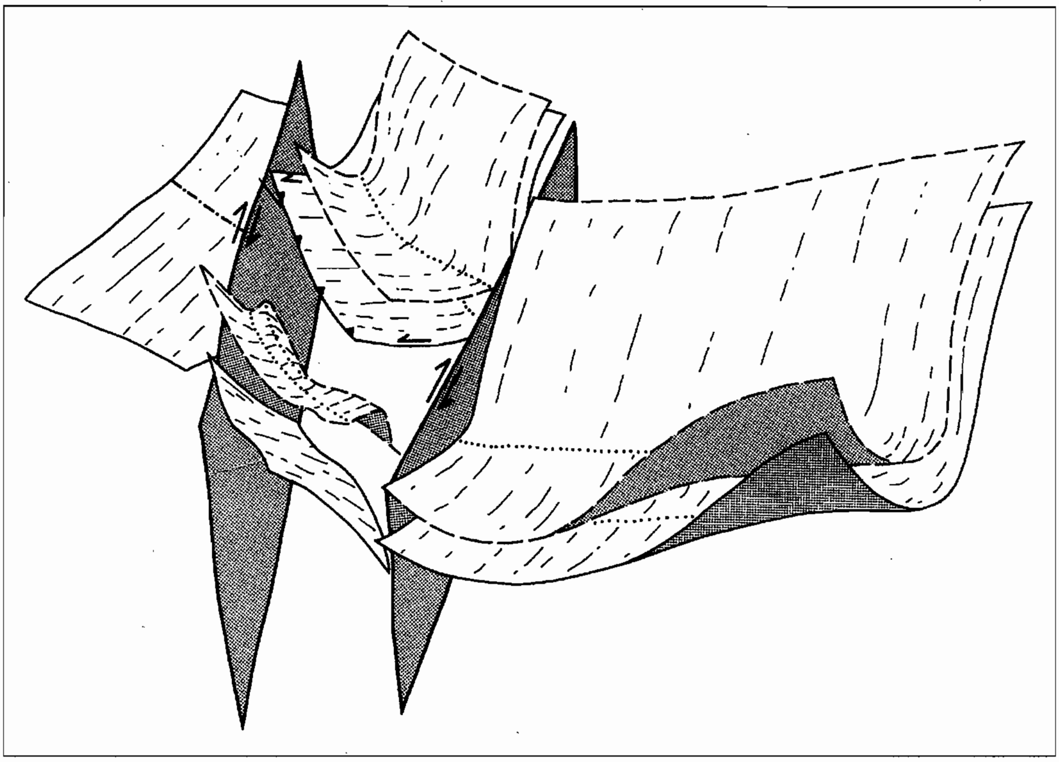
Sediment-hosted base metal deposits

P384A Sponsors Field Meeting



AMIRA/ARC Project P384A
Report 4

September 1997

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An ARC Special Research Centre

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Contents

Acknowledgements

During the period in which P384A fieldwork was carried out base metals exploration was continuing in the Kamarga Dome area in the area, with North Limited the operator in joint venture with Mount Isa Mines. These companies kindly supported the P384A studies of Stuart Bull, Suzanne Cooper and Ben Jones in the form of both logistical support through their field camp and provision of drill core and associated data generated during exploration.

We are grateful to Buka Minerals for providing continued access to the Lady Loretta deposit for research purposes. In particular, Brentan Grant and Geoff Weber are thanked for their efforts in helping with displays for this field trip.

McArthur River Mining and Mount Isa Mines are thanked for providing access to the HYC deposit and assisting with the core display for Day 7 of the trip.

P384A Sponsors Field Meeting

Leaders: Stuart Bull, Peter Winefield, David Selley, John Dunster, Mark Duffett, Peter McGoldrick, Ross Large

Itinerary

PART 1 — WESTERN SUCCESSION, MOUNT ISA

•**Day 1** (Sunday 16th September)
Travel from Mt Isa to Gregory River campsite near Gregory Pub

•**Day 2** (Monday 15th September)
Kamarga Dome — Sedimentology of the Lower McNamara Group; northern Lady Loretta Formation

8.00 AM Depart Gregory River campsite
9:30 AM Traverse Kamarga Dome (Stops KD1 to KD6)
12:00 Lunch
1:00 PM Paradise Creek Formation (Stop KD7
2:00 PM Devil's Gossan (Stop KD8A)
2:30 PM Lady Loretta Formation at Bloodwood Bore (Stop KD8B)
3:30 PM Depart for Riversleigh campsite
4:30 PM Grevillea gossan (Stop GR1)
6:00 PM Clocken ol

•**Day 3** (Tuesday 16th September)
Lady Loretta Formation at Lady Loretta mine; Lady Loretta Formation 'basal' breccia

8.00 AM Depart Riversleigh campsite for Lady Loretta mine via Thorntonia Station
9.30 AM Lady Loretta houses (Barite-chert locality)
10:00 AM Lady Loretta core
11:00 AM Lady Loretta gossan
NB May split in two groups for core and gossan
12:00 Lunch at houses
1:00PM Barite-chert ridge, Big Syncline & costean
3:00 PM Lady Annie phosphate plant (LLF basal breccia)
4:00 PM Cambrian/Esperanza Fmn unconformity
4:30 PM Return to Mount Isa
6:00 PM Clocken ol

•**Day 4** (Wednesday 17th September)
Sponsors meeting in Mount Isa
Drive to Camooweal

•**Day 5** (Thursday 18th September)
Drive to Heartbreak Hotel, Cape Crawford

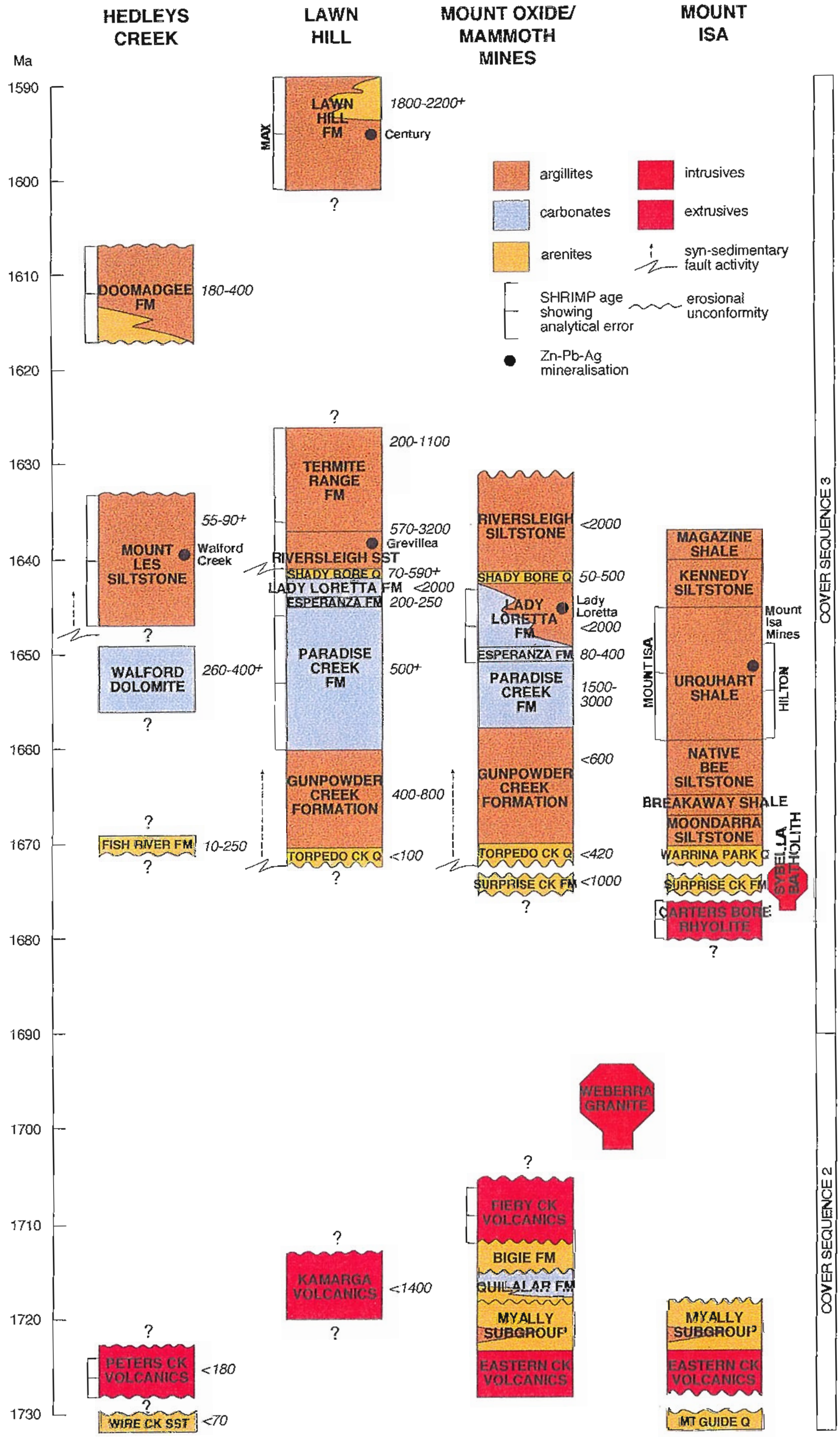
PART 2 — MCARTHUR BASIN

•**Day 6** (Friday 19th September)
7.30 AM Travel from Heartbreak to Kilgour Gorge Prospect for the day and return to Heartbreak in the evening.

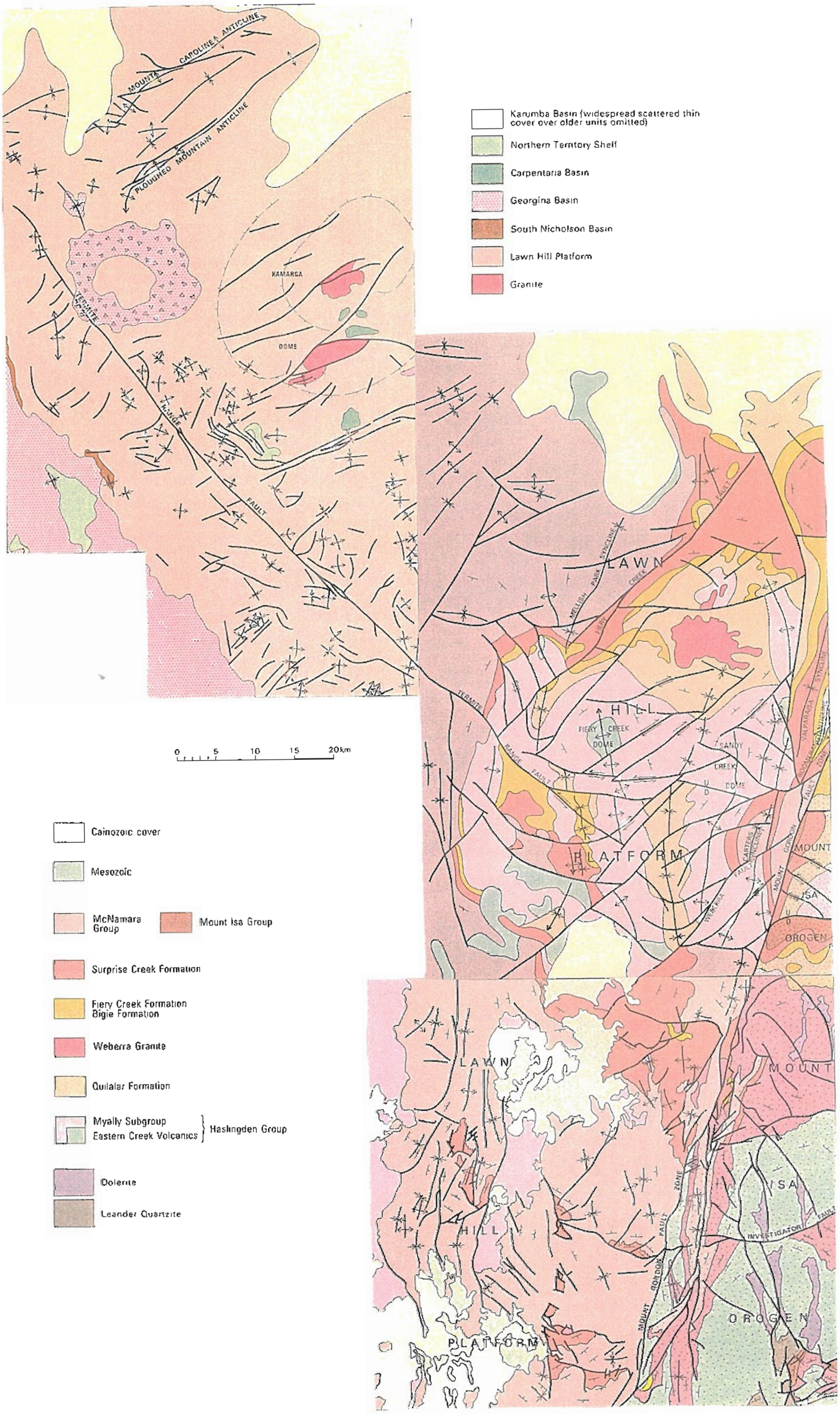
•**Day 7** (Saturday 20th September)
8.15 AM Arrive at McArthur River mine for underground visit and core display. Alternative field localities available in Myrtle Basin for anyone interested.
12.00 Lunch
1.00 PM Travel to Leila Hill where Barney Creek depositional cycle deposits are controlled by the Hot Springs Fault.
3.00 PM Travel to SW Myrtle Basin to examine evidence of syn-sedimentary structural control on Barney Creek depositional cycle deposits.
5.00 PM Return to Heartbreak.

AMIRA P384A Sponsors Field Trip

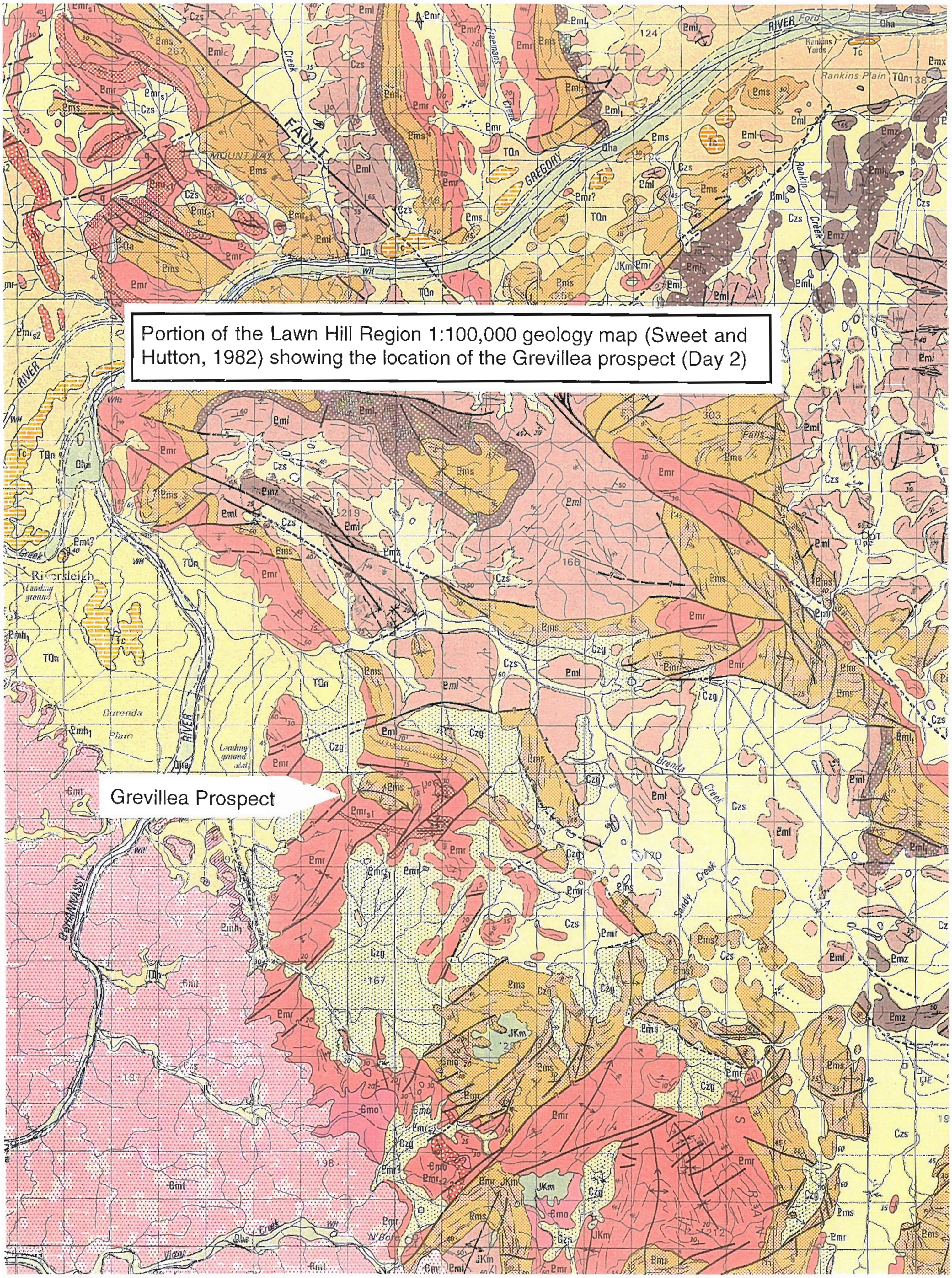
Part 1 Western Succession, Mount Isa



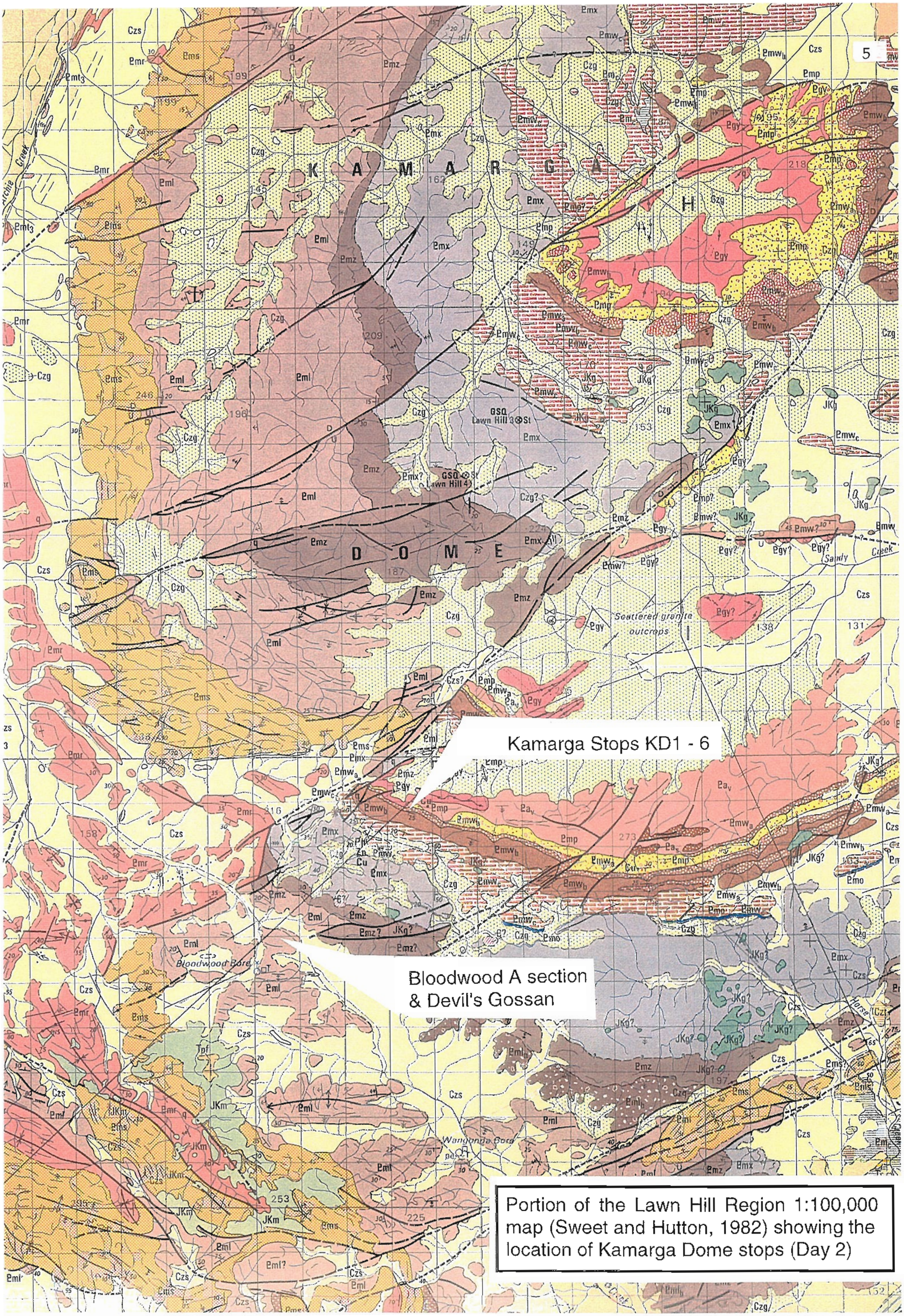
HEDLEYS CREEK
LAWN HILL
MOUNT OXIDE/ MAMMOTH MINES
MOUNT ISA
Ma
1590
1600
1610
1620
1630
1640
1650
1660
1670
1680
1690
1700
1710
1720
1730
LAWN HILL FM
1800-2200+
Century
MAX
argillites
carbonates
arenites
intrusives
extrusives
syn-sedimentary fault activity
SHRIMP age showing analytical error
erosional unconformity
Zn-Pb-Ag mineralisation
DOOMADGEE FM
180-400
TERMITE RANGE FM
200-1100
570-3200
Grevillea
RIVERSLEIGH SST
SHADY BORE Q
70-590+
LADY LORETTA FM
<2000
ESPERANZA FM
200-250
PARADISE CREEK FM
500+
GUNPOWDER CREEK FORMATION
400-800
TORPEDO CK Q
<100
MOUNT LES SILTSTONE
55-90+
Walford Creek
WALFORD DOLOMITE
260-400+
FISH RIVER FM
10-250
RIVERSLEIGH SILTSTONE
<2000
SHADY BORE Q
50-500
LADY LORETTA FM
Lady Loretta
<2000
ESPERANZA FM
80-400
PARADISE CREEK FM
1500-3000
GUNPOWDER CREEK FORMATION
<600
TORPEDO CK Q
<420
SURPRISE CK FM
<1000
MAGAZINE SHALE
KENNEDY SILTSTONE
Mount Isa Mines
MOUNT ISA
URQUHART SHALE
HILTON
NATIVE BEE SILTSTONE
BREAKAWAY SHALE
MOONDARRA SILTSTONE
WARRINA PARK Q
SYBELLA BATHOLITH
SURPRISE CK FM
CARTERS BORE RHYOLITE
COVER SEQUENCE 3
WEBERRA GRANITE
FIERY CK VOLCANICS
BIGIE FM
QUILALAR FM
MYALLY SUBGROUP
EASTERN CK VOLCANICS
KAMARGA VOLCANICS
<1400
PETERS CK VOLCANICS
<180
WIRE CK SST
<70
MYALLY SUBGROUP
EASTERN CK VOLCANICS
MT GUIDE Q
COVER SEQUENCE 2



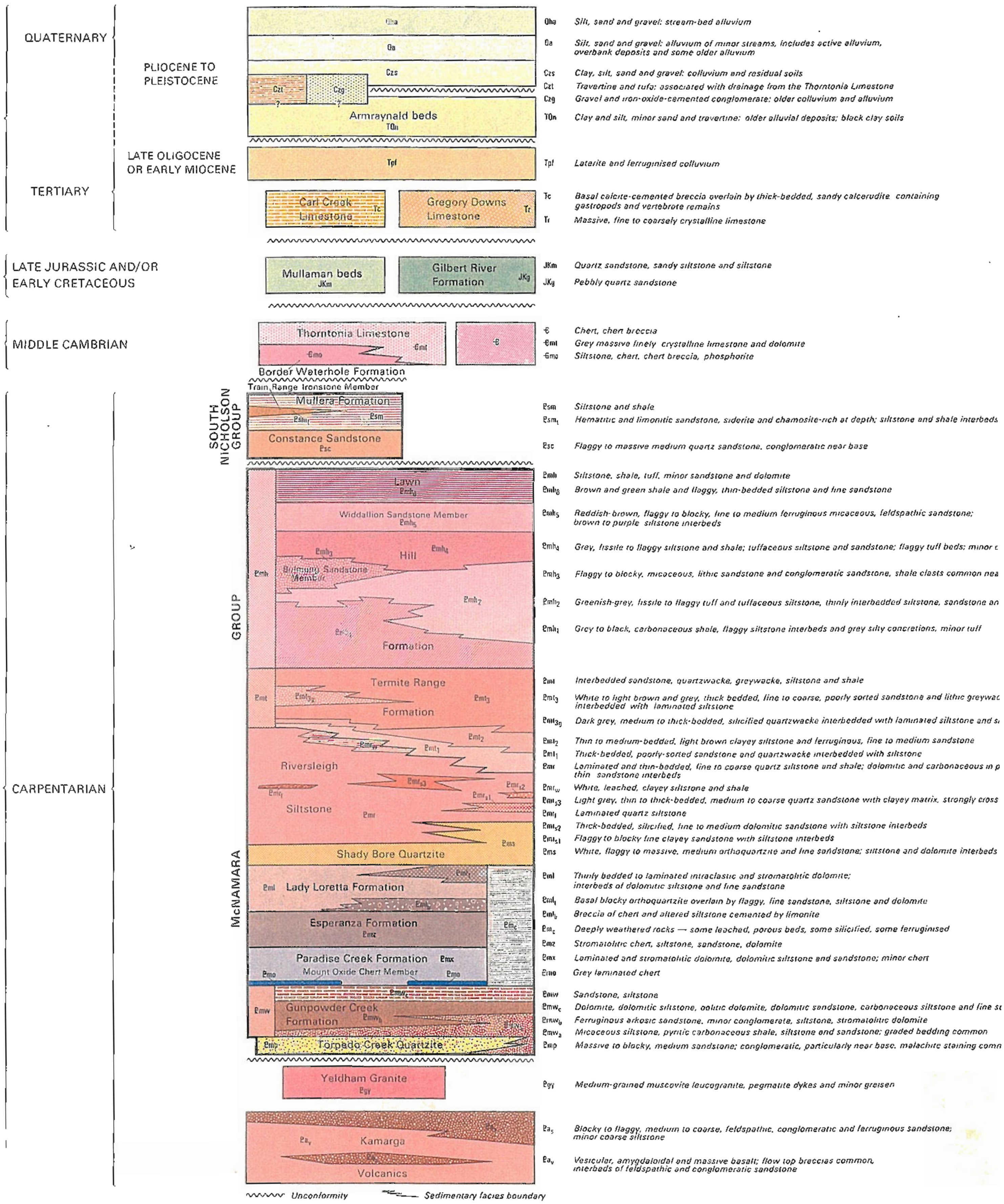
MAJOR STRATIGRAPHIC, STRUCTURAL AND TECTONIC ELEMENTS OF THE LAWN HILL PLATFORM
(FROM GSQ/AGSO MAPPING)

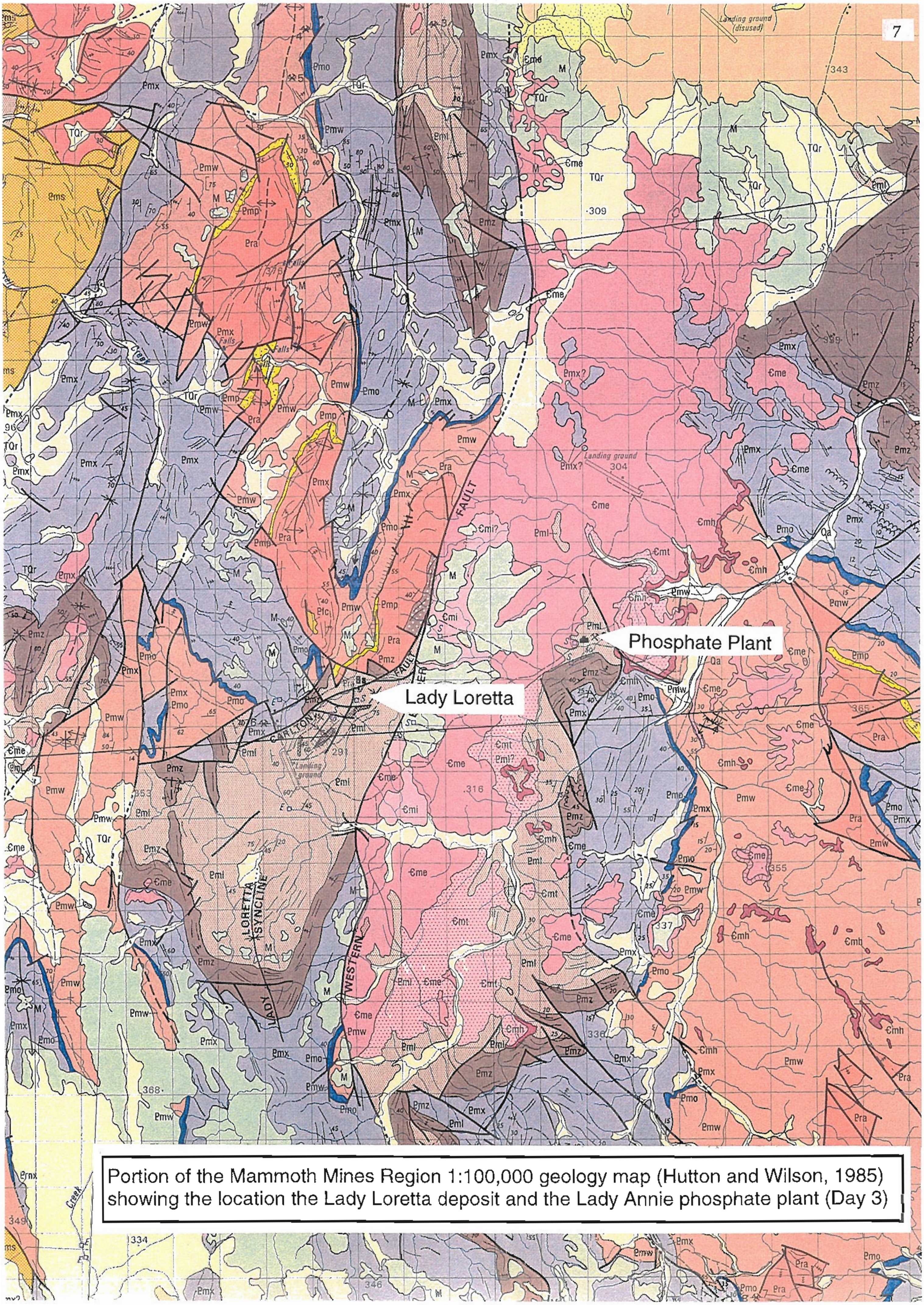


Portion of the Lawn Hill Region 1:100,000 geology map (Sweet and Hutton, 1982) showing the location of the Grevillea prospect (Day 2)

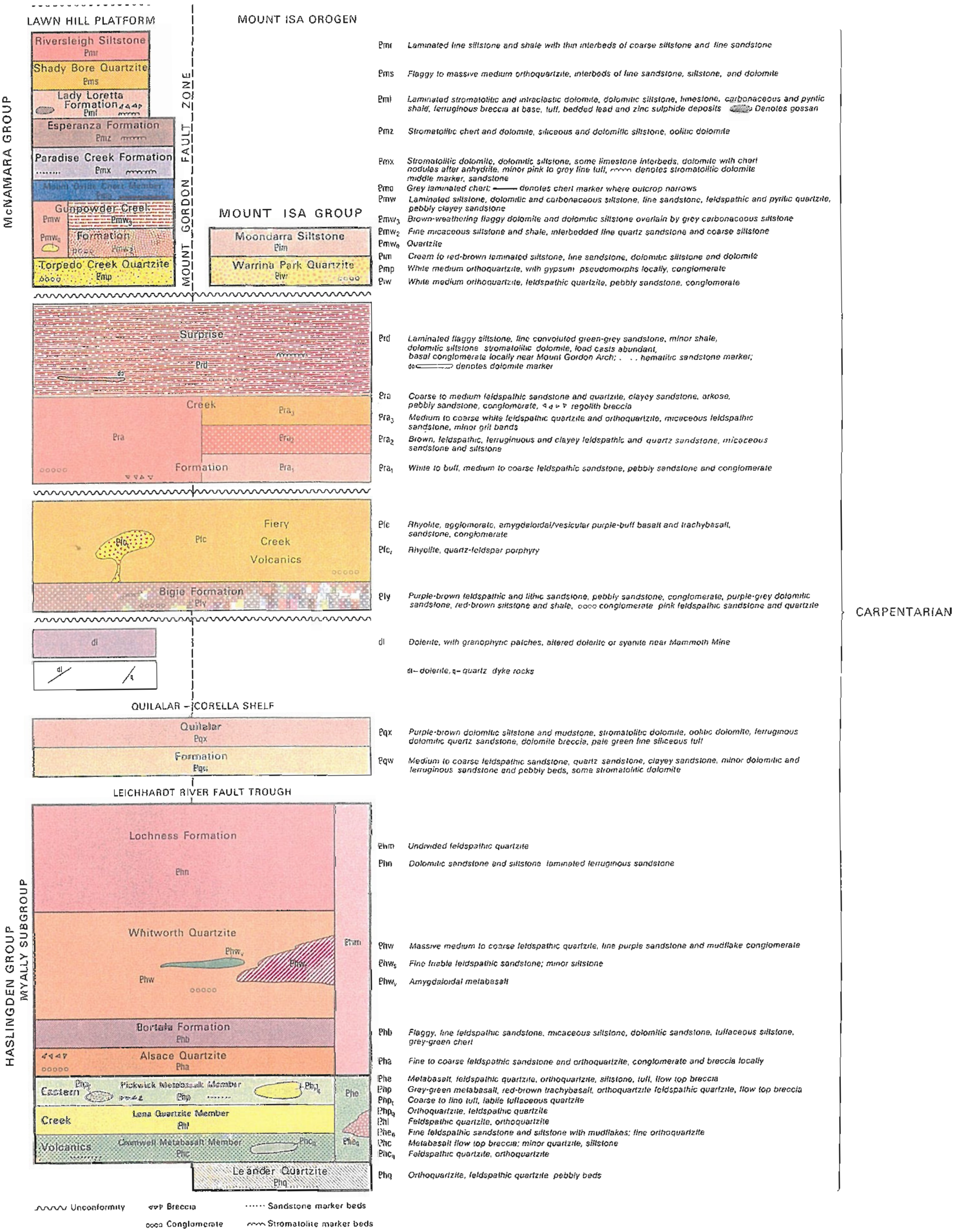


Portion of the Lawn Hill Region 1:100,000 map (Sweet and Hutton, 1982) showing the location of Kamarga Dome stops (Day 2)


QUATERNARY
PLIOCENE TO PLEISTOCENE
LATE OLIGOCENE OR EARLY MIOCENE
TERTIARY
LATE JURASSIC AND/OR EARLY CRETACEOUS
MIDDLE CAMBRIAN
CARPENTARIAN
Armraynald beds
Carl Creek Limestone
Gregory Downs Limestone
Mullaman beds
Gilbert River Formation
Thorntonia Limestone
Border Waterhole Formation
Train Range Ironstone Member
Mullera Formation
Constance Sandstone
SOUTH NICHOLSON GROUP
Lawn Hill Formation
Widdallion Sandstone Member
Bulmung Sandstone Member
Termite Range Formation
Riversleigh Siltstone
Shady Bore Quartzite
Lady Loretta Formation
Esperanza Formation
Paradise Creek Formation
Mount Oxide Chert Member
Gunpowder Creek Formation
Torpedo Creek Quartzite
McNAMARA GROUP
Yeldham Granite
Kamarga Volcanics
Silt, sand and gravel: stream-bed alluvium
Silt, sand and gravel: alluvium of minor streams, includes active alluvium, overbank deposits and some older alluvium
Clay, silt, sand and gravel: colluvium and residual soils
Travertine and tufa: associated with drainage from the Thorntonia Limestone
Gravel and iron-oxide-cemented conglomerate: older colluvium and alluvium
Clay and silt, minor sand and travertine: older alluvial deposits; black clay soils
Laterite and ferruginised colluvium
Basal calcite-cemented breccia overlain by thick-bedded, sandy calcarudite containing gastropods and vertebrate remains
Massive, fine to coarsely crystalline limestone
Quartz sandstone, sandy siltstone and siltstone
Pebbly quartz sandstone
Chert, chert breccia
Grey massive finely crystalline limestone and dolomite
Siltstone, chert, chert breccia, phosphorite
Siltstone and shale
Hematitic and limonitic sandstone, siderite and chamosite-rich at depth; siltstone and shale interbeds
Flaggy to massive medium quartz sandstone, conglomeratic near base
Siltstone, shale, tuff, minor sandstone and dolomite
Brown and green shale and flaggy, thin-bedded siltstone and fine sandstone
Reddish-brown, flaggy to blocky, fine to medium ferruginous micaceous, feldspathic sandstone; brown to purple siltstone interbeds
Grey, fissile to flaggy siltstone and shale; tuffaceous siltstone and sandstone; flaggy tuff beds; minor c
Flaggy to blocky, micaceous, lithic sandstone and conglomeratic sandstone, shale clasts common nea
Greenish-grey, fissile to flaggy tuff and tuffaceous siltstone, thinly interbedded siltstone, sandstone an
Grey to black, carbonaceous shale, flaggy siltstone interbeds and grey silty concretions, minor tuff
Interbedded sandstone, quartzwacke, greywacke, siltstone and shale
White to light brown and grey, thick bedded, fine to coarse, poorly sorted sandstone and lithic greywac interbedded with laminated siltstone
Dark grey, medium to thick-bedded, silicified quartzwacke interbedded with laminated siltstone and s
Thin to medium-bedded, light brown clayey siltstone and ferruginous, fine to medium sandstone
Thick-bedded, poorly-sorted sandstone and quartzwacke interbedded with siltstone
Laminated and thin-bedded, fine to coarse quartz siltstone and shale; dolomitic and carbonaceous in p thin sandstone interbeds
White, leached, clayey siltstone and shale
Light grey, thin to thick-bedded, medium to coarse quartz sandstone with clayey matrix, strongly cross
Laminated quartz siltstone
Thick-bedded, silicified, fine to medium dolomitic sandstone with siltstone interbeds
Flaggy to blocky fine clayey sandstone with siltstone interbeds
White, flaggy to massive, medium orthoquartzite and fine sandstone; siltstone and dolomite interbeds
Thinly bedded to laminated intraclastic and stromatolitic dolomite; interbeds of dolomitic siltstone and fine sandstone
Basal blocky orthoquartzite overlain by flaggy, fine sandstone, siltstone and dolomite
Breccia of chert and altered siltstone cemented by limonite
Deeply weathered rocks — some leached, porous beds, some silicified, some ferruginised
Stromatolitic chert, siltstone, sandstone, dolomite
Laminated and stromatolitic dolomite, dolomitic siltstone and sandstone; minor chert
Grey laminated chert
Sandstone, siltstone
Dolomite, dolomitic siltstone, oolitic dolomite, dolomitic sandstone, carbonaceous siltstone and fine s
Ferruginous arkosic sandstone, minor conglomerate, siltstone, stromatolitic dolomite
Micaceous siltstone, pyritic carbonaceous shale, siltstone and sandstone; graded bedding common
Massive to blocky, medium sandstone; conglomeratic, particularly near base, malachite staining comn
Medium-grained muscovite leucogranite, pegmatite dykes and minor greisen
Blocky to flaggy, medium to coarse, feldspathic, conglomeratic and ferruginous sandstone; minor coarse siltstone
Vesicular, amygdaloidal and massive basalt; flow top breccias common, interbeds of feldspathic and conglomeratic sandstone
Unconformity
Sedimentary facies boundary



