REGOLITH-LANDFORM CHARACTERISTICS, EVOLUTION AND IMPLICATIONS FOR EXPLORATION OVER THE SELWYN REGION, MT ISA

J.R. Wilford

CRC LEME OPEN FILE REPORT 131

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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.

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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 areas 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. Selwyn region is one of several district-scale investigations over the Eastern Succession of the Mt Isa Inlier. The Selwyn 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 Eastern 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 Selwyn area. 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 Selwyn study 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 Selwyn region (40 x 40km) approximately 140 km south southeast from 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 palaeochannels and erosional scarps. An interpretative geochemical sampling map has been generated which can be used as an aid in the interpretation of surface geochemistry and drill samples.

The maps show a complex history of landscape evolution. A combination of a long weathering history and variable degrees of stripping and exhumation has resulted in a landscape of variable regolith. Rocks exposed at the surface reflect weathering processes which operated from the Jurassic to the present day. Regolith consists of duricrusts (7% map sheet area) which may reflect both local and transported derivations, saprolite (62% map sheet area, includes bedrock) and sediments (32% map sheet area).

Duricrusts and saprolite
Duricrusts typically form the top of deeply weathered zoned profiles which include ferruginous, mottled and bleached saprolite at depth. These highly weathered materials are associated with exhume landforms and relict parts of the landscape including plateaux and mesas. Duricrusts reflect a long history of weathering from sub-aerial exposure in the Late Cretaceous to the present day. Some of the most intensely weathered bedrock is associated with palaeochannels which were probably established during the Jurassic or perhaps earlier.

Three types of ferruginous duricrust are recognised including; massive, brecciated and slabby duricrust. In places, silcrete and silicified saprolite develop instead of iron duricrusts - particularly where the underlying bedrock is siliceous. Veneers of sheet wash gravels, residual sand and clay overlying mottled saprolite are common in areas of relatively low relief (include; rises, erosional and pediments). Lithosols lying directly on bedrock or saprock occur on steeper slopes. These areas of high relief and geomorphic activity include; mountains, hills and low hills.

Sediments
Alluvium consisting of variable proportions of gravel, sand and clay is associated with channel, flood plain and sheet flow deposits. In many places, rivers are superimposed over the predominantly north-south structure of the underlying Proterozoic rocks. Silica or iron 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.

Implication for exploration
Massive and brecciated duricrusts and ferruginous saprolite have developed largely in situ and can be sampled to detect mineralisation at depth. Valley silcretes (some of which are now relief inverted) and slabby iron duricrusts are thought to be largely formed from lateral movement of silica and iron. Nevertheless, they can be used to give broad geochemical indicators.

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

1) Exhumed components of the landscape which expose in places very highly weathered kaolinised Proterozoic bedrock due to possible pre-Cretaceous weathering. Metal concentrations in these kaolinised zones are low relative to surrounding bedrock.

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

3) Deep weathering and leaching beneath palaeochannels, some of which are now relief inverted. Metal concentration within these leached zones are anomalously low.

4) Slabby ferruginous duricrusts may give false anomalies due to lateral movement of iron oxides. However, slabby duricrusts can be used to give broad geochemical indicators.
2. INTRODUCTION

2.1 Background

This report documents results from the Selwyn district which is one of several district-scale investigations over the Eastern 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 an understanding of weathering processes;
4) evolution of regolith-landforms; and
5) develop effective exploration strategies in different regolith-landform settings.
3. SELWYN STUDY AREA AND REGIONAL SETTING

3.1 Location

The Selwyn regolith-landform map is located approximately 140 km south southeast from Mt Isa and covers part of the Selwyn (7054) and Mt Merlin (6954) 1:100 000 map sheet areas (Figure 1). The map covers an area of approximately 40 km by 40 km and lies between the AMG coordinates of - 423000E: 7622000N (top left); 466000E: 7580000N (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 375 mm) occurs in the summer months between November 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 (Blake et al., 1983). Vegetation over the area consists largely of spinifex, acacia shrubs and scattered low eucalyptus trees.

3.3 Previous investigations

Blake et al. (1983) mapped the geology at 1:100 000 scale. The Eromanga Basin sequences are described by Senior et al. (1978). Descriptions of the Cambrian and Ordovician rocks of the Burke River Structural Belt are provided in Shergold and Druce (1980). Noon (1976) provides an overview of mineralisation on the Duchess 1:250 000 map sheet which includes the Selwyn region. More detailed and focused studies of the mineralisation associated with the Selwyn gold-copper mine are described by Kary et al. (1989).

Previous information on regolith and landscape evolution in the area is sparse. Twidale (1966) provides evidence of recent uplift and drainage development immediately east of the study area. When considering the Mt Isa Inlier as a whole most of the work has focussed on bedrock investigations, particularly on the Proterozoic sequences. Exceptions to this are investigations by Senior et al. (1978) (Geology of the Eromanga Basin), Smart et al. (1980) (The Mesozoic Carpentaria Basin), Connan and Hubble (1960) (Origin of laterites), Grimes (1972 and 1979) (Mesozoic and Cainozoic geology of the Cloncurry map sheet, stratigraphic sequence of old land surfaces in North QLD and Tertiary Geology of North QLD, respectively), and Twidale and Campbell (1993) (Dedunation chronology and exhumed surfaces, Mt Isa - in Australian Landforms Structure, Process and Time). More recently, regolith-landform maps and accompanying reports (Anand et al., 1996) show broad and detailed regolith characteristics over parts of the Mt Isa Inlier.

3.4 Physiography

Regolith-landform mapping is used to separate the Selwyn region into 8 major landform types. These landforms include colluvial plains and minor footslopes, alluvial plains and floodplains, pediments and erosional plains, rises, low hills, hills, escarpments and plateaux. The distribution of major landforms and their percentage cover over the Selwyn study area is shown in Figures 2 and 3.
Figure 1. (a) location of the Selwyn study area and (b) index map to adjoining 1:100 000 map sheets
Figure 2. Major landform units over the Selwyn study area.
Figure 3. Pie chart showing the proportions of major landform types.

High plateaux, mesas, scarps, hills and low hills occur over the northeast corner and extend into the central part of the map sheet (Figure 2). Relief in this area ranges from 50 -130 metres and forms part of the Selwyn Range which also extends further to the north-east. The landforms are being actively eroded by moderately dense dendritic and trellis drainage channels. The trellis patterns are following predominantly north-south jointing and cleavage planes in the underlying Proterozoic bedrock. Low relief, colluvial plains, pediments and erosional plains are associated with the Mort River catchment which extends into this area of higher relief from the south (Figure 2).

Landforms along the southern edge of the map are characterised by extensive colluvial plains, erosional plains, pediments, undulating rises and minor low hills, mesas and buttes. Similar gently undulating landforms occur over the western half of the map, including rises, pediments, erosional plains, colluvial plains, floodplains associated with major rivers and minor low hills. Well developed plateaux and associated scarps have developed largely on granitic bedrock and occur over the central part of the map sheet. Drainage patterns over these landforms are mainly dendritic with weakly developed trellis patterns following underlying bedrock structure.

The highest point, approximately 480 metres above sea level and steepest slopes occur over dissected Mesozoic plateaus at the north-east corner of the map sheet. The lowest point, approximately 240 metres above sea level is associated with floodplains of rivers draining to the south including the Mort River and Sandy Creek (a tributary of the Hamilton River).

A major divide separates rivers flowing south into the Lake Eyre basin and those draining north into the Gulf of Carpentaria (Figure 4). Sandy Creek and Little Sandy Creek are tributaries of the Hamilton River, Mort River, Mistake Creek and Limestone Creek are tributaries of the Burke River. Both the Hamilton and Burke Rivers flow into the Georgina River approximately 140 km to the south southwest. Drainages north of the divide flow into the Cloncurry River.
Figure 4. Major river divide (orange) and drainage over the Selwyn study area.
3.5 Regional Geological setting

The bedrock geology of the Selwyn region consists of Proterozoic rocks of the Mt Isa Inlier. Cambrian sediments of the Burke River Structural Belt and Mesozoic sediments of the Eromanga Basin (Blake et al., 1983). The Proterozoic rocks consists of foliated and non-foliated granites (most common are porphyritic and non-porphyritic biotite and hornblende-biotite granite), metadolerites, metabasalts, meta-arenites, amphibolites, slate, phyllite, schist, gneiss, felsic granofels, quartzite and quartz-hematite beds (Figure 5).

The Mt Isa region, including the Selwyn area, underwent major tectonism during the early Proterozoic causing uplift and exposure of the surface to sub-aerial erosion and weathering (Blake et al., 1983). Emplacement of the granites into the metamorphic sequence occurred during this time and at later tectonic events. Towards the end of the pre-Cambrian most of the landscape had been extensively eroded. During a Cambrian marine transgression shallow water sediments were laid down unconformably over the Proterozoic rocks. They consist largely of flat-lying to sub-horizontal bedded sandstones, siltstone, shale, chert, limestone, minor conglomerate and breccia. These sediments now occur mainly along the low relief western margin of the map but were once probably far more extensive over the map sheet area. Erosion and weathering of Cambrian and Proterozoic rocks then continued until an extensive cover of Mesozoic sediments were deposited. Mesozoic sediments of the Eromanga Basin are flat-lying and unconformable overlie the Proterozoic and Cambrian rocks. Mesozoic sediments consists mainly of terrestrial sandstone and conglomerate and shallow marine sandstone, siltstone and mudstone (Smart et al., 1980). Since the Late Cretaceous there has been substantial weathering and erosion to the present day.

3.6 Mineralisation

The region contains copper, cobalt, gold and minor amounts of silica flux and tungsten (Blake et al., 1983). Two major Cu and minor Au mines operate in the region - Starra (Selwyn) (Lat 21.683 Long 140.472) and Mount Elliott (Lat 21.541 Long 140.500). Primary copper ore at Starra is associated with chalcopyrite, bornite, pyrite, native gold and scheelite whereas ore at Mount Elliott is associated with chalcopyrite, pyrite and pyrrhotite. Mineralisation at Starra is associated with shear zones and a multiple-veined system hosted in carbonaceous slates and metadolerite of the Kuridala Formation, and at Mount Elliott with folded and highly sheared ironstones, quartz feldspar magnetite schist and chlorite schist of the basal part of the Stavely Formation. Regional tectonism and igneous intrusions in the region are thought to be instrumental in the concentration (developing structural pathways) and providing traps (shears and veins) for mineralised fluids to concentrate. Gold and copper mineralisation associated with quartz hematite ironstones developed due to secondary processes (Blake, et al., 1983) where Fe and mineralised fluids preferentially replaced existing porous strata. Comparison of mineralised and non-mineralised ironstone is described by Wildman (1997). The quartz-hematite rocks outcrop as massive resistant linear ironstone beds (Figure 6 and 11U).
Figure 5. Simplified geological units over the Selwyn study area.
Figure 6. Distribution of mineral occurrences and massive hematitic ironstones (yellow) draped over Landsat TM band 5 which serves to highlight major structural and landform features. Regolith polygons shown in white. Copper deposits in green, Uranium in purple, Cobalt in pink and unspecified in pale blue.
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 landforms 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 Selwyn 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,

Regolith type

ACaf1

Landform type

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 wanting to show subtle but nevertheless important difference 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.

<table>
<thead>
<tr>
<th>Regolith codes</th>
<th>Landform codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF Ferruginous duricrust</td>
<td>ls Plateau</td>
</tr>
<tr>
<td>DS Siliceous duricrust</td>
<td>ei Pediments</td>
</tr>
<tr>
<td>S Saprolite</td>
<td>ep Erosional plain (&lt;9m relief)</td>
</tr>
<tr>
<td>AC Channel deposits</td>
<td>er Rises (9-30m relief)</td>
</tr>
<tr>
<td>AO Overbank deposits</td>
<td>el Low hills (30-90m relief)</td>
</tr>
<tr>
<td>AA Alluvial terrace deposits</td>
<td>eh Hills (90-300m relief)</td>
</tr>
<tr>
<td>A Alluvial sediments undifferentiated</td>
<td>ec Escarpment</td>
</tr>
<tr>
<td>CH Sheet flow sediments</td>
<td>af Floodplain</td>
</tr>
<tr>
<td>CF Footslope deposits</td>
<td>ao Floodout, overbank plain</td>
</tr>
<tr>
<td>CF Footslope deposits</td>
<td>ol Alluvial terrace</td>
</tr>
<tr>
<td></td>
<td>fc Colluvial fan</td>
</tr>
<tr>
<td></td>
<td>pd Depositional plain</td>
</tr>
<tr>
<td></td>
<td>ep Erosional plain (&lt;9m relief)</td>
</tr>
</tbody>
</table>
4.2 Data collection and map compilation

The Selwyn map (Appendix 5.1) was based on approximately three weeks fieldwork with a similar amount of time for pre-fieldwork photo interpretation and image-processing. During fieldwork over 120 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 Selwyn Special Geological map (Blake et al., 1983) was 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. 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 Selwyn 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 and Hunt, 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 Selwyn 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:

\[
\begin{align*}
7 + 1 & \quad \text{for silica-rich materials (e.g. siliceous bedrock, quartz gravel lags)}; \\
5/4 & \quad \text{for ferrous (Fe+2) iron (e.g. hematite, Fe duricrust, ferruginous saprolite)}; \\
5/7 & \quad \text{for argillic materials - clays and carbonates}; \\
3/4 & \quad \text{for saprolite versus vegetation}; \\
4/2 & \quad \text{for ferrous (Fe+2) versus non-ferrous saprolite; and} \\
3/1 & \quad \text{for ferric (Fe+3) iron (e.g. goethitic saprolite and Fe duricrusts)}.
\end{align*}
\]

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 (see Appendix 5.3). In the three-band image (Figure 7) colluvial sheet flow deposits appeared in pale blue hues and are clearly separated from saprolitic material which appears mainly in pale red to deep red hues. Ferruginous saprolite, mottled saprolite and ferruginous gravel lags over erosional plains and rises are typically delineated in yellow. Mixtures of yellow and green indicate areas of outcropping ferruginous duricrusts together with ferruginous saprolite. Vegetation along drainage channels and water bodies appear in black or dark blue hues.

