THE UNIVERSITY OF ADELAIDE

(1) THE NATURE OF THE PRECAMBRIAN-CAMBRIAN TRANSITION IN THE NORTHERN FLINDERS RANGES, SOUTH AUSTRALIA.

(2) THE DIETARY NICHE OF THE EXTINCT AUSTRALIAN MARSUPIAL LION: *THYLACOLEO CARNIFEX* OWEN

by CHRISTOPHER NEDIN BSc

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The nature of the Precambrian-Cambrian Transition in the Northern Flinders Ranges, South Australia.

The dietary niche of the extinct Australian marsupial lion *Thylacoleo carnifex* Owen.

by

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This thesis is submitted as partial
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ABSTRACT

Previous investigations into the Ediacara Member of the late Proterozoic Rawnsley Quartzite in the Flinders Ranges have produced differing interpretations of the depositional environment. Studies at Nilpena Hills indicate that deposition was influenced by back barrier lagoonal conditions with the intermittent influx of fluidised sands which mantled lagoonal muds.

Re-interpretation of the Ediacara assemblage shows a hitherto unrecognised benthonic bias. This abundance of sessile, benthonic forms supports a sub-tidal depositional environment. However, the increase in the numbers of motile forms compared with sessile forms, preserved towards the top of the member accords well with one of two inferred shallowing upward cycles within the sequence.

A recent re-evaluation of the nature of the Precambrian-Cambrian boundary in the Flinders Ranges, suggests a conformable relationship between the Pound Subgroup and the overlying Early Cambrian beds.This is at odds with previous interpretations, which proposed that a regional disconformity occurs at the boundary. Mapping at Mt. Scott Range, Puttapa Syncline and Red Range provided ample evidence that several periods of at least partial lithification occurred within the Pound Subgroup, before the onset of Cambrian deposition. Erosive downcutting marks the contact of the Pound Subgroup-Uratanna Formation at Mt. Scott Range, Red Range and Puttapa Syncline. Erosive downcutting of the Parachilna Formation into the Uratanna Formation was mapped at Mt. Scott Range. The Pound Subgroup-Parachilna Formation contact was mapped as a disconformity which becomes a high angle unconformity near the Beltana Diapir.

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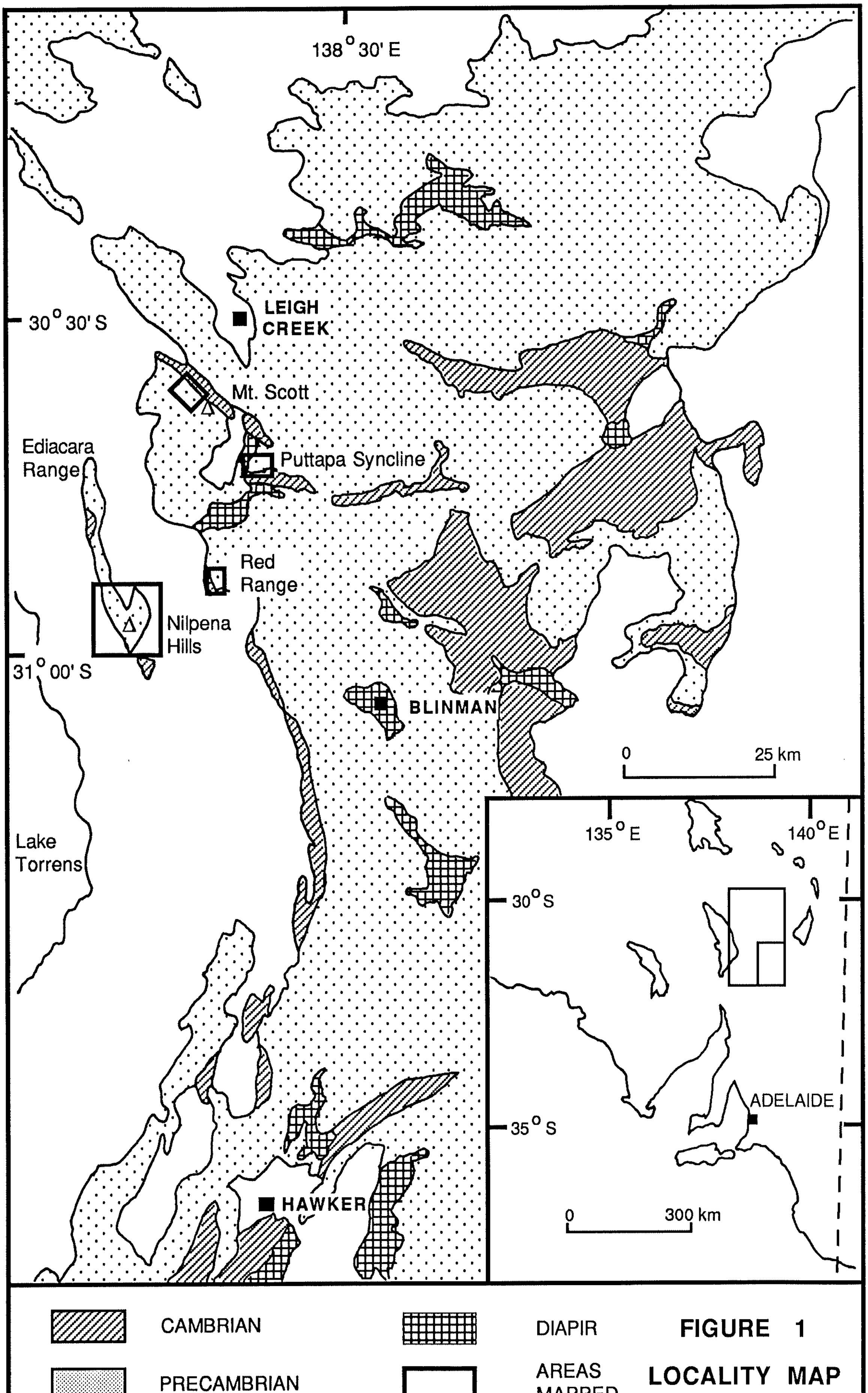


FIGURE 1

LOCALITY MAP

INTRODUCTION

The Precambrian-Cambrian transition spans a time of major change in the biosphere, during which many invertebrate groups appeared. The acquisition of hard parts however, was not abrupt, but occupied millions of years. Different groups acquired skeletons at various times in the latest Precambrian and Early Cambrian (Conway Morris 1987). Therefore, the term 'transition' is preferred to 'boundary'. However, when in the field, this event is usually delineated by a single marker horizon. In South Australia this marker is taken as the Pound Subgroup-Parachilna Formation contact. Therefore, when commenting apon the nature of this contact, the term 'Precambrian-Cambrian boundary' is applicable

Evolutionary and environmental analysis of this important interval is hampered by the scarcity of continuously fossiliferous sections and by problems of correlation. The majority of sections spanning this time contain a major unconformity, recognized as representing a period of regression, incorporating a major episode of emergence and erosion. This is supported by recent work on the carbon and oxygen isotope record from China and Iran (Brasier *et al* 1990).

Amongst the criteria used by Rozanov (1984) to define the change from Precambrian to Cambrian strata are:

1) decreasing dolomite accumulation;
2) global accumulation of large phosphorite deposits;
3) a sharp drop in stromatolite formation and a change in morphology - although this change may pre-date the transition (Aitken and Narbonne 1989);
4) the first widespread appearance of red biogenic limestones;
5) first rich assemblages of skeletonised fossils;
6) considerable change in morphology of trace fossils.

In the areas studied, changes 4-6 are represented in the change from the Rawnsley Quartzite to the richly fossiliferous Hawker Group.

The first major steps toward a consensus view on the Precambrian-Cambrian transition, came with the establishment of the Subcommission on Cambrian Stratigraphy in 1960 (at the suggestion of M.F. Glaessner) and the formation of the Precambrian-Cambrian Working Group in 1972. Since then, 13 Plenary sessions have been held and more than 17 localities have been visited.

By 1987, three candidates for the Precambrian-Cambrian Boundary Stratotype Section had emerged, Meishucan in Yunnan Province, China; the Burin Peninsula, Newfoundland and the Ulakhan-Sulugur section of the Yudoma Formation, on the Aldan River south of Yakutsk, Siberia.

As of writing, no final decision has been made. It should be noted that the section from the Flinders Ranges has not been regarded as a candidate, due to the presence of a regional unconformity at the transition. No query as to the possible conformity of the sequence was made by the Precambrian-Cambrian Working Group, at the Sydney conference of delegates in 1976, despite a major field excursion to the area.

This study was initiated to investigate the palaeoenvironment of the Ediacara Member at Nilpena Hills and other changes which occur in the transition from the late Proterozoic to the Cambrian strata in the Northern Flinders Ranges, principally at Mt. Scott Range, Puttapa Syncline and Red Range (Fig.1). This transition was taken by Daily and subsequent workers, to occur at the boundary of the Pound Subgroup and the overlying Uratanna Formation and the overstepping Parachilna Formation. These relationships are re-examined in the light of recent work.
Field studies at Nilpena Hills were carried out over a period of four weeks during May and July, concurrent with other field work at Mt Scott, Puttapa Syncline and Red Range.

PREVIOUS WORK

The Pound Subgroup of the Wilpena Group represents the last cycle of Proterozoic deposition in South Australia. It is entirely confined to the Flinders Ranges, where sedimentation originally extended over 35,00 square kilometres (Jenkins 1975). Outcrop consists of broad, open, dome and basin folds, trending north-northwest in the Central Flinders Ranges in contrast to the fault intersected, elongate, east-west striking synclines in the Northern Flinders Ranges (Preiss 1990). The Pound Quartzite, earlier described as the Edeowie Quartzite (Mawson 1937) was formally described by Mawson (1938), who stated that it was the "base of the true Cambrian in South Australia" (1938 p 253). The outcropping quartzites are the main ridge forming units in the Flinders Ranges and are named after the most prominent landmark, Wilpena Pound. Mawson placed the Precambrian-Cambrian boundary at the conformable contact between the Pound Quartzite and the underlying limestones, later named the Wonoka Formation (Dalgarno & Johnson 1964). The top of the Pound Quartzite was defined by Mawson as occurring where the arenaceous rocks grade conformably into Cambrian limestones. Segnit (1939) showed a disconformity between the Sandstone-Quartzite Series of the Flinders Ranges (his equivalent of the Pound Quartzite) and the overlying Cambrian beds at Pitchi Richi (his fig. 15), Ediacara (his fig. 23) and Aroona Creek (his fig. 27). However his findings seem to have been ignored. He also made reference to numerous "shaped clay impressions" (1939 p 61) from Ediacara, which may be the earliest reference to the Ediacara assemblage. The assumed Cambrian age of the Pound Quartzite meant that the true significance of fossil finds at Ediacara (Sprigg 1947, 1949) remained unrecognized. Noakes (1956) placed the Precambrian-Cambrian boundary at the top of the Pound Quartzite. Daily (1957) also implied a Precambrian age for the Pound Quartzite and proposed that the boundary be placed at the contact with the overlying Ajax Limestone. Webb and Horwitz (1958) proposed that the top of the Pound Quartzite be adopted as the Precambrian-Cambrian boundary. A Precambrian age for the Pound Quartzite was accepted by Glaessner (1959) and Glaessner & Daily (1959) in the first discussions on the Precambrian age of the fossils at Ediacara. The Precambrian-Cambrian contact was still seen as conformable however, due to

Mawsons placement of the upper limit of the Pound Quartzite at the first limestones. Dalgarno & Johnson (1962) mapped a regional unconformity between the Pound Quartzite and the overlying "worm-burrowed beds" (previously included within the Pound Quartzite). This horizon was formally named the Parachilna Formation (Dalgarno & Johnson 1964) and the disconformable contact with the Pound Quartzite was adopted as the Precambrian-Cambrian boundary. Daily (1972) recognized the Uratanna Formation in the Mount Scott Range. This unit rests unconformably on Pound Quartzite and these two units together are regionally overstepped by the Early Cambrian Parachilna Formation.

