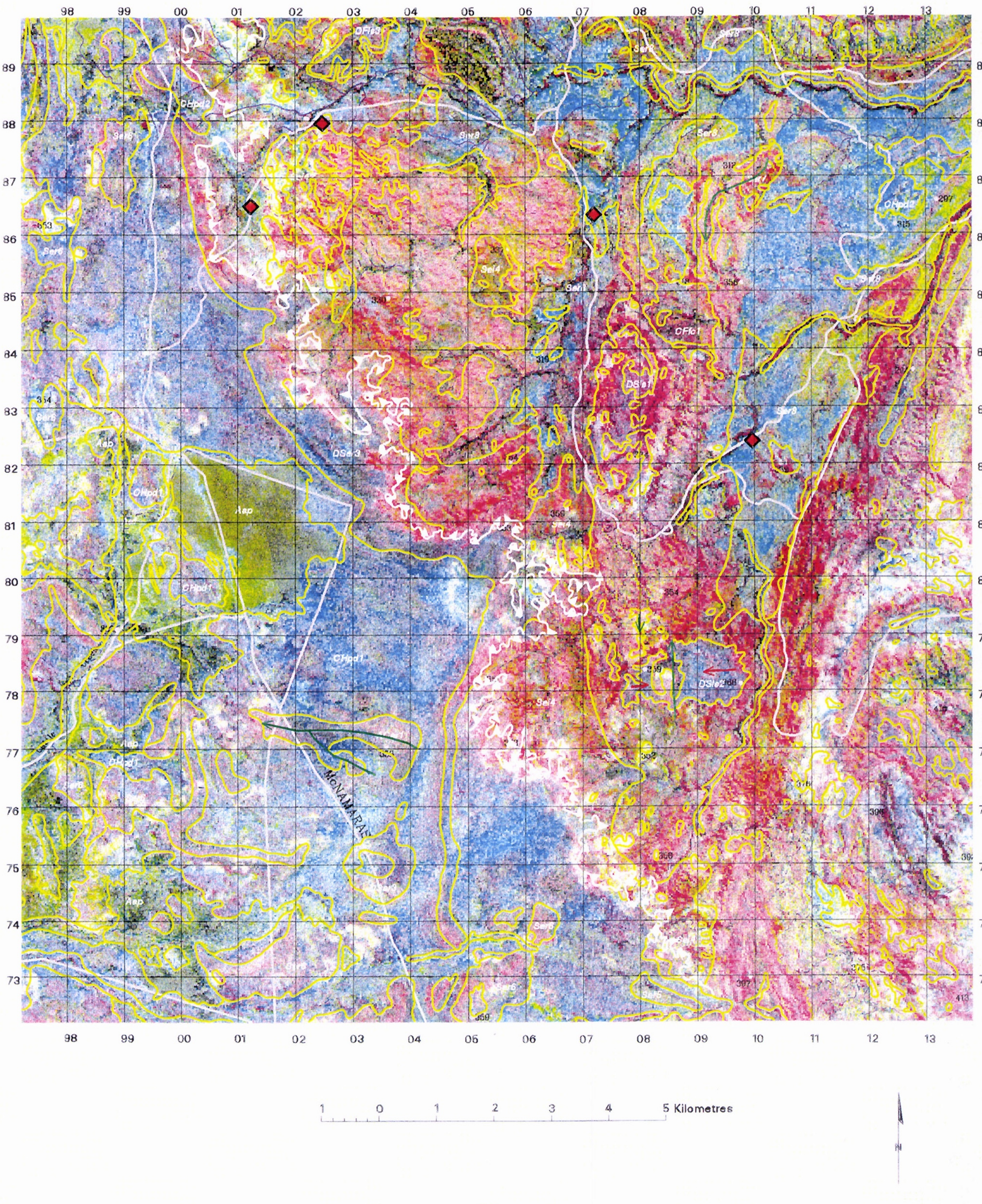


Table 1. Landsat TM spectral features

TM bands	General spectral features*	Regolith spectral responses
band 1	Ferric and ferrous iron absorption.	Fe duricrusts, ferruginous saprolite low. Hematitic iron very low. Kaolinite high.
band 2	Ferric iron absorption and ferrous iron reflection. Chlorophyll reflection peak	Fe duricrusts, ferruginous saprolite low. Kaolinite high.
band 3	Short-wavelength shoulder of ferric iron reflection. Ferrous iron absorption. Chlorophyll absorption	Moderate reflection for goethitic and hematitic iron. Kaolinite high.
band 4	Short-wavelength shoulder of ferric iron and ferrous iron absorption. Vegetation reflection peak.	Moderate reflection for goethitic and hematitic iron. Kaolinite high.
band 5	Highest reflection for most rock types. High reflection peak for hydrothermally altered rocks. Vegetation absorption.	Highly reflective for hematitic Fe duricrusts and ferruginous saprolite and clays
band 7	Absorption band for Al-O-H, H-O-H, Mg-)-H and C03 (clays, micas, carbonates, sulphates. Vegetation water absorption. Dry grass high.	Absorption associated with hydroxyl bearing minerals and carbonates (Bleached or pallid zone, secondary carbonate - calcrete and travertine) Highly reflective for hematitic Fe duricrusts and ferruginous saprolite.

General and specific regolith spectral responses associated with Landsat TM bands (excluding band 6) (*modified from Podwyzocki *et al.*, 1985)

A portion of the map showing regolith-landform units and landform features (e.g., erosional scarps) draped over the enhanced Landsat TM imagery is shown in Figure 6. The image response is used to describe and estimate the relative proportion of weathered materials (clay, Fe oxides and silica) within each regolith-landform unit. In places the processed imagery has been used to extend or further subdivide regolith units particularly in areas of poor landform expression. Superimposing regolith polygons over the Landsat imagery also provides an estimation of the relatively purity of surface materials within each regolith unit.

Combining regolith-landform and image attributes has the potential to provide useful information when interpreting surface geochemistry (e.g., soil, rock chip and stream). Geochemical sample concentrations can be interpreted in relation to the type of regolith (ie. residual, transported, highly weathered etc), landform type (actively eroding versus stable areas) and surface materials reflected in the image response (ie. clay, Fe oxides and silica).

6. BUCKLEY RIVER-LADY LORETTA REGOLITH-LANDFORM MAPS AND GIS

The digital regolith-landform map of the Buckley River- Lady Loretta region consists of polygons, lines, point features and raster images. Polygons define each regolith-landform unit. Lines are associated with cultural, drainage and landform features including palaeolandform slopes, palaeodrainage, erosional scarps and superimposed drainage. Points are associated with mineral occurrences and field site descriptions.

The regolith-landform polygons were scanned, then vectorised and labelled in ArcInfo GIS. Each polygon has a number of attributes attached as items in an INFO database table. Point attributes associated with field site observations are collected using AGSOs regolith terrain site database. Field site attributes are summarised in Appendix 2. Site information is stored digitally as attributes in a point INFO table. Site INFO attributes include a description of the regolith and landform types, presence or absence of sample collection and geochemical analyses, and, in places, scanned photographs of the field site. Mineral occurrences were extracted from the Bureau of Resource Science (BRS) MINLOC database. Mineral localities are indicated by coloured symbols. Geo-rectified raster data includes processed Landsat TM images which are stored as band inter-leaved (BIL) format in the GIS.

6.1 Regolith-landform and GIS thematic maps

Regolith-landform and various thematic maps at 1:85 000 scale were produced using the GIS to extract or emphasise different attributes within the database. Information shown on each of the maps are summarised on the map face keys below. Numbers 1-7 refer to the position of elements on the map face (Figure 7).

Map face keys

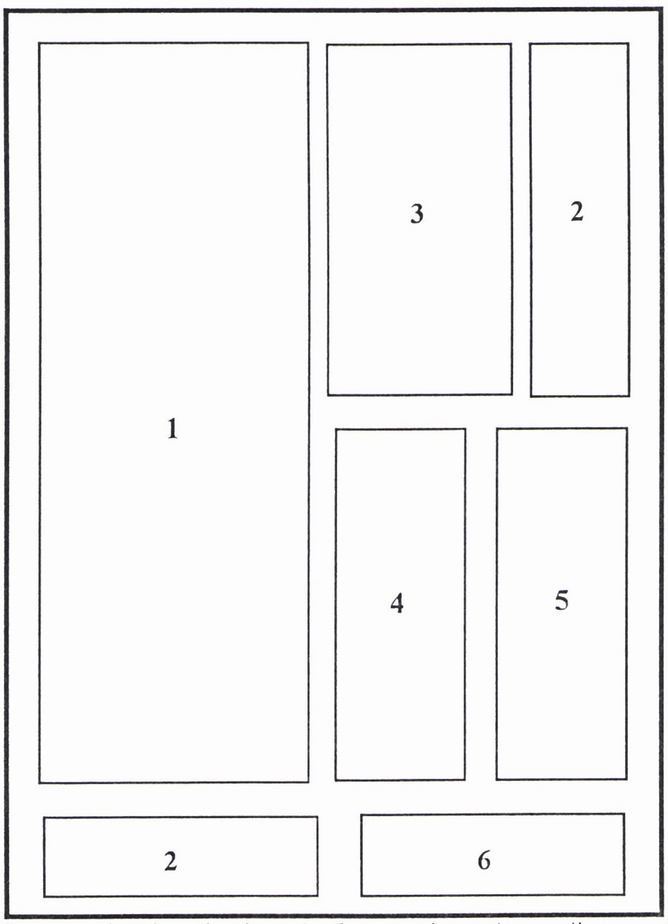


Figure 7. Map face diagram showing the layout of map elements on the regolith-landform and GIS thematic maps in Appendix 5.

6.1.1 Regolith-Landforms (Appendix 5.1)

1. Regolith-landform units, palaeodrainage lines, erosional scarps, palaeoslope drainage, mineral occurrences and major roads.
2. Slides showing representative regolith-landform features with accompanying descriptions.
3. Purely descriptive reference of regolith and landform features.
4. Simplified geology
5. Major Landform types
6. Map logos, acknowledgments, credits, copyright, location and index maps.

6.1.2 Palaeo surfaces and highly weathered Regolith over Landsat TM (band 5) (Appendix 5.2)

1. Relict indurated and very highly weathered units highlighted and draped over band 5 of Landsat TM. Also shown are palaeodrainage lines, erosional scarps, palaeoslope, mineral occurrences and major roads.
2. Slides showing representative regolith landform features with accompanying descriptions.
3. Reference with relict and very highly weathered units highlighted.
4. Simplified geological units.
5. Major Landform types
6. Map logos, acknowledgments, credits, copyright, location and index maps.

6.1.3 Regolith-landform Units over 3-Band Landsat TM image (Appendix 5.3)

1. Regolith-landform units, palaeodrainage lines, erosional scarps, palaeoslopes, drainage, mineral occurrences and major roads draped over a 3 band Landsat TM image.
2. Slides showing representative regolith landform features with accompanying descriptions.
3. Purely descriptive reference of regolith and landform features. Reference not coloured.
4. Simplified regolith showing degree of weathering.
5. Major landform types
6. Interpretative colour wheel for Landsat TM image. Map logos, acknowledgments, credits, copyright, location and index maps.

6.1.4 Interpretative Geochemical Sampling Strategy Map (Appendix 5.4)

1. Regolith/geochemical units. Interpretative map indicating the degree of masking or dilution of regolith materials to underlying bedrock. Also indicates palaeodrainage lines, erosional scarps, palaeoslopes, drainage, mineral occurrences and major roads.

2. Slides showing representative regolith landform features with accompanying descriptions.

3. Simplified sample strategy reference.

4. Landsat TM image overlain with regolith-landform units. Three band Landsat TM image enhanced for separating surface materials including clays, Fe oxides and silicates.

5. Major landforms.

6. Map logos, acknowledgments, credits, copyright, location and index maps.

7. REGOLITH-LANDFORM UNITS (RLU)

Regolith-landform units have been divided into four principle groups, they include duricrusts, saprolite and alluvial and colluvial materials. Distinction between these groups are largely based on descriptive differences rather than form of classification or hierarchical system. The legend on the regolith-landform map (Appendix 5.1) shows these four major groups, whereas the legend on geochemical sampling map (Appendix 5.4) is in part interpretative. A brief description of the regolith-landforms features within these four groups is provided. Major characteristics of each regolith-landform unit including regolith type, soils and lags, landform types, lithology and induration style are summarised in Appendix 2.

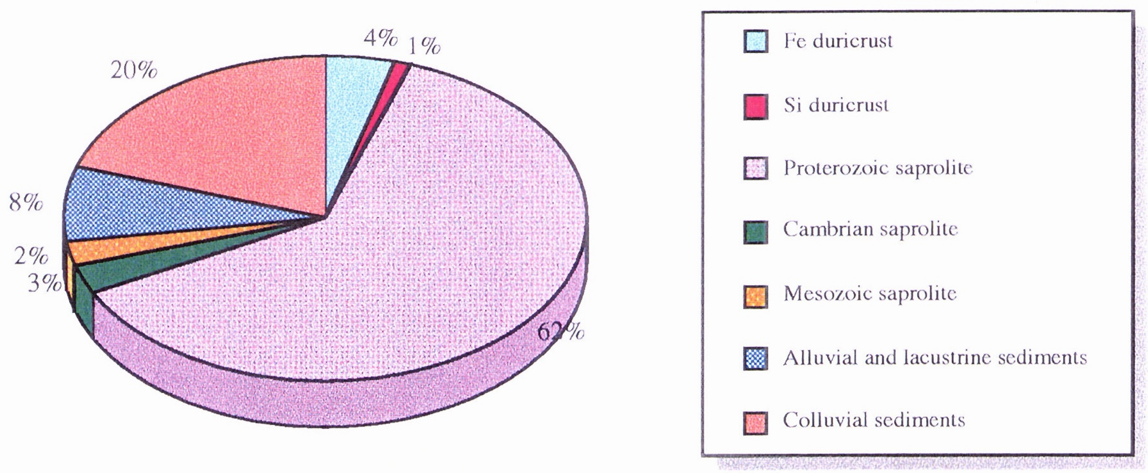


Figure 8. Pie chart of the proportions of major regolith materials.

7.1 Duricrust

The term duricrust is used to describe a mass of hard material formed within the regolith by either relative or absolute accumulations of natural cements in sediment or saprolite. Duricrusts are divided into ferruginous or siliceous depending on whether Fe or Si are the main cementing agent. Although duricrusts form only a small proportion of the Buckley River- Lady Loretta map (5%, Figure 8 and 9) they are significant when understanding and reconstructing landscape regolith evolution (see section 9). They are generally preserved on palaeolandforms including mesas, buttes, plateaux, bevelled hills and dissected plateaux.

7.1.1 Ferruginous duricrusts (DFls1, DFls2, DFls3 and DFls4)

There are four regolith-landform units in this category - DFls1, DFls2, DFls3 and DFls4. DFls1 refers to weathering of Proterozoic bedrock, whereas DFls2, DFls3 and DFls4 are associated with weathering of Mesozoic sediments. Unit DFls1 consists of massive and in places slabby Fe duricrust over ferruginous, mottled and bleached saprolite. The surface is typically mantled by a veneer of gravel lags consisting of fragments of ferruginous saprolite and ferruginous duricrust and gravel size ferruginous nodules and pisoliths. Well developed iron segregations are common in the upper part of the mottled zone. Silicification of the saprolite is also common and typically extends into the bleached zone beneath the mottled zone. Residual Fe stained sandy soils cover most of the duricrust in unit DFls2 except along the plateau edge. Duricrusts developed on Mesozoic sediments typically overlie highly weathered, mottled and in places silicified siltstones and sandstones.

7.1.2 Siliceous duricrusts (DSls1, DSls2, DSer3, DSep4, DSls5 and DSls6)

Regolith-landform units DSls1, DSls2 , DSer3 and DSep4 refer to weathering on Proterozoic bedrock. DSls5 and DSls6 are associated with weathering of mainly Mesozoic bedrock. The units consist of massive micro-crystalline silcrete, mottled silcrete, silicified iron-stained saprolite and bleached bedrock. Most of the primary minerals in the Proterozoic lithologies, particularly in the upper part of the profile have been weathered to clay (kaolinite) and replaced by silica. Silicification commonly extends into the underlying bleached zone. Silcretes and silicified saprolite are typically partly covered by gravel lags and thin residual soils.

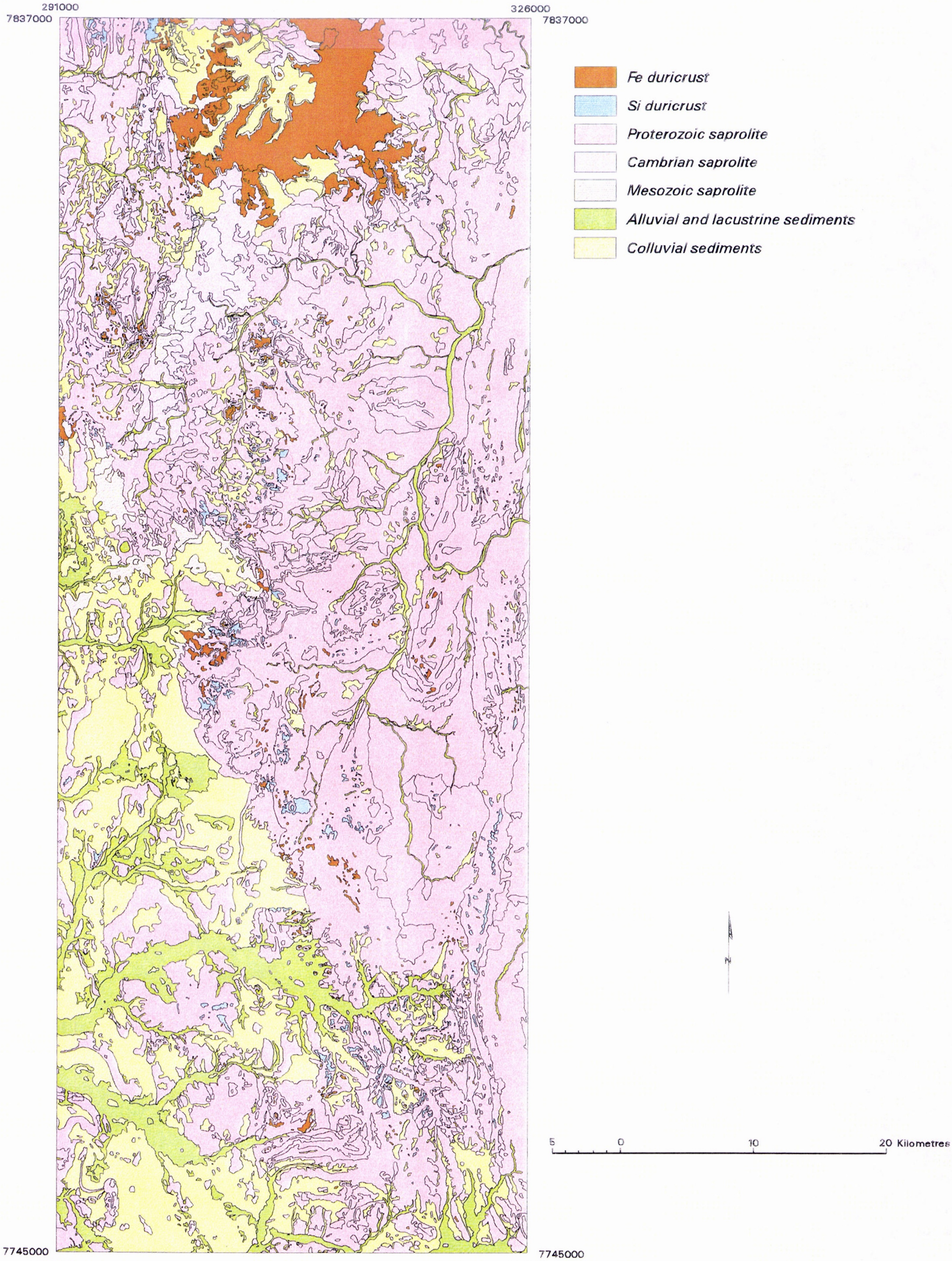


Figure 9. Major regolith types over the Buckley River-Lady Loretta study area.

7.2 Saprolite units

This category includes all units characterised by saprolite or weathered bedrock which is actively being eroded. Saprolite is defined as weathered bedrock which has formed largely *in-situ* without any significant change in volume (see glossary for more complete discussion - Appendix 1). Saprolite occurs beneath erosional landforms and although it may be partly covered by residual soils and lags, it is the major feature within the RLU. Saprolitic units are divided by the type of lithology being weathered (e.g., Cambrian, Mesozoic sediments). Saprolite units on some of the interpretative regolith-landform maps have been subdivided on the relative degree of weathering (see Appendix 5.2). The degree of weathering is described in terms of three classes; very highly, highly and moderately weathered bedrock. This subdivision is based on the degree to which the original minerals, textures and structures of the bedrock are retained based from field observations. Definitions of the degree of weathering classifications are describe in Appendix 1.

7.2.1 Proterozoic bedrock (Ser1, Sbh2, Ser3, Ser4, Sep5, Sel6, Ser7, Sep8, Sei9, See10, Seh11, and Sei12)

These units show a range of weathering characteristics and landform types. Ser1 consists of highly ferruginous saprolite and is often associated with massive or slabby Fe duricrusts. Sbh2 consists of bevelled hills which are typically capped with ferruginous saprolite (in some cases silicified) overlying mottled and bleached bedrock. Units Ser3, Ser4 and Ser7 consist of rises (9-30 metres relief) with ferruginous, mottled and bleached saprolite. Silicified saprolite is also common. Sep5, Sep8, Sei9, and Sei12 consist of erosional plains (< 9 metres relief) and pediments. Here the saprolite is largely covered by residual sands and gravel lags. Units Sel6, See10 and Seh11 consist of ferruginous saprolite and saprock on landforms of relatively high relief including low hill (30-90 metres relief), hills (90-300 metres relief), and escarpments.

7.2.2 Cambrian sediments (Sel13, Sep14, Sei15, Ser16 and See17)

Unit Sel13 forms plateau surfaces and consists of highly weathered ferruginous, mottled and in places silicified sediments. The saprolite is partly covered by gravelly lithosols over the plateau top but is generally well exposed on the surrounding escarpment (unit See17). Units Sep14, Sei15, Ser16 form low relief rises, erosional plains and pediments. These units consist of thin residual and sheetwash gravelly soils. The soils are commonly carbonate-rich, brown, with fragments of chert, ferruginous saprolite and minor Fe duricrust. In places, the top of the profile is mantled by unconsolidated, well-rounded cobbles and pebbles derived from Mesozoic sediments which probably once covered much of the area.

7.2.3 Mesozoic sediments (Ser18, Sep19, See20)

Unit Ser18 consists of rises with ferruginous and mottled saprolite partly covered by lithic lags and sheet wash clays and sands. Unit Sep19 consist of extensive veneers of gravel lags and sheet wash sands over ferruginous and in places silicified, mottled and bleached saprolite. Escarpments on Mesozoic sediments (See20) consist of mottled and bleached saprolite partly covered by rocky scree or colluvial gravels.

Figure 10 A - F Descriptions and representative photographs of regolith materials

A) Slabby Fe duricrust (goethite-rich and anomalous in Au) forms horizontal to sub-horizontal layering. Forms local resistant rise. 303465E: 7759529N.