<table>
<thead>
<tr>
<th>Table 1. Landsat TM spectral features</th>
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<td><strong>TM bands</strong></td>
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<td>band 1</td>
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<td>band 4</td>
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<td>band 7</td>
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General and specific regolith spectral responses associated with Landsat TM bands (excluding band 6) (* modified from Podwyzocki et al., 1985)

Processed Landsat TM imagery provides a great deal of surface information particularly on the distribution of clays and Fe oxides within different regolith-landform units. The interpretation of the image is enhanced when combined with digital elevation models. Three dimensional perspective views which integrate Landsat TM imagery and digital elevation models allow the TM response to be interpreted within a geomorphic framework (Figure 8). A map showing regolith-landform units draped over the enhanced Landsat TM imagery at 1:65 000 scale is provided in Appendix 5.3. The image response is used to describe and estimate the relatively proportion of regolith materials within each landform unit. Where required, the 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 (see Appendix 5.3).
Figure 7. 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. Interpretative colour wheel below.
Figure 8. Three band TM image draped over a digital elevation model. Surface spectral responses can now be interpreted with a geomorphic perspective.
6. SELWYN REGOLITH-LANDFORM MAPS AND GIS

The digital regolith-landform map of the Selwyn 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, palaeodrainages, erosional scarps and superimposed drainage. Points are associated with mineral occurrences, regolith geochemistry 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 AGSO's 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 Sciences (BRS) MINLOC database. Mineral localities are indicated by coloured symbols. Geo-rectified raster data includes processed Landsat TM and digital elevation model (DEM). These datasets 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 1:65 000 scale were produced using the GIS to extract or emphasise different attributes within the database (Appendix 5). 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 9).

Map face key

Figure 9. 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 geological units. Divided into Metamorphic, granite, Cambrian, Mesozoic bedrock and transported materials (alluvium and colluvium).
5. Landform units over Landsat TM image
6. Three band Landsat TM image enhanced for separating regolith materials.
7. Map logos, acknowledgments, credits, copyright, location and index maps.

6.1.2 Deeply weathered Regolith over Landsat TM (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. Divided into Metamorphic, granite, Cambrian, Mesozoic bedrock and transported materials (alluvium and colluvium).
5. 3-D image showing Fe duricrust and bleached/silicified saprolite associated with palaeo channel.
6. Three band Landsat TM image enhanced for clay in red, Fe oxides in green and silica in blue.
7. 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. Full reference including description of units and regolith codes. Reference not coloured.
4. Simplified geological units. Divided into Metamorphic, granite, Cambrian, Mesozoic bedrock and transported materials (alluvium and colluvium).
5. Landsat TM draped over a digital elevation model.
7. Map logos, acknowledgments, credits, copyright, location and index maps.

6.1.4 Interpretative Geochemical Sampling Strategy Map (Appendix 5.4)

1. 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.
4. Simplified geological units. Divided into Metamorphic, granite, Cambrian, Mesozoic bedrock and transported materials (alluvium and colluvium).
5. Regolith-Landform units showing indurated materials, very highly weathered bedrock, highly weathered bedrock, moderately weathered bedrock, alluvium and colluvium.
6. Three band Landsat TM image enhanced for separating surface materials including clays, Fe oxides and silicates.
7. 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 other maps (Appendix 5.2 and 5.4) are 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 3.

Figure 10. 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. Ferruginous and siliceous duricrusts occur in the Selwyn region. Although duricrusts form only a small part of the Selwyn map (7%, Figure 10) they are significant when understanding and reconstructing landscape regolith evolution (see section 9). Duricrusts are generally preserved on relict parts of the landscape including mesas, buttes, plateaux and dissected plateaux.

7.1.1 Ferruginous duricrusts (DFIs1, DFIs2, DFIs3, DFIs4 and DFIs5)

There are five regolith-landform units in this category - DFIs1, DFIs2, DFIs3, DFIs4 and DFIs5. The first three refer to regolith-landform units on Proterozoic bedrock, and the last two units occur on Mesozoic sedimentary rock. Regolith associated with these units consists of massive and in places slabby ferruginous duricrust over ferruginous, mottled and bleached saprolite (Figure 11D). The surface is typically mantled by a veneer of gravel lags consisting of ferruginous saprolite fragments, ferruginous duricrust and pisoliths. Well developed iron segregations are common in the upper part of the mottled zone. Silification of the saprolite is also common and typically extends into the bleached zone beneath the mottled zone.

DFIs2 forms flat-topped hills and minor plateau surfaces over prominent stratigraphic quartz-hematitic beds. DFIs2 consists of ferruginous duricrusts and localised re-cemented ferruginous duricrust colluvial gravels. Unconsolidated ferruginous gravels form footslope deposits immediately down slope from the stratigraphic hematite ridges.

DFIs4 and DFIs5 consists of extensive plateau landforms over the northeast corner of the map sheet. They consist of massive ferruginous duricrust and highly ferruginous saprolite over mottled (irregular to mega sub-circular) and in places bleached bedrock. Silification of the saprolite is common and in places...
silcrete caps rather than ferruginous duricrust have developed (Figure 11N). The underlying Proterozoic bedrock is typically very highly weathered, mottled, bleached and silicified.

7.1.2 Siliceous duricrusts (DSNs1 and DSNs2)

Regolith-landform units DSNs1 and DSNs2 refer to weathering on granitic and Cambrian rocks. DSNs1 consist of mottled silcrete, silicified Fe-stained saprolite over bleached bedrock. Most of the primary minerals, particularly in the upper part of the weathering profile have been weathered to clay (kaolinite) and Fe oxides. Silicification commonly extends into the underlying bleached zone. Ferruginous duricrust and highly ferruginous saprolite can also occur at the top of the weathering profile but are usually thin and patchy. The most distinguishing feature of this regolith unit is the silicification and intense bleaching of the underlying saprolite which commonly extends several 10s of metres below the surface (Figure 11B, F and M). Silicification commonly overprints ferruginous and mottled saprolite within the profile. In places, cemented quartz pebbles in the silcrete indicate that the upper part of the weathering profile is transported (Figure 11O).

DSNs2 forms isolated mesas on the western side of the map sheet and consists of silicified, ferruginous and mottled Cambrian rocks. The top of the profile commonly consists of re-cemented ferruginous and siliceous saprolite with a breccia fabric (Figure 11E).

7.2 Saprolite units

This category includes all units dominated by saprolite or weathered bedrock which are actively being eroded. Saprolite is defined as weathered bedrock which has formed largely in place (in situ) without any significant change in volume (see glossary for more complete discussion - Appendix 1). Saprolite occurs over 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. granite, metamorphics). Saprolite units on some of the interpretative regolith-landform maps have been subdivided on the relative degree of weathering. 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. Brief definitions of the degree of weathering classifications are describe in Appendix 1.

7.2.1 Metamorphic bedrock (SNs1, SNs2, SNs3, SNs4, SNs5, SNs6, SNs7, SNs8, SNs9, SNs10, SNs11, SNs12 and SNs13)

SNs1 consist of silicified iron stained and bleached saprolite which form low hills, plateaux and dissected plateaux. SNs2 and SNs3 consists of ferruginous, mottled and bleached bedrock. The bleached zone can be thick (> 10 metres) and is in places silicified and diffusely mottled. Unit SNs2 is partly covered by lithosols consisting of ferruginous/bleached lithic fragments, gravels and minor ferruginous duricrust fragments, nodules and pisoliths. Unit SNs3 is largely covered by a veneer of residual soils gravel lags of ferruginous and silicified saprolite, quartz and lithic fragments.

SNs4, SNs5 and SNs6 consists of erosional plains where saprolite is largely covered by extensive veneers of residual gravel soils, residual clays and lags consisting of ferruginous saprolite fragments, quartz, lithic fragments, minor ferruginous pisoliths and ferruginous granules (Figure 11H). Narrow tracts of alluvium occur along some stream channels. Unit SNs6 in comparison is more ferruginous, consisting of ferruginous duricrust and ferruginous lithic gravel lags and red clay soils with minor ferruginous nodules. These materials develop on Fe rich lithologies including amphibolites and meta-basalts.

Unit SNs7 and SNs8 consists of rises and low hills which consists of mottled and ferruginous bedrock partly covered by lithosols and lithic lags. The lags consists of ferruginous lithic fragments, quartz gravels with a red silt/clay matrix. SNs9 consists of saprock partly covered by lithosols and colluvium flanking steep hills. Unit SNs10 forms escarpments and consist of saprock partly covered by scree and lithosols. The upper part of the scarp maybe highly weathered with bleached and silicified saprolite.

Unit SNs12 consists of rises and low hills, and develops over Fe-rich bedrock (ie. meta-basalt). It consists of highly weathered ferruginous and diffusely mottled bedrock which is partly covered by highly ferruginous lithic gravel lags and reddish-orange clays and fine sands. There are locally developed ferruginous duricrusts and Fe segregations. Unit SNs13 is associated with stratigraphic quartz-hematitic beds which form low hills and prominent ridges (Figure 11U). Its saprolite is partly covered by Fe gravel lags, lithosols and pockets of red clay soil over massive diffusely mottled ironstone.
7.2.2 Granitic bedrock (Sls14, Sel15,Ser16,Sep17, Sep18,Ser19,Sel20 and Sec21)
Regolith units Sls14, Sel15 and Ser16 consists of plateaux surfaces, mesas low hills, rises and minor scarps. Regolith includes ferruginous, mottled, bleached and silicified saprolite. Most of the primary minerals have been weathered leaving resistant quartz and secondary Fe oxides and clays (mainly kaolinite). In places, silicification of the saprolite extends into the bleached zone (Figure 11 C, I and P). The saprolite is partly covered by a veneer of gravel lags and soils consisting of, quartz, ferruginous pisoliths, lithic fragments and residual clays.
Figure 11. Descriptions and representative photographs of regolith materials.

(A) Slabby ferruginous duricrust with clearly visible horizontal to sub-horizontal layering. The duricrust overlies mottled and silicified bleached saprolite (456200E:7601300N).

(B) Slabby ferruginous duricrust and ferruginous saprolite over silicified mottled and bleached saprolite (schist and phyllite). Intense bleaching and silicification is thought to be associated with palaeo-channels (now relief inverted) (456200E:7601300N).

(C) Deep weathering profile developed on granite. The profile consist of massive ferruginous duricrust overlying (not seen) mottled, bleached and non-bleached saprock. Although the granite underlying the duricrust still retains its original structure most of the primary minerals have been altered to kaolinite and goethite. (463911E:7596416) (see section 8 Figure 11A).

(D) Massive ferruginous duricrust forming the top of a deeply weathered zoned profile. Ferruginous duricrust overlies mottled and bleached saprolite. The ferruginous duricrust has formed from the segregation of Fe in the mottle zone. Further weathering and erosion has cemented and exposed the Fe segregations together to form massive duricrust at the surface (458695E:7599384N).

(E) Silicified and ferruginous Cambrian sediments (shales and siltstones) forming local rises. Surface bedrock is typically brecciated and partly re-cemented by Si and Fe oxides (424487E:7608250N).

(F) Comparison between bleached and partly silicified Proterozoic shale and non-bleached shale. The bleached shales occur immediately below silicified and ferruginous Mesozoic sediments. Bleached shales grade into non-bleached saprock at 20-30 metres below the Mesozoic contact (448271E:7614489N).

(G) Colluvial and residual clays and gravels consisting of ferruginous saprolite and lithic fragments overlying highly weathered and mottled Proterozoic saprolite (427416E:7607328N).

(H) Veneer of residual and colluvial sheet flow clays, sands and gravels over highly weathered and mottled saprolite. Lags consist of ferruginous saprolite, lithic and quartz gravels (451634E:7602207N).
(I) Silicified mesas and rises developed in granitic saprolite, lithosols and gravel lags occur over surrounding erosional plains (442000E;760100N).

(J) Ferruginous and mottled Mesozoic sediments (sandstone, siltstone and mudstone). Massive ferruginous duricrust forms a capping to the mesa (450528E;7617986).

(K) An example of pre-Cretaceous weathering (white areas) developed in Proterozoic bedrock. Softer Mesozoic sediments have been largely eroded leaving an exhumed deeply weathered landsurface (448540E;7614766N).

(L) Flat top concordant summits of the Selwyn region (northeast of Selwyn mine).

(M) Ferruginous breccia consisting of angular lithic fragments cemented by Fe and Si which grades over several meters into highly bleached structured saprolite. The bleached zone then grades over several meters into non-bleached (not seen) schist and phyllite at about 30 metres below the top of the breccia zone (see section 8 Figure 11B) (448394E;7614340N).

(N) Silcrete pods and gravels cemented in a ferruginous earthy matrix. The silcrete pod consist of micro-crystalline Si and have developed in Mesozoic sediments (sandstone and siltstone) (450615E;7618443N). (see section 8 - Figure 11H).

(O) Silicified river channel sands and gravels overlying highly weathered, mottled and partly silicified granitic saprolite. The channel sediments are relief inverted and now from simous disconnected mesas (441207E;7595801N).
(P) Granite tors - surrounded and partly buried by colluvial and residual feldspathic and quartz sands (461552E:7590887N).

