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LANDSCAPE EVOLUTION AND REGOLITH DEVELOPMENT OVER THE MOUNT COOLON AREA, CENTRAL EAST QUEENSLAND

Li Shu

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April 2002

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

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

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

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

PREFACE

The CRCLEME -AMIRA project 'Geochemical exploration in regolith-dominated terrain of North Queensland' (P 417) has, as its overall aim, to substantially improve geochemical methods of exploring for base metals and gold deposits under cover or obscured by deep weathering. The research includes geochemical dispersion studies, regolith mapping, regolith characterisation, geochronology of weathering profiles and investigation of regolith evolution. This report documents regolith mapping and landscape evolution from the Mount Coolon district in the Charters Towers-north Drummond Basin region. The Mount Coolon 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 north Drummond Basin.

The area around the Mount Coolon is partly covered by Suttor Formation and Quaternary sediments. This has provided some considerable challenges to geochemical exploration because of (i) its allochthenous origin and (ii) the post-depositional weathering and diagenesis. Notwithstanding this, older cover sequences have potential for mechanical or chemical dispersion from underlying mineralisation. The intent of this study was to determine the geomorphic and linked sedimentary history of this region which might have had influence on element dispersion into the regolith and use this to guide exploration programmes. The Mount Coolon area has a complex history of regolith development and landscape evolution. A combination of long weathering history and variable degrees of stripping has resulted in a landscape of highly variable regolith. The dominance of a southerly flowing river system in the early Tertiary, the formation of a large lake system in the middle Tertiary, and the reversal of the river system in the late Tertiary are the main episodes of landscape evolution. Deposition and erosion has been controlled by drainage changes.

Other reports (Scott, 1995; Scott, 1997; Scott and Li, 1996b; Anand *et al.,* 1997) have focussed on investigating dispersions in sedimentary cover and therefore this report should be read in conjunction with other reports from the area. Residual ferruginous materials developed on basement (duricrust, ferruginous saprolite, and mottles), where they occur, should be collected for district- to prospect-scale surveys. The geochemical dispersion appear to occur where the transported cover is shallow (1-5 m). Here, soil sampling would be effective. The probability of hydromorphic dispersion is better in sediments that have been weathered since deposition. In areas dominated by a thick (>5 m) cover, dispersion is predominantly mechanical near the base.

R.R. ANAND Project Leader

I.D.M. ROBERTSON Deputy Leader

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ABSTRACT

The Mount Coolon area has a complicated history of regolith development and landscape evolution. The dominance of a southerly-flowing river system in the early Tertiary, the formation of a large lake system in the middle Tertiary, and the reversal of the river system in the late Tertiary make up the main episodes.

The Eastern Highlands of Australia, in central Queensland, divide the coastal plains to the east and the inland lowlands and hills to the west. To the west of the Highlands, a southerly drainage once existed as shown by the Burdekin, Cape and Campaspe rivers, as well as the upper reaches of the Suttor River and its tributaries such as Police Creek and Rosetta Creek. Tertiary sediments are found on the ancestral southerly flowing rivers.

Eruption of a large volume of basalt around Clermont in the south disrupted the southerly drainage. Tertiary basalts, extruded from fissures and circular vents over a large area during the Tertiary, filled in valleys and blanketed sub-basaltic topography. A palaeovalley under the basalt is evident from bore hole data from various companies. As a consequence of basalt eruption in the south, the southerly flowing Burdekin River system was choked, and a large lake was subsequently formed.

With ongoing deposition in the Tertiary lake, flood waters in the Burdekin River rose to a level higher enough to find a new course along a gap through the Eastern Highlands and divert the river to the east. With a large catchment and high erosional energy, the Burdekin River incised the Highlands and formed a conspicuous gorge and, as a result, a northerly-flowing drainage was developed.

Deposition and erosion in the north Drummond Basin was dictated by these drainage changes. During the period when the southerly drainage was blocked, sedimentation took place at a rapid rate, giving rise to the Suttor Formation in the south and the Southern Cross Formation in the north. With the formation of the Burdekin Gorge, the base level of erosion for the Burdekin River was lowered rapidly, renewing erosion energy within the river system. As a result of rapid erosion, the Southern Cross and Suttor Formations were dissected and largely removed.

Once the easterly drainage system was established, sediments were deposited on the Suttor Formation and its equivalent where less affected by the major change from the southerly to the easterly drainage. New floodplains were built up again where intensive erosion of the Suttor Formations occurred. These late sediments are termed the Campaspe Formation in the Charters Towers region.

Palaeozoic rocks of the Anakie Inlier and Tertiary sediments of the Suttor Formation have been deeply weathered. Saprolites are common in the Anakie Inlier and the Drummond Basin sequence, and in most cases are mottled, bleached or silicified. Late Carboniferous volcanics, mainly rhyolites and ignimbrites, are less weathered and outcrop as saprock. Sediments of the Suttor Formation are ferruginised and silicified, giving rise to the formation of ferruginous duricrusts and silcretes. Lateritic duricrust forms mesa-cappings predominantly on Tertiary sediments, but it is also found on Palaeozoic rocks. Based on field observations, a regolith-landform map of the area (25X49 km) was prepared to a scale of 1:50,000.

This study suggests that ferruginous duricrust, nodules and pisoliths on basement saprolite are effective sample media. Stream sediment sampling may be an alternative approach to explore erosional terrains. Alluviual material, including the Suttor Formation and soils on alluvial plains, is not suitable as a geochemical sample medium. However, where the cover is less than five metre thick, soil sampling, including specific sampling of mottles, would be effective (Scott, 1995; Scott, 1997; Anand et al., 1997). The probability of hydromorphic dispersion is better in sediments that have been weathered since deposition.

1 INTRODUCTION

The Mount Coolon area lies in the northern Drummond Basin between latitudes 21°00' and 21°30'S and between longitudes 147°10' and 147°30'E, about 250 km SSE of Townsville (Figure 1). A quartz lode was discovered in 1913 and gold mining at Mount Coolon was initiated. In 1986, a gold deposit within the Late Devonian Mount Wyatt Formation was found partly under deeply weathered sediments of the Tertiary Suttor Formation at Wirralie, 40 km to the north of Mount Coolon (Fellows and Hammond, 1990; Seed, 1995a). In 1986 and 1987, sediment sampling in the Suttor River led to discovery of another gold deposit at Yandan, about 40 km northwest of Mount Coolon and 40 km southwest of Wirralie (Chenoweth, 1995; Seed, 1995b). A detailed study of landscape evolution and regolith development in this area could contribute to improving exploration techniques for further gold exploration under sedimentary covers.

The main purpose of this study was to map regolith and landforms of an area about 25 km by 49 km to provide a background of landscape evolution for more geochemically-based studies in the area. Emphasis was placed on characterizing weathering profiles on the Tertiary sediments and basement rocks and on determining the origin of Tertiary and Quaternary material. Fieldwork was carried out from October 1995 to November 1996.

With information gained from this study, the landscape evolution of the region was proposed, and a regolith-landform map was prepared to the scale of 1:50,000 (back pocket).

1.1 Previous work

The Mount Coolon area has been geologically mapped by the Geological Survey of Queensland and various mining companies. The geological map of Mount Coolon in the Australia 1:250,000 series was published 30 years ago (Malone and Jensen, 1968). A preliminary geological map, on a scale of 1:100 000, is available with an explanatory record (Hutton *et al.*, 1991). These maps provide basic information on surface geology and were used during fieldwork.

Discussions on Cainozoic mapping units, landscape evolution and weathering process can be found in Hutton *et al.* (1991) and Grimes (1979 and 1980). However, these studies were dominated by the concept of erosion surfaces, and many of the explanations are controversial. Moreover, deeply weathered profiles on Palaeozoic rocks were mistaken as duricrust on the Suttor Formation.

Geological details of individual exploration licenses within the area are available on open file at the Geological Survey of Queensland. These shed light on palaeotopography and the palaeo-environment in which the Suttor Formation was deposited. However, previous mapping by individual companies was largely based on interpretations of aerial photographs and needed to be consolidated.

