CSIRO
EXPLORATION AND MINING

AMIRA
Australian Mineral Industries Research Association Limited ACN 004 448 266

OPEN FILE REPORT SERIES

GEOCHEMICAL EXPLORATION IN REGOLITH-DOMINATED TERRAIN OF NORTH QUEENSLAND

MT ISA FIELD TRIP 26-28 July, 1995

Western Succession - Buckley River - Grey Ghost area

R.R. Anand and J. Wilford

Eastern Succession - Tringadee area

T.J. Munday, C. Phang, J.E. Wildman and K.M. Scott

CRC LEME OPEN FILE REPORT 142

April 2002

(CSIRO Exploration and Mining Report 156R, 1995.
2nd Impression 2002.)

CRC LEME is an unincorporated joint venture between CSIRO-Exploration & Mining, and Land & Water, The Australian National University, Curtin University of Technology, University of Adelaide, University of Canberra, Geoscience Australia, Bureau of Rural Sciences, Primary Industries and Resources SA, NSW Department of Mineral Resources-Geological Survey and Minerals Council of Australia, established and supported under the Australian Government's Cooperative Research Centres Program.

CRC

Australian Mineral Industries Research Association Limited ACN 004 448 266

CSIRO EXPLORATION AND MINING

GEOCHEMICAL EXPLORATION IN REGOLITH-DOMINATED TERRAIN OF NORTH QUEENSLAND

MT ISA FIELD TRIP 26-28 July, 1995

Western Succession - Buckley River - Grey Ghost area

R.R. Anand and J. Wilford

Eastern Succession - Tringadee area

T.J. Munday, C. Phang, J.E. Wildman and K.M. Scott

CRC LEME OPEN FILE REPORT 142

April 2002

(CSIRO Exploration and Mining Report 156R, 1995.
2nd Impression 2002.)

CRC LEME is an unincorporated joint venture between CSIRO-Exploration & Mining, and Land & Water, The Australian National University, Curtin University of Technology, University of Adelaide, University of Canberra, Geoscience Australia, Bureau of Rural Sciences, Primary Industries and Resources SA, NSW Department of Mineral Resources-Geological Survey and Minerals Council of Australia.
Headquarters: CRC LEME c/o CSIRO Exploration and Mining, PO Box 1130, Bentley WA 6102, Australia

CSIRO/CRC LEME/AMIRA PROJECT P417
GEOCHEMICAL EXPLORATION IN REGOLITH-DOMINATED TERRAIN, NORTH QUEENSLAND 1994-1997

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

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

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

This report (CRC LEME Open File Report 142) is a second impression (second printing) of CSIRO, Division of Exploration and Mining Restricted Report 156R, first issued in 1995, which formed part of the CSIRO/AMIRA Project P417.

Copies of this publication can be obtained from:
The Publication Officer, c/- CRC LEME, CSIRO Exploration and Mining, P.O. Box 1130, Bentley, WA 6102, Australia.. Information on other publications in this series may be obtained from the above or from http://leme.anu.edu.au/
Cataloguing-in-Publication:

Mt Isa Field Trip.
ISBN 0 643 06824 4
1. Regolith - North Queensland 2. Landforms - North Queensland 3. Geochemistry
I. Anand, R.R. II. Title
CRC LEME Open File Report 142.
ISSN 1329-4768

TABLE OF CONTENTS

PROPOSED ITINERARY

WESTERN SUCCESSION - Day 1

8:00 **Bus leaves Verona Motel, travel to stop 1**

STOP 1

Relationships between silcrete, ferruginous duricrust and lateritic nodules; implications for exploration.

STOP 2

Lateritic weathering profile on shale; soil profile on saprolite; implications for exploration

STOP 3

Formation of mesa silcrete (silicified sands and quartz gravels) by relief inversion

12:30 **Lunch**

STOP 4

Weathering profile on dolomitic siltstone with overlying transported regolith; remnant land surfaces; implications for exploration.

STOP 5

Residual and transported ferruginous materials on rise, breakaway and backslope; implications for exploration.

STOP 6

Regolith on erosional plains; implications for exploration.

17:00 **Travel to Mt. Isa**

EASTERN SUCCESSION - Day 2

8:00 Bus leaves Verona Motel, travel to Tringadee

STOP 1

Cowie Prospect - Pb, Zn, Ag gossan, implications for exploration.

STOP 2

Relationships between the base of the Mesozoic and ferruginisation; implications for exploration.

STOP 3

Weathering and ferruginisation over a Proterozoic granitoid; implications for exploration.

13:00 Lunch

STOP 4

Brumby Prospect - relationships between ferruginised fracture zones in Mesozoic cover and mineralisation; implications for exploration.

STOP 5

Black soils

STOP 6

Tringadee Prospect - relationship between anomalous Zn in Mesozoic cover rocks, ferruginisation and pathfinder elements; implications for exploration.

STOP 7

A Mesozoic lateritic weathering profile - relationships between ferruginisation, mottling, collapse breccias and silicification - implications for exploration.

17:00 Travel to McKinley

7:30 Bus leaves Walkabout Hotel, travel to seismic line and Mt. Isa

11:30 Arrive Mt. Isa

1.0 INTRODUCTION

The objective of this excursion is to introduce some of the aspects of weathering and geomorphology of the Mt. Isa region that are important to geochemical exploration in the region. Investigation of the regolith-landscape features of the Mt. Isa region commenced in April 1994 by CSIRO, AGSO and University of Queensland as a part of CSIRO/AMIRA Project 417 (Geochemical exploration in regolith-dominated terrain of North Queensland). Initially, a regional regolith-landform framework was established to characterise some of the regolith materials. A preliminary regional regolith-landform map (1:500,000) was produced to show the broad regolith-landform characteristics. Substantial district-scale investigations are continuing in the Western Succession (Buckley-River-Grey Ghost-Drifter) and Eastern Succession (Little Eva, Tringadee) (Figure 1). The work includes regolith mapping (1:25,000-1:50,000), regolith characterisation, regolith dating, orientation sampling of different sample media and correlations of these characteristics within the framework of a regional regolith-landform evolution model.

All AMG locations in this report are given for Zone: 54.

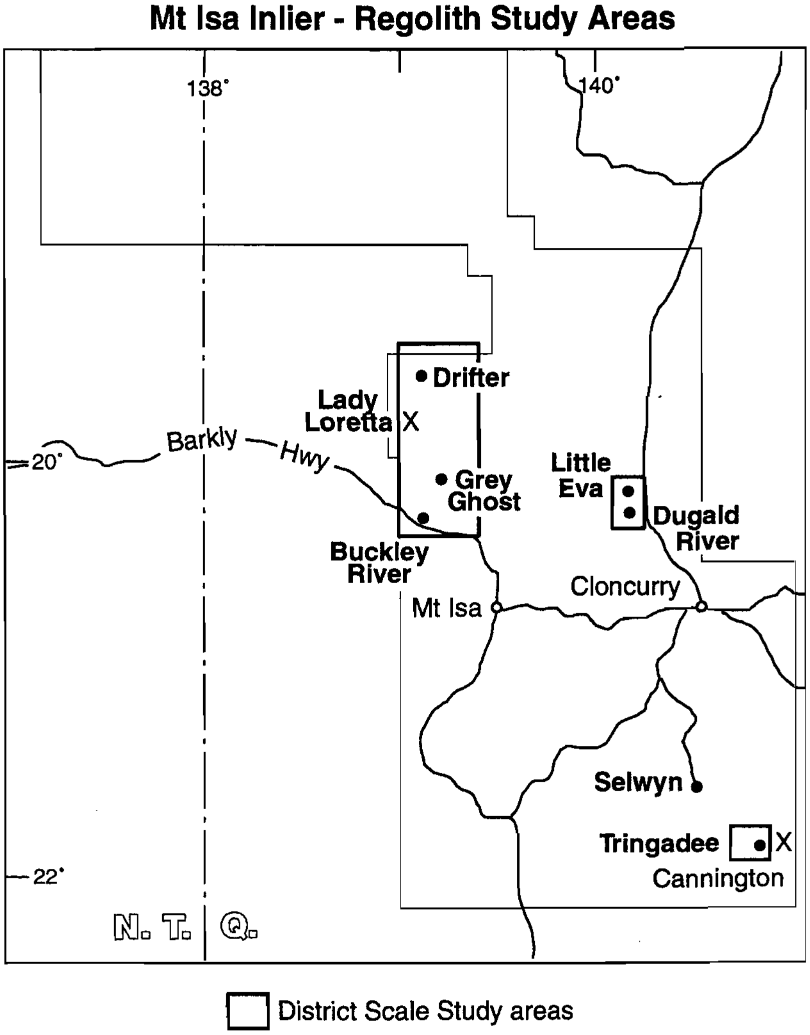


Figure 1. Map showing the locations of orientation studies, P417.

2.0 REGIONAL REGOLITH - LANDFORM CHARACTERISTICS OF THE MT. ISA REGION

The depth of weathering in the Mt. Isa region is related to the weatherability of the bedrock and is inversely related to the variable extent of erosion. Weathering profiles have developed both on Proterozoic bedrocks and Mesozoic sediments and extend to variable depths below the present land surface. Exploration drilling beneath the plains typically have recorded depths of weathering of up to 150 metres (*e.g.* 305337E 7760185N). As would be expected, no weathering profile was observed on quartzite. Although it is assumed that no profile was developed, the possibility of erosion of a prior profile can not be discounted.

The general pattern of profiles is similar at many locations, however, the individual units of the profiles are not developed uniformly. Although saprolite is common in many deep weathering profiles on Proterozoic bedrocks, the upper, ferruginous horizons (lateritic duricrust, ferruginous saprolite, mottled zone) may be absent due to incomplete formation or later erosion. Deep weathering profiles, which consist of lateritic gravel, lateritic duricrust, mottled zone, ferruginous saprolite and saprolite, occur on what are interpreted to be remnant land surfaces. However, such profiles are not common. Instead, ferruginous saprolite and mottled zone, with pockets of duricrust, are common to many weathering profiles. There is no evidence to suggest that there were ever thick sheets of a fully - developed lateritic profile in all areas. Silcrete has developed instead of a ferruginous horizon in places where the underlying Proterozoic bedrock is siliceous.

Ferruginous saprolite is the most common ferruginous zone which is developed on bedrocks of high iron content. This occurs in all elevated topographic positions (rises and mesas) and may be overlain by lateritic duricrust. However, lateritic duricrusts are better developed on remnant land surfaces. There is some geochemical evidence to suggest that, in some cases, a significant component of the iron in the duricrusts has been accumulated laterally and is not entirely derived from the local bedrock. This evidence suggests that some of the duricrusts were originally formed low in the landscape (*i.e.* valleys) and have since been inverted by erosion to higher parts of the landscape.

Weathering profiles on Mesozoic sediments are variable and are largely controlled by the composition of the sediments; more deeply weathered profiles are developed on claystones and siltstones than on sandstones. Ferruginous duricrust and silcrete have developed on Mesozoic sediments. Mesozoic sediments not only occupy topographically high areas but also occur on more gently sloping plains. The sediments are underlain by Proterozoic saprolite.

Silcrete is not only developed from the weathering of underlying rocks. It occupies older remnant land surfaces (*i.e.* mesas) but is also developed in alluvial hardpan, sands and gravels in valleys which have been inverted topographically.

Soils have developed on sediments (Mesozoic and Cainozoic), Proterozoic bedrock and saprolite formed from the bedrock. Veneers of sheet wash gravels, semi-residual sand and clay, overlying mottled saprolite, are common in areas of relatively low relief (including rises, erosional plains and pediments). Lithosols, lying directly on bedrock or saprock, occur on steeper slopes. These areas of high relief exhibit high rates of geomorphic activity and include mountains, hills and low hills.

Large areas of alluvium (channel and flood plain deposits) occur to the west and east of the Mt Isa Inlier. These areas consist of broad alluvial plains with anastomosing channel deposits intermixed with finer flood-plain deposits. In many places the upper reaches of these channels are superimposed over the predominantly northerly structural fabric of the Proterozoic rocks.

Active and generally thinner and coarser alluvial corridors occur along N-E orientated streams over the Inlier. Small areas of colluvium occur as coarse footslope deposits below steeper hill slopes.

Extensive black soil plains have developed commonly in alluvium throughout the region. Black soils are largely absent on steeper slopes and hilly areas.

3.0 BUCKLEY RIVER - GREY GHOST AREA

This section provides a brief overview of the methodology and approach used to compile the Buckley River-Grey Ghost regolith-landform map and then discusses the character and distribution of regolith-landform units over the mapped area. Descriptions of stops for the field excursion are provided below.

3.1 Regolith-Landform Units and Map Compilation

The regolith-landform unit (RLU) is the basic mapping unit. The mapping unit is defined as an area of land with consistent landform and regolith materials at a particular mapping scale. Mapping units are defined mainly on the basis of landforms due to the inherent variability of regolith materials both spatially and compositionally. Relationships between landforms and regolith are then described within each RLU. Landforms are used as a surrogate for mapping regolith because landforms and regolith are generally related both spatially and genetically. Therefore, regolith-landform units do not contain uniform regolith materials, but associated and linked landform and regolith attributes. The purity of regolith within each RLU is largely scale dependent. With increasing mapping scale (*i.e.* 250,000 to 100,000), the higher the purity or uniformity of regolith.

The Buckley River-Grey Ghost regolith-landform map was compiled using colour aerial photographs at a scale of 1:25,000 and Landsat Thematic Mapper imagery processed to enhance clay, iron oxides and silica (Figures 2 and 3). The 1:100,000 Kennedy Gap Geological map was used to recognise the major lithologies. Polygons were drawn initially to represent landform types but, in places, were sub-divided using information from the processed Landsat imagery.

3.2 Regolith Distribution

A variety of ferruginous materials, including lateritic duricrust, ferruginous saprolite, mottled zone and lateritic nodules and pisoliths occur over the mapped area (Figure 2).

Several types of duricrusts were identified which occur at all levels but some were better developed on remnant land surfaces. Lateritic duricrusts have developed *in situ* and on transported sediments and have formed by three mechanisms. These include (1) residual weathering, (2) laterally accumulation of Fe ferruginising pre-existing residual regolith and (3) laterally accumulation of Fe ferruginising sediments derived from elsewhere. In duricrusts formed by mechanisms 2 and 3, the Fe has accumulated laterally and may not be derived from the underlying bedrock. Originally these may have formed low in the landscape and the topography has since been inverted. Iron is largely derived by residual accumulation from the underlying bedrocks, although some lateral accumulation may have occurred in the residual duricrusts. These are generally underlain by ferruginous saprolite. Ferruginous saprolite, mottles and nodules are generally residual products of weathering but dominance of pisoliths on lower slopes suggests that some transport may have taken place.

Silcrete has developed instead of a ferruginous horizon where the underlying Proterozoic bedrock is siliceous. They have formed not only from the weathering of underlying rocks but also developed in Mesozoic sediments, alluvial sands and gravels. Some of these occupy topographical higher areas because of relief inversion.

The erosional areas are dominated by saprolitic material which may or may not be covered by a thin residual soil, lag or sediment. Regolith materials within the erosional areas include residual soils (lithosols, red sandy clay) over saprock, and saprolite and ferruginous sheet wash gravels over mottled saprolite. The sheetwash gravels unit is one of the most extensive units in the Buckley River-Grey Ghost area. It consists of a veneer of gravels and red sands, typically less than 3 m in depth. Their poor sorting and roughness indicates that the gravels are locally derived. Lag gravels are common where wind has removed the finer particles.