Portion of the Mammoth Mines Region 1:100,000 geology map (Hutton and Wilson, 1985) showing the location the Lady Loretta deposit and the Lady Annie phosphate plant (Day 3)


LAWN HILL PLATFORM
MOUNT ISA OROGEN
McNAMARA GROUP
MOUNT GORDON FAULT ZONE
Riversleigh Siltstone
Pmr
Shady Bore Quartzite
Pms
Lady Loretta Formation
Pml
Esperanza Formation
Pmz
Paradise Creek Formation
Pmx
Gunpowder Creek Formation
Pmw
Torpedo Creek Quartzite
Pmp
MOUNT ISA GROUP
Moondarra Siltstone
Pim
Warrina Park Quartzite
Piw
Pmr Laminated fine siltstone and shale with thin interbeds of coarse siltstone and fine sandstone
Pms Flaggy to massive medium orthoquartzite, interbeds of fine sandstone, siltstone, and dolomite
Pml Laminated stromatolitic and intraclastic dolomite, dolomitic siltstone, limestone, carbonaceous and pyritic shale, ferruginous breccia at base, tuff, bedded lead and zinc sulphide deposits Denotes gossan
Pmz Stromatolitic chert and dolomite, siliceous and dolomitic siltstone, oolitic dolomite
Pmx Stromatolitic dolomite, dolomitic siltstone, some limestone interbeds, dolomite with chert nodules after anhydrite, minor pink to grey fine tuff, denotes stromatolitic dolomite middle marker, sandstone
Pmo Grey laminated chert; denotes chert marker where outcrop narrows
Pmw Laminated siltstone, dolomitic and carbonaceous siltstone, fine sandstone, feldspathic and pyritic quartzite, pebbly clayey sandstone
Pmw3 Brown-weathering flaggy dolomite and dolomitic siltstone overlain by grey carbonaceous siltstone
Pmw2 Fine micaceous siltstone and shale, interbedded fine quartz sandstone and coarse siltstone
Pmwq Quartzite
Pim Cream to red-brown laminated siltstone, fine sandstone, dolomitic siltstone and dolomite
Pmp White medium orthoquartzite, with gypsum pseudomorphs locally, conglomerate
Piw White medium orthoquartzite, feldspathic quartzite, pebbly sandstone, conglomerate
Surprise Creek Formation
Prd
Pra
Pra3
Pra2
Pra1
Prd Laminated flaggy siltstone, fine convoluted green-grey sandstone, minor shale, dolomitic siltstone stromatolitic dolomite, load casts abundant, basal conglomerate locally near Mount Gordon Arch; . . . hematitic sandstone marker; denotes dolomite marker
Pra Coarse to medium feldspathic sandstone and quartzite, clayey sandstone, arkose, pebbly sandstone, conglomerate, regolith breccia
Pra3 Medium to coarse white feldspathic quartzite and orthoquartzite, micaceous feldspathic sandstone, minor grit bands
Pra2 Brown, feldspathic, ferruginous and clayey feldspathic and quartz sandstone, micaceous sandstone and siltstone
Pra1 White to buff, medium to coarse feldspathic sandstone, pebbly sandstone and conglomerate
Fiery Creek Volcanics
Pfc
Pfc1
Bigie Formation
Ply
Pfc Rhyolite, agglomerate, amygdaloidal/vesicular purple-buff basalt and trachybasalt, sandstone, conglomerate
Pfc1 Rhyolite, quartz-feldspar porphyry
Ply Purple-brown feldspathic and lithic sandstone, pebbly sandstone, conglomerate, purple-grey dolomitic sandstone, red-brown siltstone and shale, conglomerate pink feldspathic sandstone and quartzite
CARPENTARIAN
dl
dl Dolerite, with granophyric patches, altered dolerite or syenite near Mammoth Mine
dl - dolerite, q - quartz dyke rocks
QUILALAR - CORELLA SHELF
Quilalar Formation
Pqx
Pqw
Pqx Purple-brown dolomitic siltstone and mudstone, stromatolitic dolomite, oolitic dolomite, ferruginous dolomitic quartz sandstone, dolomite breccia, pale green fine siliceous tuff
Pqw Medium to coarse feldspathic sandstone, quartz sandstone, clayey sandstone, minor dolomitic and ferruginous sandstone and pebbly beds, some stromatolitic dolomite
LEICHHARDT RIVER FAULT TROUGH
HASLINGDEN GROUP
MYALLY SUBGROUP
Lochness Formation
Phn
Whitworth Quartzite
Phw
Phwv
Phws
Phm
Bortala Formation
Phb
Alsace Quartzite
Pha
Eastern Creek Volcanics
Pickwick Metabasalt Member
Php
Lena Quartzite Member
Phl
Cromwell Metabasalt Member
Phc
Phe
Leander Quartzite
Phq
Phm Undivided feldspathic quartzite
Phn Dolomitic sandstone and siltstone laminated ferruginous sandstone
Phw Massive medium to coarse feldspathic quartzite, fine purple sandstone and mudflake conglomerate
Phws Fine friable feldspathic sandstone; minor siltstone
Phwv Amygdaloidal metabasalt
Phb Flaggy, fine feldspathic sandstone, micaceous siltstone, dolomitic sandstone, tuffaceous siltstone, grey-green chert
Pha Fine to coarse feldspathic sandstone and orthoquartzite, conglomerate and breccia locally
Phe Metabasalt, feldspathic quartzite, orthoquartzite, siltstone, tuff, flow top breccia
Php Grey-green metabasalt, red-brown trachybasalt, orthoquartzite feldspathic quartzite, flow top breccia
Phpt Coarse to fine tuff, labile tuffaceous quartzite
Phpq Orthoquartzite, feldspathic quartzite
Phl Feldspathic quartzite, orthoquartzite
Pheq Fine feldspathic sandstone and siltstone with mudflakes; fine orthoquartzite
Phc Metabasalt flow top breccia; minor quartzite, siltstone
Phcq Feldspathic quartzite, orthoquartzite
Phq Orthoquartzite, feldspathic quartzite pebbly beds
Unconformity
Breccia
Sandstone marker beds
Conglomerate
Stromatolite marker beds

Day 2 — Kamarga Dome: Sedimentology of the Lower McNamara Group, northern Lady Loretta Formation, Grevillea gossan

Stuart Bull, Andrew Allan, Suzanne Cooper, John Dunster, Peter McGoldrick and Ben Jones

INTRODUCTION

One of the aims of the basin analysis module of AMIRA/ARC Project P384A was to examine the lower McNamara Group comprising the basal Torpedo Creek Quartzite and the overlying Gunpowder, Paradise Creek and Esperanza Formations (see frontispiece maps and correlation chart). This work had several broad objectives as follows;

1. To facilitate comparisons with the lower part of the McArthur Group in the southern McArthur Basin with which this package is traditionally correlated (e.g. Southgate et al., 1997), and which has been the focus of parallel studies in the current project.

2. To investigate the onset of McNamara Group sedimentation by studying the lowermost units, especially the basal Torpedo Creek Quartzite. Studies of the equivalent Masterton Sandstone in the southern McArthur Basin, carried out during the original P384 Project, showed that facies and palaeocurrent patterns recorded important tectonic information. In addition, it was proposed that the unit was a potential conduit for metal-bearing fluids during accumulation of the overlying carbonate-dominated package that hosts mineralisation. The Torpedo Creek Quartzite is similar to the Masterton Sandstone in terms of both sedimentary facies and tectonostratigraphic setting, suggesting that it has similar potential in the western Mount Isa Basin. Studies of the unit were carried out in both the Kamarga Dome area, where relatively continuous exposure allows its relationship to the overlying McNamara Group stratigraphy to be explored, and in the Lady Loretta area, where the aim was to provide some insight into the pre-Isan Orogeny structural framework of the area, and hence into possible fluid conduits for the base metal mineralisation.

3. To document the sedimentological setting of base metal mineralisation at the Kamarga base metal prospect to complement lithogeochemical studies reported in AMIRA P384 Final Report. In a similar fashion, John Dunster's PhD study of the Lady Loretta Formation provides context for lithogeochemical and ore genesis studies of the Lady Loretta deposit.

SUMMARY

The following are the major results of the studies in the Kamarga area that we wish to demonstrate during the field trip:

- The presence of Yeldham Granite and Kamarga Volcanics lithic fragments in the basal Torpedo Creek Quartzite, indicates that a topographic high existed in the area of the Kamarga Dome at the onset of McNamara Group sedimentation. Palaeocurrent pattern in the Torpedo Creek Quartzite and Gunpowder Creek Formation sandstones provide further evidence for this interpretation.

- The transition from the Torpedo Creek Quartzite to the Gunpowder Creek Formation represents a rapid transgression from fluvial through shallow marine to sub-wave base conditions (member 1 of the Gunpowder Creek Formation).

- A subsequent overall regression led ultimately to the deposition of a carbonate-dominated inter-tidal sheet. Associated local supra-tidal sabkha accumulations would ultimately host the epigenetic Kamarga base metal mineralisation. Thickness and facies patterns in these lower McNamara Group sediments indicate that in the Kamarga area at least, the tectonically-generated relief that initiated this depositional cycle had largely waned by the time this middle Gunpowder Creek Formation package accumulated.

- The overlying cyclic, carbonate-dominated Paradise Creek, Esperanza and Lady Loretta Formations accumulated during a period of relative tectonic quiescence (i.e. a sag-phase). The former two units are interpreted to represent a rimmed carbonate platform, however, given the syn-sedimentary relief that existed in the Kamarga area they could also represent the proximal end of a broad ramp system. The northern Lady Loretta Formation is dominated by shallow water, partly hypersaline, carbonate facies.

- The McNamara Group succession in the Kamarga area has been thickened by reverse movement on S-dipping E-W-trending (i.e. bedding parallel) faults. The timing of the compression responsible for the generation of these structures is uncertain, however, it is possible that fluid release associated with it was responsible for the epigenetic Kamarga base metal mineralisation.

- Siliceous and ferruginous duricrust crops out in several places in the Kamarga area, and are developed on both Lady Loretta Formation and Gunpowder Creek Formation. They may be base metal anomalous, but give way at depth to barren parent rock (e.g. Devil's Gossan).

STRATIGRAPHY

In the Kamarga Dome area, a core of Yeldham Granite and Kamarga Volcanics is overlain by a relatively continuous lower to middle McNamara Group succession (Fig. KD 1). Epigenetic Zn mineralisation (Kamarga prospect – Table KD 1) is present in the Gunpowder Creek Formation on the southern flank of the dome (Jones, 1986), and as a consequence there is diamond drill core available from this area.

The general characteristics of the map units exposed in the Kamarga Dome area are summarised below after Sweet and Hutton (1982) unless otherwise cited.

Yeldham Granite

The bulk of the Yeldham Granite is an equigranular medium-grained pink to grey muscovite leuco-granite. It was originally reported to intrude the Kamarga Volcanics, however, this is clearly not the case and it is actually overlain by a basal sandstone to the latter unit that contains granite clasts (Jones, 1986; Jones, 1996). A xenotime age of 1820 Ma has been obtained from the unit (Jones, 1986).

Kamarga Volcanics

The Kamarga Volcanics comprise deeply weathered massive, vesicular and amygdaloidal mafic volcanics and interbedded felspathic and ferruginous rippled sandstone and pebbly sandstone. Individual mafic flow units are up to 40 m thick and interbedded sandstone are up to 50 m thick. Examination of thin sections by the author indicates that the latter are dominated by rounded to sub-angular quartz grains. Accessory material includes feldspar, muscovite and schistose and volcanic lithic fragments.

Torpedo Creek Quartzite

The Torpedo Creek Quartzite is a medium-grained sandstone that ranges in thickness from 0-150 m in the Kamarga area (Jones, 1986). It overlies various units regionally, but at Kamarga it overlies the Kamarga Volcanics, and where this unit is absent, the Yeldham Granite. A basal conglomerate is present locally that includes clasts of both of the underlying units.

Table KD1: Kamarga prospect

- about 20 km ESE of Century; discovered simultaneously by CRA & Newmont in 1972 (18 diamond holes drilled from 1973 - 1980)
- stratabound, discordant, low-grade Zn-Pb mineralisation in evaporitic dolostones of the Gunpowder Creek Formation proximal to the Barramundi/Bream Fault
- GCF dips at about 15°to the south & mineralisation is open down dip & to the east & occupies a triangular area of 2.5 km^2
- asymetrical mineralisation with greatest thicknesses and highest grades adjacent to the Bream fault
- about 50 million tonnes @ 3% Zn+Pb; no significant Cu or Ag grades
- high grade zone of about 10 million tonnes of 5 - 10% Zn+Pb
- pyrite, sphalerite, galena; very minor chalcopyrite, barite, fluorite
- sulphides occur as disseminations, vein (open space fillings & breccia cements), or as massive & semi-massive replacements of host dolomite
- mineralisation has a highly pyritic zone adjacent to Bream fault passing to a weakly pyritic Zn (Pb)-rich zone gradually decreasing in intensity away from the fault

Gunpowder Creek Formation

The Gunpowder Creek Formation conformably overlies the Torpedo Creek Quartzite and consists, in the Kamarga area, of approximately 340 m of micaceous siliclastic siltstones and sandstones with ferruginous dolomitic lithologies becoming more prevalent upsection (Jones, 1986). The Kamarga prospect is a 50 million tonne resource of ~3% combined Zn and Pb that occurs in evaporitic sediments in the middle to upper part of the unit adjacent to the Bream Fault, a splay off the main structure in the area, the NE trending Barramundi Fault. The Gunpowder Creek Formation has been subdivided into three units on the Lawn Hill Region 1:100,000 geological sheet (Sweet and Hutton, 1982), however, Jones (1986) identified eight separate members based on his work on the Kamarga prospect drilling.

Paradise Creek Formation

The Paradise Creek Formation conformably overlies the Gunpowder Creek Formation and is dominated by locally evaporitic dolomitic lithologies with lesser sandstone, siltstone and chert. It is reported to be up to 800 m thick in the Lawn Hill region (Jones, 1986).

Esperanza Formation

The Esperanza Formation conformably overlies the Paradise Creek Formation and comprises similar facies but contains a higher proportion of chertified stromatolitic units. Jones (1986) reported that the silicification was not a surficial weathering feature (although there are several silcretes of this origin in the southern Kamarga Dome area) but persisted in the subsurface. The Esperanza Formation is 200-250 m thick in the Lawn Hill area, and in addition to chert also comprises significant dolomite siltstone, quartz sandstone and recessive highly carbonaceous shale.

Lady Loretta Formation

The northern outcrops of Lady Loretta Formation comprise laminated medium bedded dolomite, dolomitic siltstone and sandstone, stromatoloitic dolomite, and intraclastic dolomite. An evaporitic influence is indicated by the presence of halite casts and carbonate pseudomorphs after gypsum and chert after anhydrite. Sweet and Hutton (1982) describe a reference section of over 2000 m true thickness.

Much of the outcrop of the lowermost Lady Loretta Formation is an enigmatic breccia generally described as consisting of variably coloured, often banded, chert clasts in a fairly homogeneous red-brown cherty, limonitic, to rarely kaolinitic, matrix (Dunster, 1997). The breccia was mapped as an informal litho-stratigraphic member, Pml_b, by Sweet and Hutton (1982) on the Lawn Hill Region 1:100,000 scale geological map.

Isolated outcrops of this breccia, found to be anomalous in base metals, have been locally referred to as gossans (e.g., Devil's Gossan" — stop KD 8A) and have been drilled as exploration targets.

STRUCTURE

Regional structural analysis of the western Mount Isa Basin has been carried out by the Monash University structural group concurrent with the P384 and P384A projects. Some of the results of this work were recently presented in abstract, the relevant parts of which are as follows.

The McNamara Group corresponds roughly with the second of two unconformity bounded sequences deposited in response to a tectonic episode termed the Mount Isa Rift Event (MIRE; Betts and Lister, 1997; O'Dea and Lister, 1997). The development of several large domal structures, including the Kamarga Dome, as laccoliths, is interpreted to have marked the onset of the MIRE at ~1710 Ma (Betts and Lister, 1997). Dome development was apparently diachronous, as both the Fiery Creek Dome and the Kamarga Dome are overprinted by NW-dipping normal faults (? the Barramundi Fault at Kamarga). Uplift of these domal features pre/during the MIRE may have partitioned rift package into sub-basins to the NW and SE (Betts and Lister, 1997).

The MIRE involved a multiphase period of E-W to NW-SE extension with sediments accumulating in resultant E-deepening half-grabens (O'Dea and Lister, 1997). The NW-trending Termite Range Fault may have acted as a regional transfer system. The earlier depositional sequence (Betts and Lister, 1997) comprises the Bigie Formation and Fiery Creek Volcanics (rift phase) and Surprise Creek Formation (sag phase). The latter sequence corresponds roughly to the McNamara Group, although rifting is not interpreted to have begun until Gunpowder Creek Formation time (Betts and Lister, 1997). The subsequent sag phase cycle is attributed to the Paradise Creek, Esperaza and Lady Loretta Formations.

Post-sedimentary compressional tectonism termed the Isan Orogeny occurred from ~ 1590 to 1500 Ma and was interpreted by O'Dea and Lister (1997) to have involved initial N-S shortening (D1) and subsequent E-W shortening (D2). The effects of this tectonism in the western fold-belt were largely manifested as reactivation of pre-existing rift faults giving widespread basin inversion (O'Dea and Lister, 1997). Many of the fault-bounded blocks that originated during rifting continued to act as coherent structural entities during shortening.

Structural analysis in the Mount Isa Basin in P384 and P384A has been restricted to the McNamara Group in the two areas where detailed work has been carried out, the southern flank of Kamarga Dome and Lady Loretta. However, aspects of this work have implications for the regional analysis provided by Betts and Lister (1997) and O'Dea and Lister (1997) as follows:

1. There is no evidence that the main NW-trending structure in the Kamarga Dome area, the Barramundi Fault, acted as a major normal fault during deposition of the Gunpowder Creek Formation. Drill core intersections from either side of the structure intersect Gunpowder Creek Formation sediments of broadly similar facies and unit thicknesses. The thickness changes that are present are restricted the Torpedo Creek Quartzite and the lower few members of the Gunpowder Creek Formation, interpreted to indicate that the rifting episode began during accumulation of the former (Bull, 1997).

2. Conglomerate facies occur at the base of the Torpedo Creek Quartzite in both the southern Kamarga Dome and Lady Loretta areas. In the latter case, clasts of apparent Surprise Creek Formation up to 3 m in size are present, providing further evidence for the rapid generation of topography (?rifting) at this time.

3. In the southern Kamarga Dome region, south-dipping east-west trending (i.e. bedding parallel) faults are present that repeat stratigraphy. These tend to occur in fine-grained less-competent units (e.g. carbonaceous shales in the Gunpowder Creek Formation) and repeat resistant units (e.g. the Torpedo Creek Quartzite and Gunpowder Creek Formation sandstones). A fault with a similar orientation occurs in the uppermost part of the Yeldham Granite immediately below the base of the Torpedo Creek Quartzite. Folding of adjacent units and striae measurements indicate N-directed reverse movement with an associated sinistral wrench component.

The timing of these bedding parallel structures is uncertain, but in any case the manifestation of a compressional event is interesting, as it could have been implicated in the release of basinal brines to form the epigenetic Kamarga base metal mineralisation. This could have occurred during an Isan-age basin inversion (O'Dea and Lister, 1997), or alternatively, it could represent an earlier basin inversion event as seems to have occurred in the McArthur Basin (this volume). In order to time these structures it would be necessary to examine their relationship to the steeply dipping Barramundi and Tasman Fault Zones.

FIELD LOCALITIES

The first six stops lie on a traverse of the southern margin of Kamarga Dome where the Yeldham Granite and the overlying Kamarga Volcanics are onlapped by the basal units of the McNamara Group, the Torpedo Creek Quartzite and Gunpowder Creek Formation (Fig. KD 1). In overview rapid vertical and lateral changes in thickness and facies in the lower McNamara Group succession are interpreted to reflect a period of tectonic activity associated with the onset of the McNamara Group depositional cycle.

- **STOP KD 1 Low Yeldham Granite outcrops on to the east of the track to camp.**

Low rubbly outcrop includes typical equigranular medium- to coarse-grained Yeldham Granite and coarser-grained pegmatitic veins. Note some low angle faults are present. The granite has been interpreted in terms of the classification scheme of Chappell and White (1974) by Jones (1996) using geochemical data from Hutton (1983). It was interpreted to have high-level S-type affinities based on such factors as; high SiO_2 values; a high K_2O:Na_2O ratio; and >1% C.I.P.W. normative corundum.

The dark coloured, crenulated, quartz muscovite schistose material has been interpreted as greisenised granite (Sweet and Hutton, 1982). However, examination of thin sections indicates that it has a considerably lower proportion of quartz to the granite and that quartz is of a different provenance (pers. comm. P. Kitto, August, 1997). This material therefore appears to be of meta-sedimentary origin and may represent correlates of either the Murphy or the Yaringa Metamorphics. There are numerous sharply bounded outcrops of the schist in the southern Kamarga Dome area that are up to 12 by 20 m in plan and appear to have a spatial relationship with local faults (Jones, 1996; Fig. KD 2). The orientation of the main cleavage in these outcrops appears consistently ENE throughout, indicating that if they are xenoliths then the cleavages post-date granite emplacement. Alternatively the outcrops could be linked in the subsurface to comprise a major roof pendant.

- **STOP KD 2 Torpedo Creek Quartzite basal conglomerate infilling shallow channel in Yeldham Granite.**

The Torpedo Creek Quartzite channel fill overlies Yeldham Granite that has a strong bedding parallel tectonic fabric adjacent to the contact. It consists of several metres of massive, poorly sorted, clast supported, polymict, pebble to boulder conglomerate. Clasts are sub-angular to rounded and the dominant type is clean quartz sandstone. Other clast types include quartz sandstone with small pink (?Kamarga Volcanics) lithic fragments, Kamarga Volcanics lithic fragments and rare Yeldham Granite fragments. The matrix to the conglomerate is identical to the overlying Torpedo Creek Quartzite sandstone facies. It comprises quartz cemented quartz sandstone in which the grains are predominantly sub-angular. Accessory grains include rare mica and plagioclase-bearing volcanic lithic fragments. The conglomerate unit at this locality appears to represent a fluvial channel deposit. Sedimentary structures present in the overlying sandstone facies include planar and cross-bedding, lamination, ripples and locally abundant synaeresis cracks and gypsum pseudomorphs. The unit appears to have been deposited under fluvial conditions transitional to a shoreline or shallow marine environment towards the top. Limited palaeocurrent data indicates palaeoflow to the south away from the dome core (Jones, 1996; Fig. KD 3).

The provenance of the conglomerate is seemingly straightforward, in that the presence of Yeldham Granite and Kamarga Volcanics (both volcanic and intercalated sandstone) clasts indicate erosion of local basement. This constrains the generation of relief in the area now occupied by the Kamarga Dome to pre the onset of McNamara Group sedimentation (Jones, 1986). It is interesting to note, however, that while some of the quartz sandstone clasts present have common pink Kamarga Volcanics lithic fragments and are, therefore, interpreted to represent erosion of the sandstones intercalated with the Kamarga Volcanics basalt flows, most do not. There are several possible explanations for the presence of these clasts: (1) They represent "cleaner" Kamarga Volcanics sandstones. (2) They represent a lithology that was present above the Kamarga Volcanics but was subsequently eroded off at this locality (e.g. the Surprise Creek Formation). (3) They represent a lithology that overlies the Kamarga Volcanics and is still present in the subsurface to the south, where the succession accumulated prior to it being thrust to the northwest over the dome core along the high strain zone in the Yeldham Granite below the contact.

A further interesting aspect of this locality is the spectacular malachite staining. It occurs mainly on fracture surfaces and in pore spaces in the conglomerate and sandstone, and in vesicle fills in Kamarga Volcanics lithic fragments (and also in the underlying coherent volcanics). Work in progress on samples from this locality involves examining the fluid inclusion population in the sandstone and attempting to time the emplacement of the copper.

- **STOP KD 3 Kamarga Volcanics outcrops beneath Torpedo Creek Quartzite sandstones in saddle.**

Typical exposure of Kamarga Volcanics basalt flows with infilled vesicles and amygdales. Note that the strong brick red colouration is at least in part a weathering feature, as the unit is a relatively fresh grey to green colour where intersected in the base of DDH WC 1 down-dip to the south.

- **STOP KD 4 Basal Gunpowder Creek Formation coarsening/shallowing up sequence.**

The true thickness of the Gunpowder Creek Formation around the southern flank of Kamarga Dome is difficult to estimate, because mapping by the authors indicates that it is thickened by faulting, particularly to the east of the Tasman Fault Zone (Fig. KD 1). Where it appears relatively unfaulted in diamond drilling from the west of the study area either side of the Barramundi Fault, the unit is around 350 to 380 m thick (Fig. KD 4). The Gunpowder Creek Formation has been subdivided into eight members in this area by Jones (1986), and the author concurs with this interpretation based on re-logging of some of the Kamarga prospect diamond drill holes (e.g. DDH WC 1; Fig. KD 4). However, due to outcrop constraints not all members can be defined in surface mapping. The units exposed at in the creek section that comprises stops 4 to 6 represent members 1 through to four or five in the Jones (1986) scheme.

The upper part of member 1 is exposed in the southern bank of the creek. As is the case here, the lower part of this unit is almost always recessive but it in drillcores it comprises synaeresis cracked, carbonaceous, pyritic shale with interbedded fine-grained sandstone and siltstone beds. It is interpreted as a sub-wave base facies deposited on top of the Torpedo Creek Quartzite, and where this is absent the Kamarga Volcanics, in response to a rapid transgression. The exposure here of the upper part of the unit has a higher proportion of wave rippled sandstone interbeds indicating shoaling through wave base prior to the emplacement of the overlying sandstones of member 2.

The member 2 sandstones consists of a range of fine- to coarse-grained sub-facies arranged in cycles marked by abrupt increases in grainsize. Sedimentary structures present range from wave ripples and associated hummocky cross-stratification to planar and trough cross-bedding and associated current ripples. These are interpreted to indicate that the sandstone cycles represent fluctuations from shallow water to shoreline and possibly locally fluvial environments. Palaeocurrent patterns support a dominantly shallow marine interpretation, since in addition to the off the dome southerly component that dominates the Torpedo Creek Quartzite, components of flow the southeast and east (i.e. longshore) is present in these sandstones (Jones, 1996; Fig. KD 5).

- **STOP KD 5 Recessive hematitic zone between Gunpowder Creek Formation sandstone ridges.**

This ferruginous zone is difficult to interpret due to the recessive/altered/weathered nature of the exposure. If the section at this locality can be directly correlated with that in DDH WC 1 down-dip to the south (Fig. KD 1), then this interval would represent member 3 in the Jones (1986) scheme, which comprises 40 -50 m of evaporitic stromatolitic dolomite (Fig. KD 4). At other localities in the region this unit is well preserved as a silicified biostrome of laterally linked domal stromatolites (Fig. KD 1) that has been incorrectly mapped as the Mount Oxide Chert on the Lawn Hill 1:100,000 geological sheet. Some concentric lamination that could represent poorly preserved stromatolites can be observed at this locality, but these could also be the result of the liesegangue-style weathering that also occurs at this level. Other possible interpretations of this interval are that it represents a fault, a gossan or a soil horizon.

- **STOP KD 6 Evaporitic Gunpowder Creek Formation sediments, ? sabkha.**

The outcrop on the western side of the creek at this locality represents good exposure of members 4 and/or 5 of the Gunpowder Creek Formation. In the Jones (1986) scheme these units represent sabkha deposits. The author concurs with this interpretation based on drill core examination that indicates that they are made up of the thin (i.e. ~ 1 m) evaporitic carbonate cycles that are characteristic of true sabkha deposits (Warren, 19??). These comprise alternating laminated, often carbonaceous dolomite with abundant gypsum and anhydrite pseudomorphs (representing sub- to inter-tidal deposits of prone microbial mat overprinted by evaporitic brines) and abundant intraformational dolomitic breccia interpreted to represent the desiccated and eroded supra-tidal deposits. The sabkha deposits in the Gunpowder Creek Formation in the southern Kamarga Dome area are condensed in thickness and of restricted distribution (Jones, 1986; Bull, 1996). They pass laterally into thicker intervals of evaporitic inter-tidal dolomite facies associations (Bull, 1996).

Abundant cauliflower cherts after anhydrite are well preserved at this locality within ferruginous dolomitic sandstone/breccia. This could represent either the sabkha facies, or the laterally equivalent evaporitic inter-tidal dolomite facies, as the characteristic thinly bedded structure of the former is generally obscured in the ferruginous surface exposures. At the southern end of the exposure a low angle fault is present in which cauliflower cherts are strung out in the cleavage.

- **STOP KD 7 Paradise Creek Formation ridge.**

The outcrop at this locality is typical of the dolomitic parts of the Paradise Creek and Esperanza Formations, consisting of microbial units and flat pebble breccias arranged in several parasequences.

The Paradise Creek and Esperanza Formations accumulated in a variety of sub-environments within a shallow marine shelf setting (Jones, 1986; Cooper, 1996). These included sub-wave base, sub- tidal, inter-tidal, lagoonal and evaporitic supra-tidal environments. A detailed map and discussion of the facies architecture of the system can be found in Cooper (1996).

In summary, the Paradise Creek Formation shows considerable lateral facies variability and was subdivided into western and eastern domains. Seven facies associations were defined in the former that included quartz sandstone and a significant (i.e. up to 15 m thick) carbonaceous shale accumulations in addition to a range of sub- to inter- to supra-tidal dolomitic associations. Outcrop in the eastern domain is sparse but the facies associations in this area are clearly dominated by higher energy shallower water deposits. In both domains there is an increase in grainsize towards the Esperanza Formation contact giving indicating an overall transgression.

The Esperanza Formation was subdivided into five mappable facies associations that were laterally continuous across the study area. In addition to dolomitic deposits similar to those of the underlying Paradise Creek Formation these include a prominent silicified microbial biostrome that defines the base of the unit, recessive carbonaceous shales and a quartz sandstone succession.

In terms of the carbonate facies models developed by Grotzinger (1989) the Paradise Creek and Esperanza Formations are broadly interpreted to represent inner shelf deposits within a rimmed carbonate platform. However, given the syn-sedimentary relief that existed in the Kamarga area they could also represent the proximal end of a broad ramp system. In either case, in terms of the tectono-stratigraphic development of the McNamara Group this is interpreted to represent a period of relative tectonic quiescence in the Kamarga Dome area. This is evidenced by:

- The predominance of carbonate lithologies, indicating reduced clastic input and hence reduced topography.
- The sporadic occurrence of evaporitic pseudomorphs throughout the section, indicating repeated emergent environments and hence a slow generation of accommodation space.

- **STOP KD 8A Lady Loretta Formation: Devil's Gossan**

Stop at low rocky outcrop on bend in track just before Bloodwood Bore. Ferruginous banded chert and silcrete at this locality is anomalous in base metals (Table LL 2). Drilling reveals no mineralisation in the subsurface.

- **STOP KD 8B Lady Loretta Formation carbonates (Dunster's Bloodwood Section A)**

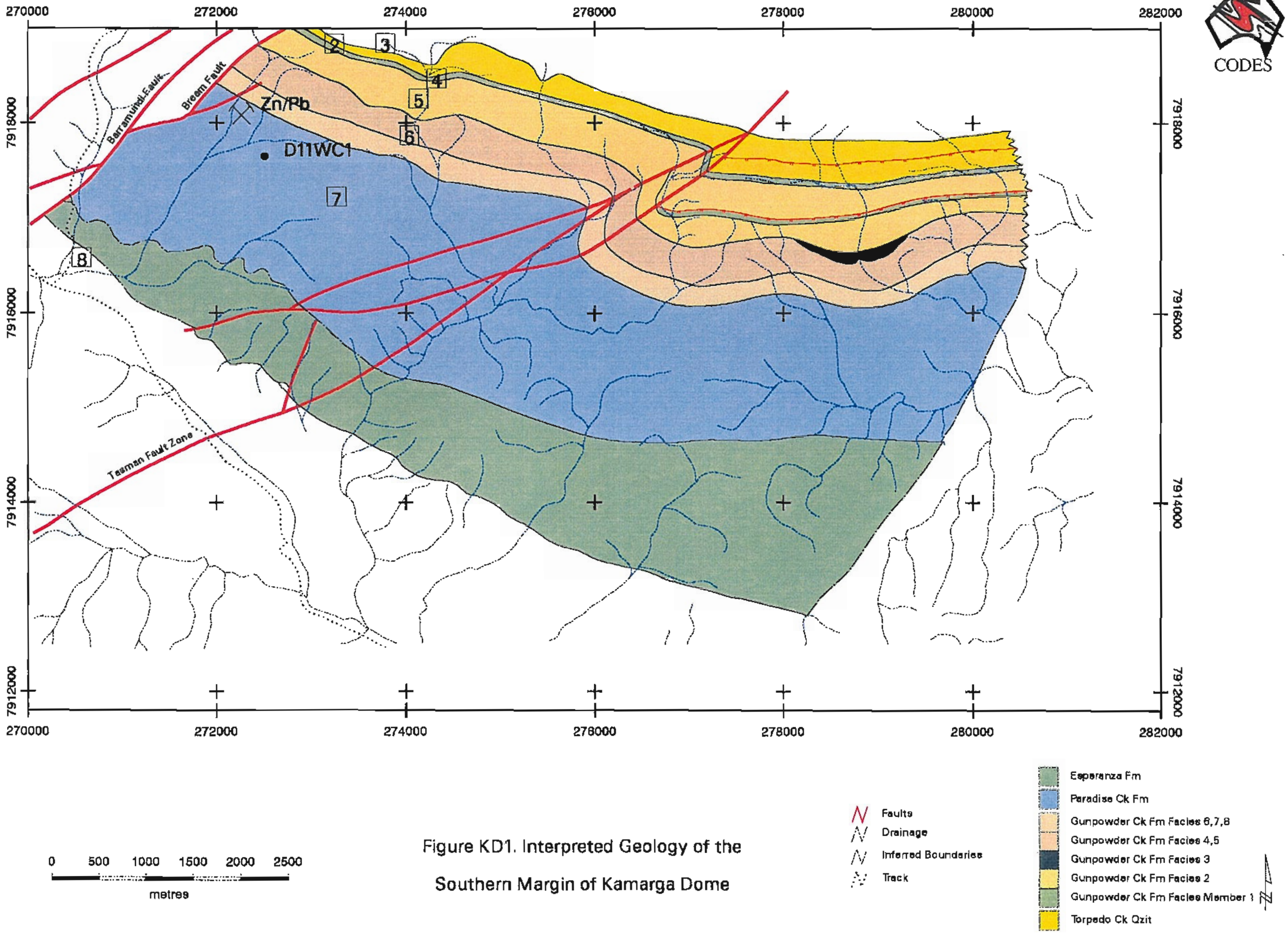
Stop on track at Bloodwood Bore and traverse south up hill (and up sequence) through 26 m (true) thickness of Lady Loretta Formation (Fig. KD 7). At this locality, as for much of the northern exposures of Lady Loretta Formation, massive, bedded and stromatolitic carbonate lithologies predominate (Fig. KD 8). Halite casts are abundant in sandy base of section. Imbricate, channellised (?swirled) plate breccias occur sporadically in the middle part of the section. Low angle cross beds, ripples, oolites and gypsum pseudomorphs are also present. Small domal microbialite merge upwards to columnar conical forms (aligned in plan).