1.2 Geology

The Mount Coolon area consists of three major structural units, the Anakie Inlier, the Drummond Basin and the Bulgonunna Volcanics. The Anakie Inlier consists of multiply deformed psammitic to pelitic metasedimentary rocks, including fine-grained sandstone, siltstone, slate, phyllite, schist and mafic igneous rocks. It forms a NNE trending basement ridge, surrounded by the Drummond Basin, and has generally been regarded as Early Palaeozoic (Murray and Kirkegaard, 1978), but K-Ar dating of the Inlier gives an age of 500 Ma which is Middle Cambrian (Withnall *et al.*, 1996).
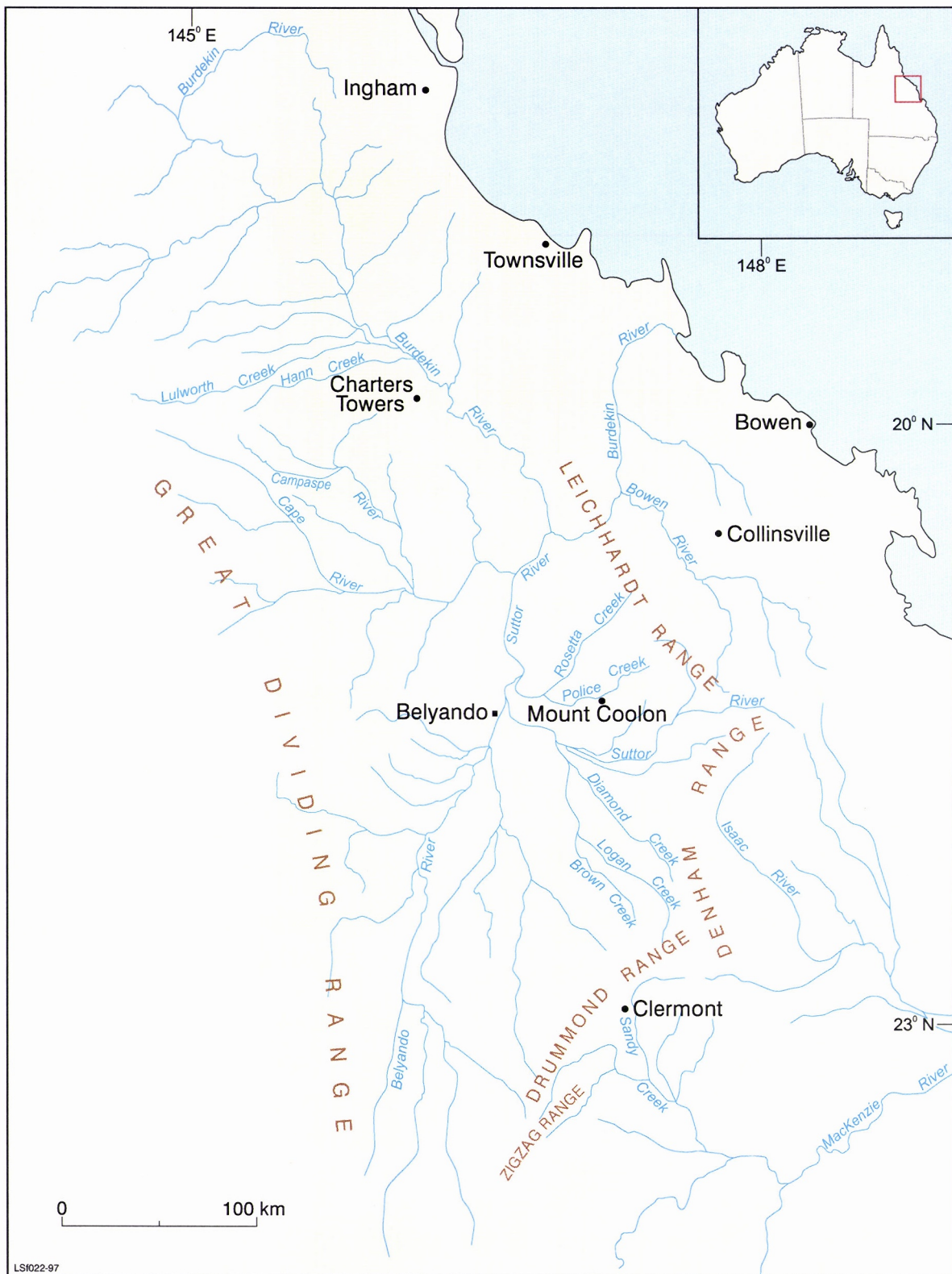
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Figure 1 Location of Mount Coolon and the drainage system of the modern Burdekin River. The study area is situated between Police Creek and Rosetta Creek. The eastern Highlands of Australia follows the Leichhardt and Denham Ranges.

The Drummond Basin sequence comprises the Mt Wyatt Formation and Silver Hills Volcanics, a mixed sequence of Devonian to Carboniferous sediments and volcanics. Lithologically, this consists of medium- to thick-bedded ignimbrites, rhyolitic and dacitic tuffs, sandstones, siltstones and shales (Hutton et al., 1991). The Bulgonunna Volcanics consist of Late Carboniferous rhyolites and ignimbrites outcropping in the northeast and the east of the area. The Volcanics are resistant to erosion and commonly form low hills.

The area has thick unlithified sediments with lignite lenses of the Suttor Formation (Hutton et al., 1991) which now occurs as isolated mesas and low rises on alluvial plains or infills valleys beneath younger alluvial material. Around Mount Coolon, such mesas are 5-25 m high on saprolites of Palaeozoic basement rocks. Drilling shows that the Suttor Formation, beneath an alluvial plain, can reach a thickness of 120 metres (Day, 1981; Strickland, 1993).

The type section of the Suttor Formation is located on Rutherfords Table, 25 km north of the Wirralie Mine (Hutton et al., 1991). The sediments are 73 m thick and form a large mesa of white, massive, fine to medium sandy claystone in the middle and oil shale in the lower part. However, the type section is not considered to be representative; less claystone is found in most other exposures of the Suttor Formation. It is commonly a deeply weathered, coarse, sandy to gravelly sediment showing surficial ferruginization as at the Police Creek Prospect (Scott, 1995).

Oil-shale has not been reported in outcrops around this area, except for the lignite found at the base of the type section at Rutherfords Table. However, drilling on the alluvial plains west of Rosetta Creek penetrated oil-shale and lignite about 45-60 m below surface (d'Auvergne, 1984). Drilling for water by Ross Mining NL also intersected oil shale in this area (Strickland, 1993). The International Mining Corporation NL drilled intensively through the Suttor Formation in the 1980's in search for oil shale in the lower part of the sequence. Bodies of oil shale were located around basement highs of Devonian volcanoclastics at Mt Harry Marsh; two of these were inferred to have oil reserves of 174 Mt at 136 l/t under 20 to 40 m of overburden (Figure 2; d'Auvergne, 1984; Hawley and Marosszeky, 1992).

The age of the Suttor Formation is controversial. Early Miocene pollens were reported from oil shales (Chaffee et. al., 1984). East of Mount Coolon, in the Byerwen area, basalts reported to underlie the formation are dated at 23.1 to 29.2 Ma (Sutherland et al., 1977). This led Hutton et al., (1991) to regard the Suttor Formation as mid-Tertiary. Later work has shown that the Suttor Formation is interbedded in these basalts. A date of 53 Ma, obtained from basalt overlying silcrete of the Suttor Formation at Mt. Dalrymole, indicates an early Tertiary age (Day et al., 1983). In view of its extent and fluvial nature, the Suttor Formation is regarded as having been deposited over a considerable time spanning much of the Tertiary.

Sediments similar to the Suttor Formation are also present in the Charters Towers region as the Southern Cross Formation. The characteristics of the sediments are the same as the Suttor Formation and the period in which the sediments were deposited also ranges from the Early Tertiary to the Miocene. Therefore, the Southern Cross Formation in the Charters Towers area is an equivalent of the Suttor Formation in the south.

Quaternary sediments are widespread in the area, covering much of the Suttor Formation on the plain. The sediments are unconsolidated colluvium and alluvium deposited by the Rosetta, Black, and Police Creeks. They were derived from weathering of basement rocks as well as reworking of the Suttor Formation. The sediments are similar to the Campaspe Formation further to the north in the Charters Towers area, but they lack a formal name at present.

Figure 2 Oil shale in Suttor Formation under the alluvial plain intersected by boreholes (compiled from various reports by International Mining Corporation NL).

1.3 Regional settings

The study area is situated to the west of the Eastern Highlands of Australia and to the east of the Great Dividing Range, and is a part of the Drummond Basin in the Tasman Fold Belt. The Basin is bounded by the Lolworth-Ravenswood Block to the north, the Bowen Basin to the east and south, and the Galilee Basin to the west. It was developed by extension in the Late Devonian to Early Carboniferous and then subjected to compression and shortening during the Carbonifierous and Triassic (Johnson, 1989). There is no evidence to indicate tectonic activity during the Cainozoic, even though faulting of the Suttor Formation was suspected in various company reports based on apparent lineations on aerial photographs.

Within this part of the Drummond Basin, palaeodrainage changes have occurred frequently. The palaeo-current direction in the Palaeozoic Mount Hall Formation is to the north. The Palaeozoic Raymond Formation consists of floodplain and meander bend deposits, with a generally northerly current direction. However, the direction of the palaeocurrent was reversed in the Mount Rankin Formation (Olgers, 1972).

During the Tertiary, a large number of small acid and basic intrusions were emplaced in the Peak Range area, some 40km to the east of Clermont. A large area was covered by basalts of the same age (Cameron and Stephens, 1984). The maximum reported thickness of basalt within the area is about 196m where it overlies a granitic basement (Pacific Coal P/L, 1991). Some boreholes intersected Permain sediment underlying Tertiary volcanics at depths ranging from 55 to 127m, such as Borehole No. WO2, WO3, 17R and 69R (see Figure 5). To the southeast of Clermont, a maximum of 130m of Tertiary units has been intersected with the lithology changing from predominantly volcanic in the north to a volcanic-sedimentary sequence in the south (Pacific Coal P/L, 1991).
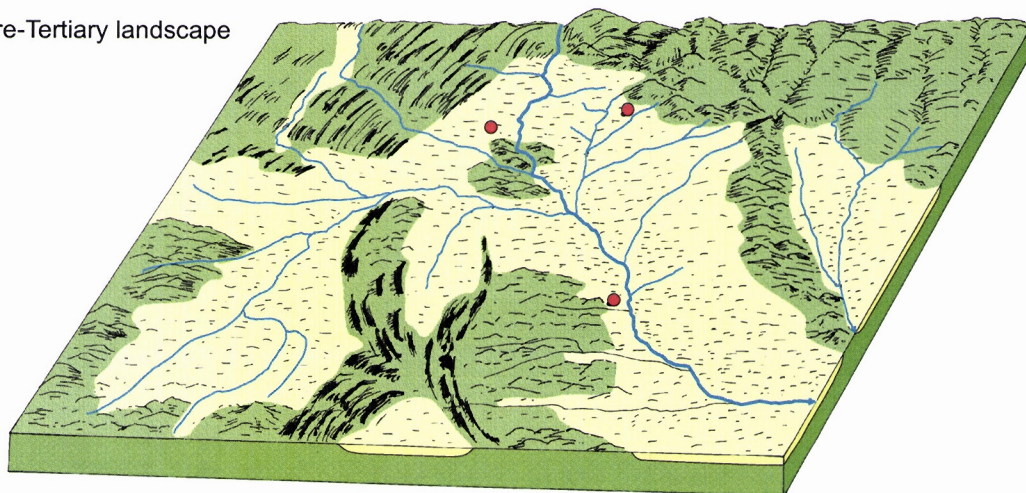
2 LANDSCAPE EVOLUTION

Changes in landscape in the north Drummond Basin have played a major part in regolith development. To understand the characteristics and distribution of the regolith, it is important to examine how the modern landscape developed. From the mineral exploration point of view, there are two major issues, the origin of the regolith and the time since the material has been either weathered *in situ* or, in the case of overburden, deposited. These aspects need to be addressed with an understanding of landscape evolution.