Depositional areas consist of colluvial and alluvial deposits. The alluvial deposits consist mostly of channel and over bank sediments. These two types of alluvium are generally difficult to distinguish from air photos due to the lack of distinguishing features. The alluvial sediment generally exhibit a fining - upwards sequence with coarser channel deposits overlain by finer over bank deposits. Channel and over bank sediments form broad, shallow flood plains in the western side of the mapped area. The flood plains are mainly orientated in a easterly direction and seem to reflect the continuation of an older palaeo-drainage system now superimposed on the predominantly northerly structural fabric of the underlying Proterozoic rocks. A typical regolith section consists of coarse gravel and sandy channel beds or lenses, which are overlain by the finer silts and clays of the flood plain. Channel deposits occur in both active and abandoned stream channels. Some of the main streams, such as the Wilfred Creek and the Buckley River, have well rounded gravels and cobbles in their channels.

More active, northerly streams are generally smaller and form narrow sediment corridors along their channels, compared with those of the easterly drainages. These smaller channels are generally less than 1 m thick and bedrock is exposed in most channel floors. In many places, channel deposits are cemented by silica, clay or iron to form alluvial hardpan, locally known as "creek rock". This hardpan commonly extends into the weathered bedrock adjacent to the channels.

BUCKLEY RIVER - GREY GHOST
REGOLITH LANDFORMS

NORTH-WEST MT ISA

1995

- Lateritic duricrust with fragments of duricrust and minor nodules and pisoliths; mesas, rises and plateaus. Developed in-situ and on transported sediments.
- Lag of Lateritic nodules, pisoliths; ferruginous lithic fragments; pockets of lateritic duricrust over ferruginous and mottled saprolite; rises and backslopes
- Massive and columnar silcrete, silicified saprolite and alluvial gravels. Silcrete typically stained and mottled with iron; plateaus and mesas.
- Silcrete / minor lateritic duricrust, ferruginised saprolite; plateaus and mesas
- Silcrete, silicified saprolite, erosional plains and rises.
- Lag of ferruginous gravels and lithic fragments in a sandy matrix over saprolite minor alluvial sediments consisting of sand and gravel; pediments.
- Ferruginous sheet wash gravels, uniform textured sandy soils and minor alluvium and colluvium over mottled saprolite; erosional plain minor flood plain.
- Ferruginous lithosols over mottled zone (in places silicified); erosional plain and rises.
- Lithosols over saprolite (saprock); low hills and hills.
- Gravel, sand and clay channel and over bank sediments on flood plains and alluvial terraces; in places the sediments have been indurated by iron, silica and clay to form alluvial hardpan.
- Coarse colluvial gravels and saprolitic fragments in a ferruginous sandy matrix over saprolite; colluvial footslopes and fans.
- Alluvial clays and silts (gilgai soils - swelling clays); pedogenic calcrete found as scattered float.
- Silicified alluvial gravels and sand over saprolite; erosional plains and rises.

N

LEGEND

- Regolith landform boundary
- Erosional break
- Drainage
- Roads and cultural features
- River capture

MAP SCALE 1:150,000

Regolith 1995, compiled by J.R.Wilford (AGSO) and R.R.Anand (CSIRO)

AGSO AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

CRCAMET

BUCKLEY RIVER - GREY GHOST
REGOLITH LANDFORMS

PRELIMINARY EDITION

1995

Figure 2.

BUCKLEY RIVER - GREY GHOST
REGOLITH LANDFORMS

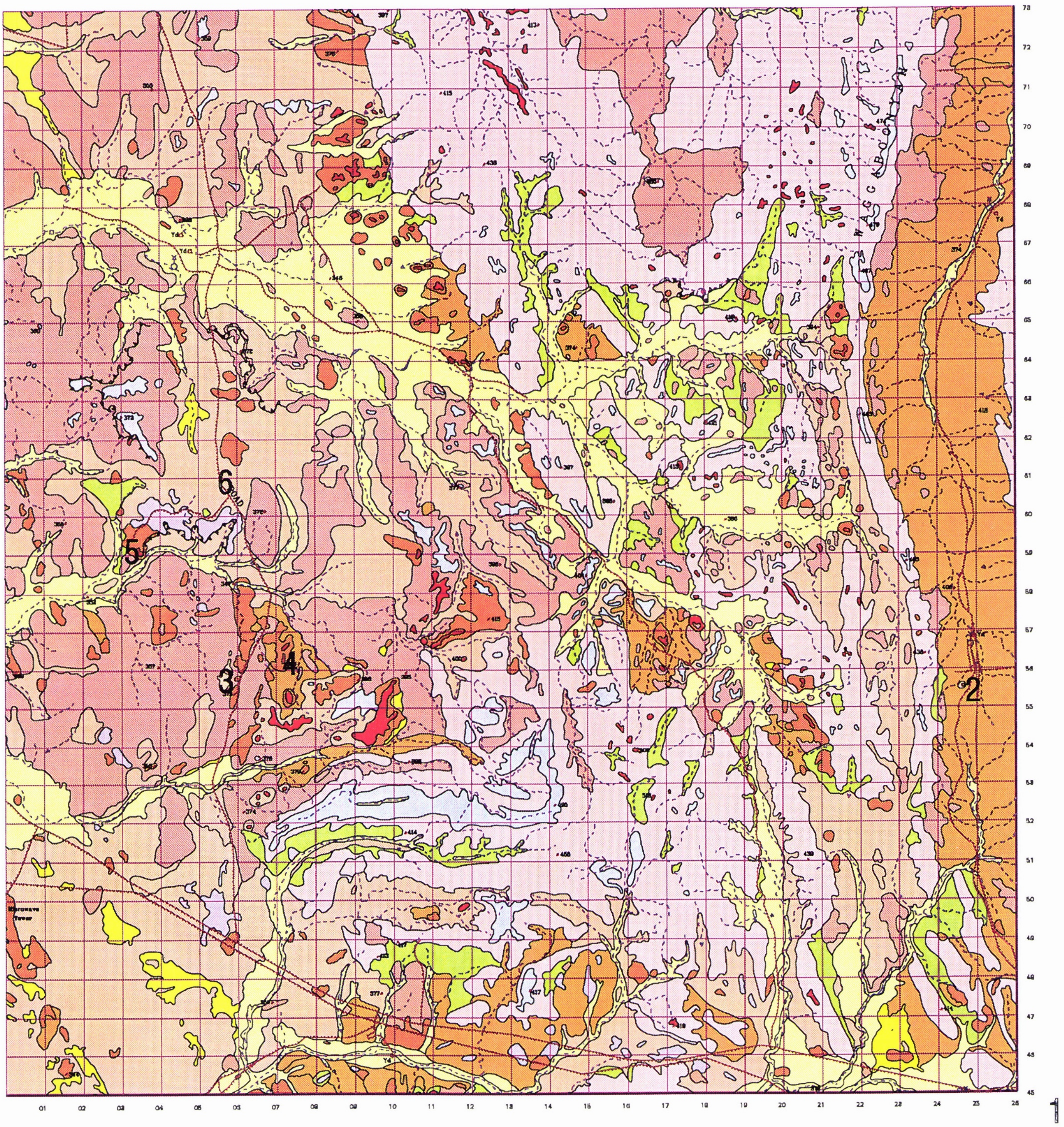
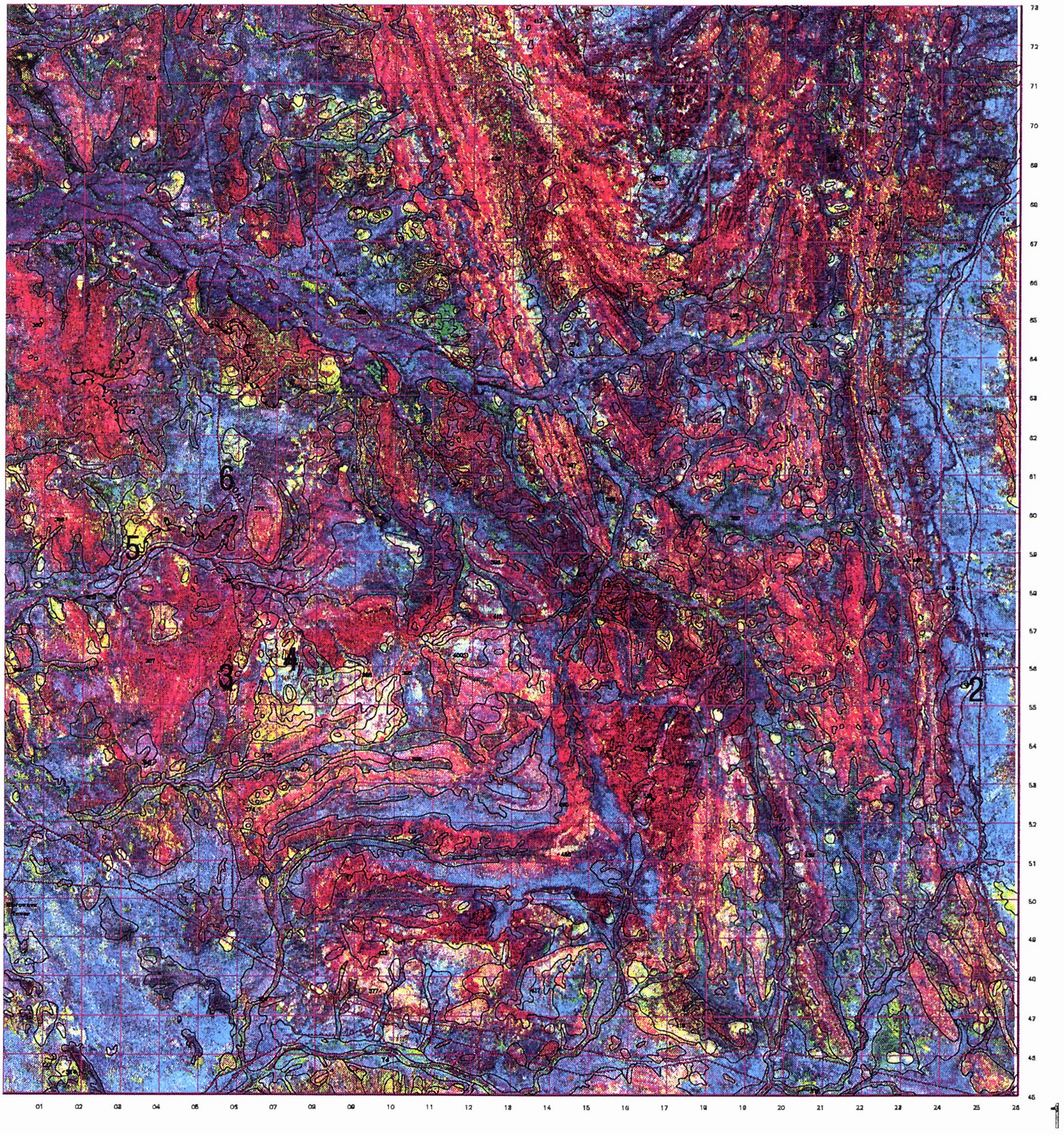


Figure 2.

Figure 3. Landsat TM imagery was enhanced for regolith mapping using a variety of enhancement techniques. One of the most successful enhancements was generated using ratios and principle components. Figure 3 was generated by using the second principle component of ratio bands 4/3 and 5/7 in red, ratio 5/4 in green and, ratio 3/1 in blue. Ferruginous duricrust and ferruginous saprolite are clearly discriminated in yellow hues.

LANDSAT TM

RED = clays; GREEN = iron oxides + clays; BLUE = iron oxides + silica



FORMULA: RED (pc2 4/3, 5/7) GREEN (5/4) BLUE (3/1)

Bands 7 + 1 can be used effectively to map silica

Figure 3.

3.3 Description of Stops

3.3.1 STOP 1

Location	*329414E 7743030N*
Geology	*Quartzite, feldspathic quartzite, minor siltstone and shale*
Landform	*Rises (9-20 m relief)*
Regolith	*Silcrete, silicified saprolite, massive lateritic duricrust, ferruginous saprolite, mottled zone and lateritic nodules*

The area generally consists of alluvial sand and sheet wash gravels over flood and erosional plains. Rises and low hills are blanketed by skeletal, gravelly soils over silicified and ferruginous saprolite.

Silcrete

There is a minor erosional break separating silcrete and silicified saprolite from sheet wash gravels, sand and alluvium to the south. The silcrete, underlain by silicified saprolite, is micro-crystalline with diffuse Fe staining throughout (Figures 4 and 5B,C). In places, well rounded to angular quartz fragments are present. The silcrete has a brecciated fabric and is dominated by quartz and anatase (Figure 4).

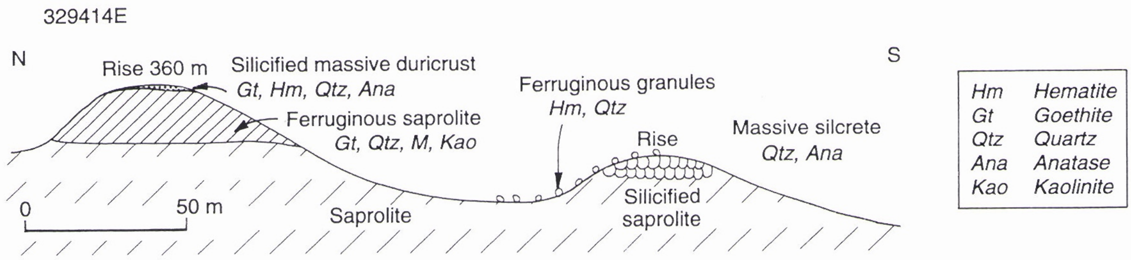


Figure 4. Diagrammatic cross section showing the relationships between silcrete and ferruginous duricrust (Stop 1).

Near surface silcrete is rich in SiO_2 (90.5%), and poor in clay related elements (Al_2O_3, MgO) which is consistent with its mineralogy (Table 1). It is also rich in TiO2 (7%) which occurs as anatase. Abundances of Cu, Pb, Zn and Ni are very low but not so Zr (820 ppm) (Table 1). Silcrete has formed from silicification of an originally very siliceous saprolite (*i.e.* siltstone). The brecciated structure may have developed from loss of soluble minerals (clays) during silicification.

STOP 1

Table 1 : Chemical composition of silcrete and ferruginous materials.

Sample No Depth(m) Regolith Type	IS-50 0 Silcrete	IS-2/2 0 Black Fe-granules	IS-3 0 Massive duricrust	IS-5 10 Ferruginous saprolite	IS-4 0 Lateritic nodules
SiO2 %	90.5	18.9	52.6	48.7	16.1
Al2O3 %	0.5	5.6	6.6	12.1	13.2
Fe2O3 %	1.3	66.8	31.6	30.4	59.5
MgO %	0.04	0.11	0.07	0.56	0.08
CaO %	0.07	0.27	0.06	0.05	0.01
Na2O %	0.00	0.03	<0.01	0.09	0.03
K2O %	0.03	0.12	0.06	3.53	0.01
TiO2 %	6.99	2.96	5.18	0.56	1.94
P2O5 %	0.065	0.087	0.073	0.049	0.064
MnO %	0.008	0.038	0.018	0.015	0.018
LOI %	0.5	2.8	4.3	4.1	9.2
Cr ppm	50	346	89	82	142
V ppm	170	1873	933	204	1279
Cu ppm	4	3	201	11	257
Pb ppm	24	33	49	32	17
Zn ppm	0	17	21	17	25
Ni ppm	14	<10	23	14	6
Co ppm	2	<1	<1	<1	2
Ga ppm	3	49	18	22	25
Ba ppm	531	5673	319	572	<30
Zr ppm	820	519	776	143	222
Nb ppm	50	13	41	<4	5
Ce ppm	50	20	26	29	18
La ppm	36	<10	16	31	<10
Rb ppm	<5	9	<5	197	2
Sr ppm	53	209	18	30	4
Y ppm	32	10	27	20	8
S ppm	400	2770	430	480	390

Ferruginous granules

Black, ferruginous granules form a patchy, thin lag over silcrete. These granules consist of hematite and quartz with small amounts of anatase and are characterised by high concentrations of Fe_2O_3 (66.7%) and lesser concentrations of SiO_2 (18.8%) and Al_2O_3 (5.5%) (Table 1). The abundances of Cu, Pb, Zn and Ni are similar to those of silcrete despite the high concentrations of Fe_2O_3 (Table 1).