Forbes (1971) formalised a two-member nomenclature for the Pound Quartzite. The lower, red, Bonney Sandstone Member and the upper, white, Rawnsley Quartzite Member. This was modified by Jenkins (1975), who elevated the Members to Formation status and the Pound Quartzite to Subgroup status. Also, he formally recognized the fossiliferous strata within the Pound Subgroup as the Ediacara Member of the Rawnsley Quartzite. With the recognition of an unconformity at the base of the Ediacara Member, Gehling (1982) suggested a further "inevitable" (p 101) subdivision of the Rawnsley Quartzite into three units, the lower sequence, below the Ediacara Member, another constituting the Ediacara Member and a third, the upper sequence. This is needed to "fulfill the requirement of genetic integrity and have boundaries determined by unconformities or marked lithological change" (Gehling 1982 p 101). However, article six of the International Stratigraphic Code states that a formation is : "a genetic unit formed under essentially uniform conditions". The lithologies and palaeoenvironment of both the lower and upper sequences of the Rawnsley Quartzite are essentially the same. Little is served then, by erecting a new formation name. It is proposed here to subdivide the Rawnsley Quartzite into three Members, The Ediacara Member is retained and two new members are erected, the Lower Rawnsley Quartzite and the Upper Rawnsley Quartzite. The nomenclature differentiates the two Members on spatial grounds i.e. below and above the Ediacara Member respectively, whilst indicating their, essentially identical, lithological characteristics, which are readily recognizable throughout the Flinders Ranges.

Extensive studies on the fossil assemblage (e.g. Glaessner 1984: Glaessner & Wade 1966; Jenkins 1975, 1981, 1985; Wade 1968, 1970) have made the Ediacara locality internationally recognised. Detailed sedimentological studies of the Ediacara Member by Goldring & Curnow (1967), Gehling (1982) and Jenkins *et al* (1983) have, however, resulted in apparently conflicting interpretations as to the depositional environments of the sequence.

REGIONAL TECTONIC SETTING

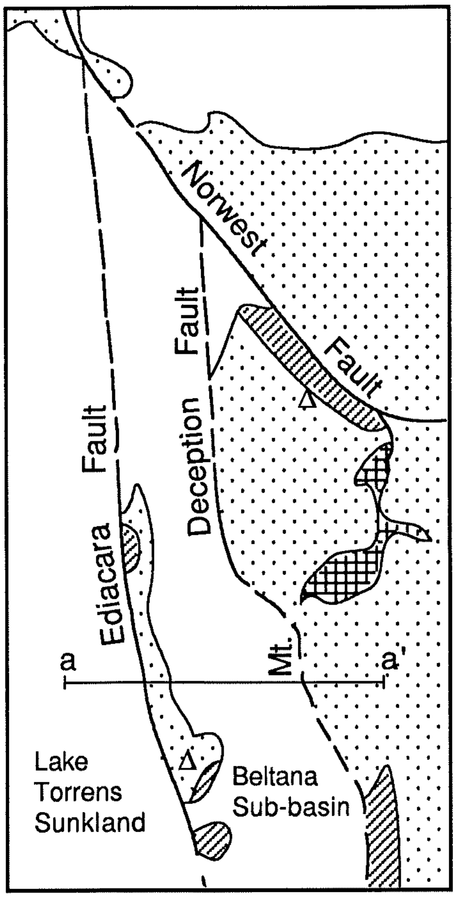
The Nilpena Hills are situated 14 km west of the main Hawker to Leigh Creek South road, approximately 47 km south of Leigh Creek South.(Fig. 1) The area comprises a series of low, barren hills composed of late Proterozoic and Early Cambrian strata, set within the Pirie-Torrens Basin. This basin marks a transition zone, separating the Adelaide Fold Belt in the east from the almost undeformed sediments of the Sturt Shelf to the west. The eastern edge of the Basin is marked by the Mt Deception Fault, whilst the western margin is marked by the Torrens Fault. Sediments of the Ediacaran Period (Jenkins 1981) are thin or absent from the Shelf (Dalgarno 1986, Haines 1987). This indicates that the shelf was emergent and possibly supplying sediment to the Adelaide Fold Belt area for some of this time.

The western margin of the Nilpena Hills is marked by the Ediacara Fault (Jack 1925) (Fig. 2). Movement along this fault has uplifted the Ediacara Range and Nilpena Hills, dividing the Pirie-Torrens Basin into the Lake Torrens Sunkland to the west and the Beltana Sub-Basin to the East (Leeson 1970). Previous tectonic interpretations described the Ediacara and Mt. Deception faults as normal faults (Fig. 2a), produced in response to extensional tectonic phases in the Tertiary and Pleistocene. The Beltana Sub-Basin was formed by tilting of the block between the two faults (Fig. 2b). This was apparently supported by seismic evidence, which showed a normal fault with a displacement of 240 m south of Nilpena Hills (Kendal in Leeson 1970). This interpretation was also followed by Coates (1973), who indicated that both the Ediacara and Mt. Deception Faults trended due north to intersect the Norwest Fault (Fig. 2a). However, recent gravimetric surveys along the Ediacara and Mt. Deception Faults highlight gravity lows closely associated and often underneath the fault planes. Also, the survey indicated that the Ediacara Fault curves abruptly to the northeast after it passes the most northerly outcrop of Proterozoic strata in the Ediacara Range. The fault then joins with the Mt. Deception fault and intersects the Norwest Fault (N. M. Lemon pers.comm. 1990) (Fig. 2c). The angle of the fault plane and its curvature in plan view implies that both the Ediacara and Mt. Deception Faults are thrust faults (Fig. 2d). A similar thrust fault, seated in the Callanna Group, has been found by drilling, at Depot Creek, 35 km north of Port Augusta (Preiss & Faulkner 1984).

Normal faults formed by extension during the deposition of the Callanna Group, may have been reactivated and reversed by probable compression from the east during the Delamerian Orogeny. This produced basement cored, west-vergent folds in the northern Flinders Ranges and the formation of a deep seated, low angle thrust fault which passed into a major décollement within the Callanna Group (Preiss 1987). Evaporite deposits within the Callanna Group would act to lubricate, and allow considerable movement along fault planes during reactivating Tertiary and Holocene compressional events (N. Lemon pers. comm. 1990). The fault bound, repeated sequences found immediately west of the Norwest Fault at Aroona Creek (Mt. Scott) (Coates 1973) and east of the Mt. Deception Fault at Red Range (Leeson 1966) (Map

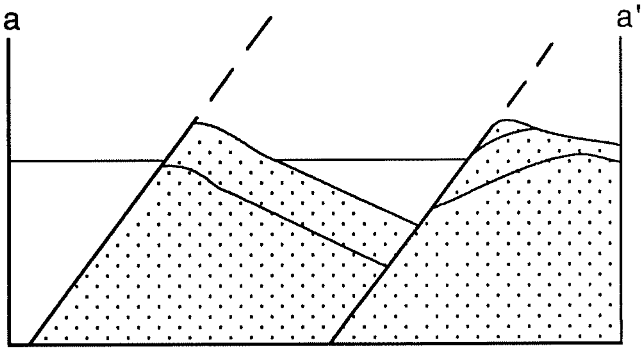
FIGURE 2

a

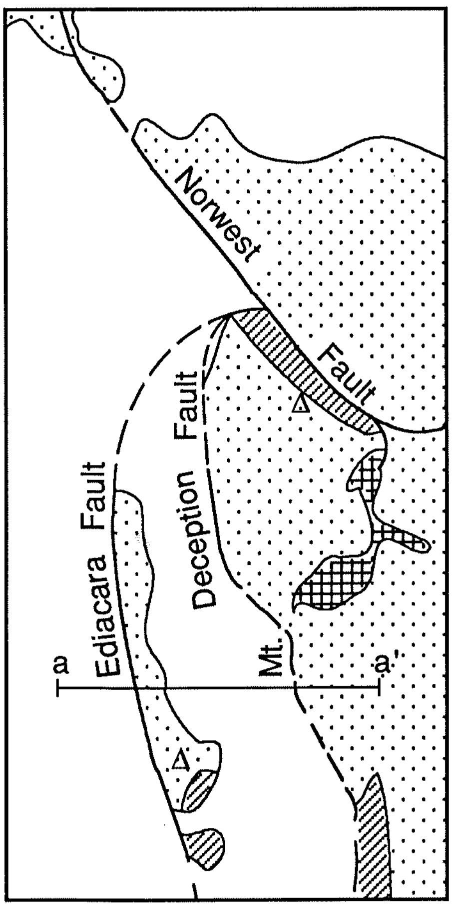


2a: Regional tectonic sketch; 2b: Interpretive cross section, (after Coates 1973). (See Fig. 1 for legend

b

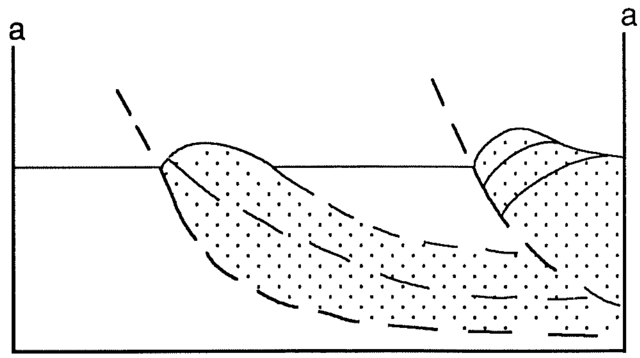


c



2c: New tectonic sketch; 2d: New interpretive cross section

d



2B), are interpreted as wedges brought up by the west verging Delamerian movements along the faults. The interpretation of the Ediacara Fault using the seismic reflection techniques of the 1960's is equivocal. The interpretive methods used would probably not been able to resolve the fault to a point where an accurate identification was possible (N.M. Lemon pers. comm. 1990).

Chapter 1 The Ediacaran Environment at Nilpena Hills

Proterozoic and early Phanerozoic successions in many parts of the world are dominated by thick, arenaceous sequences. Common to these deposits are:
1) their occurrences as sheet sequences, spread over hundreds to thousands of square kilometres (Dott *et al* 1986);
2) the poorly to non fossiliferous nature of the deposits (Long 1978);
3) the lack of interbedded mudrocks (Dott & Byers 1981);
4) *the similarity of bedforms produced in highly varied depositional environments* (Long 1978) (emphasis added).