The driving force in landscape evolution is generally drainage development. The dominance of a southerly flowing river system in the early Tertiary, the formation of a large lake system in the middle Tertiary, and the reversal of the river system in the late Tertiary make up the main episodes of landscape evolution here. Eruption of a large volume of basalt to the north-east of Clermont in the southern part of the Drummond Basin, and the breach by the Burdekin River through the Eastern Highlands are the main causes of drainage change (Figure 3).

2.1 The Eastern Highlands

The Eastern Highlands in central Queensland consist of rugged mountains, hills, and dissected plateaux. Although various names have been applied to different sections, such as the Paluma Range and the Leichhardt Range from the north to the south (Figure 1), the Highlands are morphologically a united feature standing between the coastal plains to the east and the inland lowlands and hills to the west. The northern part of the Highlands is approximately 900 m above sea level, but the central part of the Leichhardt Range is only about 500 m.

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A. Pre-Tertiary landscape

B. Early Tertiary volcanism and drainage disruption

Tertiary Lake

N
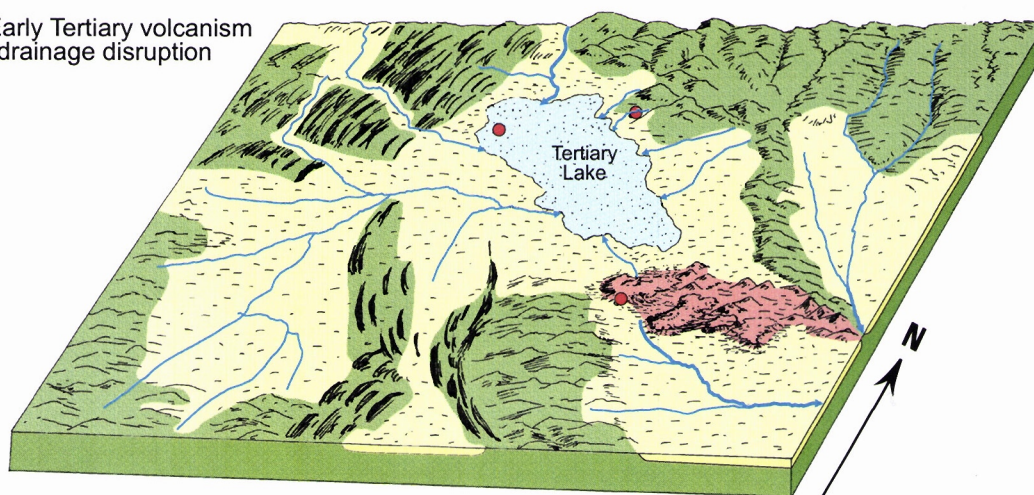
C. Establishment of the present landscape

Campaspe River   Burdekin River   Burdekin River

Cape River

Mt Coolan

Belyando

Suttor   River

River

Belyando

Clermont

Sandy

Creek

Palaeozoic volcanics

Permian sediments

Tertiary and Quarternary Sediments

Tertiary basalt
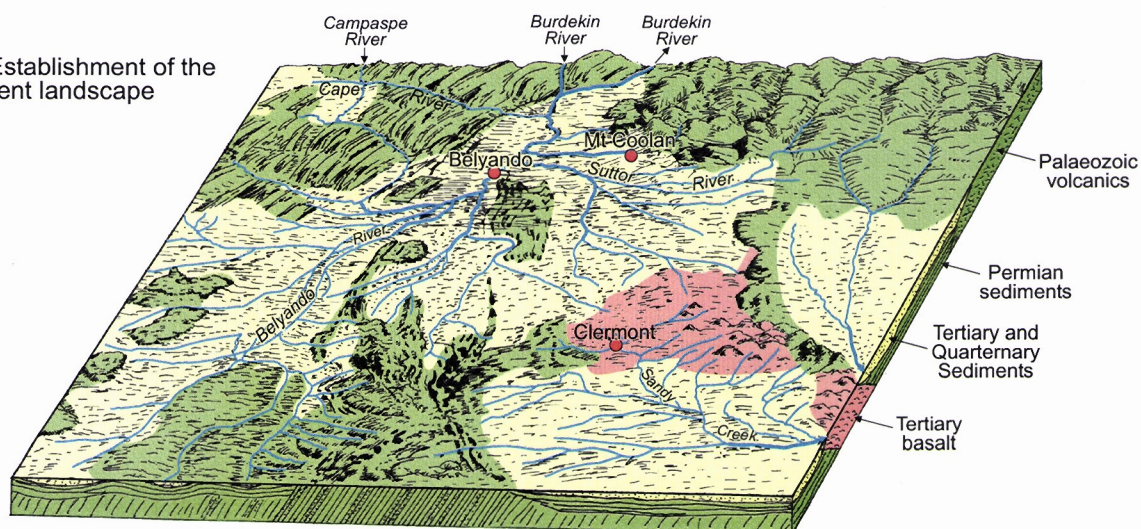
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Figure 3 Landscape evolution in the Drummond Basin. (a) A southerly flowing drainage dominated the basin prior to eruption of basalts northeast of Clermont. The Cape, Campaspe, Belyando and Suttor rivers all joined the Burdekin River tributary to the McKenzie River in the south; (b) Eruption of basalt blocked the ancestral Burdekin River and a lake was formed around the Mount Coolon area; and (c) With the breach through the Eastern Highlands, the Burdekin River took a new course to the east and northeast and established the modern drainage pattern and the present landscape.

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The coastal plains to the east of the Highlands form a corridor from Townsville to the Bowen River valley southwest of Collinsville. To the west of the Eastern Highlands, extensive plains and lowlands dominate the landscape. Alluvial plains are formed along many streams. Lateritic duricrusts on Cainozoic sediments form low mesas on the plains. There are also low granite hills and dissected tablelands on Tertiary sediments about 200-500 m above sea level.

The Eastern Highlands are formed on igneous rocks, both volcanic and intrusive. Outcrops consist of the Ordovician Ravenswood granodiorite complex, the Carbonifirous Bulgonunna volcanics and the Cretaceous intrusives. Since the igneous rocks and intrusives are more resistant to erosion than the Palaeozoic sedimentary rocks to both sides, the Highlands form a prominent feature in the modern landscape.

In the central part of the Leichhardt Range, there is a conspicuous breach through the Highlands by which the Burdekin River traverses the Range. The formation of the gorge dictates landscape evolution of the Burdekin River catchment, including the study area around Mount Coolon.

Prior to the breach across the Eastern Highlands, rivers to the west of the Highlands were unable to flow towards the east. To the west are Palaeozoic rocks which form topographic highs where the present Great Dividing Range stands, and to the north of the Ravenwoods granodiorites are the headwaters of the Burdekin River. Therefore, the palaodrainage could only be to the south. In fact, major streams in the area, such as the Burdekin, the Cape, and the Campaspe rivers, have a southeasterly drainage pattern (Figure 1). The upper reaches of the Suttor River and its tributaries of Police Creek and Rosetta Creek all flow towards the south, but, after some distance, all of them turn to the west and then north to join the Burdekin River which makes a sharp turn to the deeply incised northeast-oriented gorge. Therefore, it becomes necessary to consider a southerly flowing palaeo-drainage system.

2.2 Tertiary Campaspe - Cape River system

Both the Campaspe and the Cape rivers flow from the northwest to the southeast, parallel to the Great Dividing Range to the west. However, at the junction of these two rivers, the Campaspe made a sharp turn to the east and then the northeast, traversing the northern limb of the Scartwater Salient (Figure 4).

Following the general trend of the Campaspe River to the southeast, in the same alignment, there is a low and narrow corridor between the Scartwater Salient and the Bulliwallah Syncline. A few small tributaries of Blowhard Creek, a northerly flowing tributary of the Cape River, drain the northern part of the corridor, while southerly flowing Black Wattle Creek drains the southern part of the corridor into the Belyando River.

Both the Scartwater Salient and the Bulliwallah Syncline have been topographic highs since at least the Cretaceous. The palaeovalley along the boundary between these two geological features is actually a structural depression, so that it should be much easier for the Campaspe River to continue its southeasterly course than opening up a northeasterly channel across tightly folded ridges. Along the corridor, there are Tertiary sediments over 1 km wide and about 60 km long. This continuous distribution of the sediment indicates a large river through this corridor.