Silicified massive ferruginous duricrust

Neighbouring rises, 150 meters to the north, have a well-developed capping of lateritic duricrust (Figures 4 and 5A). This profile is in sharp contrast to the nearby silcrete and consists of massive duricrust cemented by iron and silica, which grades into ferruginous saprolite at depth. Massive duricrust largely consists of hematite and quartz with small amounts of goethite and kaolinite which is consistent with its chemical composition (Table 1). It is characterised by high concentrations of SiO_2

(52.6%) and Fe_2O_3 (31.6%) and lesser concentrations of Al_2O_3 (6.6%). The concentrations of TiO_2 (5.1%) and Zr (776 ppm) are similar to those present in the silcrete. However, the abundances of Cu (201 ppm), Pb (49 ppm), Zn (21 ppm) and Ni (23 ppm) are much greater compared to the silcrete and black ferruginous granules.

Ferruginous saprolite

The ferruginous saprolite below the duricrust consists of goethite, mica, kaolinite and quartz (Figure 4). Mica relics are common in ferruginous saprolite. The major element composition of ferruginous saprolite is similar to massive duricrust except for greater abundances of Al_2O_3 (12%) and K_2O (3.5%) and much lesser abundances of TiO_2 (0.56%) Table 1). Copper (11 ppm) and Zr (143 ppm) are much lesser in ferruginous saprolite compared to the massive duricrust (despite similar concentrations of Fe_2O_3). This may suggest that high concentrations of Cu in massive duricrust are derived from elsewhere and thus may not be related to the underlying bedrock.

Mottled zone and lateritic gravels

The mottled zone is well exposed in the road cutting. Here, the profile consists of pockets of duricrust and lateritic gravels, 1-2 meters thick, which grade into mottled zone and saprolite at depth. The upper, gravelly layer has formed from the collapse of the underlying mottled zone (Figure 5D). As the matrix dissolved, the mottles collapsed upon one another and so became increasingly abundant towards the top of the profile. Mottles were later broken into nodules. The material below this ferruginous layer consists of saprolite with reddish-orange mottling. Lateritic gravels are dominated by goethite with small amounts of hematite, kaolinite and quartz. These have goethite-kaolinite rich, 1-2 mm thick, cutans. The chemical composition of these gravels is consistent with the mineralogy. Gravels are more Fe-rich (59.5% Fe_2O_3) compared to the massive duricrust (Table 1) and are also characterised by high concentrations of Cu (257 ppm).

Implications for exploration

The differences in composition between silcrete, black ferruginous granules, massive duricrust, ferruginous saprolite and lateritic gravels suggest possible differences in genesis. It appears that there was external input of Ti, Fe and Cu into all these materials except for ferruginous saprolite and lateritic gravels. Silcrete and ferruginous granules had an external input of Ti and massive duricrust of Fe, Ti and Cu from laterally moving soilwaters and groundwaters. The origins of these materials have important implications on their geochemical interpretation. Sampling of ferruginous saprolite and lateritic gravels are preferred in this situation because they are largely residual.

Figure 5. Regolith materials and landscapes, Stops 1-5.

Stop 1:

Relationships between silcrete, ferruginous duricrust and lateritic nodules and pisoliths.

(A) Rise capped with silicified, massive ferruginous duricrust underlain by ferruginous saprolite;

(B) Silcrete with ferruginous mottling on rise;

(C) Cut surface of anatase-rich massive silcrete; and

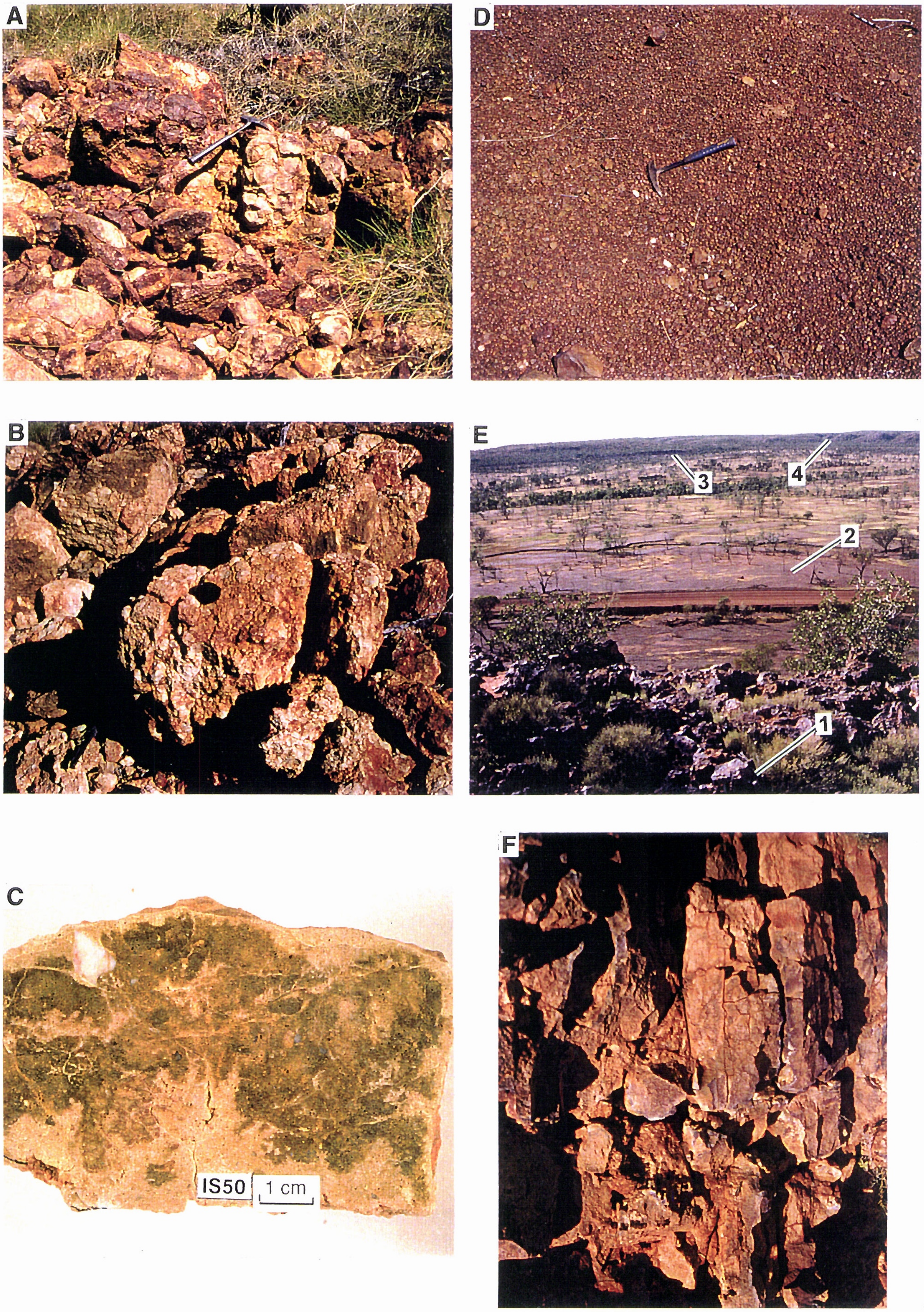
(D) Rise covered with a lag of lateritic nodules and pisoliths with yellow-brown to reddish-brown cutans; these lag gravels are underlain by mottled zone.

Stop 2:

Well-developed lateritic weathering profile on a mesa and soil profile on pediments.

(E) Mesa covered with hematite-rich, massive duricrust underlain by mega-mottle zone (1); ferruginous gravels covering pediments underlain by a shallow soil on saprolite (2); rise capped with ferruginous saprolite (3); and hills of saprock and partly weathered bedrock covered with lithosols (4).

(F) Elongated hematite-rich mega-mottled zone which underlies massive duricrust (1 in Figure E).


A
B
C
IS50
1 cm
D
E
1
2
3
4
F

3.3.2 STOP 2

Location *324701E 7755409N*
Geology *shale and metabasalt*
Landform *Local rise surrounded by thin - colluvial footslopes*
Regolith *Lateritic duricrust over mega-mottled zone.*

Residual weathering profile
This rise provides an excellent example of a well-developed residual weathering profile in the region. The weathering profile was developed *in situ* as shown by thin quartz veining cutting through the entire weathering profile (Figure 6). The local rise protrudes some 20 m above the surrounding pediments and erosional plain and consists of massive lateritic duricrust over a highly ferruginous mega-mottled zone (Figures 5E,F). The duricrust and mega-mottled zone form an indurated capping 6-8 m thick. A thin veneer of pisolitic lag occur (Figure 7A). Elongated, tubular mega mottles are well developed and are probably partly controlled by the sub-vertical cleavage of the bedrock (Figure 5F). The mottles have formed by segregation of clay and iron oxides in the saprolite. Where the clay has been removed in solution - vugs and tubular holes in the mottles and duricrust have developed. In places, these holes have been filled later with ferruginous gravels. The mottled zone grades into highly weathered, diffusely mottled, kaolinised shale at depth.

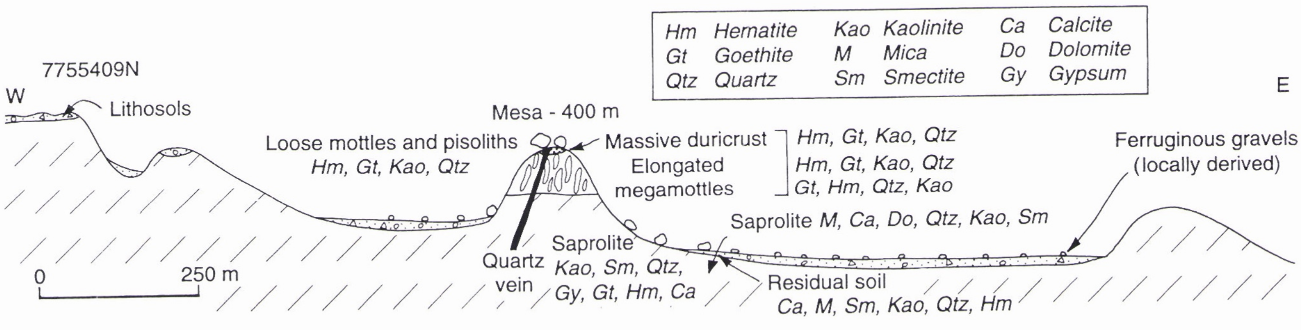


Figure 6. Schematic representation of the regolith and landforms. The landscape is characterised by complete and incomplete weathering profiles (Stop 2).

Lateritic pisoliths and mega-mottles are dominated by hematite and goethite with small amounts of kaolinite, quartz and mica (Figure 6). Clay of the mottled zone is dominated by kaolinite and quartz. The saprolite consists largely of smectite, kaolinite, quartz, goethite, gypsum, calcite and mica. Hematite increases towards the top of the profile. The mineralogy of the regolith units is consistent with its chemical composition (Table 2). Iron increases upwards; SiO_2, CaO, MgO, K_2O and Na_2O decrease and Al_2O_3 remain constant (Table 2). Zinc, Cu, Co, Ni, Ba, Sr, Mn and S are lost during weathering whereas V, Pb and Cr are enriched. Goethite and hematite are the major minerals in mottles and pisoliths and appear to have strong affinity for Cu, V, Pb and Cr. Clay of the mottled zone contain very low concentrations of these elements (Table 2).

STOP 2

Table 2 : Chemical composition of some lateritic profile units, Profile 1.

Sample No	IS-10	IS-11	IS-12	IS-13	IS-14
Depth(m)	0	3	6	6	20
Regolith Type	Lateritic pisoliths	Mega-mottle	Mega-mottle	Clay within mottle	Saprolite
SiO_2 %	17.1	19.1	41.1	63.9	43.5
Al_2O_3 %	14.4	10.2	12.3	20.5	14.1
Fe_2O_3 %	55.5	59.5	36.7	2.2	19.2
MgO %	0.07	0.04	0.06	0.08	1.79
CaO %	0.10	0.00	0.07	0.06	2.43
Na_2O %	0.02	<0.01	0.00	0.01	0.22
K_2O %	0.02	0.01	0.02	0.05	0.66
TiO_2 %	2.24	2.14	2.43	4.37	3.36
P_2O_5 %	0.117	0.138	0.168	0.041	0.121
MnO %	0.017	0.031	0.030	0.040	0.291
LOI %	10.6	8.5	7.2	8.3	10.4
Cr ppm	140	78	21	15	13
V ppm	1155	770	493	70	301
Cu ppm	325	384	176	14	509
Pb ppm	44	29	3	13	20
Zn ppm	53	43	55	16	210
Ni ppm	5	11	18	20	64
Co ppm	1	<10	14	3	34
Ga ppm	37	19	22	30	22
Ba ppm	28	<30	53	19	721
Zr ppm	262	223	177	447	389
Nb ppm	7	5	3	21	15
Ce ppm	47	27	25	43	286
La ppm	11	<10	<11	29	217
Rb ppm	6	5	3	<5	45
Sr ppm	9	3	8	12	61
Y ppm	21	12	8	21	210
S ppm	480	670	640	190	10090

Chemical composition of soil profile, Profile 2.

Sample No	IS-15	IS-16	IS-17
Depth(m)	0 - 0.3	0.3 - 0.6	0.6 +
Regolith Type	Red sandy clay	Red sandy clay	Saprolite
SiO_2 %	56.2	45.8	47.6
Al_2O_3 %	14.0	12.8	13.0
Fe_2O_3 %	15.7	9.8	6.7
MgO %	1.22	2.69	4.10
CaO %	0.79	9.74	9.00
Na_2O %	0.24	0.14	0.21
K_2O %	1.62	2.74	3.91
TiO_2 %	1.71	1.01	0.68
P_2O_5 %	0.068	0.052	0.111
MnO %	0.124	0.080	0.098
LOI %	6.6	13.3	13.0
Cr ppm	68	55	51
V ppm	268	180	128
Cu ppm	89	29	<10
Pb ppm	24	13	7
Zn ppm	57	56	69
Ni ppm	41	47	41
Co ppm	19	22	26
Ga ppm	23	20	20
Ba ppm	415	604	630
Zr ppm	361	211	150
Nb ppm	5	4	<4
Ce ppm	86	69	74
La ppm	40	35	42
Rb ppm	93	132	182
Sr ppm	85	142	154
Y ppm	40	30	27
S ppm	230	400	290

Implications for exploration

Lateritic pisoliths and mega-mottles are residual and thus are good geochemical sampling media.

Soil profile

The surrounding landforms consist of pediments and erosional plains covered with lag gravels and residual soils. Although these materials cover an extensive area, they are generally thin (less than a few meters). Red, sandy clay is common on pediments and result from *in situ* weathering of underlying saprolite (Figure 7B). Here, these soils are overlain by a locally derived, gravelly colluvium. The soils consists largely of mica, calcite, smectite, kaolinite, quartz, hematite and dolomite which is consistent with the chemistry (Table 2). The red colour is due to hematite.

Implications for exploration

The geochemistry of residual soils tends to be very similar to that of saprolite; abundances and contrasts may be lower but anomalies are broader which can result in cost saving.

Figure 7. Regolith materials, landscapes and profiles.

Stop 2:

(A) Pisoliths with hematite-rich cores (1) and goethite and kaolinite-rich cutans (2); these pisoliths form a thin lag on massive duricrust;

(B) Soil profile on a pediment. A thin layer of colluvium (1) underlain by residual soil (2) formed from the weathering of saprolite (3).