(Q) Mesas over granite bedrock. The mesa surface is silicified and diffusely stained by Fe. Rises between the mesas consist of ferruginous and bleached saprolite partly covered by gravel lags and lithosols (440947E:7595707N).

(R) Slabbly ferruginous duricrust and silicified conglomerate (Mesozoic ?) unconformably overlie weakly mottled, bleached Proterozoic saprolite. The slabby duricrust exhibits sub-horizontal layering and consists of Fe cemented sands and pebbles (see section 8 Figure 11D) (455427E:7586354N).

(S) Collapsed ferruginous breccia consisting of angular lithic fragments cemented by Fe and Si forming bluffs. The breccia overlies mottled and bleached saprolite (447615E:7613120N).

(T) Ferruginous breccia consisting of angular lithic fragments cemented by Fe and Si overlying a well developed mega mottled zone. Quartz veining indicates that the profile has formed in situ (447676E:7613534N) (see section 8 - Figure 11C).

(U) Thin colluvial Fe stone scree down slope from massive stratigraphic, hematitic ironstone ridges. Colluvial scree partly covers highly weathered kaolinised and mottled saprolite (445562E:7601717N).
Regolith units Sep17 and Sep18 consists of low-relief erosional plains and consists of bleached bedrock, partly covered by extensive veneers (generally < 1.0 m) of residual sands and gravel lags. The sands and gravels consist of mica, quartz, feldspar grains, siliceous, ferruginous and bleached lithic gravels, minor ferruginous duricrust fragments, pisoliths and nodules. Narrow tracts of alluvial sediments are associated with low order streams. Unit Ser19 and Sel20 consists of rises and low hills, respectively. They consist of ferruginous and mottled (reddish orange) granitic bedrock which is partly covered by a veneer of residual sand and gravel lags. About half of the primary minerals are weathered to clays and Fe oxides.

See21 consists of escarpments and consists of diffusely mottled granite partly covered by rocky scree and lithosols. Primary rock fabric is clearly visible. Saprolite on the upper part of the scarp edge is commonly silicified, bleached (kaolinised) and mottled. Bedrock at the base of the scarp is typically only slightly weathered.

7.2.3 Mesozoic sediments (Sep22, Ser23, Sep24, Sel25, and See26)
Units Sep22 and Sep24 consists of erosional plains. Sep22 consists of ferruginous sediments covered by a veneer of residual sand, clay and gravel lag. Lag consist of highly ferruginous saprolite, lithic fragments and minor siliceous saprolite gravels. Sep24 consists of extensive sheets of residual soils and lags which cover ferruginous, mottled and in places silicified saprolite. Lags consist of ferruginous lithic and ferruginous duricrust fragments, quartz pebbles and silcrete gravels in a reddish orange sandy to silty soil matrix. Sel25 consists of low hills and consists of highly weathered ferruginous, mottled and bleached sediments. In places, the saprolite is silicified. Ser23 is a similar to Sel25 but occurs on rises where the saprolite is largely obscured by gravelly lags, lithosols and generally thin residual soils. Unit See26 consists of Fe-stained diffusely mottled sediments developed on escarpments.

7.2.4 Cambrian sediments (Sep27, Sel28, Sep29, Sep30, Sep31, Ser32 and See33)
Unit Sel28 forms low hills and consists of highly weathered ferruginous, mottled and in places silicified sediments. The saprolite is partly covered by gravelly lithosols. Similar weathering patterns are associated with unit Ser32 over rises (9-30 metres relief). Lags and soils are more extensively developed over unit Ser32 - consist of ferruginous saprolite gravels, lithic, chert and silcrete fragments, residual clays and fine sands. Units Sep27, Sep29, Sep30 and Sep31 consists of low relief erosional plains and pediments. Unit Sep27 occurs over highly dissected erosional plains (<9m relief) and consists of highly ferruginous and mottled sediments. Here the saprolite is partly covered by thin lithic lags and lithosols. Unit Sep29 also occurs on erosional plains and is generally characterised by extensive sheets of gravel lags, consisting of ferruginous lithic and ferruginous duricrust fragments, quartz pebbles, silcrete gravels and residual reddish orange sandy soils. Unit Sep30 consists of light grey to brown silty residual clays with minor calcareous lithic and chert lags. Unit Sep31 consists of hard-setting dull green to reddish brown residual clays and swelling gilgai soils. Scattered float consists of ferruginous lithic fragments, ferruginous pisoliths and in places carbonate nodules. Unit See33 consists of ferruginous and mottled saprolite partly covered by lithosols over escarpments.

7.3 SEDIMENTS

7.3.1 Alluvial sediments
Alluvial sediments deposited on floodplains, alluvial plains and alluvial terraces occupy about 6% 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 (i.e. recent and older alluvial terraces). The sediments can be up to 20 metres thick along major river channels but in most places are less than 10 metres thick.

Unit ACal occurs on floodplains along and adjacent to major river channels, and consists of recent river channel sediments of unconsolidated interbedded gravels, sand, clay with local lens of cobble conglomerates. In places, alluvium is partly cemented by either clay, Fe or Si. Soils consist of reddish brown and grey sandy earths.

Overbank deposits AOba are formed by floodout overflow channels from major rivers, and consist mainly of alluvial sands, clay and minor gravels, typically overlying residual sands, clays and saprolite.

Alluvial sediments (AAol) developed on terraces and benches consists of interbedded sand, clay and gravel. In places truncated palaeosols indicate several cycles of deposition, erosion and weathering. Soils consist of reddish brown mottled earths and duplex soils.

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Undifferentiated channel and overbank alluvium (Aaf) consist of variable proportions of clay, sand and gravel. Alluvial channels form narrow tracts between rises, low hills and hills. Alluvial sediments are typically intermixed with minor colluvial footslope deposits adjacent to scarps, low hills and hills.

7.3.2 Colluvial sediments
Colluvial sediments are extensive and cover approximately 26% of the map sheet (Figure 10). The sediments occur beneath erosional plains, pediments, depositional plains and minor footslopes. They consist of unconsolidated polymeric gravel and gravel lags with various proportions of sand and clay. The underlying bedrock is generally very highly weathered and mottled. Sediment thickness range from 0.1 to 4 m. The sediments can have a proximal or distal source.

Unit CHpd1 is typically thicker (> 1.5 m) than CHpd2 (generally < 1.5 m). Both units include sheet flow deposits consisting of silty clay loams, clays, sands and local areas of cracking clay soils (gilligai micro-relief) which have accumulated over extensive depositional and erosional plains. The sediments overlie very highly weathered and mottled bedrock at depth (Figure 11G). The surface is partly covered by lags - consisting of ferruginous saprolite, lithic fragments and quartz with minor ferruginous duricrust fragments and Fe pisoliths. Local narrow tracts of alluvium occur along stream channels. Saprolite protrudes in places as well as patches of residual sand and clay. Unit CFFc1 comprises colluvial fan deposits consisting of quartz, ferruginous saprolite and lithic fragments in a coarse sandy to gravelly earthy matrix. Polymeric gravel lags of quartz, ferruginous saprolite and lithic fragments are common over the surface. Unit CFFc2 includes colluvial fan deposits of highly ferruginous saprolite, ferruginous duricrust, ferruginous pisoliths and lithic fragments in a ferruginous earthy matrix. Polymeric gravel lags of quartz, ferruginous saprolite, ferruginous duricrust and lithic fragments typically form a surface veneer.

CHEi3, CHEi4, CHEi5 and CHEi6 form gently sloping erosional plains and pediments (Figure 11H). CHEi3 consists of sheet flow colluvial and minor alluvial deposits forming a veneer (generally < 1m thick) of sand, clay and gravel over mottled and typically bleached bedrock (mainly metamorphic). Gravelly lags are common and consist of ferruginous saprolite, quartz and lithic fragments. Sheet flow sediments associated with CHEi4 are locally derived from granite and are developed on erosional plains and pediments (Figure 11 I). They consists of quartzoze/feldspathic sand, clay and gravels (generally < 1m thick). Residual sand, gruss, clay and protruding granite tors are common (Figure 11 P). Gravelly lags consist of siliceous, ferruginous and bleached saprolite fragments, quartz and ferruginous duricrust fragments. Minor alluvium occurs along river channels. CHEi5 comprises colluvial and alluvial clay, sand and gravel over ferruginous and mottled saprolite. CHEi6 consists of sheetflow sands and lags consisting of lithic fragments and ferruginous gravels over highly weathered Cambrian sediments (typically mottled and ferruginous). Minor amounts of sand and gravel are associated with narrow river channels.

8. WEATHERING PROFILES AND GEOCHEMISTRY

Ferruginous or siliceous duricrusts typically form the top of the most deeply weathered profiles in the Selwyn region. The duricrusts commonly overlie zoned weathering profiles. The weathering zones below the duricrust consist of mottled saprolite, bleached saprolite (kaolinised), saprock and fresh bedrock. The mottled and bleached zones are often 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 12 A-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. A complete geochemical analysis of the samples are located in Appendix 4.

8.1 Proterozoic bedrock

Weathering of Proterozoic bedrock is variable - ranging from moderately weathered to completely weathered saprolite. The duricrusts have either massive, brecciated or slabby fabric.

Massive ferruginous duricrust developed on granite are shown on the regolith-landform maps (appendix 5) as unit DF1s3. The duricrust and underlying profile (Figure 11A and Figure 12A) has developed in situ, although Fe and Si cements are likely to be derived laterally as well as from below the
The weathering profile. The profile develops on plateaux and is typically massive ferruginous duricrust, although in places it may have a weakly developed slabby or vuggy appearance. A mottled saprolite zone underlies the duricrust. The upper part of the mottled saprolite is characterised by well developed Fe segregations which are commonly silicified. The vugs in the duricrust are typically infilled with ferruginous gritty sands derived from the duricrust and cemented by Fe oxides. The mottled zone has a gradual contact over several metres to a well developed bleached zone which is typically silicified and diffusely iron stained. Bleached saprolite has a gradual irregular contact to non-bleached saprock.

The duricrust consists largely of hematite and goethite. Clay in the mottled zone is dominated by kaolinite; other minerals include quartz and mica with hematite and goethite in the mottles. 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 mineralogy is consistent with whole rock geochemistry (Figure 12A).

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, bleached and saprock zone. Rubidium, Ba, K and Sr are lost from the upper part of the profile as micas weathers to clays. Aluminium Al and Ga are low in the ferruginous duricrust and have similar trends in the mottled, bleached and saprock zones where they are likely to be associated with kaolinite and feldspars.

Highly ferruginous brecciated duricrusts consist of saprolitic fragments (typically angular) cemented by hematite and goethite. This brecciated fabric typically overlies a well developed mottled zone (Figure 11T and Figure 12B). Mega motting and silicification in the upper part of the mottled zone is common. The mottled zone grades over several metres into a bleached saprolite which is diffusely mottled and in places silicified. The bleached zone grades at depth into saprock. The profile has developed in situ as evident from quartz veining to the surface. The degree of ferruginisation in the breccia zone is variable. The breccia zone in profiles shown in Figure 11M and 12C are largely siliceous with Fe staining throughout, whereas profiles shown in Figure 11T and 12B consist mostly of Fe. Geochemical trends associated with these profiles differ as a result of the variable Fe content in the upper part of the profile. The breccia zone in profile shown in Figure 11T is relatively high in Cu, Cr, Zn and vanadium (V) due to scavenging by iron oxides. Rubidium, Ba, K and Sr increase down the profile (Figure 12B) and are largely associated with micas.

Slabby duricrust developed on Proterozoic bedrock are typically underlain by mottled and bleached saprolite (Figure 11A and B) and form cappings to rises, low hills and mesas. A slabby duricrust profile has been reconstructed from samples along a eastwest traverse (see section 9, Figure 12 D). The profile from the top to bottom consists of slabby ferruginous duricrust, Fe segregations, mottled zone, bleached and silicified zone, and Fe saprock (non-bleached, Fe rich schist). Clay in the mottled and bleached zone is largely kaolinite. Copper, Ni and Zn have strong affinities with Fe and are concentrated in the duricrust relative to the bleached zone. Aluminium is associated with clays in the bleached zone and with feldspars in the saprock. Potassium generally increases with depth and is largely associated with K-mica within the schist. Lead is largely immobile with uniform concentrations throughout the profile.

Slabby ferruginous duricrust developed on transported sediments (Mesozoic sediments ?) is shown in Figure 11R and 12E. The profile from top to bottom includes slabby ferruginous duricrust with a sharp contact to a mottled and silicified cobble conglomerate which rests unconformably over mottled, bleached and slightly weathered Proterozoic schist/sandstone. The duricrust consists mainly of hematite and goethite. Elevated Cu, Cr and V concentrations are a result of scavenging by Fe oxides in the ferruginous duricrust. Barium, Rb and K are very low in the re-worked sediments and are comparatively high in the weathered schist where they are likely to be associated with micas.
Figure 12A. Vertical distribution of major minerals and some major and trace elements in the weathering profile over granite (porphyritic biotite/hornblende-biotite granite). Profile developed on plateaux and mesas.
Weathering Profiles and Geochemistry

447615E 7613120N - Ferruginous breccia and mottled saprolite over Proterozoic bedrock (Phyllite)

**Regolith**

- Ferruginous saprolitic breccia, consisting of angular lithic fragments cemented by iron and silica
- Irregular reddish-orange mega-mottling
- Quartz vein
- Bleached saprolite with patchy, pale diffuse iron staining.