- **STOP GR 1 Grevillea gossan**

Drive to camp on Gregory River at Riversleigh Station and thence to Grevillea prospect.

The Grevillea prospect (Fig. GR1) comprises strati-form base metal mineralisation in pyritic and baritic black shales and siltstones of the lower Riversleigh Siltstone. The surface expression of the mineralisation is a prominent baritic gossan located 8 km south east of Riversleigh Homestead. Drilling in the immediate vicinity of the gossan revealed several intersections of between 15 and 25 m true thickness with Zn grades of 4-5%, up to 1% Pb, and about 35 g/t Ag in primary mineralisation. The pyritic horizon has a recognisable geophysical signature for at least 1.5 km north of the gossan.

Primary layering is recognisable in cavernous ferruginous (jarositic) gossan and in banded siliceous gossan. Barite is present in layered gossan and as cross-cutting, coarse veins. The gossan (and local drainage) has anomalous geochemistry with up to 1000 ppm Pb and 10 ppm Ag, but, interestingly, Zn levels are less than 100 ppm (Coolgardie Gold pers. comm.— see also Table LL 2).



CODES

Figure KD1. Interpreted Geology of the Southern Margin of Kamarga Dome

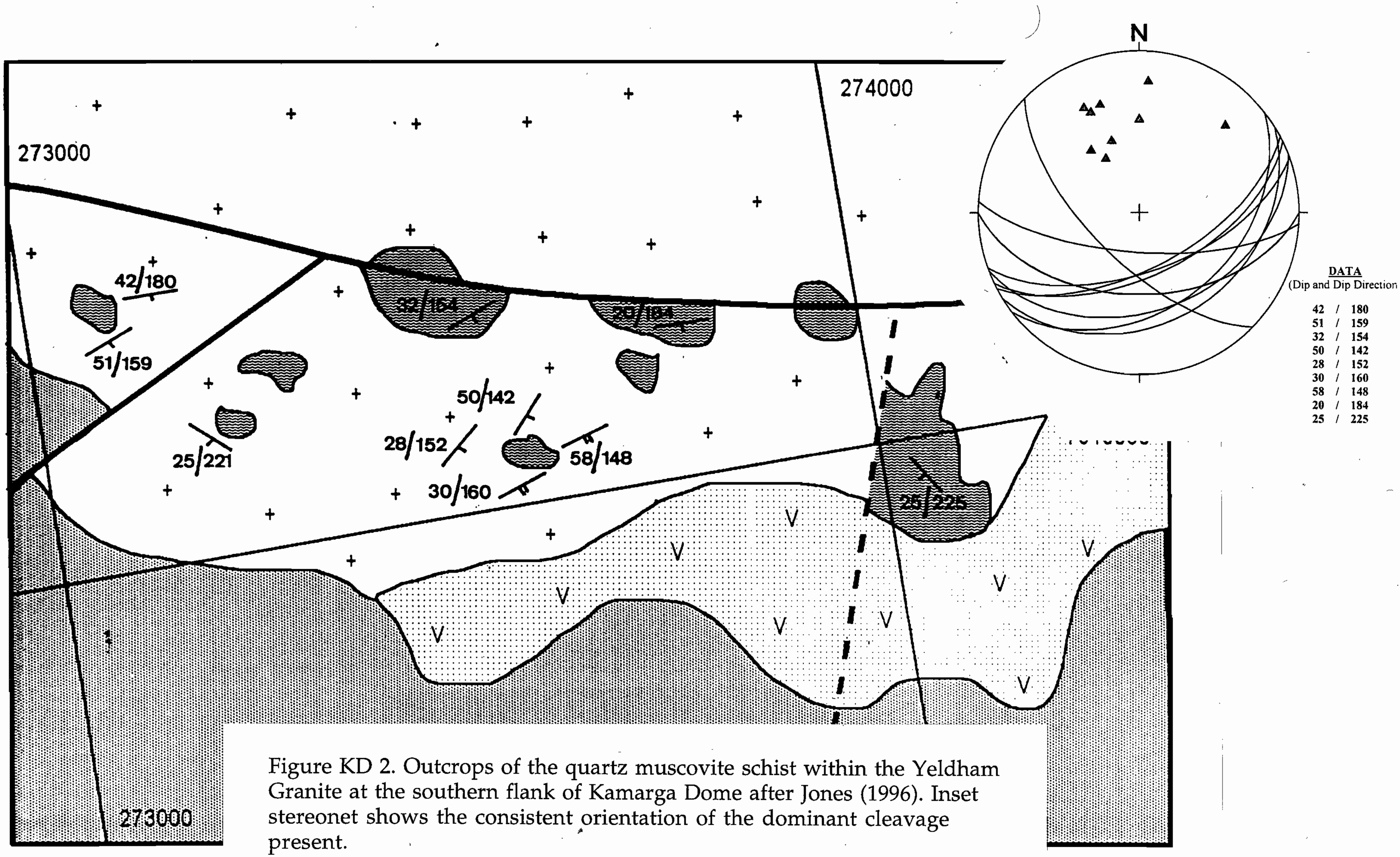
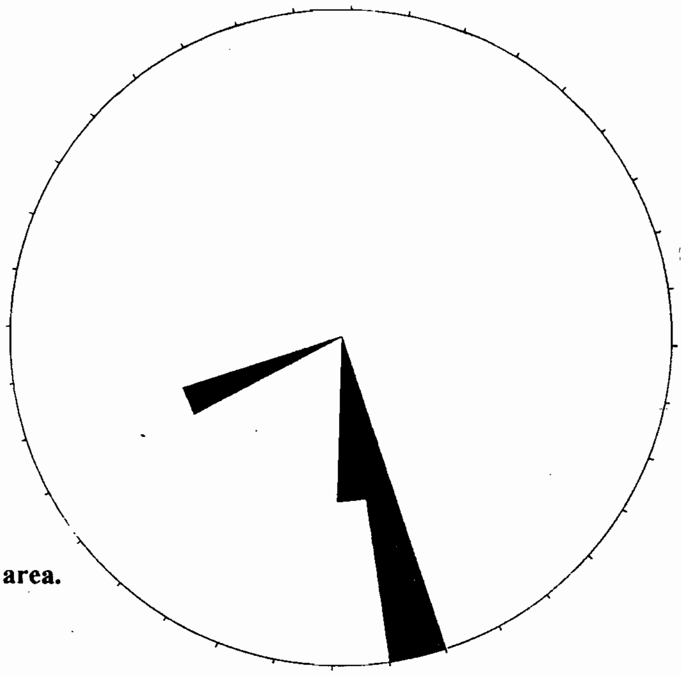
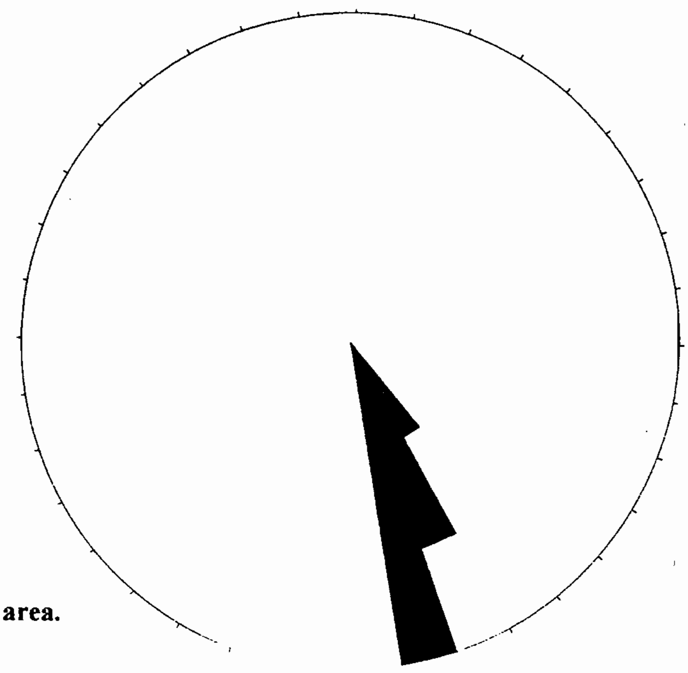


Figure KD 2. Outcrops of the quartz muscovite schist within the Yeldham Granite at the southern flank of Kamarga Dome after Jones (1996). Inset stereonet shows the consistent orientation of the dominant cleavage present.



273419/7918716.
Western end of the research area.
Crossbeds.
4 values.
Class width 10^0.



278297/7917604.
Eastern end of the research area.
Crossbeds.
6 values.
Class width 10^0.

Figure KD 3. Palaeocurrent data from cross-bedding in the Torpedo Creek Quartzite on the southern flank of Kamarga Dome after Jones (1996).

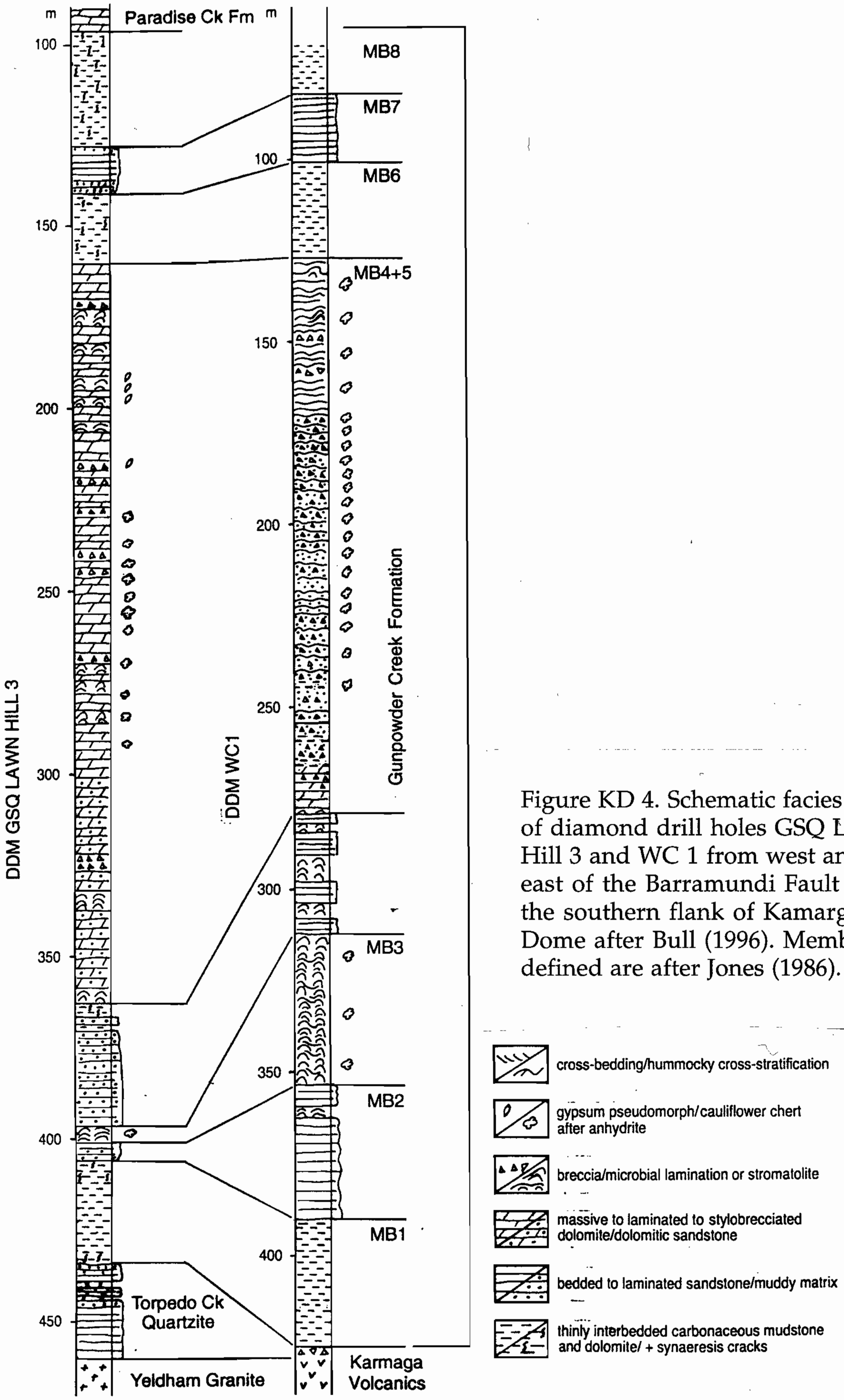


Figure KD 4. Schematic facies logs of diamond drill holes GSQ Lawn Hill 3 and WC 1 from west and east of the Barramundi Fault on the southern flank of Kamarga Dome after Bull (1996). Members defined are after Jones (1986).

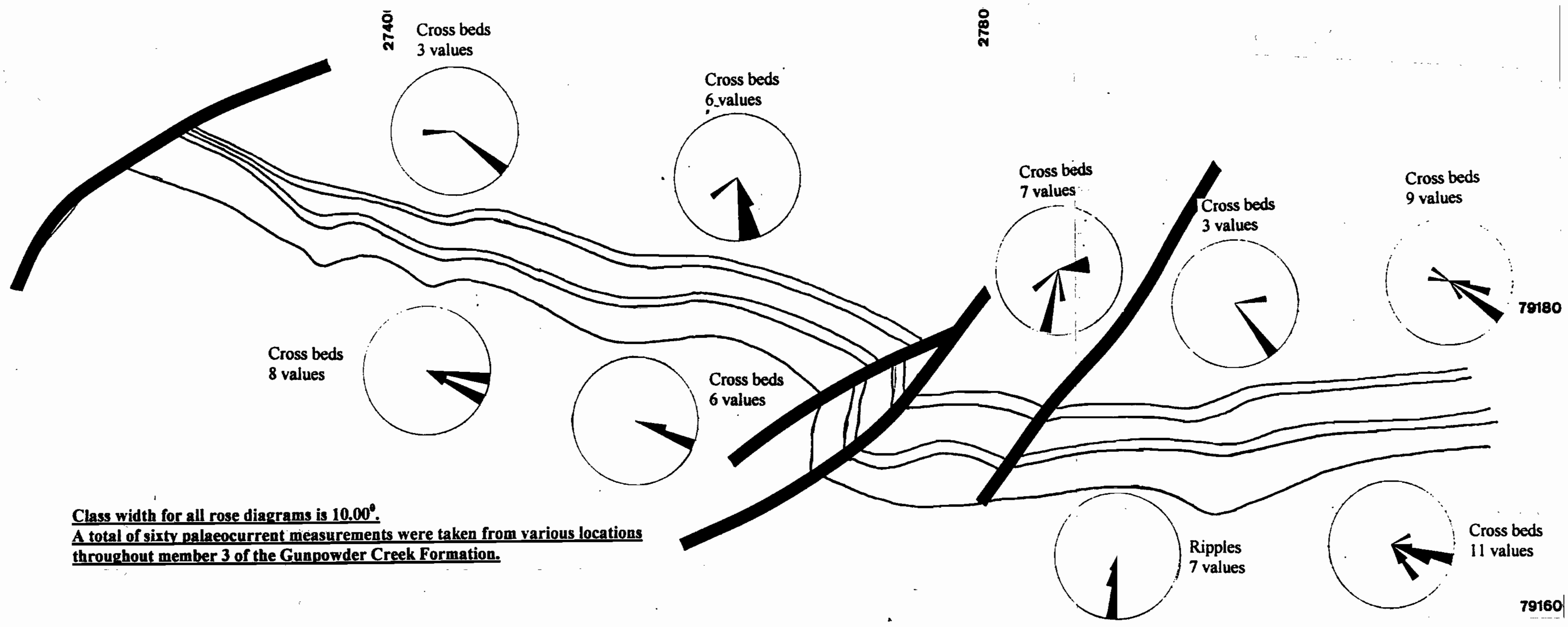


Figure KD 5. Palaeocurrent data from cross-bedding in Gunpowder Creek Formation sandstones, southern flank of Kamarga Dome after Jones (1996).

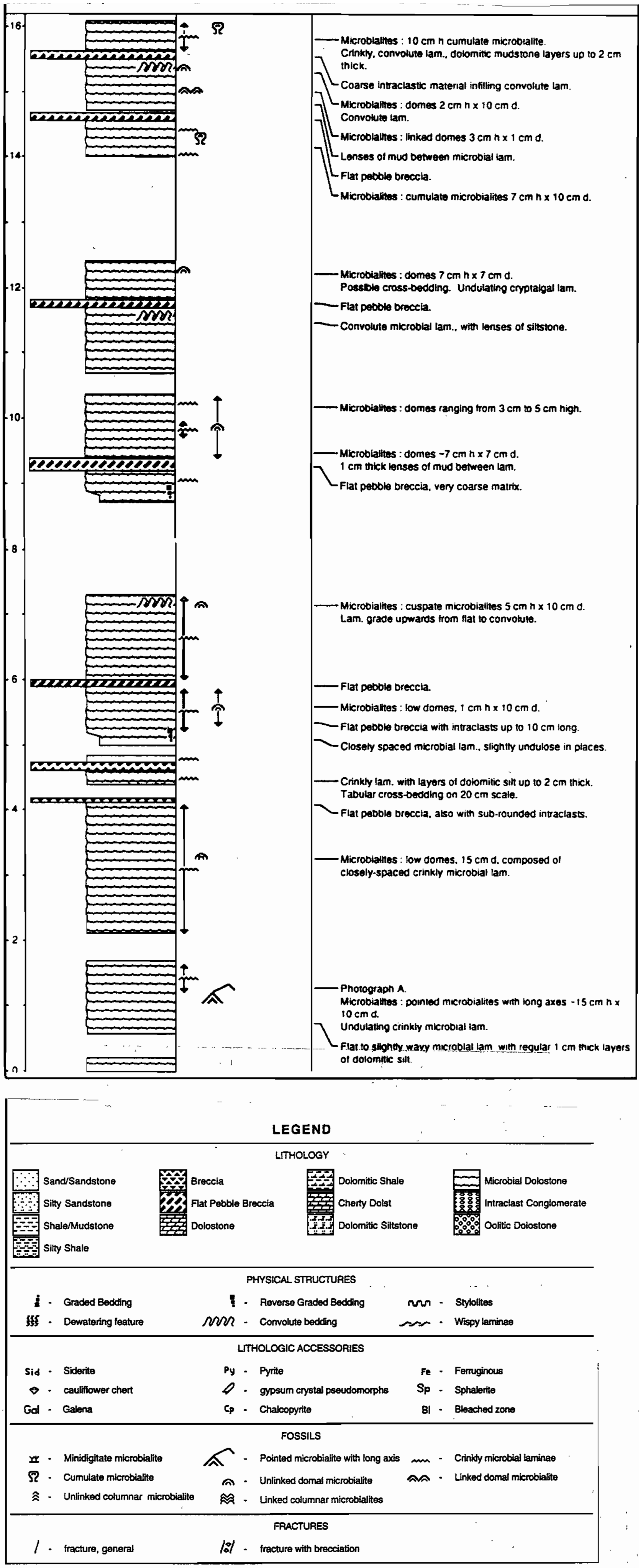


Figure KD 6. Schematic facies log of a typical Paradise Creek Formation section, southern flank of Kamarga Dome, after Cooper (1996).

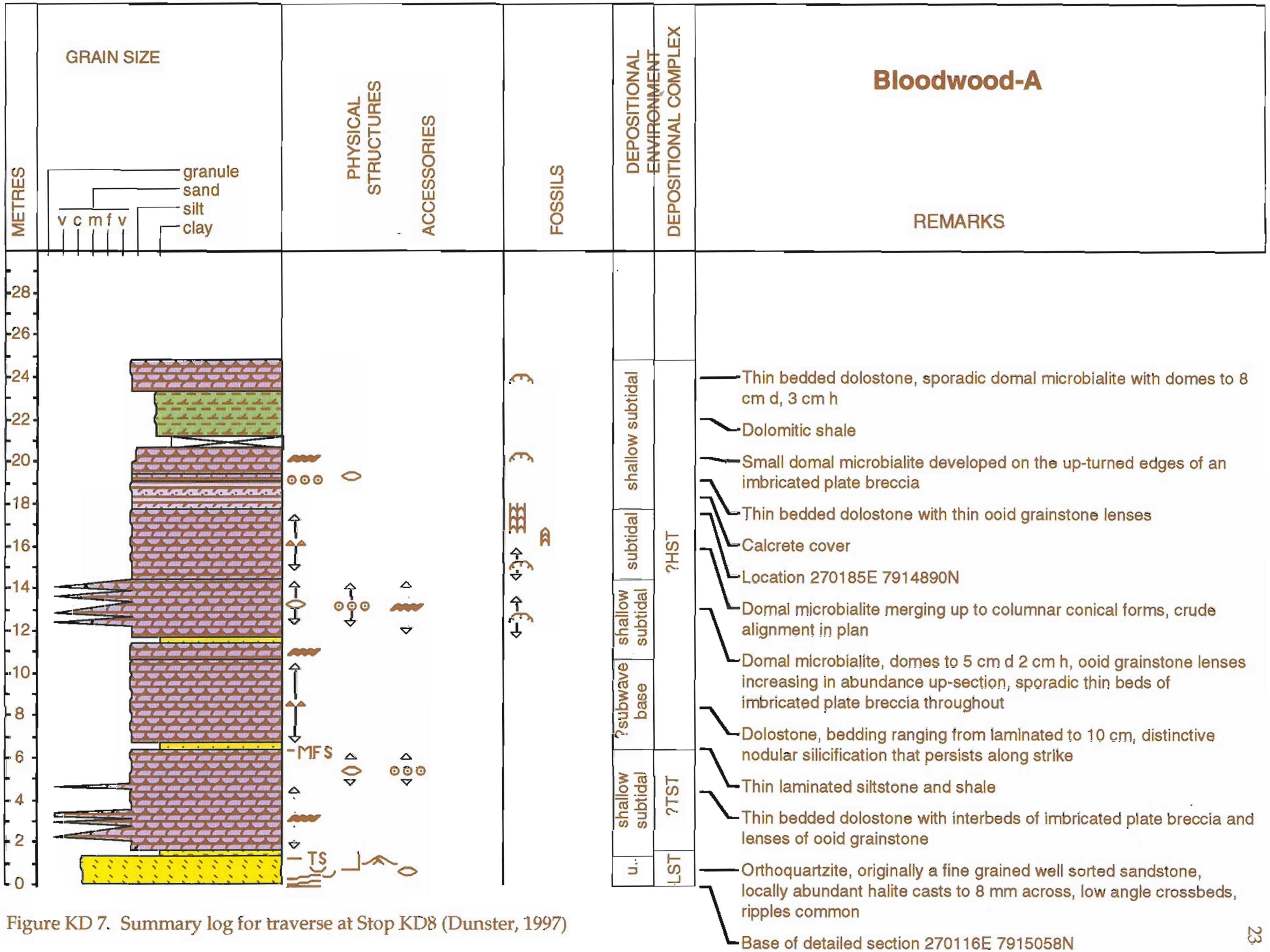


Figure KD 7. Summary log for traverse at Stop KD8 (Dunster, 1997)

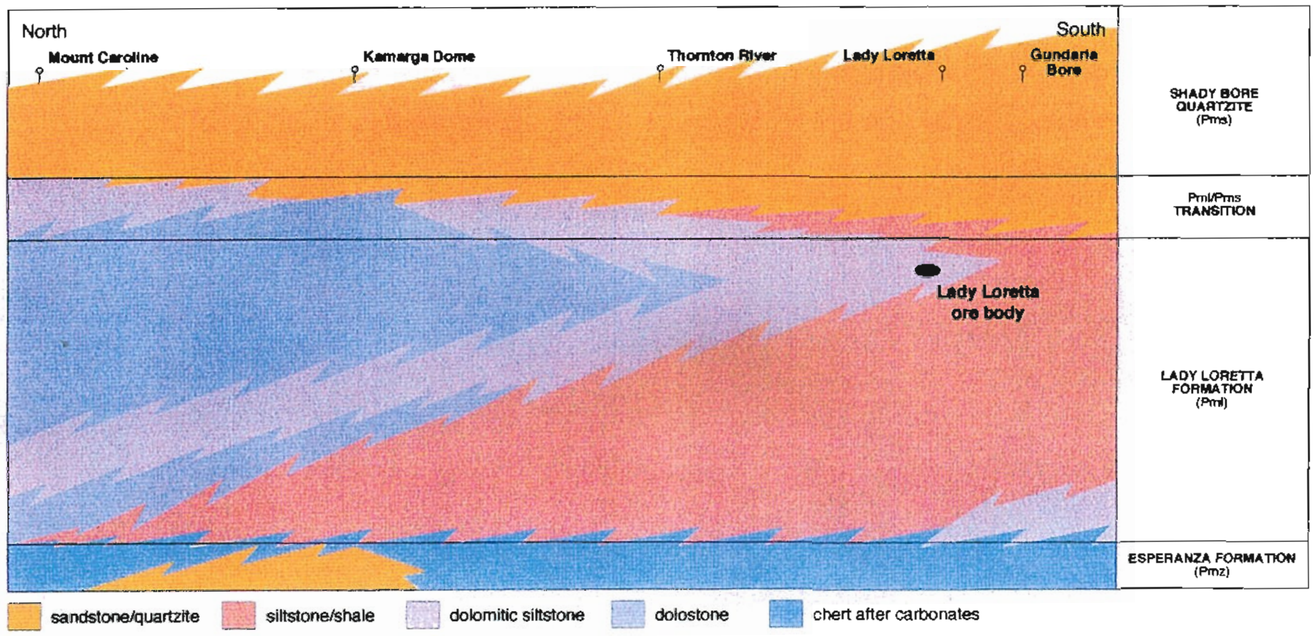


Fig. KD8 Schematic showing the regional lithostratigraphic variation in the Lady Loretta Formation (from Dunster, 1997).

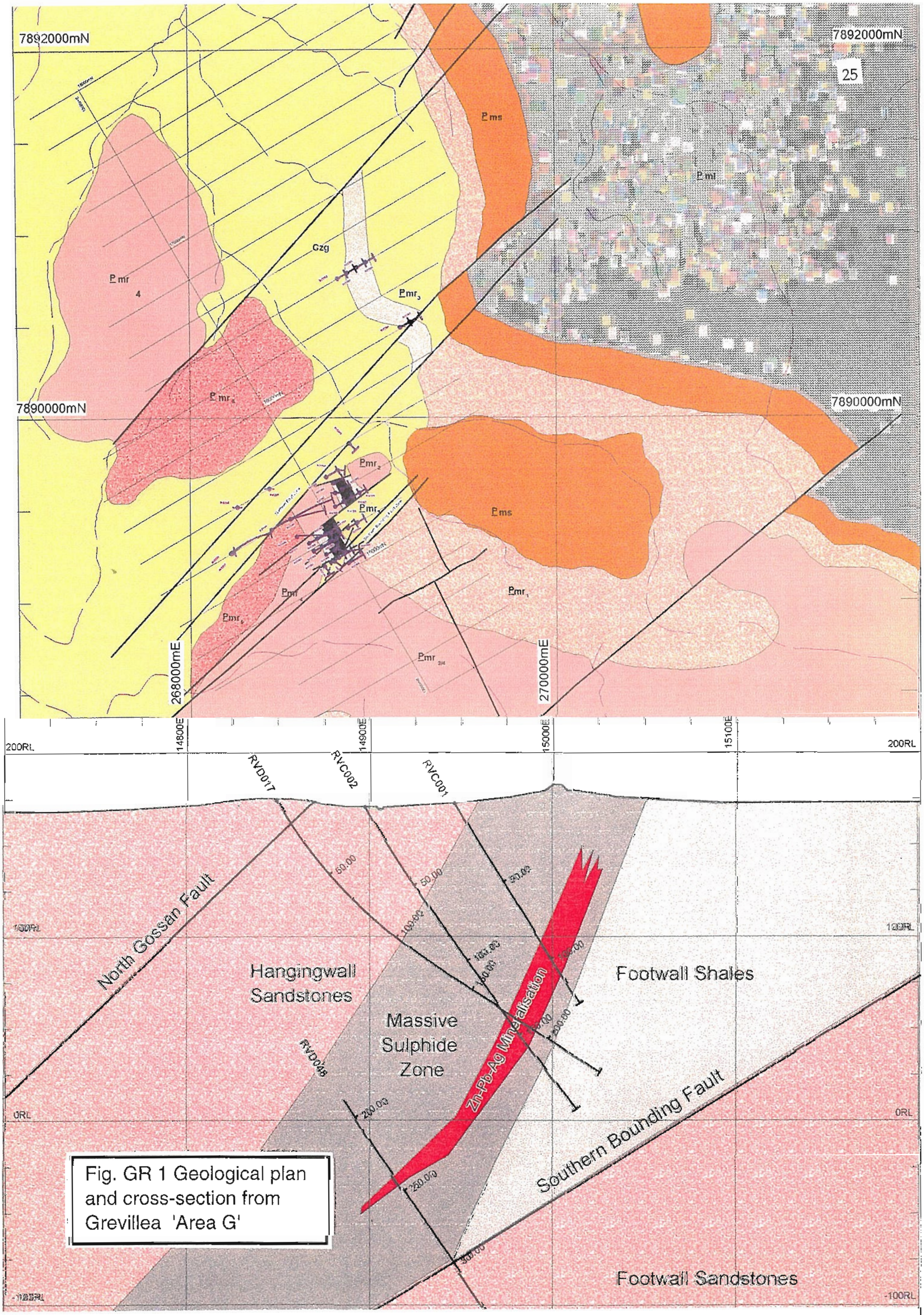


Fig. GR 1 Geological plan and cross-section from Grevillea 'Area G'

DAY 3 — Lady Loretta Formation at Lady Loretta mine; Lady Loretta Formation 'basal' breccia

Peter McGoldrick, John Dunster, and Ross Large

INTRODUCTION

The Lady Loretta deposit (Table LL1) was an important focus for the Deposit Halos module of AMIRA Project P384. This work was presented in several reports prepared for P384. It has also been the subject of ongoing ore genesis studies. Dunster (1997), in a PhD study supported initially by Pancontinental Mining and the Australian Research Council, undertook detailed sedimentological investigations of the Lady Loretta Formation at the mine and more regionally. Much of his work has been verbally communicated to P384A sponsors at previous project meetings.

Dunster (1997) interpreted the sedimentary setting of the Lady Loretta Formation as a ramp/shelf ("rimmed shelf" using the terminology of Grotzinger, 1989), with no evidence of large scale syn-sedimentary tectonic activity (see also Bull, 1997). Regionally much of the unit appears contains peritidal to shallow marine carbonates and mixed carbonates and clastics. Widespread pseudomorphs and casts/moulds of halite and sulphate minerals are interpreted to represent an evaporitic overprint produced during a regression when marine sabkha developed locally. Highly carbonaceous pyritic shale and siltstone were deposited in isolated areas, often associated with tidal flat and possible subaerial facies. At Lady Loretta mine the ores and immediate host sequence contain a variety of silicified and pyritised microbialites. Wave ripples, crossbeds with bi-polar palaeocurrent directions, and possible sulphate evaporite pseudomorphs are also present. These features, together with 'closed system' S isotope signatures, are interpreted to indicate the host rocks to the mineralisation were deposited in a restricted lagoon developed within a regional tidal flat environment.

SUMMARY

Day 3 of the field trip provides an opportunity to:

- Examine the surface expression of the mineralised sequence in both the Small Syncline (which contains the Zn-Pb-Ag orebody), and the Big Syncline (where the stratigraphic equivalent of the Zn mineralisation is bedded pyrite-barite ± hematite). A costean at the southern end of Big Syncline provides exposures of hanging wall sediments.
- View core drilled in the Small Syncline through the orebody and hangingwall and footwall sediments. Samples from similar cores were the basis for lithogeochemical halo studies at Lady Loretta.
- Visit a key exposure of the Lady Loretta Formation 'basal breccia' that shows a transition from 'normal' bedded weathered Lady Loretta Formation sediments to ferruginous siliceous breccia.
- Discuss the application of detailed potential field geophysical surveys to exploration for 'Lady Loretta' type mineralisation (see LL Appendix by Mark Duffett at the end of today's notes)

- **STOP LL 1 Barite-chert at trig point near houses**

This locality is very close to the so-called 'Syncline Dividing Fault' (?tight anticline) separating the Small Syncline and Big Syncline (Fig. LL1). Good exposures of bedded ferruginous chert (in part 'honeycomb' chert) and banded chert/barite rock. Much of the barite-rich lithologies have a strong (?mylonitic) fabric with coarse quartz 'eyes' in a finer grained barite matrix. There is a strong spatial association between honeycomb chert and the outcrop of the ore sequence at Lady Loretta (see Stop LL4 also), but similar rocks occur elsewhere in the absence of known mineralisation. The holes in the honeycomb chert vary considerably in size and shape, and their origin is enigmatic. Often holes are surrounded by iron staining, suggesting dissolution of a precursor Fe-bearing mineral (?pyrite, ?hematite, ?siderite) is involved.

Split in two groups for next two stops; one group takes track to west of trig and then turn right to gossan; the other takes track to north east of houses and down to core display.

- **STOP LL 2 Lady Loretta gossan**

Massive ironstone just west of track, below chert ridge (surface expression of the Carlton Fault). The red-brown massive hematite gossan is probably after the massive pyrite in the immediate footwall of the base metal sulphide mineralisation. Much less common, porous, bedded, yellow-brown gossan is after base metal sulphides. Anomalous levels of Pb, Ag, and As are present in both types of gossan (Table LL 2), but Zn, which has a much broader dispersion in soils than Pb, is not strongly anomalous. Thallium, an important vector to ore in unweathered core samples, is not retained in the gossan.

- **STOP LL 3 Lady Loretta core display**

Main features of the Lady Loretta mineralisation are summarised in Table LL 1) and the core display comprises three parts. Recently drilled surface holes (MET 7/8) which provide examples of hangingwall shale, siltstone and bedded pyrite ('Cyclic Unit'). An assortment of mineralisation samples skeletonised from underground ore reserve drill core, and about 100 m of footwall carbonaceous and pyritic siltstone from underground drill hole L227 ED70 comprise the rest of the display.

Figure LL 2 is a section through the central part of the Lady Loretta orebody, and this together with Figure LL 3 illustrates some of the structural complexity of the orebody. Aheimer (1994) proposed a nine-fold subdivision of sulphide ore types based on the extent of deformation-related re-texturing of the ores (Fig. LL 4). Lithotypes in the mineralised sequence can be broadly grouped into two textural types. One referred to as *sedimentary* in which the layering is sedimentary bedding, or clearly inherited from sedimentary bedding. The other, referred to as *tectonic*, includes deformed or recrystallised sulphides and sulfates, and layered mineralisation in which layering is not purely sedimentary (i.e., layering may be transposed or tectonically modified bedding). Assays for some of the high grade samples on display are presented on Table LL 3.

In the hangingwall 'Cyclic Unit' sediments, graded siltstone mudstone units are very common. Individual silt/mud couplets probably represent single depositional events. These were previously interpreted as turbidite deposits, but a tempestite origin is now favoured for the thicker units.

The footwall and hangingwall siltstone samples serve to illustrate the difficulty in recognising sideritic and ankeritic lithologies in hand specimens. Brown discolouration develops rapidly on grey siltstones on exposure to air and is not always indicative of the presence of siderite.

Several types of pyrite can be identified, and in the hangingwall rocks the most abundant forms massive, often laminated, bands separating siltstone/mudstone depositional units (Fig. LL 5). In detail, pyrite in the ores and the host sediments often has a crinkly appearance interpreted as microbial lamination. This interpretation is supported by the observation that microbially laminated chert, and small digitate and columnar stromatolites are present in the barite-sphalerite mineralisation in the north east part of the orebody.

- **STOP LL 4 Big Syncline barite-chert ridge, and costean**

Drive south west from houses back toward Lady Annie (Cu) and then to east end of southernmost costean in the Big Syncline. Climb to barite-chert ridge to south east. Barite-chert in this location is much less strongly deformed than Stop LL 1. Ripple pavements can be seen in 'Cyclic Unit' siltstones just below the ridge. Many bedding surfaces are cracked and moulds of sulphate evaporites have been identified in thin section in samples from this locality. Continue downhill to costean and walk sequence through hangingwall sediments. A variety of sedimentary and tectonic structures can be observed. Traverse end at the more subdued ferruginous chert ridge marking the outcrop of the ore sequence equivalent on the west limb of the syncline..