Stop 3:

A silcrete mesa is formed by relief inversion.

(C) Massive silcrete developed in sands and gravels (1) overlying Proterozoic bedrock (2).

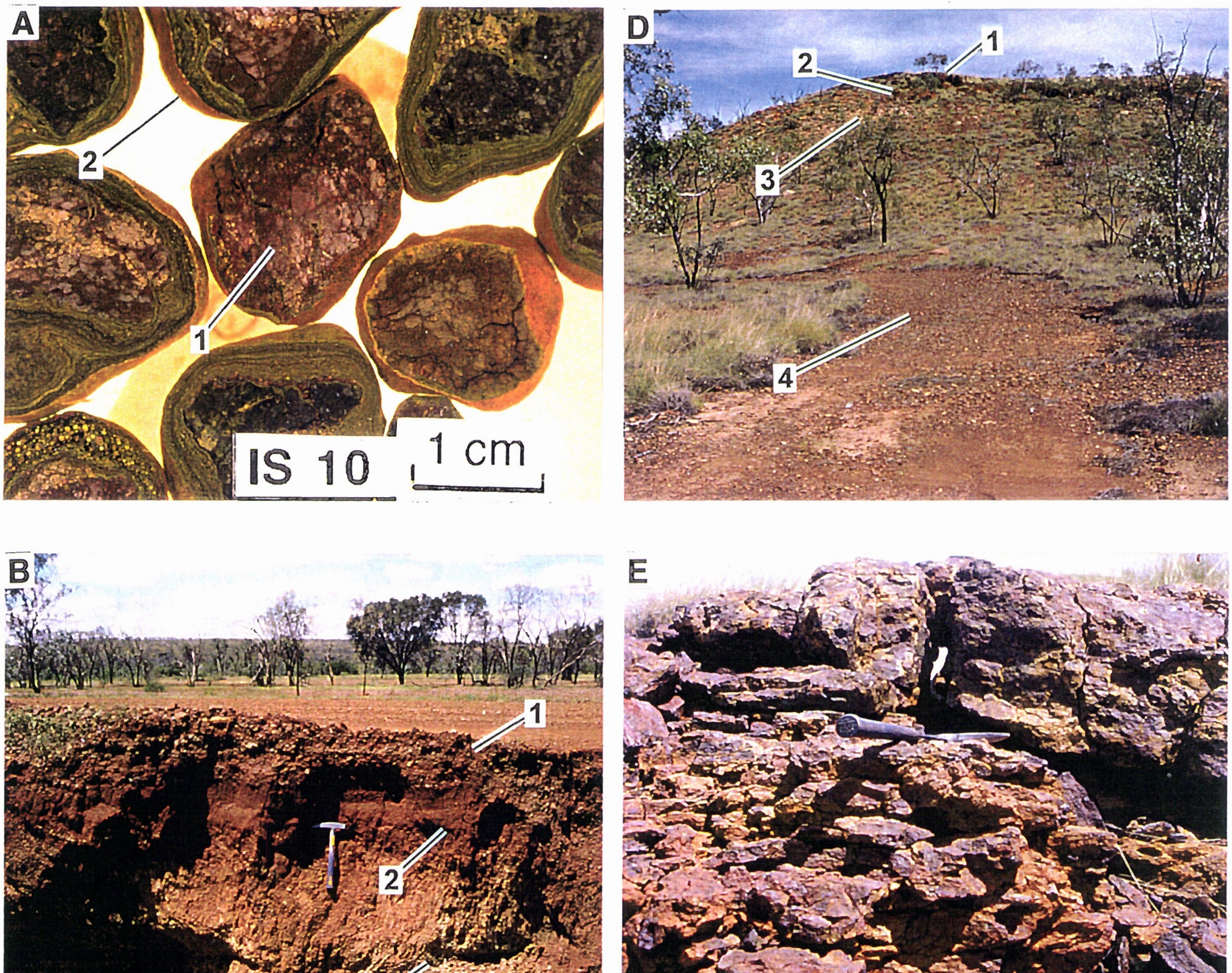
Stop 4:

(D) A major breakaway comprising an erosional escarpment that gives way to a steep debris slope below. Slabby duricrust (1), mottled duricrust (2) and saprolite (3) on breakaway face. Coarse lag of fragments of duricrust and ferruginous saprolite occurs on the pediment (4);

(E) Detail of goethite-rich slabby duricrust (1 in Figure D) which is formed by the lateral accumulation of Fe. Slabby duricrust overlies mottled duricrust.

Stop 5:

(F) Goethite-rich, slabby duricrust which is anomalous in Au.


A
2
1
IS 10
1 cm
D
1
2
3
4
B
1
2
3
E
C
1
2
F

3.3.3 STOP 3

Location	*305685E 7756112N*
Geology	*Possibly Paradise Creek Formation*
Landform	*Mesa*
Regolith	*Silcrete (micro-crystalline), silica cemented sand and minor quartz gravels on moderately weathered bedrock.*

The area consists of rises (9-30 m relief) and erosional plains (< 9 m relief) with generally thin ferruginous gravelly soils over ferruginous saprolite. Sheetwash gravels and alluvial sediments occupy the low and flat parts of the landscape which are mainly thin and discontinuous in this area. Here, an example of silicification and relief inversion may be seen. As you walk over to the site you will notice ferruginous duricrust and a lag of fragments of ferruginous saprolite over the surface. These form the top of a well-developed weathering profile which grades into a mottled and bleached saprolite at depth. These profiles are lithologically controlled and develop best on iron rich sediments (*i.e.* Gunpowder Creek Formation).

Inverted relief.

Massive silcrete and silcrete pods, 1-2 meters thick, form a capping and rest unconformably on moderately weathered shale (Figures 7C and 8). Quartz pebbles, gravels and sand within the silcrete suggest that the original material is either river channel or sheetwash deposits which have been silicified. Cementing was probably caused by fluxes of silica rich groundwaters while the sediments were low in the landscape. Induration by silicification allowed differential erosion and relief inversion to its present topographic position.

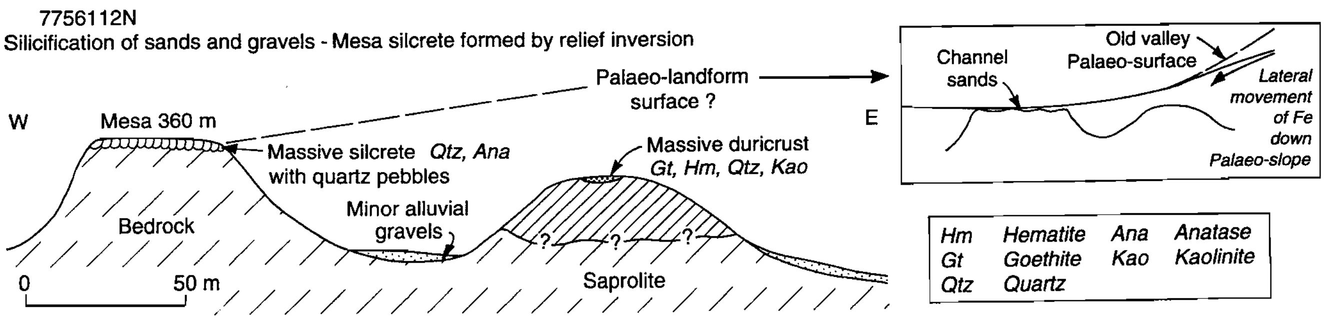


Figure 8. The development of mesa silcrete by relief inversion (Stop 3).

Silcrete consists largely of SiO_2 (97.6%) with very small amounts of Al_2O_3 (0.24%), Fe_2O_3 (0.94%) and TiO_2 (1.22%) (Table 3). The abundances of Cu, Zn, Ni, and Pb are very low. Zirconium is present in significant amounts.

STOP 3

Table 3 : Chemical composition of silcrete.

Sample No	Depth(m)	Regolith Type	SiO2 %	Al2O3 %	Fe2O3 %	MgO %	CaO %	Na2O %	K2O %	TiO2 %	P2O5 %	MnO %
IS-23	0	Silcrete	97.7	0.2	0.9	0.02	0.03	0.00	0.03	1.22	0.019	0.008
			LOI %	Cr ppm	V ppm	Cu ppm	Pb ppm	Zn ppm	Ni ppm	Co ppm	Ga ppm	Ba ppm
			0.2	5	18	<10	13	1	7	4	0	171
			Zr ppm	Nb ppm	Ce ppm	La ppm	Rb ppm	Sr ppm	Y ppm	S ppm		
			532	14	14	<10	<5	9	17	210		

3.3.4 STOP 4

Location *307251E 7756167N*
Geology *Paradise Creek Formation, dolomitic siltstone and chert*
Landform *Plateaux, rises and pediments*
Regolith *Lateritic duricrust, mottled zone and ferruginous saprolite*

This area around stop 4 consists of a series of plateaux and rises separated by erosional pediments and plains. Alluvial sediments occur as narrow corridors along streams, with bedrock exposed typically on channel floors. The most erosionally active parts of the landscape, which correspond to the best bedrock exposures, occur along stream channels and over steeper slopes associated with plateaux and rises. The tops of these rises and plateaux are characteristically capped with ferruginous duricrust and/or ferruginous saprolite (Figure 9). In places these ferruginous crusts form prominent breakaways (Figure 7D). Stop 4 shows a weathering profile through one of these plateau remnants.

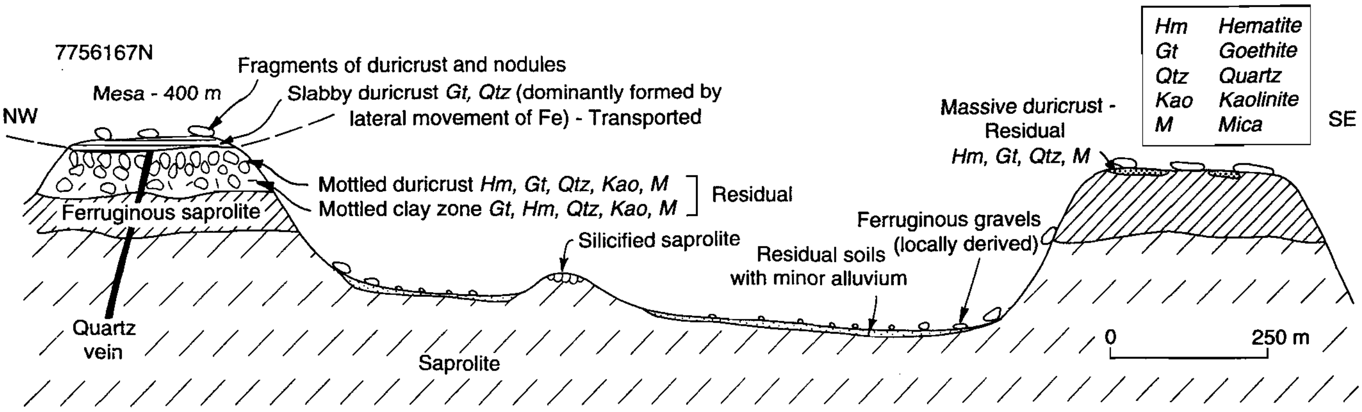


Figure 9. Cross section showing regolith and landforms. Complete weathering profile with overlying transported regolith on remnant landsurfaces and incomplete profile on pediments (Stop 4).

Weathering profile - residual and transported regolith

The profile consists of both residual and transported regolith. The residual regolith consists of saprolite, ferruginous saprolite, mottled clay zone and mottled duricrust (Figure 10). The uppermost unit of slabby duricrust seems to be transported (Figure 7E). Although there is no field evidence to suggest that this is transported, detailed mineralogy and chemistry suggest that the composition of the slabby duricrust is unrelated to the underlying bedrock. The remaining profile was formed largely *in situ,* indicated by preserved quartz veins.

Saprolite and ferruginous saprolite contain the preserved fabric and structure of the dolomitic siltstone and weathering appears to have been isovolumetric. The mineralogy is dominated by mica, quartz and kaolinite; goethite and hematite are present in the ferruginous saprolite (Figure 10). Goethite pseudomorphs after mica and carbonates are present throughout the saprolite and ferruginous saprolite horizons. The saprolite is silicified towards the top of the profile.

Ferruginous saprolite grades upwards into the mottled zone, where the fabrics of the parent rock mostly have been destroyed. Mottled zone is characterised by hard, irregular, reddish brown mottles, up to 50 mm in length, set in a yellow, kaolinite-quartz-mica matrix. Here, the major difference between mottles and matrix is the iron content of the mottles which are dominated by hematite with small amounts of goethite. Goethite pseudomorphs after mica commonly occur both in the mottles and in the matrix. Secondary silicification is also common.

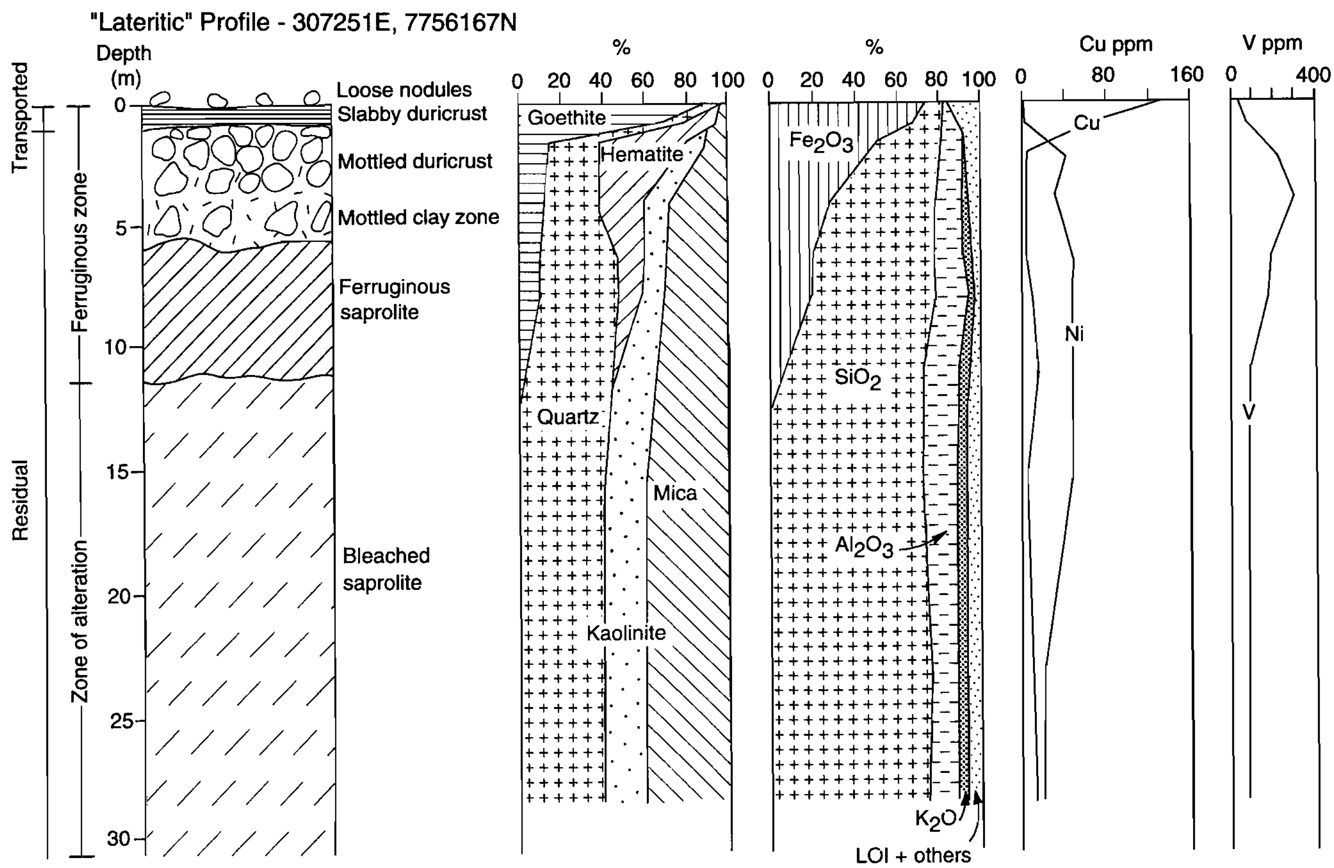


Figure 10. Vertical distribution of major minerals and some major and trace elements in the weathering profile over dolomitic siltstone.