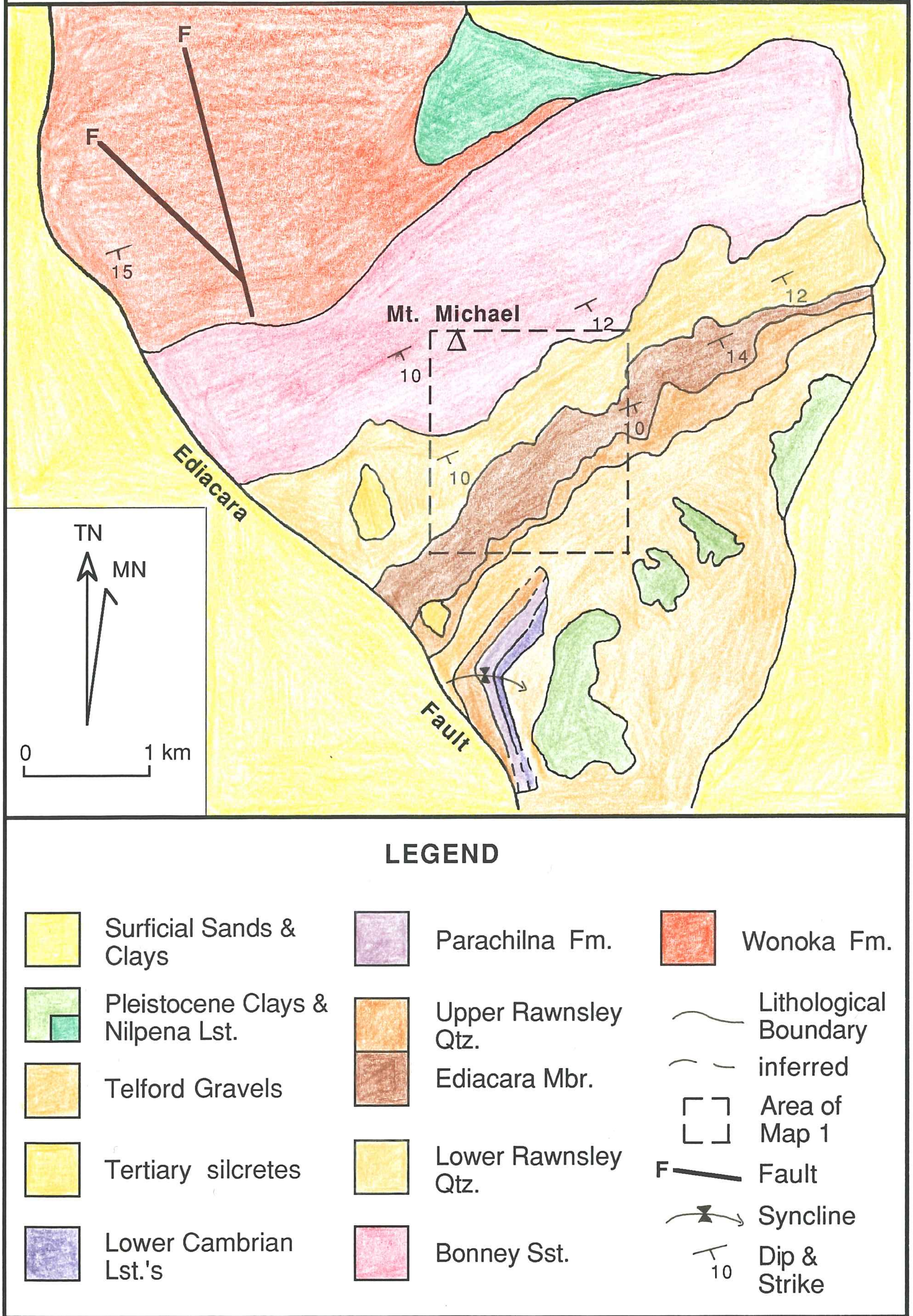
Previously, a shallow marine origin was interpreted for these sequences (e.g. Lobo & Osborne 1976). However, more recent findings reveal that the sequences contain a spectrum of environments, from alluvial fan to tidal shelf (e.g. Cudzil & Driese 1987, Fedo & Cooper 1990). Even though some sequences have been studied in great detail, interpretations still remain a "challenging problem" (Dott *et al* 1986).

The Pound Subgroup, from the Flinders Ranges, is an example of this. Though the depositional environments of the Bonney Sandstone and Rawnsley Quartzite have been successfully identified, that of the Ediacara Member remains equivocal. The most detailed sedimentological investigations have produced seemingly conflicting interpretations. This is due, in large part, to the fact that the areas of study were (palaeogeographically) in different regions, hence, in different depositional régimes. The similar bedforms found by both Gehling (1982), at Wilpena and Jenkins *et al* (1983) at Ediacara, are not necessarily indicative of a similar environment occurring at the two widely separated localities.

Wade (1970) first indicated the presence of the Ediacara fossil remains at numerous sites in the Flinders Ranges, including the Nilpena Hills, to the south of Ediacara Range. Fossiliferous float was found but no outcrop. Subsequent investigations revealed that the Ediacara Member was present and contained a channelized system topped by richly fossiliferous float (R.J.F. Jenkins pers. comm. 1989).

With a pristine fossil occurrence at Nilpena Hills, it was hoped that some biostratigraphical information could be extracted. Unfortunately, the characteristic poorly outcropping nature of the Ediacara Member (Jenkins *et al* 1983) and low dips, made observation difficult as the strata is often continuously covered in scree. Sections were measured approximately every 100 m along two base lines, one running due north, the other due east (Appendix 1). 50 x 50 m quadrates were used on a random basis in an attempt to statistically analyse fossil diversity and abundance (Appendix 2). Also, an attempt was made to establish whether a useful biostratigraphic model could be erected.

FIGURE 3 GEOLOGICAL MAP OF NILPENA HILLS



WONOKA FORMATION

FACIES DESCRIPTIONS

The Wonoka Formation is the oldest part of the succession studied (Fig. 3). It consists of four readily identifiable, conformable members correlating with units 7, 8, 10 and 11 of Haines (1987). This nomenclature will be followed here.

Unit 7

This unit comprises grey to green argillaceous to occasionally silty micritic limestones, which rarely are reddish/brown. Hummocky cross stratification, slump rolls and other sediment deformation structures commonly occur (Plate 1a) and stylonodular bedding is abundant, especially in the green limestones.

Unit 8

This comprises a sequence of thick, grey, micritic limestones, becoming thinly bedded towards the top of the section. These micrites intercalate with thin, green, silty limestones, which grade to green, calcareous mudstones towards the top of the unit.

Unit 10

This is an entirely siliciclastic unit, comprising red, micaceous, silty, very fine grained sandstones, which grade up into brown to green calcareous siltstones.

Unit 11

The topmost unit of the Wonoka Formation, comprises light brown, calcareous to dolomitic, silty limestones. The sequence exhibits decreasing carbonate content, allied with an increasing siliciclastic content away from the basal beds. An upper, olive/brown, slightly dolomitic siltstone grades conformably into the red/brown silts of the Bonney Sandstone (Plate 1b).

FACIES INTERPRETATION

Haines (1987) interpreted the Wonoka Formation as an overall shallowing upward sequence. Unit 7 comprises proximal turbidites. Unit 8 possibly records an upward diminution of wave efficiency. It culminates in lagoonal, carbonate muds. Units 10 and 11 represent continued shallow water deposition in possibly subtidal to supratidal conditions, occasionally interspersed with lagoonal deposition. It is possible that the lagoonal sediments were protected by diapiric, barrier islands.

BONNEY SANDSTONE

FACIES DESCRIPTIONS

The lower beds of the Bonney Sandstone consist of red/brown, micaceous, dominantly horizontally laminated siltstone and very fine, feldspathic, silty sandstones. Rare flaser bedding, small scale cross laminations and locally abundant interference ripples are present; local disrupted bedding and both mud cracks and synaeresis cracks occur. Middle members of the Bonney Sandstone comprise red/brown, fine to medium grained, moderately sorted, feldspathic, haematite stained, trough to horizontally stratified sandstones, with intercalated red/brown micaceous siltstones.
The upper beds are composed of granule rich, flat to trough cross bedded, fine to medium grained sandstones, with occasional interbedded red/brown micaceous siltstones. These siltstones become more prominent toward the top of the sequence. The sandstone beds, which stand in relief as a result of differential weathering, produce numerous ridges. The highest of these, composed of graded, trough cross bedded, well rounded coarse quartz sand to very well rounded granules, forms Mt Michael. At the contact with the overlying Rawnsley Quartzite, a shallow (10 m thick) channel cuts down into the Bonney Sandstone. The channel contains massive, poorly sorted lobate sand bodies (Plate 1c), overlain by white, fine to medium grained, horizontally laminated sandstones of the Lower Rawnsly Quartzite.

FACIES INTERPRETATION

The lower fine grained sandstones and micaceous siltstones represent the increased influence of siliciclastic sedimentation. The presence of interference ripples, flaser and lenticular bedding and also disrupted bedding, indicates alternating traction and suspension on tidal flats (Gehling 1982). The middle and upper sequences may represent the increasing effects of tidal reworking in front of a prograding, probably braided delta. This culminates in the clean, medium to coarse grained sandstones,which contain occasional granule beds. These trough cross bedded sandstones can be compared with tidal bars (Gehling 1982, Elliot 1986). The sequence is capped by fluvial delta plain silts, which mark the progradation of the braided delta into the more basinal setting to the east. The Bonney Sandstone represents a shallowing upward cycle culminating in a fluvial depositional regime. The erosional channel at the top of the sequence, as well as similar channels reported from elsewhere (Jenkins *et al* 1983), is consistent with the Bonney Sandstone representing a lowstand systems tract (*sensu* Vail *et al* 1977).

Plate 1

1a : Slump rolls or load casts in Unit 7 of the Wonoka formation, 1.8 km west-northwest of Mount Michael, looking south.

1b : Gradational contact between the green and brown silts of the Wonoka Formation and the red/brown silts of the Bonney Sandstone, 1.2 km west of Mount Michael, looking south.

1c : Poorly sorted, lobate sands of the Lower Rawnsley Quartzite, in the base of a channel cut into the Bonney Sandstone, 2 km northeast of Mount Michael, looking north. Notebook, at centre right of photograph, 20 cm long.

1d : Disrupted bedding of the Lower Rawnsley Quartzite, southeast of Mt. Michael, along section 8 looking southeast. The red/mauve silts from facies A of the Ediacara member can be seen in a channel at the top of the photograph. Hammer for scale in centre of photograph

1e : Red/mauve claystones (foreground) and siltstones (middle) from facies A of the Ediacara Member, immediately above sandstones figured in 1d, looking southeast. Facies B above silts, covered with float, typifying the nature of outcrop in the area.

1f : Fine grained sandstone from facies B, showing flaser bedding. Collected near section 8, sample A-932-069. Scale divisions in centimetres.

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Unit 10

This is an entirely siliciclastic unit, comprising red, micaceous, silty, very fine grained sandstones, which grade up into brown to green calcareous siltstones.

Unit 11

The topmost unit of the Wonoka Formation, comprises light brown, calcareous to dolomitic, silty limestones. The sequence exhibits decreasing carbonate content, allied with an increasing siliciclastic content away from the basal beds. An upper, olive/brown, slightly dolomitic siltstone grades conformably into the red/brown silts of the Bonney Sandstone (Plate 1b).

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1f : Fine grained sandstone from facies B, showing flaser bedding. Collected near section 8, sample A-932-069. Scale divisions in centimetres.