**Mineralogy**

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**Elements in %**

- Hm, Qtz, Hm, Gt
- Mi, Qtz, Hm, Gt
- Qtz, Kao
- Gt, Ht, Kao

---

**Regolith**

- Ferruginous saprolitic breccia, consisting of angular lithic fragments cemented by iron and silica
- Irregular reddish-orange mega-mottling
- Quartz vein
- Bleached saprolite with patchy, pale diffuse iron staining.

**Mineralogy**

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**Elements in ppm**

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- Mi, Qtz, Hm, Gt, Gt
- Mi, Qtz, Hm, Gt
- Mi, Qtz, Hm, Gt

Figure 12B. Vertical distribution of major minerals and some major and trace elements in the weathering profile over Proterozoic phyllite and schist. Profile developed on mesas and low hills.

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Figure 12C. Vertical distribution of major minerals and some major and trace elements in the weathering profile over Proterozoic phyllite and schist. Profile developed on mesas and low hills.
Weathering Profiles and Geochemistry

Figure 12D. Distribution of some major and minor trace elements across a palaeochannel (see section 9.4). The old river channel floor correlates to the zone of bleached and silicified saprolite. Slide of the image above is shown in Figure 11B.

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Figure 12E. Vertical distribution of major minerals and some major and trace elements in the weathering profile over Mesozoic and Proterozoic slate. Profile developed on mesas and rises.
Figure 12F, G and H. Vertical distribution of major regolith materials in weathering profiles over Cambrian (F) and Mesozoic (G & H) sediments.
Silcretes and silicified Proterozoic bedrock are typically impregnated by Fe to varying degrees in the form of hematitic mottling and diffuse staining. The silcretes are typically covered by a veneer of ferruginised silcrete and silicified saprolite gravel lags. They consist of massive, grey, indurated crusts which typically exhibit columnar jointing patterns. They can also form as pods 0.2-1.0 metres wide which are typically surrounded by gritty sands which are partly cemented together by iron and silica. Silcretes may be fine-grained with a micro-crystalline textures or coarse grained where silica has cemented quartzose sand and gravel. Mottled saprolite beneath the silcrete is often also silicified. Silicification is also associated with ferruginous duricrusts described above where Si has cemented the mottled and kaolinised zone beneath the duricrust. An example of a silcreted weathering profile developed on granite is shown in Figure 11 Q.

8.2 Cambrian and Mesozoic bedrock

Cambrian and Mesozoic profiles were not considered for geochemistry or mineralogy. However ‘typical’ weathering profiles developed on these lithologies are shown in Figures 11F, G and H. The most deeply weathered profiles are now preserved on remnant plateaux and mesas. Profiles developed on Cambrian sediments consist of lithosols partly covering a brecciated saprolitic layer (Figure 11F and 10). The breccia is typically stained by Fe, mottled and partly silicified. The degree of weathering beneath the breccia zone is largely controlled by lithological variation within the sedimentary sequence. Argillaceous units are typically completely weathered to residual clays whereas more siliceous units are generally only moderately to slightly weathered.

Mesozoic sediments are typically very highly weathered with either ferruginous or siliceous duricrusts overlying ferruginous and mottled saprolite (Figure 11J and K). Ferruginous duricrust are typically massive and partly covered by Fe stone lags, nodules and pisoliths. Siliceous duricrusts appear as either silicified saprolite or as silcrete pods in the silicified and ferruginous matrix (Figure 11N). Mottling varies from irregular and diffuse to clearly delineated mega mottles. Weathering of the sediments is largely controlled by variation in lithologies. Siliceous units (siltstone, sandstone) are often silicified whereas clays rich sediments (mudstone) are often highly ferruginous. The contact with the underlying Proterozoic bedrock is commonly bleached and silicified (Figure 11K).

9. REGOLITH-LANDFORM EVOLUTION

A number of regolith materials, landform and drainage features contain important information when developing an understanding regolith-landform evolution in the Selwyn area. These are discussed before a summary of landscape evolution is presented.

9.1 Duricrusts and associated deep weathering

Duricrusts have cemented in situ materials (saprolite) and sediments. They generally have a scattered distribution in the landscape. The distribution of ferruginous and siliceous duricrusts are shown on map 5.2 (Appendix 5). Duricrusts are divided on whether the major cementing agent is Fe or Si and on their physical characteristics.

9.1.1 Ferruginous duricrusts
Iron cemented materials are divided into three main categories based largely on textural differences. They are:

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

2) Slabby ferruginous duricrust (duricrust has a partly layered or slabby appearance); and

3) Ferruginous/brecciated saprolite (Fe oxides cementing a typically brecciated saprolite which grades into mottled saprolite at depth).

Massive and slabby duricrust 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 form an extensive plateau surfaces over the northeast corner of the Selwyn study area. Slabby duricrusts in comparison are less common and generally occur along the edges of plateaux and mesas. The ferruginous and highly weathered nature of the Mesozoic sediments in the Selwyn area and elsewhere over the Mt Isa inlier may relate to the 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 (i.e. valley floors, coastal inlets). Water would have accelerated the weathering process, particularly with regard to the movement of Fe and Si in the sedimentary sequence.

Massive, brecciated and slabby duricrust occur on Proterozoic rocks. These duricrusts show clear evidence (quartz veining) that they have developed largely in situ. In many cases, there is clear field evidence of a gradual transition between Fe segregations in the mottled zone and the overlying massive ferruginous duricrust. Mottling has formed by segregation of clay and Fe oxides in the saprolite. As mottling proceeds more iron and clay species are separated and concentrated in the mottled zone. This eventually leads to the formation of Fe segregations in the upper part of the weathering profile. Iron segregations are then progressively exposed and hardened due to surface weathering and erosion. The Fe segregations may either collapse and be re-worked at the surface to form gravels consisting of ferruginous saprolite, duricrust, nodules and pisoliths, or, cement together to form massive duricrust. Iron in the upper part of the profile is likely to have been sourced from the mottled zone and the underlying saprolite zone. In addition, some Fe was probably sourced laterally from upslope. However lateral sourcing of Fe is thought to be a more important process in the development of slabby ferruginous duricrusts (see section 9.2).

Breciated duricrusts (Figure 11A) are less consolidated than the massive or slabby duricrusts. They consist of angular-kaolinised saprolite fragments which are cemented by Fe oxides to form an indurated brecciated duricrust. In addition to saprolite fragments the breccia contains ferruginous nodules and pisoliths which are partly cemented in a ferruginous earthy clay matrix. The indurated breccia grades into a well developed mottled zone (mega-mottling common) and kaolinised saprolite. The breccia fabric has probably developed from the removal of clays - causing the saprolite to collapse. Reworking due to bioturbation would also contribute to surface mixing and brecciation. Mobilisation and precipitation of Fe has subsequently partly cemented the saprolite fragments and formed ferruginous nodules and pisoliths in the upper part of the weathering profile.

Slabby Fe duricrusts (Figure 11A) in comparison to the massive ferruginous duricrusts exhibit sub-horizontal to horizontal layering. The top of the slabby duricrust typically consists of lithosols which consist of 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 invariable silicified. Quartz veining through the duricrusts although discontinuous in places indicates that the profile has largely formed in situ. The origin of the layers within these slabby duricrusts is uncertain but is thought to have developed from lateral movement/accumulation of Fe and partial collapsing of the upper part of the weathering profile.

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 (i.e. humid and arid). The brecciated duricrusts have however many similarities with the Canaway weathering profile in the Eromanga Basin described by Idnurm and Senior (1978). The Canaway profile has a palaeomagnetic age of Late Oligocene.

9.1.3 Siliceous duricrusts
Silica-cemented materials consists of:

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

2) Silicified sand and gravel; and

3) Silicified saprolite (silica cementing saprolite).
Figure 13. Some of the most intense weathering is associated with Pre-Mesozoic valley floors as shown by the enhanced colour photographic/digital elevation model drape. In places, Mesozoic sediments have been removed leaving behind silicified and bleached Proterozoic saprolite. This intense weathering is likely to be due to groundwaters removing Fe and precipitating silica within the saprolite beneath the old valley floor. Slabby Fe duricrusts probably delineate the edge of the old river valley and have formed from the lateral movement of Fe oxides down palaeo slope.
Silica-cemented materials are associated with the ferruginous duricrusts (see map 5.2 - Appendix 5) and appear to have formed on a variety of different materials. Iron and Si cementing can occur within the same weathering profile. In many places Si overprints ferruginous materials suggesting that conditions more favourable for silification may have occurred more recently. Silification 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 silification. Linking the origin of some of these silified materials with palaeochannels best explains their distribution, association with ferruginous duricrusts, composition and texture. A model for the origin of these silcretes and slabby ferruginous duricrusts is explained in section 9.2.1.

Silification of saprolite is not restricted to palaeochannels but also occurs on erosional plains and rises. It is possible that silification has been occurring more or less continuously throughout the Cainozoic and earlier, cementing saprolite in different parts of the landscape at different times.

9.2 Drainage features

9.2.1 Palaeodrainage, duricrust development and relief inversion

Drainage evolution in the Selwyn region has had a long and complex history. It is thought that palaeo-river systems are intrinsically related to some of most highly weathered regolith in the landscape. Palaeohydrology is also likely to have had a major influence in the formation and distribution of indurated materials (ferruginous duricrusts and silcrete).

Sinuous, silicified concordant plateaux or dissected plateaux with either cemented quartz sands and pebbles and/or silicified saprolite occur approximately 4 km west of the Selwyn mine. The cemented quartz sands and pebbles represent old valley floor alluvium, whereas the silicified saprolite is associated with subsurface water flow beneath the old valley floor (Figure 11O). Silification and hardening of the valley floor has led to differential erosion and relief inversion.

Slabby ferruginous duricrusts are often associated with these old valley silcretes and zones of silicification. These relationships are shown in a 3-D colour photograph/digital elevation drape across an interpreted palaeo-channel (Figure 13). The old palaeochannel (depicted in Figure 13) is delineated by intense bleaching and silification of Proterozoic bedrock which was once a Fe-rich schist. Geochemical variation for selected elements across the palaeochannel is shown in Figure 12D. Bleaching of the bedrock is thought to be due to groundwaters removing Fe and precipitating silica within the saprolite beneath the old valley floor. Slabby duricrusts are likely to have formed on the valley sides adjacent to the palaeochannel by vertical and probably more importantly by lateral movement of Fe oxides down slope to the valley sides. Therefore slabby ferruginous duricrusts may mark the edge of the old valley wall. This would explain why many of the slabby duricrusts are inclined or dipping (Figure 11A). The palaeochannel was probably once filled with Mesozoic sediments which have since been eroded, what remains is cemented (Si) saprolite associated with the old valley floor (Figure 14). A diagrammatic model for the formation of silcretes and slabby ferruginous duricrusts is shown in Figure 14.

9.2.2 Drainage superimposition

There is clear evidence of drainage superimposition in the north-west part of the map sheet. Limestone Creek and other rivers flowing predominantly east-west are likely to have been inherited from a flat-lying Mesozoic sedimentary cover which blanketed most of the region during the early Cretaceous (see Appendix 5). The older east-west palaeoflow direction is now superimposed over the predominantly northsouth structural fabric of the underlying Proterozoic rocks. In the north-east corner of the map sheet large areas of Mesozoic sediment remain. Irregular thicknesses of Mesozoic sediments and undulating contacts with the underlying Proterozoic rocks in this area are best explained by sediments infilling valley and ridge palaeotopography. This suggests that there was quite substantial pre-Mesozoic relief prior to sedimentation. The underlying Proterozoic rocks along these now partly exhumed valleys are typically very highly weathered and kaolinised. This probably relates to deep weathering associated with ground waters along and beneath the palaeovalley floors.
Figure 14. Showing the development of slabby Fe duricrusts and silicified saprolite associated with palaeo-channels. (A) - silicification of valley floor and accumulation of Fe oxides along valley sides. (B) - differential erosion and relief inversion caused by induration by Si and Fe associated with the palaeo-channel.
Figure 15. Stages of exhumation exposing pre-Cretaceous weathering. (A) - most of the Cretaceous sediment preserved. (B) - Cretaceous sediments largely exhumed revealing the pre-Cretaceous weathered Proterozoic bedrock.
9.3 Exhumed surfaces

In many places 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. The exposed pre-Cretaceous surface may be highly weathered, bleached and in places silicified. The age of exhumation is younger than the Proterozoic basement affected by the erosion and older than the Cretaceous sediments which once covered the basement rocks. Several stages of exhumation or degrees of uncovering can be recognised in the Selwyn region depending on the relative rates of erosion and the original thickness of the Cretaceous sediments (Figure 15).

Exhumation has probably developed by a combination of deep weathering, competency contrast between Cretaceous sediments and underlying Proterozoic sediments and, uplift and associated active erosion. In many places exhumation has exposed highly weathered (typically bleached) possible pre-Cretaceous weathering (Figure 11 K). Exhumed landscapes in the Selwyn region are part of broader scale preferential stripping of the Cretaceous cover and exposure of basement rocks across the Carpentaria Basin (Twidale and Campbell, 1993). How closely the exhumed surface will reflect the original pre-Cretaceous topography will largely depend upon post-Cretaceous tectonism in the area.

9.4 Erosional scarps and uplift

Several active scarps occur over the western part of the Selwyn map. They flank Mesozoic and Cambrian sediments. The scarps separate relatively older landforms and regolith above from predominantly younger landforms and regolith below the scarp edge. Active erosion together with low angle dips of the sedimentary beds may relate to local warping and uplift in this region. This tectonism may be associated with the Selwyn Uplift described by Twidale (1966). Warping may also be associated with the re-activation of the Pilgrim Fault near Mt Birnie (west of the map sheet boundary) during the Cainozoic as evident by dipping (3 degrees) silcrete mesas (de Keyser and Cook, 1972). Changes of river patterns to the east of the study area was attributed by Twidale (1966) to Late Pleistocene and Early to Middle Holocene uplift. This might also explain why the highest elevations in the Selwyn study area occur along the east to north eastern margin of the map. Scarps are also associated with highly ferruginous and silicified saprolite which resist erosion due to their hardness (see maps - Appendix 5.0).