Towards the top of the profile, the mottled zone grades into mottled duricrust. This is characterised by abundant, reddish brown mottles in a very small amount of goethite-kaolinite matrix. Here, soft, clay-rich masses in the mottled zone have dissolved, leaving numerous, irregular voids. These voids weaken the structure of the mottled zone, eventually leading to its partial collapse. Both hematite and goethite increased in abundance in the mottled duricrust; kaolinite and mica decrease and maghemite is absent (Figure 10).

Slabby duricrust, which overlies mottled duricrust is highly indurated, black, highly enriched in iron and is goethitic; hematite and kaolinite are either absent or present in very small amounts (Figure 10). This contrasts with mottled duricrust where hematite, goethite, kaolinite and quartz are the major minerals. Quartz and mica are present in small amounts. Slabby duricrust is more Fe-rich (71% Fe_2O_3) than the underlying mottled duricrust (51% Fe_2O_3).

The iron oxide mineralogy of the mottled and slabby duricrusts suggests that they have developed under different hydrological regimes: free drainage and high temperature in the mottled duricrust yielded hematite; low temperature, moist conditions, and abundant organic matter produced goethite in the slabby duricrust. Goethite, in slabby duricrust, is formed by absolute accumulation of Fe in ancient low landscape positions. Although slabby duricrust occupies higher parts of the present landscape, this duricrust is a remnant of what was once an ancient valley or depression. Iron may have been derived by weathering of an ancient upland, transported laterally and precipitated into low landscape positions. This is supported by its geochemistry. The V, Ni and Cu compositions of slabby duricrust is very different from the underlying mottled duricrust and saprolite (Figure 10). Vanadium increased from 90 ppm in saprolite to 145 ppm in mottled saprolite and then decreased sharply to 45 ppm in slabby duricrust. The behaviour of Ni is similar to V. However, the behaviour of Cu and P_2O_5 is the reverse. Copper concentrations decreased from 13 ppm in saprolite to 3 ppm in mottled duricrust and then markedly increased to 128 ppm in slabby duricrust. The concentrations of P_2O_5 are very high in slabby duricrust (1.10%) relative to the mottled duricrust (0.24%) and saprolite (0.09%). This indicates that most Cu, V, Ni and P in slabby duricrust are not derived from the underlying bedrock. Thus, slabby duricrust seem to be transported and its Fe, V, Cu and Ni components have been derived from a palaeo-upland.

Implications for exploration

The origins of these materials have important implications for their geochemical interpretation. Sampling of slabby duricrust should be avoided. Instead, mottled duricrust or ferruginous saprolite should be sampled.

3.3.5 STOP 5

Location	*303465E 7759529N*
Geology	*Paradise Creek Formation, dolomitic siltstone, minor sandstone and chert*
Landform	*Rise and breakaway*
Regolith	*Lateritic duricrust, ferruginous saprolite and lateritic nodules.*

Buckley River is a Cu prospect with a widespread Cu anomaly in laterite. The sources of the anomaly is unknown.

A minor erosional scarp (15-30 m) separates highly weathered ferruginous materials over rises from alluvial sediments of the Buckley River to the south. A weathering profile has developed within the Paradise Creek Formation, which consists of dolomitic siltstone, minor sandstone and chert. Here, there are ferruginous materials with different geochemical characteristics. Some are residual and others are transported.

Slabby duricrust, silicified nodular duricrust, gritty fragments of duricrust and lateritic nodules and pisoliths

The weathering profile consist of slabby duricrust, 1-2 meters thick, which grades into ferruginous and mottled saprolite at depth (Figure 11). Slabby is used to describe the horizontal lineations and massive structure of the duricrust (Figure 7F). Gravelly soils, which cover the rise and back slope, contain ferruginous saprolite fragments and lateritic nodules. The soils are shallow (0.5 m) and show minimal soil development. Pockets of silicified nodular duricrust and gritty fragments of duricrust also occur on the rise. Scattered fragments of nodules and pisoliths are common on the back slopes where they have formed from localised reworking of the duricrust.

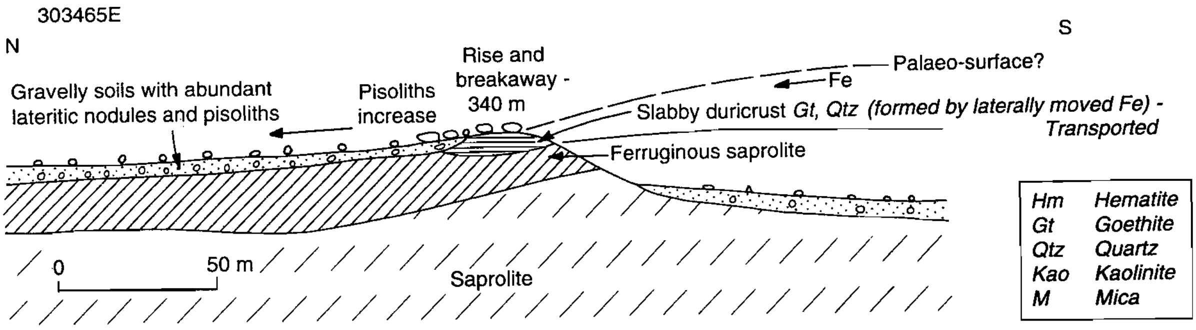


Figure 11. The development of slabby duricrust by absolute accumulation of Fe (Stop 5).

Slabby duricrust and nodules consists largely of goethite and quartz with minor amounts of kaolinite, mica and hematite. In contrast, silicified nodular duricrust and gritty fragments of duricrust consist of hematite and quartz with small amounts of kaolinite, mica and goethite. However, hematite is more abundant in gritty fragments of duricrust than in silicified duricrust where quartz is the major mineral. The mineralogy of these materials is consistent with the major element composition (Table 4).

The chemical composition of slabby duricrust is different from those of gritty fragments of duricrust and lateritic nodules (Table 4). Although Cu (163-1596 ppm), As (32-86 ppm) and Pb (38-137 ppm) are present in significant amounts in all the ferruginous materials, the abundances of Au and Sb are significantly different. Gold (84-150 ppb) is anomalous in slabby duricrust whereas it is below detection limits in silicified nodular duricrust, gritty fragments of duricrust and lateritic nodules. The reasons for the differences in the abundances of these elements are, as yet, not clear.

STOP 5

Table 4 : Chemical composition of various types of ferruginous materials, Buckley River.

Sample No	IS-46	IS-47	IS-7	IS-48	IS-8	IS-49
Depth(m)	0 - 0.5	0.5 - 1	0	0	0	0
Regolith Type	Slabby duricrust	Slabby duricrust	Silicified nodular duricrust	Gritty fragments of duricrust	Lateritic nodules	Lateritic nodules
SiO2 %	39.4	26.4	81.2	29.3	28.1	13.7
Al2O3 %	4.2	9.5	2.3	12.1	7.0	8.3
Fe2O3 %	47.6	53.5	14.5	52.7	53.8	65.6
MgO %	0.18	0.23	0.09	0.20	0.28	0.39
CaO %	0.02	0.03	0.09	0.11	0.03	0.03
Na2O %	<0.01	0.03	0.01	0.00	<0.01	0.01
K2O %	0.51	0.60	0.08	0.40	0.85	1.17
TiO2 %	0.13	0.36	0.64	0.44	0.16	0.23
P2O5 %	0.631	0.321	0.044	0.131	0.217	0.293
MnO %	0.028	0.018	0.019	0.042	0.040	0.077
LOI %	8.0	9.1	1.3	5.5	9.7	9.8
Cr ppm	16	59	0	32	49	25
V ppm	31	176	32	91	71	50
Cu ppm	460	1179	163	549	1084	1596
Pb ppm	111	68	38	137	92	80
Zn ppm	11	12	3	14	7	13
Ni ppm	20	1	15	6	<10	7
Co ppm	3	8	<1	1	12	20
As ppm	81.7	86	32	92	69.5	63.8
Sb ppm	10.7	22.1	2.72	4.66	7.24	14.7
Au ppb	150	84.2	<5	<5	<5	11.6
Ga ppm	<3	9	4	15	8	12
Ba ppm	114	178	412	122	214	357
Zr ppm	73	183	278	172	168	123
Nb ppm	<4	0	1	<4	<4	<4
Ce ppm	68	60	42	101	142	70
La ppm	20	12	22	36	53	15
Rb ppm	19	25	<5	16	30	37
Sr ppm	15	16	18	16	28	12
Y ppm	22	14	19	11	28	25
S ppm	310	650	300	330	390	220

It appears that there are several types of ferruginous materials which may have developed in differing weathering environments. Some are residual; others are transported. The iron oxide mineralogy of the gritty fragments of duricrust and slabby duricrust suggest that they have developed under different hydrological regimes. Large proportion of the iron in the goethite-rich slabby duricrust may have been derived laterally rather than from the underlying bedrock. No field sedimentological evidence has been found to support this as yet. However, if this is the case, it may be postulated that, at one stage, the slabby duricrust formed in a valley floor or valley side which has since been topographically inverted due to differential erosion caused by iron induration.

Implications for exploration
Sampling of slabby duricrust should be avoided. Instead, gritty fragments of duricrust and lateritic nodules should be sampled.

3.3.6 STOP 6

Location	*305500E 7761000N*
Geology	*Unknown*
Landform	*Erosional plain*
Regolith	*Ferruginous sheet wash gravels, sandy clay soils and minor alluvium over mottled saprolite*

The area consists of erosional plains (<9 m relief) and local rises (9-30 m relief) with ferruginous lag gravels, sandy clay soils and minor alluvium on mottled saprolite. This regolith-landform type is one of the most extensive units in the area. Soils are red, gravelly, sandy to sandy clay, kaolinitic and are generally developed in locally derived alluvium. Minor alluvial gravels are associated with this regolith-landform unit but are typically thin and discontinuous. The thicknesses of alluvium are uncertain because of lack of exposure. However, the field observations suggest thicknesses between 1-3 m.

Soils are underlain by mottled saprolite and are more mature than soils on pediments, as is indicated by lack of weatherable minerals. Gravelly soils contain fragments of ferruginous saprolite and mottles which are dominated by hematite. Minor amounts of quartz are also present. Most of the lag gravels although transported are thought to be locally derived. The ferruginous gravels of many of these soils may be in part, lag gravels formed during erosion and down-wasting of the landscape during the Late Tertiary. Where saprolite is exposed it is generally either ferruginised or silicified.

Implications to exploration
Ferruginous lag is locally derived and does not relate to the immediately underlying lithology. These fine gravels may not be suitable sample media for geochemical sampling, at the prospect scale, because the provenance is likely to be in doubt. However, these gravels can be sampled on a reconnaissance scale.

4.0 TRINGADEE AREA (Day 2)

This section provides a brief overview of the methods used to compile the Tringadee regolith-landform map and then discusses the nature and distribution of regolith-landform units over the study area. Descriptions of stops for the field excursion (Day 2) follow.

4.1 Regolith-Landform Units and Map Compilation

The basic mapping unit is as described in Section 3.1 A simplified regolith materials map for the Tringadee Area - scale 1:100,000 (Figure 12) was compiled with the aid of colour aerial photographs (scale 1:25,000), the Selwyn 1:100,000 Geological Map (simplified version shown in Figure 13) and enhanced Landsat TM imagery (*e.g.* Figure 14). Polygons representing the distribution of major regolith-material types were summarised from a more detailed map at 1:25,000.

4.2 Regolith-Landform Associations

The Tringadee area is of generally low relief with extensive depositional plains covered by well-developed black clay soils over alluvial materials. These typify the regolith to the south and south east and are commonly between 1 and 2 m thick. The plains are varied by isolated low hills and mesas which rise to generally less than 30 m above a mean altitude of some 300 m above sea level. Low hills and mesas developed in Cretaceous sediment dominate the central portion of the area. Similar landforms developed on the Proterozoic basement characterise the north and westerly portions of the mapped area (Figure 13).

There are a variety of ferruginous materials, including lateritic duricrust, ferruginous saprolite, mottled zones, lateritic nodules, ferruginised fractures and ferruginised sediments found within the study area. Several types of duricrust have been identified apparently developed *in situ* from a residual accumulation of iron during weathering. These materials have a sporadic distribution through the Tringadee district and are confined to remnant mesas and high hills. Representative sections relating to these localities are shown in Figure 15 sites 3 and 7. Ferruginous and mottled saprolite commonly underlie these duricrusts. In the Cretaceous sediments megamottles are developed.

Much of the upper part of the Cretaceous sequence has been silicified forming fragmental claystones. In places these are cut by fractures which have formed the loci for iron accumulation. The pediments flanking the remnant Cretaceous mesas are covered by a veneer of polymicitic ferruginised lithic fragments, quartz gravels and silicified claystones. These are commonly found in the central part of the mapped area.

In areas consisting of erosional rises and low hills, regolith materials are predominantly thin skeletal soils over saprolite, saprock and unweathered bedrock. On the margins of outcropping Proterozoic rocks ferruginous sheetwash gravels and sands have developed over mottled saprolite and bedrock.

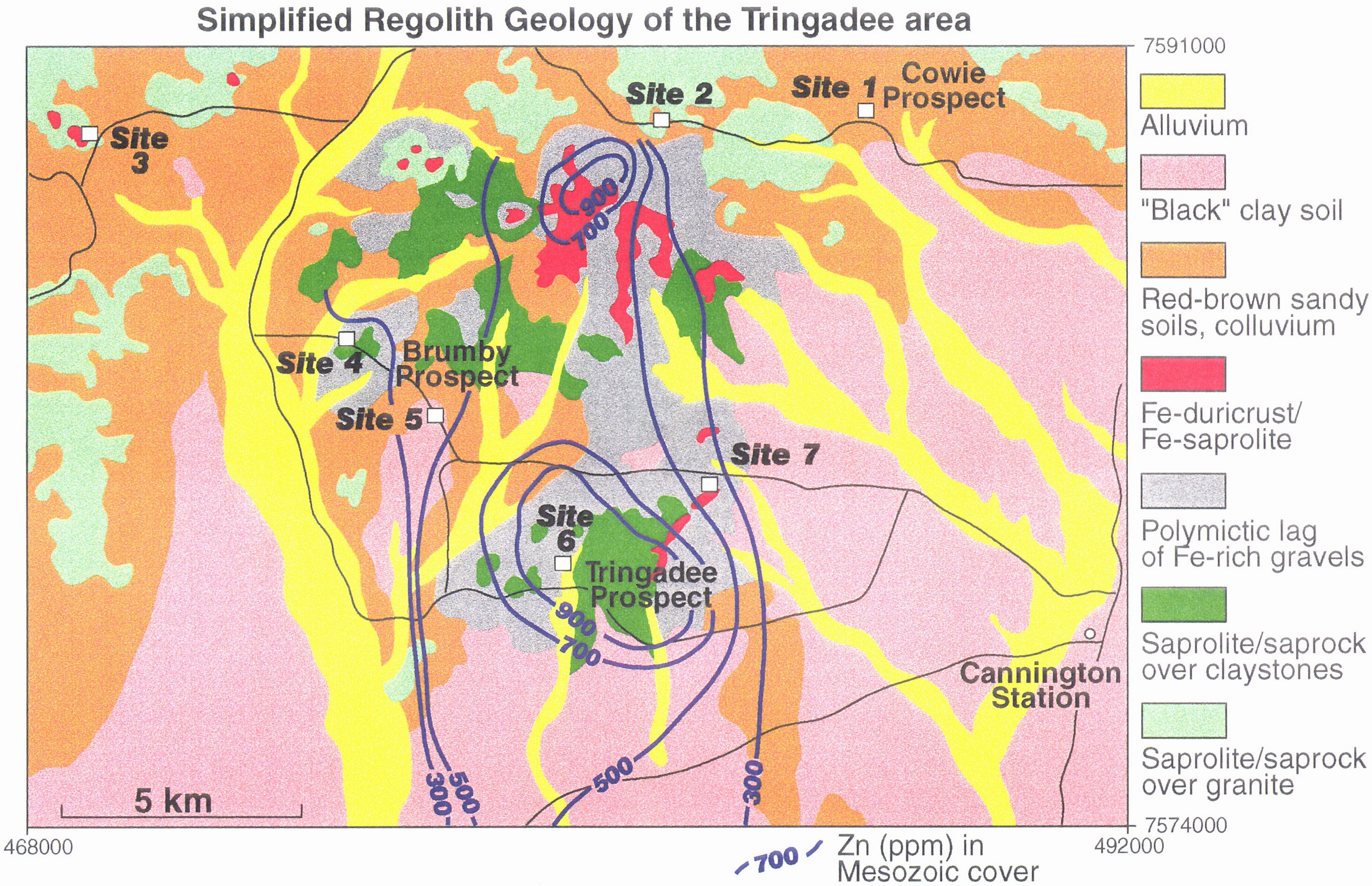


Figure 12. Simplified regolith map for the Tringadee area.