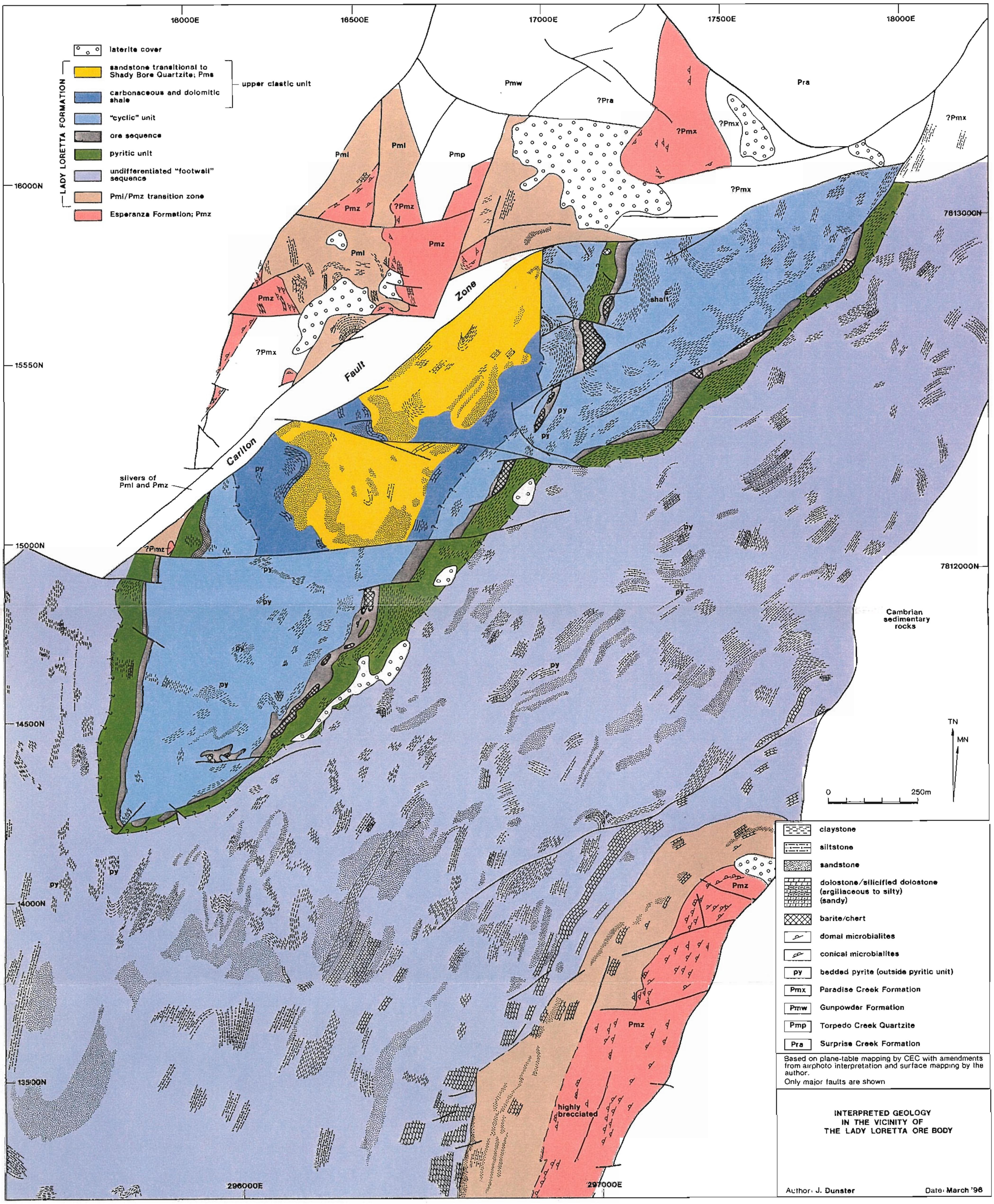
- **STOP LL 5A Lady Annie phosphate plant – Lady Loretta Formation basal breccia (4 km north east of Lady Loretta mine**

This locality is an excellent example of the regionally extensive Lady Loretta Formation 'basal' breccia (Fig. LL 6). A complete transition from 'normal' weathered, bedded siltstone and shale to siliceous, ferruginous breccia can be observed. This unit is mapped as an informal lithostratigraphic member at the base of the Lady Loretta Formation by Sweet and Hutton (1982), however, Dunster (1997) has shown that the breccia is not restricted to the lowermost Lady Loretta Formation and is therefore not stratigraphically concordant, and can develop from a variety of precursor lithologies. In most places, where evidence is available, the breccia does not persist into the subsurface.

The previously proposed sedimentary origin for the breccia can be disregarded for the following reason:
- the breccia does not continue as a sedimentary package into the subsurface
- the large apparent thickness variations are inconsistent with a sedimentary origin
- on a regional scale, the non-stratiform, non-concordant distribution cannot be explained by a sedimentary origin
- the breccia transgresses bedding locally
- the clasts commonly exhibit jigsaw fit and have not been transported

and Dunster (1997) proposed that the "basal breccia" is a duricrust. A duricrust is a hard, resistant regolith layer composed of silcrete, ferricrete, calcrete or any combination of these three elements.

- **STOP LL 5B (optional stop, time permitting) Cambrian/Esperanza Formation unconformity to south of track at the phosphate plant**


16000E
16500E
17000E
17500E
18000E
laterite cover
LADY LORETTA FORMATION
sandstone transitional to Shady Bore Quartzite; Pms
carbonaceous and dolomitic shale
upper clastic unit
"cyclic" unit
ore sequence
pyritic unit
undifferentiated "footwall" sequence
Pml/Pmz transition zone
Esperanza Formation; Pmz
16000N
15550N
15000N
14500N
14000N
13500N
7813000N
7812000N
Pmw
Pra
?Pra
?Pmx
Pmp
Pml
Pmz
?Pmz
Carlton Fault Zone
shaft
py
slivers of Pml and Pmz
Cambrian sedimentary rocks
TN
MN
0
250m
highly brecciated
296000E
297000E
claystone
siltstone
sandstone
dolostone/silicified dolostone (argillaceous to silty) (sandy)
barite/chert
domal microbialites
conical microbialites
py bedded pyrite (outside pyritic unit)
Pmx Paradise Creek Formation
Pmw Gunpowder Formation
Pmp Torpedo Creek Quartzite
Pra Surprise Creek Formation
Based on plane-table mapping by CEC with amendments from airphoto interpretation and surface mapping by the author.
Only major faults are shown
INTERPRETED GEOLOGY IN THE VICINITY OF THE LADY LORETTA ORE BODY
Author: J. Dunster
Date: March '96

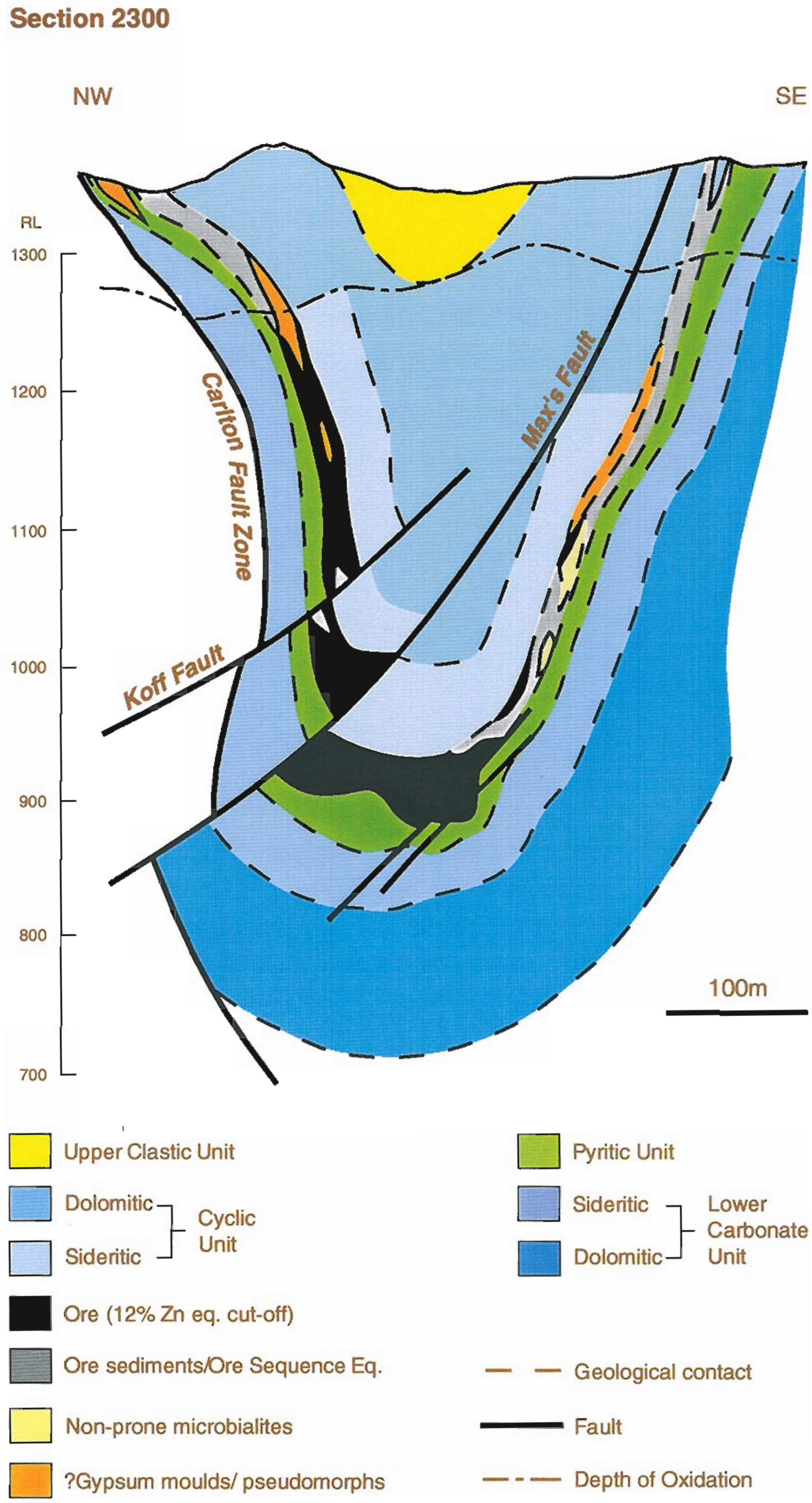


Fig. LL2 Lady Loretta cross-section, 2300 mN, mine grid.

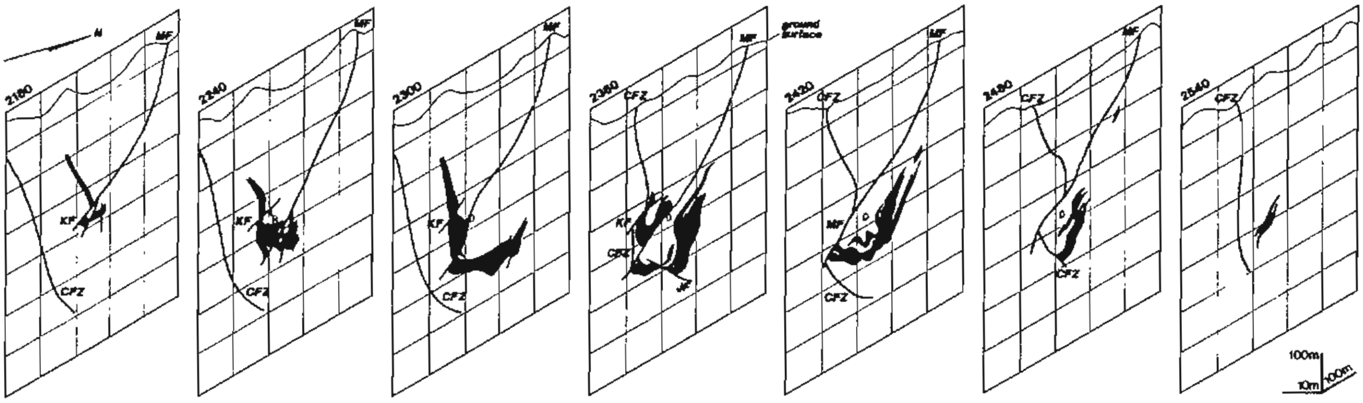


Fig. LL3 Serial perspective sections of the Lady Loretta orebody at 60 m spacing (after Dunster, 1997).

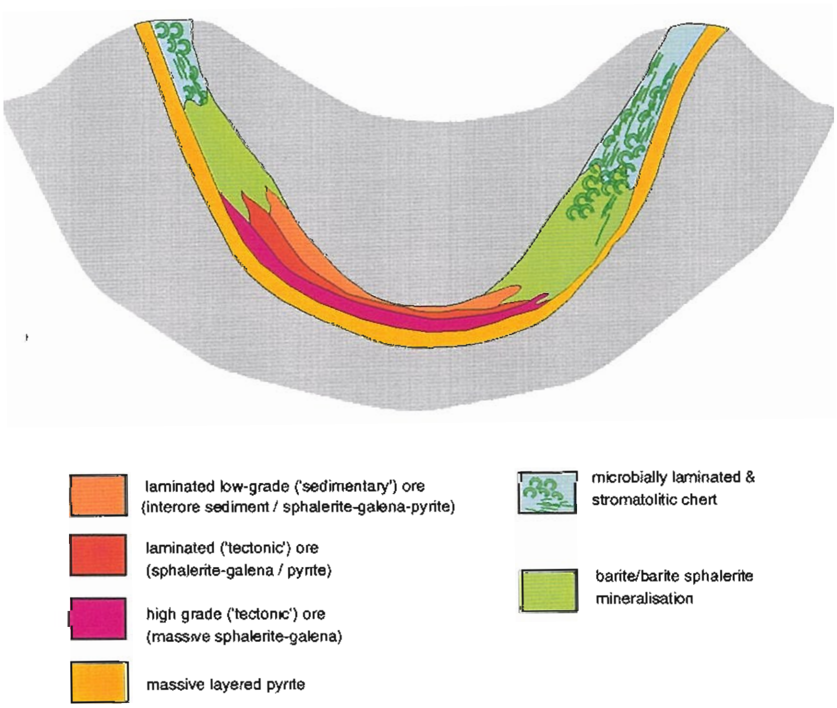


Fig. LL4 Schematic cross-section of the Lady Loretta deposit showing the distribution of major ore types (after Aheimer, 1994).

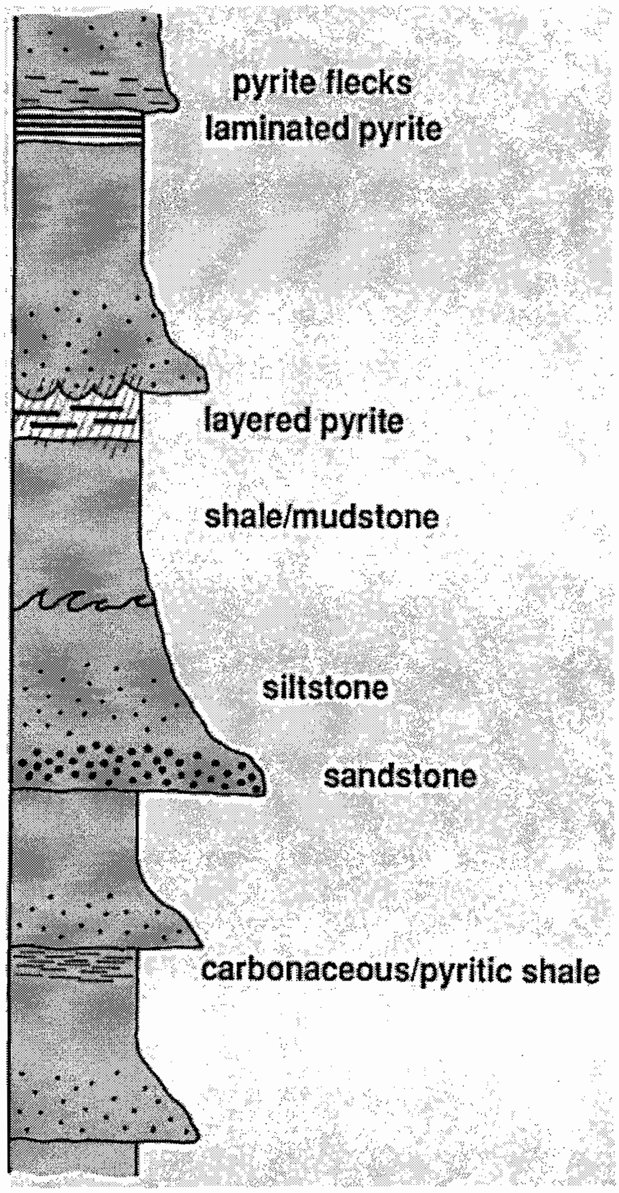


Fig. LL5 Schematic showing different pyrite types and their distribution in relation to siltstone/mudstone units.

Figure LL6 The "basal breccia" duricrust.

(a) A costean through the "basal breccia" at Redie Creek. The dip of the beds is indicated by the white lines. Note that the characteristic rounded outcrops of chert breccia do not extend into the subsurface.

(b) Chert breccia developed between the columns of columnar conical microbialite in the Esperanza Formation at Police Creek. The unaltered central core of the microbialite is visible in plan (arrowed). Elsewhere in the same outcrop all primary textures have been completely obliterated.

(c) Outcrop clearly showing the stages of "breccia" formation. (1) is unaltered dolostone. (2) represents an intermediate stage of brecciation and silicification. (3) shows the typical rounded outcrop of angular chert clasts floating in a ferruginous chert matrix. This exposure is at Kamarga Dome.

(d) Typical example of unsorted angular chert clasts in ferruginous chert matrix, Cartridge Creek, CCC133.

(e) A texture more like a conglomerate than a breccia, Phosphate Plant, PHP389.

(f) Typical outcrop of "basal breccia", Phosphate Plant.

(g) Polished slab showing an early stage in development, with original microbial fabric being brecciated in situ by the formation of ferruginous chert material, Phosphate Plant, PHP390. Coin is 3 cm d and bar scale is 1 cm.

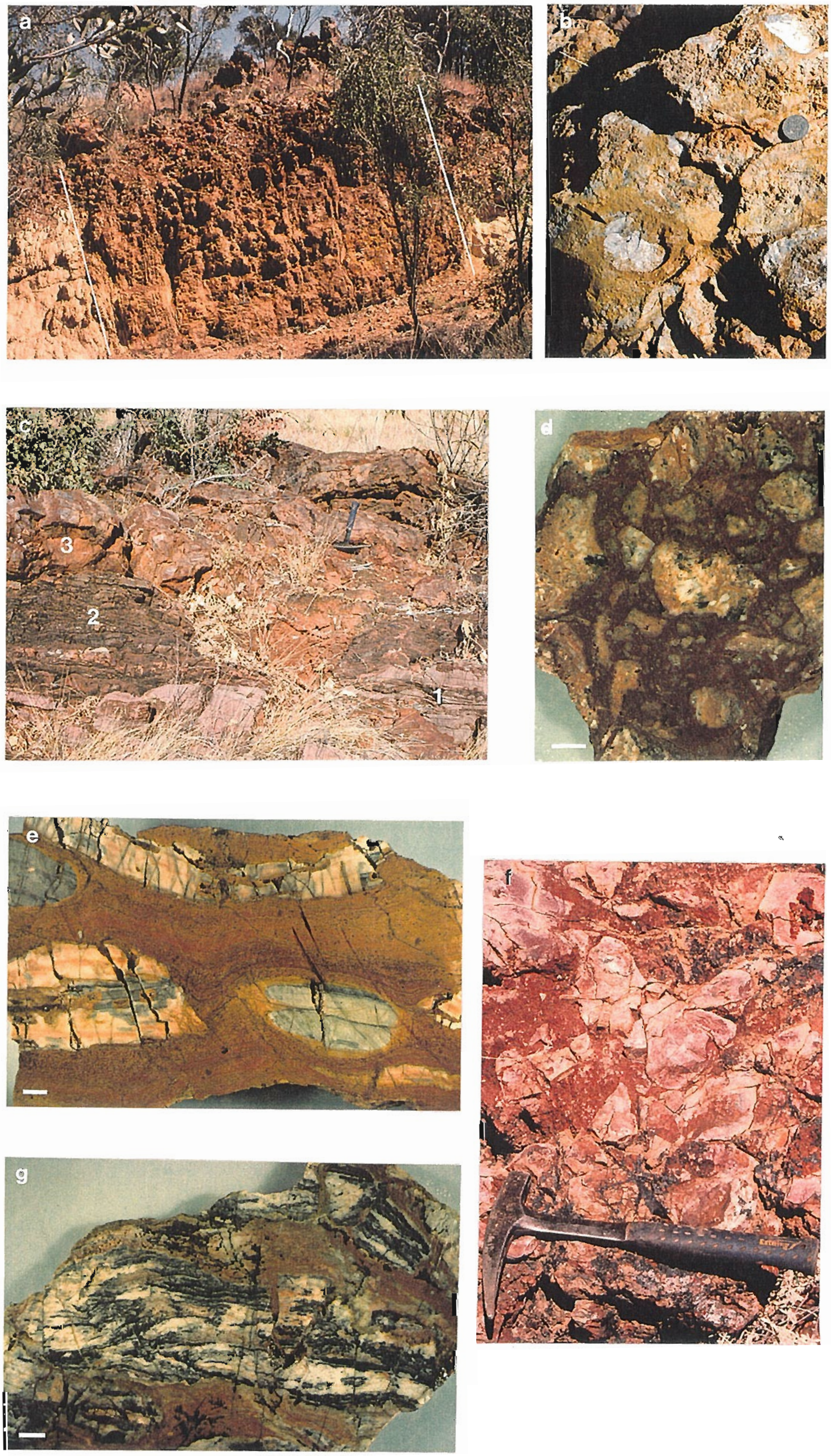

a
b
c
3
2
1
d
e
f
g

Table LL1: Lady Loretta deposit

- 8.3 million tonnes @ 18.4% Zn, 8.5% Pb, 125g/t Ag, 120 km NNW of Mount Isa
- the deposit was discovered in 1969 by Placer Prospecting / Triako JV (drilling a soil geochemical anomaly); MIM bought Placer's interest in 1975
- Pancontinental – Agip – Outokumpu JV sank a shaft to 468m and did 14km of underground drilling in 1987/88
- acquired by RGC and on-sold to Triako NL (Buka Minerals)
- mineralisation is stratiform and folded into a syncline ('Small Syncline') giving the orebody a canoe shape; abt 470m below the surface at its deepest point
- host rocks are pyritic, carbonaceous, dolomitic siltstones and shales of the Lady Loretta Formation
- the immediate footwall of the orebody comprises a 10 to 30m thick unit of 'reactive' pyrite, underlain by thinly laminated carbonaceous silstones
- the orebody is a folded and faulted banded massive sulphide lens up to 50 m thick displaying a variety of macroscopic textures (in part deformation related)
- sulphides are fine grained, constitute more than 70% of the rock, and are mainly sphalerite, pyrite & galena (DSO at footwall contact)
- barite – low-Fe sphalerite – chert mineralisation, containing digitate stromatolites and sulphate evaporite textures, occurs in the north part of the east limb
- siderite (passing out to ankerite) is the dominant carbonate for about 50m above and below the ore position

Table LL 2	Zn	Pb	Ag	Cu	Fe	As	As	Sb	Tl	Mn	Ba	S	Ni	Ni	Mo	V	Ti	Cr	Rb	Sr	Sc
Gossan & ironstone analyses	ppm	ppm	ppm	ppm	wt%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lady Loretta: Bedded Porous Gossan	59	2960	17.9	30	11.66	319	366	55.5	0.4	31	400	1040	<5	<1	6.4	11	3117	47	1.5	237	8
Lady Loretta: Massive Ironstone Gossan	10	241	7.2	18	55.85	93	116	79.3	0.3	40	400	180	<5	3	39.1	11	360	33	1.1	22	1.1
Grevillea: Cavernous Gossan	10	239	1.3	74	28.05	220	267	9.2	0.5	68	9900	6400	6	5	3.2	11	719	6	2.4	432	2.8
Grevillea: Siliceous Massive Gossan	5	53	4.7	32	13.90	51	58	8.6	0.4	41	48300	12600	<5	2	2.7	15	420	15	1.2	286	0.9
Devil's Gossan	123	30	0.3	60	32.31	22	29	1.5	0.1	657	38	58	26	30	3.3	124	300	23	12	6	15.2

Hole No.	231WD48									227WD30				230WD36
Interval	120–21	121–22	122–23	123–24	124–25	125–26	126–27	127–28	128–29	71–72	72–73	73–74	74–75	72–73
Ag ppm	300	480	520	660	700	620	340	360	600	400	490	560	500	540
Pb %	21.5	37.50	27.3	27.8	35.90	33.7	28.3	26.00	34.00	28.1	27.4	39.00	36.8	40.00
Zn %	29.8	25.30	32.3	32.4	25.40	27.5	31.4	35.10	29.00	23.1	28.2	23.3	23.0	24.50
Fe %	5.48	2.8	4.0	3.68	3.40	3.51	4.67	3.39	2.72	6.92	3.83	3.76	3.50	3.64
S %	22.2	2.3	22..7	23.70	21.3	21.9	23.10	24.00	21.80	20.8	21.8	19.60	20.50	20.60
Ba %	–		–	–	–	–	–	–	–	–	–	–	–	–
S.G	4.30	4.87	4.60	4.64	4.9	4.94	4.67	4.67	4.90	4.66	4.70	4.86	4.82	4.66

Hole No.	242ED13			242ED11		230WD65				237WD45	239ED73	248V90
Interval	53–54m	54–55	73–74	25–26	62–63	107–8	108–9	109–10	110–11	86–87	86–87	87–88
Ag ppm	2	2	138	14	12	340	280	300	280	470	300	200
Pb %	0.44	0.04	1.44	5.22	1.25	16.7	12.9	12.9	12.6	37.0	25.4	7.37
Zn%	18.10	18.5	47.8	10.90	15.90	41.1	45.00	38.10	39.5	36.70	34.2	48.80
Fe %	2.05	0.93	4.52	2.72	1.94	5.85	6.63	8.65	8.15	3.55	6.77	3.17
S %	18.30	18.00	32.0	16.10	18.90	25.4	30.20	26.1	25.6	–	24.40	30.20
Ba %	30.60	38.3	0.27	33.50	32.4	–	–	–	–	–	–	–
S.G.	3.94	4.36	3.82	4.35	4.29	4.33	4.33	4.28	4.21	4.66	4.59	4.08

Assays of high-grade intervals at Lady Loretta

Appendix

Gravity, magnetic and radiometric evidence for the geological setting of the Lady Loretta Pb-Zn-Ag deposit — a qualitative appraisal

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Keywords: Lady Loretta, gravity, magnetics, radiometrics, Riversleigh Fold Zone, McNamara Group, Haslingden Group

Abstract

Semi-regional gravity, magnetic and radiometric datasets, augmented by a prospect-scale gravity survey, have been used to qualitatively assess the geological setting of the Lady Loretta Pb-Zn-Ag deposit. Regional gravity and magnetic fields are influenced chiefly by the Eastern Creek Volcanics, and are sensitive to the thicknesses of overlying clastic and dolomitic sedimentary sequences including the McNamara Group, which hosts the mineralisation. These are primarily controlled by Isan Orogeny deformation, but a number of earlier structures are discernible. The most important of these postulated syndepositional structures are a WNW-oriented bounding fault extending from Lady Loretta to the Mount Gordon Fault Zone along the Redie Creek Fault, and a possible sub-basin or zone of alteration beneath the Lady Loretta orebody, which manifests as a magnetic low.

Prospect-scale gravity data contain anomalies clearly associated with the mineralised strata at Lady Loretta. Contrasts between McNamara Group formations as well as older units are also apparent, reflecting differences in lithology or weathering characteristics. Higher Bouguer gravity signatures tend to be associated with the more dolomitic units.

The radiometric dataset enables mapping of surface geochemical signatures which are sensitive to a number of geological parameters. These include sedimentological factors such as provenance, maturity and proportion of argillaceous material, as well as chemical alteration. This variation occurs within as well as between mapped stratigraphic units, and is itself variable across the region. Potassium-channel signatures are an example of this, implying a general westerly decrease in argillaceous or feldspathic content within some formations. Some radiometrically distinct layers visible within sedimentary units appear to be absent at the equivalent stratigraphic level elsewhere. These observations may have implications for attempts to erect a regional sequence stratigraphic framework based on gamma ray log observations from relatively few locations.

This report is extracted from a paper based on a poster which was presented in April 1996 at the MIC conference in Townsville. The paper has been accepted for inclusion in an *Economic Geology* monograph arising from the MIC conference proceedings. Only qualitative interpretations are reported here — rigorous quantitative interpretation of these datasets is currently in progress. As the paper deals with geophysical signatures in the wider Paradise Valley region as well as the Lady Loretta deposit, some sections not directly relevant to Lady Loretta have been omitted.

Introduction

Geophysical methods can be applied to exploration for stratiform sediment-hosted base metal deposits at all scales ranging from the identification of prospective rift/sag basin settings to direct detection of ore. Although genetic models for this type of base metal mineralisation are still the subject of much debate (see for example Large et al., 1996; Hinman, 1996; Perkins, 1995; and Table 1 of Eldridge et al., 1993), most authors agree on the importance of understanding structures controlling basin evolution, deformation history and mineralising fluid pathways. By providing crucial three-dimensional perspective and regional scope, gravity, magnetic and radiometric methods can contribute significantly to determination of basin geometry, nature of sedimentary fill, and subsequent alteration and deformation (e.g. Leaman, 1991); in addition to detection of ore signatures at the prospect scale. This paper aims to demonstrate qualitative applications of these methods with reference to the geological setting of a particular deposit, Lady Loretta.

Lady Loretta is a stratiform sediment-hosted base metal deposit approximately 135 km NNW of Mount Isa. Most recently published reserves are 8.3 Mt of massive sulfide ore at 8.5% Pb, 18.4% Zn and 125 g/t Ag (Hancock and Purvis, 1990). Geophysical methods (mainly induced polarization) have been applied to the prospect area since 1964, usually in efforts to discover additional copper resources to the nearby Lady Annie Cu deposit, known since before 1920 (Lewis, 1975). The Pb-Zn-Ag mineralisation was discovered in 1969 by drilling on a soil geochemical anomaly (Cox and Curtis, 1977), though unpublished internal company reports stored on site suggest induced polarization anomalies coincident with the Lady Loretta orebody were defined almost simultaneously. More recently, Anderson et. al. (1993) reported results from a new airborne EM system flown over the deposit and surrounding areas which appeared to map conductive strata effectively, though no signature unique to the location of known ore was apparent. A mining feasibility study is being conducted by the current owners of the prospect, Buka Minerals NL.

This report describes preliminary results from studies of gravity, magnetic and radiometric data from the immediate area and broader setting of Lady Loretta, which were undertaken with the goal of better defining the evolution and deformation history of the host basin. Qualitative interpretations of extracts from regional datasets are presented, along with an assessment of additional gravity data acquired at closer spacing around the deposit.

Regional Geology

The Lady Loretta mineralisation lies near the western edge of the exposed Mount Isa Basin, within a structural domain defined by McConachie et al. (1993) as the Riversleigh Fold Zone. The oldest rocks exposed in this region (Table 1) are those of the Haslingden Group; comprising thick basal quartzite (Leander Quartzite), voluminous mafic volcanics (Eastern Creek Volcanics or ECV), and predominantly siliciclastic sediments (Myally Subgroup). The ECV, the maximum measured thickness of which exceeds 7 km (Blake and Stewart, 1992), have been subdivided into three members; the Cromwell Metabasalt and Pickwick Metabasalt, separated by hundreds of metres of siliciclastic sediments (Lena Quartzite Member). Both volcanic members have compositions similar to those of continental tholeiites (Wilson et al., 1985). A number of sandstone beds are also intercalated within the volcanic members, particularly towards the top of the Pickwick Metabasalt, but these are not volumetrically significant. There is some persistence of mafic volcanic rocks into the overlying siliciclastic Myally Subgroup.

The base of the Haslingden Group is thought to mark the onset of an episode of E–W extensional rifting, with a renewed phase of rifting resulting from N–S extension commencing with the Pickwick Metabasalt and extending through to near the top of the Myally Subgroup (O'Dea et. al. 1997). The Haslingden Group was deposited between 1790±10/8 Ma and 1737±15 Ma (Page, 1983). All Haslingden Group units are intruded by dolerite dykes and sills of undetermined age. A subsequent sag phase unit, the dolomitic-arenaceous Quilalar Formation, was apparently either completely eroded or never deposited in the Lady Loretta region.

Onset of another rift-sag cycle is recorded by deposition of the Bigie Formation, a redbed conglomerate and sandstone sequence. It is overlain conformably by the bimodal, intensely altered Fiery Creek Volcanics, which have been dated by R. Page at 1709±3 Ma (pers. comm. quoted in Betts et al., 1996). Post-rift sedimentation resulted in deposition of the fining-upward siliciclastic Surprise Creek Formation over the Fiery Creek Volcanics disconformably or with slight angular unconformity

(Derrick et al., 1980). Betts et al. (1996) judged this contact to be conformable at the Fiery Creek Dome, north of Lady Loretta, but this is inconsistent with pre-Surprise Creek Formation weathering of Fiery Creek Volcanics observed in the same area by McPherson (1994). Another unconformity separates the Surprise Creek Formation from the basal formation of the McNamara Group, the Torpedo Creek Quartzite (Hutton et al., 1981), however this is claimed to be a conformable contact by Betts et al. (1996), who consider the Torpedo Creek Quartzite an upper member of the Surprise Creek Formation.

The sag phase of the rift-sag cycle continued with deposition of the McNamara Group, a sedimentary sequence dominated by varying proportions of carbonate and fine-grained clastic rocks. Broadly speaking, dolomite increases with stratigraphic level at the expense of the siliciclastic component, with siltstone and sandstone dominant overall in the Torpedo Creek Quartzite and Gunpowder Creek Formation giving way to dolomites and dolomitic shales in the overlying Paradise Creek, Esperanza and Lady Loretta Formations. The Lady Loretta Formation is host to the Lady Loretta Pb-Zn-Ag mineralisation. Renewed clastic sedimentation is recorded by subsequent McNamara Group formations outcropping in the area; the Shady Bore Quartzite and the Riversleigh Siltstone. The depositional age of the McNamara Group is constrained by a Paradise Creek Formation zircon-bearing tuff dated at 1653 Ma by Page et al. (1994a), and a similar tuff in the Lawn Hill Formation (upper McNamara Group; host to the Century Zn-Pb deposit) with an age of 1595±6 Ma (Page et al., 1994b).

At least three post-McNamara Group regional deformation events have been recognised by previous workers in the Mount Isa Basin. D_1 has been interpreted as extensive north-to-south directed thrusting (Bell, 1983). D_2 accompanied peak regional metamorphism (lower- to sub-greenschist facies in this region), and caused major tight to open, upright, gently north- or south-plunging folds. The Mount Gordon Fault Zone (separating the Riversleigh Fold Zone from the Cloncurry Orogen to the east) is an example of D_3, which is manifest as an episode of predominantly strike-slip faulting in this region, resulting from brittle style sub-E–W compression (Keele, pers. comm.). While the total magnitude of displacement on the Mount Gordon Fault Zone is unknown, similar faults in the Mount Isa Basin record displacements of many kilometres.

Prospect Geology

A local stratigraphic subdivision within the Lady Loretta Formation has been established and refined by previous workers on the deposit (McGoldrick, this report). Of particular interest geophysically due to high density and or electrical conductivity are the siderite, massive pyrite and carbonaceous shale-bearing units, as well as the ore sequence itself. Sulphides constitute over 75% of the ore beds, comprising finely banded sphalerite, galena and pyrite, and up to 90% of the Pyritic Unit (Hancock and Purvis, 1990). Carr (1984) also records significant proportions of pyrite (up to over 50%) extending further into both the footwall and hanging wall (Cyclic Unit) sequences. The ore sequence also contains a barite-chert Zn-rich Pb-poor facies, mainly confined to the north-eastern edge of the orebody. Further details may be found in McGoldrick (this report).

Economic mineralisation at Lady Loretta is confined to the limbs and keel of a syncline, locally known as the 'Small Syncline'. Plunge is gently to the southwest in the northern part of the syncline, but to the northeast in the southern part, imparting an overall rough canoe-shape to the orebody such that depth of the ore sequence never exceeds 500 m. The stratigraphic equivalent of the ore sequence can be traced within another, north-plunging syncline immediately to the southwest (local name: 'Big Syncline'), but the original geometric relationship between the two synclines, now separated by the N–S trending Syncline Dividing Fault, is not clear. The Big Syncline equivalent of the ore sequence is dominantly pyritic, with only minor mineralisation present (Hancock and Purvis, 1990).

The Lady Loretta deposit lies near the convergence of a number of significant structures, most of which appear from geological survey (Figure 1; Hutton et.

Table 1 Unit descriptions.

Cainozoic	Sand, gravel, silt, colluvium, black soil, Fe-oxide cemented cobble conglomerate, duricrust
Mesozoic	Sandstone, conglomerate, siltstone, claystone
Cambrian	Siltstone, limestone, phosphorite, conglomerate
McNamara Group	
Riversleigh Siltstone	Fine siltstone, shale; thin coarse siltstone interbeds
Shady Bore Quartzite	Orthoquartzite; fine sandstone & siltstone interbeds
Lady Loretta Formation	Dolomite, dolomitic siltstone, limestone, carbonaceous & sulphidic shale
Esperanza Formation	Chert, dolomite, siliceous and dolomitic siltstone
Paradise Creek Formation	Dolomite, dolomitic siltstone, minor tuff
	Mount Oxide Chert
Gunpowder Creek Formation	Siltstone, dolomitic & carbonaceous siltstone, fine sandstone, feldspathic & pyritic quartzite
Torpedo Creek Quartzite	Medium orthoquartzite, conglomerate
Surprise Creek Formation	Siltstone, feldspathic sandstone, quartzite
Fiery Creek Volcanics	Rhyolite, agglomerate, basalt & trachybasalt
Bigie Formation	Feldspathic & lithic sandstone, pebbly sandstone
Quilalar Formation	Dolomitic siltstone & mudstone, feldspathic sandstone
Haslingden Group	
Myally Subgroup	Feldspathic quartzite & sandstone, dolomitic siltstone
Eastern Ck Volcanics	Metabasalt, feldspathic quartzite, orthoquartzite
	Pickwick Metabasalt
	Lena Quartzite
	Cromwell Metabasalt
Leander Quartzite	Orthoquartzite, feldspathic quartzite

al., 1985) and local prospect mapping to have been reactivated a number of times during the structural history. The ore sequence is truncated to the northwest by the NE-trending Carlton Fault Zone, which juxtaposes older basin units to the north against the Lady Loretta Formation to the south. The Carlton Fault swings into convergence with the NNE-trending Western Border Fault, which truncates Cambrian and Mesozoic cover rocks 1.5 km east of the deposit. A similar distance north of the deposit, the arcuate Leopard Fault defines the southern boundary of two blocks of Surprise Creek Formation, implying over a kilometre of apparent vertical displacement. The Leopard Fault has been identified as a growth fault during deposition of the upper Surprise Creek Formation and lower McNamara Group (R. Keele, pers. comm.), but no sedimentological evidence for growth faulting during deposition of the Lady Loretta ore sequence has been found. Carr (1981) proposed the Carlton Fault as the source conduit for Pb-Zn mineralising fluids, but this has not been borne out by later work (Aheimer, 1994).