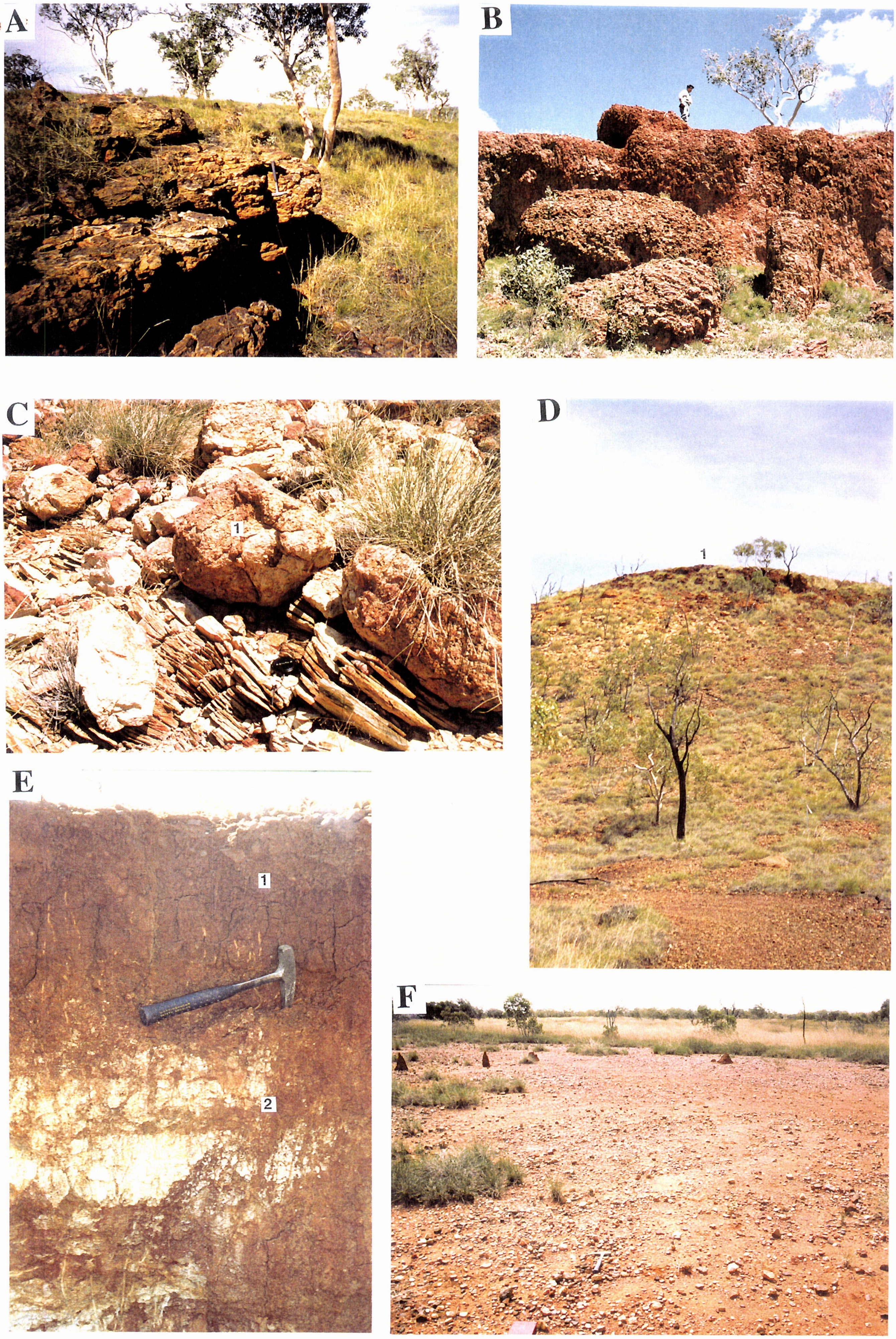
B) Indurated ferruginous fragmental saprolite forming resistant rises and blocky exposures. The breccia fabric has formed from the removal of clay leading to collapse of more resistant siliceous saprolite fragments. 325510E: 7749247N.

C) Massive silcrete cementing alluvial and colluvial sands and gravels overlying bleached and partly silicified Proterozoic shales. The sands and gravels have been relief inverted due to the silicification 305685E: 7756112N.

D) Slabby Fe duricrust (1) over mottled and ferruginous saprolite. The Fe in slabby duricrust is throughout to be derived laterally and has a difference trace element signature from the saprolite below. 303465E: 7759529N.

E) Veneer of sheet wash colluvium and residual clay (1) over saprolite (2). Forms pediments downslope from surrounding rises and hills. 324605E: 7755409N.

F) Sheet flow deposits on pediments over saprolite. Lags consist of ferruginous lithic fragments, quartz and ferruginous duricrust fragments. For profile view see photograph (E). 324605E: 7755409N.


A
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D
1
E
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F

Figure 10 G - K Descriptions and representative photographs of regolith materials

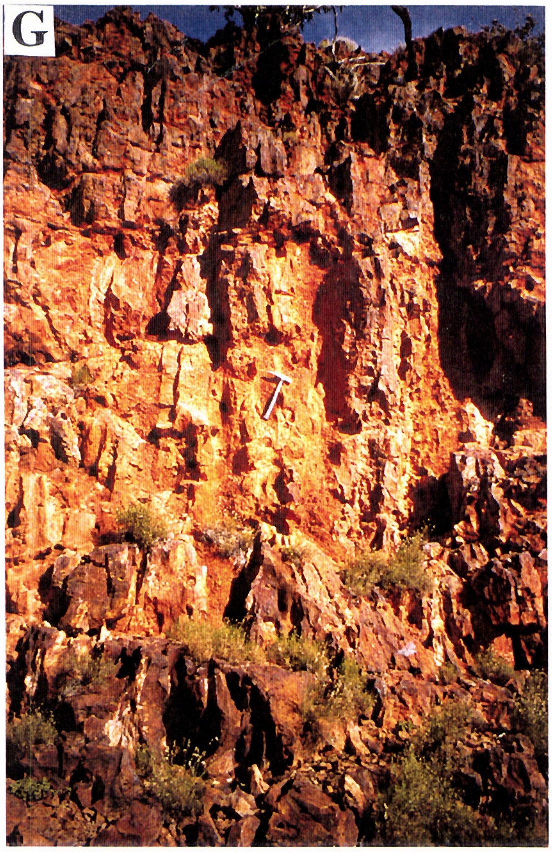
G) Massive ferruginous duricrust over elongated hematite-rich indurated mega-mottled zone. Forms resistant rise. Profile developed *in situ* as evident by quartz veining to the surface. 324701E : 7755409N.

H) Fragmental ferruginous duricrust (1) formed from collapse of Fe segregations in the mottled zone over mottled and bleached saprolite (2). 320691E: 7745974N.

I) Massive silcrete (1) forming resistant capping over bleached saprolite (2) (Proterozoic shale). Occurs on the edge of a major erosional scarp. 306193E: 7793961N.

J) The G-pick marks the contact between ferruginous duricrust developed in Mesozoic conglomerate (top) and Proterozoic shales (Below). The duricrust overlies mottled and partly silicified Proterozoic saprolite. Forms bevelled ridge top. 298119E: 7826200N.

K) Pre-Cretaceous concordant summits forming palaeoplains and mesas. Proterozoic sediments are capped by either ferruginous or siliceous duricrusts (1) which overly bleached saprolite (2). looking west from 305764E: 7798698N.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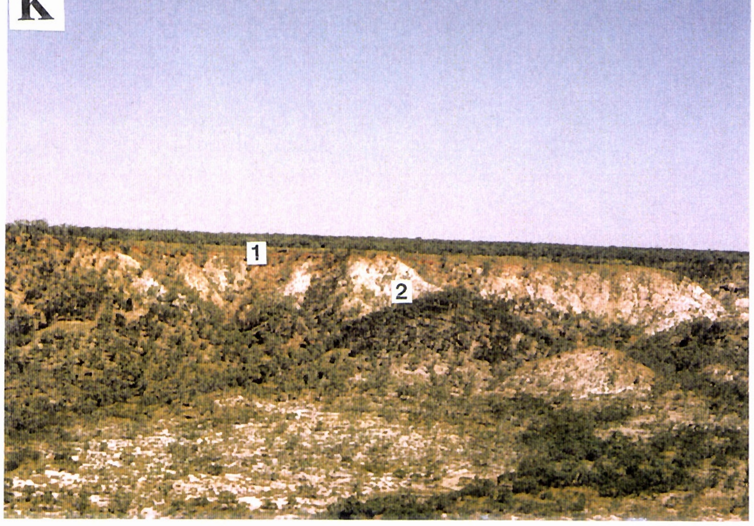
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Figure 10 L - S Descriptions and representative photographs of regolith materials

L) Sheet flow colluvial gravels (1) over bleached structural saprolite (2). 297142E: 7821720N.

M) Silcreted gravel and sand. Interpreted as silicified river channel deposits with now form local rise. Gravels range in size from 0.5-3 cm. 305715E: 7768301.

N) Bevelled hills capped with ferruginous duricrust (1) over Proterozoic saprolite (2).293800E: 7814516N.

O) Massive ferruginous duricrust cementing Mesozoic sediments (sandstone and conglomerate) over ferruginous Proterozoic saprolite (on mesa near to Lady Loretta Mine).

P) Ferruginous Mesozoic sandstone with Cu mineralisation (1) over weathered Proterozoic sediments. 298481E: 7827877N.

Q) Partly cemented (silica and Fe oxides) channel alluvium forming 'creek rock'.294245E: 7825596N

R) Massive micro-crystalline silcrete overlying cherty breccia (not seen) near to the Cambrian-Proterozoic unconformity. 298004E:7827168N

S) Cherty breccia (Cambrian) re-cemented by Si, Fe and Mn oxides. Commonly anomalous in base metals. 303541E: 7807869N.


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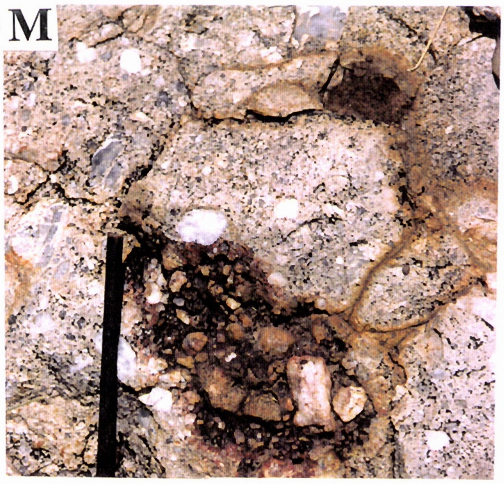
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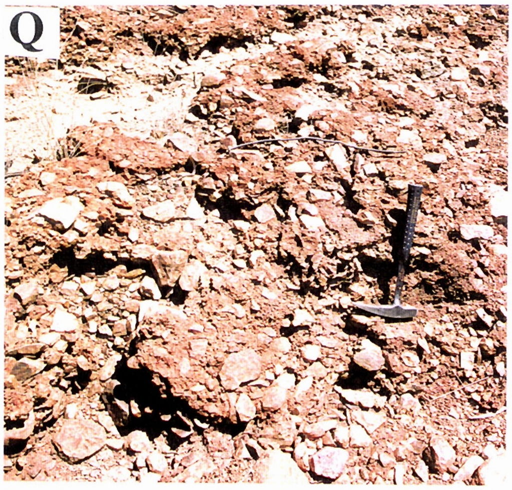
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7.3 Sediments

7.3.1 Alluvial sediments

Alluvial sediments deposited on floodplains, alluvial plains and alluvial terraces occupy about 8% of the study area (Figure 3). Sediments consists of varying proportions of sand, gravel, clay, silt and minor cobbles. The sediments are weathered to varying degrees depending largely on their age (ie. recent and older alluvial terraces). The sediments can be up to 15 meters thick along major river channels but in most places are less than 5 meters thick. Alluvial sediments have been divided into three groups.

Unit Aaf includes channel, overbank and terrace deposits consisting of various proportions of clay, sand and gravels. Recent river channel sediments consist of unconsolidated interbedded gravel, sand and clay with local lens of cobble conglomerate. In places, alluvium is partly cemented by clay, Fe or Si. Soils developed on floodplains consist of reddish brown and grey sandy to clay earths.

Alluvial and lacustrine deposits (unit Aap) consist of massive cracking olive green, grey-brown smectitic clay soils over mottled saprolite. The smectitic soils form treeless plains with gilgai micro-relief. The clays generally thin (< 2 m) with local outcrops of residual clays and gravel lags over saprolite. Pedogenic calcrete and 'heaved' saprolite fragments are commonly found as scattered float over the swelling clay plains.

Unit ACer1 consists of much older (Tertiary ?) silicified alluvial and colluvial sand and gravel. Minor quartz pebbles (generally 1-4 cm) are common. The silicified alluvium now forms subtle relief inverted landforms.

7.3.2 Colluvial sediments

Colluvial sediments cover approximately 20 % of the map sheet (Figure 8 and 9). They occur on erosional plains, pediments, depositional plains and minor footslopes, and consist of unconsolidated polymictic gravel and gravel lags with various proportions of sand and clay. The underlying bedrock is generally highly weathered and mottled. Sediment thickness ranges from 0.1 to 4 m. The sediments can have a proximal or distal source.

CHpd1 consists of depositional plains and minor erosional plains underlain by extensive colluvial sheet flow deposits. These sediments are typically > 1.5 metres thick and include lags of ferruginous and siliceous saprolite, lithic fragments, ferruginous granules, quartz and silcrete gravels with minor ferruginous duricrust and ferruginous pisoliths, sheet flow and residual sands and gravels. These sediments overlie mottled, bleached and typically silicified saprolite at depth. Unit CHpd2 consists of similar materials as CHpd1 but is generally thinner, overlie mottled and bleached saprolite. Soils consist of lithosols and gravelly earths.

Units CHpd3 and CHpd4 consist of extensive colluvial sheet-flow depositional plains and erosional plains underlain by iron-stained quartzose sands, clays and lags over ferruginous and mottled saprolite. Residual sands and ferruginous nodules are common and minor ferruginous gravel lags.

Units CFfc1 and CFfc2 consist of footslope deposits including quartz, ferruginous saprolite, ferruginous duricrust and lithic fragments in a coarse, poorly sorted sandy to gravelly earthy matrix. The colluvium in unit CFfc2 is indurated by Fe and Si cements.

Regolith-landform unit CFpd1 consists of weakly consolidated sandstone and gravel-cobble size conglomerate partly cemented by Fe oxides and clay. The sediments infill valleys between Mesozoic plateaux and are typically covered by sandy earths and scattered gravel lags.

8. WEATHERING PROFILES AND GEOCHEMISTRY

Ferruginous or siliceous duricrusts typically cap the most deeply weathered profiles in the Buckley River-Lady Loretta region. The duricrusts commonly overlie zones of mottled saprolite, bleached saprolite (kaolinised), saprock and fresh bedrock. The mottled and bleached zones are commonly silicified. However, in different parts of the landscape, one or more of the underlying weathering zones may be poorly developed or absent. Representatives of these deeply weathered profiles over different lithologies have been summarised into a series of profile diagrams (Figure 11A-H). Some of these profiles have been sampled and analysed for major and trace elements by XRF and mineralogy by XRD. Selected major and trace elements for these profiles are shown on the right hand side of the regolith profile. Complete geochemical analyses of the samples are given in Appendix 4. These analyses complement more detailed regolith geochemical work (Anand *et al.*, 1995 and 1996) within several district scale study areas including the Grey Ghost, Buckley River, Lady Loretta, Drifter and Blinder prospects.

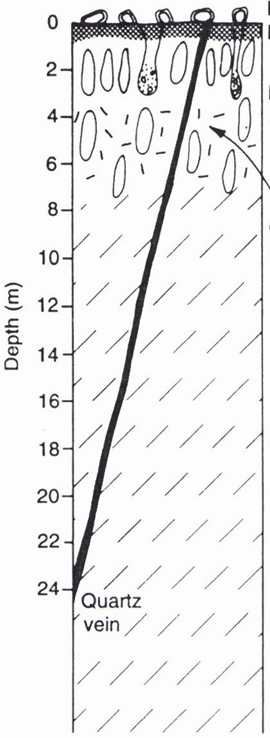
8.1 Proterozoic bedrock

Proterozoic bedrock varies from being moderately weathered to completely weathered with little or no original rock structure preserved. Duricrusts developed on Proterozoic rocks are either massive, fragmental or slabby in appearance.

Massive and fragmental ferruginous duricrusts developed on Proterozoic bedrock are shown on the regolith-landform maps (Appendix 5) as unit Dfls1. These duricrusts typically overlie mottled and bleached saprolite at depth and form cappings to mesas and local rises. The duricrust consists largely of hematite and goethite. Clay in the mottled zone is mainly kaolinite; other minerals include quartz and mica with hematite and goethite in the mottles. The mottled zone has a gradual contact over several metres to a well developed bleached zone which is typically silicified and diffusely iron-stained. The bleached zone typically has a gradual and irregular contact to non-bleached saprock or structural saprolite. The bleached zone consists largely of kaolinite, quartz, secondary silica with minor amounts of mica and goethite. Saprock consists of quartz, feldspars, kaolinite and minor goethite. The vertical distribution of major minerals and some major and trace elements in a massive ferruginous duricrust weathering profile are shown in Figure 11A.

The mineralogy is consistent with whole rock geochemistry. Iron and Si are inversely related - with Fe increasing towards the top of the profile as Si decreases. Copper, Cr, Zn and Ni have strong affinities with Fe and are concentrated in the duricrust relative to the mottled saprolite and saprock.

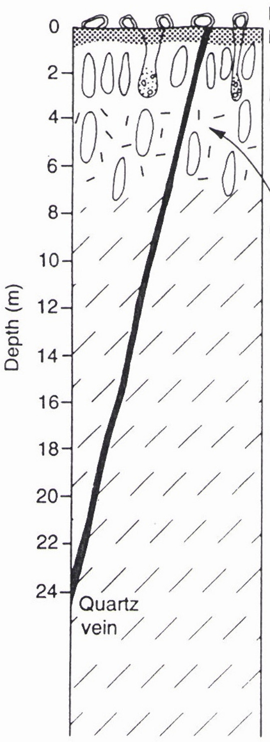
324605E 7755409N - Weathering profile on shale



Regolith units	*Mineralogy*	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	MgO %	MnO %
Loose pisoliths	*Hm, Gt, Kao, Qtz, Ana*	17.12	14.42	55.45	0.10	0.07	0.02
Massive duricrust	*Hm, Gt, Kao, Qtz, Ana*	18.10	10.23	59.93	0.02	0.04	0.02
Mega-mottled zone	*Hm, Gt, Kao, Qtz, Ana*	19.12	10.21	59.47	0.00	0.04	0.03
	Gt, Hm, Qtz, Kao	41.12	12.25	36.68	0.07	0.06	0.03
Clay of mottled zone	*Kao, Qtz*	63.86	20.52	2.16	0.07	0.08	0.04
Mottled saprolite	*Kao, Sm, Qtz, Ca, Gt*	43.40	14.05	10.16	2.43	1.79	0.29

Hm *Hematite*
Gt *Goethite*
Kao *Kaolinite*
Sm *Smectite*
Ca *Calcite*
Ana *Anatase*
Qtz *Quartz*

324605E 7755409N - Weathering profile on shale



Regolith units	*Mineralogy*	Cu ppm	Zn ppm	Ni ppm	Pb ppm	Cr ppm	V ppm
Loose pisoliths	*Hm, Gt, Kao, Qtz, Ana*	325	53	5	44	140	1155
Massive duricrust	*Hm, Gt, Kao, Qtz, Ana*	378	45	9	30	80	780
Mega-mottled zone	*Hm, Gt, Kao, Qtz, Ana*	384	43	11	29	78	770
	Gt, Hm, Qtz, Kao	176	55	18	3	21	493
Clay of mottled zone	*Kao, Qtz*	14	16	20	13	15	70
Mottled saprolite	*Kao, Sm, Qtz, Ca, Gt*	509	210	64	20	13	301

Hm *Hematite*
Gt *Goethite*
Kao *Kaolinite*
Sm *Smectite*
Ca *Calcite*
Ana *Anatase*
Qtz *Quartz*

Figure 11A. Vertical distribution of major minerals and some major and trace elements in the weathering profile over basalt. The profile consists of massive duricrust over ferruginous and mottled saprolite (from Anand, *et al.*, 1996).

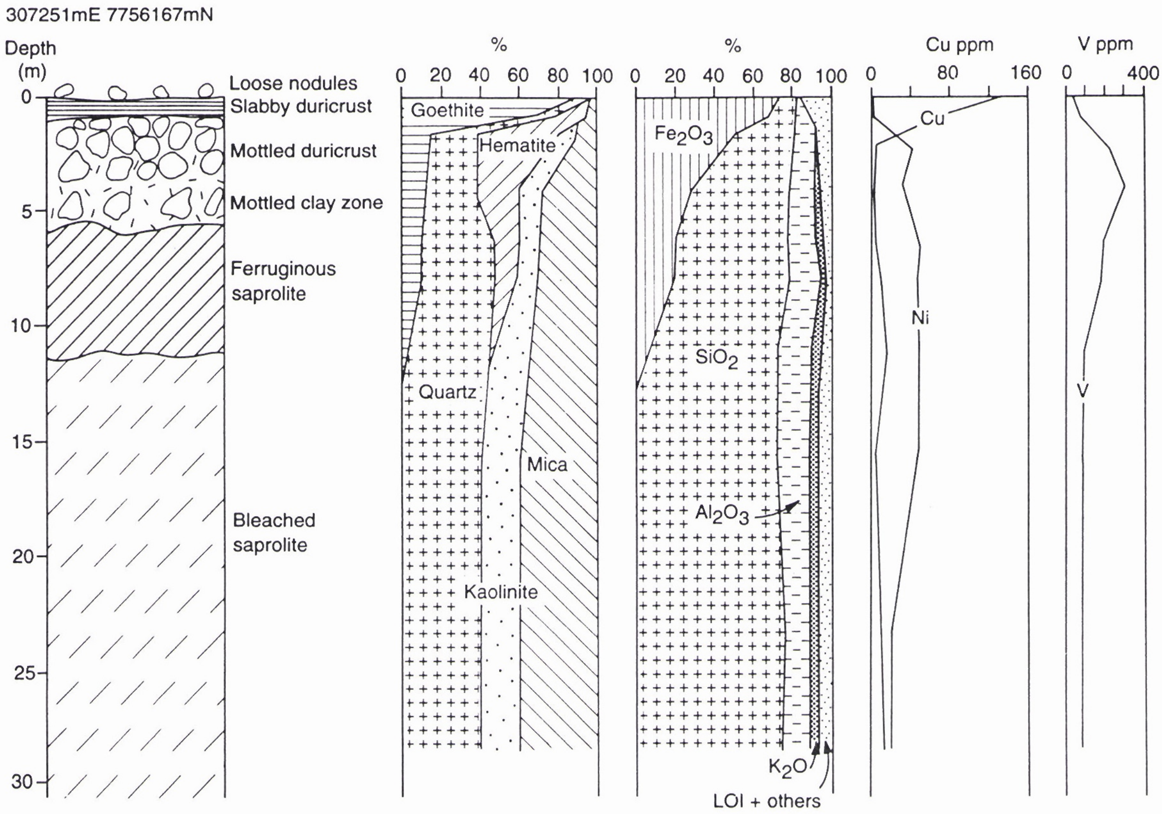


Figure 11B. Vertical distribution of major minerals and some major and trace elements in the weathering profile over dolomitic siltstone. The profile consists of slabby Fe duricrust over ferruginous and mottled saprolite (from Anand, *et al.*, 1996).

Slabby duricrust developed in Proterozoic bedrock are typically underlain by mottled and bleached saprolite. The vertical distribution of major minerals and some major and trace elements of a slabby duricrust profile east of the Buckley River prospect is shown in Figure 11B. Quartz veining almost to the surface of this weathering profile indicates that the profile has formed *in situ*. However geochemical differences in the top half metre of the profile (lower V and Ni and elevated Cu, see Figure 11B) compared with the underlying profile indicates a transported origin. Evidence from field relationships and geochemical trends are therefore contradictory. These differences may be explained by the lateral movement of iron and associated elements into the weathered bedrock. The Fe would replace more soluble minerals as the rock weathered whereas resistant minerals such as quartz (veining) would be retained. Mineralogy of the ferruginous and mottled saprolite is dominated by mica, quartz, kaolinite, hematite and goethite. Goethite pseudomorphs after mica and carbonates are present throughout the mottled and ferruginous saprolite. The mottled zone consists of irregular reddish brown mottles in a pale yellow kaolinite-quartz-mica matrix. The slabby ferruginous duricrust (71% - Fe2O3) is mainly goethite iron with minor quartz and hematite. Below the slabby duricrust a mottled duricrust zone consisting of reddish brown mottles forms a transition zone to the underlying saprolite.

Siliceous crusts including silcrete and silicified saprolite are typically impregnated by iron to varying degrees in the form of hematite mottling and diffuse staining. The silcretes are typically covered by a veneer of ferruginised silcrete and silicified saprolite gravel. The silcretes are either massive or form columnar blocks, breccia or nodular fabrics (Anand *et al.*, 1996). They also occur as pods up to 1.0 metres wide which are typically surrounded by gritty sands partly cemented by iron and silica. The silcretes vary from being fine-grained with a micro-crystalline texture or coarse-grained where silica has cemented quartzose sand and gravel. The silcretes are approximately 90% SiO2, relatively rich in TiO2 (1-7%) which occurs as anatase, and poor in elements associated with clay minerals (Al203, MgO). The mottled saprolite beneath the silcrete is often silicified. Silicification is also associated with Fe duricrusts where silica has cemented the mottled and kaolinised zone beneath the duricrust. An example of a silcrete-capped weathering profile developed over Proterozoic bedrock is shown in Figure 11C. The profile consists of iron-stained silcrete, collapsed ferruginous and silicified mottled saprolite, bleached saprolite and saprock. The saprock is mineralised with Cu (Figure 11C).

Silcrete at the top of the profile in Figure 11C is almost completely composed of silica (96%). However, trace elements (Zr and V) are much higher in the silcrete than the underlying bedrock suggesting that the upper part of the profile is unlikely to reflect weathering of the bedrock below. This suggest a lateral source for the trace elements. TiO2 is also higher in the silcrete than the underlying saprolite (see Appendix 4). Ferruginous granules over the silcrete have elevated metal values (Cu, Ni and Cr) due to scavenging by Fe oxides. Aluminium (Al) and gallium (Ga) are low in the silcrete and have higher concentrations in the mottled, bleached and saprock zones where they are likely to be associated with kaolinite and feldspars.