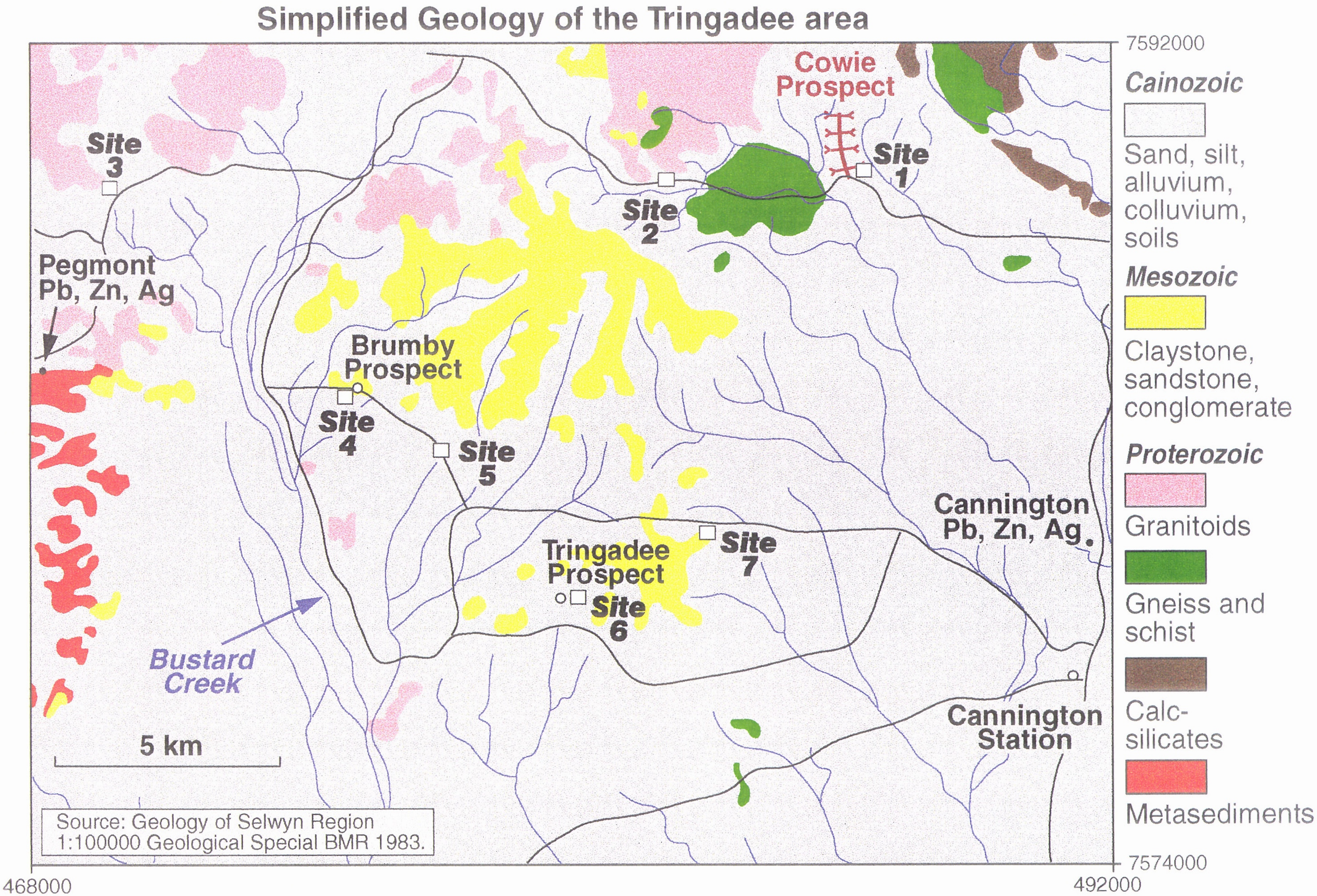


Figure 13. Simplified geological map of the Tringadee area.

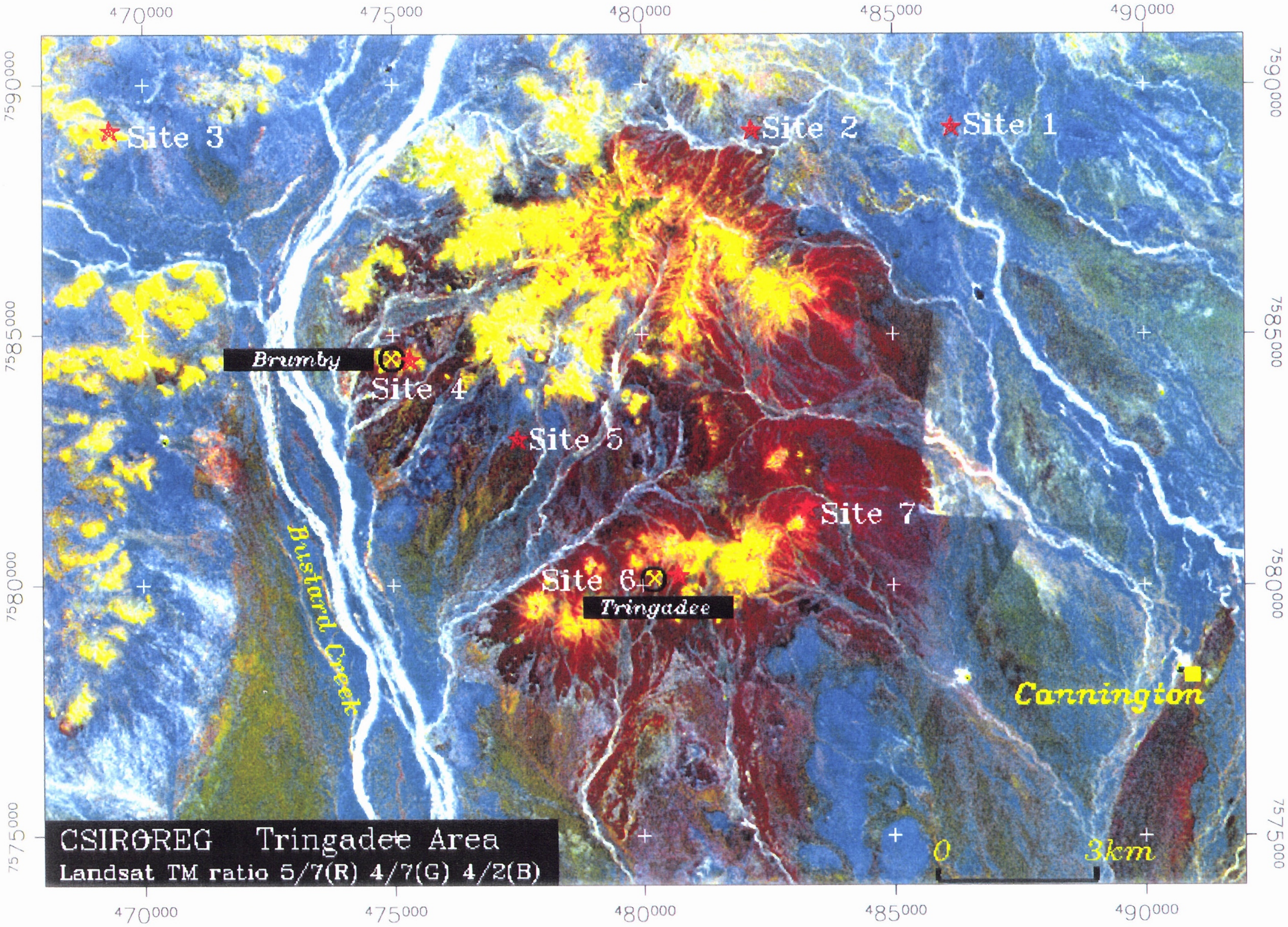


Figure 14. Landsat TM ratio colour composite - Bands 5/7 (Red), 4/7 (Green), and 4/7 (Blue. Yellows are indicative of silicification and ferruginisation. Both the Proteroxoic and Mesozoic rocks have these characteristics. Blues are indicative of sandy alluvial plains. Red-purples relate to polymictic lag gravels dominated by ferruginised lithic fragments.

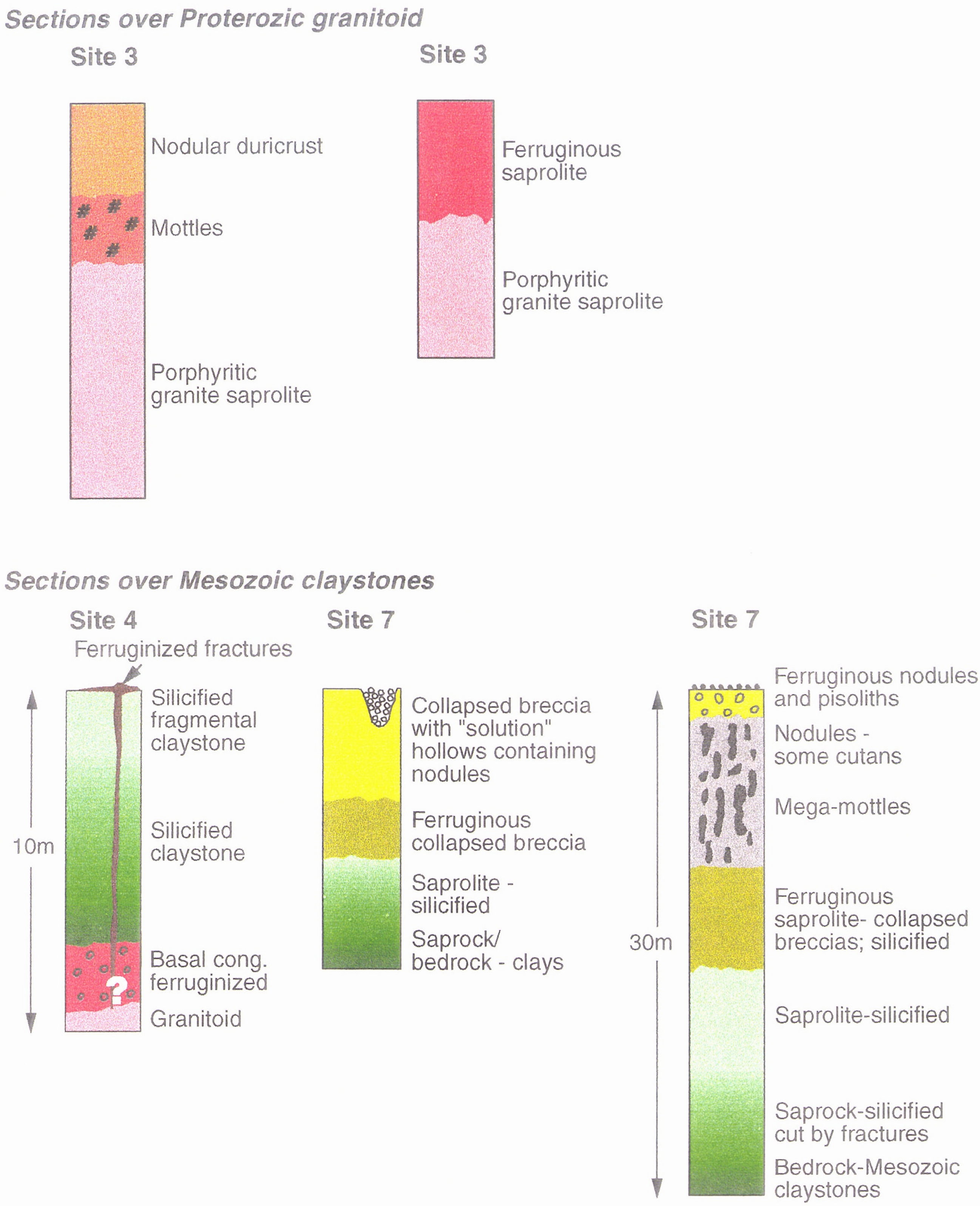


Figure 15. Representative sections for the Tringadee area.

4.3 Description of Stops

4.3.1 STOP 1:

Location	*486108E 7589140N*
Geology	*A Zn, Pb, Ag gossan in foliated quartz-garnet gneiss. Lower Proterozoic Soldiers Cap Group.*
Landform	*Depositional plain*
Regolith	*Variable thickness (0-2 m) of predominantly sheetwash deposits, over bedrock weathered to approximately 30 m.*

Limited stratabound mineralisation at Cowie crops out as a banded manganiferous gossan hosted by biotite-muscovite and quartz-feldspar-mica schists. The mineralisation consists of sphalerite and pyrite, associated with minor chalcopyrite and galena. Magnetite represents a major component at Cowie where Zn is the dominant base metal, along with moderate Pb and Ag and low Cu. Cowie is characterised by a distinct N-S zonation as evidenced in. Table 5). Samples from Cowie North leave a significantly higher Pb and Zn content by comparison with those from Cowie South. These variations may be related to a significantly higher Pb and Zn content by comparison with those from Cowie South. These variations may be related to a primary zonation. The higher levels of Pb, Zn, P_2O_5 and SO_3 may also indicate the immaturity of the gossan reflecting its low iron sulphide content and a stripping of the gossan profile (Taylor and Scott, 1982). The gross mineralogy of the Cowie Gossan also varies from N-S (Table 6) with hematite and magnetite more common to the southerly extension of the gossan.

Implications for exploration

The geochemical signature of outcropping gossan or oxidised mineralised gossan is dependent on the degree of truncation of the oxidised profile. All but the most resistant elements tend to be leached from the uppermost zones. Deeper erosion may expose zones of supergene mineralisation and enrichment. Zinc tends to be strongly dispersed from the zone of weathering over Zn-rich sulphides. At Cowie Zn grades are relatively high suggesting more limited leaching and dispersion. Zn is principally retained by the iron oxide phases in weathering. Dispersion trains and anomalies detected in stream systems will depend on the degree of leaching and hydromorphic dispersion. At Cowie anomalies are weak and limited in extent.

STOP 1

Table 5: Average composition of samples and Cowie North and Cowie South prospects, majors in wt %; traces in ppm (Nisbet and Joyce, 1980).