The elevations of the top surface of the sediments decrease to the southeast from 245 m to 225, 214 and 194 m. In brief, the ancestral Campaspe River followed this southeast trend through the low corridor. To the west of the Bulliwallah Syncline, the pattern of Tertiary sediments suggests another palaeochannel which ran southeast and then swung around the southern limb of the Bulliwallah Syncline where it joined the ancestral Campaspe River. As it is aligned to the course of the modern Cape River, it is very likely the ancestral course of the Cape River.
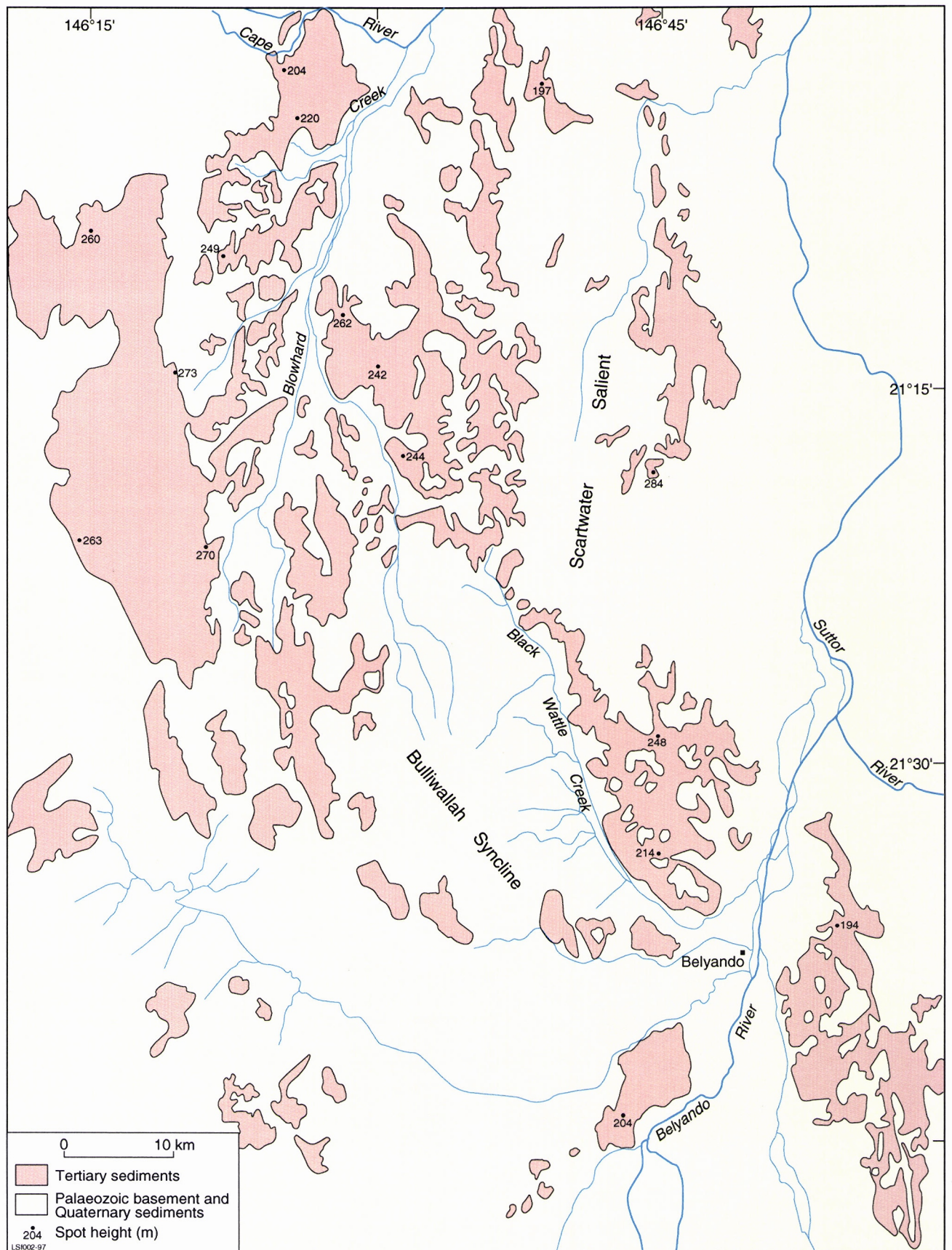
Figure 4 Distribution of Suttor Formation between the Cape River and the Belyando River. The sediments were deposited probably by the ancestral Cape River running southeasterly along Black Wattle Creek (geology simplified from Olgers and den Hertog, 1969).

2.3 Clermont Valley

As the Burdekin, the Campaspe and the Cape rivers flowed south to the present catchment of the Suttor River, a question arises as to the location of this palaeodrainage. One section of the present divide between the Suttor and the McKenzie rivers is located on the Tertiary volcanics about 10 km north and northeast of Clermont. Logan Creek drains to the north into the Suttor River and Wolfang Creek to the south via Sandy Creek and Theresa Creek into the McKenzie River (Figure 1).

The area is covered by Tertiary basalt which filled in valleys and blanketed sub-basaltic topography. Some volcanic plugs stand out on extensive plains (Figure 5). As the plains are very flat, punctuated by some volcanic plugs and domes, it is difficult to envisage the existence of a major sub-basaltic watershed through the plains.

Many bores have been sunk through the basalt in search for Permian coal. Bore 16R located on the divide, was drilled through 197 m of basalt by Pacific Coal Pty Ltd. If the thickness of basalt is substracted from the present elevation of the bore site, the sub-basaltic surface at bore 16R is 167 m. Sub-basaltic elevations for bores WO3, CLD153R and CLD152R to the southeast are 156 m, 152 m and 141 m, respectively. A sub-basaltic valley is evident to the south under the Tertiary basalt, which is probably the southern continuation of the Burdekin River system. The Tertiary river had a very gentle gradient (0.00015). However, the Clermont Valley could have had a lower elevation before the eruption of the Tertiary basalt because, during the period of basalt outpouring, the area might have been uplifted to some extent. Moreover, the area where the Belyando and the Suttor rivers joined is likely to have been subjected to isostatic subsidence due to significant loading in relation with the development of a large lake, which will be discussed later. If all of these factors are taken into consideration, the Tertiary drainage through the Clermont Valley must have had a gradient steeper than that calculated from the bore data.
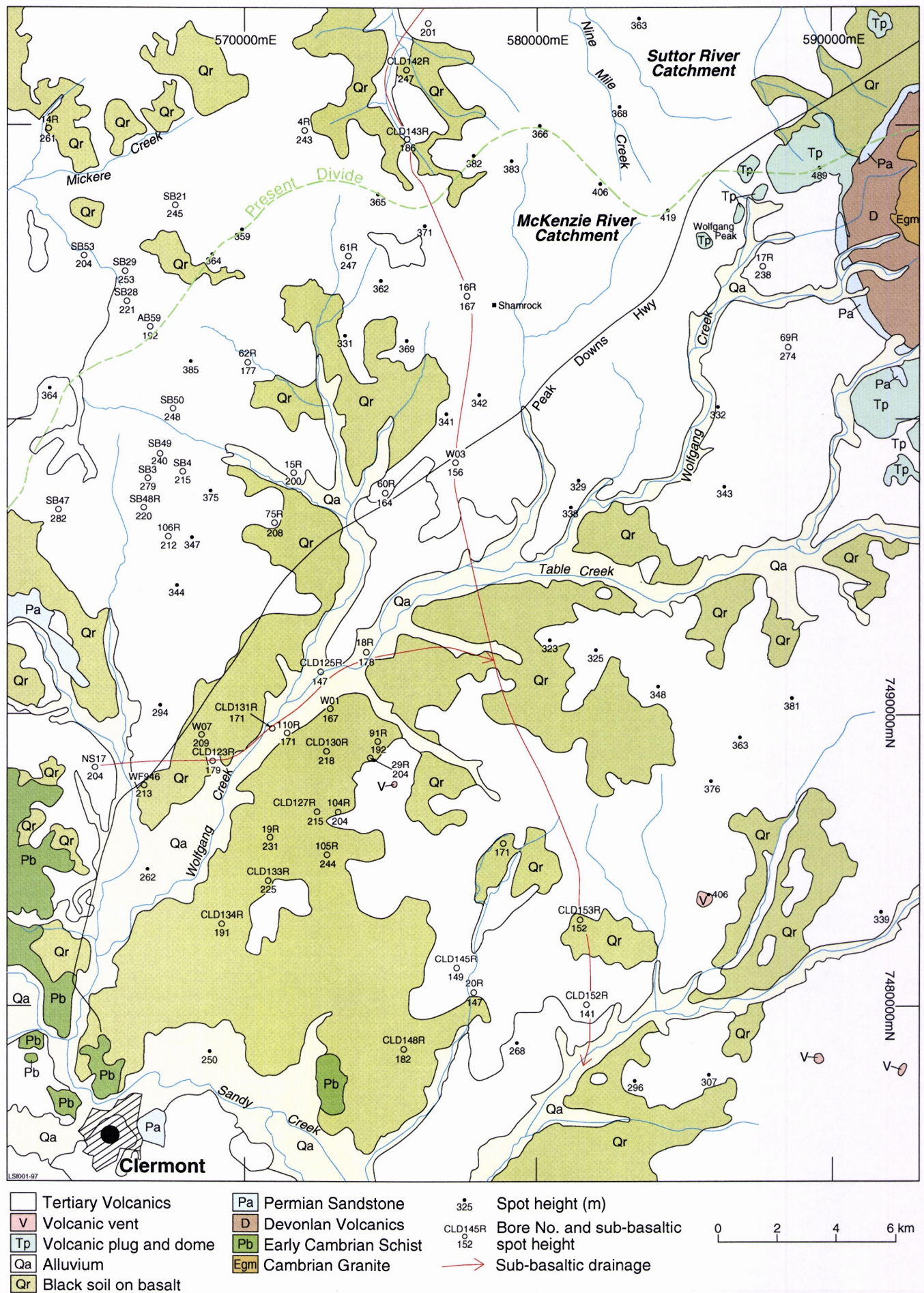
In brief, the modern divide northeast of Clermont, between the Suttor and the McKenzie rivers, did not exist prior to Tertiary volcanism. The Tertiary Burdekin River system, including the Burdekin, the Cape, the Campaspe, and the Suttor rivers probably drained through the Clermont sub-basaltic valley to join the McKenzie River (Figure 1) and via the Fitzroy River to enter the sea at Rockhampton.