8.2 Cambrian and Mesozoic bedrock

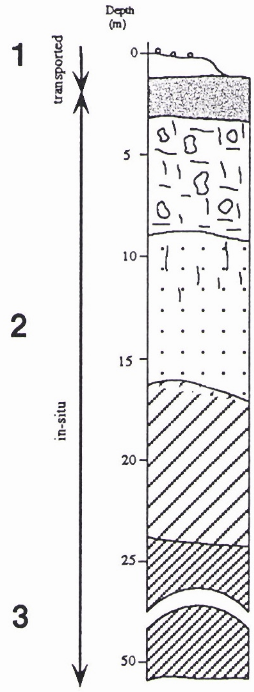
'Typical' weathering profiles on Cambrian and Mesozoic sediments are shown in Figures 11D E & F. Deeply weathered Cambrian sediments on plateaux form highly ferruginous brecciated saprolitic crusts with local pockets of ferruginous duricrust over mottled and ferruginous saprolite (Figure 11 E & F). Silicification is common and in places silcrete layers occur (Figure 11 D) within the weathering profile. The cherty breccia associated with the Drifter and Blinder prospects has anomalous Cu, Zn and Pb but there is no known mineralisation at depth (Anand *et al.*, 1996). Possible sources of these metals are described in the discussion. Cherty breccias are rich in Fe oxides, Si and Mn oxides. Elevated metal values within these materials are likely to be associated with Fe and Mn oxides in the breccia. Unconformities between the Mesozoic, Cambrian and Proterozoic sediments are often characterised by a zone of silicified saprolite or silcrete (Figures 11D).

The most deeply weathered Mesozoic profiles are now preserved on plateaux and mesas over the northern end of the map sheet. The weathering profile on these plateaux consists of massive or nodular ferruginous duricrust, ferruginous saprolite with Fe segregations, mottled saprolite, bleached saprolite and saprock. The ferruginous duricrusts are rich in hematite, goethite and quartz with traces of kaolinite and mica (Anand *et al.*, 1996). Metal concentrations are generally low whereas resistate minerals (titanium minerals and zircon) are high. The vertical distribution of some major and trace elements in a massive ferruginous duricrust developed in Mesozoic sediments over Proterozoic bedrock is shown in Figure 11G. Copper, Cr, and Zn are relative low in the ferruginous duricrusts Mesozoic sediments and highest in Fe segregations in the weathered Proterozoic bedrock beneath the massive duricrust.

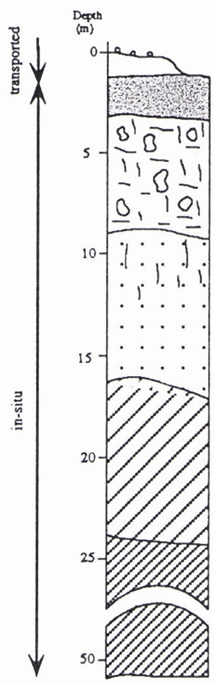
In places the Mesozoic sediments contains Cu mineralisation hydromorphically dispersed from mineralised Proterozoic bedrock (Figure 10P). Elsewhere in the area silcrete or silicified Mesozoic sediments form instead of ferruginous duricrusts. Where the underlying Proterozoic bedrock is also silicified the contact between the two rock types is difficult to detect. In places the concentration of resistate minerals such as zircon which are usually higher in the Mesozoic sediments can be used to locate the boundary.

306193E 7793961N - SILICIFIED, MOTTLED AND BLEACHED SAPROLITE (PROTEROZOIC SILTSTONE)

Landform type: Escarpment



Regolith	SiO2	Al2O3	Fe2O3	CaO	MgO	MnO	K2O
	Elements in %						
Ferruginous gravels	81.88	3.52	9.17	.02	.005	.008	.08
Fe stained & mottled silcrete	96.3	.8	.85	.02	.03	.004	.04
Collapsed breccia (ferruginous)	75.3	13.31	1.38	.11	.85	.008	2.14
Silicified and partly ferruginous saprolite. Diffuse reddish orange mottling	74.47	16.24	.47	.08	.72	.005	1.57
Clear contact to:	81.46	12.79	.35	.03	.05	.003	.03
Bleached (white) with very diffuse Fe staining. Upper part silicified. Consists mainly of kaolinite							
Gradual contact over 1-2 m to:	70.58	9.6	6.2	.03	7.42	.03	.03
Olive green to pale reddish orange structural saprolite	63.01	13.9	10.5	.04	3.89	.02	.02
Gradual contact to:							
Pale reddish orange mottled saprolite	64.67	11.48	8.68	.03	8.81	.017	.04
Saprock; typically ferruginous with diffuse mottling throughout. Cu mineralisation	33.37	4.46	48.96	.02	.3	.03	.03



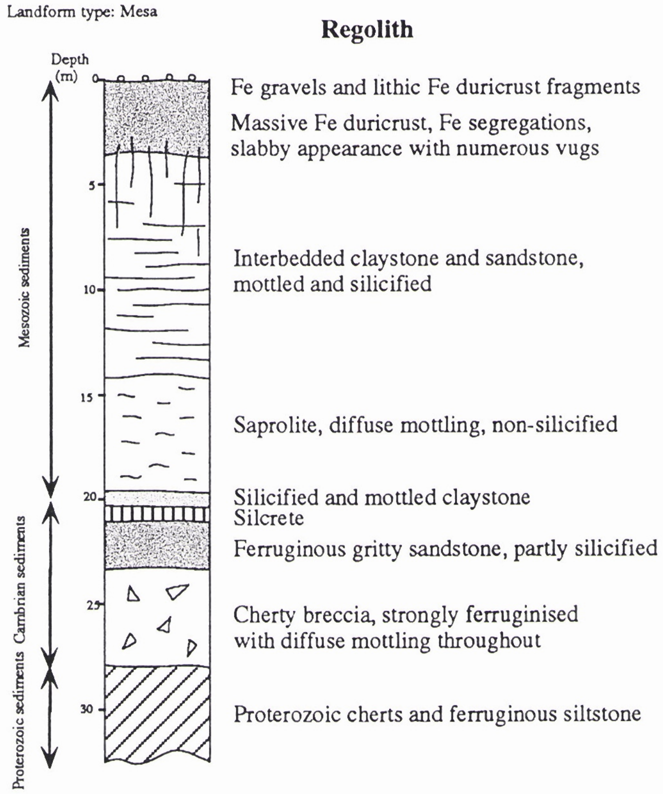
Regolith	Cu	Zn	Ni	Pb	Cr	V	Zr
	Elements in ppm						
Ferruginous gravels	61	4	224	31	75	218	883
Fe stained & mottled silcrete	11	1	10	15	9	30	400
Collapsed breccia (ferruginous)	56	12	4	28	37	73	148
Silicified and partly ferruginous saprolite. Diffuse reddish orange mottling	106	7	13	20	24	55	161
Clear contact to:	38	2	3	19	17	42	197
Bleached (white) with very diffuse Fe staining. Upper part silicified. Consists mainly of kaolinite							
Gradual contact over 1-2 m to:	1704	37	85	33	31	48	131
Olive green to pale reddish orange structural saprolite	3282	46	84	42	67	102	152
Gradual contact to:							
Pale reddish orange mottled saprolite	2013	34	98	26	58	69	137
Saprock; typically ferruginous with diffuse mottling throughout. Cu mineralisation	22040	141	28	13	59	210	76

Figure 11C. Vertical distribution of some major and trace elements in the weathering profile over Proterozoic bedrock (phyllite and shale). Profile on escarpment edge.

Numbers 1, 2 and 3 correspond to pictures of the profile on the opposite page.

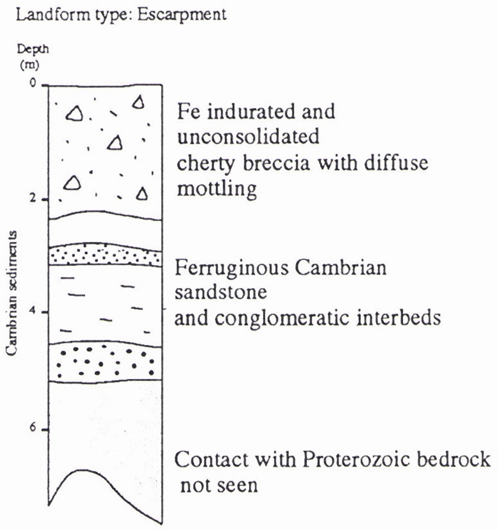
297953E 7830256N - FERRUGINOUS DURICRUST AND MOTTLED ZONE DEVELOPED OVER MESOZOIC, CAMBRIAN AND PROTEROZOIC SEDIMENTS

(D)



(E)

303810E 7813376N - FERRUGINOUS CHERTY BRECCIA (BEETLE CREEK FM) OVER SANDSTONE AND CONGLOMERATE (MT HENDRY FM)



(F)

303957E 7822607N - SILICIFIED AND MOTTLED CAMBRIAN SEDIMENTS

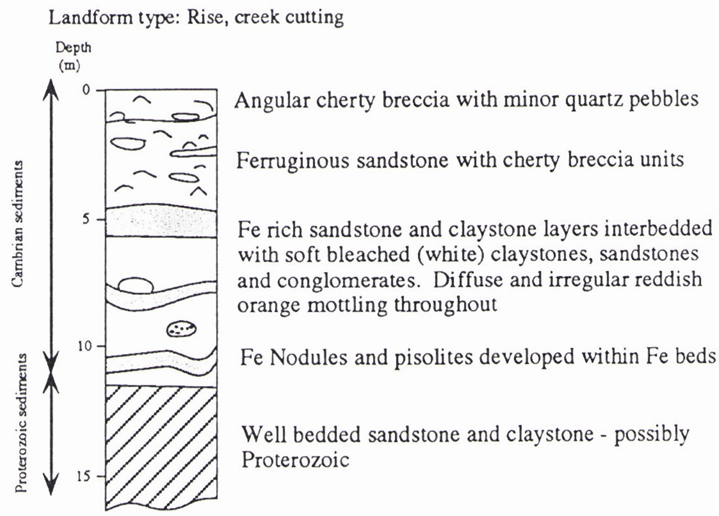
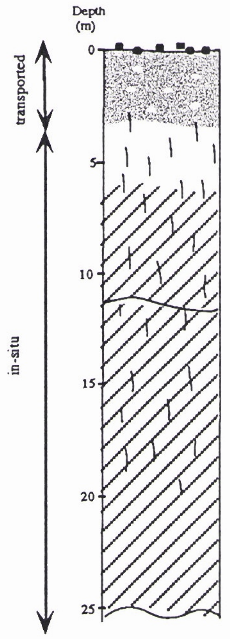


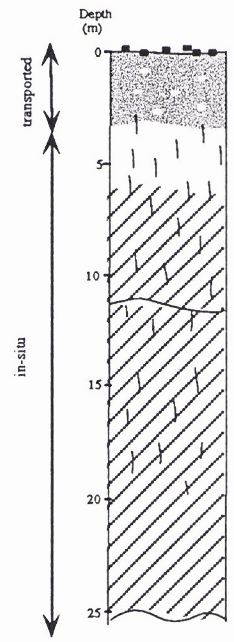
Figure 11 D, E & F. Vertical distribution of regolith materials developed on (D) Mesozoic, Cambrian and Proterozoic bedrock and (E & F) Cambrian bedrock. Profile developed on mesas and rises.

298119E 7826200N - FERRUGINOUS DURICRUST AND MOTTLED ZONE DEVELOPED OVER PROTEROZOIC SEDIMENTS

Landform type: Mesa



Regolith	Si02	A1203	Fe203	Ca0	Mg0	Mn0	K20
	Elements in %						
Fe granules	62.02	6.99	25.08	.12	.12	.053	.16
Conglomerate and sandstone indurated by Fe and Si. Iron segregations and silicification extends into underlying saprolite	40.03	6.68	43.23	.01	.58	.016	.136
Saprolite with silica overprinting	84.53	9.06	1.14	.03	.35	.006	.93
Saprolite, diffuse mottling - non silicified (shale and siltstone)	82.4	6.6	4.87	.13	.62.	067	3.21



Regolith	Cu	Zn	Ni	Pb	Cr	V	Zr
	Elements in ppm						
Fe granules	44	29	7	29	18	67	266
Conglomerate and sandstone indurated by Fe and Si. Iron segregations and silicification extends into underlying saprolite	164	39	-1	19	34	142	94
Saprolite with silica overprinting	18	3	0	22	13	32	353
Saprolite, diffuse mottling - non silicified (shale and siltstone)	18	1	3	11	6	26	73

Figure 11G. Vertical distribution of some major and trace elements in the weathering profile with Mesozoic sediments overlying Proterozoic bedrock. Profile developed on bevelled hill.

9. REGOLITH-LANDFORM EVOLUTION

Several regolith materials and landform features contain important clues to understanding the evolution of the Buckley River-Lady Loretta area. These are discussed before a summary of landscape evolution is presented.

9.1 Duricrusts and deeply weathered zoned profiles

Duricrusts are cemented *in-situ* materials (saprolite) and transported sediments (Cambrian and Mesozoic). Any models explaining their origin must account for their physical and chemical characteristics and their distribution in the landscape. The distribution of ferruginous and siliceous duricrusts are shown in Figure 9. Duricrusts are classified into two main types depending whether the major cementing agent is iron or silica.

9.1.1 Ferruginous duricrusts

Iron cemented materials can be divided into three main categories based largely on textural differences. They are:

1) Massive Fe duricrust (has little or no internal differentiation);

2) Fragmental Fe duricrust. They may be consolidated or unconsolidated;

3) Slabby Fe duricrust (duricrust has a partly layered or slabby appearance); and,

4) Nodular Fe duricrust.

Massive, fragmental and slabby duricrusts occur on Fe rich lithologies (e.g., Gunpowder Creek Formation). They cap deeply weathered profiles which include mottled and bleached zones. The massive and fragmental duricrusts show clear evidence (quartz veining) that they have formed largely *in-situ.* Massive duricrust appears to have formed from the concentration of Fe in the saprolite or from the fusion of iron segregations which initially develop in the mottled zone beneath the duricrust. Iron in the segregations have probably been derived from re-mobilisation of Fe in the mottled zone and Fe souced via capillary action from the underlying bleached zone. In addition, some Fe was probable sourced laterally. However, lateral sourcing of Fe is thought to be a more important process in the development of 'slabby' Fe duricrusts. In many places, there is clear field evidence of a gradual transition between Fe segregations in the mottled zone and the massive or fragmental duricrust layer. Mottling developes as iron and clay species are separated and concentrated. This separation of Fe eventually leads to the formation of Fe segregations in the upper part of the mottled zone. Iron segregations are then progressively exposed and hardened due to surface weathering and erosion. The Fe segregations may either;

1) collapse at the surface and break down to form a fragmental Fe gravel layer, or

2) cement together to form massive duricrust.

The fragmental gravel layer consists of ferruginous saprolite fragments. duricrust fragments and minor Fe nodules and pisoliths. Pisoliths have probably formed by secondary re-working of the fragmented gravels by pedogenic processes. The gravels are dominated by goethite with minor hematite, kaolinite and quartz. The fragmental layer is generally unconsolidated due to bioturbation resulting in re-working and mixing of the gravels (Figure 10H).

Elsewhere a partly consolidated ferruginous collapsed saprolite can develop which consists mainly of angular kaolinised lithic fragments cemented by Fe. Ferruginous nodules and pisoliths are also common and are partly cemented in a ferruginous earthy clay matrix surrunding the lithic fragments (Figure 10B). Some fragmental saprolites have a high silica content particularly if the rock fragments are prodominantly siliceous. The fragmented fabric has probably developed from the removal of clays - causing the saprolite to collapse. Re-working due to bioturbation would also contribute to surface mixing and fragmentation. Mobilisation and precipitation of Fe has subsequently partly cemented the saprolite fragments and formed Fe nodules and pisoliths in the upper part of the weathering profile. Similar fragmental duricrusts in the Selwyn study area (Wilford, 1997) grade into a mottled and kaolinised zone.

Slabby Fe duricrusts (Figure 10A) are characterised by sub-horizontal to horizontal layering. The top of the slabby duricrust profile typically consists of lithosols comprising ferruginous duricrust gravels, pisoliths and nodules. Slabby duricrusts have a sharp contact with the underlying mottled zone and are typically associated with a well developed bleached zone which is invariably silicified. Quartz-veining through the duricrusts, although discontinuous in places, indicates that the profile has largely formed *in-situ*. Near the Buckley River prospect the lack of quartz veining and marked trace element differences (Figure 11B) between the slabby duricrust and the underlying ferruginous or mottled zones suggest that the duricrusts are not related to the underlying weathering profile. Geochemical differences within these duricrust and underlying bedrock may by explained by the lateral sourcing of Fe oxides (Anand *et al.*, 1996). At Selwyn (Wilford, 1997), slabby duricrusts are thought to be associated with the valley sides of palaeochannels and it is suggested that a similar model may operate with the slabby duricrusts in the Buckley River-Lady Loretta region (Figure 12).

Massive or slabby duricrusts have not been dated. However they have more than likely formed from continual weathering during the Tertiary with periods of active and less active formation depending on changing climatic conditions (ie. humid and arid).

Massive and nodular duricrusts also occur on Mesozoic sediments and probably reflect a long history of weathering from sub-aerial exposure of the sediments in the Late Cretaceous through to the present day. Massive duricrusts underlie extensive plateau surfaces at the northern end of the study area, locally called the 'Desert'. The ferruginous and highly weathered nature of the Mesozoic sediments in the Buckley River-Lady Loretta area and elsewhere over the Mt Isa inlier (Anand *et al.*, 1996 and Wilford, 1997) may relate to the original abundance of water in the sedimentary sequence. Water would have been associated with the initial deposition of the shallow marine/terrestrial sediments and then later with groundwater flow while the sediments still occupied lower parts of the landscape (ie. valley floors, coastal inlets). The availability of water would have accelerated the weathering process, particularly with regard to the movement of Fe and Si in the sedimentary pile.

Nodular duricrust appear to have developed by cementing of ferruginous pisoliths and nodules in the soil. Surface weathering cemented the pisoliths and nodules to form indurated pavements. The soils appear to be largely residual and the ferruginous pisoliths and nodules largely locally derived.

Cambrian lithologies generally weather to form ferruginous saprolite and cherty breccia. The cherty breccia is typically indurated by Fe and Mn oxides and silica. The brecciated nature of the Cambrian sediments is most likely related to weathering and removal of carbonates and clays from the original sediments, resulting in the collapse of the more resistant cherts and siliceous siltstones beds. These resistant materials have now been re-cement by Si, Fe and Mn oxides.

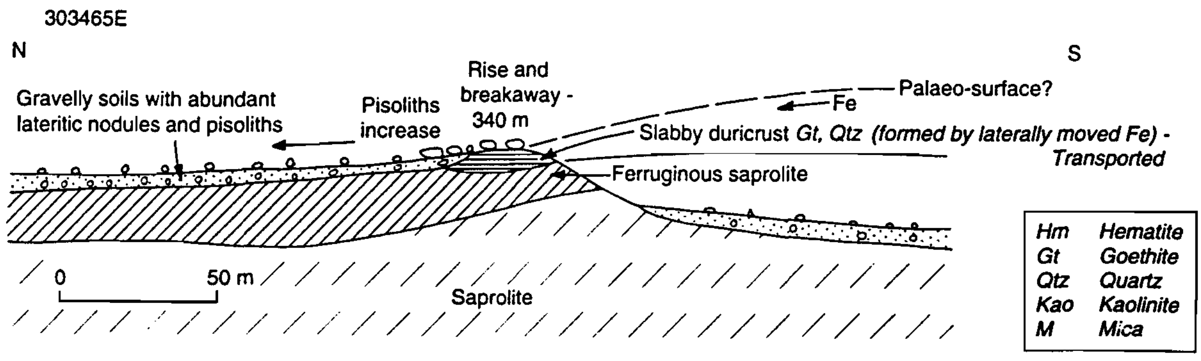


Figure 12 The development of slabby duricrust by absolute accumulation of Fe (from Anand, *et al.*, 1996)

9.1.2 Siliceous duricrusts

Silica-cemented materials are widespread over the Buckley River-Lady Loretta area, and have many different fabrics and textures. Siliceous materials are broadly divided into three main groups including:

1) Silcrete (completely silica-cemented microcrystalline duricrust);

2) Silicified sand and gravel; and

3) Silicified saprolite (silica cementing saprolite).

Silcretes and silicified saprolite occur on Proterozoic and Mesozoic sediments. Although they form on a variety of bedrock types they are most common on siliceous lithologies. Stromatolitic shales and siltstones are particularly susceptible to silicification and typically form resistant rises, hills and ridges. The silcretes form massive blocks, pods and nodules and consist of grey microcrystalline silica with diffuse Fe-staining or mottling. The massive silcretes may be associated with groundwater precipitation of silica. However, other structures within some silcretes including columnar jointing patterns and candle-stick beading could be indicative of a pedogenic origin. Jointing may reflect columnar peds in a palaeosol and candle-stick beading may relate to the movement of solute particles down an old soil profile with has since been silicified. Alternatively the jointing may relate to shrinking and cracking of the silcrete due to de-watering. The origins of these silicretes appears to be complex and requires further work.

Silicified saprolite by definition still retains some of the original bedrock structures and fabric. Silicified saprolite common occurs below the silcrete or within the bleached quartz-kaolinite zone beneath the mottled zone of weathering profiles.

Silcretes and silicified saprolite typically weathers at the surface to form a lag of Fe-stained silicified gravels, pods and nodules.

In places silica has cemented alluvial sands or sheet wash sands and gravels (Figure 10C and M). The sands and gravels are well rounded to angular. Silicification has led to differential erosion and relief inversion of the sediments forming rises. The inversion can be very subtle with only a few metres elevation difference between the older silicified alluvium and the present-day channel. Silicification is probably associated with fluxes of silica-rich groundwaters while the sediments were low in the landscape (Figure 13). Proterozoic saprolite below the silicified sediments is typically highly bleached and also partly silicified.

Elsewhere in the Mt Isa Inlier (Wilford, 1997) silcretes/silicified saprolites and slabby Fe duricrusts are associated with palaeochannels. Silicification appears to be occurring at the present day with siliceous hardpans developing within extensive low-lying colluvial plains. In places silica appears to be cementing angular quartz gravel lags and forming pods within the bedding planes of siliceous lithologies (ie. siltstones). Both iron and silica secondary cements are common within the same weathering profile. In many places silica overprints ferruginous materials suggesting that conditions more favourable for silicification may have occurred more recently. Silicification of the bleached or kaolinised zone of the deeply weathered profiles is common. This suggests that weathering and kaolinisation of the bedrock occurred prior to silicification. However, silicification of Cambrian, Mesozoic and Proterozoic sediments suggest several episodes of silcrete development during the Late Cretaceous and Cainozoic.

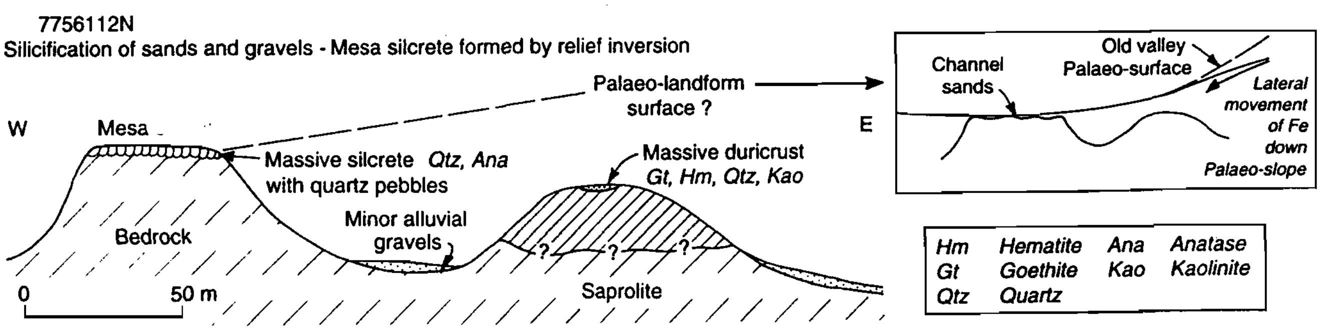


Figure 13. The development of silcrete and subsequent relief inversion due to differential erosion. (from Anand, et al., 1996)

9.2 Drainage features

9.2.1 Drainage superimposition, relief inversion and capture.

There is clear evidence of drainage superimposition of major eastwest river channels across the map sheet. Predominantly eastwest flowing drainages including Wilfred Creek, Buckley River and West Thornton Creek are likely to have been inherited from a flat-lying Mesozoic sedimentary cover which blanketed most of the region during the Early Cretaceous (see regolith landscape evolution)). The older eastwest palaeoflow direction is now superimposed over the predominantly northsouth structural fabric of the underlying Proterozoic rocks. Only the larger streams are superimposed, minor streams which show weak trellis drainage are structurally controlled by the basement rocks. In places, streams flowing to the west which include the original headwaters of the Buckley River have been captured and diverted to the north as more youthful northsouth drainages erode the landscape (Figure 4). Extensive floodplain deposits associated with the Buckley River are likely to reflect a more extensive headwater drainage system extending eastward which has now been partly truncated or captured (see regolith maps Appendix 5).