No of samples	Cowie North 12	Cowie South 5
Fe2O3	15.5	41.0
K2O	0.11	0.21
P2O5	3.97	0.44
MnO	7.99	1.96
SO3	0.39	0.18
Ag	2	1
As	400	120
Ba	150	110
Bi	27	1
Cd	<1	<1
Co	10	90
Cr	<10	<10
Cu	150	230
Ga	10	16
Ge	13	9
In	<1	<1
Mo	3	4
Ni	4	15
Pb	7.58%	150
Sb	<30	<30
Sn	4	8
Sr	1 060	58
Tl	<1	<1
Zn	6 000	1 530

Table 6: Gross mineralogy of gossans and ironstones from the Cowie North and Cowie South prospects, as determined by X-ray diffraction (Nisbet and Joyce, 1980).

Cowie North
Quartz + garnet + apatite + carbonaceous matter + plumbogummite ± goethite ± chlorite ± cryptomelane (coronadite)

Cowie South
Hematite + magnetite + quartz ± goethite ± garnet ± chlorite ± carbonaceous matter

4.3.2 STOP 2:

Location	*482363E 7588872N*
Geology	*Proterozoic-Mesozoic boundary (?)*
Landform	*Depositional plain*
Regolith	*A ferruginised sediment comprising coarse sand with pebbles subcropping in an area of alluvial sands and sheetwash gravels.*

The general area consists of alluvial sands and sheetwash deposits in a depositional plain. Low hills and rises comprising outcropping Proterozoic granites and gneiss are located to the north of the stop.

Ferruginised Sediment
This material has a slabby character and subcrops in scattered localities through the area. It consists of a medium to coarse sand with pebbles of quartz indurated by iron. The material is interpreted as the interface between the Cretaceous cover and the underlying Proterozoic basement. Ferruginisation may be related to the lateral accumulation of iron in a more permeable sedimentary unit at the base of the Cretaceous cover.

Implications for exploration
Anomalous values of Zn may be associated with this zone. The source of this element may be from the hydromorphic dispersion from adjacent areas with the Zn accumulating and being retained by iron oxides. As a result anomalous values may bear no relation to underlying basement mineralisation.

4.3.3 STOP 3:

Location	*469115E 7589130N*
Geology	*Proterozoic porphyritic biotite and hornblende-biotite granite*
Landform	*Mesa*
Regolith	*Lateritic duricrust, lateritic nodules and pisoliths, ferruginous saprolite and saprock*

The weathering profile observed at this locality typifies that found over significant parts of the granites of the Cloncurry-Selwyn Zone in the Eastern Succession. It consists of a patchy nodular duricrust, interpreted as residual, overlying a mottled zone and/or a ferruginous saprolite. The duricrust is relatively iron-rich (by comparison to equivalents developed over Cretaceous sediments). The granites are commonly deeply weathered and there is evidence of silicification in the upper parts of the profile, particularly where the granite forms breakaways. Table 7 provides a limited breakdown of the geochemistry of select samples of duricrust and lateritic nodules. Representative sections through the regolith over granitic terrains are given in Figure 15.

Implications for exploration
Where present, the duricrust and nodules are appropriate sampling media given that they are likely to have developed *in situ*.

STOP 3

Table 7 : Chemical composition of duricrust and lateritic nodules developed over granite

Sample No	Depth(m)	Regolith Type	SiO2	Al2O3 %	Fe2O3 %	MgO %	CaO %	Na2O %	K2O %	TiO2 %	P2O5 %	MnO %
TG-204	0	Duricrust	23.0	14.2	50.5	0.07	0.06	<0.01	0.05	1.04	0.083	0.006
TG-205	0	Lateritic nodules	15.9	12.0	60.5	0.04	0.02	<0.01	0.06	0.70	0.068	0.007
			LOI %	Cr ppm	V ppm	Cu ppm	Pb ppm	Zn ppm	Ni ppm	Co ppm	Ga ppm	Ba ppm
TG-204	0	Duricrust	10.9	129	705	115	9	28	<10	12	37	105
TG-205	0	Lateritic nodules	10.6	153	603	258	17	28	<10	18	28	21
			Zr ppm	Nb ppm	Ce ppm	La ppm	Rb ppm	Sr ppm	Y ppm	S ppm		
TG-204	0	Duricrust	300	27	35	<10	3	12	7	850		
TG-205	0	Lateritic nodules	214	15	19	<10	4	7	8	410		

4.3.4 STOP 4

Location *475240E 7584595N*
Geology *Quartz feldspar and psammite*
Landform *Low hills less than 10m high*
Regolith *Silicified saprolite and ferruginous veining*

Brumby is a Cu-Au prospect, situated within the Tringadee area. The prospect is situated in low hills of Mesozoic cover within which there is a Cu-Au anomaly. There are several styles of ferruginous materials in the area some of which may represent remnants of mineralisation or they may be ground water accumulations scavenging local minor anomalies (Figure 16). Understanding the geochemical behaviour of these materials in this area will be essential for exploration. A representative section through the regolith at Brumby is given in Figure 15 (site 4).

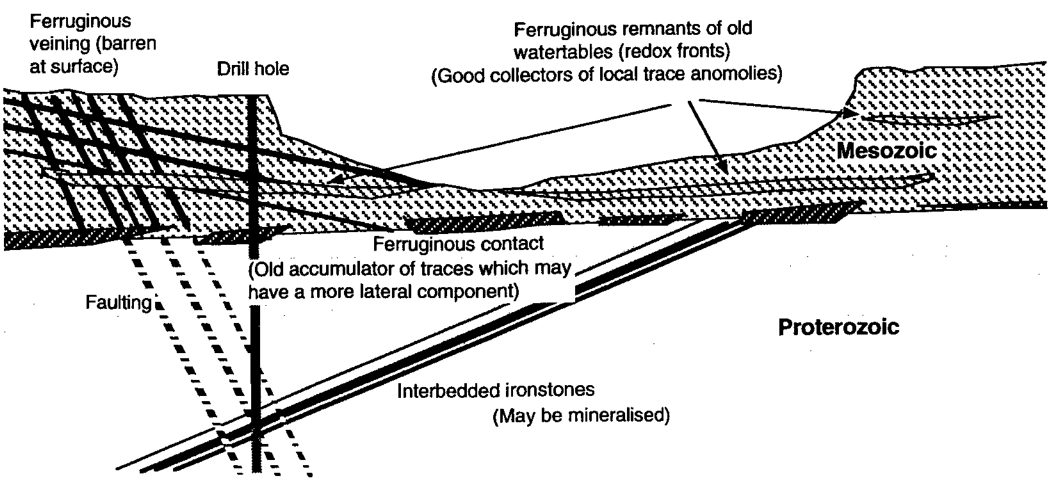


Figure 16. Brumby Prospect stratigraphic model.

Surface sampling
Surface samples were collected along two transects over minor mineralisation drilled by Aberfoyle. These materials are ferruginous veining which follow bedding planes and fault systems in the Mesozoic. The samples are ferruginised silty clays consisting largely of hematite, goethite, kaolinite and quartz. Some of the ferruginisation is restricted to veining but it also indurates the porous clay structure to varying extents. Goethite tends to increase with depth.

Bulk analyses showed Au below detection limits (5 ppb) and low levels of Cu (50 ppm). Partial extractions using buffered ammonium acetate followed by hydroxylamine hydrochloride did not add to the bulk analysis information.

Subsurface sampling
Sub surface samples were chosen from a cluster of RAB holes around a percussion hole (PETD6) for which there was a consistent set of Aberfoyle's data. The Aberfoyle data from RAB drilling showed copper less than 50 ppm in the 15 m of Mesozoic drilled. The Mesozoic is approximately 45 m deep at this point. Zinc increases in the top ten metres showing an accumulation which is not related to mineralisation. No analyses for Fe or Au were done on the RAB samples so no evaluation of deeper ferruginous veins in the Mesozoic could be made from this data.

Twenty extra multielement analyses were done to provide data from 0 to 55 m in percussion hole PETD6 (Figure 17). These showed a strong Fe accumulation at the Proterozoic/Mesozoic boundary at 45 to 50 m depth which is described as 'gossan/banded iron formation?' in the drill core logging. This may also be related to a preferred pathway for solutions and perhaps a persistent water table position. Copper, Zn and other trace elements increase around the Mesozoic/Proterozoic boundary. Two peaks in Au concentrations show above 45 m indicating gold mobility into the Mesozoic. Copper in PETD6 became increasingly depleted towards the surface dropping from a maximum of 9,000 ppm in the Proterozoic to 400 ppm at 25 m and 40 ppm at the surface.

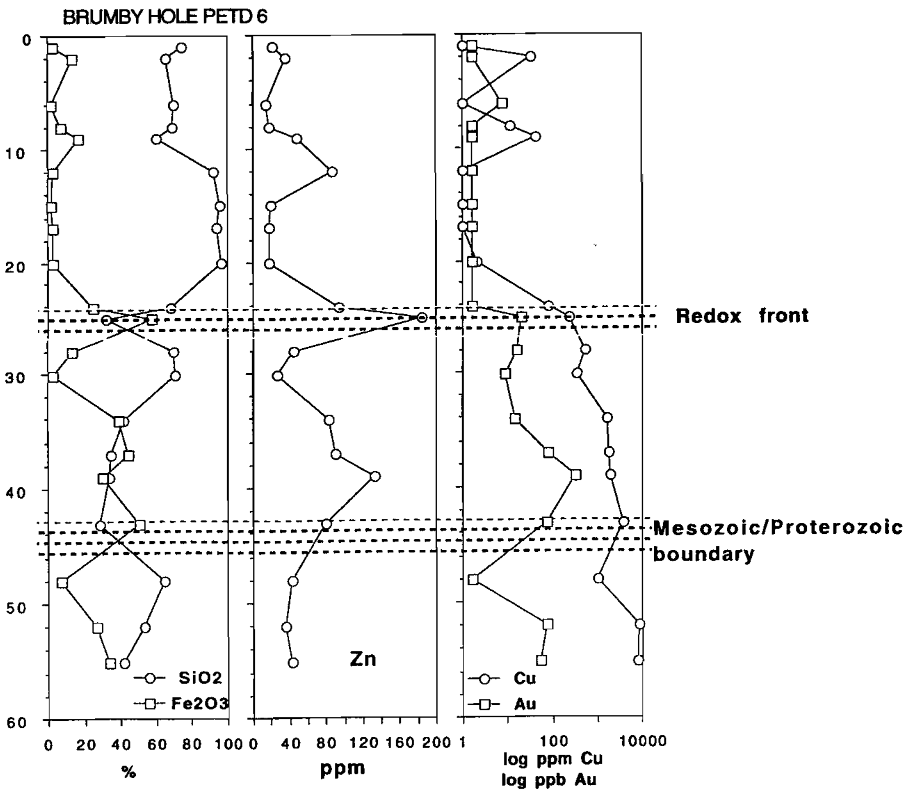


Figure 17. Brumby Prospect percussion drill hole PETD 6

Below 25 m Fe, Au and Cu correlate well but above 25 m the correlation between Au and Cu, and Au and Fe break down. The relevance of 25 m is that it is or has been a hydromorphic boundary that has accumulated Fe and other elements above the other major interface at the Mesozoic/Proterozoic boundary. Below this depth Au can be mobile complexed with sulphur species in a reducing environment as is indicated by the 60 to 100 ppb through the Proterozoic boundary into the Mesozoic. Above 25 m Cu accumulates with Fe but Au peaks at 6 m where there is no Fe peak. The sample at 6 m is clayey and contains elevated levels of Pb, and rare earth elements (REE). This association has been noticed in some Au deposits in WA.

Implications for exploration
Ferruginous materials recognised at Brumby are A. Veining through the Mesozoic that gives little indication of mineralisation at surface. B. Goethitic layers at past or present watertables (25 m and 45 m) which accumulate traces. C. Primary veining in the Proterozoic which may be mineralised.

Gold and Cu are mobile below 25 m which may represent a significant past or present redox front.

Zinc, a relatively mobile element, appears to correlate with variations in the amount of iron. There is a significant peak in the Zn value at a redox front. Whether this represents a residual accumulation or is indicative of accumulation from the lateral migration of Zn with Fe along a permeability barier within the Mesozoic is unclear. Zn does not correlate with Cu/Au mineralisation.

4.3.5 STOP 5:

Location	*477492E 7582830N*
Geology	*Varied*
Landform	*Depositional plain*
Regolith	*Black clay soils*

The blacksoil plains are characterised by gilgai microrelief caused by drying and swelling of smectitic clays. The black soils are usually dark brown to black depending on the physiographic position, with darker coloured soils occupying low-lying areas. Their formation is favoured in an environment where smectite can be formed, with high Ca and Mg and a high silica potential. In terms of particle size distribution, the black soils contain about 70% $<75\mu m$ fraction with the rest dominated by quartz grains and pebbles. The chemical composition of black soils $<75\ \mu m$ fraction is given in Table 8. The black soils, compared to other regolith materials found in the Mesozoic and Proterozoic mesas have relatively higher Mn, Mg, Ca and Zr. It contains mainly quartz with smectite, some kaolinite and feldspars.

The black soils are commonly 1 m to 2 m thick developed over colluvium/alluvium overlying Mesozoic saprolite.

STOP 5

Table 8 : Chemical composition of black soils, <75μm fraction (n=8)

Element	Mean	Min	Max	Range	Median
SiO_2 %	62.1	57.2	67.1	9.9	62.1
Al_2O_3 %	14.6	12.5	16.1	3.6	15.0
Fe_2O_3 %	6.4	5.1	8.8	3.8	6.1
MgO %	1.11	0.78	1.45	0.67	1.19
CaO %	0.66	0.42	1.00	0.58	0.58
Na_2O %	0.44	0.24	0.66	0.42	0.42
K_2O %	0.96	0.70	1.21	0.51	0.97
TiO_2 %	0.9	0.8	1.0	0.2	0.9
MnO %	0.12	0.08	0.17	0.081	0.111
P_2O_5 %	0.06	0.04	0.09	0.04	0.05
LOI %	8.2	6.7	9.1	2.4	8.3
Cr ppm	63	52	73	21	63
V ppm	142	93	226	133	139
Cu ppm	20	12	31	19	20
Pb ppm	21	14	27	13	21
Zn ppm	67	41	92	51	71
Ni ppm	67	25	143	118	54
Co ppm	21	12	38	26	20
As ppm	7	4	14	9	6
Sb ppm.	0.4	0.3	0.5	0.2	0.4
Mo ppm	<5	<5	<5	<5	<5
Ag ppm	<5	<5	<5	<5	<5
Ga ppm	18	15	21	6	17
W ppm	<2	<2	<2	<2	<2

Element	Mean	Min	Max	Range	Median
Ba ppm	456	372	532	160	473
Zr ppm	403	230	555	325	414
Nb ppm	8	<4	17	14	7
Au ppb	<5	<5	<5	<5	<5
Ce ppm	105	79	158	79	93
Cs ppm	4	3	5	2	4
Eu ppm	2.3	1.7	4.6	2.9	2.1
Hf ppm	11.0	6.3	16.0	9.7	11.1
Ir ppb	7	7	7	0	7
La ppm	48.6	33.9	80.8	46.9	43.5
Lu ppm	0.8	0.6	1.3	0.7	0.7
Rb ppm	66	48	79	31	68
Sm ppm	10.4	7.7	15.4	7.7	10.0
Sc ppm	14.6	12.7	16.3	3.6	14.7
Se ppm	<5	<5	<5	<5	<5
Ta ppm	1.65	1	2	1	2
Th ppm	16.9	11.2	30.5	19.3	14.9
Yb ppm	5.4	3.9	9.1	5.2	5.1
Br ppm	5	2	9	7	5
Sr ppm	143	116	212	96	132
U ppm	<2	<2	3	3	<2
Y ppm	49	33	90	57	43
Cl ppm	<20	<20	<20	<20	<20
S ppm	159	120	190	70	165

4.3.6 STOP 6:

Location *479500 - 479550E 7580000N*
Geology *Mesozoic clay/siltstone*
Landform *Alluvial/colluvial plains*
Regolith *Silicified saprolite, saprolite and ferruginous vein in saprolite*

There is a widespread Zn anomaly in the Mesozoic cover (Figure 12). The source of the Zn is unknown. Representative sections showing the nature of the regolith and the locality of the Zn anomaly in the Mesozoic cover are shown in Figure 18. As part of a more detailed study directed to explaining the Zn anomaly two RAB drill holes, ROTR 155 (479500mE/7580000mN) and ROTR 156 (479500mE/7580000mN) with Zn anomaly >1000 ppm were examined. Figure 19 is a schematic regolith profile of ROTR 156 showing the dispersion of Zn and related elements in the regolith. Profile ROTR 155, which is not presented here, exhibits similar geochemical dispersion patterns.