2.4 The Tertiary lake

Basalt eruption northeast of Clermont has significantly affected the course of landscape evolution in the Drummond Basin. As a result of channels being filled with basalt, the southerly flowing Burdekin River system was blocked. Consequently, a lake was formed along the lower reaches of the modern Suttor River. Analysis of the pollen from the Suttor Formation suggests a lacustrine environment (Beeston, 1994). Accumulation of a gypsum layer in the lower part of the Suttor Formation is likely to indicate desiccation of the lake (Figure 6A). The exact size of the lake is unknown, due to removal of Tertiary sediments by later erosion and the paucity of drill hole data.

2.5 Drainage changes and sedimentation

Fluvial sediments, deposited by streams, form alluvium plains. However, dynamically active streams would frequently shift their courses according to climatic conditions, channel gradients and aggradation. Where streams change their courses or incise deep enough to drain floodwaters, former floodplains are abandoned and sub-aerial weathering can take place. Streams may return to its abandoned courses, and deposit sedimentary loads on former alluvial plains, with an unconformity between the two suites of sediments.

9

570000mE 580000mE 590000mE

Suttor River Catchment

201

CLD142R 247

Qr

14R 261

Qr Qr Qr

Mickere Creek

4R 243

CLD143R 186

Present Divide

366

382 383

406

419

Nine Mile Creek

363

368

Tp

Tp 489

Pa

D Egm

SB21 245

359

365

McKenzie River Catchment

Wolfgang Peak

Tp

Tp

Tp

Pa

SB53 204

SB29 253

Qr 364

61R 247

371

Tp

17R 238

Qr

SB28 221

362

16R 167

Shamrock

Qa

69R 274

AB59 192

331

369

Peak Downs Hwy

Wolfgang Creek

62R 177

385

Qr

Qr

342

332

SB50 248

341

329

343

SB49 240

SB3 279 SB4 215

15R 200

Qa

W03 156

338

Pa

SB47 282 SB48R 220

375

75R 208

60R 164

Qr

SB47

106R 212 347

Qr

Table Creek

Qa

Qr

344

Qa

323 325

Qr

348

381

Pa

18R 178

CLD125R 147

Qr

Qr

Qr

294

CLD131R 171

W01 167

Qa

363

7490000mN

Qr

W07 209 CLD123R 179

110R 171

CLD130R 218

91R 192

Qr

376

NS17 204

WF946 213

29R 204

V

Qr

CLD127R 215 104R 204

Qr

Qr

19R 231

Qr Qr

105R 244

171

Qr

Pb

262

CLD133R 225

V 406

CLD134R 191

CLD153R 152

Qr

339

Qr

CLD145R 149

Qr

7480000mN

Qa Pb

Pb

250

CLD148R 182

20R 147

268

CLD152R 141

Qr

V V

Pb

Pb Pb

Qr

296 307

Qa

Pb

Pa

Qa

Sandy Creek

Qa

Qr

Clermont

LSf001-97

	Tertiary Volcanics		Pa	Permian Sandstone	325	Spot height (m)
V	Volcanic vent		D	Devonian Volcanics	CLD145R 152	Bore No. and sub-basaltic spot height
Tp	Volcanic plug and dome		Pb	Early Cambrian Schist		
Qa	Alluvium		Egm	Cambrian Granite	→	Sub-basaltic drainage
Qr	Black soil on basalt					

0 2 4 6 km

Figure 5   A southerly drainage beneath Tertiary basalts and across the present divide between the Suttor River and Wolfgang Creek, NE of Clermont (geology after Withnall *et al.*, 1995).

If channel incision takes place, the alluvial plain will be partly eroded away, creating space for later deposition of stream sediments. Where part of a former alluvial plain is completely removed, colluvium and river sediments may form a lower floodplain. These more recent sediments are topographically lower than the old alluvium.

Applying these considerations to the Mount Coolon area, geomorphological processes provide the key to understanding the Southern Cross, Suttor, and Campaspe Formations. The Campaspe Formation is generally formed at a lower position in the landscape than the Southern Cross Formation to the north of the study area because, by the time the Campaspe Formation was deposited, the streams had already dissected the Southern Cross Formation. However, in some places, the Campaspe Formation unconformably overlies the Southern Cross Formation, as at the Red Falls, northwest of Charters Towers (Scott and Li, 1996a). This is due to return of a stream to its former course. The concept of cyclic sedimentation does not apply to the Southern Cross Formation, because they are deposited in different episodes of drainage development but may not have characteristics of sedimentary rhythms. River sedimentation is, in general, a continuous process. Due to course changes, the stratigraphy of fluvial sediments may have unconformities at a specific site.

2.6 Concept of erosion surfaces

The concept of erosion surfaces, that is, near-level surfaces shaped by the disintegrating and wearing action of streams, was improperly extrapolated in the literature prior to the 1960's but, subsequently, Grimes (1979 and 1980) heavily used the concept in his studies of the Drummond Basin. However, although planation occurs on a local scale, there are no *regional* near level erosion surfaces. Many erosion surfaces proposed in the literature are actually common leveled surfaces in various local settings of the landscape.

As discussed above, landscape evolution of the north Drummond Basin is largely dominated by drainage changes in many cases. Fluvial activities contribute to the formation of locally near-flat surfaces. For instance, a large floodplain may first be built up along a major river but, after the main river incised or shifted its channel, the former floodplain may be deconstructed. This is exactly what happened to the Southern Cross and Suttor Formations. Deposited in the ancestral Burdekin River system, these Formations have been dissected and largely removed by erosion so that only remnants of the fluvial sediments remain as mesas. Concordance of the mesa tops reflects river sedimentation rather than erosion (stripping or etching), so that the surfaces of the mesas are not erosion features.

As the top surfaces of the Southern Cross and Suttor Formations are a sedimentary feature, built up in various sub-catchments of the Burdekin River, it is easy to understand why they occur at various levels in the landscape when compared laterally. Since each sub-catchment has its own base level of erosion, the plains built up in different sub-catchments could have different elevations. Moreover, the rate of sedimentation in neighbouring sub-catchments can vary significantly due to variations in lithology and relief, so that one plain can be built higher than the other. A river can also build many terraces in the process of incision. Therefore, the difference in elevation of the Southern Cross and Suttor Formations and the Campaspe Formation can not be correlated.

In the study area, a real, near-level surface does not exist on basement rocks. At the lower level of the modern landscape, erosion plains or planation surfaces have formed locally, such as the plain around the Pajingo Gold Mine (Robertson, 1997). Quaternary colluvium and alluvium, however, also largely cover even this plain. At the middle and upper levels of the landscape, any flat surface or remnant of a near-level land surface on Palaeozoic rocks was not observed despite many traverses. Therefore, the concept of erosion surfaces is not viable in the north Drummond Basin.

3 REGOLITH

3.1 Regolith mapping units

3.1.1 Duricrust

1) Massive ferruginous duricrust developed over mottled and bleached saprolite on Palaeozoic rocks with a lag of ferruginous lithic fragments; mesas bounded by scarps.

Duricrust, in which Fe, Al or Si oxides dominantly accumulate or replace a pre-existing soil or rock, is common over ferruginous, mottled and bleached saprolite on Palaeozoic bedrock (Figure 6B). Massive, ferruginous duricrust is less common on Palaeozoic rocks than Tertiary sediments, and is easily confused with the latter. Metamorphic fabrics and a lack of sedimentary structure or rounded clasts suggest the duricrust has developed on basement rocks. On the surface of the duricrust, there is a veneer of gravel lag, consisting of fragments of ferruginous saprolite and nodules. Indurated material forms a hard layer capping mottled saprolite, usually about 1 to 3 m thick. Beneath the duricrust, iron segregations develop in mottled zone in most cases, or the duricrust may cap the bleached zone in which the upper part of the profile has been weathered to clay. As the duricrust is resistant to erosion, it occurs as mesas bounded by bluffs about 2 to 5 m high.

2) Massive duricrust of silicified and ferruginised sediments on deeply weathered Tertiary Suttor Formation; mesas bounded by scarps.

The Tertiary sediments of the Suttor Formation have been ferruginised and/or silicified to form ferruginous duricrust and silcrete. The sediments are generally only poorly consolidated, but are commonly mottled (Figure 6C). In most cases, the upper part of the profile is a hardened cap of duricrust, under which sands are Fe-stained (Figure 6D). A lag of Fe nodules, pisoliths and fragments of broken mottles occur at the top of the mesas or surrounding them. Fluvial structures such as crossbedding may be apparent. In other cases, the sediments under the duricrust are highly bleached and sedimentary structures are difficult to identify. Careful examination may reveal some rounded clasts indicating a fluvial origin. In places, sediments are highly silicified and silcrete cements the upper part of the profile. For example, weathered sediments at Police Creek and at the Warrilie Mine are highly ferruginised, with mottles and mega-mottles developed throughout the whole profile. Silicification took place wherever silica-rich surface water or ground water was available. Silcrete occurs at the top of mesas, in the middle or at the bottom of weathered profiles. In some cases, the whole profile of about 5 to 8 m is silicified. Morphologically, the duricrust occurs as mesas with bluffs. Where blocks of the duricrust fall, parallel scarp retreat of takes place, leaving accumulation duricrust debris at the foot of the mesa.

3.1.2 Saprolite and saprock

1) Bleached, ferruginised and silicified saprolite partly covered by lithosols with a lag of ferruginous lithic fragments; low hills and local rises.