9.5 Summary of Regolith-landform history

A summary of the regolith-landform events from the Late Jurassic to the present day are outlined below. However, due to the lack of regolith dating around the Selwyn area age relationships and correlations are at best speculative. The stages of regolith-landform evolution are show diagrammatically in Figure 16.

9.5.1 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. Highly weathered Proterozoic bedrock beneath the Mesozoic sediments indicates either pre-Mesozoic kaolinitisation prior to valley infilling or deep weathering after sedimentation. Ferruginous Proterozoic rock fragments were in places incorporated in the basal units of these sediments.

9.5.2 Late Cretaceous

As the sea fell during 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 south southwest to the Eromanga Basin. north-east drainage superimposition across the predominantly north south structural grain of the Proterozoic rocks reflects an early drainage pattern inherited from the exposed sea floor cover. This inheritance strongly suggests that the Mesozoic cover extended over a large part if not all of the Selwyn region. Resistant strata may have protruded as islands surrounded by a Mesozoic sea. Immediately after emergence the area was relatively flat with early Cainozoic weathering and erosion bevelling Proterozoic rock which protruded through the sedimentary cover. Most of the soft Mesozoic sediments had been eroded by the end of the Cretaceous uncovering the basement of the Mt Isa Inlier. Regional uplift of the inlier and
modest down warping of the Carpentaria and Eromanga basins would appear to be the primary driving forces behind regional erosion and aggradation. Differential erosion following emergence left the Proterozoic rocks basement rocks high in the landscape, particularly over the central and eastern half of the Selwyn map sheet area.

9.5.3 Cainozoic
By the early Cainozoic the Mesozoic sediments had been largely eroded except in the northeast, southeast and southwest corners of the Selwyn area. In places pre-Cretaceous weathered Proterozoic rocks have been exposed. Weathering and differential erosion from the Late Cretaceous and during the Cainozoic has formed most of the present day landforms and drainage divide. Up-warping of the Selwyn highlands was active in the Late Cainozoic (Twidale, 1966). In places valley floors and sides became cemented by iron and silica. Subsequent erosion has left these very resistant siliceous and ferruginous duricrusts as mesas and plateaux, some of which now form relief inverted landscape elements. These resistant landforms have developed on Proterozoic and Mesozoic and to a lesser extent on Cambrian sediments. Some of the best examples are approximately 4km west of the Selwyn mine and over the southeast corner of the map sheet (Figure 11Q).

Weathering continued during the Tertiary with periods of active and less active formation depending on changing climatic conditions (e.g. humid or arid conditions). Deep weathering and duricrusts developed on exposed stable parts of the landscape. Duricrusts also developed in response to lateral water flow associated with valley floors and valley sides. Silicification of weathering profiles became more common as climatic conditions became more arid from the Late Miocene to the present day.
Landscape evolution in the Selwyn Region

1. Late Jurassic

Proterozoic rocks with marked relief, weathering occurring in valley floors.

2. Early Cretaceous

Highest hills protrude above Mesozoic sea. Mesozoic sediments (conglomerates, sandstone and siltstones) infills valleys within Proterozoic rocks. Local relief is reduced due to valley infilling and bevelling of hills by deposition and erosion.

3. Late Cretaceous

Weathering and erosion of Mesozoic and Proterozoic rocks. Weathering products retained where rate of weathering is greater than rate 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 and Cambrian Proterozoic rocks form Mesas and resistant rises and hills. Relief inversion occur on some of the indurated surfaces. Colluvium develops down slope from adjacent hills. Alluvial sediments accumulates in floodplains, alluvial plains and sheetwash plains. Valley widening and pediment development takes place.

5. Present Day

Fe duricrust
Pediments and colluvial plains
Sillified saprolite
Weathering of exposed bedrock
Bleached and silicified saprolite
Bleached saprolite
Colluvial sediments

Mesoic sediments infilling valley
Cambrian sediments
Colluvium and alluvium
Duricrust/indurated Fe-saprolite/silcrete
Weathering

Figure 16. Stages of regolith-landform evolution over the Selwyn region of the Mt Isa Inlier.
10. DISCUSSION AND IMPLICATIONS FOR MINERAL EXPLORATION

The Selwyn region has a highly variable regolith cover which reflects weathering processes from the Jurassic to the present day and variable degrees of erosion and exhumation. 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. Different regolith materials will require different approaches when sampling and interpreting surface and drill hole geochemistry. 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.

10.1 Geochemical sampling strategy map

To provide a direct tool for the interpretation of surface geochemistry and drilling, regolith-landform units have been classified 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

```
Duricrusts and Saprolite
  Major bedrock type
  Proterozoic and Post-Proterozoic

  Duricrust - Fe and Si
  Saprolite
    Bleached - ferruginous
  Saprolite covered by lags and thin residual soils

Transported
  Alluvial sediments
  Colluvial sediments
    old silicified - recent
    Thin (< 1.5 m) - thick (> 1.5m)
```

Figure 17. 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 regolith
derived from these rocks 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 an 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.

Several major regolith-landform associations which are highlighted on the sampling strategy map should be considered carefully when interpreting surface and drill hole geochemistry. These associations are described below.

10.2 Weathering profiles on Proterozoic bedrock with or without thin cover

Regolith materials in this category include a range of materials from relatively unweathered saprock to highly weathered zoned profiles which are often capped with either ferruginous or siliceous duricrusts. Areas of saprock correspond to actively eroding parts of the landscape. Soil/rock geochemical sampling is recommended in this type of terrain. Ferruginous and siliceous materials require more careful and selective sampling. Massive and brecciated ferruginous duricrusts develope 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 iron oxides and associated metals. Slabby duricrust probably once developed along valley sides or in topographic lows where groundwaters precipitated Fe oxides. Therefore, slabby duricrusts can be sampled to give broad geochemical indications. In siliceous landscapes mottling and ferruginous granules derived from the weathering of the silcretes can be used as an indicator of geochemistry at depth. Silcretes, however, should be interpreted independently from ferruginous duricrusts since they invariably show much lower metal concentrations.

Some of the most deeply weathered bedrock is associated with palaeochannels and exhumed landscapes. Metal concentrations within leached kaolinitised bedrock associated with these features are anomalously low compared with the surrounding saprock.

10.3 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. Sampling of these duricrusts are unlikely to directly relate to mineralisation at depth. The use of ferruginous duricrusts as sample media requires an appropriate orientation study. However, re-worked Proterozoic bedrock and metals precipitated from groundwaters in the sediments may provide regional dispersion indicators. Since Mesozoic sediments largely infilled old valleys, anomalies in the sediments may relate to mineralisation higher up in the palaeochannel.

10.4 Saprolite covered by colluvial and alluvial deposits

Colluvial deposits consisting mainly of sheetwash sands, clays and gravels are best developed over low relief areas of the Selwyn study area. Sampling of ferruginous materials including lithic fragments, pisoliths and nodules can be useful in reconnaissance geochemical interpretations. Alluvial sediments consisting of clays, sands and conglomerates form relatively narrow floodplains associated with sandy Creek. Mort River, Mistake Creek and Limestone Creek. Rotary air blast (RAB) and stratigraphic drilling is recommended to sample and characterise saprolitic materials beneath the sediments. Sediments can be used to give reconnaissance stream sediments geochemical indicators.
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12. REFERENCES


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 in 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.

Shallow soil on fresh bedrock or lithosols
In some areas, particularly on steep slopes, or on young surfaces, the regolith consists of soil material up to 2 m thick formed directly on the underlying bedrock. Commonly the soil has a skeletal profile, and is less than 1 m thick.

Slabby Fe duricrust
Duricrust which is has a partly layered or slabby appearance
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 graney 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.

Stratigraphic ironstones
In situ weathering products of Fe-rich lithologies

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. Corestones, 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 conglomerates 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.

**Escarment**
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 unidirectional 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.

**Pedicent**
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

Regolith point attributes

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

S1
449981 7603040
Quartz gravel lag and residual red clay (30-40cm) over highly weathered structural saprolite (schist). Landform: Rises (9-30m relief).

S2
451884 7603073
Silicified saprolite (Proterozoic sandstone schist) over mottled bedrock. Landform: Plateau.

S3
451634 7602207
Red clay soils, quartz gravel and ferruginous lithic (40cm) lag over highly weathered saprolite. The saprolite is kaolinised and weakly mottled. Landform: Erosional plains (<9m relief)

S4
452407 7601194
Channel and over bank sediments consisting of sand, silt and clay with lenses of conglomerate. Conglomerate consists of quartz and silicified saprolite and minor Fe nodules in sandy matrix. Landform: Flood plain

S5
453684 7596701
Veneer of sheet wash sand and clays over ferruginous structural saprolite. Gravel lags common. Erosional plain (<9m relief).

S6
453723 7590402
Ferruginous and partly indurated granitic saprolite over mottled bedrock. Forms: local rises and mesas.

S7
455422 7586339
Slabby Fe duricrust and silicified conglomerate over Proterozoic schists and sandstone. The conglomerate is silicified and silicification extends into the Proterozoic basement. Landform: rise

S8
456443 7583571
Ferruginous saprolite over mottled bedrock. Forms local rises surrounded by gravelly pediments. Landform: rises (9-30 metres relief).

S9
458278 7588302
Conglomeritic sandstone (mainly quartz pebbles rounded to sub angular with Fe Oxide staining throughout. Sandstone exhibits reddish orange mottling and is silicified in places (Mesozoic sediments) Landform: low hills and rises.
S10
459221  7589000
Partially silicified sandstone with basal conglomerate over very highly weathered granite (kaolinised, with diffuse reddish orange mottling) Bedrock: granite/Mesozoic sst. Landform: Low hills, plateau top.

S11
459091  7589705
Silicified Mesozoic sandstone over very highly weathered granite. Minerals within the granite have been altered and partially kaolinised with diffuse reddish orange mottling. Bedrock: granite/Mesozoic. Landform: low hills

S12
463415  7596753
Fe duricrust cementing channel sands and gravels forming capping to highly weathered granite. Landform: Plateaux.

S13
463911  7596415
Fe duricrust over highly weathered granite. The granite is strongly bleached (kaolinised) and partially silicified in places. The ironstone exhibits an elongated tubular fabric, mottles infilled with gritty sand and cemented by Fe. Landform mesa. Bedrock granite

S14
461919  7597072
Fe duricrust over ferruginous mottled saprolite. Landform: low hills, ridge.

S15
459762  7591730
Alluvial channel and over bank sediments (5m) consisting of gravel and clay. In places partially indurated by clay and Fe. Landform: Flood plain.

S16
461561  7590893
Slightly weathered granite forming tors. Exfoliated boulders with thin weathering lines. Landform: Rises.

S17
464648  7589911
Partially silicified granite over very highly weathered granite where most minerals have been altered to clay and Fe Oxides. Landform: Low hills.

S18
453310  7585341
Ferruginised structural saprolite surrounded by ferruginous gravel, lithic and sand lags. Landform: Local rise.

S19
445376  7600782
Reddish brown clays over highly weathered saprolite. Carbonate nodules occur within the soil profile and ferruginous lithic lags occur at the surface (derived form haematitic ridges upslope). Landform: footslope

S20
445121  7600709
Ironstone (haematite) forming strike ridges with locally developed Fe scree slopes and footslopes. Landform: Low hills.
Highly weathered and mottled schist covered in most places by a veneer of residual red clay and ferruginous, lithic and quartz lags. Landform: Erosional plain.

Sheet wash (10-30cm) and gravel lags (mostly quartz) over granitic saprolite. Landform: Erosional plain.

Gravel lags and red clay over saprolite (schist, quartzite). Landform: Rise.

Ferruginous earthy soil over highly weathered schist. Landform: Low hills.

Highly ferruginous saprolite with a collapsed brecciated fabric over mottled saprolite. Landform: Hill.

Fe rich gravel lags (amphibolite), residual red clay over saprolite. Patchy outcrop. Swelling cracking clays with Fe nodules. Landform: Erosional plain.

Ferruginous lithic fragments (siltstone, sandstone) forming gravel lags and swelling calcareous clays. Landform: Erosional plain adjacent to low hills.


Silicified siltstone over highly weathered mottled saprolite forming local mesas. Landform: Low hills, plateaux.

Ferruginous Fe and Quartz lags, red earthy and mottled clays with Fe nodules. Landform: Rises.

Red sandy earths with quartz and lithic (sandstone lags) over ferruginous saprolite. Local channel alluvium. Landform: Rises.

Red earths (40cm) with quartz and lithic (sandstone lags) over ferruginous saprolite. Soils contain scattered Fe nodules. Bedrock: schist/amphibolite? Local channel alluvium. Landform: Rises.

Ferruginous structured saprolite partially covered by lithosols. Landform: Rises.

Alluvial clay (1m) and silt over highly weathered saprolite. Adjacent areas: bedrock outcrops surrounded by sheetwash gravel lags. Landform: Flood plain.

Weathered Cambrian calcareous siltstone with vuggy textures. Partly buried by red sandy clays and quartz gravel lags. Landform: rises.

Red clay soils and gravel lags consisting of quartz, lithic fragments, Fe nodules and pisolites (<1m) over saprolite. Landform: Rises.


Highly weathered saprolite with ferruginous gravelly soils grading into mottled saprolite at depth. Minor Fe duricrust. Landform: Bevelled hills.

Ferruginous clays and gravels infilling cracks and mottles in highly weathered shales. Landform: Bevelled hills and ridges.