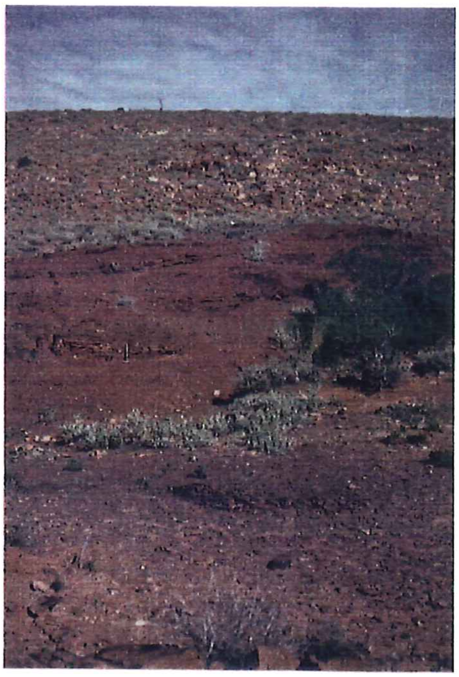
a

b

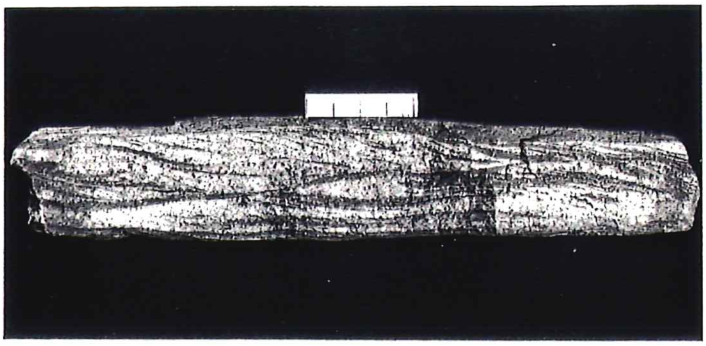
c

d

e



f



LOWER RAWNSLEY QUARTZITE

FACIES DESCRIPTIONS

The sequence contains pink to dominantly white, feldspathic, medium to coarse, well rounded quartz arenites. Sets comprise thin to thick, planar to cross stratified, tabular beds. Clay content decreases up section away from granule rich basal beds. These beds grade upward into fine to coarse grained, well rounded, moderate to poorly sorted, flat laminated to ripple topped sandstones. High in the sequence, disrupted bedding (Plate 1d), dish structures exhibiting polygonal outlines in planar section and sand volcanoes occur in massive, poorly sorted sandstones with medium bedded (20 cm) trough cross beds.

FACIES INTERPRETATION

The cross bedded and rippled, clay free, fine to coarse grained sands are indicative of shallow water. The gradual change from planar cross stratification to disrupted, rippled sands has been likened to a tidal sequence, perhaps intertidal sand flats (Gehling 1982). The association of trough cross stratified beds with dish structures and sand volcanoes compares with the upper beach-sand flat, channel sequences from the mid to late Proterozoic Rewa Formation of India (Bose and Chaudhuri 1990). Ripple marks at Nilpena Hills indicate a dominantly ESE flow direction. Since this is the direction of basin deepening (Gehling 1982, Preiss 1987), it seems likely that the ripples were the product of ebb flow.

The environment of deposition is interpreted as being intertidal, ebb flow dominated sand flats, incised by broad, shallow channels which became filled by rapidly deposited, poorly sorted sands.

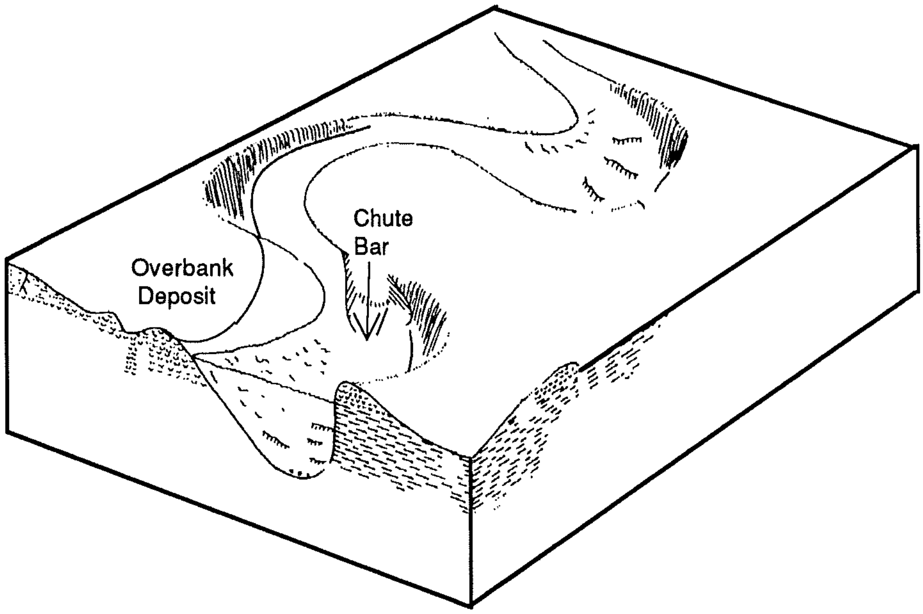
EDIACARA MEMBER

FACIES DESCRIPTIONS

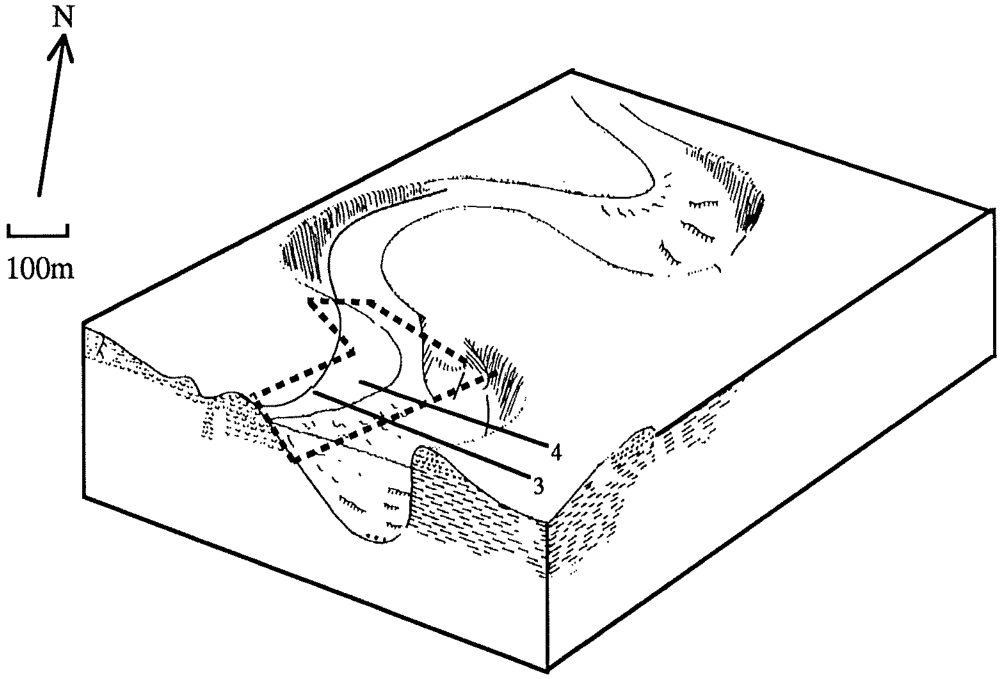
Facies A

(Gehling facies L, Jenkins *et al* facies A)

Facies A comprises red to mauve, thinly bedded to massive, micaceous siltstones and claystones (Plate 1e). Bedding planes, when present are commonly featureless. The siltstones and claystones grade upward into interbedded siltstones and white (weathers red) sub rounded to rounded, very fine to fine grained, thinly bedded, well sorted quartz arenites which exhibit occasional microripples. Uncommon, very coarse, well rounded, discrete quartz grains occur within the siltstones.



Meandering stream model after Walker and Cant (1984).



Approximate exposure of meander system at Nilpena Hills, with position of traverses 3 and 4 for reference

Buff, green, grey, very thin, flat laminated to undulating beds occur in a well defined channel (Map 1, fig 4). These beds vary from red silts to well rounded, very fine to medium grained sandstones, with the finer sandstone fraction showing micro-crossbedding. Grading is reversed in some beds. In plan view, this channel curves from approximately north-south to run southeast. In sectional view, the eastern edge (outside curve) is steep, close to the deepest part of the channel, with channel beds abruptly onlapping or grading into (contact not seen) a massive, white, fine to very coarse grained, poorly sorted, well rounded, feldspathic sandstone. The western edge (inside curve) in contrast, shallows gradually and the mid channel beds thin westward and grade into buff to brown very fine sandstones, before grading into red/mauve siltstones.
Neither body fossils nor ichnofossils were found, but elsewhere examples of diffuse circular impressions and trails referable to Forms B and F of Glaessner (1969) have been reported (Gehling 1982, Jenkins *et al* 1983). Maximum thickness 10 metres.

Facies B

(Gehling top facies L, Jenkins *et al* facies B)
White, thinly bedded fine grained quartz arenites intercalated with red/mauve, micaceous siltstones comprise Facies B, with occasional thin, flaggy, medium to coarse grained, well sorted, quartz arenite lenses. Flaser bedding (Plate 1f) and starved ripples are common. Low amplitude ripples occur on the upper surfaces of the thicker sandstone beds. Rare fossil impressions occur on the bases of the medium grained sandstone beds. Uncommonly, beds are sharply overlain by isolated lenses of Facies E. Maximum thickness 13 metres.

Facies C

(Gehling facies M, Jenkins *et al* facies C)
Wavy bedded, light coloured, mature quartz arenites interbedded with thin, coarse siltstones comprise Facies C (Plate 2a). The quartz arenites are flaggy, thinly bedded but becoming thicker up section, fine to medium grained and well sorted. The top surfaces of the flagstones are irregular with common wave oscillation ripples. Interference ripples are reported elsewhere (e.g. Goldring and Curnow 1967, Gehling 1982). Bottom surfaces are typically smooth to undulatory, or uncommonly have a 'clotted' texture. Beds commonly exhibit normal grading although mud clasts are common near the top of the beds. Reverse grading has however been reported from the equivalent facies at Ediacara (Jenkins *et al* 1983). Fossils are common to abundant. Maximum thickness 12 metres.

Facies D

(Gehling facies N, Jenkins *et al* facies D)

This facies comprises white, well indurated, medium to coarse grained, feldspathic sandstones, with low angle planar to trough cross bedding. Bedding surfaces are often picked out by thin silty drapes. Uncommonly beds of Facies D pass sharply into discrete bodies of Facies E sandstones. Fossils are sparse and occur more commonly in the Facies E sand bodies. Maximum thickness 19 metres.

Facies E

(Gehling facies J, Jenkins *et al* facies E)

Light coloured, thin to thickly bedded, massive, non graded, mud-clast bearing sandstones comprise Facies E. The beds commonly fill scours and channels (Plate 2b) which show high width to depth ratios and exhibit sharp, erosive contacts with the underlying sediments. Bed geometry is commonly lenticular to sheet sand. The facies is rarely fossiliferous. Elsewhere, pseudomorph cavities after barytes rosettes have been described from an equivalent facies (Jenkins *et al* 1983). Maximum thickness 1 metre.

FACIES INTERPRETATION

Facies A

The flat laminar to unbedded siltstones indicate deposition in a quiet, low energy environment, probably representing sediment input via wash load from Proterozoic fluvial regimes, such as described by Long (1978). Discrete very coarse, frosted quartz grains are probably of aeolian origin.

The brown, green, grey channelized beds may represent a subaqueous extension of a deltaic distributory channel, with red silts representing drape during slack water and the sandstones represent deposition during periods of waxing and waning flow within a descrete channel. Coarse sedimentation is confined to the middle and outside curve of the channel, where hydrodynamic energy was greatest, whereas on the inside curve, sedimentation of finer material occurs due to decreasing hydrodynamic energy. Deposition here possibly represents overbank deposits, where suspension once more became the dominant form of sedimentation and red/mauve silts were deposited. The poorly sorted, massive sandstone on the outer curve probably represents a slump deposit formed by collapse of the eroding outer bank. Alternatively, with numerous small channels present, the sandstone could be a chute bar deposit. The channel sedimentation conforms to the classic geometry of a meandering channel discussed by Walker & Cant (1984) (fig. 4). However, in upstream transition zone meanders, sedimentary structures are less well ordered and grading may be reversed (Jackson 1976, Collinson 1986 p. 39-40). Thus the channel appears to be part of an upstream meander system, with deposition probably influenced by the interaction of channel currents and the waxing and waning lagoonal tidal flow.