Data Sources

Gravity data have been acquired at two scales, the first at approximately 250 m spacing in a 6 x 5 km area including the deposit, and the second at 1 km spacing on vehicular tracks within 30 km of Lady Loretta. Height control for the former survey was mainly from spot heights on detailed topographic maps derived from controlled photogrammetry, as well as surveyed trig. points and drill collars, with independent control from a pair of micro-barometers. Accuracy of heights for the prospect-scale survey is hence estimated at 1.5 m, while many stations will be of substantially better accuracy than this. Overall accuracy for the local survey is estimated at 0.3 mgal.

Elevation determinations for the semi-regional survey were chiefly derived from loop traverses with three micro-barometers, utilising the methods of Leaman (1984) and absolute height controls from state permanent marks, bench marks and spot heights wherever practicable. Horizontal positions were determined with the aid of a hand-held GPS unit. The resulting uncertainty in absolute Bouguer gravity values for this survey is estimated not to exceed 0.5 mgal. All prospect-scale gravity data were fully terrain-corrected out to a radius of 21 km, as well as the semi-regional traverse data wherever the terrain effect was judged likely to exceed 0.05 milligals. These data have been merged with regional Geological Survey of Queensland 1 km spaced traverse and Australian Geological Survey Organisation reconnaissance data as well as a limited number of stations acquired by mineral exploration companies. The principal source for airborne magnetic and K-U-Th radiometric data displayed in this paper is a survey flown by Geoterrex for Ashton Mining in 1987. Flight lines were oriented north–south, with a nominal spacing of 250 m and terrain clearance 80 m.

Rock Properties

Published petrophysical data from rocks of the Lady Loretta region are scarce, however large data sets (Fallon and Busuttil, 1992; Young ,1984) are available from correlative units in the vicinity of the Mount Isa Cu-Pb-Zn mine some 130 km to the SSE. These, together with data from a province-wide study by Hone et. al. (1987), new data from Duffett (in prep.) and bulk properties inferred by Leaman (1991 and previous AMIRA project reports) are summarised in the table below. Density values given are broad probable bulk wet specific gravity ranges for unweathered, typical samples of the formations listed; statistical analysis of the most recent work being not yet completed. In the case where units have not been adequately characterized by measured data, and for all radiometric signatures, the qualitative interpretation has assumed likely properties inferred from lithological and petrological descriptions.

Unit	Density t/m^3	Suscepti-bility $SI.10^{-3}$
Cambrian sediments	2.50-2.64	0.05
Lady Loretta Formation	2.75-2.78	0.44
Esperanza Formation	2.66-2.71	0.10
Paradise Creek Formation	2.69-2.76	0.11
Gunpowder Creek Formation	2.68-2.73	0.35
Torpedo Creek Quartzite	2.64	0.04
Surprise Creek Formation	2.56-2.65	0.13
Fiery Creek Volcanics	2.62-2.65	0.23
Bigie Formation	2.57-2.62	0.13
Myally Subgroup	2.59-2.60	0.10
Eastern Creek Volcanics	2.85-2.91	50-80

Gravity

On regional compilations of the Bouguer gravity anomaly (e.g. Wellman, 1992), the Mount Isa Inlier can be discerned as a series of sub-longitudinal, gently arcuate belts of alternating highs and lows, superimposed on a general regional high. The arcuate belts roughly correspond to major geological divisions defined from surface mapping. The Lady Loretta region lies astride the edge of the westernmost of these belts; the gravity field here (Figure 2) decreases gently westwards towards the edge of the Inlier. Superimposed on this regional gradient is a gravity high east of the Mount Gordon Fault Zone associated with exposure of the Eastern Creek Volcanics (ECV), and a low west of Lady Loretta caused by Palaeozoic and, possibly, Neoproterozoic sediments of the Undilla Basin, a sub-basin of the Georgina Basin. Much Bouguer anomaly character in areas of McNamara Group outcrop is interpretable in terms of an inverse relationship with preserved thickness of McNamara Group, Surprise Creek Formation and Myally Subgroup metasediments overlying the dense ECV. This is in turn primarily controlled by N–S trending D_2 fold structures formed during the Isan Orogeny.

However, more subtle effects can also be interpreted from sequences within the McNamara Group on close inspection. A gross fining-upwards trend, in conjunction with an increasing proportion of dolomitic sediments, leads to implied increased density values in the McNamara Group from the Torpedo Creek Quartzite to the Lady Loretta Formation, partly offsetting the effect of increasing vertical distance from the ECV.

There are suggestions of E–W to WNW and sub-NE trends offsetting the major N–S structures. The WNW-trending low passing through the Lady Loretta and Lady Annie deposits and continuing south of the WNW-trending Redie Creek Fault (GR 315000E 7808000N) may be a manifestation of thicker McNamara Group sediments filling the 'Paradise Graben' of Dunnet (1976). This trend has also been noted as a regional axis defining a change in fold plunge direction by R. Keele (pers. comm.). Alternatively, the thicker development of McNamara Group may simply be an artefact of basin inversion geometry, in which case the (half) graben would have been located north of the Redie Creek Fault.

Prospect Gravity

In the Lady Loretta area (Figures 1 and 2), variations within McNamara Group sequences are more apparent. The most prominent structure is coincident with the western end of the mapped Carlton Fault, but diverges along or, more precisely, beneath the Gunpowder Creek Formation/Surprise Creek Formation unconformity north of the deposit. Another structure mapped as a major fault, the Western Border Fault, has a more subdued expression. Lowest Bouguer values are associated with the Paradise Creek Formation, while the highest are associated with outcrops of Lady Loretta Formation both south of the Carlton Fault, and inferred beneath Cambrian cover east of the Western Border Fault. The more siliciclastic and hence less dense units – Gunpowder Creek Formation, Torpedo Creek Quartzite, Surprise Creek Formation and Bigie Formation, paradoxically are also associated with relatively high Bouguer values, reflecting the lower structural level exposed. This is especially apparent across the arcuate WNW- to NNW-trending Leopard Fault, which juxtaposes a block of Surprise Creek Formation (relative Bouguer high) against Paradise Creek Formation (relative Bouguer low) northwest of Lady Loretta.

Subtle character within formations may be largely due to differential weathering of various lithologies. An example of this is a shallow (amplitude approximately 1 milligal) gravity low at GR 294800 7812800, immediately W of the Lady Annie Cu deposit, which is the position of the 'Mount Lorrie Deep Weathering Trough', defined by drilling as a zone of deep oxidation extending below 320 m depth (Lewis, 1975). Exploration drilling (unpublished company data held on site) demonstrates that depth of weathering, though variable, frequently exceeds 100 m in this region, deepest oxidation usually being associated with faults.

The Lady Loretta mineralisation is evident as a high of about 1 mgal amplitude, spatially associated with the keel of the Small Syncline. Pb-Zn ore, with a bulk density (dry) of 4.0±0.5 $t.m^{-3}$ (R.A. Rivera and A. Challis, 1972; Placer Prospecting Ltd. unpublished data) is at least partially responsible for the anomaly, though massive pyrite above and below the ore sequence, barite within the ore sequence, especially near the surface, and the sideritic halo are all significant additional contributors. A weaker gravity high over the axis of the Big Syncline (GR 296200 7812000), deeper than the keel of the Small Syncline, is also interpreted as being due to pyrite and siderite in and surrounding the correlative ore sequence. As the Big and Small Synclines have similar geometries, and the sulphidic ore sequence is known to be present in the Big Syncline, it is reasonable to speculate that the increased intensity of the anomaly (implying greater excess mass) in the Small Syncline is due wholly to the presence of galena-rich ore. An irregularly developed linear feature hundreds of metres into the footwall, evidently untested by drilling, may denote another horizon of massive sulphide, but is more likely to arise from a more dolomite-rich or weathering-resistant facies of the Lady Loretta Formation, based on considerations of surface dips, anomaly amplitude and anomaly wavelength.

Magnetics

The aeromagnetic data (Figure 3) are very effective in mapping the Eastern Creek Volcanics both in outcrop and subcrop as well as beneath the Mount Isa Basin sediments. Within the ECV, the Pickwick Metabasalt appears far more magnetic than the thicker mafic member beneath it (Cromwell Metabasalt). Caution must however be exercised in interpreting these units as coherent magnetic entities, as magnetite abundance in the ECV appears largely controlled by alteration systems (Wyborn, 1987). Clear alteration effects can be observed along many faults cutting the ECV, both as magnetic highs (magnetite productive) and lows (magnetite destructive).

No magnetic response is discernible either from the sediments (cf. Anderson et al., 1993) or the Fiery Creek Volcanics, though further processing and filtering may enable recognition of a magnetic signature from basalts contained in the latter (Betts et al., 1994), which field and hand specimen measurements show to have a susceptibility of around $1x10^{-3}$ SI.

As with the gravity, broad linear anomalies associated with N–S trending uplifts correspond to anticlines mapped at the surface. These uplifts or domes may have been emplaced during D_1 N–S directed thrusting (Van Dijk, 1991), or may be a simple consequence of D_2 E–W shortening. More intense, localised anomalies denote uplifts of possibly earlier origin in the vicinity of Redie Creek, Mount Kelly and beneath outcrops of Surprise Creek Formation north of Lady Loretta. The largest magnetic anomaly in the Mount Kelly area (GR 310000E, 7798000N) surprisingly coincides with outcrops of Paradise Creek and Esperanza Formations. If this magnetic anomaly is wholly due to Eastern Creek Volcanics metabasalts, as has been assumed throughout this region, this implies that a great deal of the intervening sedimentary section (from Myally Subgroup to Gunpowder Creek Formation) is missing; having been removed structurally (by a fault dipping shallowly to the north), erosionally, or never deposited. The latter two possibilities would suggest that this area may have been on the uplifted footwall or flexural margin of a WNW-trending rift graben during deposition of the lower McNamara Group.

A linear magnetic low superimposed on (or overprinted by) other structures links Lady Loretta with the Redie Creek and Investigator Faults, corresponding to the gravity signature of the 'Paradise Graben'. An alternative or additional explanation for the magnetic low beneath and to the west of the Lady Loretta deposit is magnetite-destructive alteration of ECV by hydrothermal fluids as mapped on a wider scale in the footwall of the Mount Isa Mine by Leaman (1991). This interpretation is supported by relatively very low magnetic susceptibilities ($0.25x10^{-3}$ SI) measured on greenstones drilled from over 500 m depth 1.5 km north of Lady Annie. It is interesting to note that the areal extents of the magnetic low at Lady Loretta and the magnetite-destructive alteration mapped by Leaman at Mount Isa (2–3 km^2 versus 18–20 km^2) are in similar proportion to that of total amounts of Pb-Zn mineralisation present at each deposit (~2.2 Mt combined Pb-Zn metal at Lady Loretta versus ~20 Mt estimated pre-mining combined Pb-Zn metal at Mount Isa, calculated from figures contained in Hancock and Purvis (1990) and Forrestal (1990)).

As at Mount Kelly, the presence of high-frequency, high-amplitude anomalies coincident with outcrops of the Surprise Creek Formation and Fiery Creek Volcanics north of Lady Loretta implies the presence of magnetic Eastern Creek Volcanics at relatively shallow depths (of the order of hundreds of metres) in these areas. The sedimentary section between the Myally Subgroup and Surprise Creek Formation, inclusively, is therefore interpreted to be greatly thinned in this region also, consistent with this area having been relatively high during the corresponding period of basin evolution.

Radiometrics

Radiometric data (Figure 4) reveal many stratigraphic details not present in published geological mapping, as well as mapping intraformational variations in K, U and Th abundance.

The Bigie Formation and, surprisingly given the level of potassic alteration mapped elsewhere (Hutton and Wilson, 1984), the Fiery Creek Volcanics appear to be generally low in all channels. Only one outcrop of Fiery Creek Volcanics is of sufficient areal extent in this area to have its radiometric signature mapped reliably, and here it is low, with the exception of a K and U-enriched patch on the eastern side (GR 324000E 7835000N).

There is a striking contrast between the lower and upper members of the Surprise Creek Formation. Through most of the region (the blocks of Surprise Creek Formation north of the Carlton and Leopard Faults being good examples), only the lower, arenaceous unit has been preserved/deposited, and outcrops of it are of generally low total count. The upper unit is strikingly high in all channels, consequent from its much more argillaceous composition. The radiometric signal tends to diminish in outcrops to the west due to increasing masking effects from Phanerozoic weathering and cover, or dilution by a mature, quartzose sedimentary source.

The Torpedo Creek Quartzite at the base of the McNamara Group is often too thin (less than 100 metres) to be delineated by airborne radiometrics, especially where it directly overlies the compositionally similar arenaceous unit of the Surprise Creek Formation. Only where the argillaceous Surprise Creek Formation has been preserved beneath relatively flat-lying Torpedo Creek Quartzite can the Torpedo Creek Quartzite be clearly distinguished as a low count, arenaceous unit.

The Gunpowder Creek Formation is one of the most radioactive of all outcropping units in this region, equalled only by the upper argillaceous/micaceous member of the Surprise Creek Formation. At least three members of the Gunpowder Creek Formation are discernible from regional radiometric images. A thin, patchy basal member of low readings in all channels, albeit relatively Th-rich, soon gives way to high-count micaceous siltstones, sandstones and carbonaceous shales, which diminish slightly near the middle of the formation, possibly resulting from an increase in proportion of carbonates, before peaking again at the top of the formation, interpreted to correspond to carbonaceous shales known to occur in this stratigraphic position (Hutton and Wilson, 1985). All three members are arguably discernible in the core of the syncline north of Lady Loretta, though here the stratigraphic resolution of the radiometric data is reduced due to unfavourable geometry and coarse Cainozoic material weathered from the topographically higher Surprise Creek Formation blocks.

Potassium dominates the radiometric signature of much of the Paradise Creek Formation, though this influence diminishes to the south and west. A number of factors could be responsible, including variations in the proportion of tuffaceous input to sedimentation, and reductions in total clastic input, with a corresponding increase in dolomite content. Heterogeneity of radiometric signature is most clearly demonstrated north and south of the Redie Creek Fault, an example being a low-K bed at the top of the formation (GR 313000E 7815000N) which has no counterpart below the Esperanza Formation south of the fault (GR 317000E 7804000N).

A potassium-rich horizon clearly marks the base of the Esperanza Formation, probably corresponding to the maximum flooding surface identified from gamma ray logging by Southgate et al. (1996); however this signature is obscured in areas where bedding is steeply inclined, thus restricting outcrop area. The remainder of the Esperanza Formation, however, is generally low in all channels; thin silty bands of high-K only becoming apparent when shallow dips enable apparent bed thicknesses to exceed sample spacing.

The Lady Loretta Formation marks a return to the generally higher-count, more potassic signatures of the Paradise Creek Formation, though the Lady Loretta Formation is the most heterogeneous of all McNamara Group units. A distinct absence of potassium at the base possibly denotes the onset of a new depositional cycle, though the high level of uranium in relation to potassium implies a dolomite-rich facies. Resumption of shale- and siltstone-dominant deposition can be seen regionally in the red bands overlying the basal unit; however this facies is either obscured or absent in the Dayview or Debut Syncline north of Lady Loretta (GR 299000E 7826000N). No distinct signature related to the Lady Loretta mineralisation is manifest except for low counts in all channels on the limbs of the Small and Big Synclines, probably influenced by elevated topography as well as geology, and a possible slight increase in counts through all three channels relative to other Lady Loretta Formation outcrops in the core of the Lady Loretta Syncline.

Patches of high U-channel count within Phanerozoic cover west of Lady Loretta relate to uranium associated with major Cambrian accumulations of phosphate. Some extraction of these deposits has taken place intermittently over the last few decades at the Lady Annie Phosphate (not to be confused with the nearby Lady Annie Cu deposit) and Lady Jane mines.

All McNamara Group formations with the possible exception of the Gunpowder Creek Formation exhibit a distinct increase in K and Th from west to east, approaching the Leichhardt River Fault Trough, possibly reflecting increasing immaturity, tuffaceous input to sedimentation and/or proximity to a mixed felsic/mafic sediment source. These and other regional intraformational radiometric variabilities arising from sources other than eustatic sea level changes may indicate possible pitfalls in attempts to construct a regional sequence stratigraphic framework based on gamma logs from a small number of locations (for example Southgate et. al., 1996), in that gamma ray peaks and cycles present in some areas appear likely from the remotely-sensed data to be subdued or completely absent in others. This problem may however represent an opportunity, in that remotely-sensed radiometric data may be used to track at least the low frequency variations in gamma-ray signature across the entire outcrop area of the basin, thus assisting in correlation between detailed logging sites and possibly defining areas of anomalous sub-basin development.

Conclusions

The gravity field in the region of Lady Loretta is primarily controlled by variations in both composition and geometry of the basement to the McNamara Group, with relative gravity lows generally corresponding to increases in preserved thickness of McNamara Group. Variations on this general theme can be interpreted in terms of primary basin structures. An example of this is a possible WNW-trending palaeo-graben bounded by the Redie Creek and Leopard Faults, and adjacent to the Lady Loretta mineralisation. Such putative basin development structures and later Isan Orogeny overprints are however difficult to separate by qualitative inspection. Similar principles and limitations apply to the magnetic field, though its interpretation is better constrained by the assumption that the Eastern Creek Volcanics are the dominant magnetic unit, and constitute 'magnetic basement' in this region. An uplifted footwall or flexural margin bounding a half-graben which developed during lower McNamara Group time to the north is implied by a magnetic high directly underlying Paradise Creek and Esperanza Formation in the Mount Kelly area.

Semi-detailed gravity data centred on Lady Loretta clearly demonstrates a paradoxical positive Bouguer anomaly contrast between the Lady Loretta and Paradise Creek Formations; an effect opposite to that expected from the implied increased vertical depth to 'basement' (Eastern Creek Volcanics). This may reflect a gross change in McNamara Group lithology up-sequence, with predominantly siliciclastic sedimentation giving way to denser dolomitic and shaly lithologies; structurally controlled variation in the lower siliciclastic units; or simply differential weathering. Prospect-scale gravity data demonstrate the possibility of detecting sediment-hosted Pb-Zn mineralisation (Small Syncline) within a dolomite/shale host, standing out above anomalies arising from other sulphidic/sideritic accumulations (Big Syncline) and differential weathering.

Alteration types in the Eastern Creek Volcanics, possibly related to Pb-Zn and Cu mineralising events, can be distinguished and mapped using a combination of aeromagnetic and radiometric datasets. Such a base-metal-mobilising alteration event signature may be present as a component of the magnetic low centred near the Lady Loretta mineralisation. Variations in the broader magnetic signature of the Eastern Creek Volcanics may be ascribed to gross structural controls, namely dip and preserved thickness.

Radiometric data are clearly useful in this environment as a means of defining lithological changes within formations, as well as being an aid to general geological mapping. They are capable of discriminating quite subtle lithogeochemical differences, providing insights into the regional variations of sediment maturity, provenance and carbonaceous content. As such, aero-radiometrics should be used wherever possible to complement attempts to erect a sequence stratigraphic framework using gamma ray logging at relatively few locations.

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Lady Loretta - Geological Setting

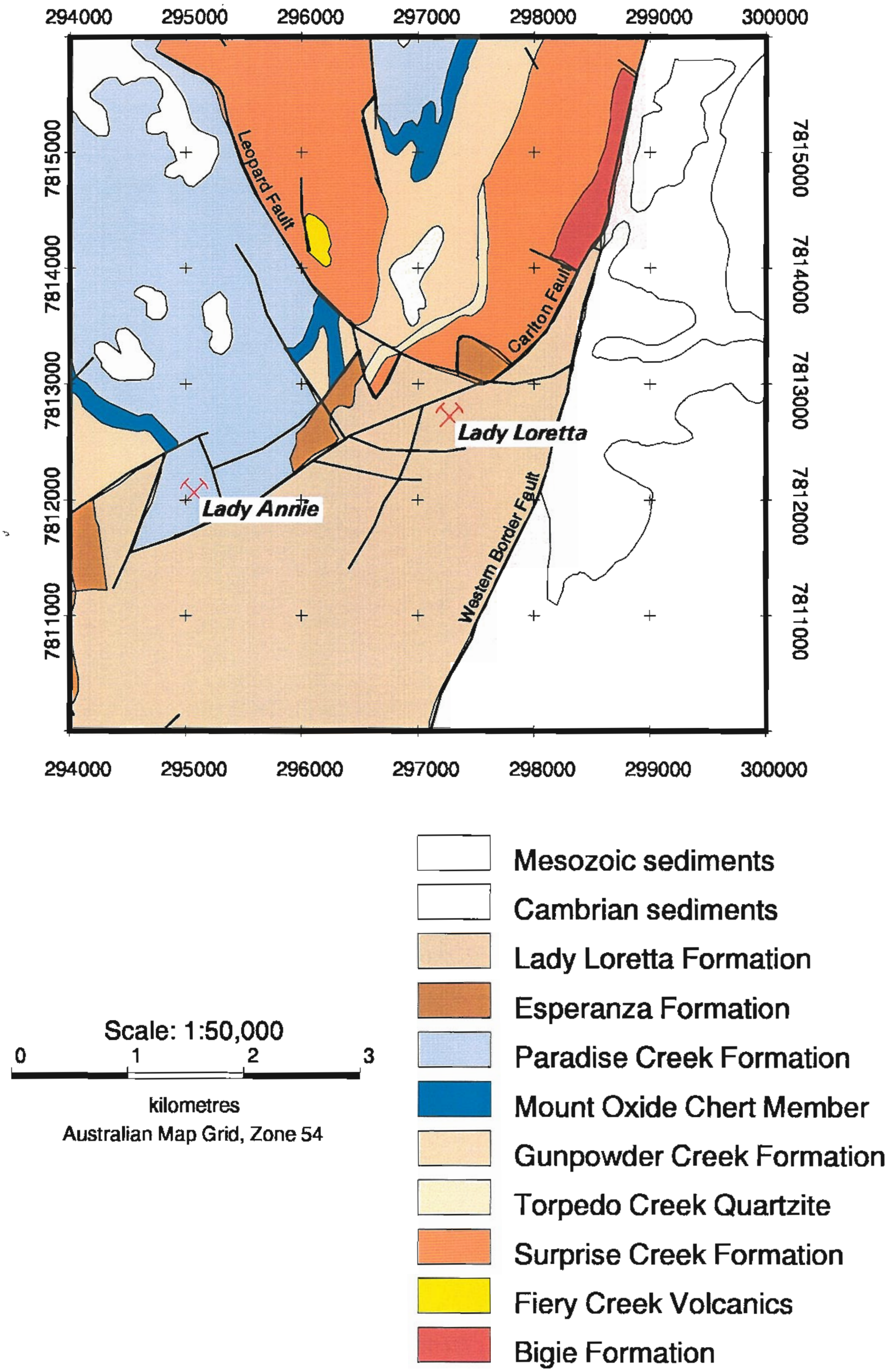


Figure 1

Geology from BMR/GSQ Mammoth Mines 1:100,000

LADY LORETTA - BOUGUER GRAVITY

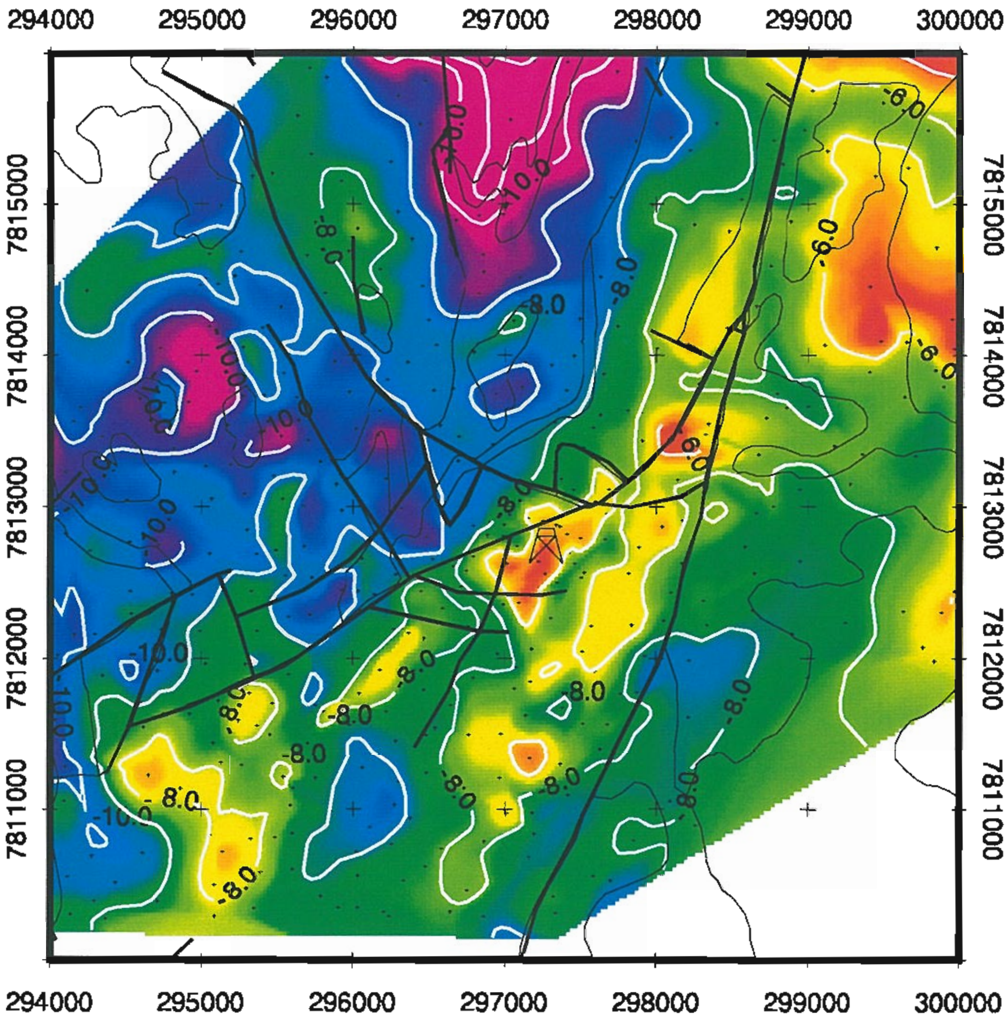


Image: Residual from 5th-order polynomial surface

Contours: Terrain-corrected Bouguer gravity

Lady Loretta shaft

Gravity station

Scale: 1:50,000

0 1 2 3

kilometres

Australian Map Grid, Zone 54

CODES SRC

University of Tasmania

September 1997

Figure 2

Lady Loretta - Magnetics

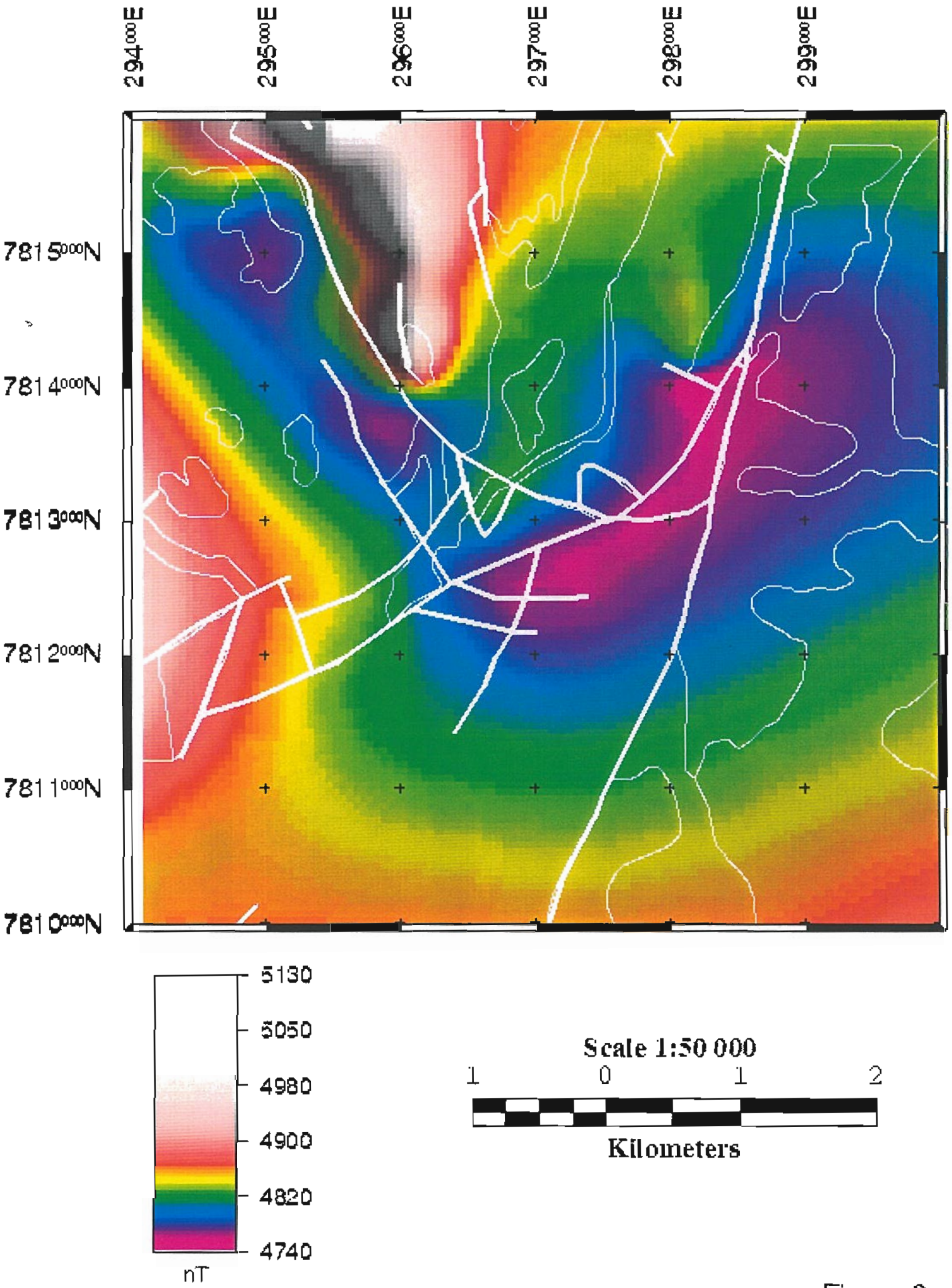


Figure 3

Lady Loretta - Radiometrics

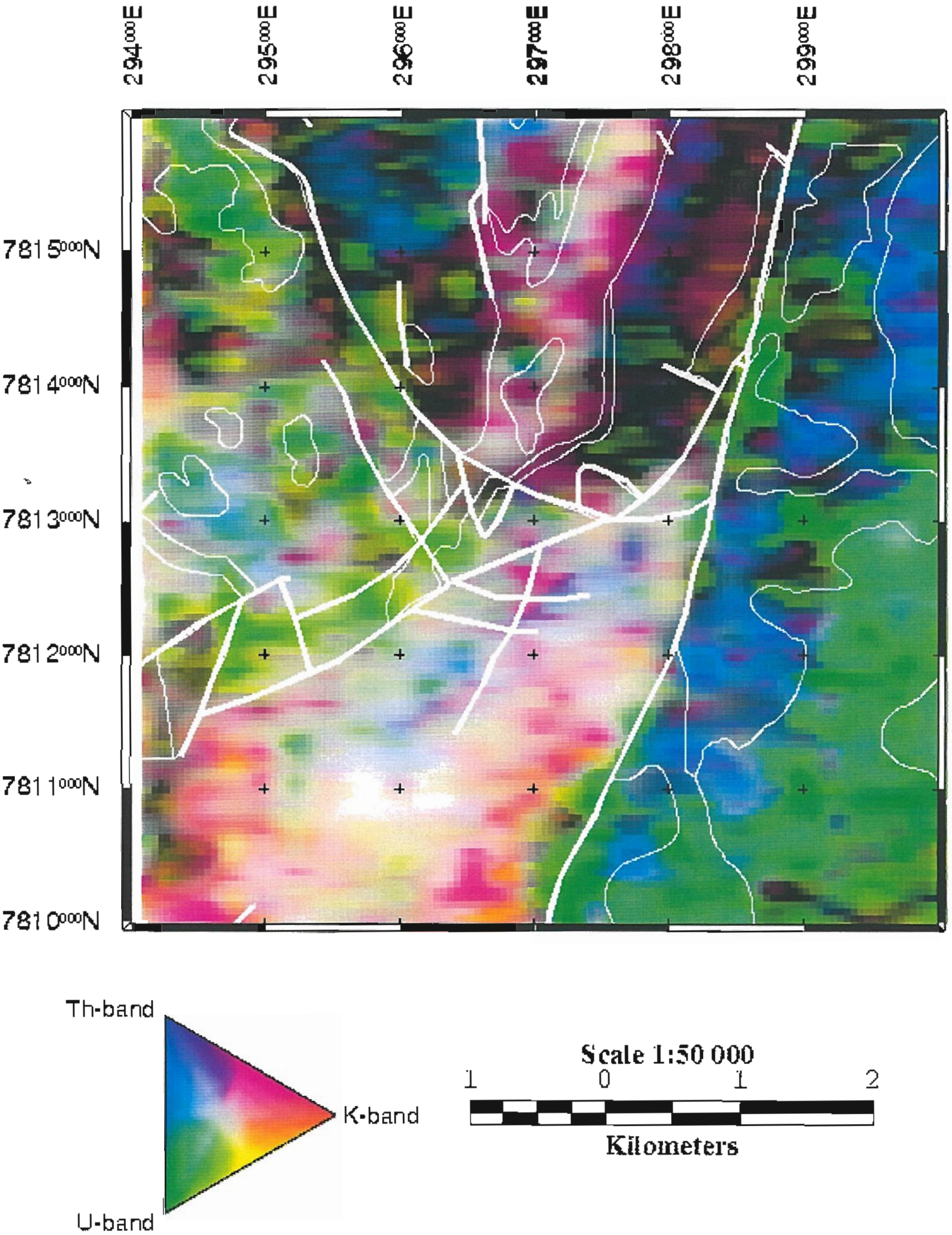
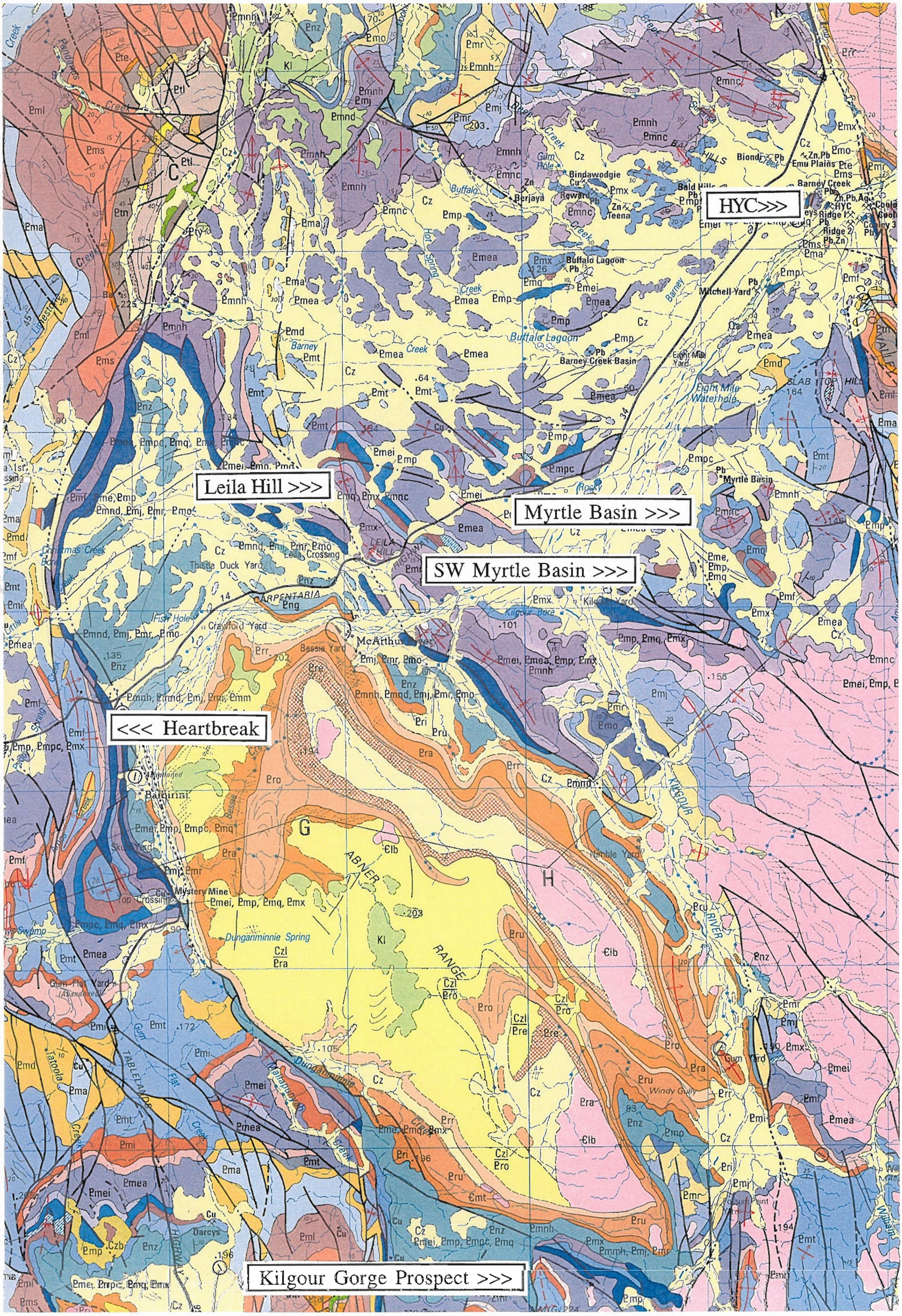


Figure 4

AMIRA P384A Sponsors Field Trip

Part 2 Southern McArthur Basin


HYC>>>
Leila Hill >>>
Myrtle Basin >>>
SW Myrtle Basin >>>
<<< Heartbreak
Kilgour Gorge Prospect >>>
Bald Hills
Barney Creek
Buffalo Lagoon
Mitchell Yard
Eight Mile Waterhole
Myrtle Basin
Thistle Duck Yard
Leila Crossing
Crawford Yard
McArthur River
Kilgour Bore
Balbirini
Mystery Mine
Dunganminnie Spring
Abner Range
Kilgour River
Windy Gully
Gum Flat Yard
Darcys
Buffalo
Hot Spring
Carpentaria
Top Crossing
Christmas Creek

DAY 6 and DAY 7 — McArthur Basin

Peter Winefield, David Selley and Stuart Bull

INTRODUCTION

Field-based work carried out in the southern McArthur Basin in the original P384 project included integrated structural and sedimentological studies of areas of the basal Tawallah Group (Rogers and Bull, 1994; Bull and Rogers, 1996; Rogers, 1996). This dramatically advanced our understanding of the basin history and resultant architecture beyond the concept of a layer cake stratigraphy unaffected by structural activity, and gave insight into a complex and dynamic depositional system that records the effects of both syn-sedimentary and post-depositional tectonism. Work on the overlying McArthur Group consisted of collaborative sedimentological and geochemical studies. The field and drillcore based sedimentological aspect focussed chiefly on evaluating existing shallow water to emergent sabkha models for the deposition of the host rocks to the HYC mineralisation. This culminated in the proposal of a contrasting sub-wave base model for these deposits.