Inverted silicified alluvial and colluvial sands and gravels developed on palaeoplains occur over the lower western part of the map sheet as unit AC. These units are probably more extensive than shown on the map since they are typically partly obscured by more recent colluvium. The flow direction of these silicified channels broadly parallels the older eastwest flowing drainages.

9.3 Land surfaces, erosion and deep weathering

Cycles of deposition, erosion and weathering leading to the development of several land surfaces over the Mt Isa region have been proposed by Grimes (1979). These cycles include the Aurukun surface (Oligocene), Kendell surface and the third cycle which started towards the end of the Tertiary and is active at the present day. Regolith-landform mapping of the Buckley-River-Lady Loretta region indicates that the landscape is 'stepped' with two main surfaces. Whether these surfaces correlate with those proposed by Grimes is problematical, since erosional surfaces will have different ages on different parts of the surface. Also evidence to support cyclic models of weathering are at best tenuous.

The higher of the two stepped topographic surfaces forms a palaeoplain which occurs on the central western part of the map sheet (Appendix 5.2) and is bounded along its eastern edge by an erosional scarp (see erosional scarps). The surface consists of erosional plains and rises with typically highly weathered siliceous, ferruginous, mottled and bleached saprolite (Figure 10K). The surface was probably developed by the mid to late Mesozoic. Since then relatively low erosional rates due to the low relief have preserved some of the most deeply weathered regolith over the map sheet area. Exploration drilling over this palaeoplain typically records depths of weathering of up to 150 metres. Bevelled Proterozoic bedrock hills and extensive Mesozoic plateaux ('The Desert') around the Lady Loretta and Drifter prospects to the north may have also been part of this broad plain. However, irregular thicknesses of Mesozoic sediments and undulating contacts with the underlying Proterozoic and Cambrian rocks suggest that this surface was not flat but broadly undulating. In places, a lower stepped surface in the form of benches or plateaux are preserved below this higher surface. The bedrock on this lower level is generally not as weathered (eg. saprock near to surface) as that of the palaeoplain above.

9.4 Exhumed surfaces

The area around the Drifter Prospect (AMG:298200E:7827700N) the pre-Cretaceous land surface or a derivation similar to it has been re-exposed or exhumed. The term exhumation refers to a process relating to the exposure by denudation of a land surface that has in the past been buried. At a local scale around the Drifter Prospect it would appear that erosion during the Tertiary has exhumed the unconformity between the Proterozoic and Cambrian sediments. The unconformity is delineated by either silcrete or silicified Proterozoic bedrock. Exhumation has probably developed by a combination of deep weathering and competency contrast between the siliceous layer and softer Cambrian and Mesozoic sediments which have now been largely removed. How closely the exhumed surface will reflect the original pre-Cretaceous topography will largely depend upon post-Cretaceous tectonism in the area. There is evidence of Post-Cambrian tectonic movements immediately to the west of the Buckley River-Lady loretta study area (see summary of Regolith-landform history).

9.5 Erosional scarps

An important feature on the Buckley River-Lady-Loretta map is a major erosional scarp trending north north-west over the central part of the map sheet. The scarp separates old landforms and regolith over a palaeoplain on the western side from younger landforms and regolith on the east (Figure 14). The eastern side of the scarp is dominated by erosional processes and consists mainly of thin skeletal soils over slightly to moderately weathered bedrock. However, exceptions to this are isolated mesas which preserve older remnant surfaces of the palaeoplains which once extended further to the east. These mesas consist of siliceous or ferruginous duricrusts and are common around the Grey Ghost Prospect. Other smaller, less continuous scarps occur around the headwaters of some drainage basins, around mesas, and parallel to some streams (ie Buckley River). In many places these scarps form important contacts between different types of regolith, with generally older and typically indurated (iron or silica) regolith materials above and younger materials below. For example scarps are associated with highly ferruginous and silicified saprolite which resist weathering due to their hardness (see maps - Appendix 5).

9.6 Summary of Regolith-landform history

The sequence of events listed below are based on conclusions drawn from regolith-landform and geological mapping over the Buckley River - Lady Loretta area. However, due to the lack of regolith dating - age relationships and correlations are at best speculative. The stages of regolith-landform evolution show diagrammatically in Figure 15.

9.6.1 Late Jurassic - Early Cretaceous

Rising sea level in the Early Cretaceous caused sedimentation in the lower stretches of the main drainages and, eventually, sediments drowned all but the highest parts of the local topography. Irregular thicknesses of Mesozoic sediments and undulating contacts with the underlying Proterozoic rocks indicate that sediments infilled valley and ridge palaeotopography. The sediments are thickest in the north and northeast towards the depo-centre of the Carpentaria Basin. Highly weathered Proterozoic bedrock beneath the Mesozoic sediments indicates pre-Mesozoic kaolinisation prior to valley infilling or deep post-Jurassic weathering. The sea re-worked the upper part of the deep weathering profiles resulting in the accumulation of sea-floor sediments.

9.6.2 Late Cretaceous

As the sea retreated the Late Cretaceous the sea floor was exposed. Drainages were initiated on the sea bed sediments, flowing generally north to the subsiding Carpentaria Basin and southwest to the Georgina Basin. Eastwest drainage superimposition across the predominantly northsouth structural grain of the Proterozoic rocks reflects an early drainage pattern inherited from the exposed sea floor cover. In places, streams flowing to the west have been captured and diverted to the north as more youthful northsouth drainage's erode the landscape. This inheritance strongly suggests that the Mesozoic cover extended over a large part if not all of the Buckley River-Lady Loretta region. Some resistant ridges may have protruded as islands surrounded by a Mesozoic sea. Immediately after emergence the area was relatively flat with most of the Proterozoic hills bevelling as a result of the marine transgression. Most of the relatively soft Mesozoic sediments had been eroded by the end of the Cretaceous uncovering the basement rocks of the Mt Isa Inlier. Regional uplift of the inlier and modest down warping of the Carpentaria and Georgina basins would appear to be the primary driving forces behind regional erosion and aggradation. Differential erosion following emergence left the Proterozoic basement rocks high in the landscape. Local areas of Post-Cambrian faulting and recurrent movement on faults to the West of the study area has been described by de Keyser and Cook (1972) but no faulting has been recorded within the area.

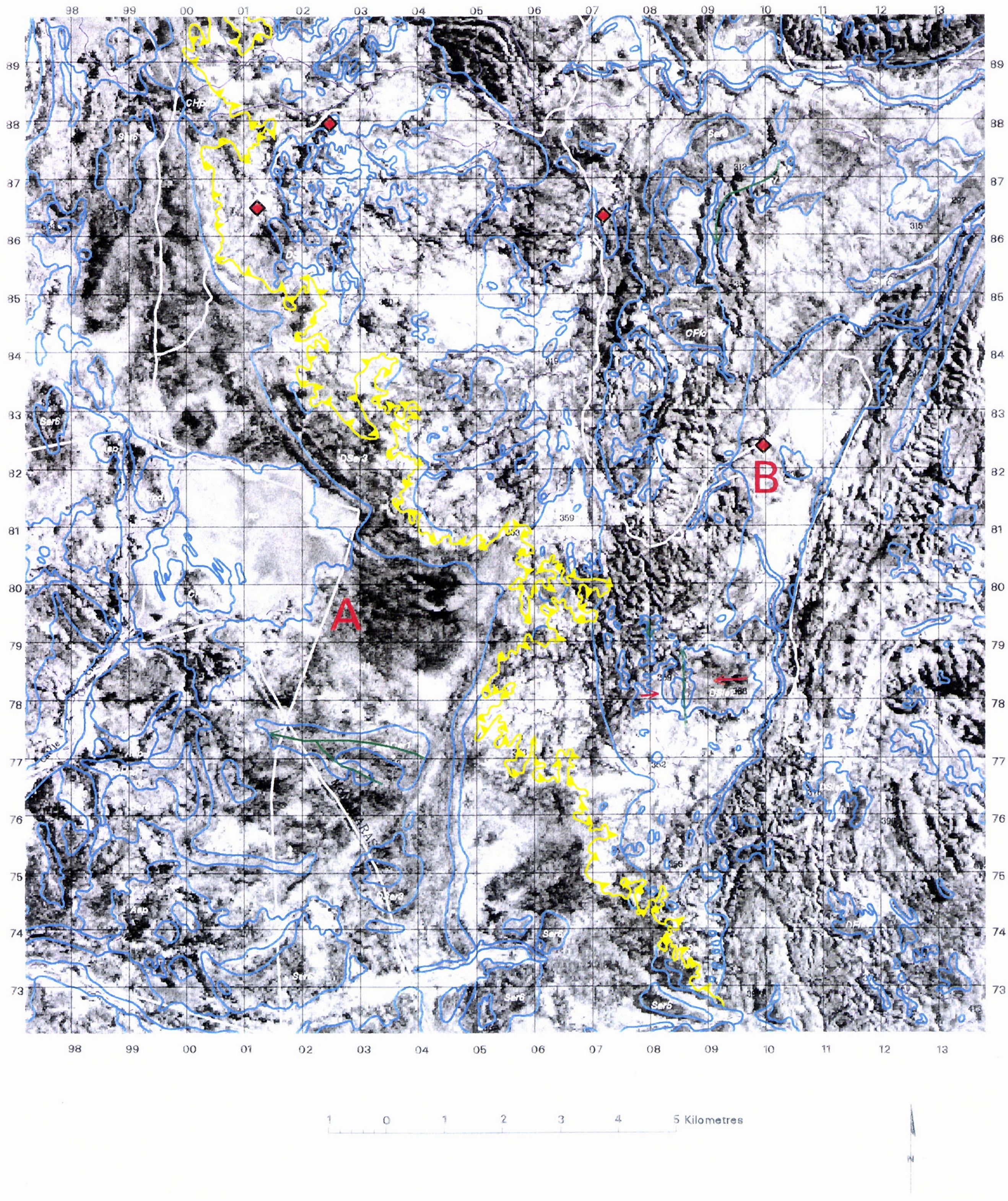
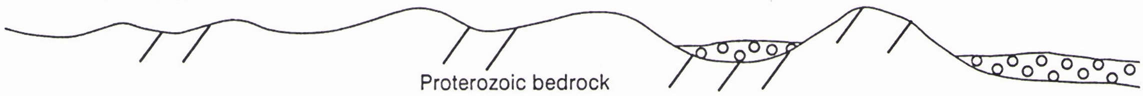


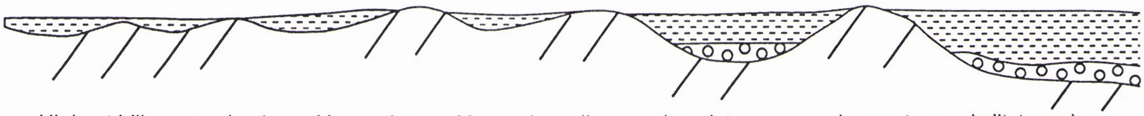
Figure 14. Landsat TM band 5 overlain with regolith polygons (blue), erosional scarps (yellow), palaeo slopes (red) and palaeo channels (green). A - Landforms above the scarp are highly weathered silicified, mottled and bleached saprolite. The saprolite is largely covered by a blanket of colluvial sands and gravels. B - Landforms below the scarp are generally less weathered consisting of ferruginous and mottled saprolite and saprock. The saprolite is partly covered by lithosols. Soil geochemical surveys are likely to mainly reflect regolith materials above the scarp and bedrock lithology below the scarp. Mineral deposits are shown with red diamonds. These deposits all occur on the less weathered side of the scarp (B). Therefore landscapes and regolith associated with (A) may well be concealing buried mineral deposits.

1.Late Jurassic



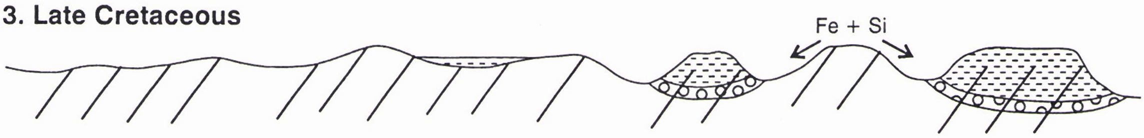
Proterozoic rocks forming undulating plains and hills, weathering occurring in valley floors.

2. Early Cretaceous



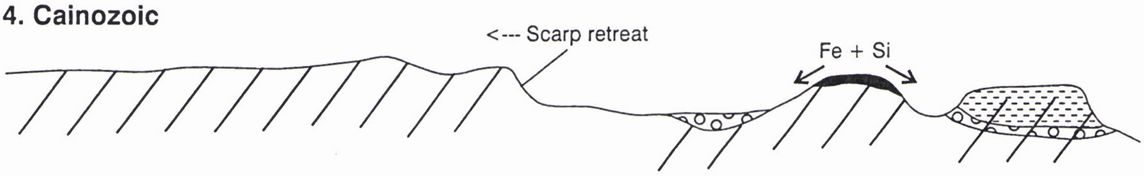
Highest hills protrude above Mesozoic sea. Mesozoic sediments (sandstones, conglomerates and siltstones) infill valleys within Proterozoic bedrock landforms. Local relief is reduced due to valley infilling and bevelling of hills by erosion.

3. Late Cretaceous



Weathering and erosion of Mesozoic and Proterozoic rocks. Weathering products are retained where rates of weathering is greater than the rates of erosion.

4. Cainozoic



Differential rates of erosion and weathering form a variety of different weathering styles on Mesozoic, Cambrian and Proterozoic rocks. Ferruginisation and silicification of Mesozoic, Cambrian and Proterozoic rocks form mesas and resistant rises and hills. Some E-W flowing rivers are captured and directed to the north. Relief inversion occurs in places over palaeo surfaces. Alluvial sediments accumulate in floodplains, alluvial plains and sheet wash plains. Scarp retreat, valley widening and pediment development takes place.

5. Present Day

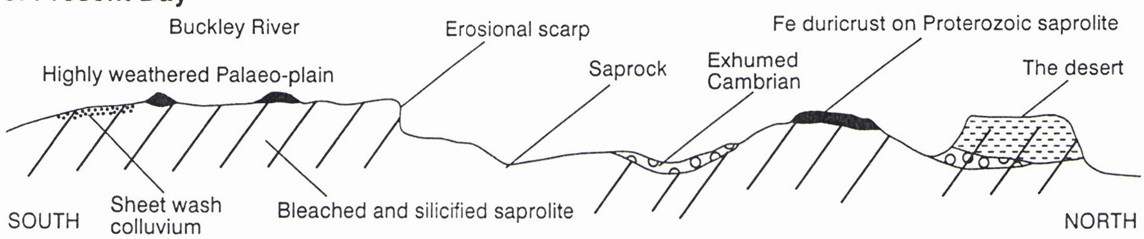


Figure 15. Stages of regolith-landform evolution over the Buckley River-Lady Loretta region of the Mt Isa Inlier.

9.6.3 Cainozoic

By the early Cainozoic the Mesozoic sediments had been largely eroded except in the central and northern part of the map sheet area. Highly and deeply weathered Proterozoic bedrock over the southwest part of the map have been preserved due to the low relief and induration by Fe and Si. The Mesozoic cover was probably never very thick over this part of the landscape and was likely removed shortly after uplift, thereby exposing the Proterozoic rocks to weathering throughout the Cainozoic. Weathering and differential erosion from the Late Cretaceous and during the Cainozoic has formed most of the present day landforms. In places river channel and sheet wash deposits have been silicified. Subsequent erosion has left these resistant siliceous duricrusts as relief inverted landscape elements. Ferruginous duricrusts developed on Mesozoic and Fe-rich Proterozoic lithologies.

Weathering continued during the Tertiary with periods of active and less active formation depending on changing climatic conditions (e.g., humid or arid conditions). The drainage divide separating streams flowing into the Georgina and Carpentaria Basins shifted westwards due to scarp retreat. Deep weathering and duricrusts developed on exposed stable parts of the landscape. Deeply weathered profiles are now best preserved on an extensive palaeoplain over the central western part of the Buckley River-Lady Loretta map. Several periods of silicification probably occurred during the Cainozoic, however, silicification became more common as climatic conditions became more arid from the Late Miocene to the present day. Silica precipitating appears to be occurring at the present time, forming hardpans within colluvial sediments. Tertiary weathering of the Cambrian sediments led to development of ferruginous and siliceous cherty breccia as carbonates were removed from the sediments.

Weathering and erosion during the Tertiary has in places developed a 'stepped' topography, with highly weathered benches and mesas forming below a bevelled but undulating Mesozoic surface (stepped topography is well developed in the Grey Ghost area - AMG: 303875E: 777700N).

10. DISCUSSION AND IMPLICATIONS FOR MINERAL EXPLORATION

The Buckley River-Lady Loretta region has had a complex history of landscape evolution. A combination of a long weathering history and variable degrees of erosion and exhumation has resulted in a landscape of highly variable regolith. Rocks exposed at the surface reflect weathering processes from the Jurassic to the present day. In addition relief inversion processes add to the complexity of the present day landscape.

Standard geochemical sampling methods are unlikely to be effective across the whole study area. For geochemical surveys to be effective, an understanding of the origin of the sampling media, style of weathering, geomorphic processes and regolith-landform relationships are necessary. Several major regolith-landform associations should be considered carefully when interpreting surface and drill hole geochemistry. These associations are described below.

10.1 Weathering profiles on Proterozoic bedrock with or without thin cover.

Landforms particularly along the eastern half of the map sheet are being actively eroded and as a result bedrock is well exposed consisting of thin soils and lags over saprolite. Soil/rock geochemical sampling is recommended in this type of terrain. In places either ferruginous and siliceous duricrusts are preserved, forming indurated cappings to mesa and bevelled hill tops. The distribution of duricrusts is strongly controlled by lithology. Ferruginous duricrusts are more likely to develop on ferruginous lithologies whereas silcretes are more likely to develop on siliceous lithologies. Local environmental controls such as palaeodrainage have also played an important role in their formation. Duricrusts are therefore unlikely to be the remains of an extensive deeply weathered mantle across the landscape. Massive and fragmental ferruginous duricrusts are thought to have developed largely *in situ* and are likely to be useful indicators of geochemistry at depth. The duricrust, ferruginous saprolite, ferruginous nodules and pisoliths are all useful sampling materials. However, slabby Fe duricrusts may give false anomalies due to lateral movement of Fe oxides and associated metals. Slabby duricrust probably once developed along valley sides or in topographic lows where groundwaters precipitate Fe oxides. In the Selwyn area (150 km south south-east of Mt Isa) slabby Fe duricrusts and bleached saprolite are thought to be associated with groundwaters along palaeodrainage channels which have developed in a relatively tectonically stable environment (Wilford, 1997). Therefore slabby duricrusts can be sampled to give broad geochemical indications. In siliceous landscapes mottling and Fe granules derived from the weathering of pedogenic silcretes can be used as a indicator of geochemistry at depth. Silcretes, however, should be interpreted independently from ferruginous duricrusts since they invariably show much lower metal concentrations.

10.2 Saprolite covered by extensive colluvial deposits

Colluvial deposits consisting mainly of sheetwash sands, clays and gravels are best developed over the central and western area of the map sheet. Here the colluvium forms an extensive blanket over a deeply weathered (up to 150 meters) palaeoplain. The saprolite beneath the colluvium is exposed along a major erosion scarp which forms the eastern edge of the palaeoplain. Along the scarp edge the weathering consists of either Fe or Si cemented duricrusts or saprolite over mottled (typically showing mega mottling) and bleached saprolite which grades into saprock at approximately 40-70 metres below the plain surface (Figure 10 K). Sampling of ferruginous materials including lithic fragments, pisoliths and nodules can be useful in reconnaissance geochemical interpretations. Silicified river channel sediments (now relief inverted) are commonly associated with palaeoplains. Interpreting geochemical signatures from these materials should be predicated on the fact that they may not relate to present day river catchments.

10.3 Saprolite covered by alluvial sediments

Alluvial sediments consisting of clays, sands and conglomerates form broad floodplains associated with Buckley River, Cattle Creek and Johnson Creek in the southwestern half of the map. Rotary air blast (RAB) and stratigraphic drilling is recommended to sample and characterise saprolitic materials beneath the sediments. Otherwise sediments can be used to give reconnaissance stream sediments geochemical indicators.

10.4 Weathering profiles on Cambrian and Mesozoic sediments

Regolith developed on Mesozoic sediments are most common over the northern end of the map sheet where they form ferruginous duricrust plateaux. The use of ferruginous duricrusts as sample media requires an appropriate orientation study. However, it is possible that there may be hydromorphic dispersion from the underlying mineralisation into ferruginous materials, if these materials were weathered at the same time.

Cambrian sediments have weathered to form cherty breccia and ferruginous saprolite. These sediments typically have elevated base metal values with no traceable mineralisation in the underlying Proterozoic bedrock. High metal concentrations may relate to de-watering of the thicker and deeper water Cambrian sediments during diagenesis (per comm. Peter Southgate, AGSO). As the sediments were compacted mineralised fluids would have migrated through porous sedimentary units. The clay-rich Inca Formation (Hutton and Wilson, 1985) would have acted as an impervious cap thereby trapping the fluids below and forcing then to move laterally. Therefore anomalous metal concentrations in the sediments may therefore have migrated some distance from their original source. Weathering of the Cambrian sediments during the Tertiary would have further concentrated metals. In places, the Cambrian sediments have been largely exhumed, leaving a landscape which delineates the unconformity between the Cambrian and underlying Proterozoic bedrock. The process of exhumation has left a landscape with pockets of highly weathered Cambrian sediments juxtaposed with Proterozoic saprolite. Geochemical sampling in this terrain requires detailed regolith mapping and separation of weathered Cambrian and Proterozoic materials.

10.5 Geochemical Sampling Strategy Map

To provide a direct tool for the interpretation of surface geochemistry and drilling, the regolith-landform associations described above have been used to generate a interpretative geochemical sampling strategy map. The strategy map divides the landscape into major geochemical sampling groups as outlined below;

Geochemical Sampling Groups

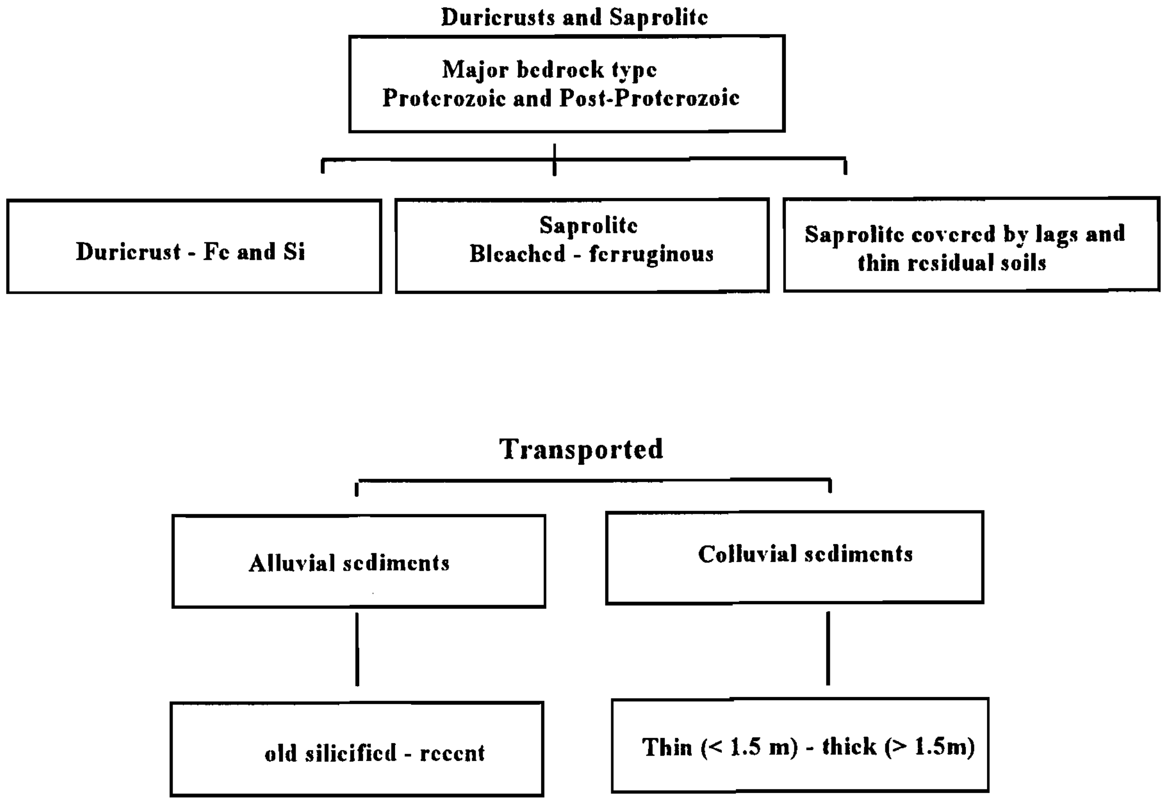


Figure 16. Shows the major geochemical sampling groups which are used in the geochemical sampling strategy map (Appendix 5.4).