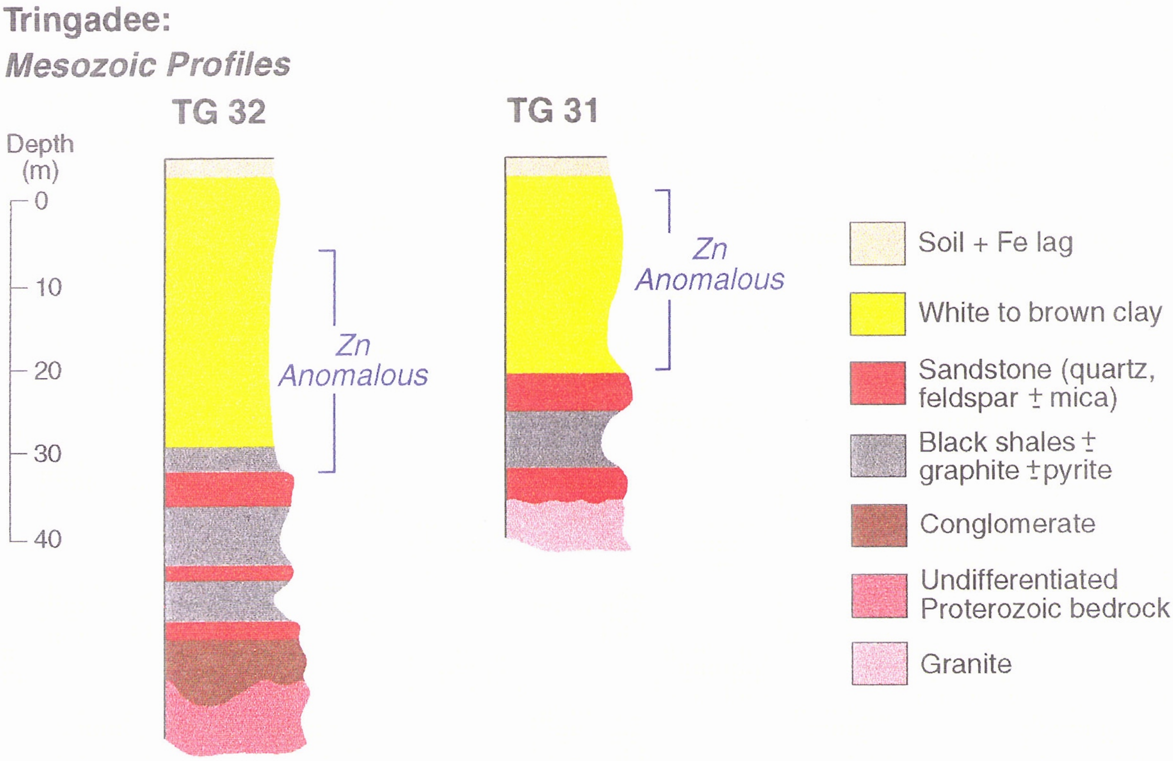


Figure 18. Representative sections through the Mesozoic cover at the Tringadee prospect show locality of anomalous Zn (Aberfoyle Resources).

A geochemical orientation study to determine the sample size fraction that gives the best geochemical signature of the target and pathfinder elements was initially carried out. Based on the median values for the concentration of target element Zn and pathfinder elements like Cu, Pb, As, Sb, the trend is for size fractions >2000µm and 710-2000µm to give comparable values. These may be suitable sampling fractions. These fractions are mainly the ferruginous rich fractions.

Based on this geochemical information, together with the practicability of getting enough of these suitable fractions, the >710µm fraction was selected for further analysis. When there is not enough >710µm fraction, the <710µm fraction was chosen. Selected depths subject to geochemical analyses were based mainly on colour change in the profile. For ferruginous zones occurring in the saprolite, the >710µm fraction was further analysed and separated into Mn rich and goethitic rich materials.

Zinc is found to be relatively enriched in the subsurface ferruginous zones at depths of 20-25 m. This interval contains goethite with digital overgrowths of hollandite. The Zn abundance is 1300-2000 ppm in the ferruginous materials and < 200 ppm in the clay-rich materials. The ferruginous materials and hollandite serve as hosts for elements that became mobilised during weathering and soil formation processes. The Mn oxide shows strong sorption capacity for Cu, Pb, Zn, Ni, Co, Ba, K, Na, Ce.

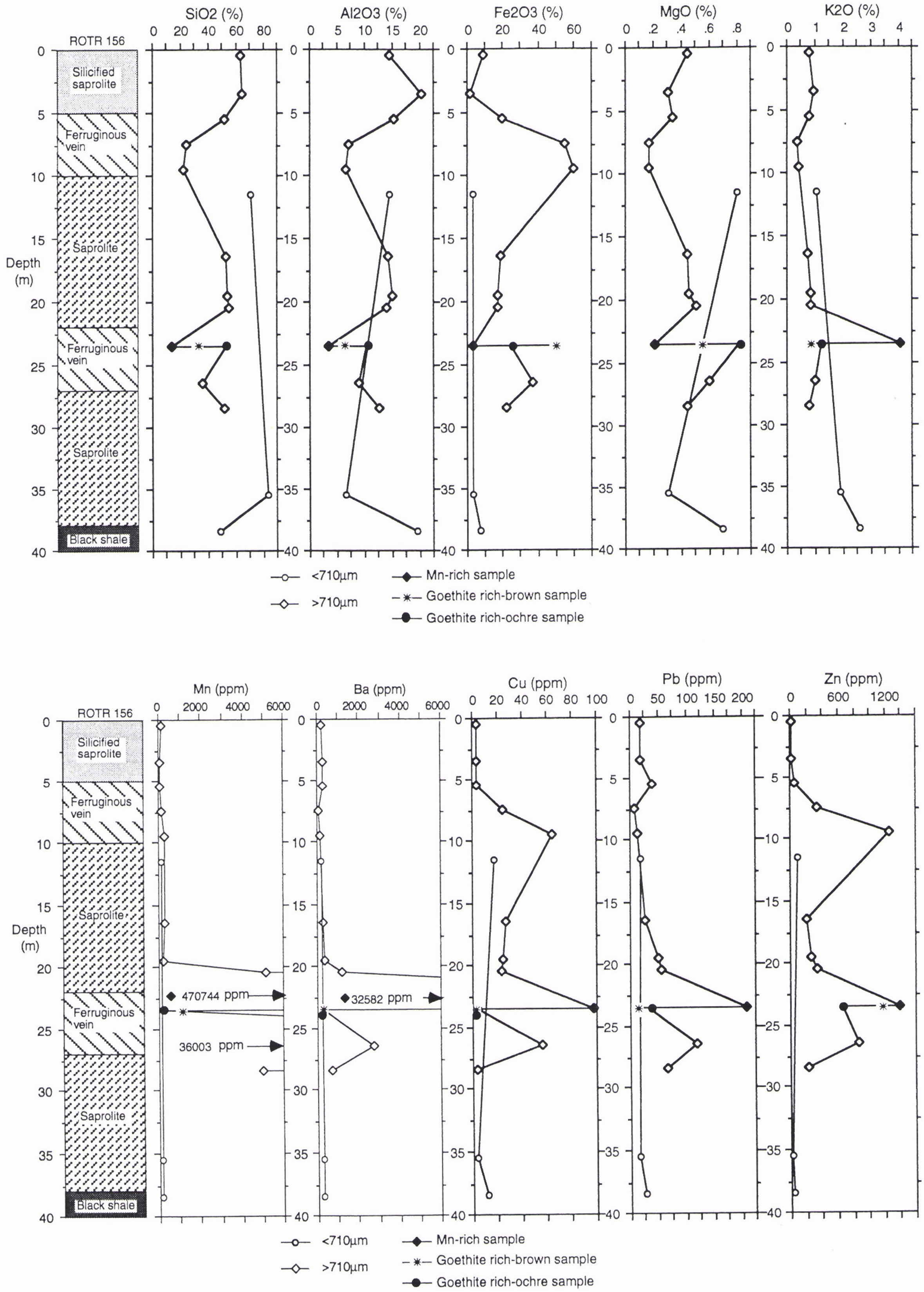


Figure 19. Schematic of the regolith profile for RAB drill hole ROTR 156 with distribution patterns for certain majors and elements.

Implications to exploration
From data generated from these two RAB holes together with observations from Aberfoyle's RAB holes geochemical data, it appears the Zn anomaly in the Mesozoic cover is associated with the accumulation of Fe-oxide and Mn-oxide, probably related to a fluctuating water table and fractures in the Mesozoic cover which appear to conduct Fe-rich fluids from the Proterozoic or from external sources. From Aberfoyle's data of RAB holes with Fe values, it is observed that Zn is better correlated to Fe-oxide than Mn-oxide, but when Fe-oxide is associated with high Mn-oxide, the Zn values are highly accentuated up to >1000ppm. It is likely the Zn is sourced from the Proterozoic itself and has accumulated with iron, with Mn-oxide helping to scavenge anomalous amount of Zn at specific locations where its concentration is extremely high.

4.3.7 STOP 7

Location	*482988E 7581477N*
Geology	*Siltstone/claystone*
Landform	*Mesozoic mesa, approx 300 m asl, with dendritic gorge incision*
Regolith	*Massive, mottled duricrust, lateritic nodules, mega mottles, mottled zone, collapsed saprolite, ferruginous saprolite, ferruginous vein and saprolite*

This is a typical weathering profile on a Mesozoic claystone. Silicification is more extensive in the upper part of the mesa. The lateritic profile contains patchy, lateritic nodules overlying massive, mottled duricrust which diffuses into a mottled zone characterised by blocky megamottles. The mottled zone is underlain by ferruginous saprolite and saprolite (see Figure 15, site 7).

The geochemistry of the regolith materials are shown in Table 9. The massive, mottled duricrust contains 33.1% Fe_2O_3, 40.3% SiO_2 and 13.5% Al_2O_3. The Fe-oxide is mainly goethite, with some hematite, and is concentrated as coatings in voids and as infillings in cracks in the claystone, forming a network pattern. Silicon is present mainly as quartz with some opal-CT. Lateritic nodules were formed by physical breakdown of massive, mottled duricrust or mega mottles. The mottled, massive duricrust and the nodules are rich in V (2500 - 9000 ppm) and are enriched in Si, Al, Pb, Ba, Cr compared to other regolith materials in the mesa

The underlying mottled zone consists of abundant blocky mega-mottles. The boundary between the ferruginous duricrust and the mega mottles is gradational. The matrix of the mottled zone is a highly siliceous porcellanite with quartz and opal-CT minerals and contains up to 75.9% SiO_2, 8.4% Al_2O_3 and 7.4% Fe_2O_3. The Fe-veins, within the mottled zone appear laminated, are rich in Fe (68.1% Fe_2O_3) and consists mainly of goethite, with some mica and kaolinite.

There is collapsed ferruginous saprolite below the mottled zone and the boundary between them is very uneven. The collapsed saprolite consists of siliceous breccias impregnating a yellowish brown clay matrix. This grades into underlying white, brown or purple saprolitic clays which are generally near the foot of the mesa. These clays are smectitic and contain some kaolinite, goethite and mica. Associated with the saprolitic clays are nearly flat ferruginous bands which form a steplike microrelief. They consist mainly of goethite, quartz, some mica and kaolinite. The Fe-oxide in these bands can have up to 34.7% Fe_2O_3.

The geochemical composition of the silicified mottled zone matrix is similar to the saprolitic clays except for more Si, Fe, Cr and V and lesser Al, K, Na and Mg than the clays. The saprolitic clays are relatively rich in Mg, Ca K, Rb and Sr compared to other regolith materials.

STOP 7

Table 9 : Geochemical characteristics of regolith developed over Mesozoic claystone

Sample No Depth(m) Regolith Type	TG 73 0 Lateritic duricrust	TG 72/74 0 Loose Nodules	TG 75 10 Silicified Mottled zone	TG 76 10 Fe vein in Mottled zone	TG 78 40 Fe vein in saprolite	TG 79, 128-130 60 Saprolite (<75µm fraction)
SiO2 %	40.3	23.2-29.4	75.9	15.3	42.3	56.7-63.0
Al2O3 %	13.5	14.5-16.7	8.4	4.9	11.5	19.2-21.7
Fe2O3 %	33.1	42.2-52.4	7.4	68.1	34.7	1.4-9.1
MgO %	0.10	0.06-0.10	0.34	0.12	0.22	0.70-0.78
CaO %	0.09	0.06-0.09	0.19	0.02	0.08	0.21-0.36
Na2O %	0.04	0.00-0.05	0.07	0.03	0.05	0.10-0.17
K2O %	0.06	0.02-0.10	0.69	0.25	0.70	1.19-1.36
TiO2 %	1.2	1.0-1.3	0.6	0.3	0.6	0.8-1.0
P2O5 %	0.02	0.05-0.06	0.04	0.30	0.41	0.07-0.15
MnO %	0.012	0.007-0.013	0.007	0.034	0.011	0.006-0.010
LOI %	10.1	7.7-9.9	7.4	9.0	9.0	7.2-9.2
Cr ppm	438	367-413	65	204	70	39-54
V ppm	8914	2313-2552	427	451	568	103-169
Cu ppm	25	16-18	<10	22	60	<10-11
Pb ppm	235	55-60	28	<5	12	22-28
Zn ppm	60	39-60	18	158	56	23-32
Ni ppm	22	<10	<10	89	<10	<10-101
Co ppm	<10	<10-22	<10	45	9	<10
Ga ppm	26	27-33	17	9	21	19-24
Ba ppm	466	776-821	197	100	120	237-386
Zr ppm	289	257-313	146	106	106	118-175
Nb ppm	11	5-14	6	4	9	<4-6
Ce ppm	22	6-23	32	17	47	54-83
La ppm	11	<10	22	<10	7	32-49
Rb ppm	<5	<5-5	31	10	35	58-68
Sr ppm	32	31-51	102	36	115	266-530
Y ppm	24	15-22	13	5	21	16-17
S ppm	580	550	160	870	380	160-220

5.0 REFERENCES

Taylor, G.F. and Scott, K.M. 1982. Evaluation of the gossans in relation to lead-zinc mineralisation in the Mt. Isa Inlier, Qld. BMR J. Aust. Geol. Geophysics, 7: 159-180.

Nisbet, B. and Joyce, P., 1980. Squirrel Hills Zn-mineralisation Mt. Isa Belt, Qld. In Butt, C.R.M. and Smith, R.E. (eds), Conceptual models in exploration geochemistry, 4 - Australia. Elsevier, Amsterdam, p.169-174.

6.0 ACKNOWLEDGEMENTS

Ian Robertson is thanked for making comments on the manuscript. Pearl Phillips and Jenny Porter are thanked for their assistance in preparing and compiling this Guide. Diagrams were drafted by Angelo Vartesi and Colin Steel.