Sandstones and siltstones of the Anakie Inlier and volcanics of the Drummond Basin sequence have been weathered to saprolite. Generally, the saprolite is partly ferruginised to form large mottles, or bleached to white clays (kaolinite). Silicification of the clay is common. On the surface, a lag of lithic fragments occurs where the slope is gentle; otherwise, iron segregations may occur. Clayey soil, formed from the saprolite, is generally very thin, with a large mount of lithic fragments. Morphologically, it forms low hills up to 15 m high or local rises about 2 to 5 m high.
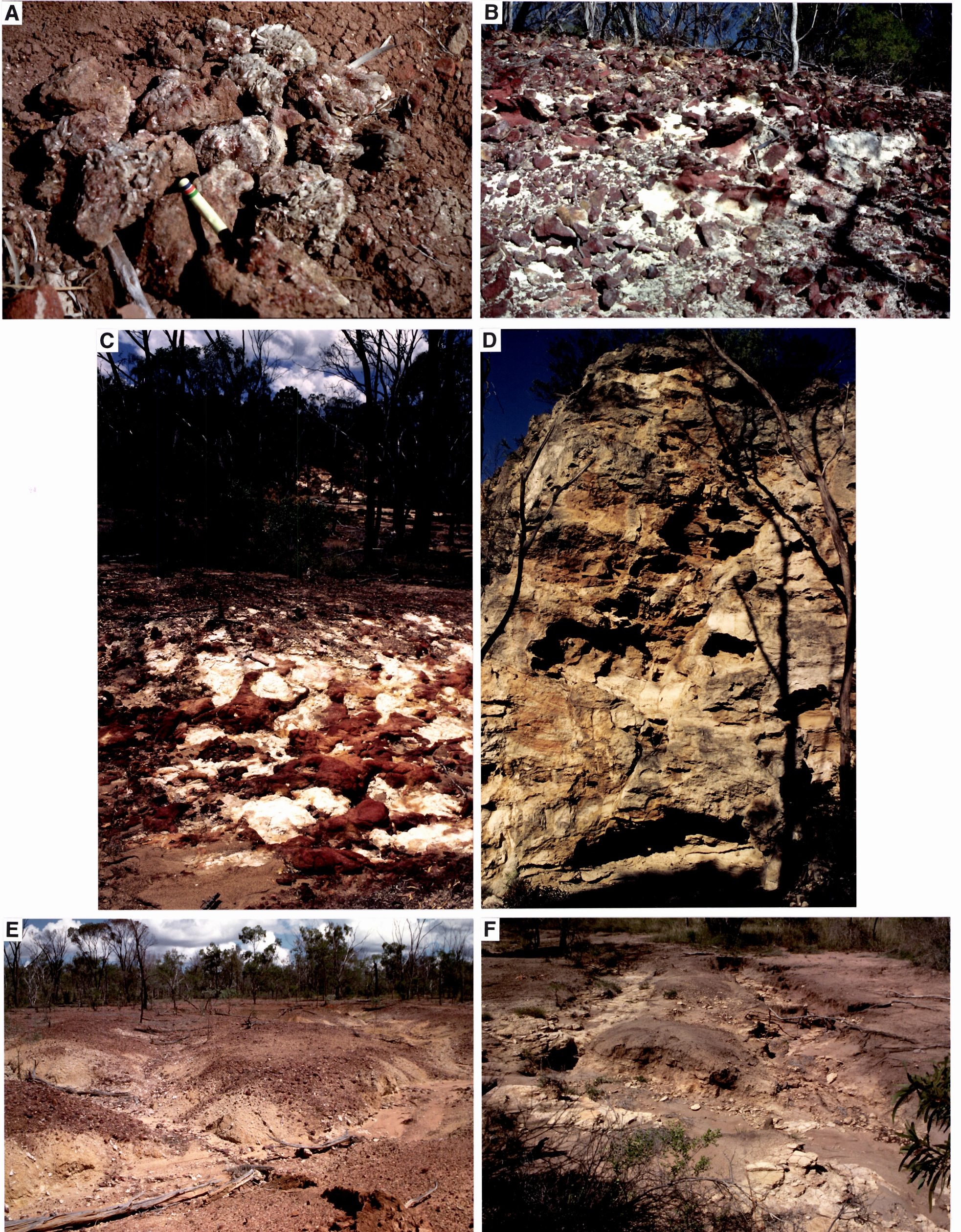
Figure 6 (A) A layer of gypsum (1.5 m thick) under 4 m of the Suttor Formation. Crystal growth would require free space and probably occur in association with evaporation. (B) Ferruginous duricrust on Palaeozoic volcanics. Mottles on saprolite collapsed where clay in the saprolite was removed. (C) Weathering of the Suttor Formation. The Tertiary sediments have been mottled in the foreground. A scarp in the background forms a mesa. (D) The scarp of a mesa consisting of fluvial sediments with cross-beddings. The upper part of the profile is ferruginised and silicified. (E) Ferruginous nodules on shallow, residual soil over saprolite of Palaeozoic rocks, forming a gently sloping plain. (F) Fe-nodules and ferruginised lithic fragments mixed with residual soil on saprolite.

2) Residual lithic soil with Fe oxide nodules on mottled saprolite; gently sloping erosional plains.

During mesa formation, small erosion plains developed where Tertiary sediments and basement rocks have been removed. The plains are partly covered by a residual soil layer about 0.5 to 1 m thick. Ferruginised fragments of the saprolite and small ferruginous nodules occur as surface lag (Figure 6E).

3) Lithic fragments and colluvium on local pockets of bleached and ferruginised saprolite; channel beds of streams and gullies.

Gullies and small creeks have incised into the alluvial plains, exposing bleached and ferruginised saprolite (Figure 6F). This unit consists of lithic fragments in clays and sands, washed by the streams from alluvium nearby. The saprolite, exposed in stream beds, is, in general, bleached to white clays, but there are many cases in which saprolite is highly ferruginised and mottled.

4) Fragments of ferruginous saprolite on volcanics and sands and gravels from the Suttor Formation; sloping pediment plains.

Many mesas occur on saprolite of Palaeozoic rocks where the surroundings have been removed. At the foot of the mesas, there is a mixture of sediments derived from the Suttor Formation and fragments of mottled saprolite, forming a blanket of colluvium. Sands and small clasts in the colluvium are closely associated with the Suttor Formation. Mottled saprolite of basement rocks, commonly under a shallow cover of colluvium, may be exposed. Degradation products of the saprolite add to the Tertiary sediments. At the Police Creek Prospect and Wirralie Mine, the colluvium is slightly mottled (see Figure 8C). As it contains material reworked from the Suttor Formation and, is slightly mottled, this colluvium is generally thought to have been deposited in the late Tertiary and Quaternary. Morphologically, it forms pediment plains gently sloping toward major drainages.

5) Outcrop or subcrop of metamorphic and volcanic rocks as slightly weathered saprock; erosion plains with low rises.

Palaeozoic metamorphic and volcanic rocks have been slightly weathered to saprock. On the saprock, residual soil may be developed in small pockets, with soft, lithic fragments broken down from weathered bedrock. The thickness of the saprock ranges from 1 to 2 m on fresh bedrock and it forms pediments and gently sloping plains.

6) Outcrop or subcrop of volcanic rocks as slightly weathered saprock; low hills.

The Late Carboniferous Bulgonunna Volcanics (mainly rhyolites and ignimbrite) are only slightly weathered. Bedrock is weathered along shears and fractures, with less than 20% of the weatherable minerals altered. Lithic fragments, with very little soil, cover this unit. As the bedrock is resistant, the saprock generally forms low hills.

3.1.3 Alluvium and colluvium

1) Fluvial sediments and river gravels; modern channel beds.

Streams and creeks are filled with sediments and gravel mainly derived from weathering of Palaeozoic rocks and the Suttor Formation in the eastern and northern parts of the area. Coarse sands and fine gravel are common in the headwaters of streams and on alluvial plains; the sediments in the streams are very fine.

14

Figure 7 (A) Alluvial plain built by sediments from Police, Blacks and Rosetta creeks at Mount Coolon, view to the northwest. Extensive grey soil is developed on the plain and, where poorly drained, black soil is formed with a high smectite content.   The chimney marks Mount Coolon on the side of Police Creek. (B) Weathering of the Anakie Inlier.   Saprolite on sandstone and siltstone have been ferruginised in the foreground, and have been bleached to white clay in the background. (C) Weathering of the Suttor Formation. The whole profile has been mottled. Duricrust is formed on the upper part of the profile. (D) Lateritic duricrust is common on the Suttor Formation and ferricrete is found in many localities.

2) Grey to black clayey soils on alluvium; lower alluvial floodplains.

Grey soil is developed on alluvium along Police, Blacks and Rosetta creeks, forming extensive alluvial plains (Figure 7A). Where poorly drained, the soil is smectitic, and swells after rain.

3) Silica-cemented alluvium; lower alluvial plains.

Alluvium close to standing water in creeks is silicified in many places, indicating stream water in the area has a high content of silica (see Figure 8D). Sands and gravel up to 1 to 1.5 m thick can be cemented with silica. The degree of silicification varies with availability of stream water. Where water stands for a long period of time, sediments are aggregated, giving an appearance of concrete. Although they have not yet been consolidated, the cemented sediments are harder than the surrounding material.

4) Brown soil with ferruginous nodules on slightly weathered alluvium; river terraces and higher alluvial plains.

Brown soil, 1-2 m thick on high alluvial plains or river terraces contains clay with a variety of clasts, including poorly sorted sands with angular quartz grains, and fine to medium sized fragments of mottles. It is largely depositional, and the mottle fragments could be reworked from mottles from the Suttor Formation and from ferruginous saprolites on Palaeozoic rocks.

3.2 Regolith development

In the study area, both Palaeozoic basement rocks and Tertiary sedimentary cover have been deeply weathered. Saprolites are common in the Anakie Inlier and the Drummond Basin and are, in most cases, mottled, bleached or silicified. Sediments of the Suttor Formation are also deeply weathered, and mottles, silcretes and ferruginous duricrusts are common. Late Carboniferous volcanics, mainly rhyolites and ignimbrites, are weathered only to saprock.