Each of these groups with the exception of the alluvium and colluvium are divided into Proterozoic and Post-Proterozoic bedrock types. Subdividing regolith materials on whether the bedrock is Proterozoic or Post-Proterozoic is essential since they have a completely different geochemical significance and require different interpretations. Each unit within these groups describe regolith properties in a geochemical context. For example, highly weathered bleached regolith is separated from ferruginous saprock, and thick (> 1.5m) colluvial cover which is likely to have a more dilute geochemical response is separated from thin colluvium over bedrock. Recommended sampling approaches are also described for each unit. Clustering regolith-landform units into major regolith-geochemical groups is an interpretative process. Although the subdivision have been largely based on the physical and chemical characteristics of the regolith, genetic landscape models are also involved in the decision making process. Therefore, the geochemical strategy map (Appendix 5.4) is a interpretive thematic layer which has been generated from the original descriptive regolith-landform map (Appendix 5.1). Separating factual from interpretative information allows the user to generate new interpretative maps based on different landscape and geochemical models from the original factual data.

11. ACKNOWLEDGMENTS

I wish to thank Dr R.R. Anand who made several suggestions to improve the report. I am grateful for assistance in the field by Dr L Rogers. I also wish to thank the geologists at Lady Loretta mine for all their help. In addition I am grateful to MIM for use of the gamma-ray spectrometric data over the Buckley River-Lady Loretta area in the compilation stage of producing the map.

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13. APPENDICES

Appendix 1 - Definitions and glossary

In this section terms used to describe mapping units and regolith units of the weathering profile are defined. They are largely derived from Terminology and classification of laterites and associated ferruginous materials (Anand et al., August, 1989), Classification and Atlas of regolith-landform mapping units (Anand et al., 1993) and RTMAP regolithdatabase field handbook (Pain et al, 1991).

Regolith Stratigraphy

Duricrust
Mass of hard material formed within the regolith by either relative or absolute accumulations of natural cements in sediment (which may be variably weathered), saprolite or partially weathered rock.

Ferruginous Saprolite
Ferruginous saprolite is commonly developed over Fe-rich bedrocks. It is firm to hard, massive to mottled, and is dominated by goethite and kaolinite. Fragments of ferruginous saprolite are yellowish-brown to reddish-brown, non-magnetic, and may have an incipient nodular structure. Ferruginous saprolite may form a continuous blanket and is generally overlain by collapsed ferruginous saprolite where soft, soluble, less ferruginised material has been removed by leaching, causing the whole structure to collapse.

Ferruginous Granules
Fragments of Fe-rich (hematite, goethite, and maghemite) material, somewhat rounded, between 2 and 4 mm in diameter, generally having no cutans, and comprised of a mixture of magnetic and non-magnetic iron oxides. Commonly occur in soils or as surface lag.

Lag
Lag covers much of the surface in the Mt Isa region and consists of a variety of clast types, including lithic fragments, ferruginous granules, pebbles and cobbles, lateritic pisoliths, nodules, and quartz clasts. Lag reaches the surface by deflation of the soil by wind and water, by root plucking and by eluviation. The various clast types are commonly mixed but their distribution may be related to source material, such as regolith substrate, and to the regolith-landform framework.

Lateritic Residuum
Lateritic residuum is a collective term for certain ferruginous units of the laterite profile. It is formed by weathering, precipitation of minerals, and residual accumulation in the upper part of a lateritic weathering profile. Lateritic residuum includes units consisting of loose lateritic pisoliths and nodules (forming lateritic gravel) as well as lateritic duricrust. The colour of this regolith unit varies from yellowish-brown, through dark reddish-brown to very dark brown. The mineralogy is mainly kaolinite, hematite, goethite, with or without subordinate and variable amounts of gibbsite, quartz, maghemite, muscovite, zircon, ilmenite, and anatase. Lateritic residuum may occur at surface or subsurface when the weathering profile has been buried.

Lateritic Duricrust
Lateritic duricrust is indurated lateritic residuum, consisting of various secondary structures such as nodules, pisoliths, and ooliths, set in a matrix of kaolinite and Fe-oxides. Both magnetic and non-magnetic varieties of nodules and pisoliths occur in lateritic duricrust. The magnetic properties are due to maghemite.

Lateritic Gravels
Lateritic gravels consist of loose lateritic nodules, pisoliths, and hardened mottles. Lateritic pisoliths and nodules typically have 1-2 mm thick, yellowish-brown to greenish cutans around hematite-rich, black to red nuclei. Both lithic and non-lithic nodules are common in this unit.

Lateritic Nodule
A ferruginous lateritic particle with an irregular shape, usually with rounded edges, in the 2 to 64-mm diameter range, and which may have a cutan around a nucleus or core. As sphericity increases, the term pisolith becomes appropriate. The core can be of a variety of materials, such as hardened, variably ferruginised sandy grit, lithorelics, etc. Lateritic nodules commonly occur as loose aggregates, as a lag, in soil, and in lateritic duricrusts.

Lateritic Pisolith
A ferruginous lateritic particle resembling a pea in shape, by definition of 2 mm or more in diameter. Pisoliths can have a concentric internal structure, but concentric lamination is not diagnostic; however, most pisoliths have a cutan. Lateritic pisoliths and nodules commonly occur together, but the former rarely exceed 20 mm in diameter.

Massive Fe duricrust
Duricrust which has little or no internal differentiation.

Massive Silcrete
Completely silica cemented duricrust which has little or no internal differentiation and consist largely of micro-crystalline silica.

Mottled Zone
The mottled zone differs from the lateritic residuum above by lesser accumulation of Fe-oxides and lacks induration. The mottled zone has contrasting kaolinite-rich bleached domains and Fe-mottles, which may be distinguished easily in outcrops and in samples on a centimetre scale.

Nodular Fe duricrust
Duricrust which is differentiated internally and gives the appearance of cemented nodules.

Nodules
Nodules are irregular to spherical units of regolith material that occur enclosed within the regolith, as lag or soils. They typically have a greater concentration of some constituent (ie , carbonate, silica, iron or clay) difference in internal fabric or a distinct boundary with the surrounding material. They may contain pisoliths and/or concretions.

Pisoliths
Small round or ellipsoidal accretions resembling a pea is shape and size. Typically composed of either iron or carbonate. They may have radial or concentric structures.

Residual sand
A deposit of sand sized material, commonly composed largely of quartz, covering the land surface, and derived from the removal of finer material either in solution or suspension in subsurface water. It includes the sandy top of some soil types.

Residual clay
Clay material that remains behind after weathering has removed part of the original rock. A common example is the clay soil material found on limestone after solution has removed the calcareous part of the rock.

Slabby Fe duricrust
Duricrust which is has a partly layered or slabby apperance

Silcrete pods
Silcrete which forms discrete pods or lumps, sometimes up to a metre across. Commonly found in alluvial sediments, it may also be found in other locations.

Siliceous saprolite
Where secondary silica is abundant (>50%) and partly or completely cements the saprolite. It often has a grany texture and may be mottled. In many cases the type of bedrock can be identified.

Saprolite

Saprolite is weathered rock that retains much of the fabric and structure of the parent bedrock. Saprolite can be firm (rather than hard), soft, or friable. Isovolumetric weathering is commonly envisaged. Saprolite may become more massive upwards as the proportion of clay increases and cementation by secondary silica, carbonates, and especially Fe-oxides is common. Saprolite is lighter in colour than the overlying mottled zone and lateritic residuum. Its mineralogy is variable, depending upon the nature of the parent bedrock.

Saprock

Saprock is a compact, slightly-weathered rock of low porosity, with less than 20% of the weatherable minerals altered. The boundary between bedrock and saprock is not generally a plane, but is very irregular and corestones of fresh rock may occur in the saprock and saprolite.

Degree of bedrock Weathering (saprolite)

Slightly weathered

Slightly weathered rock has traces of alteration, including weak iron staining, and some earth material. Corestones, if present, are interlocked, there is slight decay of feldspars, and a few microfractures. Slightly weathered rock is easily broken with a hammer.

Slightly weathered sediments have traces of alteration on the surfaces of sedimentary particles, including weak iron staining. Some earth material may be present, filling voids between coarse particles.

Moderately weathered

Moderately weathered rock has strong iron staining, and up to 50 % earth material. Corestones, if present, are rectangular and interlocked. Most feldspars have decayed, and there are microfractures throughout. Moderately weathered rock can be broken by a kick (with boots on), but not by hand. Moderately weathered sediments have strong iron staining, and up to 50 % earth material. Labile particles up to gravel size are completely weathered. Larger particles have thick weathering skins. Most feldspars in larger particles have decayed.

Highly weathered

Highly weathered rock has strong iron staining. and more than 50% earth material. Core stones, if present, are free and rounded. Nearly all feldspars are decayed, and there are numerous microfractures. The material can be broken apart in the hands with difficulty.Highly weathered sediment has strong iron staining, and more than 50% earth material. All except the largest particles are weathered right through. Boulders have thick weathering skins.

Very highly weathered

Very highly weathered rock is produced by the thorough decomposition of rock masses due to exposure to land surface processes. The material retains structures from the original rock. It may be pallid in colour. and is composed completely of earth material. Corestones, if present, are rare and rounded. All feldspars have decayed. It can easily be broken by hand.Very highly weathered sediment is thoroughly decomposed. but still retains the shapes of the original sediment particles. as well as laminations and bedding. It is composed completely of earth material.

Completely weathered

Completely weathered rock retains no structures from the original rock. There are no corestones, but there may be mottling. It is composed completely of earth material.

Completely weathered sediment retains no structures from the original sediment. It is composed completely of earth material. There may be mottling.

Sedimentary Deposits

Alluvium
A general term for clay, silt, sand, and gravel deposited as a sorted or semi-sorted sediment during comparatively recent geological time on the bed or flood plain of a river or stream.

Channel deposits
Alluvium which is deposited in an alluvial channel. It is commonly coarser than surrounding deposits, and is found in both active and relict channels. It includes deposits in cut-off meanders, and point bar deposits.

Colluvial Deposits
Colluvial deposits, generally less than 5 m thick, occur as footslope deposits adjacent to steeper ridges and hills. The deposits are typically poorly sorted and consist largely of sheet flow deposits and fanglomerates overlain by stony soils. Near valley floors, these deposits typically inter finger with alluvial sediments.

Lacustrine sediments
Sediments deposited from transport by waves and from solution and suspension in still water in a closed depression on land.

Over bank deposits
Alluvium which is deposited outside an alluvial channel from flowing water which has overflowed from the channel. It includes levees and back swamp deposits.

Sheet flow deposit
Colluvium deposited from transport by a very shallow flow of water as a sheet, or network of rills on the land surface. Sheet flow deposits are very thin except at the foot of a slope and beneath sheet flood fans.

Landforms

Alluvial terrace
Former flood plain on which erosion and aggradation by channelled and over-bank stream flow is slightly active or inactive because of deepening or enlargement of the stream channel has lowered the level of flooding. A pattern that includes a significant active flood plain, or former flood plains at more than one level, becomes terraced land.

Alluvial swamp
Almost level, closed or almost closed depression with a seasonal or permanent water table at or above the surface, commonly aggraded by over bank stream flow. They typically have a gilgai micro-relief caused by shrinking and swelling of soil (i.e. montmorillonite and mix layered illitic clays).

Breakaways
Erosional scarps usually capped indurated and subindurated parts of the weathered mantle. Breakaways can mark the limits of the erosional destruction of a deeply weathered landsurface.

Colluvial footslope
Very gently to moderately inclined complex landform pattern of extremely low relief with a generally fan-shaped plan form. Divergent stream channels are commonly present, but the dominant process is colluvial deposition of materials. The pattern is usually steeper than an alluvial fan.

Drainage Floors
Flat alluvial tracts having little, if any, stream incision. Major floors are to 0.5 km wide. Small floors are <0.2 km wide.

Depositional plain
Level landform pattern with extremely low relief formed by unspecified depositional processes.

Escarpment
Steep to precipitous landform pattern forming a linearly extensive, straight or sinuous inclined surface which separates terrains at different altitudes, that above the escarpment commonly being a plateau. Relief within the landform pattern may be high (hilly) or low (planar). The upper margin is often marked by an included cliff or scarp.

Erosional plain
Level to undulating or, rarely, rolling landform pattern of extremely low relief (<9 m) eroded by continuously active to slightly active or inactive geomorphic processes.

Flood plain
Level landform pattern with extremely low relief. The shallow to deep alluvial stream channels are sparse to widely spaced, forming aunidirectional integrated network. Alluvial plain characterised by frequently active erosion and aggradation by channelled or over-bank stream flow. Unless otherwise specified, "frequently active" is to mean that flow has an Average Recurrence Interval of 50 years or less.

Hills
Landform pattern of high relief (90-300 m) with gently sloping to precipitous slopes. Fixed, shallow erosional stream channels, closely to very widely spaced, form a dendritic or convergent integrated tributary network. There is continuously active erosion by wash and creep and, in some cases, rarely active erosion by landslides.

Low hills
Landform pattern of low relief (30-90 m) and gentle to very steep slopes, typically with fixed erosional stream channels, closely to very widely spaced, which form a dendritic or convergent integrated tributary pattern. There is continuously active sheet flow, creep, and channelled stream flow.

Pediment
Gently inclined to level (<1% slope) landform pattern of extremely low relief, typically with numerous rapidly migrating, very shallow incipient stream channels which form a centrifugal to diverging integrated reticulated pattern. It is eroded, and locally aggraded, by frequently active channelled stream flow or sheet flow, with subordinate wind erosion. Pediments characteristically lie down-slope from adjacent hills with markedly steeper slopes.

Plateau
Level to rolling landform pattern of plains, rises or low hills standing above a cliff, scarp or escarpment that extends around a large part of its perimeter. A bounding scarp or cliff may be included or excluded; abounding escarpment would be an adjacent landform pattern.

Rises
Landform pattern of very low relief (9-30 m) and very gentle to steep slopes. The fixed erosional stream channels are closely to very widely spaced and form a dendritic to convergent, integrated or interrupted tributary pattern. The pattern is eroded by continuously active to slightly active creep and sheet flow.

Sheet-flood fan
Level (< 1% slope) to very gently inclined landform pattern of extremely low relief with numerous rapidly migrating very shallow incipient stream channels forming a divergent to unidirectional, integrated or interrupted reticulated pattern. The landform pattern is aggraded by frequently active sheet flow and channelled stream flow, with subordinate wind erosion.

Valley Floors
This is applied to valley bottoms when the site, in question, is not on other features that might be present within the valley, such as alluvial or colluvial plains. Alluvial sediments Materials deposited on the landsurface from transport by flowing water confined to a channel or valley floor.

Drainage Definitions

Drainage Pattern

Drainage pattern refers to the plan shapes made by drainage channels on the land surface. It should not be confused with channel pattern, which refers to the plan shape of river reaches. Drainage patterns reflect a number of elements in the landscape. They may reflect underlying rock structures, or the nature of the original surface on which they were developed (Pain et al., 1991) Simple rivers have a dendritic pattern. Complications to a dendritic pattern mean that the drainage has been affected by rock structure or events in its geomorphic history or both. Proper interpretation of drainage patterns contributes to an understanding of the geomorphic history of an area, and so to an understanding of regolith development. Drainage patterns are often one of the oldest features in a landscape, because they are developed very soon after an area is exposed to surface activity, and they can persist through several tectonic and erosional episodes. Drainage patterns described in this report include;

Dendritic

Integrated drainage patterns where small branch channels join, usually at acute angles, to feed a trunk channel. They show no preferred orientation, and are typical of areas where the underlying rock is more or less homogeneous.

Trellis

A drainage pattern where secondary channels flow at right angles to the main channel. The secondary channels are in turn joined at right angles by small tributaries flowing parallel to the main channel. This pattern is common in well bedded rocks, commonly with scarp and dip slopes. Small tributaries on the scarp slopes are short and steep, while those on the dip slopes are longer and more gently sloping.

Drainage Type

Drainage type refers to the relationship between drainage lines and landscape evolution. Currently the following types are recognised.

Superimposed

Superimposed drainage occurs when a river cuts down through rocks of varying hardness from above. Softer rocks are readily removed, but harder rocks remain as higher parts of the landscape. This commonly leads to rivers flowing in gorges right through high areas.

Appendix 2 - Summary table of map units

Summary table of map units including a description of the regolith profile, lags, soils, bedrock type, landform types and induration type.

	DFls1	DSls1	DSls2
Regolith; Profile desc	Massive and slabby Fe duricrust or collapsed ferruginous saprolite over mottled and bleached saprolite. Silicification of the saprolite is common and typically extends into the bleached zone.	Silicified and ferruginised saprolite overlying mottled and bleached saprolite.	Silicified Proterozoic saprolite which is in places overlain by silicified Mesozoic sediments. Silcrete typically stained and mottled with iron.
Soil & lags	Lags of ferruginous lithic fragments, Fe duricrust gravels and pisoliths.	Ferruginous saprolite partly covered by lithosols and gravel lags.	Lags and lithosols consist of silcrete pods, silicified saprolite gravels, ferruginous saprolite
Landforms	Plateaux, mesas & buttes	Mesas, minor rises and bevelled hill tops.	Plateaux, mesas & buttes
Bedrock lithology	Siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, felspathic quartzite	Siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite	Siltstone, quartzite. tromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite
Regolith Induration	Massive and slabby Fe duricrust	Silicified saprolite, minor silcrete	Massive and columnar silcrete, silicified saprolite.

	DSler3	DSep4	DFls2
Regolith; Profile desc	Fe stained silcrete and silicified saprolite forming massive pavements over mottled and bleached saprolite.	Fe stained silcrete and silicified saprolite forming massive pavements. Silcrete overlies mottled and bleached saprolite at depth.	Massive and nodular Fe duricrust over highly ferruginous, mottled saprolite and in places bleached saprolite. Minor slabby Fe duricrust. Pods of Fe segregations in the mottled zone.
Soil & lags	Lags and lithosols consist of silcrete pods, silicified saprolite gravels, ferruginous saprolite and minor ferruginous granules.	Sheet wash sands, gravels and lags. Lags of silcrete pods, silicified saprolite and minor Fe gravels.	Red sandy loams, cemented Fe pavements and lags of Fe duricrust gravels and nodules.
Landforms	Rises (9-30 m relief).	Erosional plain (< 9m relief).	Plateaux, mesas & buttes
Bedrock lithology	Proterozoic; siltstone quartzite. Stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite	Proterozoic; siltstone, quartzite. Stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite	Mesozoic; sandstone, siltstone, mudstone and conglomerate.
Regolith Induration	Silcrete and silicified saprolite	Silcrete and silicified saprolite	Fe duricrust, in places silica overprinting

Regolith Landform units

	DFls3	DFls4	DSls5
Regolith; Profile desc	Massive Fe duricrust and highly ferruginous saprolite over mottled and in places bleached bedrock. Pods of Fe segregations in the mottled zone in places extends into Proterozoic saprolite.	Ferruginous saprolite with patches of massive Fe duricrust over mottled and in places bleached bedrock. In places silcreted caps rather than Fe duricrusts have developed.	Silcrete, silicified saprolite and iron-stained sediments over kaolinised and ferruginous Proterozoic bedrock. Silcrete pods common. In places Fe duricrust rather than silcrete have developed.
Soil & lags	Fe duricrust and ferruginous saprolite gravel lags.	Fe duricrust and ferruginous saprolite gravel lags.	Siliceous lithic gravel lags and lithosols.
Landforms	Plateaux, mesas and minor erosional plains.	Dissected plateaux, mesas and buttes.	Plateaux, mesas and buttes.
Bedrock lithology	Mesozoic; sandstone, siltstone, mudstone and conglomerate.	Mesozoic; sandstone, siltstone, mudstone and conglomerate.	Mesozoic; sandstone, siltstone, mudstone and conglomerate.
Regolith Induration	Fe duricrust and ferruginous saprolite	Minor Fe duricrust and silicified saprolite	Silcrete and silicified saprolite, minor Fe duricrust.

	DSer6	Ser1	Sbh2
Regolith; Profile desc	Patchy veneer of silicified Mesozoic sediments (silcrete) (siltstones and sandstones) over silicified, mottled and bleached Proterozoic saprolite.	Highly ferruginous saprolite with pockets of Fe duricrust over mottled saprolite.	Ferruginised saprolite overlying mottled and bleached saprolite. In places silicified saprolite and minor silcrete.
Soil & lags	Gravel lags of ferruginous lithic, silcrete, quartz pebbles and silicified saprolite gravels. Veneers of sheet wash sand, minor clays and Fe pisoliths	Lithosols and gravel lags consisting of Fe duricrust, ferruginous saprolite, Fe nodules and pisoliths.	Lithosols and gravel lags.
Landforms	Rises (9-30m relief). minor erosional plains (<9m relief).	Rises (9-30m relief)	Bevelled hill tops minor mesas.
Bedrock lithology	Mesozoic; sandstone. siltstone, mudstone and conglomerate.	Proterozoic; siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite	Proterozoic; siltstone. quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite
Regolith Induration	Silcrete and silicified saprolite	Minor Fe duricrust.	Ferruginous saprolite, minor silcrete

Regolith-landform Unit

	Ser3	Ser4	Sep5
Regolith; Profile desc	Ferruginous, silicified and mottled saprolite. In places bleached saprolite exposed. Silcrete pavements and pods common.	Bleached and ferruginous saprolite. In places silicified saprolite. Local pockets of deep weathering and Fe duricrust typically on argillaceous lithologies.	Ferruginous saprolite over bleached saprolite which is in places silicified. Local pockets of deep weathering and Fe duricrust typically on argillaceous lithologies.
Soil & lags	Lithosols, gravel lags, residual sands and clays. Lags and lithosols consist of ferruginous lithic gravels, silcrete pods and gravels, silicified saprolite and Fe duricrust gravels.	Lithosols, shallow earths and gravel lags. Local scree and colluvial gravels flanking steeper slopes. Lags of lithic, ferruginous saprolite, bleached saprolite, Fe duricrusts fragments and minor Fe pisoliths. Minor alluvium.	Extensive cover of lithosols. sheet wash gravels and lags. Lags consist of lithic, ferruginous saprolite, bleached saprolite, Fe duricrusts fragments and minor Fe pisoliths. Minor alluvium.
Landforms	Rises and erosional plains	Rises (9-30m relief).	Erosional plains, minor pediments (<9m relief).
Bedrock lithology	Proterozoic; siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite	Proterozoic; siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite	Proterozoic; siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite
Regolith Induration	Silcrete and silicified saprolite	Silicified saprolite and minor Fe duricrust	Silicified and ferruginised saprolite

	Sel6	Ser7	Sep8
Regolith; Profile desc	Ferruginous and mottled saprolite, in places silicified. Local pockets of deep weathering and Fe duricrust typically on argillaceous lithologies.	Ferruginous, mottled and bleached saprolite (in places silicified)	Ferruginous and in places silicified saprolite.
Soil & lags	Saprolite partly covered by lithosols, shallow earths and gravel lags. Lags of lithic, ferruginous saprolite, Fe duricrusts fragments and minor Fe pisoliths. Minor alluvium.	Saprolite largely covered by a veneer of sheet wash gravels, residual gravelly earths, lithosols and lags. Lags of lithic fragments, quartz, Fe duricrust fragments, ferruginous saprolite and minor Fe pisoliths.	Sheet wash gravels, residual gravelly earths, lithosols and lags. Lags of lithic fragments, quartz, Fe duricrust fragments, ferruginous saprolite and minor Fe pisoliths.
Landforms	Low hills (30-90m relief) and local mesas.	Rises and local mesas	Erosional plains (< 9m relief).
Bedrock lithology	Proterozoic; siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite	Proterozoic; siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite	Proterozoic; siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite
Regolith Induration	In places silicified saprolite	Minor Fe and Si duricrusts	Ferruginous and silicified saprolite

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Regolith-landform Unit

	Sei9	See10	Seh11
Regolith; Profile desc	Ferruginous and mottled mainly Proterozoic saprolite	Weathering variable including; ferruginous, bleached and silicified saprolite and minor saprock.	Ferruginous saprolite and saprock. Bedrock structure and fabric well preserved. Local pockets of deep weathering typically on argillaceous lithologies.
Soil & lags	Extensive sheet flow colluvial, lags and minor alluvial deposits forming a veneer (generally < 1m thick) of sand, clay and gravel.	Saprolite (mainly Proterozoic) partly covered by scree and lithosols.	Saprolite partly covered by lithosols and colluvium flanking steep hill slopes. Narrow corridors of alluvial sands and gravels.
Landforms	Pediments and minor erosional plain (<9m relief).	Escarpment.	Hills (90-120m relief).
Bedrock lithology	Proterozoic; Siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite	Proterozoic; Siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite	Proterozoic; Siltstone, quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite
Regolith Induration	Ferruginous saprolite	nil	Ferruginous saprolite