The finding of rare fossils indicates that organisms were present at the time of deposition of Facies A. The paucity of fossils suggests that the environment was not conducive for life processes, or was unsuitable for the preservation of organic remains. This may indicate that the environment experienced either extreme or fluctuating salinity levels, a common occurrence in back barrier lagoons (Elliot 1986).

The facies is interpreted as a proximal, back barrier lagoonal sequence containing channelized grainflow deposits. Deposition appears concentrated within drowned palaeodrainage channels, eroded into the underlying Lower Rawnsley Quartzite. The deepest parts of the channels acted as conduits for transport of coarser grained sediments. At Wilpena Pound, the distal part of one such channel erodes 200 metres into the underlying sediments (Gehling 1982). The central channel fill is dominated by fine to medium grained sandstones. Away from the channels, deposition is by suspension sedimentation transported by wash load. The presence, at Nilpena Hills, of large quartz grains, probably wind transported from nearby aeolian environments, indicates that the area was proximal to the mainland. The absence of fossils points to abnormal, probably low salinity levels commensurate with an inferred position near to fluvial outflows. The environment resembles the fluvial dominated, proximal portion of Lankford's (1978) Type III B coastal lagoon. The facies represents a cut in local sand sediment supply, possibly by a rise in relative sea level (Walker 1978) or by switching of major river drainage patterns. Once deepening had occurred, even small scale barriers would be effective at dampening wave and tidal action on shallowly dipping shelf environments (Shaw 1964).

Facies B

The presence of medium to fine grained sandstones with coarse grained flaggy beds indicates a more energetic depositional environment. Also, arenaceous sediment was once more becoming available. Deposition probably alternated between traction and suspension sedimentation. Starved ripples testify to the presence of gentle traction currents. Some workers have questioned the tidal origin of flaser bedding due to insufficient time to deposit enough sediment between tides (eg. Hawley 1981). However, the very much greater amounts of sediment available during the Proterozoic and early Phanerozoic due to the lack of land vegetation (Schuman 1968, Smith 1976) would allow tidal flaser bedding to form. Hence the presence of flaser bedding is taken as indicative of tidal processes (although it is not in itself conclusive). At Ediacara, oscillation and ladder ripples have been reported from the equivalent facies (Jenkins *et al* 1983), although none were observed at Nilpena Hills.

The facies is interpreted as representing a shallowing up, lagoon margin facies, in which storm, tidal and channel introduced sands interfinger with lagoonal silts. Waves moulded the tops of the sand bodies, producing rippled tops before a return to dominantly suspension sedimentation. The facies represents a transition from the lagoonal environment to a subtidal to occasionally intertidal mud flat indicating a relative fall in sea level. This fall was probably due to the filling of the lagoon, since in

Plate 2

2a : Flaggy quartzites of Ediacara Member, facies C, near section 2, looking east. The only outcrop of facies C found at Nilpena.

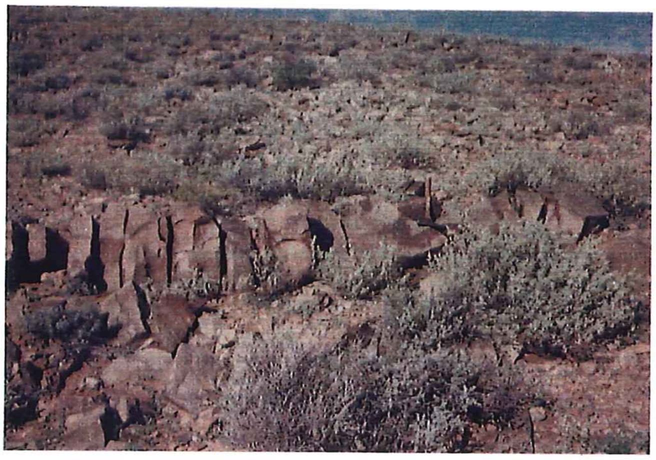
2b : Thin, massive sandstone channel deposit typifying Ediacara Member, facies E, within facies D. Near section 5, looking east.

2c : Symmetrical ripples found on the top of a slab of Ediacara Member facies C. Note bifurcating ripple crests, typical of wave induced ripples. Sample A-932-101, collected near section 3. (Note: for view of fossiliferous bottom surface of slab, see Plate 4c).

2d : Posterior portion of a contorted *Dickinsonia costata* within the massive sandstones of Ediacara Member, facies E, indicating rapid deposition and that *Dickinsonia* were still present during the deposition of facies D. Collected near section 8, Sample A-932-009.

a

b



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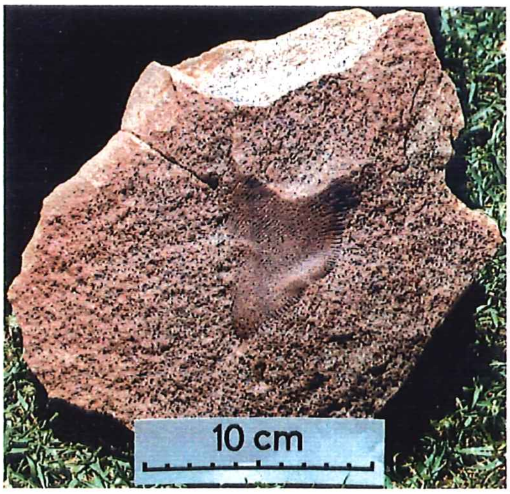


slowly subsiding areas, negligible sediment input is necessary to maintain the lagoon. In outcrop, the beds resemble the subtidal to low intertidal upper units of the Planeview Sandstone Member of the Cretaceous South Platte Formation, Colorado (Weimer & Land 1972). The absence of mud cracks and run-off features indicates that the area probably remained submerged, except in cases of exceptionally low tide. However, emergence may have been more common at Ediacara where a shallower régime is envisaged. The presence of channels containing Facies E sands is indicative of tidally influenced channels incising the mud flats. The occurrence of body fossils here and in the equivalent facies at Ediacara indicated a 'normalization', or stabilization of salinity levels which became conducive to colonization by organisms. This stabilizing of salinity levels was probably due to the increased interaction between the open ocean to the east and the lagoon, possibly allied to the increased influence of tidal forces as indicated by the presence of flaser bedding. However, high energy deposits, represented by Facies D and the Rawnsley Quartzite sands, are absent. This indicates that barrier bar systems were still effective in dampening storm and wave action.

Facies C

The smooth bottomed sandstones represent storm induced mantling of flat laminated lagoonal silts. Grading occurs due to the sudden decrease in energy experienced by the washover and flood deposits as they entered the lagoon. Thus the sediment became fluidized, achieving almost neutral bouyancy and hence had little effect on the underlying silts. However, some sandstone beds in this facies may represent fan distributary channels. Such channels carry fan sediments deeper into the lagoon. These deposits consist of lenticular, thin, planar stratified sand units, commonly separated by muddy sediment representing periods of channel inactivity (McCubbin 1982). The entraining of mud chips toward the top of the beds may have been due to the boyancy and low sinking rates of flat bodies in water (Leeder 1982 p 40). The rounded clay galls may have been derived from the tidal mud flats skirting the lee side of the barrier bar and may have been algal bound, but are known in washover deposits, to have been brought in from the open ocean (McCubbin 1982). Analysis of ripples from one, large slab (Plate 2c) agrees with other investigations in showing that the rippled tops of the beds were wave induced (Appendix 3), probably during storm activity. The return to fair weather conditions witnessed the deposition of silt from suspension. Bose *et al* (1986) describe similar flat bottomed, ripple topped sandstones dispersed in lagoonal silts from the Ghuneri member of the Jurassic Bhuj Formation in India.
Fossil impressions are most commonly found on the base of the sandstone flags and only rarely on the upper surface. Organisms feeding on, or anchored in the silts lining the bottom of the back bar lagoon, were entombed by rapidly deposited sand bodies. Resistant organisms remained intact whilst the sand grains locked together, producing a concave mould in the overlying sand e.g. *Spriggina, Dickinsonia, Tribrachidium.* Other, less resilient forms disintegrated whilst the sand was still soft, and infilling of the cavity left by the organism produced casts showing convex relief e.g. *Ediacara.*

The increase in sandstone thickness, decrease in silt interbeds and the more pronounced wave induced ripples which occur up the sequence was interpreted by Gehling (1982) as representing shallowing from a sublittoral setting in a proximal shelf environment. Here it is interpreted as the progradation of the barrier bar towards the mainland. This would increase the thickness of washover deposits, thus producing the shallowing upward cycle, but in a different environment than that suggested by Gehling.

The environment is interpreted as a back barrier lagoonal sequence, into which storm and possibly tidally induced washover deposits periodically inundated. The lack of flaser bedding, whilst not diagnostic, indicates a depth below tidal influence and hence deeper water than during Facies B deposition. Therefore a relative rise in sea level is envisaged. The abundance of fossils points to a stable environment indicating good connection with the open ocean. Under repeated storm surge activity, areas of the lagoon may have received enough local sediment to become emergent for short periods during very low tides, leading to the possible formation of the desiccation cracks and run off features interpreted from Ediacara (Jenkins *et al* 1983), which probably represents a slightly shallower environment than at Nilpena Hills.

Facies D

The presence of planar and trough cross bedded sandstones (Plate 3a) mark a return to a shallow sub-beach environment caused by the breakdown and progradation of relic sand bars westward, towards the mainland. Barrier bar sequences have very low preservation potentials in prograding regimes (Sanders and Kumar 1975, Rampino and Saunders 1980) and so their absence in the rock record is not surprising. The thin silt drapes were laid down during slack water and were either mostly removed or rapidly covered by the next depositional event. In plan view the trough cross beds exhibit a semicircular outline similar to beds figured by Reinick (1963) from modern intertidal sand flats in the North Sea. The rarity of fossils at Nilpena Hills is consistent with an intertidal to subtidal, high energy environment. However the equivalent facies at Bunyeroo and Brachina Gorges has abundant fossils (Jenkins *et al* 1983), although none were recorded from this facies by Gehling (1982). This points to a subtidal environment during this period at the location of Bunyeroo and Brachina Gorges, which is to be expected for an inferred distal setting.

The environment is interpreted as a transgressive, prograding shoreline, reworking sand bars on tidal to subtidal sand flats incised by channels.

Facies E

The unbedded, sharp based, lenticular nature of these bodies indicates deposition as channel fills via the grainflow mechanism of Walker (1978). Rare fossils within this facies exhibit extreme contortion and folding (Plate 2d) indicative of rapid, turbulent deposition. Pseudomorphs after barytes rosettes indicate the interaction of freshwater containing barium, with the sulphate in sea water, since freshwater streams and rivers contain much higher amounts of Barium in solution than sea water The rocks of the

Gawler Ranges are rich in barium (Giles 1988, K Stewart pres. comm. 1990), a very mobile element which reacts with sulphate to precipitate $BaSO_4$. Hence sediment was probably derived from the west. The angular clay galls were probably derived from nearby supratidal mud flats which possibly suffered desiccation cracking.

UPPER RAWNSLEY QUARTZITE

FACIES DESCRIPTION

The Upper Rawnsley Quartzite consists of fine to coarse grained, well sorted, mature sandstones. Beds are dominantly trough cross stratified and flaggy. Interference ripples are common on the tops of beds. Interstitial clay is almost absent. Rarely, beds contain pseudomorphs after barytes. Whilst beds are similar to those occurring in the Lower Rawnsley Quartzite, the disruptive bedding occurring in the lower beds are not as prevalent within the upper sequence.