The regolith on basement rocks, in particular the Anakie Metaphorphics, show that these rocks have been subject to prolonged weathering. In many cases, the bedrock has been weathered to saprolite; Fe was leached from them to leave white clay-rich rocks which were subsequently either ferruginised or silicified to ferruginised saprolite and silcrete, respectively. The dark minerals of granite or ignimbrite, are weathered and bleached to white, silicified saprolite (Figure 7B).

Throughout the whole profile of the Suttor Formation, ferruginisation and silicification occur commonly, with duricrusts developed at the top (Figure 7C). Parts of the fluvial sediments have also been bleached to a white clay (kaolinite). Where silica or iron moved in hydromorphically, the bleached sediments are converted to silcrete and ferruginous duricrust (Figure 7D). Field evidence and petrography indicate that some silcretes have been subsequently de-silicified. A similar process applies to ferruginous duricrust.

When weathering effects have obscured the original sedimentary structures, field identification of parent rocks can be difficult. Weathering of diverse parents, such as Devonian sandstones or granites, result very similar products. In particular, duricrusts formed on mottled, bleached and silicified saprolites of Palaeozoic rocks are similar to those on mottled, bleached and silicified sediments of Suttor Formation. Petrographic studies of some silcretes failed to determine their origin. Field experience shows that fabric of crossbedded sands and small rounded gravels (a few millimeters across) may, however, be present in duricrust on Tertiary sediments.

Initially, all mesas with duricrusts were mapped by photointerpretation as Suttor Formation but fieldwork showed that some of the mesas are actually mottled saprolite on volcanics. The differences

Figure 8 (A) The bluff of a mesa with silcrete boulders in its lower part. The whole profile is highly silicified. (B) Silcrete on the top surface of the mesa shown on (A). (C) Mottled colluvium locally derived from the Suttor Formation and saprolites at Police Creek. (D) The process of silicification is proceeding in the modern streams. The sediments near the hammer are silica cemented.

between weathered claystone of the Suttor Formation and silicified, bleached saprolite from microgranite, or sandstone and siltstone within the Anakie Metamorphics, are all very subtle. In other cases, duricrusts are partly on the Suttor Formation and partly on saprolite over basement rocks, where a very thin layer of the Suttor Formation was left on the saprolites.

Previous study has correctly identified silicification in the Tertiary sediments as a common phenomenon (Grimes, 1979 and 1980; Hutton *et al.*, 1991). Along Bungobine Creek, a large mesa provides a profile in which there are many boulders of silcrete mixed with other volcanic boulders at the base of the mesa (Figure 8A). These boulders were rounded, showing they were not silicified *in situ*, even though the sediments above the boulders were strongly silicified (Figure 8B). In deep lead workings at Rutherfords Table, silcrete boulders up to 1 metre across are found among granite boulders at the base of the Suttor Formation. The granite boulders have been weathered to saprolite; the silcrete boulders have remained hard rocks. Here the sediments above these boulders are not silicified. The only explanation is a complex history of silicification. In view of the high Au content in the silcrete at Wirralie Mine (Scott and Li, 1996b), further study on silcrete formation may lead to some insights into geochemical dispersion.

Weathering of Quaternary sediments has also occurred at the Police Creek Prospect (Scott 1995 and 1997) and nearby Wirralie Mine. Small mottles have developed in the sediments under soil profiles (Figure 8C). However, they are "incipient" and not comparable to those developed in basement saprolite or in the Suttor Formation. Recent sediments are also silicified, indicating the process still operating (Figure 8D).

4 IMPLICATIONS FOR MINERAL EXPLORATION

Ferruginous duricrust on saprolite of basement rocks is thought to have developed largely *in situ*. Ferruginous duricrust, nodules and pisoliths probably indicate composition of underlying parent bedrock (Scott, 1997).

In erosional areas, a thin layer of residual soil on shallow saprolite of basement rocks or lithic soil on saprock may be useful for geochemical exploration, especially if the $-75 \mu m$ fraction is used for Au and the $+2$ mm is used for Fe, As and Sb (Scott, 1997). However, weathering products from basement rocks are commonly stripped away soon after they are available, the anomalies, if found in the soil, are very local. Stream sediments derived from the erosional area might be useful sampling media, especially for regional exploration.

Regolith developed on the Suttor Formation is unlikely to contain chemical signatures that relate directly to mineralization at depth. Reworked mottles from saprolites on Palaeozoic rocks and metals precipitated from groundwater in the Tertiary sediments may give false anomalies. The Suttor Formation contains gold in some places, but the gold is largely due to mechanical rather than chemical dispersion (see also Scott, 1997), as also shown by detrital gold from deep lead workings at Ruthfords Table. At the Wirralie Mine, gold in the Suttor Formation is largely due to input of colluvial material from the mineralization to the Tertiary sediments nearby (Scott and Li, 1996b). However, ferruginous nodules and mottles can be sampled if the duricrust developed on the Tertiary sediments is located directly on saprolites of basement rocks.

Regolith material consisting of fragments of mottles or ferruginous saprolite on basement rocks, with colluvial material derived locally from the Suttor Formation, is also suitable for sampling. The mottles and the fragments can carry geochemical signature for the minerals under the cover of the regolith, as at the Police Creek Prospect (Scott, 1997). The colluvial material may, however, dilute geochemical responses to minerals it covered.

Alluvial material on grey soil plains or brown soil plains is transported and generally does not reflect mineralogy of basement rocks it blanked. The provenance of alluvium is difficult to identify and, if there is an anomaly, its source cannot be ascertained. Therefore, geochemical soil sampling is not viable in depositional areas.

5 ACKNOWLEDGMENTS

REFERENCES

Anand, R.R., Fraser, S.J., Jones, M.R., Li Shu, Munday, T.J., Phang, C., Robertson, I.D.M., Scott, K.M., Vasconcelos, P., Wildman, J.E. and Wilford, J. 1997. Geochemical exploration in regolith-dominated terrain, north Queensland (CRC LEME – Amira P417) Final Report. CSIRO Australia, Division of Exploration and Mining Restricted Report 447R/CRC LEME Restricted Report 63R, 130p.

Beeston, J.W. 1994. Tertiary palynology in the Mount Coolon and Riverside areas. Queensland Geology, vol.6, Department of Minerals and Energy, Queensland.

Cameron, R.A. and Stephens, M. 1984. ATP3476M Final report. Open file No. CR12935.

Chaffe, E., Ekstrom, A., Fookes, C.J.R., Gilkson, M., and Loeh, H., 1984. An examination of the oil shale from the Mount Coolon deposit. In Proc. 2nd Aust. Workshop on Oil Shale, Brisbane, CSIRO, Sutherland, p.56-61.

Chenoweth, L.M. 1995. Geochemical orientation for stream sediment and soil sampling at the Yandan gold deposit, Drummond Basin, North Queensland. In Camuti, K.S. (ed.), Extended Abstracts, 17 IGES 15-19 May 1995, Townsville, EGRV Contribution 54 p.55-61.

Clarke, D.E. and Paine, A.G.L. 1970. 1:250,000 Geological series – Explanatory notes: Charters Towers, Qld. The Bureau of Mineral Resources, Geology and Geophysics, Department of National Development and Energy. Reprinted in 1982.

Day, R.W. 1981. Oil shale in Queensland. Queensland Government Mining Journal, p.214-222.

Day, R.W., Whitaker, W.G., Murray, C.G., Wilson, I.H. and Grimes, K.G. 1983. Queensland Geology. A companion volume to the 1:2,500,000 scale map (1975). Geological Survey of Queensland, Publication 383, 194p.

d'Auvergne, P. 1984. IMC Authority to Prospect 3521m Mount Coolon oil shale project. Unpublished report held by Queensland Department of Resource Industries as CR13538.

Fellows, M.L. and Hammond, J.M. 1990. Wirralie gold deposit. In Hughes, F.E. (ed.): Geology of the mineral deposit of Australia and Papua New Guinea. The Australasian Institute of Mining and Metallurgy, p.1489-1492, Melbourne.

Grimes, K.G. 1979. The stratigraphic sequence of old land surfaces in Northern Queensland. BMR Journal of Australian Geology and Geophysics, 4: 33-46.

Grimes, K.G. 1980. The Tertiary geology of north Queensland. In Henderson, R.A. and Stephenson, P.J. (ed.): The geology and geophysics of northeastern Australia, Geological Society of Australia, Queensland Division, Brisbane, p.329-347.

Gunn, R.H., Galloway, R.W., Pedley, L. and Fitzpatrick, E.A. 1967. Lands of the Nogoa - Belyando area, Queensland. CSIRO Land Research Series, 18.

Hawley, D. L. 1990. Annual report for Bungobine A to P 3882M, central east Queensland. Unpublished report held by Queensland Department of Resource Industries as Open File CR22280.

Hawley, D. L. and Marosszeky, A. 1992. Reassessment of IMC's EPM 3882 Bungobine oil shale deposit, Mount Coolon. Unpublished report held by Queensland Department of Resource Industries as Open File CR24224.

Hutton, L.J., Grimes, K.G., Law, S.R. and McLennan, T.P.T. 1991. Geology of the Mount Coolon 1:250,000 sheet area., Record 1991/19, Queensland Department of Resource Industries, 113p.

Johnson, S.E. 1989. Structural development of the Drummond Basin, Northeast Queensland. In AMIRA P247 Field conference: Gold deposits of the North Drummond Basin, October 30 - November 4, 1989.

Malone, E.A. and Jensen, A.R. 1968. Australia 1:250,000 Geological series: Mount Coolon, Queensland. The Bureau of Mineral Resources, Geology and Geophysics, Department of National Development.