The field-based work carried out in the southern McArthur Basin in the P384A project extension was designed to build on the strengths and concepts developed in the original project. The aim of this field trip is to present the integrated results of this work, while visiting some of the key localities on which it is based.

One major objective of the project extension was to expand the sedimentological studies, both stratigraphically and geographically, beyond the thick Barney Creek Formation intersections initially examined. An aspect of this work considered particularly important, was to overcome the inherent limitations of the drillcore-based data used in both our initial study, and in other recent studies of the middle McArthur Group. This was achieved by identifying key areas for detailed sedimentary and structural mapping and analysis. The Top Crossing area that had been the focus of some sedimentological and geochemical work in the original project was clearly one such area. Another was identified on the Kilgour River at the southern end of the Abner Range, that subsequently became the major focus of the fieldwork component of Peter Winefields PhD Project.

A second major objective of the project extension was to extend the structural analysis from the Tawallah Group into the overlying mineralised McArthur Group sediments. As a result, David Selley has been involved in the latter part of the project extension in collecting structural data to complement Peter Winefield and Stuart Bulls sedimentological studies. The ultimate aim was to produce an integrated analysis of the Barney Creek depositional cycle (BCDC) in the southern McArthur Basin. Structural data was initially collected along a 70 km segment of the Tawallah Fault (Kilgour Gorge northward to Leila Creek), with the aim of characterising 2D variation in facies architecture along a sinuous fault that potentially coincided with a basin margin during the BCDC. During the final stages of the mapping project, focus was shifted "basinward" (i.e. east of the Tawallah Fault) in order to establish the relationship between sedimentation and BCDC structures in areas distal to major NW to NNE fault systems. This systematic, regional scale approach, in combination with the geophysical interpretations of David Leaman and Mark Duffet, has provided the basis for a 3D basin evolution model of the BCDC.

SUMMARY

The following are the major results of the integrated geophysical, structural and sedimentological studies of the middle McArthur Group:

- The acicular, radiating fans or 'Coxco needles' that characterise the Coxco Dolomite Member of the Teena Dolomite occur in a number of lithofacies that represent a range of depositional settings. They are, therefore, interpreted to have been the result of a subtle but significant change in water chemistry at this point in the basin's history. As such they represent a time line upon which much of the following interpretation is based.

- The tectonically-controlled BCDC may overlie a karst surface in the Emmerugga Dolomite, and in terms of the currently published stratigraphy includes the Teena Dolomite, Barney Creek Formation and at least the Caranbirini Member of the Lynott Formation.

- The Hot Springs and Donnegan Members of the Lynott Formation may represent the final infill of the tectonically-generated accomodation space.

- The regionally extensive HYC Pyritic Shale Member of the Barney Creek Formation is a lithofacies association that represents the deepest water (i.e. basinal) conditions attained during accumulation of the McArthur Group.

- Other party time-equivalent lithofacies associations include:

  Transitional facies (= W-Fold Shale Member and represents the onset of deepening in areas that will become the major basinal depocentres).

  Slope facies (= thicker bedded and coarser grained turbiditic deposits associated with sediment re-cycling, sliding and slumping).

  Marginal/shoal facies (often mapped as Reward Dolomite = clean dolomite with evidence of shallow water conditions such as stromatolites, tempestite plate breccias etc.).

  Breccia units of various types including talus breccias, slides, debris flows and tectonically generated units.

- Under the current stratigraphic subdivision of the McArthur Group, these genetically related lithofacies associations span the Umbolooga–Batten Sub-Group boundary, and those that are considered as map units are interpreted to be layer-cake in nature. As this is misleading, they will all be considered here as members that occur within the BCDC, but have no other stratigraphic implication.

- Integration of sedimentological and geophysical data reveals a complex sub-basin geometry during the BCDC. We contend that differing rates and degrees of subsidence or uplift can be explained in terms of a mild NNW–SSE compressional episode, D_1, which resulted in the development of two end-member sub-basin types. The first of these sub-basin types was mainly controlled by local heterogeneities in the regional stress field which responded to changes in strike of major fault systems (ie. Tawallah, Hot Springs and Emu Fault systems). These steeply dipping structures were active as sinistral transfer zones during D_1, with deep, elongate depocentres such as the HYC sub-basin having formed close to their present day traces. Smaller sub-basins of this type developed adjacent to the Tawallah and Hot Springs Fault systems and at the SW Myrtle basin. Depocentre maxima (defined by the maximum thickness of basinal facies strata, ie. "conventional" Barney Creek "formation"), occurred adjacent to NNW- to N-striking segments of major fault systems (extensional or "releasing" zones) whereas basin minima or 'shelf' positions (defined by marginal/shoal facies and absence of basinal facies) are best demonstrated adjacent to NNE- to NE- striking faults ("restraining" zones).

- The second sub-basin type formed distal to major steeply dipping fault systems and was filled mainly by upward shallowing slope facies associations. We interpret these depocentres as segmented WSW–ENE trending synclinal depressions formed in response to forced flexural subsidence during

NNW-directed shallow thrusting. Well exposed examples of this sub-basin type occur at the Myrtle basin and the Kilgour Gorge. Another potential depocentre of this type beneath the Abner Range has been revealed by geophysical modelling. Basin geometry to the southeast of the Tawallah Fault system was controlled largely by the restraining transfer zone (i.e. NNE- to NE-striking fault segment) north of Top Crossing. This bend in the fault system inhibited displacement and development of transfer-related sub-basins, with progressive strain hardening leading to fault inactivity during the late BCDC, and accumulation of strain along the more suitably oriented Hot Springs Fault system.

- Our interpretation of compressional deformation during the BCDC, dramatically effects modelling of fluid flow mechanisms and development of mineralising systems. Most importantly, it provides a means by which large volumes of basinal brine can be actively displaced ("pumped") from deep structural levels towards suitably dilated sites (ie. NW- to NNW-striking "releasing" transfer zones), where metals can be "trapped" if suitable reduced lithologies are present.

- Inversion of transfer-related sub-basins occurred during D_2 (?Isan) transpressive reactivation of major steeply dipping NW- to NE-striking fault zones. Anomalously high strains accumulated in deeper stratigraphic levels of the basin-infills in the form of high amplitude, close to isoclinal N- to NNE-trending upright folds and shallow to steeply dipping sinistral/reverse faults. Strain was dissipated upward, producing *apparent* high angle unconformable relationships within the BCDC stratigraphy.

STRATIGRAPHY

Sedimentological work carried out in the initial P384 project concentrated on thick Barney Creek Formation intersections dominated by sub-wave base (i.e. basinal facies association) dolomitic siltstones. Detailed facies analysis clearly indicated that an agitated shoreline facies association co-existed with these basinal deposits (Bull, 1995), and it was postulated that this might be represented by areas mapped as Reward Dolomite. Mapping of key field localities during the P384A project extension, based on the recognition of the Coxco Dolomite Member as a potential marker horizon, has demonstrated that there are actually several lithofacies associations that represent depositional environments time and/or stratigraphically equivalent to the basinal facies association generally mapped as Barney Creek Formation. These only partly correspond to the map units that comprise the current published stratigraphy for this part of the McArthur Group, and as a result, this scheme is inadequate for the purposes of our work. In this study the lithofacies associations are considered as members within a genetically related, tectonically generated depositional package termed the Barney Creek Depositional Cycle (BCDC). This succession may overlie a karst surface in the Emmerugga Dolomite, and includes units mapped as Teena Dolomite, Barney Creek Formation and at least the Caranbirini Member of the Lynott Formation. The preliminary results of this work are summarised in Table 1, although much of the data collected during the 1997 field season has yet to be placed into context. Six facies associations have been identified thus far as follows:

'Coxco needle' facies association

Prior to the commencement of the current AMIRA project, lateral lithofacies variability in the Teena Dolomite was largely unrecognised, with the presence of radiating, acicular fans or 'Coxco needles' used to discriminate between the lower Teena Dolomite and the Coxco Dolomite Member. Winefield (1997a) reported that the overall depositional setting, crystal morphology, and petrographical and sedimentological relationships shown by individual needle fans is more consistent with an aragonitic precursor than the previously interpreted gypsum. Perhaps more significant for the McArthur Basin study, is the recognition and description of several stratigraphically equivalent lithofacies that represent different depositional environments, all of which contain Coxco needle fans (Table 1).

Facies associations	Lithofacies	Distinctive features	Lithostrat.	Depositional environments	References
1. 'Coxco' facies	Cox1	laminated dololutite and dolostone with abundant Coxco needles	Coxco Dol. Mb.	deep ramp	Winefield (1997)
	Cox2	plumose' microbialite with pervasive Coxco needles	Coxco Dol. Mb.	ramp to sub-tidal	Winefield (1997)
	Cox3	linked &/ unlinked conical and domal microbialites with common Coxco fans	Coxco Dol. Mb.	intertidal	-
	Cox4	Coxco fans in massive dololutite interbedded with finely laminated dolomitic siltstone and shale	Coxco Dol. Mb.	deep ramp to basin	Winefield (1997)
	Cox5	Coxco needles in red, 'oxidised' dololutite intimately associated with microbial mat, teepee structures and possible evaporitic textures	Coxco Dol. Mb.	supratidal	-
2. Basinal facies	BCF1	finely laminated to massive pyritic, carbonaceous and dolomitic siltstone and shale	HYC Pyritic Shale Mb.	basin	Bull (1995)
	BCF2	thicker bedded, normally graded fine grained dolomitic siltstone and dololutite with varaible well-developed stylonodular textures	Reward Dolomite	basin	
3. Transitional facies	BCF3	finely laminated to thinly bedded clean carbonate and red/pink/green dolomitic siltstone. Occassional flaser & lenticular bedding. Carbonate nodules, concretions and well-developed microfaults are also well-developed in certain DDH intersections	W-Fold Shale Mb.	basin	Bull (1995)
4. Slope facies	BCF4	thick bedded and coarser grained turbiditic deposits with associated sediment re-cycling, sliding and slumping	Barney Creek Fm./Reward Dolomite	proximal to distal slope	-
5. Marginal/platform facies	BCF5	linked domal/columnar microbialites in dolomitic siltstone and dololutite	Barney Creek Fm./Reward Dolomite	subtidal?	-
	BCF6	low relief cuspate and prone microbial mat with associated cross-laminated quartz-rich dolomitic sandstone	Reward Dolomite	supratidal	-
	BCF7	linked low-relief columnar and high relief conical and bulbous microbialites	Reward Dolomite	subtidal	
	BCF8	intensively stylolaminated dololutite and dolomitic siltstone	Barney Creek Fm.	subtidal	-
6. Breccias	BRX1	spar-ball breccias with polymict fragments of cemented dolomite rimmed by fibrous dolomite marine 'cement	Emmerugga & Teena Dolomites	infilling syn-sedimentary fractures & associated with slope development	Winefield et al. (1997)
	BRX2	large allochthous/slide blocks of marginal/platform facies (e.g. Gorge Prospect) included within slope/basinal facies. In places with apparent channelised bottom and 'ponded' top contacts.	Barney Creek Fm.	upper slope	-
	BRX3	various tectonic breccias	N/A	N/A	-
	BRX4	talus breccias	N/A	N/A	-
	BRX5	Matrix-rich breccias; consist of angular clasts of dolostone in a massive or faintly disrupted silty matrix. Exhibits some features suggestive of liquifaction	Coxco Dolomite Mb., Barney Creek Fm. & Reward Dolomite	N/A	-

Table 1 Barney Creek depositional cycle (BCDC): preliminary lithofacies and facies associations.

The recognition of that Coxco needle fans were formed in a range of deposition environments indicates that precipitation of the precursor mineral, whether it was gypsum or aragonite, was facies independent and therefore likely to be related to a subtle change in water chemistry related to a major basin event (e.g. restriction of the water body or a significant change in the bathymetry of the basin). In essence, the presence of Coxco fans in different lithofacies would appear to represent a chrono-stratigraphic marker horizon that places important constraints on basin architecture and depositional patterns.

Transitional facies association

Transitional facies intervals are characterised by thinly interbedded pale dolomite and dark dolomitic siltstone. The latter lithology often exhibits a mixture of green and red coloration that may represent variations in redox conditions during deposition, or alternatively may be a diagenetic feature. In terms of the published stratigraphy, this facies association is generally logged as W-Fold Shale Member of the Barney Creek Formation when intersected in drilling. It is interpreted to represent the transition from dolomitic marginal/shoal facies to basinal siltstones and shales (Bull, 1995), and tends to be proportional in thickness to the overlying reduced package.

Basinal facies association

The basinal facies association consists dominantly of variably carbonaceous and pyritic dolomitic siltstone. Intercalated dolomitic turbidites that are generally less that 10 cm in thickness occur in varying proportions. Occurrences of the basinal facies association are generally logged/mapped as undifferentiated Barney Creek Formation unless they have a relatively high proportion of pyrite and low proportion of dolomite, in which case they are often designated HYC Pyritic Shale Member. In either case it accumulated in a quiet, reduced, sub-wave base environment that represents the deepest water conditions developed during McArthur Group sedimentation (Bull, 1995).

Slope facies association

Facies analysis of the BCDC, particularly in the Gorge Prospect area, has allowed the definition of a slope facies association consisting of coarse to very coarse dolorudites and dolarenites, interbedded with the varying amounts of finely laminated dolomitic siltstone and shale. A spectrum of depositional mechanisms can be recognised from debris flows and very coarse dolorudite with minor dolomitic siltstone and shale (proximal slope) to fine, normally graded turbiditic dolomitic siltstone (distal slope). Soft-sediment deformation features (i.e. development of pseudo-nodular textures, 'boudinaged' breccia clasts, convolute and chaotic bedding and well-developed intra-stratal folds) is common within slope deposits recognised in the Gorge Prospect area. Allochthonous slide blocks are also present where carbonate marginal/shoal material has been transported downslope.

Slope development is also recorded by the dilation or localised extension of early cemented carbonate sequences, resulting in fractures opening up parallel to the strike of the slope. These were subsequently infilled by syn-sedimentary marine cements, brecciated dolomite fragments and laminated internal sediment.

Marginal/shoal facies association

The marginal/shoal facies association includes a number of lithofacies that have been mapped as either Reward Dolomite or (rarely) Barney Creek Formation. It is dominated by carbonate-rich lithologies that have abundant shallow water features such as stromatolites, flat pebble breccias, oolites etc, but are clearly lateral and time-equivalent to basinal and slope facies. This interpretation is supported by the recognition of clasts of marginal/shoal carbonate lithofacies in debris flows and allochthonous slide blocks, and the interpretation of the Coxco Dolomite Member as a marker horizon. Table 1 summarises those lithofacies that have been defined loosely as a marginal carbonate platform/shoal facies assem-blage. Analysis of field data is ongoing and will hopefully allow more constraints to be placed on the depositional setting and platform architecture of this particular facies association.

Breccias

A number of breccia units have been recognised within the BCDC. Although the origin of many remains enigmatic, several examples are thought to be related to syn-sedimentary deformation of pre-lithified and early cemented carbonate sediments. These include 'spar-ball' and matrix-rich breccias. Spar-ball breccias consist of angular dolomite clasts rimmed by fibrous marine cement and infill large fractures (discussed in more detail in Winefield et al., 1997). Matrix-rich breccias are generally recognised adjacent to faults consist of brecciated, angular dolostone clasts in a massive, silty matrix with features suggestive of 'liquefaction-like' processes.

DAY 6 — GORGE PROSPECT

Overview

The Gorge Prospect area is approximately 60 km SW of HYC, along the Kilgour River and represents the southern-most limit of BCDC exposure between the Tawallah and Emu Fault systems. We argue that this distribution is not simply an artefact of present levels of exposure, but rather defines the position of a southern margin of the BCDC depo-system. The evidence that we will present is derived from detailed analysis of the facies architecture and structural geometry of the lower BCDC.

The main results of the basin analysis are as follows:

The middle to lower portion of the BCDC (ie. Barney Creek 'Formation' and Reward Dolomite) is characterised by rapid vertical and lateral facies variation. Two major facies associations are recognised in the Gorger Prospect area: (1) Slope facies — the area to the north and east of the Kilgour River is dominated by coarse- to fine-grained siliciclastic units. These attain a maximum thickness adjacent to a SSW-striking splay off the Hot Springs Fault system and progressively thin towards the west. Deposition of this package occurred for the most part on a gravitationally unstable slope; (2) Marginal/shoal facies — the second major facies association is exposed south of the Kilgour River and comprises relatively clean stromatolitic dolostone sequence, with only minor coarse-grained lithic arenite. This facies association is interpreted to have been deposited on an elevated basin margin or carbonate shoal.

Basin slope and marginal/shoal sedimentation occurred both contemporaneously and proximally. Two main lines of evidence support this. Firstly, laterally extensive and voluminous slide sheets or blocks comprising marginal/shoal facies strata are hosted by relatively fine-grained slope facies deposits. Deformation features contained within the slide sheets indicate that marginal/shoal facies debris was redeposited to deeper water basin positions whilst unlithified. Secondly, the upper and lower surfaces of both facies associations are linked by two timelines. The lower surface overlies Coxco needle bearing carbonates of the Teena Dolomite. The upper surface is defined by a thin (<5 m) but laterally extensive, sheet-like conglomerate unit that contains rounded cobbles and boulders derived from lower to middle parts of the McArthur Group stratigraphy.

The conglomerate unit at the top of the slope-margin interval records emergence of lower to middle McArthur Group stratigraphy (i.e. Emmerugga Dolomite and Teena Dolomite) during the BCDC. Although we have recognised angular clasts of similar provenance in other parts of the southern McArthur Basin (e.g. SW Myrtle basin), only in the Kilgour Gorge area are these clasts sufficiently texturally mature to unequivocally demonstrate that lower stratigraphic levels were uplifted such that clasts were reworked and abraded in very shallow or sub-aerial environments.

Gravitationally induced mesoscopic structures (i.e. intra-folial folds) indicate a dominant NW- to N-dipping palaeoslope during BCDC sedimentation, however localised reversals or deviations from this trend occur at a number of stratigraphic levels and geographic positions. In the area to the north of the

Kilgour River, where bedding in lower BCDC strata swings abruptly into roughly N–S orientations, the palaeoslope dipped initially ENE to ESE and SSE during later stages of sedimentation. The change in palaeoslope at this locality, coupled with an anomalous thickening of coarse-grained facies, is interpreted to define the position of a narrow NNW–SSE to N–S trending depocentre. Although strata are presently steeply dipping (a result of D_2 transpression), we consider the palaeoslope to have been a relatively shallowly inclined (<30°) E-dipping ramp developed at an 'accommodation zone' that linked discrete segments of the regionally E–W trending basin margin.

The preferred model for basin development during deposition of the lower and middle BCDC, involves the generation of a roughly ENE–WSW-trending major depocentre in response to flexural subsidence during D_1 NNW-directed thrusting. Evidence in support of a compressional model includes thrust-repetition within the pre- to lower BCDC dolostone succession and the development of a shallowing and coarsening upward cycle of sedimentation (ie. Barney Creek 'Formation' and Reward Dolomite), characterised by cannibalisation of older strata and culminating in the emergence and erosion of lower to middle McArthur Group stratigraphy.

We recognise that a similar facies architecture as that in the Kilgour Gorge area may have formed in a half-graben setting developed during regional N–S extension. However, we favour the compressional model due to the fact that no obvious steeply-dipping growth fault can be identified.

Gravity modelling of preserved McArthur Group thicknesses indicates a maximum thickness approximately 15 km NNW of the Kilgour Gorge area. This position potentially represents the nadir of the BCDC basin system located between the Tawallah and Hot Springs Fault systems.

- **Stop 1 Allochthonous/Slide Block in the Barney Creek Formation**

Travel from Heartbreak on the Tableland Highway (for 37 km) and turn off to the Mallapunyah Station. Turn right before the station along the station track that leads to Archies Creek. At about 5 km there is a relatively concealed turnoff to the left marked by a piece of blue flagging tape (589098E; 8121625N). The track continues to the east until it hits a N–S fenceline where it heads off to the north. After approximately 2 km, the track crosses the fenceline (593807E; 8125104N) and follows an E–W fenceline over Balbirini Dolomite for roughly 2 km before swinging SE and into the Gorge Prospect area.

- **Stop 1a Allochthonous/slide block (602682E; 8123695N)**

Driving east, the track crosses a creek containing boulders of light grey dolostone and then after 100 m passes to the north of a prominent dolostone outcrop that is the focus of this stop (Figure G1). The dolostone consists of internally disrupted laminated dololutite, stromatolitic dolostone and large clasts or 'rafts' of dolomitic siltstone. No Coxco needle fans have been recognised within the dolostone, which is surrounded to the east and south by undisturbed finely laminated dolomitic siltstone and dololutite. The lower contact is sharp, while the upper contact is obscured due lack of outcrop. Of interest is the relict sedimentary textures within the dolostone, in particular the linked columnar and domal microbialites morphologically similar to those in the marginal/shoal lithofacies that overlies Coxco Dolomite Member to south of Kilgour River (refer to measured section KP97/7; Figure G7).

- **Stop 2**

From Stop 1 travel eastwards along the track for approximately 300 m and walk to the north over low-lying outcrop of the Coxco Dolomite Member towards outcropping ridges of dolomitic siltstone.

- **Stop 2a Matrix-rich monomict breccia, Coxco Dolomite Member**

Immediately to the north of the track, low-lying outcrop of the Coxco Dolomite Member is exposed that consists of angular clasts of Coxco needle-bearing dololutite in a massive light coloured, silty matrix. In places, faint 'convolute lamination?' within the matrix is suggestive of deformation prior to or during lithification/cementation of the carbonate sequence. This is supported by the lack of fibrous cement infilled fractures abundant further to the east.

- **Stop 2b Stromatolitic slide blocks hosted by fine-grained dolomitic siltstone**

A small cliff exposure of thinly bedded dolomitic siltstone contains a number of lensoidal stromatolitic dolostone blocks. Internally, the dolostone blocks exhibit chaotic deformation, that is in marked contrast to the relatively coherent siltstone host. This feature is best demonstrated near the top of the cliff, where columnar stromatolites contained within one block are rotated and ductilely sheared out, indicating that deformation occurred prior to lithification. The contrast in strain between the two lithotypes and pervasive pre-lithification deformation within the dolostone blocks, suggests emplacement or re-deposition of marginal/shoal facies debris as exotic slide blocks. This slope facies association provides good evidence for a proximal basin margin during the BCDC.

Ductile-brittle layer-parallel shear zones exceeding 1 m in thickness are well developed within dolomitic siltstone immediately overlying the slide block division. Shear zones are dominated by low amplitude intra-folial folds (F_1) with moderately inclined to recumbent axial surfaces. The majority of these folds possess NNW to N vergences, however an additional component of SW–NE to E–W shearing is evidenced by complex fold interference geometries. Although unequivocal evidence for a syn-BCDC origin of these shear zones is lacking, transport directions and structural morphology are compatible with other D_1 structures mapped in the Kilgour Gorge area. Furthermore, the close spatial association with exotic slide blocks provides clear evidence for syn-depositional slope instability. A D_1 origin is thus considered most likely for these shear zones, that were potentially generated as near surface, gravitationally induced slide surfaces. Alternatively, they may represent high-level, tectonic thrust surfaces, that root into deeper structural levels towards the south.

Located at the western end of the cliff is a NNE-plunging, ESE-verging F_2 monoclinal closure with roughly 10 m amplitude. Dolomitic slide blocks appear to be restricted to the east of this structure, which may therefore have defined a zone of topographic relief during BCDC. This isolated F_2 closure potentially relates to D_2 transpressive reactivation of a D_1 (syn-BCDC) N–S trending "accommodation" zone.

- **Stop 2c D_1 thrust surfaces and F_3 kinks in dolomitic siltstone**

Continue WNW for about 50 m to another small cliff of thinly bedded dolomitic siltstone. Sedimentological and structural relationships are less complicated than the last stop, with strata dipping shallowly and consistently to the NNE. The dominant mesoscopic structures are steeply inclined F_3 kinks. F_3 axial surfaces dip mainly southward, however a sub-ordinate N-dipping conjugate set (with extensional offsets) is developed locally. NNE-transport directions, moderate amplitude and the brittle character of F_3 kinks distinguish this generation of folding from F_1.

Close examination of strata folded by F_3 reveals an earlier episode of small-scale layer-parallel thrusting and shearing. Individual sedimentary layers are structurally repeated and narrow shear zones defined by internal bedding truncation surfaces are common. Although transport directions associated with these early structures are difficult to establish, a gross NW sense of shear is inferred. This style of deformation is compatible with D_1 thrusting/sliding observed at Stop 2b.

- **Stop 3 Channel developed in slope facies**

Approximately 350 m further to the east, the track passes close to another large dolostone outcrop that appears to truncate and downcut thick bedded coarse grained dolarenites and finely laminated dolomitic siltstones and shales. As with Stops 1 & 2, the dolostone outcrop consists of linked columnar and pseudo-columnar stromatolites that appear ductilely deformed. Occasional 'rafts' of finely laminated dolomitic siltstone and shale are also present.

The lowermost contact of the dolostone block is very sharp and truncates interbedded dolarenite and dololutite. Along strike to the west of the contact a number of imbricate shear microstructures bounded by undisturbed finely laminated dololutite, indicate layer parallel shearing to the east. The upper contact is difficult to discern at this location, but is better exposed further to the east and may be visited as part of Stop 4.

- **Stop 4 Matrix-rich brecciated Coxco Dolomite Member and section through upper BCDC**

From Stop 3 continue eastwards along the track for approximately 500 m before stopping next to a large knoll of brecciated Coxco Dolomite immediately to the south of the track.

- **Stop 4a Monomict matrix-rich breccia, south of track**

At this locality, the outcrop consists of mostly angular fragments of Coxco needle-bearing dolomite in a light grey silty matrix with occasional faint irregular, 'convolute lamination'. These features are identical to the monomict matrix breccia visited in Stop 2a, and a similar mechanism of brecciation is suggested.

- **Stop 4b Measured section KP97/5**

To the north of the track, a large allochthonous/slide block of stromatolitic dolostone is exposed hosted in finely laminated dolomitic siltstone. The upper contact of the slide block is unexposed, but several metres above is an outcrop of cross-laminated quartz-rich dolomitic sandstone overlain by low relief cuspate and domal microbialites and medium grained dolarenite. This lithofacies sequence is thought to represent a shallowing upward as accommodation space decreased.

- **Stop 4c Conglomerate**

Exposed on the north side of the hill is approximately 2–3 m of variably silicified, poorly sorted conglomerate comprising rounded cobbles and boulders of various lithologies including clasts that contain Coxco needles, large conical stromatolites and peloidal grainstone. This clearly demonstrates that in the Gorge Prospect area, lower McArthur Group was uplifted to very shallow or subaerial environments during BCDC deposition. It is also important to note that several boulders contain sediment and silicified, fibrous cement infilled fractures which provide important timing criteria on the formation of neptunian dykes in this region.

- **Stop 5 Syn BCDC Accommodation Ramp**

From Stop 4 continue east along the track that soon swings to the south mimicking the distinctive swing in strike of the strata in this area (see Figure G2). From where the track turns to the south continue for 1 km before stopping between two hills of NE dipping dolomitic siltstone.

At this locality, an episode of localised ESE–WNW extension recorded within lower BCDC strata is related to the development of an ESE-dipping slope associated with a D_1 "accommodation zone". The attitude of the slope probably did not exceed 30° and roughly marks the position at which the siliciclastic portion of the middle BCDC (ie. Barney Creek "formation" and lower Reward Dolomite) thickens markedly to the east. Further north of this locality, lower BCDC strata are rotated to sub-vertical and structurally repeated within a D_2 transpressive fault zone.

Note that the majority of stratigraphic and facies information from this locality is summarised on Measured Section KP96/1 included as Figure G5. Individual stop localities are marked on Figure G2.

- **Stop 5a Haematitic, ferruginous outcrop**

Rubbly outcrop of haematitic, ferruginous material is present at the contact between the Coxco Dolomite and the Barney Creek Formation, some of which has a well-developed cubic habit. Interestingly, there are a number of similar haematitic or sideritic(?) horizons recognised in the Teena Dolomite and or at the contact between the Coxco Dolomite and Barney Creek

Formation. The origin of these Fe-rich horizons is somewhat enigmatic and requires further study.

- **Stop 5b Cave infill and neptunian dykes**

Uphill from Stop 5a within Coxco Dolomite Member dipping at approx. 30° is a well-exposed cave infilled with sub-horizontally laminated internal sediment. This implies the rotation of early BCDC sediments prior to infilling of the cavity. Note also the 'stalactite-like' growths at the top of the cavity.

Particularly well-developed at this location are fibrous marine cement infilled fractures or 'neptunian dykes'. These are interpreted to have formed due to localised extension or dilation of a cemented carbonate platform. They were subsequently infilled by fibrous marine cement, laminated internal sediments and spar-ball breccias.

- **Stqp 5c lower Coxco Dolomite Mb and Teena Dolomite lithofacies**

To the west of Stop 5b, stromatolitic Coxco and Teena Dolomite lithofacies can be recognised. Coarse-grained peloidal grainstones and planar laminated dololutite with occasional imbricated flat pebble conglomerate are mapped as Teena Dolomite on Figure G2. These lithofacies are interpreted to have been deposited in agitated, shallow marine conditions. Conformably overlying these deposits are linked columnar/conical microbialites with common Coxco needle fans. Upsection these grade into more planar laminated dololutite and massive dolostone with abundant well-developed Coxco needle fans thought to mark the onset of a broadly transgressional cycle.

- **Stop 5d Steep breccia zones in the Coxco Dolomite Member**

This locality is about 150–200 m north of Stop 5c. Large brecciated clasts of dolostone (some of which contains visible Coxco needles) within a silty and fibrous marine cement matrix infill an elongated fracture that is up to 2 m wide and traceable laterally for approx. 10–15 m. The fracture is orientated roughly N–S and is associated with a number of similarly orientated fibrous cemented neptunian dykes. The similarity in infill and orientation of both this larger fracture and the smaller dykes suggests a common origin.

- **Stop 5e Upper contact of the Coxco Dolomite Member**

The nature of the contact between the Coxco Dolomite Member and the base of the siliciclastic slope facies association (Barney Creek' Formation') is best demonstrated on a small saddle about 50 m east of Stop 5d. Although extensional strain has accumulated along this contact, it is otherwise conformable, with insignificant variation of bedding attitude within either package. Immediately underlying the contact, massive dolostone to planar laminated dololutite of the Coxco Dolomite Member is intensely fractured and sub-vertical, and layer-parallel neptunian dyke and sills are densely developed. The consistent NNW- to N-strike of steeply dipping neptunian dykes indicates a local WSW–ENE phase of extension in this area.

Just above the contact, mesoscopic extensional structures oriented shallowly with respect to layering are well developed. Extensional faults have listric geometries and ENE-directed transport directions. Antithetic block rotation and Riedel fracture development within the hangingwalls of listric normal faults is common. Evidence for a surficial slide origin for these structures, such as upper erosional truncation surfaces, is lacking, and indeed it is very difficult to prove beyond doubt that they record an episode of syn-BCDC deformation. The best evidence in support of a D_1 origin for these extensional faults is that they indicate a similar extension direction to that required to generate the steeply-dipping neptunian dyke set within the underlying Coxco Dolomite Member.

- **Stop 5f D_1 shear zone breccias and coarse-grained deposits within the slope facies association**

Following the spur eastward for about 100 m reveals abundant D_1 brittle shear zone fabrics. Breccia units range from a few cm to more than 1 m in thickness and are bounded by relatively coherent thinly bedded dolostone. Although these units superficially resemble debris flow deposits, in some cases it is possible to demonstrate upper gradational contacts into undeformed strata. Breccias must therefore have generated *in situ*, probably via post-depositional layer-parallel sliding. The rather chaotic character of their internal structure resulted from fragmentation and subsequent rotation and mixing of competent dolostone divisions with less competent intervening siltstone layers. A remarkable breccia unit at the tip of the spur involves a large winged porphyroclast of buff coloured silty dolostone contained within a sheared argillaceous "matrix". It is very difficult to explain this fabric in terms of mass flow emplacement. Shearing along bedding surfaces within a sedimentary package possessing marked competency contrast is a more likely explanation.

Directly overlying the shear zone breccia interval is a thick succession of tabular, medium-bedded dolarenite and dolororudite. This influx of coarse-grained detritus marks the onset of basin activity in the stratigraphy. These coarse-grained beds are commonly interbedded with finely laminated dolomitic siltstone and shale, and contain abundant soft-sediment deformation features (e.g. development of pseudo-nodular textures).

- **Stop 5g Modified F_1 folds within sandstone-siltstone division**

Close to isoclinal NNE-plunging upright folds are well developed within sandstone-siltstone intervals on the north-eastern slopes of the spur. Fold styles are complex and characterised by non-cylindrical geometries, and sinuous hinge-lines. Although upright profiles hamper transport direction determination, consistent NNE-trends of these folds are compatible with slide generation on a broadly E-dipping slope. Close inspection of fold profiles reveals that anticlinal closures are commonly cored by massive sandstone. Fold development must, therefore, have occurred whilst the sediment was incompletely lithified to have allowed sand to migrate into hinge positions. This style of deformation is clearly syn-BCDC and folds of this type may be confidently identified as F_1. The non-cylindrical character of these F_1 closures may reflect primary geometries, or alternatively it may have resulted from refolding or tightening by NNE-trending F_2 folds.

- **Stop 6 D2 transpressive zone at the contact of Coxco Dolomite Member and slope facies association (optional)**

Moving northward from stop 5, structural complexity increases dramatically, with lower BCDC strata rotating to sub-vertical on the limb of an ESE-verging monocline and structural slicing or repetition of Coxco Dolomite Member. Mesoscopic fold geometries have also become more complicated. F_1 closures have been refolded by open to tight, shallow to steeply plunging, NE- to NNE-trending F2 wrench and drag folds.

The contact between the Coxco Dolomite Member and the overlying slope facies association is defined by a sub-vertically dipping brittle fault zone approximately 5 m in width. Most of the strain has accumulated within the less competent dolomitic siltstone units, and is characterised by an anastomosing network of NNE- to NE-striking fault surfaces that link both along-strike and down-dip. Kinematic indicators on or adjacent to these fault surfaces include sub-horizontally plunging fibre vein lineations and drag folds. Consistent sinistral to sinistral-reverse displacements can be demonstrated. The anastomosing geometry of the faults isolates small lensoidal domains that have failed internally along arrays of mesoscopic fractures oriented at high angles to the bounding fault surfaces. The majority of these small-scale fractures have dextral offsets and strike W to NW. These fractures are interpreted as antithetic Riedel shears. A less common fracture type forms a conjugate array of NW-striking sinistral faults and SW-striking dextral faults (?X-shears).

The association of NNE-striking sinistral faults and NE- to NNE-plunging folds is interpreted to reflect transpression during D_2 NW–SE shortening. This transpressive zone initially formed by development of high amplitude F_2 wrench folds generated above the pre-existing E-dipping D_1 'accommodation zone'. With increasing strain and tilting of strata to sub-vertical, suitably oriented bedding surfaces became activated as sinistral faults. It is noteworthy that many of the W- to NW-striking mesoscopic fractures lie within the extensional field of strain and thus potentially involve a component of dilation. Development of similarly oriented dilational structures at larger scales may be important in focussing mineralising fluids during the D2 deformation event.