FACIES INTERPRETATION

The Upper Rawnsley Quartzite marks a return to the tidal sand flat environment which typified the Lower Rawnsley Quartzite. Hence the similarity of bedforms found in both sequences. The occurrence of pseudomorph cavities after byrites, possibly indicates an intertidal to predominantly supratidal environment in an arid climate, where pre-evaporitic conditions occasionally prevailed. The lack of halite and gypsum casts indicates that true evaporitic conditions were never achieved.
The Upper Rawnsley Quartzite crops out only in a small area at Nilpena Hills (Fig. 3) and so detailed analysis of the Precambrian-Cambrian transition was not possible at this location, especially since the contact with the overlying Parachilna Formation is obscured.

PARACHILNA FORMATION

FACIES DESCRIPTION

This Formation consists of red (or green) to grey, fine to coarse grained, feldspathic, clayey sandstones. Sorting is poor to moderate, with very well rounded granules concentrated on some bedding planes. Usually the sandstones exhibit a bimodal grain size distribution. The sandstones are interbedded with green or white, sandy claystones, which are commonly feldspathic and weather easily. Mud cracks are common on bedding planes. Characteristically, the basal Parachilna Formation contains abundant *Diplocraterion* Torrel (Dalgarno and Johnson 1964). At Nilpena Hills these burrows are commonly less than 6 cm deep. The contact with the underlying Upper Rawnsley Quartzite was not seen.

Towards the top of the formation, beds become increasingly calcite rich. Beds of silty limestone intercalate with calcareous sandstone until the Formation grades, conformably, into the Woodondina Dolomite.

FACIES INTERPRETATION

This formation records a marine transgression and represents the basal portion of a transgressive systems tract (*sensu* Vail *et al* 1977). *Diplocraterion* is recognised as indicative of energetic, shallow, tide dominated environments (Cornish 1987, Bjerstedt & Erickson 1989), especially during transgressive episodes. The bimodal grain size also indicates a near shore beach environment (Fuller 1962). The *Diplocraterion* have spreiten which are between the arms of the tubes and are therefore protrusive (Goldring 1964) (Plate 3b). This is indicative of an erosive environment, since protrusive spreiten were produced by deepening of the burrow in response to removal of the overlying sand beds. (Fig. 5). Due to the susceptibility to weathering of the basal claystone beds, the contact with the underlying Rawnsley Quartzite is obscured.

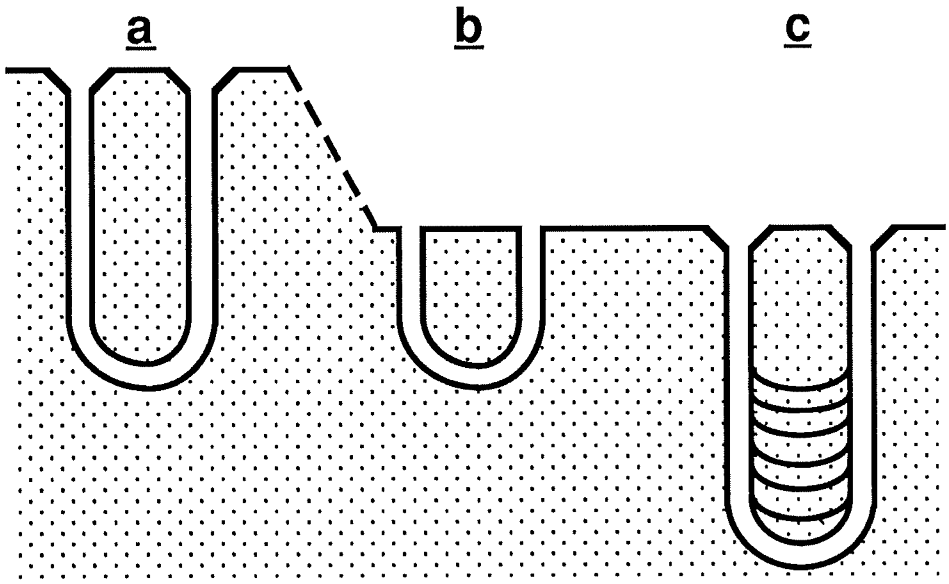


Figure 5

Production of Protrusive Spreiten by *Diplocraterion*

a)*Diplocraterion paralellum* Torrel; b) burrow after extensive erosion of sand bed; c) re-establishment of burrow length, producing protrusive spreiten

Plate 3

3a : Trough cross bedding and flat stratification in sandstones of facies D, Ediacara Member, from 100 m south of section 1, looking west (almost 90 degrees to strike), beds dip 12 degrees to southeast. (Pencil for scale near top right corner).

3b : *Diplocraterion* from the Parachilna Formation, collected 3.5 km south of Mt. Michael. Note protrusive spreiten between the arms of the burrow (either side of scale bar), indicating an erosional environment. Sample A-932-047. Scale divisions in millimetres.

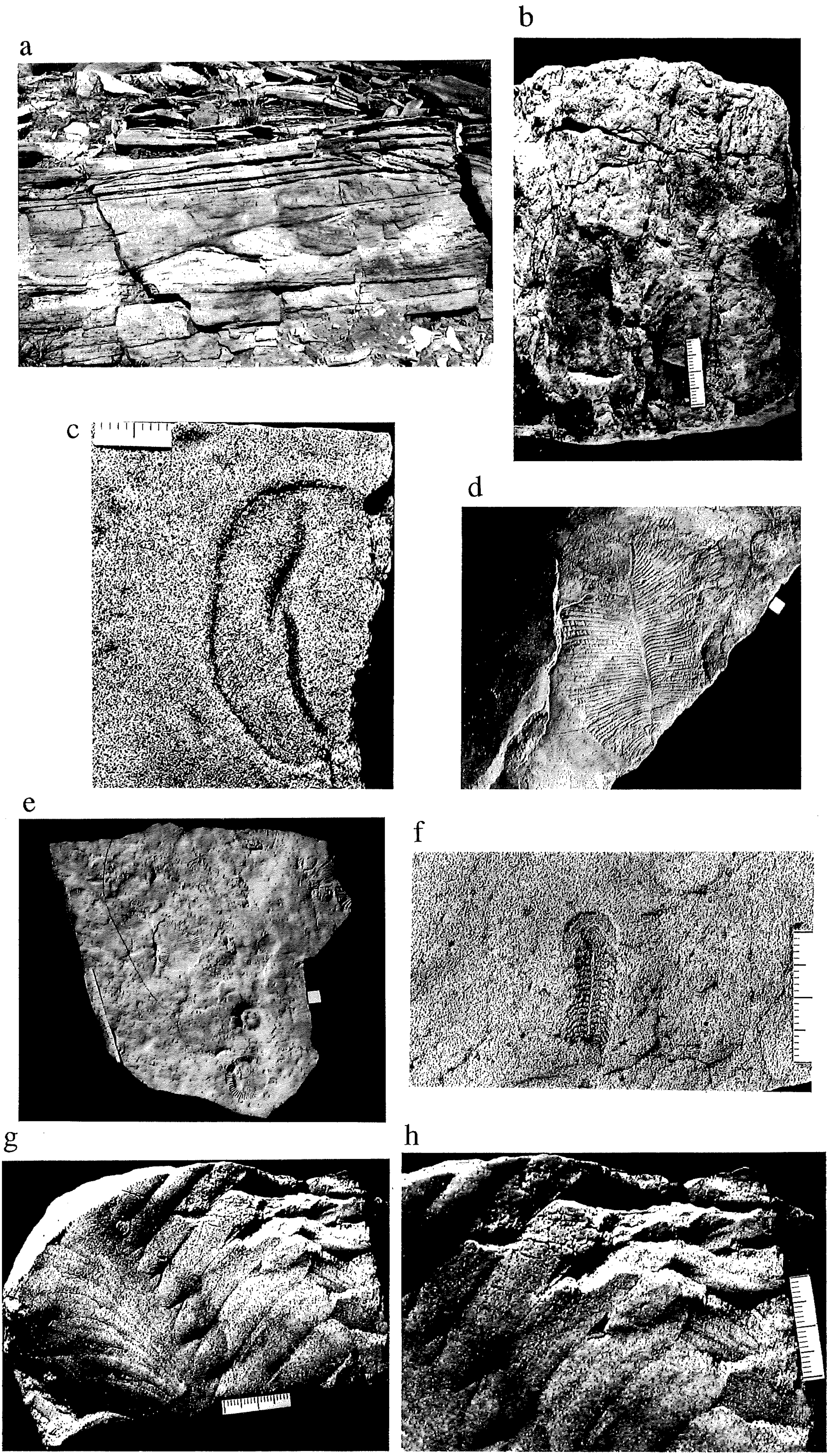
3c : *Dickinsonia lissa* with separated, possibly double gut, from facies C, Ediacara Member, collected near section 4. sample A-932-082. Scale divisions in millimetres.

3d : *Dickinsonia costata* from facies D, collected 100 m south of section 1. Sample A-932-009. Scale in centimetres.

3e : Sample from 'Dickinsonia bed' in facies C, showing five specimens of *Dickinsonia costata*, all showing dorsal groove indicating they were preserved in life position. Collected from facies C near section 13. Sample A-932-001. Scale in centimetres.

3f : *Spriggina floundersi* from facies C, collected near section 6. Sample A-932-078. Scale divisions in millimetres.

3g,h : Specimen of sea-pen-like organism of uncertain affinities, possibly Pennatulacean, allied to Charniidae, collected from facies E, near section 6, sample A-932-089. Scale divisions in millimetres.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b
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h

WOODONDINA DOLOMITE

FACIES DESCRIPTION

The unit comprises mud cracked dolomites and limestones, with quartz sand interbeds. The sequence grades from black micritic limestones to herringbone cross stratified oolite beds well above the contact with the underlying Parachilna Formation

FACIES INTERPRETATION

Sedimentation occurred on muddy tidal flats, with migrating intertidal to shallow subtidal ooid shoals becoming dominant, probably on a shallow shelf platform.

PALAEONTOLOGY

It was hoped that work at a pristine site might lead to a biostratigraphy of the Ediacara Member. Unfortunately, due to the paucity of outcrop and the lack of a complete section, fossils were only found on float. This float could be relocated to a particular facies in most instances, but not with any accuracy within that facies. Hence any biostratigraphic information can only be general at best, since the palaeontological changes seen between facies are most likely indicative of changing environments, rather than evolutionary processes.

50 m x 50 m quadrats were sampled along the section in an effort to establish links between and within fossil occurrences (Apendix 2). However, the size of the quadrats (needed so that the survey was statistically valid) were too large to differentiate between fossil occurrences within any particular facies. Therefore, the only valid results obtained by this method were relative abundances of particular genera, specifically within Facies C and no more detailed analyses were possible.

The presence of a through gut with caeca (Glaessner & Wade 1966) has established the dickinsoniidae within the Annelida. A recent interpretation of *Dickinsonia* showing a double gut system (Jenkins 1989a) is possibly supported by one specimen from Nilpena Hills, a *D. lissa* which may show a contorted and shrunken double gut (Plate 3c).

The presence of a clearly defined medial groove on the mould of the dorsal surface, formed by molding of the gut (Plate 3d), lends itself to easy recognition as to the 'way up' of the organism when buried. If the organism had been transported to the site of burial, preservation of the dorsal and ventral surfaces should be random. However, analysis of sixty five well preserved specimens showed a clear bias toward the dorsal surface i.e. the 'right way up' or in life position. Sixty four per cent of the specimens were preserved as dorsal surfaces ($P = <0.05$ at 95% confidence). Although the sample

Plate 4

4a : *Cyclomedusa radiata*, positive relief cast, from facies C. Central bulbous base compressed into a series of annular rings. Collected from facies C near section 4, sample A-932-067. Scale in centimetres.