	Sei12	Sel13	Sep14
Regolith; Profile desc	Mottled and bleached mainly Proterozoic sediments. Saprolite is in places silicified.	Highly ferruginous and mottled saprolite consisting of sandstone and chert breccia and siltstone. Underlying Proterozoic rocks are typically mottled and silicified.	Ferruginous, mottled and bleached bedrock over mainly Cambrian sediments.
Soil & lags	Sheet wash gravels, lithosols and lags. Lags and sheet wash consist of mainly bleach lithic fragments together with quartz, Fe duricrust fragments, ferruginous saprolite and minor Fe pisoliths.	Soils consist of thin reddish brown earths and lithosols. Local pockets of Fe duricrusts.	Saprolite is covered by an extensive but thin blanket of soils and gravel lags of ferruginous saprolite, cherty breccia and chert. Quartz and lithic pebbles common as scattered float. Brown calcareous earths overlie mottled and typically bleached saprolite. Minor scattered Fe nodules and travertine.
Landforms	Rises (9-30m relief) minor pediments.	Plateau surfaces and mesas.	Erosional plains (< 9m relief).
Bedrock lithology	Proterozoic; Siltstone. quartzite. stromatolitic dolomitic siltstone, shale, chert, meta-basalt, feldspathic quartzite	Cambrian; siltstone, sandstone, limestone, chert, cherty breccia, silicified shale, conglomerate, phosphorite and phosphatic siltstone.	Cambrian; siltstone, sandstone, limestone, chert, cherty breccia, silicified shale, conglomerate, phosphorite and phosphatic siltstone.
Regolith Induration	Silicified saprolite, ferruginous gravels	In places silicified saprolite	Ferruginous saprolite

Regolith-landform Unit

	Sei15	Ser16	See17
Regolith; Profile desc Soil & lags	Very highly weathered and mottled Cambrian saprolite. Highly Ferruginous sheet flow, alluvial channel and residual deposits consisting of various proportions of clay, sand and gravel. Typically < 1.5m thick. Lags of ferruginous saprolite, Fe duricrust fragments and lithic fragments (shale and chert), with minor Fe pisoliths. Minor alluvium.	Ferruginous, mottled and bleached mainly Cambrian sediments. Saprolite is partly covered by residual gravelly brown earths with chert breccia fragments, calcareous brown earths and red sands. Lags of well rounded to angular quartz, sandstone and chert pebbles and cobbles. Minor scattered Fe nodules and travertine. Minor alluvial clay and gravel.	Ferruginous and mottled saprolite (mainly Cambrian) Saprolite partly covered by lithosols, ferruginous saprolite, cherty gravel scree and thin brown stony earths.
Landforms	Pediments, minor erosional plains (< 9 m relief).	Rises (9-30m relief).	Escarpment.
Bedrock lithology	Cambrian; siltstone, sandstone, limestone, chert, cherty breccia, silicified shale, conglomerate, phosphorite and phosphatic siltstone.	Cambrian; siltstone, sandstone, limestone, chert, cherty breccia, silicified shale, conglomerate, phosphorite and phosphatic siltstone.	Cambrian; siltstone, sandstone, limestone, chert, cherty breccia, silicified shale, conglomerate, phosphorite and phosphatic siltstone.
Regolith Induration		Ferruginous saprolite	Ferruginous saprolite

	Ser18	Sep19	See20
Regolith; Profile desc Soil & lags	Ferruginous and diffusely mottled Mesozoic sediments. In places islands of mottled and bleached Proterozoic saprolite protrude through the sediments. Saprolite typically partly silicified. Gravel lags of, Fe duricrust fragments, ferruginous saprolite, quartz, minor Fe pisoliths and nodules. Soil are usually thin (< 1m) and consist of lithosols; sheet wash clays and sands. Locally developed Fe duricrusts and Fe segregations.	Ferruginous and silicified saprolite overlies mottled and bleached bedrock at depth. Extensive veneers of gravel lags including ferruginous lithic, silcrete and quartz pebbles. Sheet flow sands and clays. Minor alluvium.	Mottled, bleached and in places silicified saprolite. Saprolite partly covered by Fe gravel scree, colluvial clays, sand and gravel from adjacent plateau edge.
Landforms	Rises (9-30m relief), minor plateaus.	Erosional plains (<9m relief) and minor rises.	Escarpment.
Bedrock lithology	Mesozoic sediments; sandstone, siltstone, mudstone & conglomerate	Mesozoic sediments; sandstone, siltstone, mudstone & conglomerate	Mesozoic sediments; sandstone, siltstone, mudstone & conglomerate
Regolith Induration	Ferruginous saprolite, minor Fe duricrust	Ferruginous and silicified saprolite	Minor silicified saprolite

Regolith-landform Unit

	Aaf	Aap	ACer1
Regolith; Profile desc Soil & lags	Alluvial channel, overbank and terrace sediments consisting of various proportions of clay, sand, gravel and minor cobbles. In places partly cemented by clay, Fe or silica. Overbank and terrace sediments are typically finer textured consisting mainly of clay and sand. Soils consist of reddish orange, brown and grey earths and duplex soils. Minor pebble silcrete.	Alluvial and lacustrine clays and silts. Massive cracking olive green, grey-brown smectitic clay soils over mottled saprolite. Forms treeless plains with gilgai micro-relief. Clays generally thin (< 2 m) with islands of residual clays and gravel lags. Pedogenic calcrete and 'heaved' saprolite fragments as scattered float.	Silicified alluvial and colluvial sands and gravels forming silcrete. Minor quartz pebbles (generally 1-4cm). Silcrete pods and silicified sandstones fragments as float. Underlying saprolite typically bleached and silicified . Silcrete commonly diffusely stained and mottled with Fe.
Landforms	Flood plains, alluvial terraces and channel floors.	Alluvial plains and lacustrine plains.	Rises (9-30m relief), erosional plains (<9m relief) and local mesas.
Bedrock lithology	unknown	unknown	Proterozoic sediments
Regolith Induration	In places partly cemented by clay, Fe or silica to form hardpans	nil	Silcrete

	CHpd1	CHpd2	CHpd3
Regolith; Profile desc	Colluvial sheet flow deposits. Sediments typically > 1.5 metres thick include silty clay loam, clay, sand, gravels and minor Fe pisoliths. Sediments overlie mottled and typically silicified saprolite.	Colluvial sheet flow, residual and minor alluvial deposits consisting of variable proportions of sand, clay and gravel (generally < 2 m thick). Ferruginous sand and gravels overlie mottled and bleached saprolite.	Colluvial sheet flow and residual iron stained quartzose sands and minor clays over mottled saprolite.
Soil & lags	Local cracking clay soils (gilgai micro-relief). Extensive lags of ferruginous and siliceous saprolite, lithic fragments, ferruginous granules, quartz and silcrete gravels with minor Fe duricrust and Fe pisoliths. Siliceous hardpan common at approximately 60cm depth. Minor alluvium and residual soils.	Soils consist of lithosols and gravelly earths. Extensive lags of Fe duricrust fragments, lithic fragments, quartz and ferruginous saprolite gravels. Minor alluvial sand and gravel.	Light reddish brown sandy earths and uniform textured sands. Fe nodules common and minor ferruginous gravel lags.
Landforms	Depositional plains minor erosional plains (<9m relief).	Depositional and erosion plains (<9m relief).	Depositional plains minor erosional plains (<9m relief).
Bedrock lithology	unknown	unknown	Sheet flow deposits cover Cambrian and Proterozoic sediments.
Regolith Induration	Fe gravels and pisoliths, siliceous hardpan	nil	nil

Regolith-landform Unit

	CHpd4	CFpd1	CFfc1
Regolith; Profile desc Soil & lags	Highly ferruginous sheet flow and residual sands overlying mainly Cambrian saprolite. In places islands of highly ferruginous and mottled saprolite protrude through the sandy cover. Minor clays and alluvial sediments. Minor lithic and quartz pebble lags.	Weakly consolidated gravel and cobble conglomerate partly cemented by Fe oxides and clay. Sandy ferruginous soils with minor Fe duricrust fragments and pebble lags. In places alluvial gravels are silicified to form silcrete. In fills valleys between Mesozoic plateaus (> 10 metres deep in places).	Colluvial footslopes consisting of quartz, ferruginous saprolite, Fe duricrust and lithic fragments in a coarse poorly sorted sandy to gravelly earthy matrix.
Landforms	Depositional plains minor erosional plains (<9m relief).	Depositional plain and colluvial footslopes.	Footslopes.
Bedrock lithology	Sheet flow deposits over mainly Cambrian sediments.	unknown	unknown
Regolith Induration	nil	silcrete	

	CFfc2	CFfc3	
Regolith; Profile desc Soil & lags	Indurated colluvium forming partly dissected benches; consist of sandstone, chert, silcrete conglomerates and ferruginous lithic gravels cement by silica and Fe oxides. Clasts are poorly sorted and overlie mottled Proterozoic saprolite. Colluvium forms down slope and adjacent to highly weathered and ferruginised bedrock.	Colluvium consisting of quartzose sands, gravels of Fe duricrust fragments and ferruginous saprolite in a reddish orange earthy matrix. Occurs down slope and adjacent to duricrusts Mesozoic Plateaus. Minor sheetwash gravels and sand.	
Landforms	Footslopes.	Footslopes.	
Bedrock lithology	Proterozoic saprolite	Likely to be mainly Mesozoic sediments	
Regolith Induration	Silica and iron	nil	

Appendix 3 - Site Descriptions

Regolith point attributes

Field data was recorded using AGSO RTMAP site notebook and database. The 'abstract' field description are printed out below.

Field site abstract descriptions layout;
Site No
Amg coordinates
Abstract description

4000
305800 7755488
Silicified gritty sandstone with well rounded quartz pebbles (1-4cm) on rises over saprolite (shale - Proterozoic)

4001
305857 7755925
Silicified sandstone (containing rounded quartz pebbles) and silcrete pods a float on rises over moderately weathered saprolite (shale - Proterozoic)

4002
305634 7759921
Silcrete pods and coarse pebble sandstone cemented by Fe and silica as scattered float over weathered shale - on local rise

4003
303335 7799284
Highly ferruginous saprolite over saprock - bedrock Mesozoic siltstones, forms mesa

4004
305600 7766800
3-4metres of channel gravels and overbank silts and clays - on alluvial floodplain

4005
305542 7767505
Alluvial gravels and sands in places ferruginous and partly cemented by silica and Fe. minor cobbles - on alluvial floodplain

4006
305412 7767982
Micro-crystalline silcrete as float - on rise

4007
304990 7770400
Silcrete forming low ridge and breakaway, soils consist of lithosols

4008
301943 7777407
Ferruginised and silicified sandstone forming local rise age uncertain ?

4009
301877 7777607
Ferruginised and silicified sandstone possible old river sediments.

4010
301322 7778851
Gravel lag and sheet wash gravels and sand over quartzite on erosional plain

4011
306984 7780500
Fe duricrust and highly ferruginous saprolite forming capping on local mesa, over bleached shale.

4013
325785 7749640
Fe duricrust and ferruginous saprolite forming local rise - sheet wash gravels down slope from rise.

4014
310672 7777748
Silicified sandstone (Tertiary or Mesozoic ?) and conglomerate on palaeosurface. Landform - mesa.

4015
309581 7777178
Ferricrete and ferruginous sandstone with minor well rounded pebbles, on mesa.

4016
309808 7776910
Alluvial channel hardpan mottled and cemented by Fe, over highly weathered saprolite (sandstone and shale).

4017
311800 7783264
Thin sheet wash gravels over highly weathered ferruginous saprolite (poss shale? Proterozoic) minor Fe duricrust.

4018
311879 7783250
1-3 metres of channel alluvium over ferruginous bedrock.

4019
311434 7783864
Lithosol on ferruginous saprolite, on rises.

4020
308819 7781514
Lithosol on saprolite, narrow corridors of alluvial sediments along river channels.

4021
311550 7784439
3-4 metres red sandy alluvium with gravel interbeds

4022
314018 7786428
Overbank sediments consisting of clays and sands

4023
314354 7784871
Channel gravels and sand over saprolite

4024
314611 7783604
Sheet wash gravels and sand on erosional plain, minor alluvial sands and gravels along creeks

4025
316615 7780466
Overbank sands and clays

4026
317884 7781001
Lithosols over ferruginous saprolite, rises

4027
318223 7781112
Channel and overbank sands and clays

4028
324519 7781666
Channel sands and gravels generally less than 2metres

4029
325368 7780520
Sheet wash gravels and sand with protruding bedrock

4030
326122 7768577
Lithosols and locally derived gravel lags (minor lateral movement) over saprolite (shale).

4031
323890 7765480
Alluvium with interbedded sand and gravel beds.

4032
324863 7758963
Ferruginous Fe nodular soil over highly weathered saprolite (shale).

4033
323034 7765034
Fe duricrust and ferruginous saprolite in places covered by residual soils and gravel lags.

4034
320546 7764687
Colluvial gravels and cobbles (angular) in sandy matrix.

4035
317653 7764419
Sand, clay and gravel alluvium minor cobbles.

4036
316962 7764354
Interbedded sand and gravel alluvium with basal conglomeratic beds indurated with Fe.

4037
313829 7763171
Quartz veins outcropping on local rise - lithosols.

4038
309661 7764451
Overbank clays on floodplain.

4039
309185 7764861
Silicified sandstone and conglomerate as float age uncertain.

4040
306022 7766377
Cemented and mottled conglomeratic alluvial hardpan.

4041
302472 7776563
Veneer of ferruginous sands and gravels over silicified bedrock.

4042
302038 7777199
Silcrete as float contains quartz grains and pebbles- forms gentle, rise.

4043
300786 7780812
Gilgia relief swelling clays with scattered calcrete as float.

4044
300613 7794196
Ferruginous sandstone and shale weathering to shallow rubble soils on rise - possibly Proterozoic bedrock?

4047
302674 7796160
Massive and nodular (pisoliths) Fe duricrust which is also silicified in places (bedrock likely to be shale - age uncertain).

4048
301700 7799098
Massive micro-crystalline silcrete along upper edge of eroding scarp.

4049
300382 7802664
Fe duricrust with minor rounded and angular quartz fragments - on mesa.

4050
298192 7805973
Lithosols (numerous rock fragments) over ferruginous saprolite.

4051
297300 7808565
Ferruginous saprolite on rises

4052
297158 7812197
Ferruginous and mottled saprolite forming stony pavements - on erosional plain.

4053
297128 7809826
Silcrete forming capping on mesa

4054
297696 7807632
Silicified and ferruginous bedrock on rises

4055
298062 7806745
Calcareous rubble earth, lithosols - in places travertine forms surface crusts

4056
305349 7765035
Channel gravels

4058
304121 7779362
Ferruginous sand, silt and clay Fe gravel (and buckshot gravels) as surface lag.

4059
319179 7752789
Ferruginous saprolite (shale), lithosols on rises.

4060
318922 7753481
Alluvial hardpan (sand and gravels) cemented by Fe and clay, over weathered shale.

4061
318934 7753713
Saprolite (shale) with silcrete pod developing along bedding planes and as scattered float. Local rise.

4062
318458 7754467
1-2.5 metres of coarse gravel alluvial hardpan, over mottled saprolite.

4063
317575 7756005
Silcrete forming mesa capping.

4064
316121 7757760
Micro-crystalline silcrete forming capping on mesa.

4065
316103 7757830
Alluvial gravels and sand.

4066
316525 7757219
Lithosols on erosional plain.

4067
317267 7756248
Silicified shale forming local mesa - palaeosurface.

4068
318239 7754729
Massive ferricrete (shale on Gunpowder creek - Proterozoic).

4069
319303 7752542
Sand, silt and clay overbank sediments - thickness uncertain.

4070
305803 7764592
Local rise capped with silcrete, in places silcrete contains quartz and lithic pebbles (over siltstone bedrock).

4071
305158 7759401
Silicified saprolite on erosional plain near erosional scarp (bedrock siliceous shale?).

4072
303462 7759087
Ferruginous saprolite and Fe duricrust along scarp edge over Paradise Creek FM.

4073
304670 7759645
Silicified saprolite forming breakaway.

4074
320691 7745974
Ferruginous saprolite (shale) over mottled zone, soils contain numerous Fe nodules and ferruginous rock fragments

4075
305685 7756405
Silicified sandstone unconformable and overlying moderately weathered saprolite (shale).

4076
306815 7757380
Ferruginous saprolite and Fe gravels over mottled saprolite, Fe gravel lags on erosional plain.

4 077
306222 7759866
Thin residual lags over mottled bedrock on erosional plain.

4078
303879 7797171
Silcrete as float.

4079
304925 7795867
Silcrete as float.

4080
306096 7794133
Silicified and ferruginous saprolite forming resistant capping along edge of erosional scarp - below mega mottling developed within the saprolite. (bedrock - shale and siltstone).

4081
304713 7796011
Gilgai soils with scattered Fe nodules within the profile.

4082
302521 7797240
Residual clay and gilgai soils - scattered buckshot gravels on surface.

4083
301928 7795986
Ferruginous sandstone, lithosols on rises.

4084
300894 7796150
Micro-crystalline silcrete forming indurated pavements.

4085
298984 7795176
Fe duricrust over saprolite on erosional plain.

4086
297520 7795112
Massive silcrete on local rise (lithosols).

4087
293031 7795462
Cracking brown clays, gilgai soils.

4088
293716 7794513
Ferruginous pebbly sandstone minor cobbles - poss Tertiary age.

4089
301044 7794531
Ferruginous saprolite (shale) on erosional plain.

4090
299548 7783879
Ferruginous sandy soil with numerous Fe nodules over mottled saprolite on erosional plain.

4091
305815 7754591
Fe duricrust forming local rise (on shale).

4092
306816 7758151
Recent alluvial sands and gravels over older mottled conglomeratic hardpan over highly weathered shale.

4093
303373 7762290
Silcrete and/or siliceous bedrock (siltstone? chert?) as outcrop, lithosols on rises.

4094
304157 7760070
Silicified saprolite - possible silicification of the mottled zone?

4095
305094 7761498
Ferruginous saprolite and nodular Fe duricrusts as pavements - lithosols on low rise (bedrock chert and shale - Proterozoic)

4096
305443 7761885
Ferruginous and silicified saprolite as surface rubble on erosional plain.

4097
305459 7764186
Sheet wash gravels > .5 metres.

4098
305561 7767769
Alluvial hardpan cemented by clay and silica. Silicified alluvial sediments on higher river terrace.

4099
301763 7777630
Silicified sandstone with minor well rounded quartz pebbles over mottled and in places silicified saprolite, on local rise.

4100
302270 7756882
Lithosols on chert (contains stromatolites) forming local ridge.

4101
304167 7757065
Fe duricrust forming breakaways over highly weathered saprolite (bedrock shale).

4102
305250 7760006
Drill core - mottled (8metres) and bleached zone (40metres) over weathered shale. Fe nodules common in mottled zone. Saprock at 60 metres.

4103
308932 7776181
Ferricrete and highly ferruginous saprolite forming along clay rich beds within the bedrock. Minor alluvial gravels and sand (alluvial hardpan in creek).

4104
309593 7776100
Fe duricrust and ferruginous shale approx 1 metre thick on hill top.

4105
308866 7775944
Pebbles and well rounded cobbles as scattered float on rises.

4106
308077 7777519
Silicified saprolite with irregular Fe staining forming mesa, minor quartz pebbles as float.

4107
309906 7778589
Silicified sandstone (Tertiary?) with minor gravels and pebbles over ferruginous Proterozoic shales, forming mesa. Basement clasts within the silcrete

4108
309944 7778253
Silicified sandstone (Tertiary?) with minor gravels and pebbles over ferruginous Proterozoic shales, forming mesa. Basement clasts within the silcrete

4109
311010 7778587
Partially silicified sandstone over Proterozoic shales and siltstones, forming mesa capping.

4110
310319 7777334
Highly weathered saprolite (shale- Proterozoic) highly ferruginous and Fe indurated material occur within argillaceous beds.

4111
311566 7783735
Highly weathered calcareous shales - form cast relief - travertine forming surface crusts.

4112
298481 7827877
Fe duricrust over ferruginous sandstone (Mesozoic) - Cu mineralisation visible in the sandstone.

4113
298518 7827337
Ferruginous cherty breccia forming local hill, lithosols.

4114
298051 7827021
Fe duricrust on sandstone (Mesozoic - with pebbly beds) forming mesa over weathered Proterozoic rocks.

4115
298004 7827168
Massive silcrete (micro-crystalline) poss Cambrian age over cherty breccia

4116
299200 7827210
Fe duricrust on sandstone over a unit (1-2metres) silcrete over ferruginous Proterozoic rocks (shales and cherts). Forms mesa.

4117
300420 7823830
Fe duricrusts (ironstones) developed on dolomitic shale beds within the Paradise Creek FM.

4118
303828 7822445
Ferruginous alluvial sediments consisting of sands, gravels and cobbles in clay matrix over Cambrian breccia.

4119
307760 7824740
Mottled claystone (contains Fe nodules) over ferruginous saprolite (sandstone Mesozoic), edge of erosional scarp.

4120
308193 7823779
Fe duricrust developed on Esperanza FM (Proterozoic) - relief rises (9-30 metres)

4121
306143 7751466
Silcrete pods and silicified sandstone over moderately weathered saprolite, forming local rise.

4122
305418 7752946
Alluvial channel gravels and cobbles

4123
305542 7753703
Silicified pebbly sandstone (channel sands and gravels) forming local rise - possible relief inversion.

4124
305822 7754596
Fe duricrust (ironstone) forming local rise on Proterozoic shales.

4125
303442 7759088
Ferruginous saprolite and Fe duricrust gravels as scattered float.

4126
303227 7759529
Ferruginous saprolite and Fe duricrust on backslope - bedrock Proterozoic shale.

4127
303603 7759615
Highly ferruginous saprolite and Fe duricrust on local rise - bedrock Proterozoic shale.

4128
304085 7774217
Red earth (silt, clay and minor sand) with veneer of buckshot gravels.

4129
307750 7774589
Ferruginous saprolite and Fe duricrust, over bleached (kaolinite) saprolite - edge of erosional scarp - bedrock Proterozoic shale.

4130
308122 7775645
Ferruginous pebbly sandstone (poss Tertiary?) over silicified mottled and bleached claystone over well bedded Proterozoic shales. Outcrops along eroding scarp edge.

4131
308276 7775837
Fe duricrusts forming local hill - bedrock Proterozoic shale.

4132
309684 7775337
Massive ferricrete >5 metres on plateau surface (old erosional surface) bedrock Proterozoic shales and cherts (Gunpowder Creek FM)

4133
307709 7774907
Mottled saprolite (partially silicified at top) with strataform ironstones. Ferruginous gravel surface lag - along edge of scarp.

4134
303503 7799441
Silicified siltstone and silcrete pods on mesa - bedrock Mesozoic siltstone.

4135
303469 7800728
Silicified Proterozoic shales and siltstones forming local rise - in places the bleached zone is silicified.

4136
300502 7824907
Fe duricrust (2-3 metres - on Mesozoic sandstone) over highly ferruginous saprolite and silicified bedrock (cherts and siltstones).

4137
300159 7824996
2-3 metres of ferruginous and partially cemented alluvial gravels and cobbles over bleached and mottled saprolite (shale).

4138
300322 7823450
Ferricrete capping ferruginous and silicified sandstone and siltstone - age uncertain.

4139
300957 7820525
Highly ferruginous saprolite (porous sandstone) on rises - Cambrian - Beetle Creek FM

4140
301054 7820896
Thin sand plain - consisting of sheet wash and alluvium

4141
300000 7821482
Ferricrete - massive Fe sandstone (poss Mesozoic?)

4142
301757 7836395
8 metres of unconsolidated gravels and cobbles with mottled clay matrix. Nearby siliceous gravels on slight rise.

4143
302480 7835720
10 metres of ferruginous and in places weakly silicified sandstone - moderately weathered saprolite forming mesa

4144
303773 7833876
Ferricrete pods developing down into the mottled zone, forms mesas - surface consists of ironstone gravels and ferruginous sands. developed on Mesozoic.

4145
303768 7835087
Fe duricrust over mottled sandstone (Mesozoic) - forms mesa.

4146
302743 7835897
Alluvium consisting of sand and Fe gravels partially cemented by clay and Fe.

4147
301585 7837647
Siliceous sandstone and silcrete gravels and cobbles as scattered float.

4148
301949 7835332
Ferruginous sandstone (Mesozoic), porous sandstone Fe staining only, on mesa.

4149
298936 7831916
Ferruginous saprolite and cherty breccia as scattered float.

4150
298990 7828755
Ferruginous saprock possible Esperanze FM on rises.

4151
299230 7827007
Fe duricrust and ferruginous sandstone over siliceous bed over bleached Proterozoic shales, cherts and breccia sample is in Mesozoic duricrust.

4152
304219 7814946
2-3 metres of sand and gravel alluvium and colluvium.

4153
309517 7811061
Fe duricrust and ferruginous saprolite forming local rise - Paradise Creek FM ?

4154
309373 7813162
Ferruginous gravelly soil over kaolinised structured saprolite (shale).