- **Stop 7 D2 fault zone and coarse-grained slope facies with fracture- and vuggy-style mineralisation (optional)**

This stop is located at the eastern margin of a 100 m wide brittle fault zone. In contrast to the steep E-dip of strata within the fault zone to the south, bedding here dips only shallowly to moderately to the north. Close to tight F_2 wrench folds were not developed in this region. This variation in fold geometry may indicate that strain accumulated along shallowly dipping thrust or detachment surfaces in the northern part of the fault zone, rather than in the form of high amplitude folds. In support of this argument are the development of numerous mesoscopic, upward convex thrust surfaces throughout the brittle fault zone. These thrusts splay off steeply dipping, NE-striking faults (?P-shears) and die out into bedding surfaces. Associated with these layer-parallel thrusts are abundant low amplitude WNW- and ESE-verging, NNE-plunging F_2 decollement folds.

Coarse galena is observed infilling fractures and vughs in coarse grained dolarenite and dolorudite of the Barney Creek Formation (Figure G1). Associated with the galena is white crystalline dolomite cement and abundant pyrobitumen. The dolomite cement generally lines vughs and fractures with porosity occluded by the coarse galena and/or pyrobitumen. An adjacent E–W fault that offsets the Barney Creek Formation in this area by several metres is thought to be associated with mineralisation.

- **Stop 8 F_1 decollement folds in Coxco Dolomite Member**

A knoll of macroscopically folded Coxco Dolomite Member is situated approximately 500 m southeast of the Kilgour River. The folds have angular closures and amplitudes in the order of 10 m. Vergence is consistently northward, with axial surfaces dipping moderately towards the south and striking roughly E–W. Strata within the underlying arenaceous Teena Dolomite and Emmerugga Dolomite are not deformed by this generation of folds, hence a detachment surface is inferred at the base of the Coxco Dolomite Member.

Although fold orientation is compatible with D_3 NNE–SSW directed compression, analysis of mesoscopic structures associated with the closures indicates that a D_1 origin is more likely. Up to three episodes of syn-BCDC deformation have been identified. The earliest of these involves NNE- to NE-directed layer-parallel transport, as indicated by the orientation of dramatically inclined columnar stromatolites at the Teena Dolomite/Coxco Dolomite Member contact (south end of knoll). The relatively ductile nature of deformation at the contact makes it unlikely that strata were completely lithified during this deformation episode. We therefore infer that deformation occurred early in the depositional history of the Coxco Dolomite Member.

The most useful structures for establishing the timing and kinematics of later D_1 deformation episodes are neptunian dykes, which are pervasively developed within the hinge regions of anticlinal closures. Multiphase dyke development is clearly shown within the steeply-dipping limb of the northern-most anticline, with evidence suggesting that most dykes formed during a single progressive folding and shearing event. At least four generations of dykes have been identified, the first three of which strike ENE–WSW, but vary considerably in dip. The fourth set strikes NNW and dips sub-vertically. The variation in dip of generations 1 to 3 is interpreted to have resulted from progressive NNW-directed layer-parallel shear and ultimately rotation of bedding to near vertical during the growth of high amplitude F_1 folds. Evidence in support of NNW-directed shearing during dyke development includes sigmoidal dyke geometries and consistent anticlockwise overprinting relationships. Other structures indicative of the low angle NNW-transport event include mesoscopic thrust faults and associated folds. Structures associated with this D_1 episode are correlated with similarly oriented mesoscopic folds and shear zones contained within the BCDC slope facies association north of the Kilgour River, and thus probably post-date deposition of the Coxco Dolomite Member.

The orientation of the latest dyke generation indicates a period of ENE–WSW extension, which may correspond to that recognised at the "accommodation zone" northwest of the Kilgour River (Stop 5).

Within the oolitic/peloidal grainstones of the Teena Dolomite at this locality, there is a texturally destructive stratiform sideritic(?) horizon with very coarse crystalline dolomite crystals infilling large vughs. It is possible to trace the horizon along for several tens of metres to a N–S orientated fault. The recognition of a number of such horizons at a similar stratigraphic level would appear significant for studies of basin fluid composition and timing of fluid movement.

- **Stop 9 'Elevated' basin margin/carbonate shoal**

Approximately 1.5 km south of the Kilgour River, east of the Tawallah Fault, slightly brecciated Coxco Dolomite is overlain by marginal/shoal facies consisting of linked low-relief columnar and pseudo-columnar microbialites grading into larger bulbous and conical microbialites with lenticular bedded dolarenite and dololutite. The microbialites evident in this particular lithofacies are identical to those recognised in the allochthonous/slide blocks within slope facies visited in Stops 1–4. The upper contact of the 'Reward Dolomite' is erosional and overlain by a poorly sorted conglomerate consisting of rounded boulders and cobbles of Coxco, Teena, and Emmerugga Dolomite. Sedimentary log KP97/7 summarises the aforementioned relationships and is included as Figure G7.

- **Stop 10 Shallow thrusting in the Teena Dolomite (optional)**

To the southwest of Stop 4 (approx 1 km), brecciated lower Teena Dolomite is noted overlying shallowly dipping Coxco Dolomite Member The actual faulted contact is difficult to discern, but the two units are able to be traced laterally for several tens of metres. The thrusting and facies repetition within the Teena Dolomite and older stratigraphy at this locality may be related to D_1 NNW-directed thrusting invoked in a compressional model for basin development during BCDC deposition.

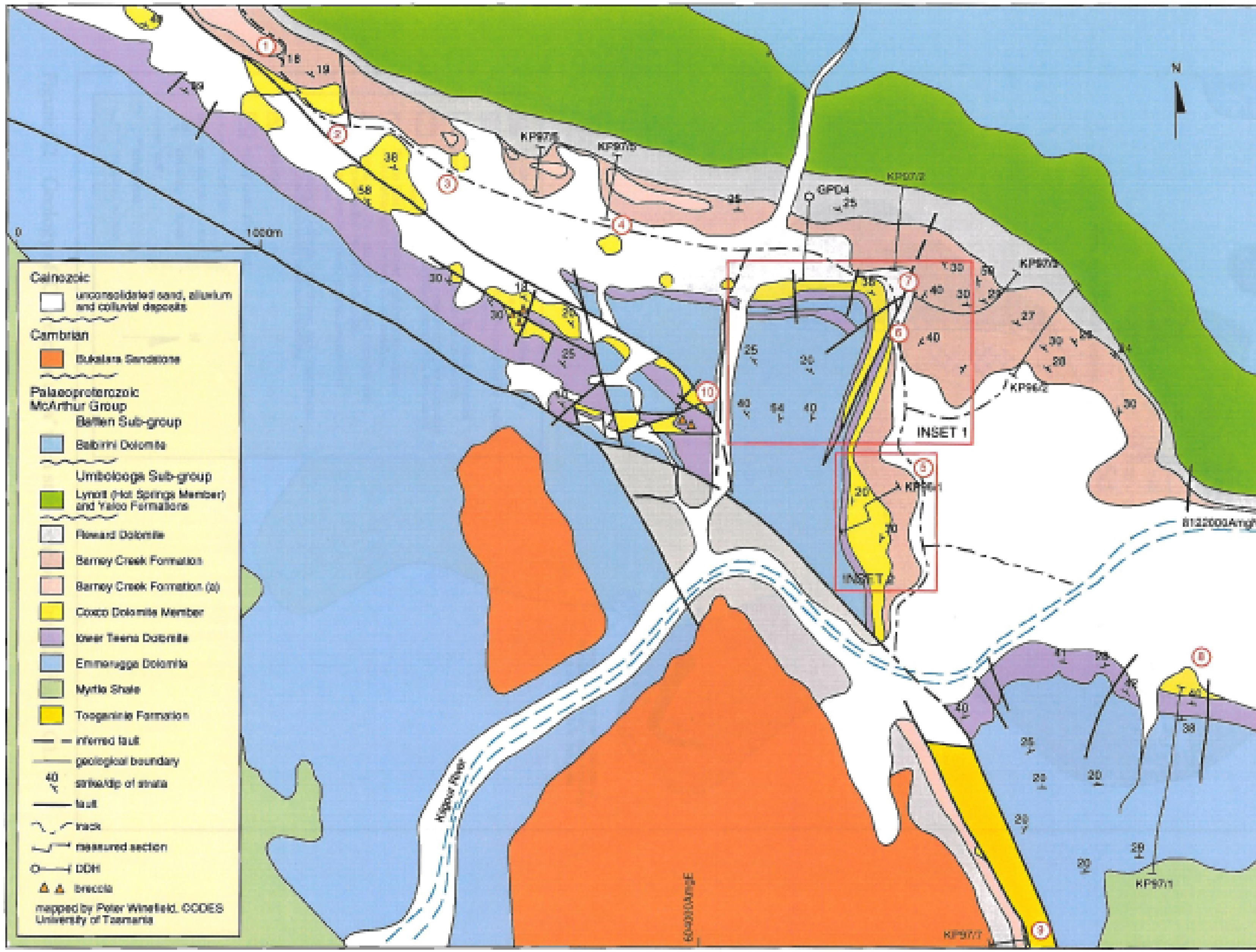


Figure G1 Geology of the Gorge Prospect, south of the Abner Range.

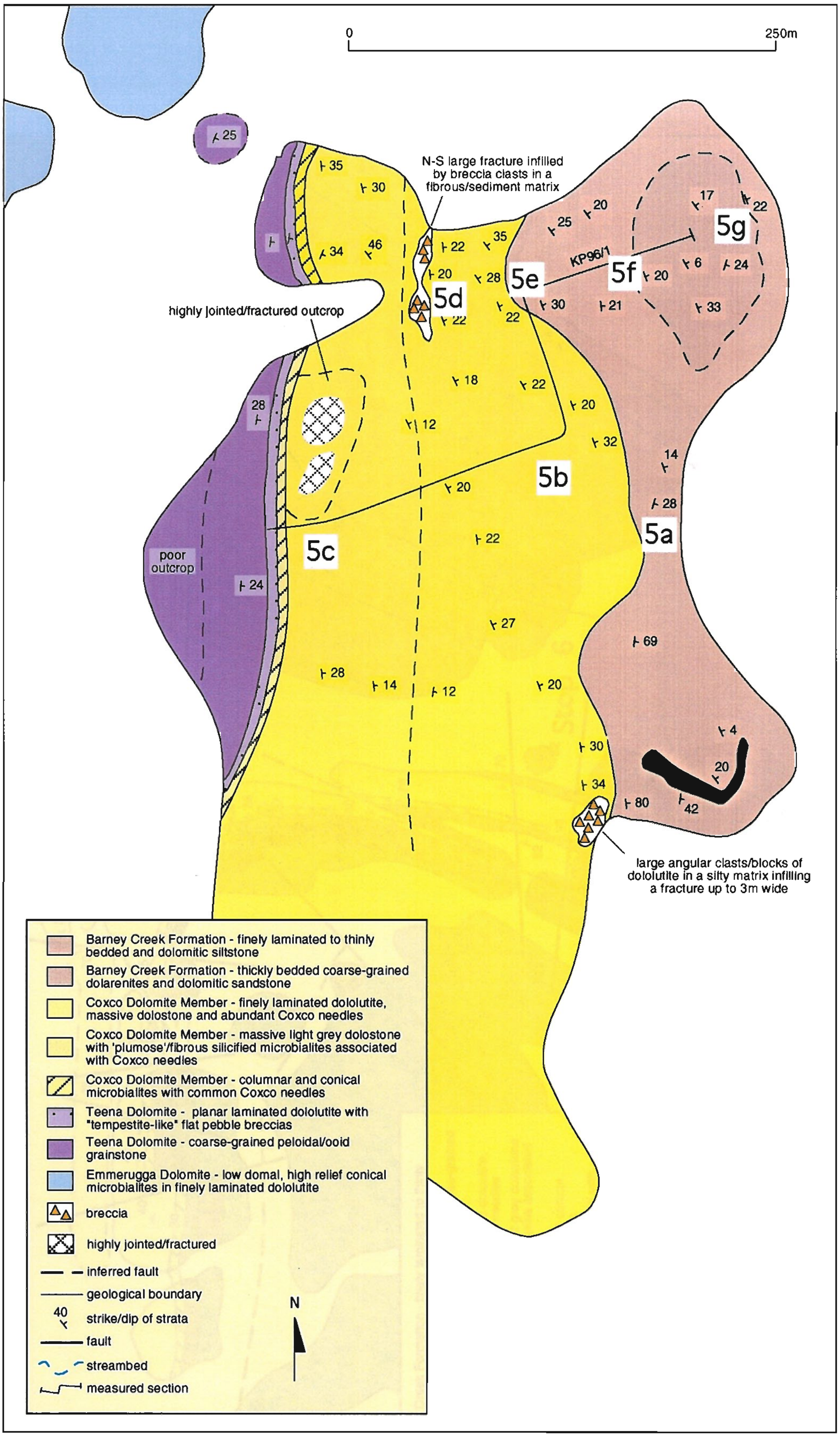


Figure G2 Geology of 'Coxco cave area' with stop locations. Inset 2, Figure G1.

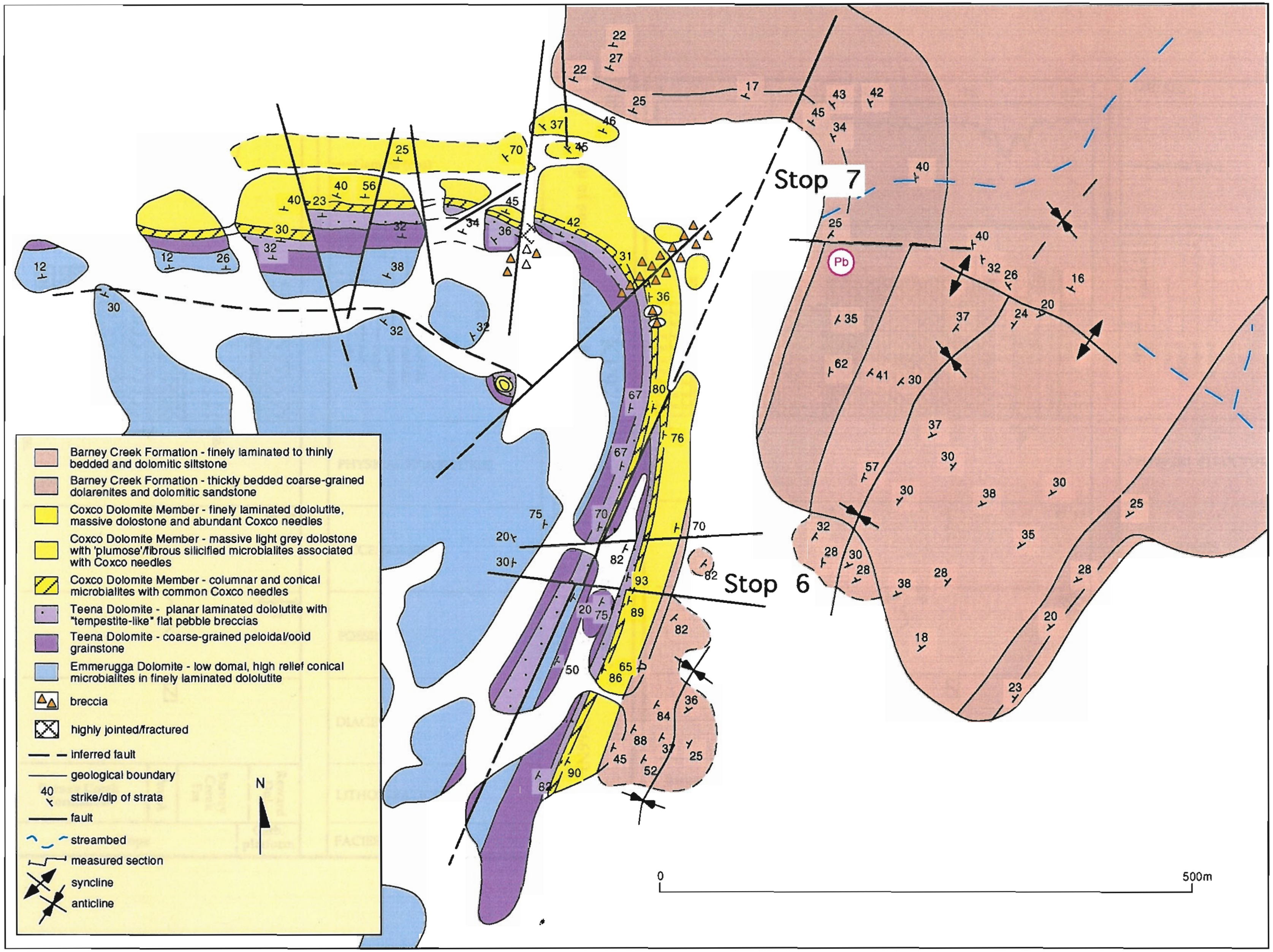
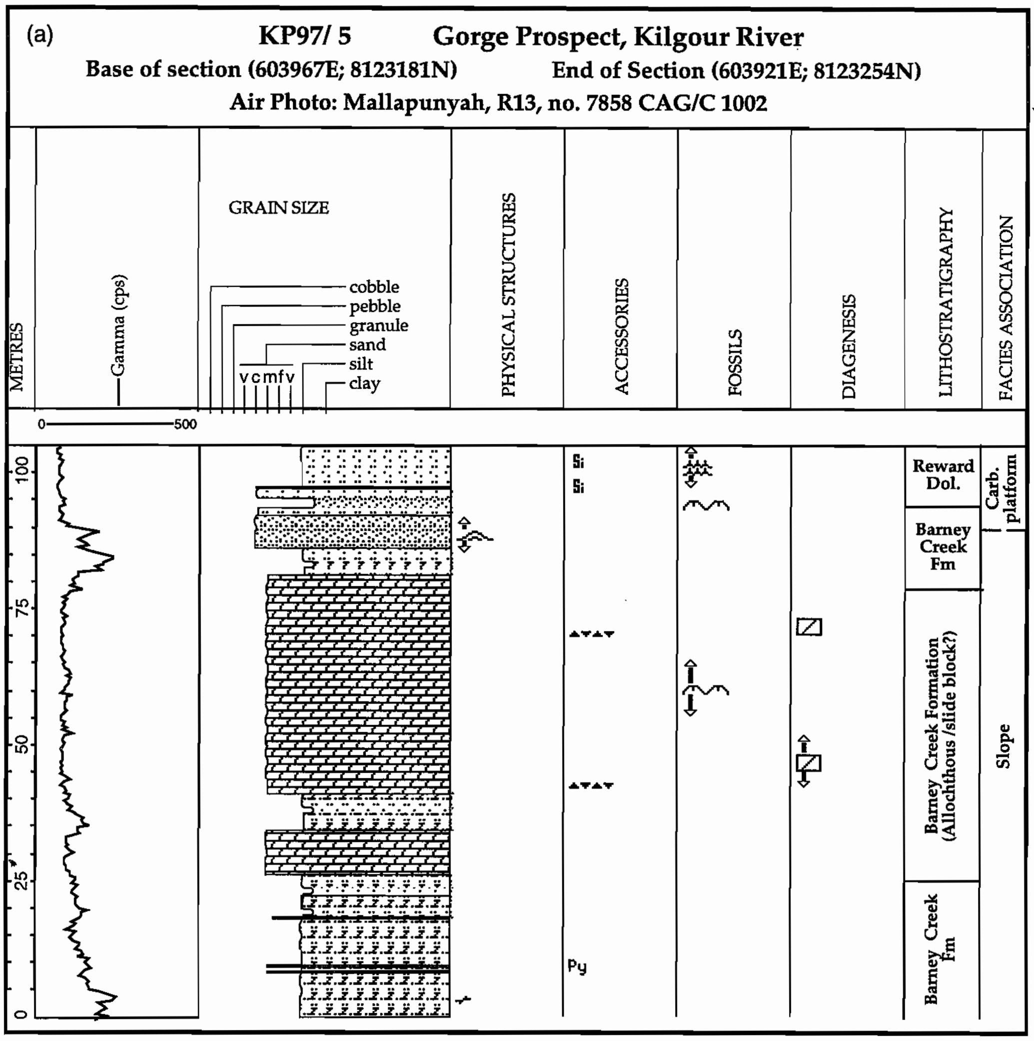


Figure G3 Geology of 'Coxco corner' with stop locations. Inset 1, Figure G1.



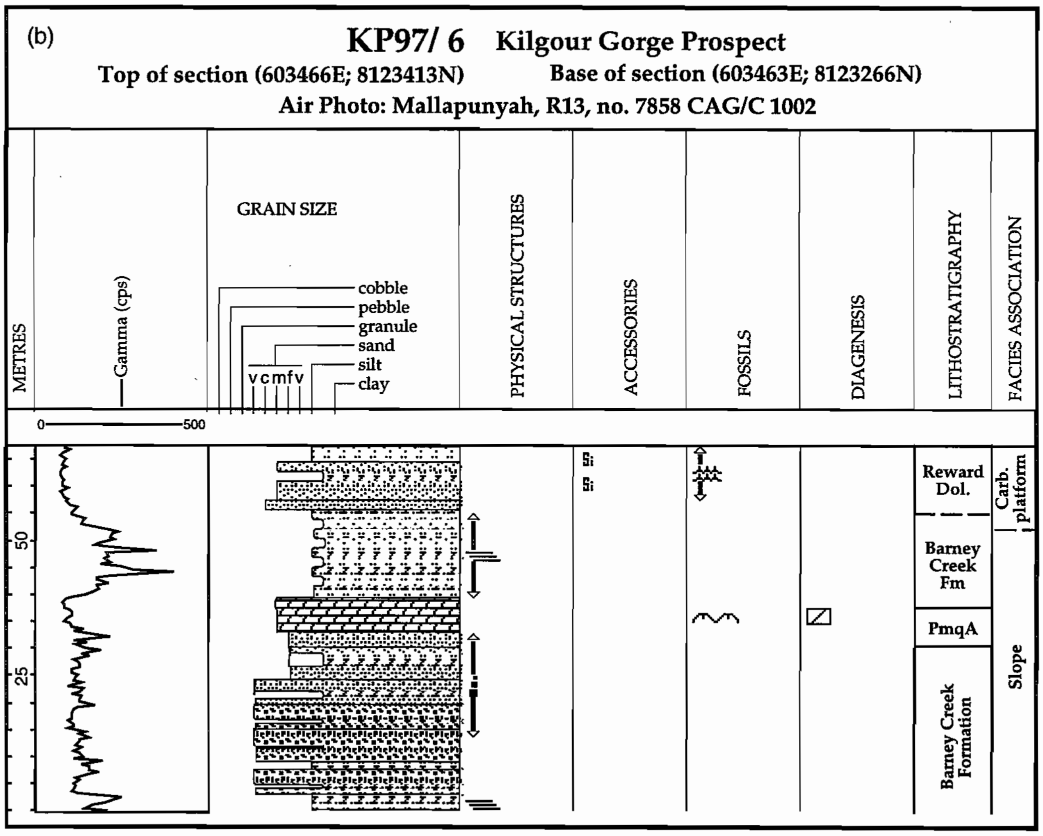


Figure G4 Measured sections KP97/5 (a) and KP97/6 (b). Refer to the Legend included as Appendix 1 for lithologies, symbols etc.

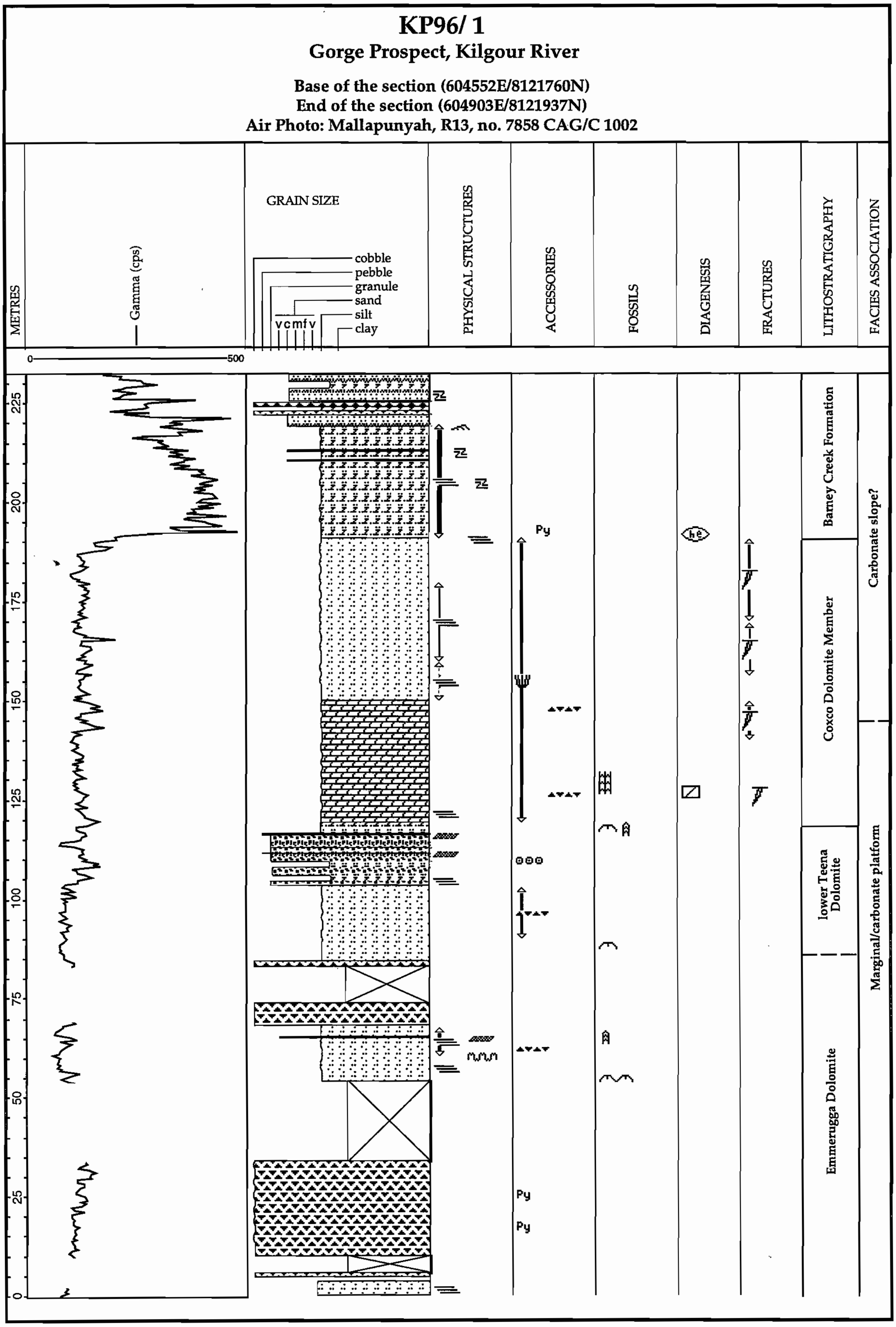


Figure G5 Measured section KP96/1.

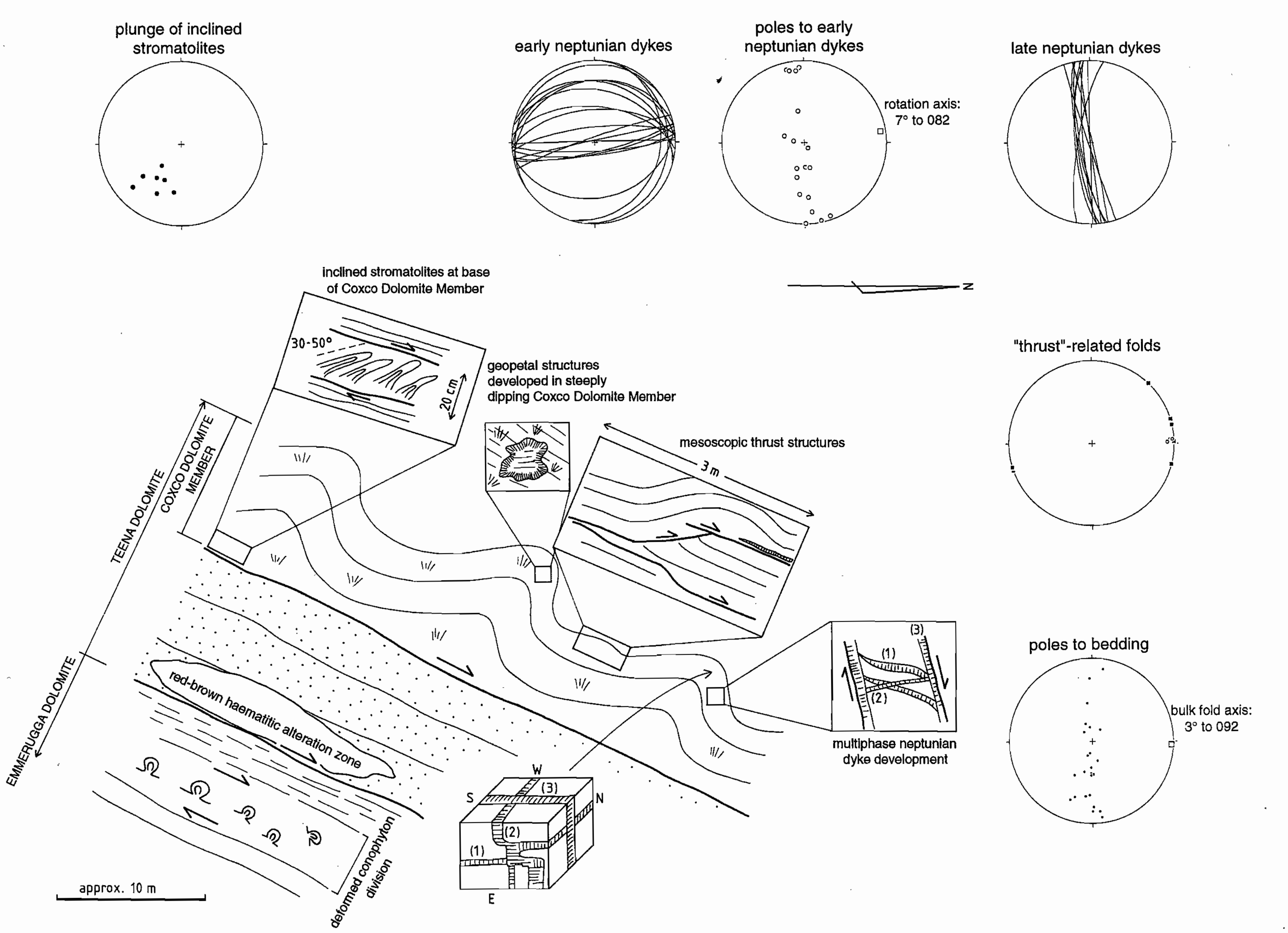


Figure G 6 Schematic summary of the features evident at Stop 8 (refer to the text for further details).

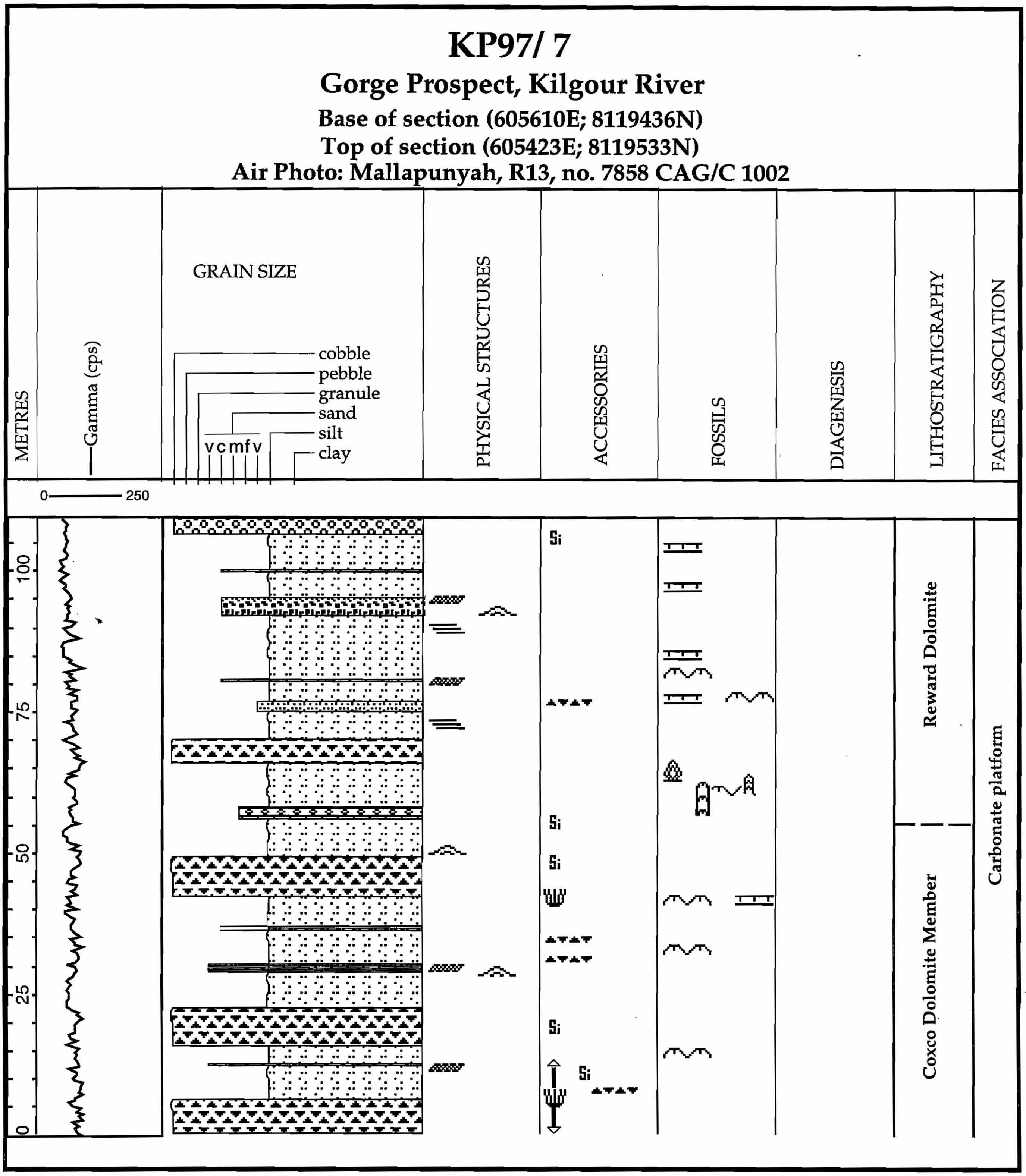
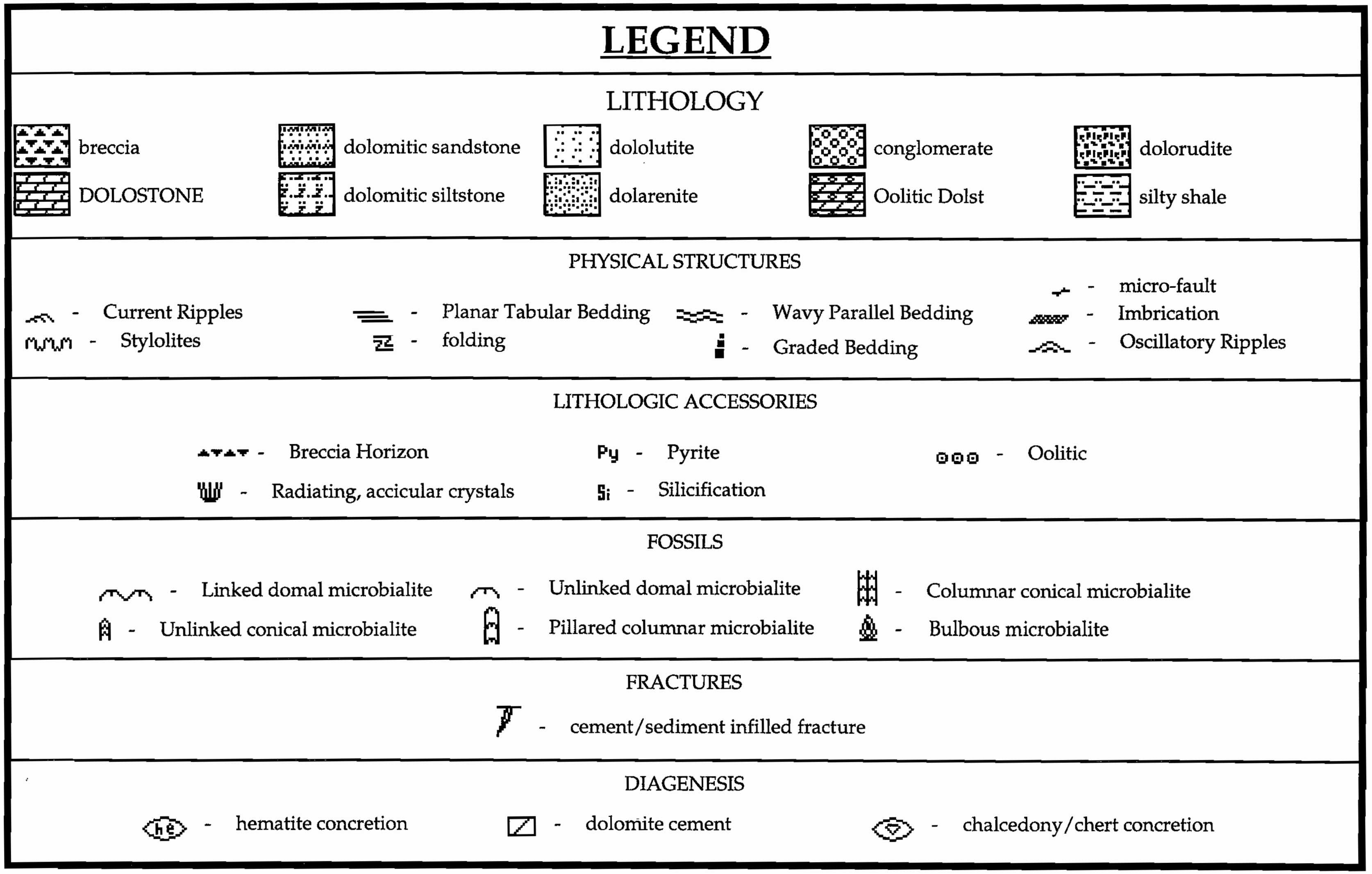


Figure G7 Measured section KP97/7.