Very highly weathered granite consisting mainly of kaolinite and Fe Oxides. In places silicified. Landform: Mesas.

Ferruginous saprolite with cemented gravels and clay infilling cracks and mottles, lithosols. Landform: Hills, ridges.

Ferruginous colluvial gravels and clay over highly weathered saprolite. Landform: Footslope.

S45
448271    7614489
Silicified sandstone and quartz gravels with reddish orange mottling over brecciated and mottled schist. Landform: Plateau top.

S46
448299    7614567

S47
448541    7614766
Fe duricrust developed on sediments (minor quartz gravels) with reddish orange mottling over bleached Proterozoic bedrock. Landform: Plateau surface.

S48
448733    7614662
Ferruginous mottled and in places silicified sediments overlying schist. Mesa edge.

S49
448715    7614408
Mesozoic sandstone and conglomerates with fragments of Proterozoic bedrock. Mesa.

S50
445304    7610932
Gritty quartz lags. Residual red clays over very highly weathered saprolite with carbonate veins and fragments. Erosional plain.

S51
47423     7618591
Ferruginous saprolite over mottled saprolite forming local bluffs and mesas. Secondary silicification in places.

S52
450303    7618128
Silcrete breccia and silicified saprolite (Mesozoic sandstone and siltstone) over mottle bedrock. Fe staining throughout. At the surface old silicified mega mottles are in filled with sand. Landform erosional scarp. Bedrock Mesozoic sandstone.

S53
450528    7617986
Massive iron stone and highly ferruginous saprolite over mottled (reddish orange)saprolite (Mesozoic interbedded sandstone). Mega mottled textures at surface. Landform: mesa.

S54
450523    7618262
1-1.5 metres of red clay and gravel alluvium over mottled sandstone (Mesozoic) Gravels include ferruginous and siliceous lithic fragments and Fe nodules. Landform: alluvial Flood plain.

S55
450615    7618443
Silcrete, sand, clay and Fe nodules cemented by silica over silicified saprolite (Mesozoic sandstone) Fe staining and diffuse mottling throughout. Landform: mesa.

S56
450317    7618587
Silicified sandstone (Mesozoic) and Si breccia (.5-1.5 metres) forming indurated capping to mesa.
S57  
449686         7618307  
Ferruginous saprolite developed on Proterozoic schist. Landform: low hill - rise.

S58  
447429         7621222  
Ferruginous and partly silicified sandstone and conglomerate (Mesozoic) over mottled (large reddish orange) and bleached (in places silicified) Proterozoic saprolite (schist and siltstone). Landform: Mesa. Bedrock Mesozoic sandstone.

S59  
447856         7621557  
Silicified, mottled and ferruginous saprolite (Mesozoic) over highly weathered diffusely mottled granitic saprolite (upper part silicified). Landform: mesa.

S60  
447533         7619939  
Highly ferruginous brecciated saprolite (lithic fragments in a earth red matrix) over ferruginous and mottled (diffuse reddish orange)saprolite. Landform: local bluff.

S61  
447137         7620446  
Highly ferruginous brecciated saprolite (lithic fragments in a earth red matrix) over ferruginous and mottled (diffuse reddish orange)saprolite. Landform: mesa.

S62  
447173         7620325  
Red clay earth with a well developed ferruginous lithic lag (1 meter) over saprolite. Landform erosional plain.

S63  
447069         7620316  
Red clay earth - mantled by a quartz gravel lag (30cm)over saprolite. Landform erosional plain.

S64  
455575         7597666  
Slabby iron duricrust over diffusely mottled and bleached saprolite (schist). Ferruginous and Fe nodules form a thin lag over the surface. Landform: mesa.

S65  
456235         7601174  
Massive iron duricrust and mottled saprolite over bleached saprolite (schist). Landform: mesa.

S66  
453645         7601150  
Sheetwash sands and minor quartz lags and clay. Typically less than 1 meter deep. Landform: erosional plain - sheet flood plain.

S67  
441474         7597793  
Red earthy clays - mantled by quartz gravel lags over highly weathered saprolite (schist). Landform: erosional plain.

S68  
441207         7595801  
Silicified quartz gravels (Mesozoic ?) over silicified ferruginous and mottled granitic saprolite. Landform: mesa.
Silicified conglomerate, sandstone and silcrete over silicified and mottled granitic saprolite. Palaeo-channel, inverted relief?. Landform: mesa.

Ironstone and quartzite ridge protruding from erosional plain. Surrounding plains are mantled by a veneer of quartz and ferruginous lithic lag over red silty loam and highly weathered saprolite. Landform ridges and hills.

Ferruginous saprolite in places silicified over structured saprolite with diffuse reddish orange mottling. Landform: mesa.

Red clay earths and silty earths. Patchy sheet wash colluvium and quartz lags. Landform erosional plains.

Silicified quartz pebble conglomerate (Mesozoic) with Fe staining throughout. Landform: rise.

Red earthy clay soils developed on alluvial clay, sand and gravel beds (3 metres). Landform: flood plain.

Brown swelling-cracking clays, minor gritty lag consisting mainly of quartz, ferruginous nodules and fragments. Landform erosional plain.

Reddish orange clay (non-cracking) with gritty sands and minor quartz gravel lags. Landform; erosional plains.

Silicified saprolite (mudstone with chert beds) in places covered with a veneer of fine grained silcrete and ferruginous gravels. Landform: rises.

Silicified alluvial sands and gravels over mottled saprolite (siltstone). Thin gravel lags consists of silcrete and ferruginous lithic fragments. Landform: erosional plain.

S80
430013  7585999
Silicified claystone with Fe staining. Lags consists of siliceous lithic fragments, buckshot gravels and minor quartz gravels in and red sandy matrix. Landform: erosional plain.

S81
430004  7585265

S82
430732  7583145
Silicified and ferruginous sandstone (Mesozoic). Silcrete and ferruginous lithic lags. In places silcrete forms massive blocky outcrops. Landform: rises with stepped topography

S83
423635  7590985

S84
424246  7591375
Silicified and mottled sandstone grading into mottled (soft) saprolite. Silcrete and ferruginous lithic lags. Well rounded as scattered float. Landform: erosional scarp.

S85
448535  7605102
Ferruginous saprolite in places silicified (granite) forming rocky bluffs and bevelled hill tops. Landform: hills.

S86
444138  7608806
Ferruginous and mottled saprolite (granite). Landform: mesa.

S87
444968  7609128
Highly ferruginous red clays mantled with a veneer of ferruginous lithic lag. Ferruginous saprolite outcrops in places. Landform: rises.

S88
446184  7617554
Highly ferruginous saprolite (schist and meta sandstones) forming bluffs. Minor Fe duricrust. Landform: rises and low hills.

S89
445900  7617073
Ferruginous saprolite (2 metres) with diffuse reddish orange mottling at depth over bleached (soft) kaolinised saprolite (3 + metres) (bedrock; schist) Landform: low hills.

S90
430186  7621337
Ferruginous and silicified Mesozoic sandstone and conglomerate over ferruginous and mottled saprolite (schist) Landform: mesa.

S91
431832  7617665
Red residual earthy clay mantled by a veneers of ferruginous lithic and quartz lag. Exposed ferruginous saprolite (amphibolite) in places. Landform: erosional plain.
S92
431759  7617054
Alluvial sediments consisting clay, sand and interbedded gravels. Landform: flood plain.

S93
432977  7618753

S94
434257  7618820
approx 2 metres of alluvial clay with conglomeratic beds. Landform: flood plain.

S95
438982  7618481
Channel conglomerate (1.5 metres) over very highly weathered saprolite (Phyllite). Landform: river channel.

S96
441443  7618165
Quartz, ferruginous saprolite and lithic lags over ferruginous saprolite (silt and siltstone). Landform: pediments and erosional plains.

S97
445289  7620054
Ferruginous saprolite and lithic gravel lag and lithosols over very highly weathered and mottled saprolite. Landform: rises.

S98
452182  7619118
Silicified and ferruginous over mottled granitic saprolite. Minor Fe duricrust. Fe segregation's developing in the mottles. Landform: mesa.

S99
451557  7618781
Ferruginous sandstone (Mesozoic) over very highly weathered (kaolinised) granitic saprolite. Landform: mesa.

S100
438429  7603363
Highly ferruginous and in places silicified saprolite forming indurated capping (duricrust). Bedrock Proterozoic schist, sandstone and phyllite. Landform: Mesa

S101
430284  7604324
Lithic and quartz lags in earthy red matrix over saprolite (Phyllite). Patchy outcrop in places. Landform: erosional plain.

S102
429944  7601287
Gravel lags (quartz gravels and ferruginous lithic fragments) and residual red ferruginous clay over highly weathered saprolite (amphibolite). Landform: erosional plain.

S103
429383  7597029
Residual red clay and minor alluvial clays and sands. In places veneers of quartz and ferruginous lags over highly weathered saprolite. Landform: erosional plains and pediments.
Several metres of alluvial sand and clay over mottled saprolite. Landform: Flood plain.

Ferruginous red clay (30-60cm) over saprolite (silicified sandstone). Surface quartz and lithic lag with minor buckshot gravels. Landform: erosional plain and rises.

Silicified and ferruginous saprolite over mottled saprolite (Cambrian: sandstone, siltstone and claystone)-forming indurated capping. Landform: rise.

Cracking clay - reddish orange with a veneer of siliceous and ferruginous gravel lags. Landform: erosional plain

Massive Fe duricrust over mottled saprolite (schist, sandstone and quartzite). Fe duricrust commonly silicified. Landform: bevelled hill top.

Fe duricrust (partly silicified) over mottled and bleached saprolite (schist, sandstone, quartz veining). Landform: bevelled hill top.

Silicified structural saprolite. Bedrock; Proterozoic schist. Landform: mesa

Very highly weathered ferruginous, mottled and in places silicified granitic saprolite. Bedrock; granite. Landform: mesa.

Coarse gritty quartz sands containing feldspathic and micaceous grains over highly weathered granitic and mottled granitic saprolite. Sands are largely locally derived. Bedrock; granite. Landform: erosional plains.

Silicified sandstone and conglomerate (Mesozoic) over bleached (upper part silicified) Proterozoic saprolite (schist and sandstone). Landform: rise.

White Mesozoic siltstone with diffuse Fe staining surrounded by gravel lags and sheet wash sands. Landform: rises.

Moderately weathered Fe saprolite (schist) covered in part by lithosols and sandy pockets. Landform: rise
S117
455662 7597623
Silicified and mottled saprolite below slabby Fe duricrust. Landform: low hills.

S118
455584 7597748
Highly weathered partly mottled and silicified saprolite (schist). Landform: low hills.

S119
455578 7597721
Completely weathered Fe cemented duricrust. Slabby Fe duricrust forming resistant capping over mottled and silicified saprolite (schist). Fe segregations. Landform: mesa.

S120
455498 7597671
Bleached and partly silicified schist. Landform: low hills.

S121
455284 7597914
Bleached and partly silicified schist. Landform: low hills.

S122
455055 7598160
Fe saprolite, non bleached schist. Landform: low hills.

S123
455193 7596028
Very highly weathered, mottled and silicified saprolite (granite) Fe segregations developing in mottled zone. In places silicified and Fe stained sst and claststone (Mesozoic ?) overly granitic saprolite. Landform: mesa edge.

S124
454933 7595442
Silicified, bleached and Fe stained saprolite froming resistant capping. Landform: mesa.

S125
454873 7595442
Fe stained and diffusely mottled saprolite (non silicified). Landform: mesa edge.

S126
441902 7590590
Ferruginous sandstone (Mesozoic). X-bedded conglomeratic sst with numerous quartz gravels forming lags surrounding outcrop Landform: local rise (9-30m relief)

S127
440575 7589080
Quartz gravels cemented by Fe unconformable over highly cleaved schist. Landform: mesa.

S128
440603 7589796

S129
440736 7590137
Fe rich conglomerate and sst in places silicified forming a erosional scarp edge to mottled and silicified schist. Fe segregation in mottled zone. Landform: mesa. Bedrock: Mesozoic/Proterozoic.

Slabby Fe duricrust and silicified conglomerate over diffusely mottled schists and sandstone. Silicification extends into the Proterozoic basement. Landform rise. Bedrock Proterozoic.

Massive Fe duricrust, slabby in places and containing quartz grit over mottled and bleached saprolite. Appears to be insitu. Landform: mesa. Bedrock: granite.

Highly bleached and in places silicified saprolite, approx 80 metres below scarp edge. approx 50% of primary minerals altered to clays, fe oxides and secondary silica. Bedrock granite. Landform: Low hills.

Silicified Mesozoic siltstone over very highly weathered and mottled granitic saprolite with grades into moderately to slightly weathered granite at depth. Landform Mesa. Bedrock Mesozoic/Proterozoic.

Polyminic gravel lags (ferruginous saprolite, lithic fragments, quartz, buckshot gravels) and course textured soils over highly weathered and mottled schist. Sheet wash colluvium several metres thick in places. Landform: erosional plain/pediments. Bedrock; Proterozoic schist.

Fe duricrust and Fe segregation in the mottled zone developed in sandstone with minor quartz pebbles. Landform; mesa/low flat topped hill. Bedrock Mesozoic sst and siltstone.

Ferruginous sandstone and claystone containing numerous quartz gravels over intensely weathered highly ferruginous saprolite. Fe segregation developing within the mottled zone. Landform; Low Hill. Bedrock Mesozoic over Proterozoic.