4155
300812 7814620
Fe duricrust - ferricrete on mesa (possible Mesozoic sediment)- bedrock shale, age uncertain likely Proterozoic. Sample collected base of hill

4156
305383 7814745
4 metres of alluvial sand and gravels.

4157
304553 7814497
Lithosol and gravel lag over saprolite.

4158
304432 7813930
colluvial and alluvial clay, sand and gravel - sheet wash & footslopes.

4158
304154 7814628
.5 metres of brown stony earths (clay matrix with Fe rock fragments) over partially kaolinised saprolite.

4159
296795 7825943
1.8 metres of gravel and cobble alluvium.

4160
294245 7825596
Unconsolidated alluvial gravels and alluvial hardpan (cemented by Fe) over moderately weathered saprolite (partially ferruginised and kaolinised).

4161
292965 7823567
Thin soil ,40cm over ferruginous saprolite (shale).

4162
292878 7820464
Lithosols and stony earths over highly weathered saprolite.

4163
292913 7818123
Thin calcareous stony soil over weathered shale and dolomite, travertine as scattered float.

4164
292283 7815574
Fe duricrust and ferricrete forming ironstone capping on hill over kaolinised shale - Proterozoic.

4165
293800 7814516
Ferruginous saprolite with ferricrete capping nearby hills.

4166
295338 7813977
Fe duricrust over kaolinised saprolite (shale - Proterozoic).

4167
295239 7813415
Ferruginous saprolite developed on shales and cherts - Proterozoic.

4168
295480 7811423
Ferruginous gravels and ferricrete gravels over bleached saprolite (kaolinised).

4169
297275 7809837
Silicified claystone forming mesa - age uncertain.

4170
296888 7807321
Ferruginous saprolite and Fe duricrusts (forming Fe pavements) on rises - bedrock shales (likely Proterozoic).

4171
296431 7805512
Fe duricrust (developed on shale) capping local rise - ferruginous gravels around edge of rise.

4172
295892 7804034
Ferruginous saprolite and ironstone float on erosional plain.

4173
294796 7803092
Ferruginous sandstone and conglomerate - Mesozoic?.

4174
294704 7802688
Ironstone lag over ferruginous saprolite (at depth typically mottled and partially bleached)

4175
294498 7801808
Highly ferruginous and ironstone gravels forming rubble surface.

4176
293214 7798662
Ferruginous saprolite over bleached (kaolinised) saprolite - likely Proterozoic (quartz veining to surface).

4177
298681 7811310
Ferruginous interbedded claystones, gritty sandstone and conglomerate. Saprolite bleached at depth .

4178
298609 7811842
Ferruginous gravel lag over mottled claystone (Mesozoic).

4179
299121 7812124
Ferruginous sandstone and minor conglomerate (Cambrian ?).

4180
300677 7813112
Cherts with Fe and Mn staining forming local rise and gravel lags.

4181
311451 7826217
Residual sand and Fe nodules over mottled sandstone - Mesozoic.

4182
307342 7822377
Highly weathered saprolite with thin sandy cover - Proterozoic - Paradise Creek FM.

4183
305174 7820653
Scattered alluvial gravels and cobbles in sandy matrix as float - on erosional plain.

4184
303180 7822500
Fe duricrust over chert breccia and gravels (age uncertain possibly Cambrian)

4185
298985 7825706
Ferruginous gravelly earth over highly weathered saprolite (lithosols with ironstone gravels) intense iron staining.

4186
303869 7820985
Bleached (kaolinised) and in places ferruginous interbedded siltstone, chert and sandstone. Weathers to brown stony earths.

4187
303951 7813519
Ferruginous cherty breccia with manganese coating over saprolite (sandstone) - edge of escarpment.

4188
303195 7808268
Highly ferruginous saprolite (minor Fe duricrust) over Fe stained and bleached (kaolinite) saprolite (bedrock - shale & siltstone - Proterozoic).

4189
302955 7806556
Fe duricrust forming capping on mesa over Fe stained and bleached saprolite - bedrock shale and cherts - (Esperanza FM ?)

4190
306110 7793902
Silicified saprolite (Proterozoic shales) over a bleached zone along edge of major erosional scarp. Some beds (more argillaceous) are ferruginised.

4191
302079 7813706
Moderately weathered chert - stromatolitic fabric (Proterozoic) adjacent to Cambrian sandstone with chert clasts. Landform low hills - ridge.

4192
302051 7814140
Laminated cherts overlain by cherty breccia (silicified). Layers of limonitic Fe and silica forming laminations in the chert. Landform: rises.

4193
298093 7813318
Silicified conglomerate (sandstone, ferruginous shale fragments and cherty clasts) over mottled Proterozoic saprolitic shale and quartzites. Landform; forms benches adjacent to hills.

4194
309867 7811130
Ferruginous lithosols consisting of Fe gravels and ferruginous saprolite over highly ferruginous saprolite. Minor fe duricrust. Landform; hills.

4195
311798 7810517
Highly ferruginous and Fe duricrust developed on gently dipping sandstone and conglomerate sedimentary beds (Cambrian ?). Underlying saprolite is diffusely mottled and bleached (Proterozoic shales and siltstones). Landform: mesa.

4196
316193 7806792
Veneer of coarse river channel alluvium over saprolite. Landform: floodplain (river channel).

4197
294879 7812900
3-4 metres of massive silcrete (with fe staining) over partly silicified saprolite with diffuse Fe staining over soft (G-pick) bleached saprolite (sub vertical bedding) Bedrock: shale and siltstone (Proterozoic) Landform: mesa.

4198
295372 7812370
Very highly weathered and mottled Fe saprolite with pockets of Fe duricrust forming resistant ridges. Soils - lithosols. Bedrock Fe shales. Landform: ridge.

4199
295118 7812382
Silicified and highly ferruginous saprolite over mottled and bleached saprolite. Soils - lithosols. Bedrock: shale, sandstone and chert. Landform: mesa

4200
296394 7805781
Highly ferruginous and mottled saprolite (sub vertical cleavage in places). Bedrock: Proterozoic siltstones, sandstone and cherts. Landform: bevelled hill top.

4201
296466 7805528
Ferruginous lithic lags, minor carbonate nodules. Lags thicken down slope. Soils - lags over lithosols. Landform: rises (9-30 metres relief)

4202
296404 7804272
.5 m of red clay with lithic fragments over highly weathered saprolite (bleached). Surface veneer of quartz and lithic gravel lag. Bedrock: shale. Landform: erosional plain.

4203
295332 7804029
Shaley lithic lag over diffusely mottled moderately weathered saprolite. Bedrock: shale. Landform: scarp edge.

4204
294576 7802772
Mottled and partly silicified conglomerate with well rounded quartz and ferruginous lithic and fe duricrust fragments in a clay (white) matrix. Fe duricrust fragments silicified. Underlying saprolite also partly silicified. Landform: rises

4205
294493 7801832
ferruginous (fe duricrust and lithic fragments) and quartz gravels with minor silcrete lags over ferruginous conglomerate (quartz and lithic clasts). Bedrock Mesozoic ? conglomerate. Landform: rises.

4206
292640 7797733
Olive brown cracking and swelling clays containing carbonate, quartz and lithic gravels. Landform erosional plains.

4207
290307 7796962
Reddish brown clay, silicified lithic fragments as scattered float, minor fe lithic lag. Landform: erosional plains (< 9 m relief)

4208
295899 7794868
Micro-crystalline silcrete as float partly covered by si and ferruginous lithic lags. In places si cements quartz gravel lags into angular pavements. Quartz veining to the surface. Bedrock: Proterozoic quartzite? Landform: rises

4209
297652 7795280
Micro-crystalline silcrete, silica cementing angular quartz gravels. Diffuse fe staining throughout. Landform: rises.

4210
303400 7799469
Diffusely mottled and silicified siltstone. Bedrock: siltstone (Mesozoic ?). Landform: mesa

4211
303643 7800537
Highly ferruginous structural saprolite with diffuse irregular reddish orange mottling. Veneer of Fe duricrust lag. Bedrock: Proterozoic. Landform: ridge.

4212
303577 7799632
Massive silcrete with diffuse fe staining over silicified saprolite. Bedrock: Proterozoic shales and siltstone. Landform: mesa.

4213
304836 7800311
Massive silcrete (3m) with nobbly and spheroid textures grading into silicified (4m) and soft (G-pick) bleached saprolite (20 + M) at depth. Bedrock: Cambrian ? or Mesozoic ? siltstone and mudstone. Landform: mesa.

4214
304800 7800573
Ferruginous diffusely mottled saprolite with pockets of Fe duricrust. Bedrock: Cambrian? siltstone. Landform: mesa/ridge.

4215
305324 7799633
Fe duricrusts developing as fe segregations within saprolite forming indurated capping over mottled and ferruginous structural saprolite. Colluvial footslopes down slope. Bedrock: Proterozoic shale and siltstone. Landform: mesa.

4216
305354 7799272
Fe duricrust with fe segregations developed in mottled highly ferruginous saprolite over diffusely mottled and bleached saprolite at depth. Bedrock: Proterozoic siltstones, chert and dolomite?. Landform ridge.

4217
308184 7798310
Coarse alluvial gravels (.5 metres) over moderately weathered saprolite. Landform floodplain/river channel.

4218
307568 7798357
Interbedded siltstone and sandstone variably weathered - strong lithological control. Bedrock partly silicified. Nearby Cu mineralisation and strataform Fe stones. Bedrock: Proterozoic siltstone and sandstone. Landform: rises.

4219
305757 7797960
Vuggy Fe duricrust and Fe segregations over mottled and partly silicified saprolite. Bedrock: Proterozoic siltstone and shale. Landform: mesa.

4220
305762 7798697
Fe duricrust (2-2.5 metres) and fe segregations over ferruginous and diffusely mottled structural saprolite. Landform mesa.

4221
303353 7821159
Quartz pebble and cobble lag overlying residual sands?. Bedrock: Cambrian. Landform: erosional plain.

4222
304054 7821070
Silicified gravels overlying ferruginous sandstone. Bedrock: Cambrian sediments (shale, conglomerate). Landform: rises.

4223
303810 7813376
Ferruginous cherty breccia over ferruginous saprolite. Bedrock: chert, sandstone and siltstone. Soil - brown stony earth, lithosols on edge of scarp. Landform: edge of erosional scarp.

4224
303541 7807869
Patchy veneer of ferruginous sandstone over cherty breccia and sandstone. Bedrock sandstone and chert (Cambrian). Landform: mesa.

4225
303618 7818769
Cherty and ferruginous saprolitic lag (.5 metres)over coarse textured brown earths which overlie mottled saprolite. Bedrock: sandstone and chert (Cambrian). Landform: erosional plain.

4226
303277 7821812
Veneer of well rounded to angular quartz and lithic (sandstone, quartz, chert) pebbles and cobbles(1 metre thick) over cherty breccia. Minor scattered Fe nodules - clasts up to 80 cm. Bedrock Cambrian sandstone and conglomerate. Landform: rises.

4227
303077 7823064
Ferruginous porous fossiliferous sandstone diffusely mottled at surface. Bedrock: Cambrian sandstone. Landform: local rise.

4228
302516 7822887
Fine residual and sheet wash quartzose sand with minor silt. Landform: erosional plain.

4229
300478 7823598
Highly ferruginous and mottled sandstone with concentric and nodular Fe concretions over ferruginous and silicified siltstone and sandstone. Bedrock: Mesozoic sandstone. Landform: rise.

4230
300140 7824744
Ferruginous sandstone and minor conglomerate over white silicified sandstone with minor Fe staining. Bedrock: Mesozoic sandstone. Landform: mesa.

4231
300591 7825114
Fe duricrust and mottled highly ferruginous saprolite (Mesozoic 2-3 metres) over highly weathered diffusely mottled Proterozoic shale. Landform: mesa.

4232
299354 7825896
Several metres of poorly sorted angular colluvial gravels. Landform : footslope.

4233
294888 7825391
Creek rock - cemented alluvial gravels and cobbles by Fe oxides and clay. Alluvial sediments 2-3 metres thick. Landform: river channel.

4234
296614 7824183
Highly ferruginous saprolite with intense mottling and minor Fe duricrust. Bedrock: Proterozoic shale. Landform: bevelled hill top.

4235
297016 7822371
Veneer of coarse gravel lags (lithic and quartz) and locally derived colluvium over very highly weathered saprolite. Soils - lithosols Landform: rises/footslopes.

4236
297047 7821005
Highly ferruginous saprolite and Fe duricrust (2-3m)forming indurated capping over ferruginous structural saprolite (40 metres +). Bedrock: Proterozoic cherts, siltstones and shales. Landform: mesa.

4237
295427 7813888
Silicified and ferruginous saprolite forming indurated capping. Bedrock: Proterozoic sandstone. Landform: mesa.

4238
292404 7815776
Local strike ridges highly ferruginous saprolite with minor Fe duricrust (forming as Fe segregations). Lithic Fe lags, lithosols and thin red earths down slope. Bedrock: siltstones chert. Landform: rises.

4239
293230 7819254
Lithosols over mottled saprolite consisting of ferruginous and non ferruginous lithic fragments in a fine gravelly silty matrix. Bedrock: shale. Landform: rises.

4240
293017 7820610
Lithosols (.5 metres) and gravel lags over mottled saprolite. Minor sheet flow gravels. Landform: erosional plain.

4241
298119 7826200
Silicified Fe-duricrust (conglomerate) over silicified and mottled saprolite and saprock. Bedrock: Mesozoic conglomerate/Proterozoic shale. Landform: mesa.

4242
298634 7826881
Cherty breccia. Bedrock: Cambrian. Landform: rises.

4243
297953 7830256
Massive slabby and vuggy Fe duricrust over mottled and silicified saprolite (Mesozoic sandstone and siltstone) silicified and ferruginous sandstone and chert breccia (Cambrian) over Proterozoic cherts and sandstone. Landform: mesa.

4244
298468 7830273
Ferruginous and silicified sandstone. Bedrock: Mesozoic sandstone over Proterozoic saprolite. Landform: mesa.

4245
304289 7816271
Rubble brown clayey earth (.5 metres) with mottled cherty breccia fragments throughout over mottled saprolite. Bedrock: Cambrian breccia, chert and sandstone. Landform: rises.

4246
309254 7829145
Pavements of Fe nodules (.2-10 mm), sand and lithic fragments over nodular ferricrete. Bedrock: Mesozoic sandstone. Landform: erosional plain.

4247
300715 7785743
Silicified saprolite over mottled (irregular pale reddish orange) and bleached saprolite. Bedrock: sandstone and mudstone. Landform: scarp edge.

4248
302371 7787804
Fe duricrust (slabby appearance in places) over mottled and partly silicified saprolite over bleached (with pale Fe staining) saprolite. Bedrock: Proterozoic sandstone and shale. Landform: mesa.

4249
302418 7788236
Highly ferruginous saprolite over highly weathered oxidised saprock. Mine workings. Bedrock: Proterozoic siltstone and chert. Landform: rise.

4250
303662 7821470
Angular cherty breccia (6m) weakly cemented by Fe and clay. Bedrock Cambrian cherts. Landform: rises (9-30m relief)

4251
303957 7822607
Angular cherty breccia over very highly weathered sedimentary beds (some ferruginous others not). Diffuse irregular mottling common. Bedrock: Cambrian sandstone, siltstone and chert. Landform: rise.

4252
306285 7794346
Silicified (2-3 metres) and mottled (10-20 metres) saprolite over bleached (15-20 metres)and then ferruginous saprock (20 metres +) at depth. Fe segregations developing in mega mottling. Bedrock: shale. Landform: scarp edge.

4253
306302 7790456
Silcrete (silicified claystone, sandstone and minor conglomerate with diffuse reddish orange mottling (15 metres)) over partly si saprolite(10 metres) and strongly bleached saprolite (35 metres +) at depth. Silcrete has candle drip and Columnar structures. Landform: mesa.

4254
306190 7793992
Deeply weathered profile. From the top down includes - silcrete (Mesozoic ?) silicified mottled saprolite (Proterozoic) bleached saprock and diffusely mottled saprock. Bedrock: Proterozoic shale. Landform: scarp edge.

4255
297251 7812938
Highly ferruginous saprolite with pockets of Fe duricrust over mottled saprolite. Landform: edge of scarp.

4256
300454 7802810
Highly ferruginous saprolite with patches of Fe duricrust over mottled saprolite. Has a breccia fabric in places. Bedrock: siltstone & sandstone. Landform: mesa.

4257
305715 7768301
Silcrete - silica cementing river channel sands and pebbles. Landform: gentle rise.

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Appendix 4 - Regolith Geochemistry

Major and trace element geochemistry of selected regolith matials collected over the Buckley river-Lady Lorretta map sheet. Additional regolith geochemistry can be found in Anand et al., (1996).

Sample No	Eastings	Northings	Regolith	Geology	SiO2%	Al2O3%	Fe2O3%	MnO%
4223A	303810	7813376	Cherty breccia	Cambrian sediments	69.5	0.58	24.22	0.22
4223B	303810	7813376	Cherty breccia	Cambrian sediments	53.16	2.83	14.03	18.264
4241A	298119	7826200	Fe duricrust	Mesozoic conglomerate	62.02	6.99	25.08	0.053
4241B	298119	7826200	Ferruginous saprolite minor Fe duricrust	Proterozoic shale	40.03	6.68	43.23	0.016
4241C	298119	7826200	Diffusely mottled and silicified saprolite	Proterozoic shale	84.53	9.06	1.14	0.006
4241D	298119	7826200	Saprock - redish brown shale/siltstone	Proterozoic shale	82.4	6.6	4.87	0.067
4248A	302361	7787801	Fe duricrust	Proterozoic shale	8.56	3.32	75.69	0.235
4248B	302361	7787801	Mottled saprolite	Proterozoic shale	29.62	6.45	51.92	0.095
4248C	302361	7787801	Ferruginous saprolite	Proterozoic shale	83.83	8.87	0.49	0.008
4248D	302361	7787801	Bleached saprolite	Proterozoic shale	78.79	11.33	0.49	0.005
4249A	302418	7788242	Highly ferruginous saprolite	Proterozoic siltstone	40.58	4.96	45.16	0.14
4249C	302592	7788377	Highly ferruginous saprolite	Proterozoic siltstone	43.83	9.09	36.63	0.086
4254A	306193	7793961	Mineralised (Cu) saprock	Proterozoic shale (minor chert)	33.37	4.46	48.96	0.03
4254B	306193	7793961	Diffusely mottled saprock	Proterozoic shale (minor chert)	64.67	11.48	8.68	0.017
4254C	306193	7793961	Ferruginous saprolite - with olive green mottling	Proterozoic shale (minor chert)	63.01	13.9	10.5	0.02
4254D	306193	7793961	Ferruginous saprolite - with reddish orange mottling	Proterozoic shale (minor chert)	70.58	9.6	6.2	0.03
4254E	306193	7793961	Bleached saprolite	Proterozoic shale (minor chert)	81.46	12.79	0.35	0.003
4254F	306193	7793961	Silicified and diffusely mottled saprolite	Proterozoic shale (minor chert)	74.47	16.24	0.47	0.005
4254G	306193	7793961	Ferruginous (Fe staining)/ silicified breccia	Proterozoic shale (minor chert)	75.29	13.31	1.38	0.008
4254H	306193	7793961	Silcrete with Fe staining	Proterozoic shale (minor chert)	96.3	0.8	0.85	0.004
4254I	306193	7793961	Fe granules as lag over silcrete	Proterozoic shale (minor chert)	81.88	3.52	9.17	0.008

Sample No	MgO%	CaO%	Na2O%	K2O%	TiO2%	P2O5%	Ba ppm	Ce ppm	Cl ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	La ppm	Ni ppm	Nb ppm
4223A	0.02	0.13	0.03	0.04	0.02	1.183	50	25	-60	-3	23	110	4	3	165	-3
4223B	0.84	1.11	0.1	1.35	0.1	0.776	4794	5	30	0	218	2311	2	4	263	0
4241A	0.12	0.12	-0.01	0.16	0.55	0.246	382	87	30	18	-14	44	8	43	7	8
4241B	0.58	0.01	0	1.36	0.22	0.334	101	71	-10	34	-1	164	12	42	-1	3
4241C	0.35	0.03	-0.01	0.93	0.31	0.09	308	62	-40	13	3	18	7	46	0	8
4241D	0.62	0.13	0.03	3.21	0.19	0.184	268	102	-50	6	1	18	11	62	3	4
4248A	0.29	0.05	-0.04	0.2	0.17	0.246	43	35	10	65	74	8	0	-1	69	2
4248B	0.24	0.07	0	0.35	0.32	0.259	265	26	60	119	3	24	8	13	21	1
4248C	0.29	0.04	0.05	4.69	0.27	0.039	527	91	-40	18	1	5	6	55	20	4
4248D	0.61	0.04	0.05	6.01	0.35	0.024	380	62	-50	20	2	14	10	25	8	9
4249A	0.25	0.1	-0.01	0.11	0.17	0.225	153	43	50	23	48	435	6	13	32	2
4249C	0.51	0.12	0.02	1	0.29	0.635	146	68	180	63	34	54	9	25	88	7
4254A	0.3	0.02	-0.02	0.03	0.2	0.024	6	86	20	59	141	22040	3	19	28	5
4254B	8.81	0.03	0.01	0.04	0.42	0.05	40	67	30	58	45	2013	16	37	98	9
4254C	3.89	0.04	0.03	0.02	0.58	0.057	74	101	270	67	220	3282	16	53	84	10
4254D	7.42	0.03	0.06	0.03	0.35	0.024	76	87	680	31	98	1704	14	50	85	8
4254E	0.05	0.03	0.02	0.03	0.4	0.014	59	58	-10	17	5	38	12	32	3	6
4254F	0.72	0.08	0.04	1.57	0.42	0.03	187	50	-40	24	2	106	14	44	13	8
4254G	0.85	0.11	0.04	2.14	0.58	0.02	974	44	-40	37	2	56	19	24	4	8
4254H	0.03	0.02	0	0.04	0.94	0.006	95	13	-50	9	1	11	3	9	10	11
4254I	0.05	0.02	-0.01	0.08	3.3	0.03	73	23	-20	75	-2	61	7	4	224	45

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Sample No	Pb ppm	Rb ppm	S ppm	Sr ppm	V ppm	Y ppm	Zn ppm	Zr ppm	OXIDES %	TotalTr ppm	lod	loi	total
4223A	25	0	20	13	216	5	2328	10	95.9	2932	0.27	3.78	99.9
4223B	101	36	40	158	88	13	2317	55	92.6	10429	0.36	7.37	100.3
4241A	29	5	240	60	67	15	29	266	95.3	1325	0.31	4.86	100.5
4241B	19	47	250	83	142	37	39	94	92.5	1133	0.21	7.59	100.3
4241C	22	31	90	89	32	31	3	353	96.4	1080	0.23	3.19	99.8
4241D	11	82	0	64	26	24	1	73	98.3	713	0.1	1.24	99.6
4248A	5	21	180	1	89	71	40	105	88.7	811	0.32	10.86	99.9
4248B	11	27	410	15	216	38	39	183	89.3	1482	0.38	10.35	100
4248C	51	119	70	37	29	25	5	147	98.6	1169	0.14	1.42	100.2
4248D	26	155	20	23	34	50	10	250	97.7	1050	0.21	1.97	99.9
4249A	3	3	170	8	53	29	36	117	91.7	1221	0.2	7.87	99.8
4249C	4	34	280	10	116	55	42	165	92.2	1378	0.25	7.82	100.3
4254A	13	3	120	4	210	20	141	76	87.4	22992	0.79	9.03	97.2
4254B	26	-1	-10	27	69	29	34	137	94.2	2725	0.36	5.63	100.2
4254C	42	3	90	27	102	37	46	152	92	4675	0.48	7.07	99.5
4254D	33	-5	130	13	48	25	37	131	94.3	3242	0.49	7.33	102.1
4254E	19	-2	20	3	42	26	2	197	95.1	533	0.17	4.83	100.1
4254F	20	62	40	34	55	21	7	161	94	812	0.65	5.67	100.3
4254G	28	91	240	45	73	18	12	148	93.7	1777	0.95	5.04	99.7
4254H	15	-2	30	7	30	12	1	400	99	605	0.05	0.48	99.5
4254I	31	1	60	10	218	29	4	883	98	1733	0.18	1.93	100.1

Appendix 5 - Regolith Landform and GIS thematic maps

A3 copies of the regolith-landform and derivative maps are enclosed. Hradcopy prints of the regolith-landform (Appendix 5.1) and the Geochemical Sampling Strategy map (Appendix 5.4) will be provided to sponsors in two scales;

- poster size plots (non standard scale) with full map surrounds (Appendix 5.1 = regolith-landform map and Appendix 5.4 sampling strategy map), and

- standard plots (1:100 000) with reference only (Appendix 5.1a = regolith-landform map and Appendix 5.4a sampling strategy map)

These maps will be supplied to sponsors in a map tube which will accompany this report. Postscript files of all the maps shown in Appendix 5 will be supplied to sponsors on CDrom. These maps include;

- Regolith-Landforms (Appendix 5.1)

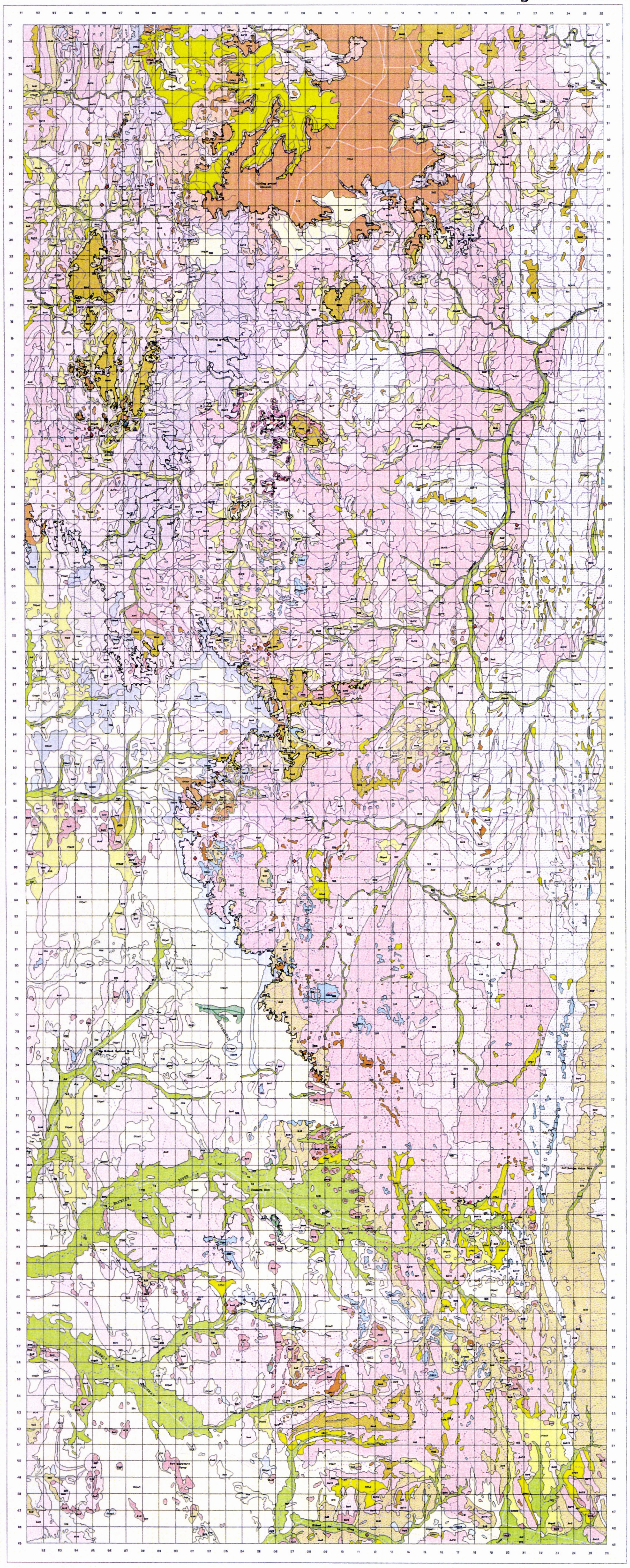
- Palaeo surfaces and highly weathered Regolith over Landsat TM (band 5) (Appendix 5.2)

- Regolith-landform Units over 3-Band Landsat TM image, (Appendix 5.3) and

- Interpretative Geochemical Sampling Strategy Map (Appendix 5.4)

Regolith polygons and associated attributes will also be supplied digitally on CDrom in MapInfo format. The CDrom will be supplied when all reports and maps have been sent to sponsors.