4b : *Cyclomedusa radiata*, positive relief cast from facies C. Central bulbous base compressed laterally to the left. Collected from facies C near section 3, sample A-932-052. Scale in centimetres.

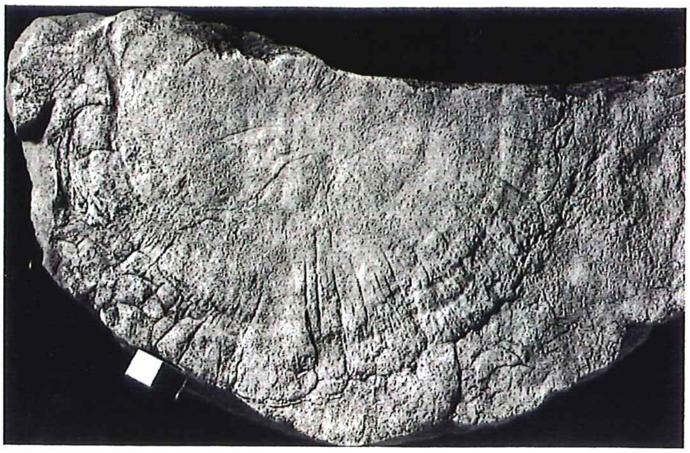
4c : Base of a quartzite slab from facies C, showing five *Cyclomedusa* . One whole specimen, top left; two partial specimens far right and two poorly preserved specimens to the left of the scale bar. Collected from facies C near section 3, sample A-932-101. Note for view of rippled top surface of slab, see Plate 2c.

4d : Magnified view of complete specimen from 4c, coated to enhance contrast. Note deflated stem (St) running from the left margin of the *Cyclomedusa* to the left margin of the slab before turning sharply towards the top margin

4e : *Cyclomedusa* with more highly defined stem still attached (St). Also fragment of another *Cyclomedusa* with well defined ribbing and possibly surrounded by the torn remnant of the outer membrane. Collected from facies C near section 4, sample A-932-095. Scale divisions in millimetres.

a

b



c

d

e

was small, the outcome compares well with a similar analysis by Gehling (1982), in which sixty seven per cent of specimens were preserved as dorsal surfaces (n = 58, P = <0.05 at 95% confidence). This would seem to indicate that the majority of *Dickinsonia* are preserved in life position. One bed in Facies C produced abundant *Dickinsonia* specimens, all of which were preserved in life position. This '*Dickinsonia* bed' was located just below the contact with the overlying Facies D.The bed weathers into small slabs with as many as five small (juvenile?) *Dickinsonia* preserved on them (Plate 3e). The large number of motile forms and lack of sessile forms in this bed possibly indicates a stranding in an intertidal environment, since sessile forms would not colonize areas which are experience periodic subarial exposure, this accords with a shallowing upward cycle through Facies C to Facies D.
The assertion that *Dickinsonia* individuals approximately 15 cm long could "lift a column of sand 20- 50 cm thick" (Runneger 1982 p 231) is clearly invalid. Large, intact *Dickinsonia*, presumably in life position, commonly occur on flags only a few centimetres, or even less than one centimetre, thick. Thus even small amounts of sand were enough to pin the organism to the muddy substrate. This indicates that the musculature was not well developed, at least not to the stage where the organism could extract itself once buried. This assumes that the animals were not torpid when buried. Presumably, this also meant that the organism was not able to move quickly or swim well. There would not have be a problem with predators since they were presumably absent (Glaessner 1984), however, problems would occur connected with respiration due to the viscous nature of water. Simple respiration across an immersed membrane produces a thick diffusion boundary layer or 'halo of oxygen depletion' to form (Graham 1990), hence the effective diffusion of oxygen is slowed, especially if the organism were slow moving and currents were weak. Therefore, the organism most probably had a surface ventilating capacity, utilizing cilia. Also, the organism would have almost certainly needed a circulatory system as Runneger (1982) postulated. Therefore, *Dickinsonia* was probably a slow moving, sediment feeder, possessing a through, possibly double, gut and a circulatory system. The organism was probably benthonic and was unable to extract itself when overwhelmed by mantling sands.

Spriggina seems to have a sclerotised head, which is not known amongst living polychaetes. However, the presence of parapodia and probable setae, together with the obvious segmentation, mark the organism as having close affinities with the polychaeta. The resistant bundles on either side of the medial groove, probably represent longitudinal muscle blocks. The circular bulge seen inside the median portion of the posterior margin (Plate 3f) is probably equivalent to the buccal mass (Glaessner 1984). *Spriggina* was probably an errant polychaete, feeding on algae covered sediment.

Cyclomedusa (Plate 4a, b) is the most widespread of all faunal elements (Wade 1972, Glaessner 1984) and is the most abundant form at Nilpena Hills (Appendix 2).

Plate 5

5a : *Conomedusites lobatus* in positive relief cast, showing ring of tentacle-like impressions. A less well preserved specimen lies below it. On the far left top margin is a small *Dickinsonia costata.* Also visible are numerous small circular impressions after *Intrites*, of uncertain affinities. Collected from facies C near section 4, sample A-932-094. Scale in centimetres.

5b : *Conomedusites lobatus* in positive relief cast, showing lobate structure of body. Collected from facies C near section 6, sample A-932-086. Scale divisions in millimetres.

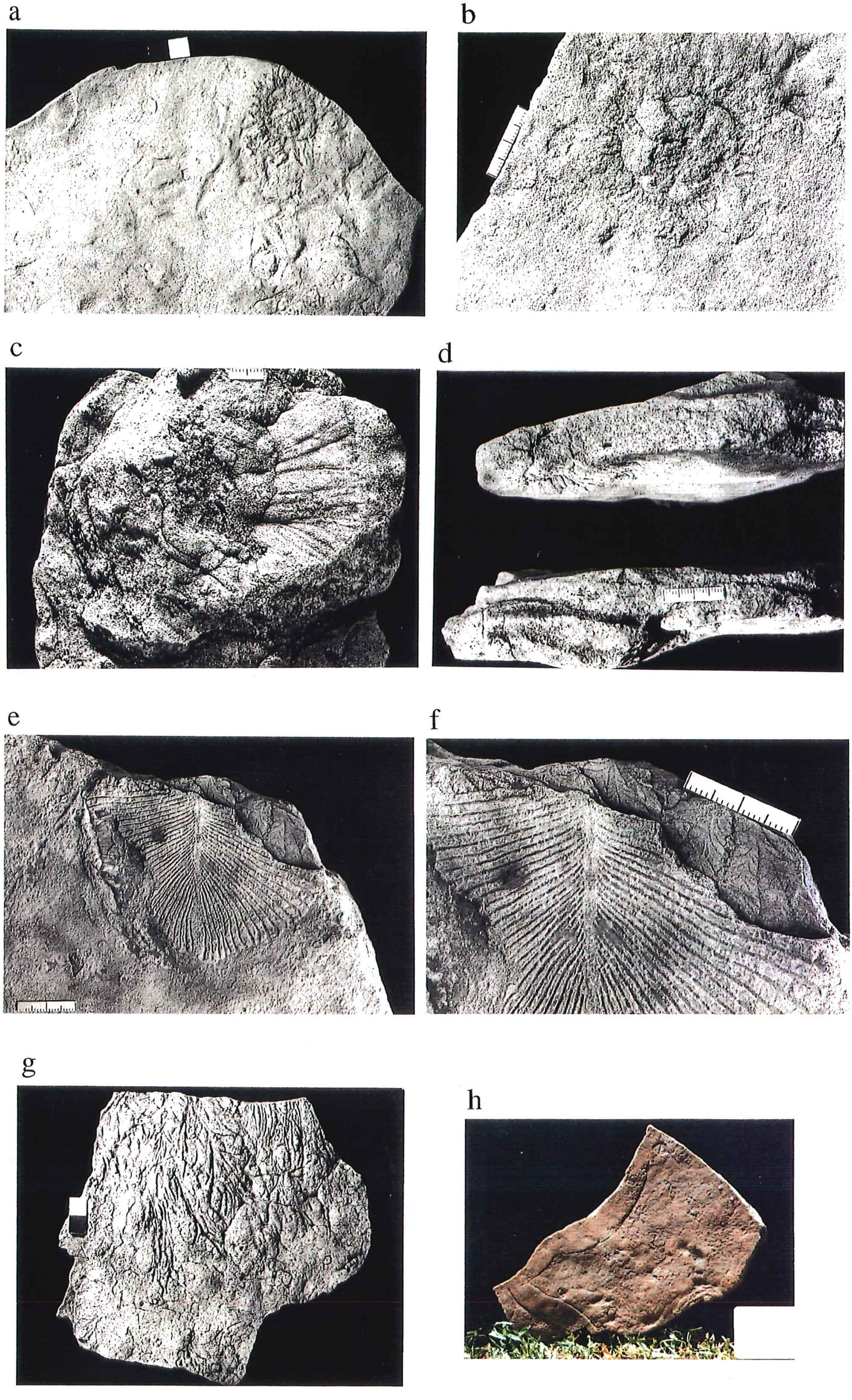
5c : *Medusina filamentis* showing ventral surface with filamentous impressions radiating from a disrupted central region. Collected from facies C near section 5, sample A-932-087. Scale divisions in millimetres.

5d : Two *Medusina filamentis*, orientated in fossilization position. Top: form showing filaments on basal surface and central disturbed area rising through overlying sand unit. Collected from facies C near section 4, sample A-932-072. Bottom: side view of specimen figured in 5c, showing three dimensional aspect of fossil. Scale divisions in millimetres.

5e,f : *Dickinsonia costata*, dorsal view, showing damage to right dorsal surface, probably the product of decay, draped by *Rangea schneiderhoehni* (?), which shows several fronds with third order divisions visible. Collected from facies B, near section 4, sample A-932-096a

5g : Trace fossil *Chondrites*, collected from facies C near section 3, sample A-932-003. scale in centimetres

5h : Trace fossil Form D, with *Parvancorina minchami* at apex of rock fragment. Collected from facies C near section 6, sample A-932-054. Scale box five centimetres.


a
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Previously the genus has been allied with the Hydrozoa (Wade 1972) and the Scyphozoa (Glaessner 1984). However, a recent study by Jenkins (1989b) interprets the genus as a holdfast-like organ at the base of the peduncle of colonial Cnidaria. Finds of sea-pen-like fossils with associated bulbous bases indicates that this interpretation is essentially correct. A slab bearing five *Cyclomedusa* (Plate 4c) was collected from Facies C at Nilpena Hills. Next to one *Cyclomedusa* , the faint impression of a stem can be seen (Plate 4d). This as well as another specimen (Plate 4e), appears to substantiate the interpretation of Jenkins (1989b) as to the Pennatulacean affinities of *Cyclomedusa* . Since the International Code of Zoological Nomenclature has no provision for the independent naming of body parts as "form genus" or "parataxon", the genus and species names are retained, due to the common occurrence of the fossil, but are reduced to informal status.

The positive relief of the casts of *Conomedusites* indicate that the form was embedded in the muddy substrate. Mantling sands would have filled either the body cavity, or the cavity left after the organism had decayed. The fact that the majority of forms show an almost complete to complete ring of tentacles (plate 5a, b), indicates that the 'tentacles' were probably rigid structures, perhaps acting as the bases for the actual tentacles. In some instances, the body of the organism has been displaced laterally. This may indicate the direction of sand movement. As sand moved over the living organism, either during or just after deposition, the induced drag may have displaced the body in the direction of flow. *Conomedusites* has been compared with the juvenile, sessile stephoscyphus stage of living Coronatida and the scyphopolyps of other scyphomedusae (Glaessner 1984). Bischoff (1978) placed *Conomedusites* close to the stem form of the Scyphozoa, indicating it was a primitive, sessile Scyphozoan.