Ferruginous saprolite with well developed Fe segregation developing within the mottled zone. Saprolite between Fe segregation largely weathered to clay (kaolinite?). Landform mesa local bluff


Ferruginous breccia with Fe segregation over mega mottled saprolite over ferruginous diffusely mottled moderately weathered saprolite. Weathering profile approx 40 metres to moderately weathered saprolite. Landform: mesa - bluff. Bedrock: Proterozoic sediments.
Silicified sandstone and quartz gravels with reddish orange mottling over brecciated, mottled and highly bleached schist. Landform Plateau top. Bedrock: Proterozoic schist
APPENDIX 3

Polygon unit description summary.

**Regolith-landform Unit**

<table>
<thead>
<tr>
<th></th>
<th>DFIs1</th>
<th>DFIs2</th>
<th>DFIs3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regolith;</td>
<td>Massive &amp; collapsed ferruginous saprolite over mottled and bleached</td>
<td>Massive blocky Fe duricrust over ferruginous and mottled saprolite.</td>
<td>Massive and in places slabby Fe duricrust over ferruginous, mottled</td>
</tr>
<tr>
<td>Profile desc</td>
<td>ferruginous saprolite over mottled and bleached saprolite. Minor slabby duricrust</td>
<td>Duricrust is associated with massive stratigraphic hematitic beds.</td>
<td>and bleached saprolite. Bleached zone typically &gt; 20m thick</td>
</tr>
<tr>
<td>Soil &amp; lags</td>
<td>Lithosols, lags of lithic fragments, Fe duricrust gravels and pisoliths.</td>
<td>Lithosols; lags of ferruginous lithic gravels, fragments of Fe duricrust and pisoliths.</td>
<td>Lithosols, lags of ferruginous lithic gravels, fragments of Fe duricrust, pisoliths &amp; gritty sands.</td>
</tr>
<tr>
<td>Landforms</td>
<td>Plateaux, mesas &amp; buttes</td>
<td>Flat top hills, minor plateaux</td>
<td>Plateaux, mesas &amp; buttes</td>
</tr>
<tr>
<td>Bedrock lithology</td>
<td>Proterozoic; meta-siltstone, meta-arenite, gneiss, schist, phyllite and quartzite.</td>
<td>Proterozoic; meta-siltstone, meta-arenite, gneiss, schist, phyllite and quartzite.</td>
<td>Proterozoic; foliated and non-foliated biotite granite, hornblende-biotite granite, tonalite and granodiorite.</td>
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### Regolith-Landform Unit

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<tr>
<th>Regolith; Profile desc</th>
<th>DSls1</th>
<th>DFls4</th>
<th>DFls5</th>
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<tbody>
<tr>
<td>Soil &amp; lags</td>
<td>Lithosols, lags of silicified and ferruginous saprolite.</td>
<td>Lithosols, lags of Fe duricrust fragments, lithic and siliceous gravels.</td>
<td>Lithosols, lags of Ferruginous saprolite, lithic and siliceous gravels.</td>
</tr>
<tr>
<td>Landforms</td>
<td>Plateaux, mesas &amp; buttes</td>
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<td>Plateaux, mesas &amp; buttes</td>
</tr>
<tr>
<td>Bedrock lithology</td>
<td>Proterozoic; foliated and non-foliated biotite granite, hornblende-biotite granite, tonalite and granodiorite.</td>
<td>Mesozoic sediments; sandstone, siltstone, mudstone &amp; conglomerate</td>
<td>Mesozoic sediments; sandstone, siltstone, mudstone &amp; conglomerate</td>
</tr>
<tr>
<td>Regolith Induration</td>
<td>Silcrete &amp; silicified saprolite (bleached zone) Minor Fe duricrust.</td>
<td>Massive Fe duricrust, silicified saprolite and minor silcrete.</td>
<td>Minor Massive Fe duricrust, ferruginous and in places siliceous saprolite. Minor silcrete</td>
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<table>
<thead>
<tr>
<th>Regolith; Profile desc</th>
<th>DSls2</th>
<th>Sls1</th>
<th>Sel2</th>
</tr>
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<tbody>
<tr>
<td>Soil &amp; lags</td>
<td>Lithosols, lags of lithic fragments, silicified and ferruginous saprolite fragments</td>
<td>Lithosols; lags of silicified saprolite, minor fragments of Fe duricrust.</td>
<td>Lithosols consisting of ferruginous/bleached lithic fragments, gravels and minor Fe duricrust nodules and pisoliths.</td>
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<tr>
<td>Landforms</td>
<td>Plateaux, mesas &amp; buttes</td>
<td>Low hills, mesas, plateaux and dissected plateaux.</td>
<td>Low hills, minor scarps and rises.</td>
</tr>
<tr>
<td>Bedrock lithology</td>
<td>Cambrian; siltstone, sandstone, limestone, chert. silicified shale and dolomite.</td>
<td>Proterozoic; meta-siltstone, meta-arenite, gneiss, schist, phyllite and quartzite.</td>
<td>Proterozoic; meta-siltstone. meta-arenite. gneiss, schist, phyllite and quartzite.</td>
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<tr>
<td>Regolith Induration</td>
<td>Silicified saprolite</td>
<td>Silicified saprolite, minor Fe duricrust gravels.</td>
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<td>Regolith-landform Unit</td>
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<td><strong>Sep 3</strong></td>
<td><strong>Sep 4</strong></td>
<td><strong>Sep 5</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Regolith; Profile desc</strong></td>
<td>Ferruginous and mottled saprolite. Mottled zone overlies bleached saprolite. Partly covered by</td>
<td>Mottled saprolite partly covered by lithosols and lags. Upper part of the profile typically highly ferruginous.</td>
<td>Highly weathered mottled saprolite covered by extensive veneers of residual soils and lags. Minor alluvium along stream channels.</td>
</tr>
<tr>
<td><strong>Soil &amp; lags</strong></td>
<td>Lags of ferruginous and silicified saprolite, quartz and lithic fragments. In places lags overlie bleached saprolite.</td>
<td>Thin soils and lags of highly ferruginous saprolite fragments and lithic gravels.</td>
<td>Residual clay/gravelly soils and lags of ferruginous saprolite, quartz, lithic fragments and minor Fe pisoliths and ferruginous gravels.</td>
</tr>
<tr>
<td><strong>Landforms</strong></td>
<td>Erosional plains.</td>
<td>Highly dissected erosional plain (&lt; 9m relief).</td>
<td>Erosional plain (&lt; 9m relief).</td>
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<td><strong>Bedrock lithology</strong></td>
<td>Proterozoic; meta-siltstone, meta-arenite, gneiss, schist, phyllite and quartzite.</td>
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<td><strong>Regolith Induration</strong></td>
<td>Silicified and ferruginous saprolite</td>
<td>Ferruginous saprolite</td>
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<th><strong>Sep 6</strong></th>
<th><strong>Ser 7</strong></th>
<th><strong>Sel 8</strong></th>
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<tbody>
<tr>
<td><strong>Regolith; Profile desc</strong></td>
<td>Ferruginous and diffusely mottled saprolite. Colluvial gravels are associated with fans and aprons flanking steeper slopes. Minor river sediment.</td>
<td>Saplroline partly covered gravelly soils and lags.</td>
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<tr>
<td><strong>Soil &amp; lags</strong></td>
<td>Polymictic gravel lags (generally &lt; 1.0 metres thick) of ferruginous lithic and saprolite fragments, minor quartz, Fe pisoliths and ferruginous gravels.</td>
<td>Lithosols and lags of ferruginous lithic fragments and quartz. Gravelly red silt/clay soils.</td>
</tr>
<tr>
<td><strong>Landforms</strong></td>
<td>Erosional plains and minor pediments</td>
<td>Rises (9-30m relief).</td>
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<tr>
<td><strong>Bedrock lithology</strong></td>
<td>Proterozoic; meta-siltstone, meta-arenite, gneiss, schist, phyllite and quartzite.</td>
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</tbody>
</table>
## Regolith-landform Unit

<table>
<thead>
<tr>
<th>Seh9</th>
<th>See10</th>
<th>Sel11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regolith; Profile desc</strong></td>
<td>Saprock</td>
<td>Saprock. Weathering is variable ranging from highly weathered bleached and silicified bedrock to slightly weathered bedrock.</td>
</tr>
<tr>
<td><strong>Soil &amp; lags</strong></td>
<td>Saprolite partly covered by lithosols and colluvium flanking steep hill slopes.</td>
<td>Saprock partly covered by scree and lithosols.</td>
</tr>
<tr>
<td><strong>Landforms</strong></td>
<td>Hills (90-120m relief)</td>
<td>Escarpment</td>
</tr>
<tr>
<td><strong>Bedrock lithology</strong></td>
<td>Proterozoic; meta-siltstone, meta-arenite, gneiss, schist, phyllite and quartzite.</td>
<td>Proterozoic; meta-siltstone, meta-arenite, gneiss, schist, phyllite and quartzite.</td>
</tr>
<tr>
<td><strong>Regolith Induration</strong></td>
<td>nil</td>
<td>In places silicified saprolite</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ser12</th>
<th>Sel13</th>
<th>Sls14</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regolith; Profile desc</strong></td>
<td>Highly ferruginous and diffusely mottled saprolite. Locally developed Fe duricrusts and Fe segregations.</td>
<td>Highly ferruginous bedrock associated with stratigraphic hematitic beds.</td>
</tr>
<tr>
<td><strong>Soil &amp; lags</strong></td>
<td>Saprolite partly covered by highly ferruginous lithic gravel lags and reddish orange clays/fine sands.</td>
<td>Saprolite partly covered by ferruginous gravel lags, beds lithosols and pockets of red clay soil over massive diffusely mottled hematitic bedrock.</td>
</tr>
<tr>
<td><strong>Landforms</strong></td>
<td>Rises, minor low hills (30-90m relief).</td>
<td>Low hills (30-90m relief) and ironstone ridges</td>
</tr>
<tr>
<td><strong>Bedrock lithology</strong></td>
<td>Proterozoic; meta-siltstone, meta-arenite, gneiss, schist, phyllite and quartzite.</td>
<td>Proterozoic; Quartz-hematite beds</td>
</tr>
<tr>
<td><strong>Regolith Induration</strong></td>
<td>Minor Fe duricrust and segregations</td>
<td>Ferruginous saprolite</td>
</tr>
</tbody>
</table>
### Regolith-landform Unit

<table>
<thead>
<tr>
<th>Regolith; Profile desc</th>
<th>Sel15</th>
<th>Ser16</th>
<th>Sep17</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soil &amp; lags</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferruginous saprolite and mottled saprolite over bleached bedrock. Most feldspars and micas weathered to clays and Fe oxides.</td>
<td>Lithosols and gravel lags over saprolite.</td>
<td>Ferruginous and mottled saprolite over bleached saprolite. Most of the soluble minerals in the upper part of the profile have weathered to clays (kaolinite) and Fe oxides.</td>
<td>Bleached granitic saprolite.</td>
</tr>
<tr>
<td><strong>Landforms</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low hills (30-90m relief) and minor scars</td>
<td>Rises and mesas (9-30 metres relief).</td>
<td>Erosional plains (&lt; 9m relief).</td>
<td></td>
</tr>
<tr>
<td><strong>Bedrock lithology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proterozoic; foliated and non-foliated biotite granite, hornblende-biotite granite, tonalite and granodiorite.</td>
<td>Proterozoic; foliated and non-foliated biotite granite, hornblende-biotite granite, tonalite and granodiorite.</td>
<td>Proterozoic; foliated and non-foliated biotite granite, hornblende-biotite granite, tonalite and granodiorite.</td>
<td></td>
</tr>
<tr>
<td><strong>Regolith Induration</strong></td>
<td>Silicification in mottled and upper part of the bleached zone</td>
<td>In places silicified saprolite</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regolith; Profile desc</th>
<th>Sep18</th>
<th>Ser19</th>
<th>Sel20</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soil &amp; lags</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granitic saprolite covered by extensive residual sands and lags. Local river channel alluvium and sheet flow sediment of sand and gravel.</td>
<td>Residual sands (generally &lt; 1.0 m) and gravel lags of mica, quartz and feldspar sands; siliceous &amp; ferruginous and bleached saprolite fragments and minor fragments of Fe duricrust.</td>
<td>Upper part of the profile is ferruginous &amp; diffusely mottled. About half of primary minerals (feldspars and micas) weathered to clays and oxides.</td>
<td></td>
</tr>
<tr>
<td><strong>Landforms</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosional plains (&lt; 9m relief).</td>
<td>Rises (9-30m relief).</td>
<td>Low hills (30-90m relief).</td>
<td></td>
</tr>
<tr>
<td><strong>Bedrock lithology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proterozoic; foliated and non-foliated biotite granite, hornblende-biotite granite, tonalite and granodiorite.</td>
<td>Proterozoic; foliated and non-foliated biotite granite, hornblende-biotite granite, tonalite and granodiorite.</td>
<td>Proterozoic; foliated and non-foliated biotite granite, hornblende-biotite granite, tonalite and granodiorite.</td>
<td></td>
</tr>
<tr>
<td><strong>Regolith Induration</strong></td>
<td>Ferruginous saprolite</td>
<td>Ferruginous saprolite</td>
<td></td>
</tr>
</tbody>
</table>
## Regolith-landform Unit