BUCKLEY RIVER - LADY LORETTA
Regolith - Landforms



REGOLITH TYPES

Major bedrock type

Duricrust

Proterozoic bedrock

Ferruginous

Proterozoic bedrock — DFla1

Siliceous

DSla1, DSla2, DSer3, DSep4

Post-Proterozoic bedrock

Ferruginous

Mesozoic sediments — DFla2, DFla3, DFla4

Siliceous

DSla5, DSla6

Saprolite

Proterozoic bedrock

Proterozoic bedrock — Sap1, Sap2, Sai3, Sai4, Ssr5, Ssr6, Ssr7, Ssr8, Ssh9, Ssl10

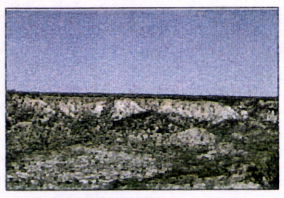
Post-Proterozoic bedrock

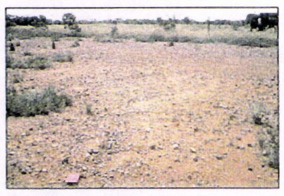
Cambrian sediments

Mesozoic sediments

Alluvial sediments

Colluvial sediments





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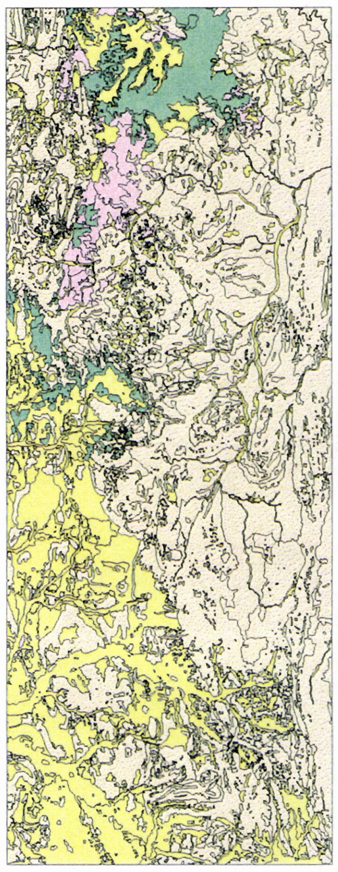
UNIVERSAL TRANSVERSE MERCATOR

SIMPLIFIED GEOLOGY



MAJOR LANDFORMS

Hills (90-120m relief) | Escarpments | Plateau surfaces | Ramified hills (90-120m relief) | Colluvial plains and minor footslopes | Floodplains, lacustrine plains and alluvial plains

INDEX TO ADJOINING SHEETS

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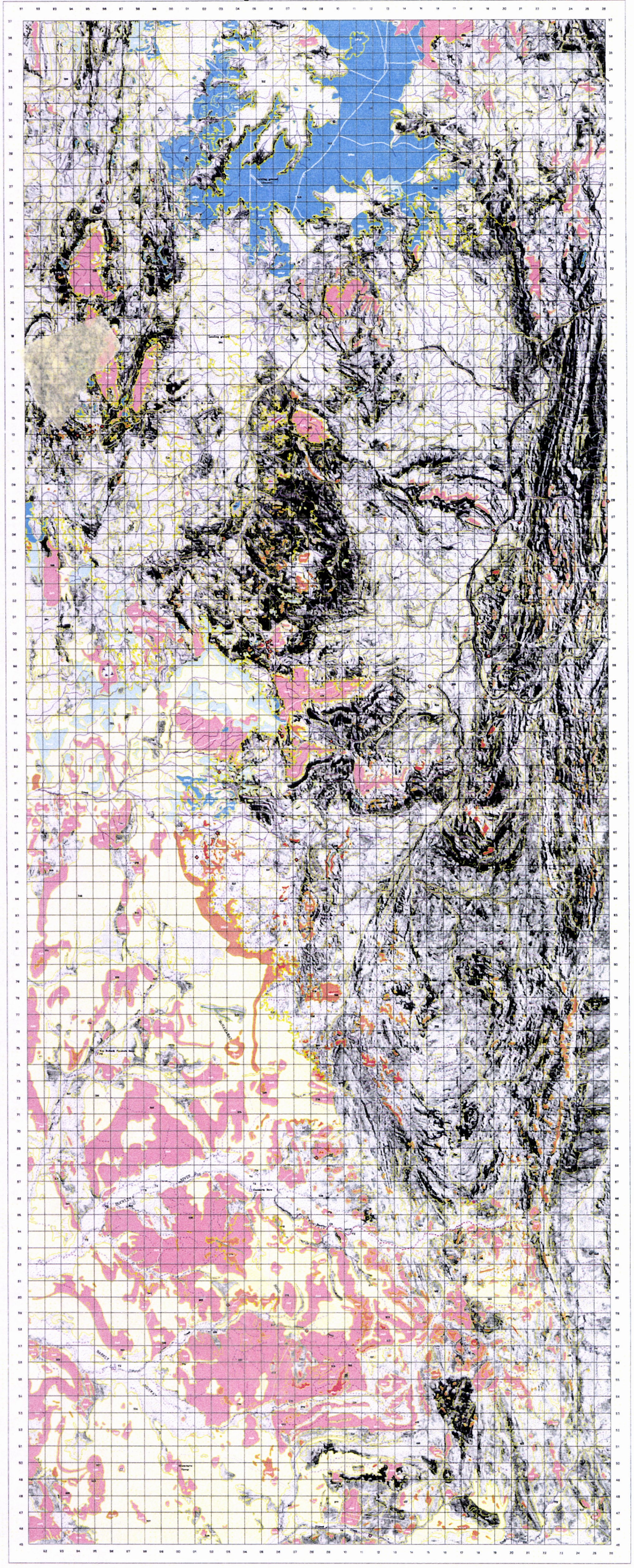
Appendix 5.1

Palaeo surfaces and highly weathered regolith over Landsat TM (band 5)

BUCKLEY RIVER - LADY LORETTA Regolith - Landforms



SCALE 1 : 85,000

UNIVERSAL TRANSVERSE MERCATOR

REGOLITH TYPES

Major bedrock type

Duricrust

Proterozoic bedrock

Ferruginous

Proterozoic bedrock

Siliceous

Post-Proterozoic bedrock

Ferruginous

Mesozoic sediments

Saprolith

Proterozoic bedrock

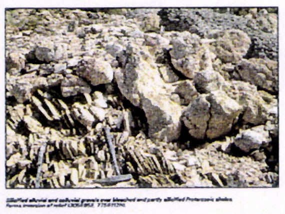
Post-Proterozoic bedrock

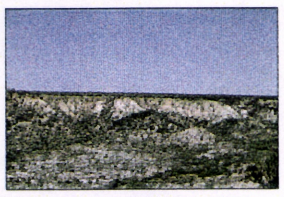
Cambrian sediments

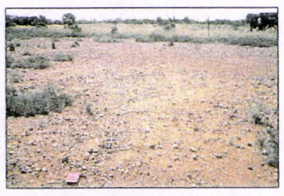
Mesozoic sediments

Alluvial sediments

Colluvial sediments







LANDSAT TM IMAGE

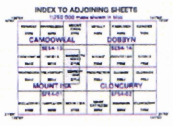
SIMPLIFIED REGOLITH

Fe duricrust | Cambrian saprolite | Alluvial and lacustrine sediments

Si duricrust | Mesozoic saprolite | Colluvial sediments

Proterozoic saprolite

INDEX TO ADJOINING SHEETS



Compiled by J.R.Wilford (CRC LEME/AGSO), 1996

Cartography by D.Rutowski, J.R.Wilford, A.Sedgmen and P.Jones (AGSO), 1996
Geographic Information Systems by D.Rutowski, A.Sedgmen, P.Jones and J.R.Wilford (AGSO), 1996

It is recommended that this map be referred to as:
J.R.Wilford, R.R.Anand and L.Rogers 1996 - Buckley River-Lady Loretta Regolith-Landforms (1:85,000 map scale). Cooperative Research Centre for Landscape Evolution and Mineral Exploration, (CRC LEME) Perth/Canberra

Regolith-Landforms polygons are based on interpretation of 1:25,000 colour airphotos, enhanced Landsat TM imagery, airborne gamma-ray imagery and field observations.

Published by CRC LEME, Canberra, Australia.

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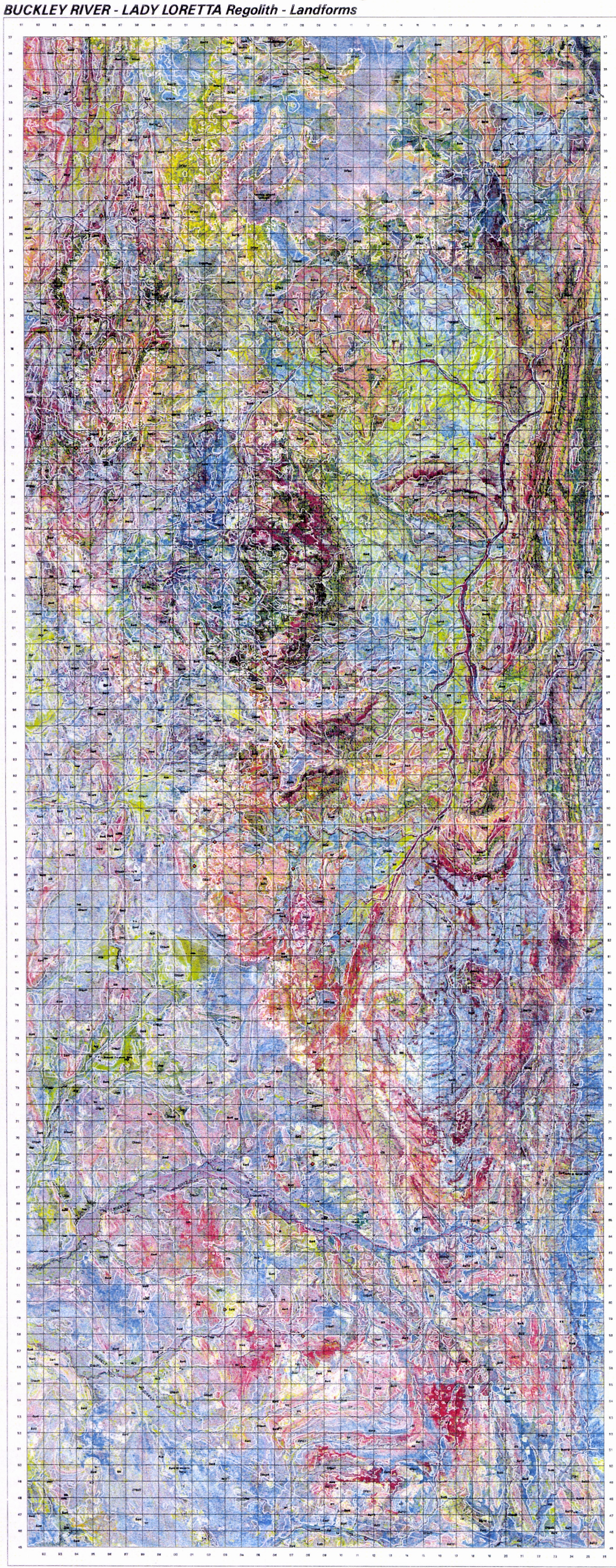
CRC LEME is an unincorporated joint venture between the Australian National University, University of Canberra, Australian Geological Survey Organisation and CSIRO Exploration and Mining, established and supported under the Australian Government's Cooperative Research Centres' Programme.

Regolith-landform units over 3-band Landsat TM

BUCKLEY RIVER - LADY LORETTA Regolith - Landforms



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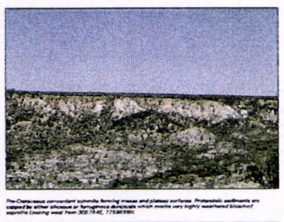
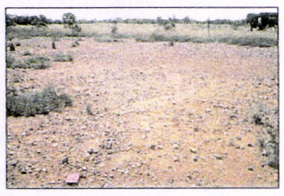
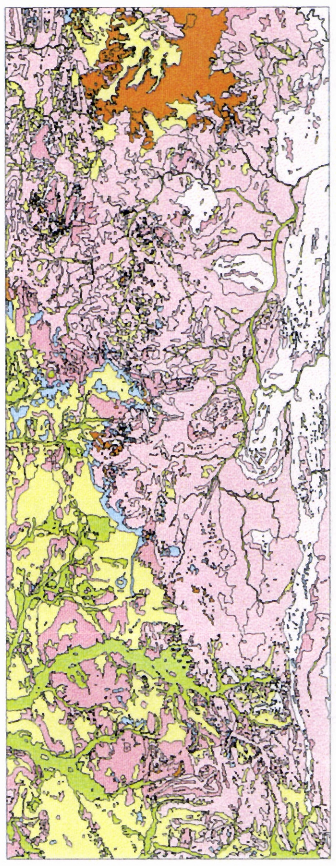
REGOLITH TYPES

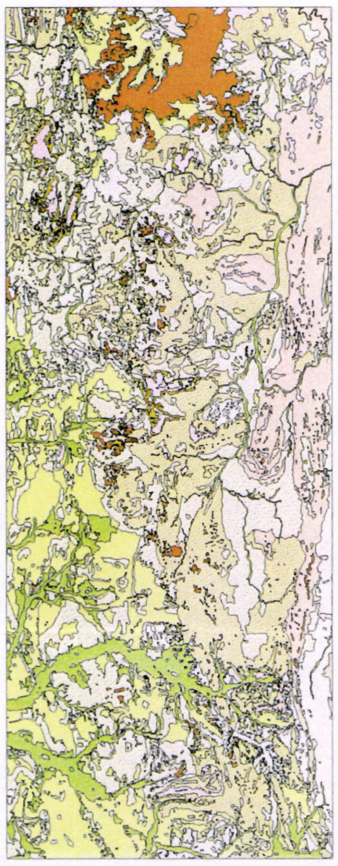




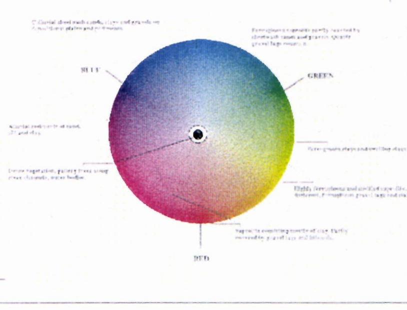
SIMPLIFIED REGOLITH SHOWING DEGREE OF WEATHERING



MAJOR LANDFORMS



LANDSAT TM INTERPRETATIVE KEY



Compiled by J.R.Wilford (CRC LEME/AGSO), 1996

Regolith-Landforms polygons are based on interpretation of 1:25 000 colour airphotos, enhanced Landsat TM imagery, airborne gamma-ray imagery and field observations.

Published by CRC LEME, Canberra, Australia

CRC LEME acknowledges the support provided for the production of this map by AMIRA.

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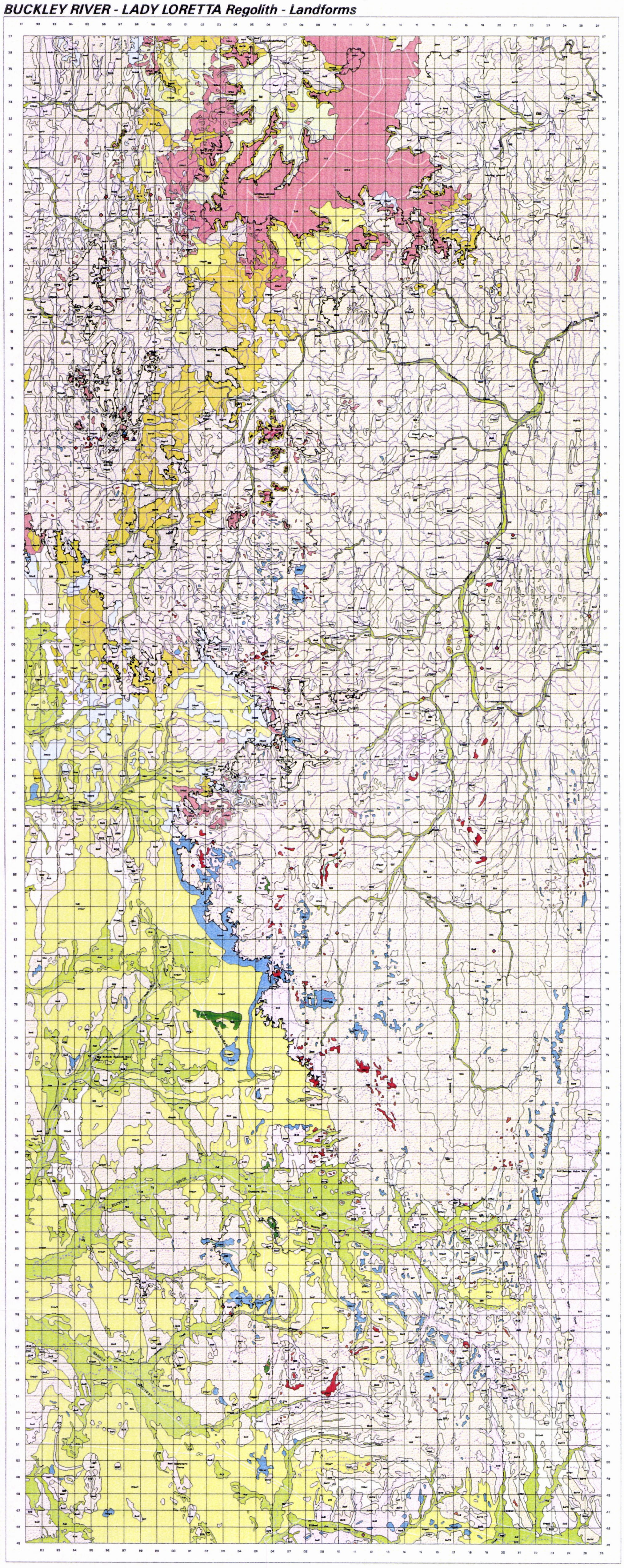
Interpretative Geochemical Sampling Strategy Map

BUCKLEY RIVER - LADY LORETTA Regolith - Landforms



SCALE 1 : 85,000

UNIVERSAL TRANSVERSE MERCATOR

REGOLITH/GEOCHEMICAL SAMPLING GUIDE *

Duricrust

Proterozoic bedrock

Ferruginous

Siliceous

Post-Proterozoic bedrock

Ferruginous

Siliceous

Saprolite and skeletal soils

Proterozoic bedrock

Post-Proterozoic bedrock

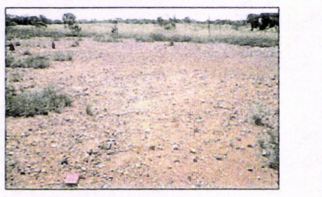
Saprolite covered by extensive lags and thin residual soils

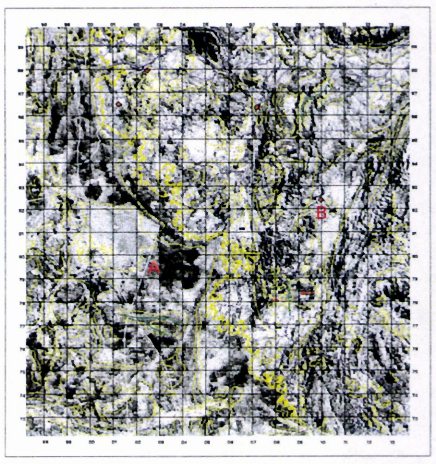
Proterozoic bedrock

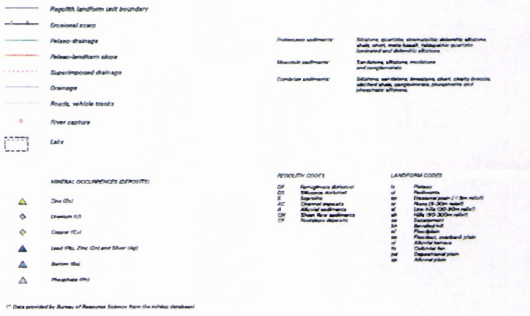
Post-Proterozoic bedrock

Alluvium

Colluvium

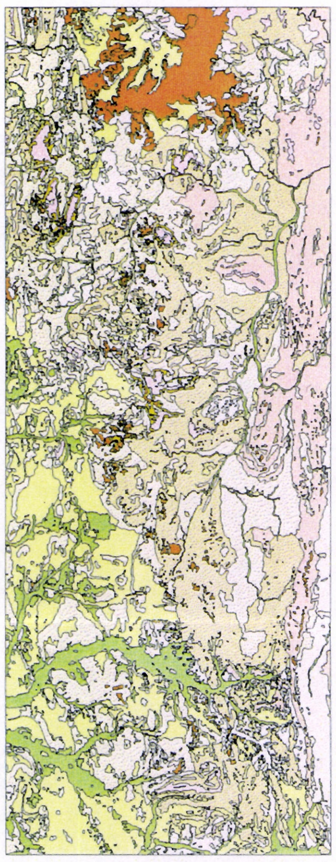






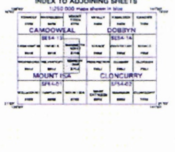
LANDSAT TM IMAGE

MAJOR LANDFORMS



Erosional plains and pediments (<9m relief)	Hills (90-120m relief)
Rises (9-30m relief)	Escarpments
Low hills (30-90m relief)	Plateau surfaces
Bevelled hills (90-120m relief)	Colluvial plains and minor footslopes
	Floodplains, lacustrine plains and alluvial plains

INDEX TO ADJOINING SHEETS



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Appendix 5.4