Murray, C.G. and Kirkegaard, A.G. 1978. The Thomson Orogen of the Tasman Orogenic Zone. In Scheibner, E. (ed.): The Phanerozoic structure of Australia and Variations in Tectonic style, Tectonophysics, 48: 229-325.

Olgers, F. 1972. Geology of the Drummond Basin Queensland. Department of Minerals and Energy, Bureau of Mineral Resources, Geology and Geophysics Bulletin 132, Australian Government Publishing Services, Canberra, 78p.

Olgers, F. and Den Gertog, J.G.A. 1969. Australia 1:250,000 Geological series: Buchanan, Queensland. The Bureau of Mineral Resources, Geology and Geophysics, Department of National Development and Energy. Reprinted in 1982.

Robertson, I.D.M. 1997. Dispersion into the Southern Cross Formation around the Scott and Cindy Lodes, Pajingo, N.E. Queensland. CSIRO Australia, Division of Exploration and Mining Restricted Report 449R/CRC LEME Restricted Report 65R, 41p.

Pacific Coal P/L. 1991. Report on the area of Exploration Permit Coal 443 Clermont - relinquished on 24 March 1991. Open file No. CR23598.

Scott, K.M. 1995. The geochemistry of transported soils and weathered bedrock at Police Creek, Drummond Basin – a progress report. CSIRO Division of Exploration and Mining Report 157R.

Scott, K.M. 1997. Soil, bedrock and profile geochemistry at Police Creek, Drummond Basin, Queensland. CRC LEME Restricted Report 25R (CSIRO Exploration and Mining Report 323R).

Scott, K.M. and Li Shu 1996a. Red Falls. In Scott, K.M., Li Shu, Fraser, S., Campwell, I., Anand, R. and Robertson, I.D.M., Charters Towers – North Drummond Basin field excursion. CRC LEME Restricted Report 11R (CSIRO Exploration and Mining Report 286R), p.10-12.

Scott, K.M. and Li Shu 1996b. Wirralie case study. In Scott, K.M., Li Shu, Fraser, S., Campwell, I., Anand, R. and Robertson, I.D.M., Charters Towers – North Drummond Basin field excursion. CRC LEME Restricted Report 11R (CSIRO Exploration and Mining Report 286R), p.69-72.

Seed, M. 1995a. Discovery history, geology and geochemistry of the Yandan Gold Deposit. In Beams, S.D. (ed.), Mineral Deposits of Northeast Queensland: Geology and Geochemistry, 17 IGES EGRV Contribution 52, p.79-90.

Seed, M. 1995b. Discovery history, geology and geochemistry of the Wirralie Gold Deposit. In Beams, S.D. (ed.), Mineral Deposits of Northeast Queensland: Geology and Geochemistry, 17 IGES EGRV Contribution 52, p.91-99.

Strickland, C. D. 1993. Ross Mining NL Yandan water bore program. Unpublished report held by Yandan Mine.

Sutherland, F.L., Stubbs, D. and Green, D.C. 1977. K-Ar ages of Cainozoic volcanic suites, Bowen - St Lawrence hinterland, North Queensland. Journal of the Geological Society of Australia, **24** 447-459.

Withnall, I.W., Blake, P.R., Crouch, S.B.S. and Rapkins. 1995. Australia 1:100,000 Geological special - Geology of the southern part of the Anakie Inlier, Queensland. The Department of Minerals and Energy, Queensland.

Withnall, I.W., Golding, S.D., Rees, I.D. and Dobos, S.K. 1996. K-Ar dating of the Anakie Metamorphic Group: evidence for an extension of the Delamerian Orogeny into central Queensland. Australian Journal of Earth Sciences, 43: 567-572.

REGOLITH - LANDFORM MAP OF THE MOUNT COOLON AREA, CENTRAL EAST QUEENSLAND
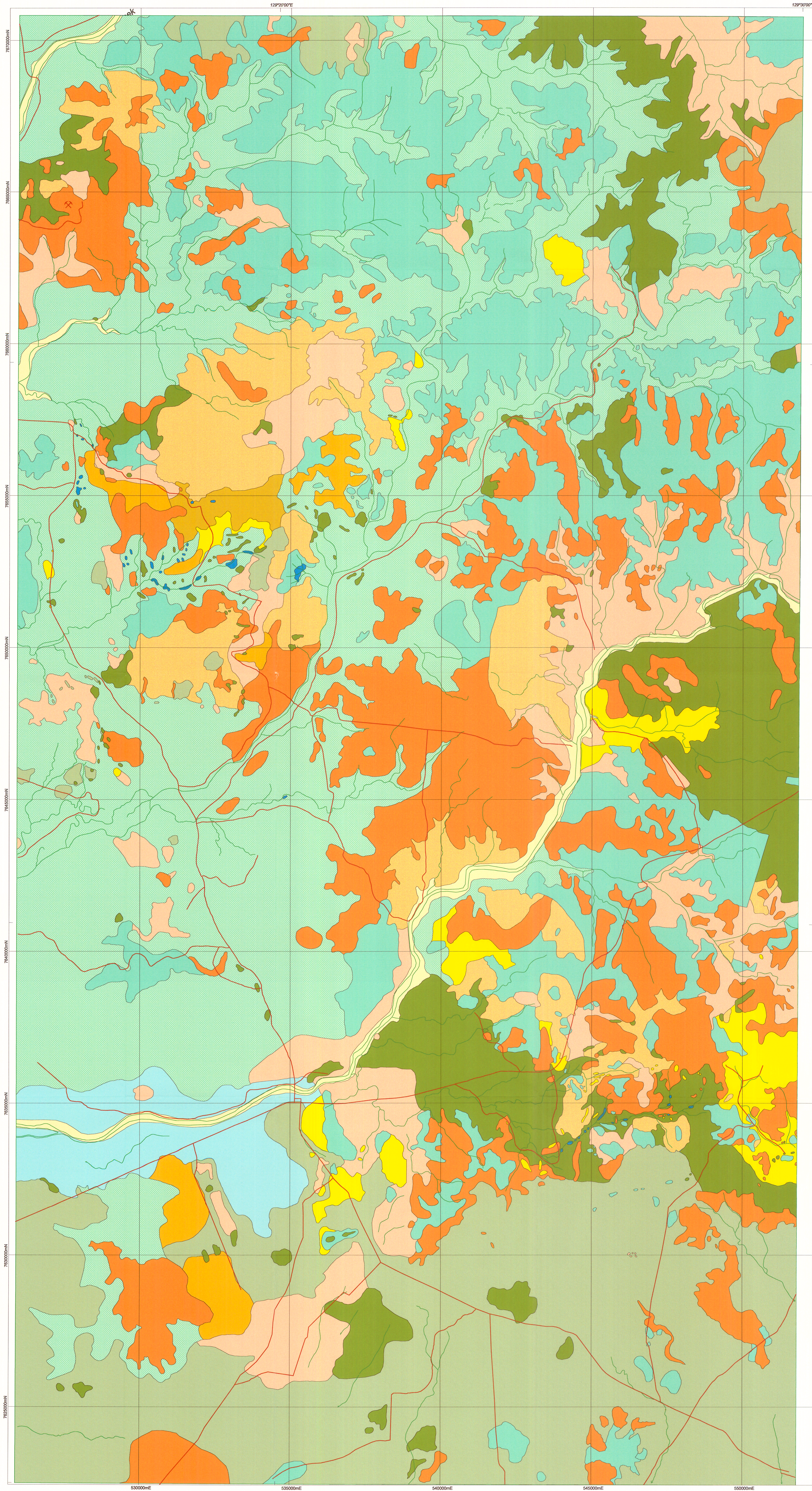
Weathering of Suttor Formation - duricrust developed on mottled fluvial sediments, forming mesas bounded by bluff.

Weathering of Palaeozoic rocks - mottled and bleached saprolite forming massive duricrust, which is similar in characteristics to those developed on Tertiary sediments.

Thin residual lithic soil with large corestones on bleached and mottled saprolite

DURICRUST

PALAEOZOIC BEDROCK

Ds Massive Fe duricrust over mottled and bleached saprolite with lags of ferruginous lithic fragments; mesas bounded by scarps

TERTIARY SEDIMENTS

Sf Massive duricrust common as silicified and lateritic ferruginised sediments on deeply weathered Tertiary Suttor Formation; mesas bounded by scarps

SAPROLITE AND SAPROCK

PALAEOZOIC BEDROCK

Sl Bleached, ferruginised and silicified saprolite partly covered by lithosols with lags of ferruginous lithic fragments; hills and local rises

Rs Residual lithic soil with Fe-nodules on mottled saprolite; gently sloping erosion plains

Sv Lithic fragments mixed with colluvium on local pockets of bleached and ferruginised saprolite; channel beds of streams and gullies

Col Fragments of mottled Suttor Formation and broken saprolite mixed with colluvium on volcanics; Gently sloping plains

Sp Outcrop or subcrop of metamorphic and volcanic rocks as slightly weathered saprock; erosion plains with low rises

Sh Outcrop or sub-outcrop of metamorphic and volcanic rocks as slightly weathered saprock; low hills

ALLUVIUM AND COLLUVIUM

All Fluvial sediments and river gravels; modern channel beds

Bs Brown soil with Fe-nodules on slightly weathered alluvium and colluvium; river terraces and higher alluvial plains

Gs Grey to black clayey soil on alluvium; lower floodplains

Si Colluvium and alluvium cemented loosely by silica; alluvial plains

Cs Slightly mottled colluvium and alluvium containing sediments derived from Suttor Formation and fragments of ferruginous saprolite on volcanics; sloping plains

1 : 50 000

0   1   2   3   4   5 km

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