<table>
<thead>
<tr>
<th>Regolith; Profile desc</th>
<th>Sep21</th>
<th>Sep22</th>
<th>Ser23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil &amp; lags</td>
<td>Saprolite partly covered by scree and lithosols.</td>
<td>Ferruginous saprolite covered by a veneer of residual soils and lags.</td>
<td>Ferruginous and mottled saprolite, in places silicified,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landforms</td>
<td>Escarpment.</td>
<td>Erosional plains (&lt;9m relief).</td>
<td>Rises (9-30m relief).</td>
</tr>
<tr>
<td>Bedrock lithology</td>
<td>Proterozoic; foliated and non-foliated biotite granite, hornblende-biotite granite, tonalite and granodiorite.</td>
<td>Mesozoic sediments; sandstone, siltstone, mudstone &amp; conglomerate</td>
<td>Mesozoic sediments; sandstone, siltstone, mudstone &amp; conglomerate</td>
</tr>
<tr>
<td>Regolith Induration</td>
<td>Minor silicified saprolite</td>
<td>Ferruginous saprolite</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regolith; Profile desc</th>
<th>Sep24</th>
<th>Sel25</th>
<th>See26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil &amp; lags</td>
<td>Ferruginous saprolite covered by residual sand, clay and lags. Saprolite is typically mottled and partly silicified.</td>
<td>Ferruginous and mottled saprolite and saprock. In places the saprolite is bleached and silicified.</td>
<td>Saprock, Fe-stained and diffusely mottled saprolite.</td>
</tr>
<tr>
<td></td>
<td>Lags of ferruginous lithic &amp; Fe duricrust fragments, quartz pebbles and silcrete gravels in a reddish orange sandy to silty soil matrix.</td>
<td>Saprolite partly covered by lithosols.</td>
<td>Saprolite partly covered by scree and lithosols.</td>
</tr>
<tr>
<td>Landforms</td>
<td>Erosional plains (&lt;9m relief).</td>
<td>Low hills (30-90m relief).</td>
<td>Escarpment</td>
</tr>
<tr>
<td>Bedrock lithology</td>
<td>Mesozoic sediments; sandstone, siltstone, mudstone &amp; conglomerate</td>
<td>Mesozoic sediments; sandstone, siltstone, mudstone &amp; conglomerate</td>
<td>Mesozoic sediments; sandstone, siltstone, mudstone &amp; conglomerate</td>
</tr>
<tr>
<td>Regolith Induration</td>
<td>minor silicified saprolite</td>
<td>Ferruginous and silicified saprolite</td>
<td></td>
</tr>
</tbody>
</table>

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### Regolith-landform Unit

<table>
<thead>
<tr>
<th>Sep27</th>
<th>Sep28</th>
<th>Sep29</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regolith; Profile desc</strong></td>
<td>Ferruginous and mottled saprolite.</td>
<td>Mottled and in places ferruginous and silicified saprolite.</td>
</tr>
<tr>
<td><strong>Soil &amp; lags</strong></td>
<td>Saprolite mostly covered by thin lithic gravel lags and lithosols.</td>
<td>Saprolite partly covered by gravelly lithosols.</td>
</tr>
<tr>
<td><strong>Landforms</strong></td>
<td>Erosional plains (&lt; 9m relief) minor pediments.</td>
<td>Low hills (30-90m relief).</td>
</tr>
<tr>
<td><strong>Bedrock lithology</strong></td>
<td>Cambrian; siltstone, sandstone, limestone, chert, silicified shale and dolomite.</td>
<td>Cambrian; siltstone, sandstone, limestone, chert, silicified shale and dolomite.</td>
</tr>
<tr>
<td><strong>Regolith Induration</strong></td>
<td>Ferruginous saprolite</td>
<td>Ferruginous saprolite</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sep30</th>
<th>Sep31</th>
<th>Ser32</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regolith; Profile desc</strong></td>
<td>Mottled saprolite largely covered by residual soils and lags.</td>
<td>Mottled saprolite covered by extensive soils.</td>
</tr>
<tr>
<td><strong>Soil &amp; lags</strong></td>
<td>Soils of pale grey to brown silty clays and calcareous clays with minor calcareous lithic and chert lags.</td>
<td>Soils; hard setting residual dull green to reddish brown clays, swelling gibbary soils and minor gravel lags.</td>
</tr>
<tr>
<td><strong>Landforms</strong></td>
<td>Erosional plains (&lt; 9m relief).</td>
<td>Erosional plains (&lt; 9m relief).</td>
</tr>
<tr>
<td><strong>Bedrock lithology</strong></td>
<td>Cambrian; siltstone, sandstone, limestone, chert, silicified shale and dolomite.</td>
<td>Cambrian; siltstone, sandstone, limestone, chert, silicified shale and dolomite.</td>
</tr>
<tr>
<td><strong>Regolith Induration</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Regolith-landform Unit

<table>
<thead>
<tr>
<th>See33</th>
<th>ACaf</th>
<th>AOao</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regolith; Profile desc</td>
<td>The upper part of the weathering profile typically ferruginous, mottled.</td>
<td>Recent alluvium consisting of interbedded gravel, sand and clay with local lenses of unconsolidated cobble conglomerate.</td>
</tr>
<tr>
<td>Soil &amp; lags</td>
<td>Saprolite partly covered by lithosols.</td>
<td>Soils are reddish brown and grey sandy earths.</td>
</tr>
<tr>
<td>Landforms</td>
<td>Escarpment</td>
<td>Flood plains, channel floors.</td>
</tr>
<tr>
<td>Bedrock lithology</td>
<td>Cambrian; siltstone, sandstone, limestone, chert, silicified shale and dolomite.</td>
<td>unknown</td>
</tr>
<tr>
<td>Regolith Induration</td>
<td>Ferruginous saprolite</td>
<td>In places partly cemented by clay, Fe or silica to form hardpans.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AAol</th>
<th>Aaf</th>
<th>CHpd1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regolith; Profile desc</td>
<td>Alluvial terrace sediments consisting of interbedded sand, clay and gravel. In places truncated palaeosols indicate several cycles of deposition, erosion and weathering.</td>
<td>Undifferentiated alluvial channel and overbank sediments consisting of various proportions of clay, sand and gravel. Typically intermixed with minor colluvial footslope deposits adjacent to scarps, low hills and hills.</td>
</tr>
<tr>
<td>Soil &amp; lags</td>
<td>Mottled reddish brown earths and duplex soils.</td>
<td></td>
</tr>
<tr>
<td>Landforms</td>
<td>Alluvial terraces</td>
<td>Flood plains.</td>
</tr>
<tr>
<td>Bedrock lithology</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td>Regolith Induration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regolith-landform Unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Regolith; Profile desc</strong></td>
<td><strong>Sheet flow &amp; residual deposits consisting of various proportions of clay, sand &amp; gravel. Local cracking clay soils. Typically &lt; 1.5m thick &amp; overlie very highly weathered &amp; mottled saprolite. Minor alluvium.</strong></td>
<td><strong>Sheet flow colluvial and minor alluvial deposits forming a veneer (generally &lt; 1m thick) of sand, clay and gravel over mottled and typically bleached saprolite.</strong></td>
</tr>
<tr>
<td><strong>Soil &amp; lags</strong></td>
<td><strong>Extensive lags consist of ferruginous saprolite, lithic fragments and quartz with minor Fe duricrust fragments and Fe pisoliths.</strong></td>
<td><strong>Gravelly lags are common and consist of ferruginous saprolite, quartz and lithic fragments.</strong></td>
</tr>
<tr>
<td><strong>Landforms</strong></td>
<td><strong>Depositional/erosional plains</strong></td>
<td><strong>Pediments</strong></td>
</tr>
<tr>
<td><strong>Bedrock lithology</strong></td>
<td><strong>unknown</strong></td>
<td><strong>likely to be mainly metamorphic bedrock</strong></td>
</tr>
<tr>
<td><strong>Regolith Induration</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regolith; Profile desc</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regolith; Profile desc</strong></td>
</tr>
<tr>
<td><strong>Soil &amp; lags</strong></td>
</tr>
<tr>
<td><strong>Landforms</strong></td>
</tr>
<tr>
<td><strong>Bedrock lithology</strong></td>
</tr>
<tr>
<td><strong>Regolith Induration</strong></td>
</tr>
</tbody>
</table>
**Regolith-landform Unit**

<table>
<thead>
<tr>
<th>Regolith; Profile desc</th>
<th>Colluvial footslope deposits consisting of highly ferruginous saprolite, Fe duricrust fragments, Fe pisoliths and lithic fragments in a ferruginous matrix.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil &amp; lags</td>
<td></td>
</tr>
<tr>
<td>Landforms</td>
<td>Footslopes, minor pediments.</td>
</tr>
<tr>
<td>Bedrock lithology</td>
<td>unknown</td>
</tr>
<tr>
<td>Regolith Induration</td>
<td></td>
</tr>
</tbody>
</table>
### APPENDIX 4 - Major and trace element geochemistry of selected regolith materials collected over the Selwyn map sheet area.

<table>
<thead>
<tr>
<th>Sample no</th>
<th>Eastings</th>
<th>Northings</th>
<th>Regolith &amp; sample depth (m) S= surface</th>
<th>Geology</th>
<th>SiO2</th>
<th>Al2O3</th>
<th>Fe2O3</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na2O</th>
</tr>
</thead>
<tbody>
<tr>
<td>sel13a</td>
<td>463911</td>
<td>7596416</td>
<td>fe duricrust (s)</td>
<td>granite</td>
<td>6.56</td>
<td>3.06</td>
<td>77.34</td>
<td>0.006</td>
<td>0.05</td>
<td>0.01</td>
<td>-0.03</td>
</tr>
<tr>
<td>sel13b</td>
<td>463911</td>
<td>7596416</td>
<td>mottled &amp; partly Si saprolite (3.5)</td>
<td>granite</td>
<td>71.37</td>
<td>18.4</td>
<td>1.11</td>
<td>0.005</td>
<td>0.05</td>
<td>0.06</td>
<td>0</td>
</tr>
<tr>
<td>sel120</td>
<td>454123</td>
<td>7600711</td>
<td>fe stone hematitic beds (s)</td>
<td>quartz hematite</td>
<td>10.43</td>
<td>1.45</td>
<td>86.46</td>
<td>0.013</td>
<td>0.09</td>
<td>-0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>sel109</td>
<td>458695</td>
<td>7599384</td>
<td>fe duricrust (s)</td>
<td>schist</td>
<td>24.61</td>
<td>16.26</td>
<td>48.33</td>
<td>0.026</td>
<td>0.05</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>sel136</td>
<td>447394</td>
<td>7617999</td>
<td>fe duricrust (s)</td>
<td>mesozoic sst</td>
<td>31.28</td>
<td>8.39</td>
<td>51.98</td>
<td>0.008</td>
<td>0.07</td>
<td>0.16</td>
<td>0.03</td>
</tr>
<tr>
<td>sel116</td>
<td>455728</td>
<td>7597672</td>
<td>ferruginous saprolite (s)</td>
<td>schist</td>
<td>61.61</td>
<td>18.87</td>
<td>6.61</td>
<td>0.031</td>
<td>0.27</td>
<td>0.29</td>
<td>0.36</td>
</tr>
<tr>
<td>sel117</td>
<td>455662</td>
<td>7597623</td>
<td>silicified &amp; mottled saprolite (s)</td>
<td>schist</td>
<td>76.08</td>
<td>10.8</td>
<td>5.69</td>
<td>0.016</td>
<td>0.77</td>
<td>0.05</td>
<td>0.08</td>
</tr>
<tr>
<td>sel118</td>
<td>455564</td>
<td>7597748</td>
<td>saprolite (s)</td>
<td>schist</td>
<td>69.12</td>
<td>18.56</td>
<td>1.79</td>
<td>0.005</td>
<td>0.37</td>
<td>0.05</td>
<td>0.17</td>
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<tr>
<td>sel119</td>
<td>455578</td>
<td>7597721</td>
<td>fe duricrust (s)</td>
<td>schist</td>
<td>3.88</td>
<td>3.31</td>
<td>79.42</td>
<td>0.005</td>
<td>0.08</td>
<td>0.01</td>
<td>-0.02</td>
</tr>
<tr>
<td>sel120</td>
<td>455498</td>
<td>7597671</td>
<td>bleached saprolite (s)</td>
<td>schist</td>
<td>72.98</td>
<td>16.56</td>
<td>1.36</td>
<td>0.005</td>
<td>0.27</td>
<td>0.03</td>
<td>0.17</td>
</tr>
<tr>
<td>sel121</td>
<td>455284</td>
<td>7597914</td>
<td>bleached saprolite (s)</td>
<td>schist</td>
<td>62.25</td>
<td>23.36</td>
<td>2.22</td>
<td>0.007</td>
<td>0.51</td>
<td>0.04</td>
<td>0.39</td>
</tr>
<tr>
<td>sel122</td>
<td>455055</td>
<td>7598160</td>
<td>non bleached saprolite (s)</td>
<td>schist</td>
<td>57.53</td>
<td>21.43</td>
<td>7.31</td>
<td>0.038</td>
<td>1.87</td>
<td>0.24</td>
<td>0.42</td>
</tr>
<tr>
<td>sel140a</td>
<td>447615</td>
<td>7613120</td>
<td>fe segregations in mottled fabric (.5)</td>
<td>schist and meta-sst</td>
<td>12.67</td>
<td>9.82</td>
<td>68.08</td>
<td>0.016</td>
<td>0.05</td>
<td>0.03</td>
<td>0</td>
</tr>
<tr>
<td>sel140b</td>
<td>447615</td>
<td>7613120</td>
<td>white clay between fe segregations (.5)</td>
<td>schist and meta-sst</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sel140c</td>
<td>447615</td>
<td>7613120</td>
<td>white clay mottled zone (5)</td>
<td>schist and meta-sst</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>sel140d</td>
<td>447615</td>
<td>7613120</td>
<td>ferruginous mottles (5)</td>
<td>schist and meta-sst</td>
<td></td>
<td></td>
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Appendix 5 - Regolith Landform and GIS thematic maps

A3 copies of the regolith-landform and derivative maps are enclosed. Hracyprint 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.