Appendix 1 Legend for measured sections.

DAY 7 — LEILA HILL AND MYRTLE BASIN

- **Stop 1 Leila Hill**

Two field sections and one diamond drill log have been completed in this area (Fig. LH 1) in order to study the effects of the Hot Spring Fault on the Barney Creek depositional cycle (BCDC). In summary, the structure clearly had a major control on sedimentation since basinal and slope facies associations (mapped as Barney Creek Formation and Caranbirini Member of the Lynott Formation, and Reward Dolomite respectively) are present to the east of the fault and absent to the west of it where marginal/shoal facies are dominant. This supports the model presented here that NNW trending structures were sites of growth during accumulation of the BCDC.

- **Stop 1a section immediately west of Hot Springs Fault**

Travel from Heartbreak towards Borroloola for ~ 20 km. Turn left onto station track at Leila Creek and travel 3.5 km. A section was measured (Fig. LH 2a) up the NW trending ridge to the left mapped as Reward Dolomite overlain by the Caranbirini and Hot Spring Members of the Lynott Formation (509700E/8165400N).

At this locality, massive to crudely bedded dolomite with radiating clusters of Coxco needles forms the base of the slope (facies 1). The overlying section has been subdivided into four additional facies (Fig. LH 2a):

- facies 2 comprises 11 m of thinly bedded laminated grey dolomite with rare bedding normal layers of Coxco needles;
- facies 3 comprises 53 m of massive to bedded/laminated grey dolomite with occasional plate breccias and various microbial forms including prone microbial mat and cuspate, domal, turbinate and digitate stromatolites. Abundant bedding parallel layers and nodules of silicification are present that seem to have formed preferentially in more porous and/or permeable layers such as prone microbial mat and plate breccias;
- facies 4 comprises 14 m of largely recessive laminated and wave rippled siltstone;
- facies 5 comprises 3 m of laminated, scoured and cross-bedded medium to coarse-grained sandstone.

The stratigraphic interval represented in this section is constrained by the presence of Coxco needles at the base in facies 1 and 2, and by the occurrence of cross-bedded coarse-grained quartz sandstones at the top in facies 5. The latter lithofacies marks the base of the Hot Springs Member of the Lynott Formation on the 1:100,000 mapping in the Leila Hill region (Fig. LH 1). The intervening interval (mapped as Reward Dolomite) consists almost entirely of relatively shallow water marginal/shoal deposits, as evidenced by the clean nature of the dolomite and the occurrence of abundant microbial forms and scattered plate breccias. In the conventional stratigraphic framework this represents Barney Creek and Reward Dolomite time. However, only facies 4 (? mapped as the Caranbirini Member) is silty enough that it could be interpreted as a basinal deposit, and it includes wave rippled fine-grained sandstone that is absent from typical basinal facies (e.g. HYC Pyritic Shale). As a result, we consider this area to the west of the Hot Springs Fault to have been elevated throughout the BCDC.

- **Stop 1b section east of Hot Springs Fault**

Continue along station track to the NW for ~2.5 km. Go through gate, turn right along fence line and travel ~2 km to where track crosses small rocky knoll (590400E/8168500N).

The valley to the north of the knoll is interpreted to correspond to ~100 m of recessive basinal facies siltstones and shales. This is underlain by low rubbly outcrops of massive grey dolomite with occasional radiating clusters of Coxco needles. The fenceline at this locality corresponds roughly to the Barney Creek Formation/Reward Dolomite contact as mapped. A detailed section has been measured from this locality (Fig. LH 2b). The base of the section to the north of the fence comprises laminated dolomitic siltstone with variable proportions of interbedded fine-grained dolomitic turbidites (i.e. typical basinal facies association). At around the position of the fenceline the grainsize increases dramatically. The base of this interval is marked by several beds of plate breccia. These are overlain by 13 m of dolomitic sandstones to conglomerates that are severely disrupted and brecciated. In the lithofacies scheme presented here these are interpreted as slope deposits. They are overlain by a recessive zone at this locality that is capped by the basinal deposits of the Caranbirini Member of the Lynott Formation on the published mapping.

In contrast to stop 1a, where basinal facies were effectively absent, the section at stop 1b is dominated by basinal and slope facies. It is unclear whether there are any true marginal/shoal facies present in this section. The plate breccias at the base of the slope deposits could represent a transient shallow water environment. However, they are tabular bedded and could equally represent mass flows of shallow water material re-mobilised down slope.

Another section on the eastern sided of the Hot Spring Fault is provided by DDH Leila Hill 1 (Fig. LH 3) that was collared approximately 5.5 km south of the section at stop 1b (Fig. LH 1). It is also dominated by shaly dolomitic basinal deposits (interpreted as Barney Creek Formation and basal Lynott Formation on the company log). It is interesting to note that the less shaley and more dolomitic interval thatseparates these basinal lithofacies intervals (logged as Reward Dolomite) consists dominantly of thicker and more abundant fine-grained carbonate-rich turbidites. If this correlates with the slope deposits at stop 1b 5.5 km to the north (which also separate thick shaly basinal facies intervals), then it is clearly in a more distal position and implies a slope inclined to the south in this region.

When the three sections are taken together, the distribution of basinal facies across the NNW trending Hot Spring Fault in the Leila Hill area is interpreted as evidence of growth on the structure during the BCDC, with a sense of east block down.

- **Stop 2 SW Myrtle Basin**

Correlates of the BCDC and older Emmerugga Dolomite record a complex and protracted history of basin activity in the SW Myrtle basin area (Fig. MY1). Features indicative of basin activity include voluminous breccia units, probably sourced from elevated fault scarps or gravitationally unstable slopes, neptunian dykes, "spar-ball" breccia zones, decollement folds and abundant shallowly dipping, layer sub-parallel shear zones (Figs. MY 2a and MY 2b). Lowermost breccia units in the BCDC (hosted by BCDC basinal facies) are restricted in their distribution to the western end of the study area and are potentially related to growth on adjacent NNW- to N-striking growth faults. A younger breccia unit, which directly overlies BCDC marginal/shoaling facies association deposits, appears to display more laterally extensive distribution. It is tentatively interpreted to have been deposited on roughly ENE-WSW trending basin slopes. Volumetrically significant breccia occurrences that are both texturally and compositionally (?and temporally) analogous to the younger breccia facies have been mapped during this study from the Myrtle basin (~ 611300E 8166200N) and near the "type section" of the Lynott Formation (Jackson et al, 1987: ~ 605600E 8157250N).

On the basis of present mapping in this region, shallowly dipping shear zones are interpreted as probable syn-BCDC thrust surfaces, with NNW- to N-directed transport. BCDC correlates are presently folded about non-cylindrical NW-SE to WNW-ESE trending upright, open to tight closures (Fig. MY 3). This fold geometry is compatible with the regionally developed D_3 (?Isan) NNE-SSW compression event. The non-cylindrical character of folds is interpreted to have resulted from imposition of the D_3 stress field on an inherited (?syn-BCDC) structural framework.

- **Stop 2a Dilational structures in Emmerugga Dolomite correlate**

This low lying knoll comprises mainly massive to crudely laminated, medium grey, clean dolostone. An association of silicified columnar stromatolite intervals coupled with the lack of Coxco needles forms the basis of correlation with the Emmerugga Dolomite. The closest exposure to the east consists of tectonically intercalated Coxco Dolomite Member and basinal facies of the BCDC.

The most distinctive and abundant structures at this locality are neptunian dykes with both fibrous mineral and sediment infill. Dykes mainly strike NNW with sub-vertical dips, indicating a local ENE-WSW to E–W extension direction (Fig. MY 1). A numerically subordinate set is oriented sub-parallel to shallowly N-dipping bedding surfaces. Although most dykes appear purely dilational, a few demonstrate evidence of normal offset, or have themselves been rotated within narrow layer-parallel shear zones. Transport directions indicated from the latter are top to the NE and potentially record movement (?related to slope instability) that was contemporaneous with dyke formation.

We interpret the high density of D_1 dilational fractures, coupled with the abrupt change in structural level towards the east, as evidence for a nearby early (syn-BCDC) extensional or trans-tensional fault. The presence of BCDC talus breccia (potentially derived from this fragmented lithotype) 500 m to the east supports this interpretation of a proximal growth fault. Although a crude NNW-trending lineament can be identified along the eastern margin of this outcrop, we have been unable to trace the structure over any significant distance to the NNW.

- **Stop 2b Silicified needles in Coxco Dolomite Member**

The development of and/or preservation of Coxco needles is generally poor in this unit on the western and southern side of the ridge, where bedding is folded and brecciated. Along strike to the west it consists of pale coloured dolomite in which the bedding is only faintly visible and in which no needles have been found. However, a silicified horizon at this locality at the western end of the ridge preserves abundant Coxco needles, some of which are particularly large and have hollow cores, allowing the unit to be correlated with the Coxco Dolomite Member. It is worth noting that the authors have observed folded and/or brecciated and/or disrupted apparent Coxco Dolomite Member in other areas that does not preserve needle pseudomorphs or bedding. This may be a function of the effects of the deformation on the potential of the needles to be preserved. For example, fluid flow in localised fracture systems associated with the deformation could have caused alteration that obliterated the needle pseudomorphs.

- **Stop 2c Highly strained basinal facies strata (Barney Creek "Formation")**

Structural geometry is particularly complicated in the area between **stops 2b and 2c** and contrasts with the relatively simple E-W trending, open to close folding further to the east (Fig. MY 3). Thrust repetition of the Coxco Dolomite Member occurs at one locality and macroscopic folding is markedly non-cylindrical. The relatively high strains close to the contact of basinal facies strata (thinly bedded siltstone) and underlying Coxco Dolomite Member at this locality are interpreted to have accumulated during the D_3 compressive event. The tightly folded siltstone unit probably represents a sliver of basinal facies strata caught up along a thrust surface that roots into the older dolomitic succession.

- **Stop 2d Layer parallel shearing and folding in Coxco Dolomite Member**

Passing from **stop 2c to 2d,** Coxco Dolomite Member dips steeply to just overturned. Narrow layer-parallel shear zones containing steeply plunging intra-folial folds are common and interpreted as early thrust or slide surfaces that were refolded during D_3. At **stop 2d,** a brecciated ?decollement fold is developed above one of these shear zones. Brecciation is concentrated within the hinge of the fold and along a cross-cutting backthrust, and involves rotated angular fragments surrounded by silty ?milled groundmass. Although the attitude of the major fold is difficult to constrain due to the brecciation, a crude NE- to E-plunge is inferred on the basis of mesoscopic fold geometry. This fold geometry is inconsistent with D_3 NNE-SSW compression and as such we infer that it reflects an earlier (?D_1) thrusting event. The non-cylindrical character of folding throughout this area probably results from retightening or modification of early folds during D_3.

- **Stop 2e Sheared contact of Coxco Dolomite Member and basinal facies strata**

The contact between the Coxco Dolomite Member and basinal facies strata is a 2.5 m wide, shallowly dipping shear zone. A pervasive fabric within the shear zone is defined by thin layer-parallel shear surfaces that are locally deformed into NNW- to NNE-verging intra-folial folds. Striations can be identified on a few shear surfaces that plunge both ESE and NNE. Below the shear zone, brecciated Coxco Dolomite Member fragments are enclosed within a mineralised "matrix", the composition and texture of which superficially resembles that which fills neptunian dykes. We term this texture "spar-ball" breccia and interpret that it formed during fragmentation and dilation along D_1 fault surfaces.

Low angle shear zones such as this are a common feature throughout the SW Myrtle basin and Myrtle basin proper. Although much of the strain within these zones is likely to have accumulated during D_2 and/or D_3 events, we consider that the spatial association of ?early "spar-ball" breccia in this case, and voluminous sedimentary breccia/soft sediment deformation at other localities, lends support to the interpretation that thin-skinned structures were initially generated during D_1 (syn-BCDC) tectonism. We favour a compressional model to explain their development (i.e. shallow shear zones represent thrusts), however we have been unable to demonstrate significant structural repetition in association with these shear zones.

- **Stop 2f Talus breccia unit within basinal facies carbonaceous siltstones**

Overlying the sheared upper contact of the Coxco Dolomite Member is a large wedge shaped breccia body. The unit is bounded to the west by a steeply dipping, N-S striking brittle fault and pinches out eastward into thinly bedded siltstone over a distance of about 100 m. The internal structure of the breccia is extremely chaotic, involving angular boulders and blocks (up to 4 m in diameter) of grey dolostone which "float" in a crudely stratified "matrix" of thinly bedded/laminated siltstone. The term "matrix" is used loosely here, as it closely resembles the host facies (although locally sheared at the base of the breccia) and displays little evidence to suggest that it has been redeposited. Clasts are internally massive, parallel laminated or stromatolitic and some contain faint Coxco needles. They are considered to have been derived from underlying stratigraphic intervals (Emmerugga Dolomite and Coxco Dolomite Member). A few show jigsaw fit textures, indicating that at least some fragmentation occurred *in situ*. Of considerable importance, are clasts that contain neptunian dykes. These structures terminate at the clast margins, providing unequivocal evidence that dilation and dyke development occurred during a syn-BCDC deformation event.

The breccia represents a classic example of talus spalled from a growth fault. It is lacking in true matrix and comprises fragments which have clearly seen minimal transport. Determining the exact position and orientation of the fault that sourced the dolomitic blocks is difficult, however the fact that the unit pinches out eastward, coupled with the intense development of NNW-striking dykes 500 m to the west (**stop 2a**), leads us to infer that the growth structure was originally oriented NNW-SSE to N-S (Fig. MY 2a). The fact that basinal facies debris is lacking within the breccia unit suggests that the up-thrown margin of the fault was a site of non-deposition and thus can be considered as a true sub-basin margin.

- **Stop 2g Breccia unit of dolomitic slope facies association**

A thick sedimentary breccia unit is exposed on the steep northern slopes of the ridge. It is positioned higher in the stratigraphy than the talus breccia seen at **stop 2f** and is hosted by nodular purple-grey dolomitic siltstone and fine sandstone (Reward Dolomite in the conventional stratigraphic classification). Exposed immediately at the base of the conglomerate is a parallel-stratified shallow water dolostone unit containing digitate stromatolites. The breccia unit itself is completely unstratified, mainly clast-supported and has an estimated thickness of

30 m. Clasts are angular and polymictic and a significant proportion contain gypsum pseudomorphs.

In contrast to the talus breccia unit (**stop 2f**), there is no evidence to suggest that detritus was derived from significantly older stratigraphic levels. Indeed, many fragments are internally contorted, suggestive of fragmentation and redeposition prior to lithification. Furthermore, material occupying space between rigid clasts locally comprises discrete compacted, incompetent mudstone fragments that form a pseudo-matrix rather than a true granular matrix. In light of these observations, we consider the breccia unit to have been deposited from one or a series of debris flows, probably transformed from an incompletely lithified slide sheet(s) (Fig. MY 2b).

The presence of gypsum pseudomorphs throughout many of the clasts indicates that the ultimate source of the breccia was an evaporitic marginal/shoal environment. In the compressional model for basin development, these shallow/emergent deposits may have been perched on intra-basinal bulges or thrust-thickened highs adjacent to the basin margin. In either case, flexural subsidence or uplift would have led to gravitational instability and redeposition of marginal/shoal facies debris to deeper basin environments. Alternatively, it could also be argued that similar environments could have existed on uplifted half graben footwall blocks generated in response to extensional tectonism. In terms of facies architecture alone, we are unable to discriminate between these two scenarios.

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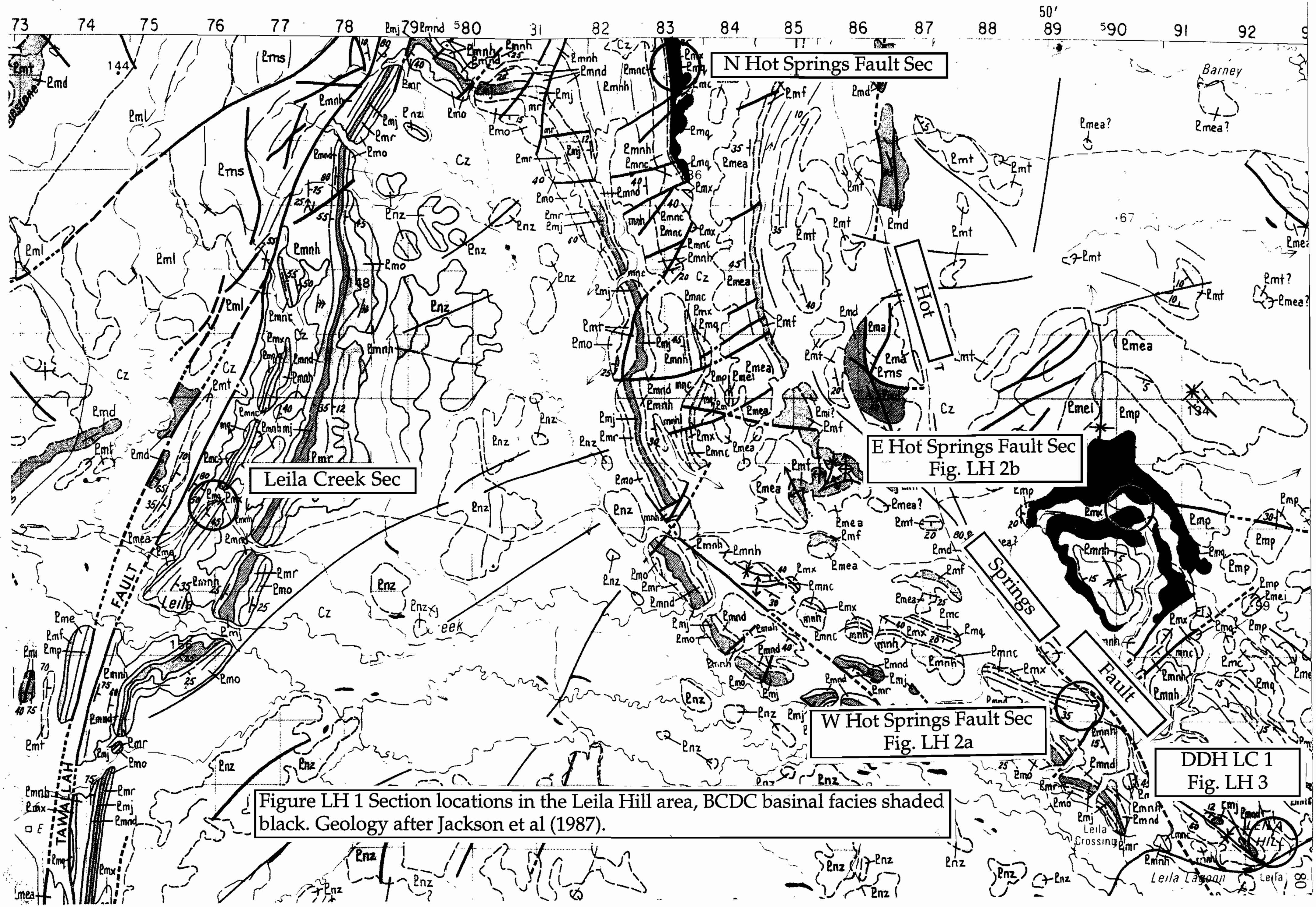

Figure LH 1 Section locations in the Leila Hill area, BCDC basinal facies shaded black. Geology after Jackson et al (1987).

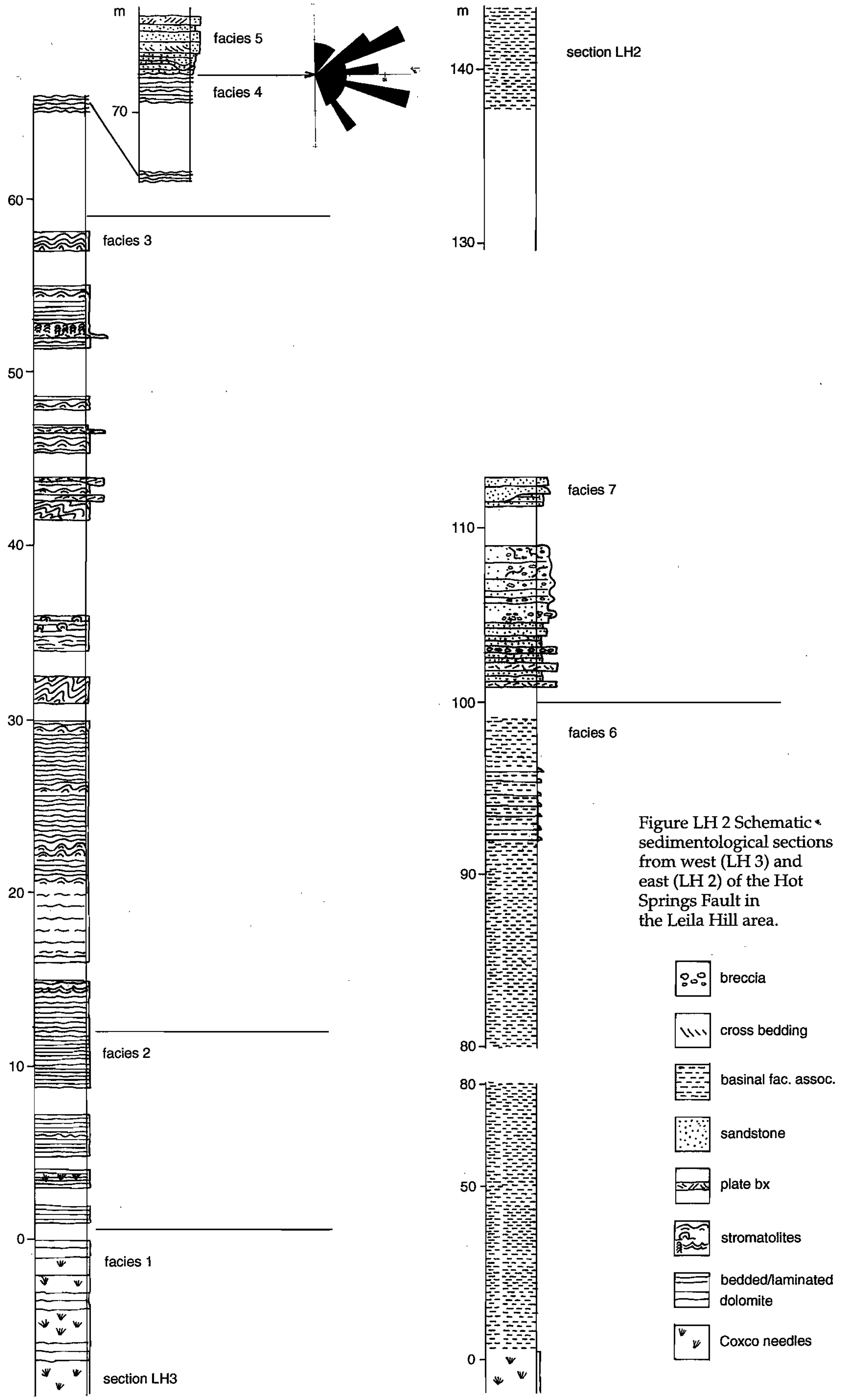

Figure LH 2 Schematic sedimentological sections from west (LH 3) and east (LH 2) of the Hot Springs Fault in the Leila Hill area.

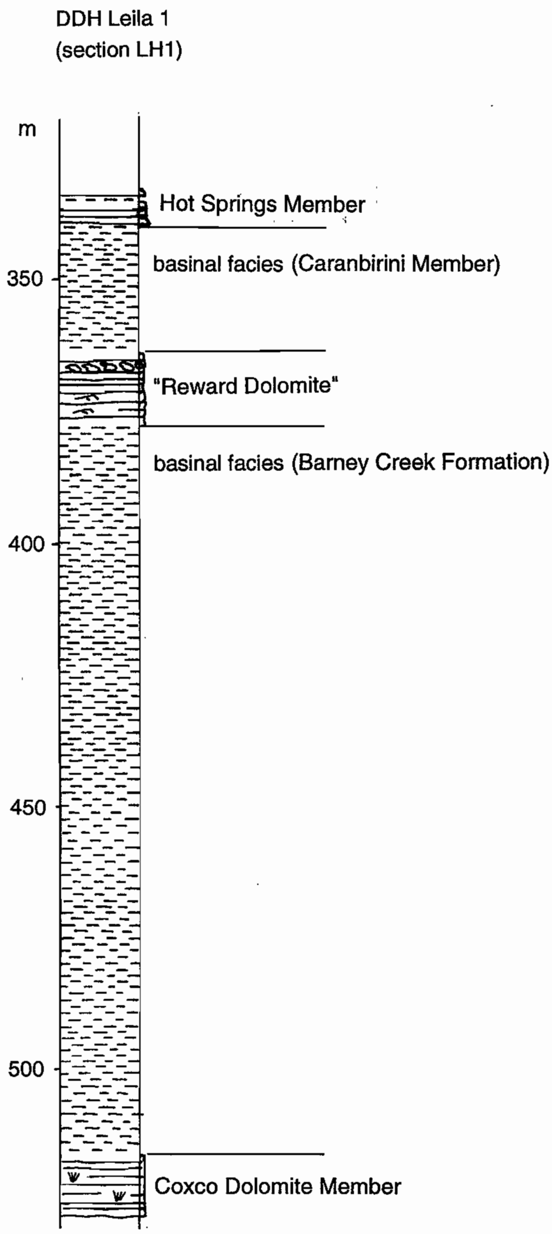

Figure LH 3 Schematic sedimentological log of DDH Leila Creek 1 from east of the Hot Springs Fault in the Leila Hill area.

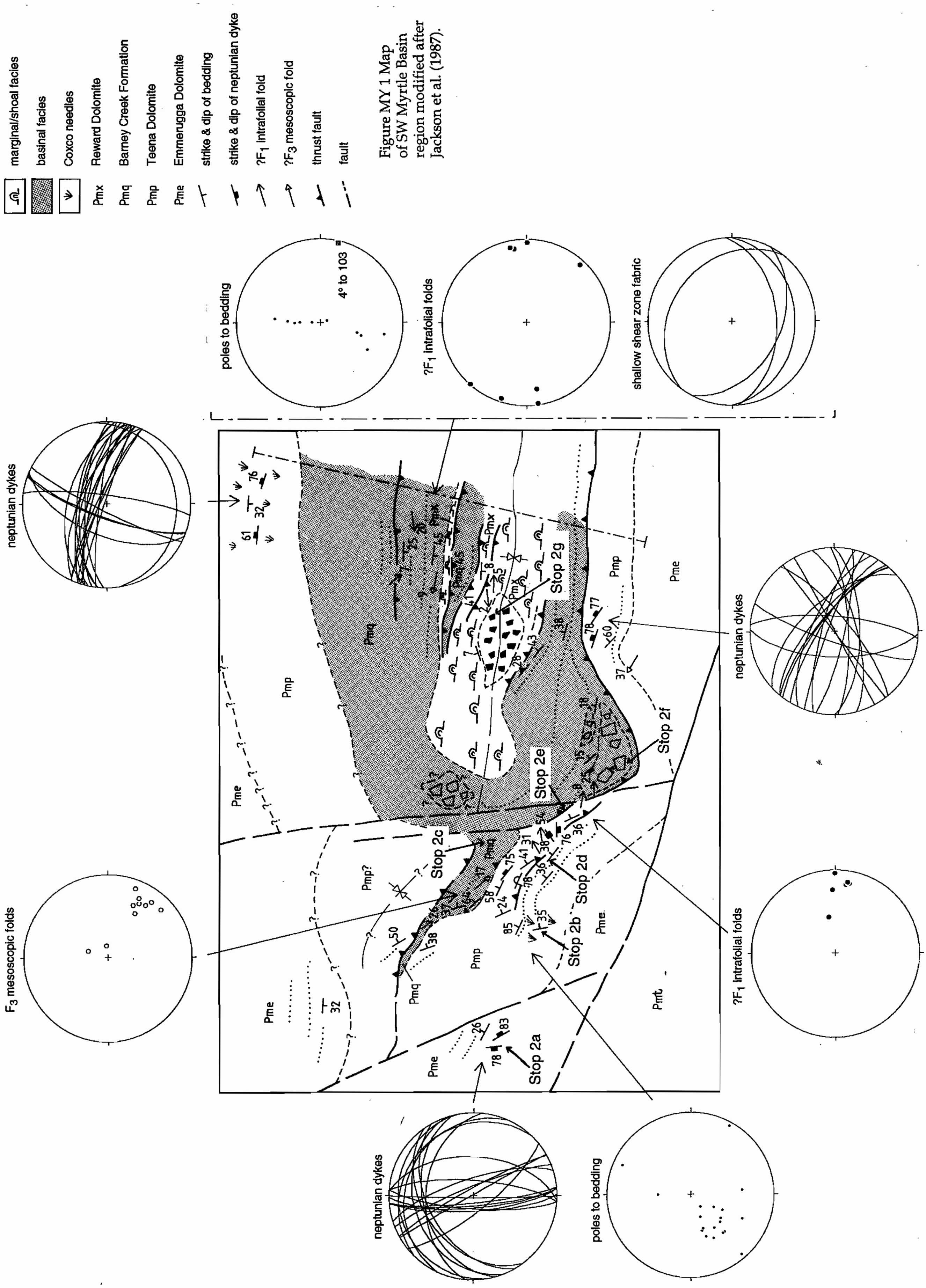

Figure MY 1 Map of SW Myrtle Basin region modified after Jackson et al. (1987).

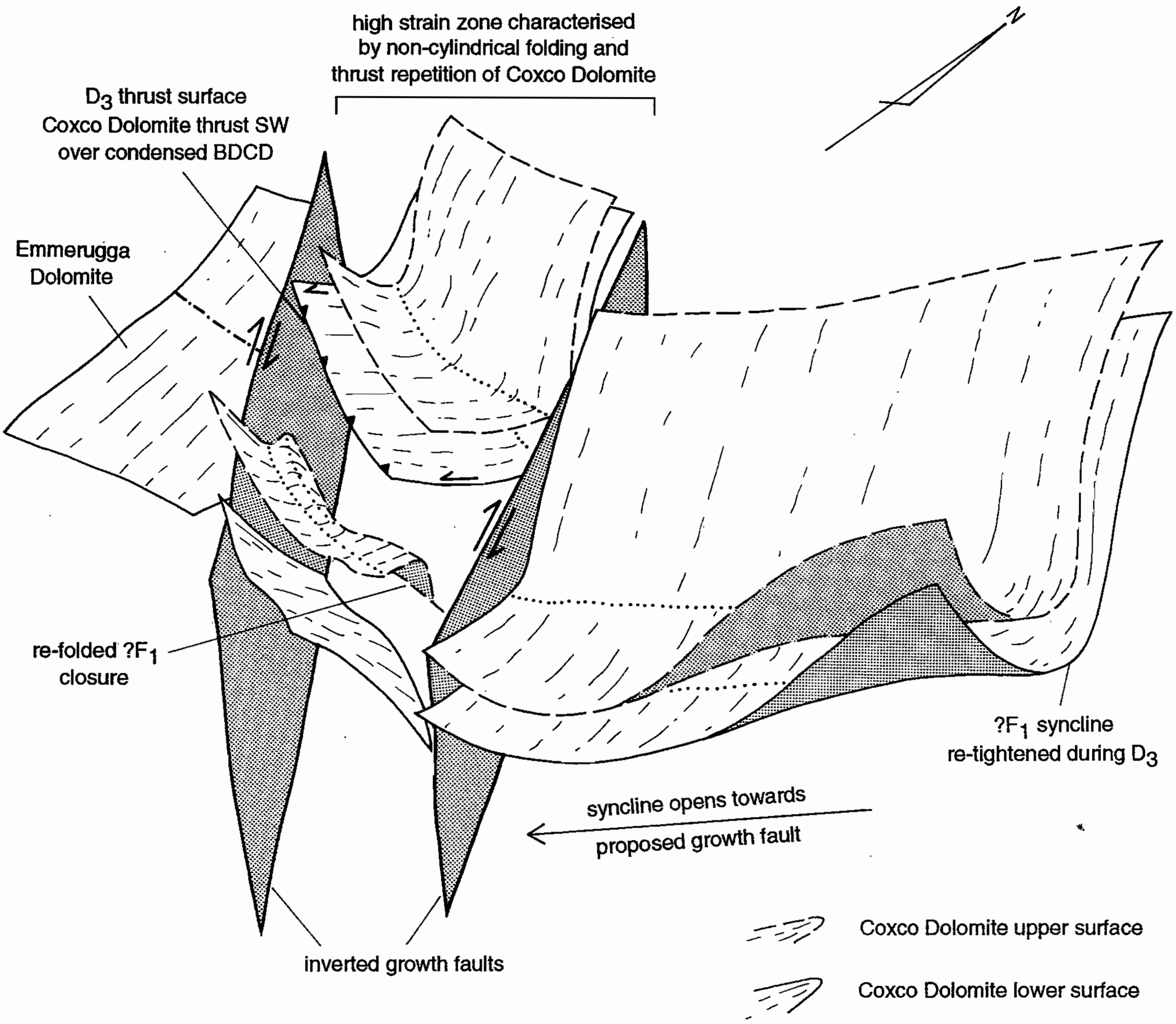

Figure MY 2 Schematic tectono-sedimentary reconstruction of the SW Myrtle Basin area (a) basinal phase (b) marginal/shoal phase.

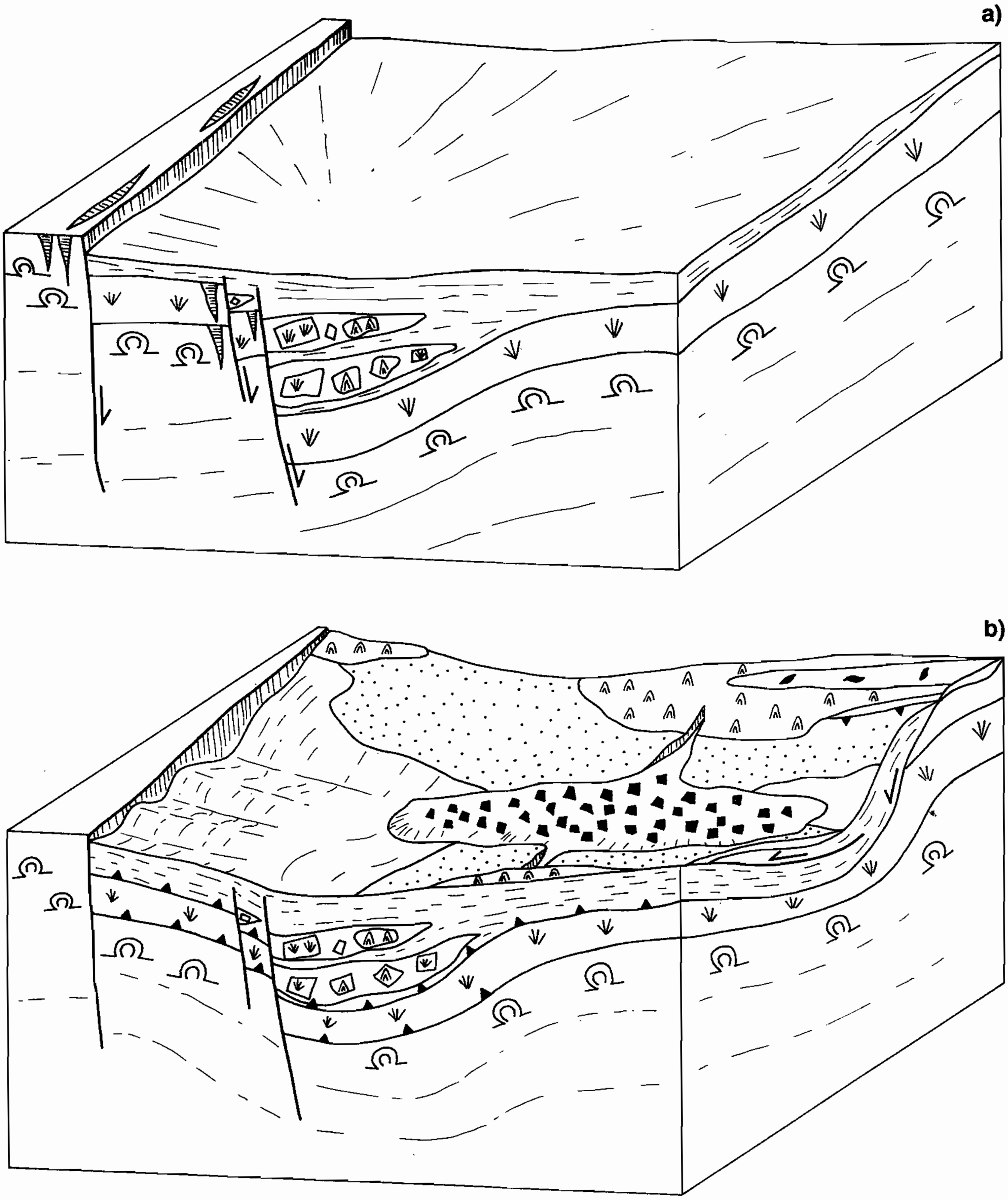

Figure MY 3 Schematic representation of fold geometries in the SW Myrtle Basin area. Surfaces shown are base and top of Coxco Dolomite Member.