One specimen of *Medusina filamentis* shows a three dimentional, discoidal structure, similar to *Cyclomedusa* (Plate 5c). The central region appears to continue upwards through the overlying sand unit. This structure is also shown in another specimen (Plate 5d). The genus *Medusina* Sprigg, first described as "Medusoid Problematica", was re-interpreted by Glaessner & Wade (1966) as *Medusinites*. However, *Medusina filamentis* was separated from *Medusinites* and allied with *Pseudorhizostomites*. Whilst the separation seems warranted, the assertion that *Medusina filamentis* is allied to *Pseudorhizostomites* is questionable. Since *M. filamentis* possesses a well defined, cylindrical central region and occupies a three dimentional structure external to the main sand body i.e. a positive relief cast, it is more probably allied to *Cyclomedusa*. Since *Pseudorhizostomites*, are thought to form by the decay of organic matter and the escape of gas through the sand bed, they cannot, therefore, occur outside the sand bed. *Medusina filamentis* is therefore interpreted as a holdfast-like organ for colonial Cnidarians. The genus and species names are retained, but reduced to informal status.

DISCUSSION

The pattern of relative sea level rise, shallowing, then rise and final shallowing, envisaged for the Ediacara Member at Nilpena Hills, can be correlated with the two shallowing upward sequences seen in the Ediacara Member at Brachina, Bunyeroo and Parachilna Gorges (Jenkins *et al* 1983). Facies A (Gehling 1982, facies L) represents offshore muds, seaward of the developing barrier bars. Such shelf muds can occur in water depths of as shallow as 8 metres on low energy coasts, but even on high energy coasts, muds occur at depths of only 17 metres (Howard & Reinick 1979). These muds commonly contain thin, ripple topped, lenticular sandstone bodies (McCubbin 1982) The capping of this facies with Facies D and E (Gehling 1982, facies J & K) is interpreted as progradation eastward (basinward) of the barrier bar complex, including barrier bar channels and frontal barrier foreshore, across these muds. This correlates with the relative shallowing associated with Facies B. The next cycle starts with the deposition of lower shoreface silts. This was caused, probably, by re-location of the barrier bar complex towards the west (shoreward). This correlates with the relative sea level rise associated with Facies C. However, the increased energy present in the system may have caused increased deposition of sand landward and seaward of the barrier bars, especially.during storms. Finally, the relative shallowing associated with Facies D resulted in the capping of the second shallowing upward cycle with deposition of Facies D and E sands as an intertidal (at Nilpena Hills) to subtidal (at the Heysen Range) shelf became established. A similar sequence, from offshore muds to back barrier lagoon sediments, is reported from the Permian Vryheid Formation, Durban, South Africa (Taverner-Smith 1982).

If the interpretation of *Cyclomedusa* is correct, then the assemblage appears to be dominated by benthonic, mainly sessile organisms. The remainder of the assemblage consists mainly of other sessile forms (*Conomedusites*, *Medusina* and *Tribrachidium*), as well as motile benthonic forms (*Dickinsonia*, *Spriggina* and *Parvancorina*). Free swimming forms constitute a very small portion of the overall assemblage (Appendix 2). This differs from previous interpretations which have maintained, due to the classification of *Cyclomedusa* as a medusoid, that free swimming Cnidarian medusoids dominate the assemblage (e.g. Glaessner and Wade 1966, Wade 1972, Glaessner 1984). The paucity of free swimming forms and small proportion of motile forms found in Facies C supports the interpretation of a subtidal environment which experienced periodic inundation by sand. Sessile organisms would be trapped *en mass*, whilst motile organisms would have some latitude to escape. The only free swimming organisms preserved, would be those which had settled to the bottom of the lagoon after death, or swimming close to the sediment-water interface during inundation. Hence this process would be expected to impart a 'benthonic bias' to the assemblage. Where shallower conditions are envisaged, e.g. Facies B, D and E, motile forms

dominate (Appendix 2). This is to be expected where fluctuating tides may strand organisms foraging close to the shoreline.
Rangea schneiderhoehni has been considered an older form than the more common sea-pen like organisms from the Ediacara assemblage (Jenkins 1985). The finding of *R schneiderhoeni* within Facies B (Plate 5e, d), lower in the sequence than other sea-pen like organisms, confirme this.

Plate 6

6a : Uratanna Formation from Red Range exhibiting typically bold relief, above dipping Rawnsley Quartzite. View looking south, over Rawnsley Quartzite toward Cambrian limestones (unseen). (Uratanna cliff approx. 8 metres).

6b : Uratanna Formation channel sandstone, northwest margin of major channel in Mt Scott Range (near section 2). Water escape structure indicates rapid deposition of poorly sorted sands.

6c : Unconformable relationship between the Rawnsley Quartzite (below) and the Uratanna Formation basal sandstones (above) at Mt. Scott Range. Base of hammer handle at contact. Head of hammer and bottom of notebook mark the same bedding plane. Looking northeast, down dip. Note the pseudomorphs after barites at extreme top left of photograph, these characterize this section of the Uratanna Formation and are not found within the Rawnsley Quartzite, near the contact, in Mt. Scott Range.

6d : *Diplocraterion* penetrating the topmost Rawnsley Quartzite at Ediacara Range. Maximum depth of penetration less than one centimetre.

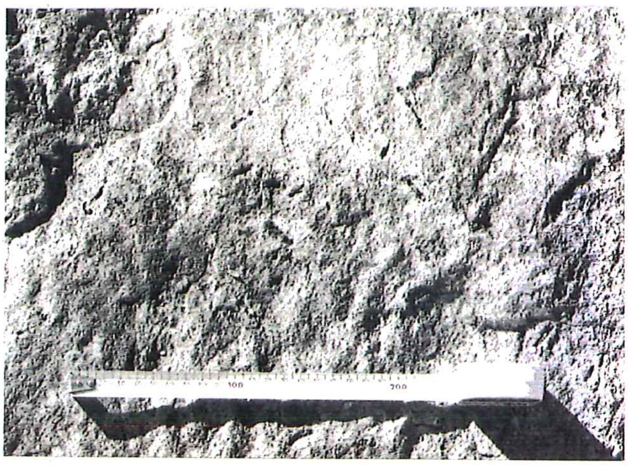
6e : Uratanna Formation olive green silts and shales above the basal sandstones at Daily's type section in Mt. Scott Range. View northwest, silts dipping 45 degrees to northeast, hammer head on bedding plane.

a

b

c

d



e

Chapter 2 The Precambrian-Cambrian Transition in the Northern Flinders Ranges, South Australia.

A recent re-evaluation of the Precambrian/Cambrian (Ediacaran) unconformity in the Flinders Ranges, South Australia (Mount 1989), attempts to show that no significant stratigraphic break exists. Mount asserts that the Rawnsley Quartzite was unlithified at the time of deposition of the Uratanna and Parachilna Formations and so these units represent a continuous depositional sequence, thus obviating the regional unconformity mapped by Dalgarno and Johnson (1964). Further, the presence of the Ediacara Member close to the top of the Rawnsley Quartzite in some areas is considered to be a product of the diachronous occurrence of crucial lithofacies, indicating a close correlation in age between Ediacaran and Cambrian assemblages.

However, it is considered that the work of Mount (1989) contains a number of possible inaccuracies, discussed below.

Field work was undertaken in the Mount Scott Range, Red Range and at Puttapa Syncline where, in contrast to Nilpena Hills, the Pound Subgroup-Uratanna-Parachilna relationships are well exposed.

POUND/URATANNA BOUNDARY

The Uratanna Formation and the nature of the Pound Subgroup/Uratanna boundary near Mount Scott (Map 2A), was first discussed by Daily (1973). The presence of channelized, rapidly deposited Uratanna sandstones (Plate 6a,b) was re-interpreted by Mount as reflecting syndepositional grabens. However, detailed remapping of the area failed to find any evidence of faulting associated with the sides of the channels and, in fact, confirmed Daily's original findings that, "Normal faulting can be excluded because individual beds of Pound Quartzite can be traced continuously along strike below the level of the channels" (Daily 1973, p 204). Nor does the graben theory adequately account for the fact that an intermediate sand of the Uratanna Formation can be traced continuously away from the southern channel, to the southeast, forming a drape over the flanking Rawnsley Quartzite at Daily's type locality in the Mount Scott Range.

A small cross fault, with a displacement of 50 metres, was mapped at Daily's type locality (Map 2A). Apparently missed by both Daily and Mount, the fault was traced from within the Wonoka Formation, through the Pound Subgroup, to within close proximity of a large channel filled by the Uratanna Formation. Contact relationships below the base of this channel were obscured by scree. Detailed mapping of the overlying Uratanna and Parachilna Formations along the projected strike of the fault and along the channel, failed to show any displacement of strata, suggesting that the fault terminates at the Uratanna Formation - Pound Subgroup contact. This relationship is *prima facie* evidence for an unconformity.

Also, in the Mount Scott range, the Upper Rawnsley Quartzite/Uratanna contact was observed in outcrop to be disconformable (Plate 6c).

POUND/PARACHILNA BOUNDARY

Three stratigraphic relationships are used by Mount in his analysis of the Pound Subgroup-Parachilna Formation relationship;

a) the presence of *Diplocraterion* burrows penetrating up to 10 cm into the Rawnsley Quartzite: this was cited as proof that the whole Pound Subgroup was unlithified.

b) locally derived pebble lag conglomerates occurring at the contact, also occur within the uppermost Rawnsley Quartzite: this was considered to indicate that no lithification occurred before deposition of the Parachilna Formation, but represents reworking of pre-existing pebble lags.

c) *Diplocraterion* is restricted to fine to medium, moderate to poorly sorted sandstones and does not occur in the trough and tabular cross-stratified sandstones which characterize the Rawnsley Quartzite: the occurrence of this trace was attributed to an environmental change rather than a time related ingression.

Much was made in the re-evaluation, of the shallow penetration of the topmost Rawnsley Quartzite by *Diplocraterion* burrows (Plate 6d). However, this does not necessarily preclude a time gap. Lithification in clean, well sorted, mature sands where there is no authigenic cementation, such as those of the upper Rawnsley Quartzite, is dependent on diagenetic, intergranular pressure solution (dissolution) at grain contacts (Palmer and Barton 1987). This is in turn, dependent on the effective stress, linked to depth of burial in this instance and only indirectly to age [e.g. the 170 million year old, unlithified Grantham Sand from Cambridgeshire (Palmer and Barton 1987), the Cambrian sands of the superlaminarite horizon on the Baltic Shield (Semenenko *et al* 1960) and the unlithified Vendian sands of the White Sea, northern Russia (Fedonkin 1981)]. Therefore, substantial portions of the broad, flat lying, gently subsiding (to the East) sand flats of the uppermost Rawnsley Quartzite could have remained unlithified for a long interval since there is no evidence to suggest deep burial or the introduction of an authigenic cement before the onset of Cambrian sedimentation. Therefore burrowing from the Parachilna Formation could have occurred before silicification of the Rawnsley Quartzite (Glaessner 1990). Also, burrowing of the top surface is not good evidence for stratigraphic continuity, rather the reverse, as disconformity surfaces are commonly burrowed. When exposed (during a late Ediacaran regression), the topmost levels of the Rawnsley Quartzite would have provided little relief to initiate and sustain erosion and hence succeeding sediments may be expected to be paraconformable.

Whilst it is true that the pebble lag conglomerates of Rawnsley Quartzite pebbles such as seen at the transition also occur within the upper Rawnsley Quartzite, their very presence indicates some degree of lithification must have existed within parts of the

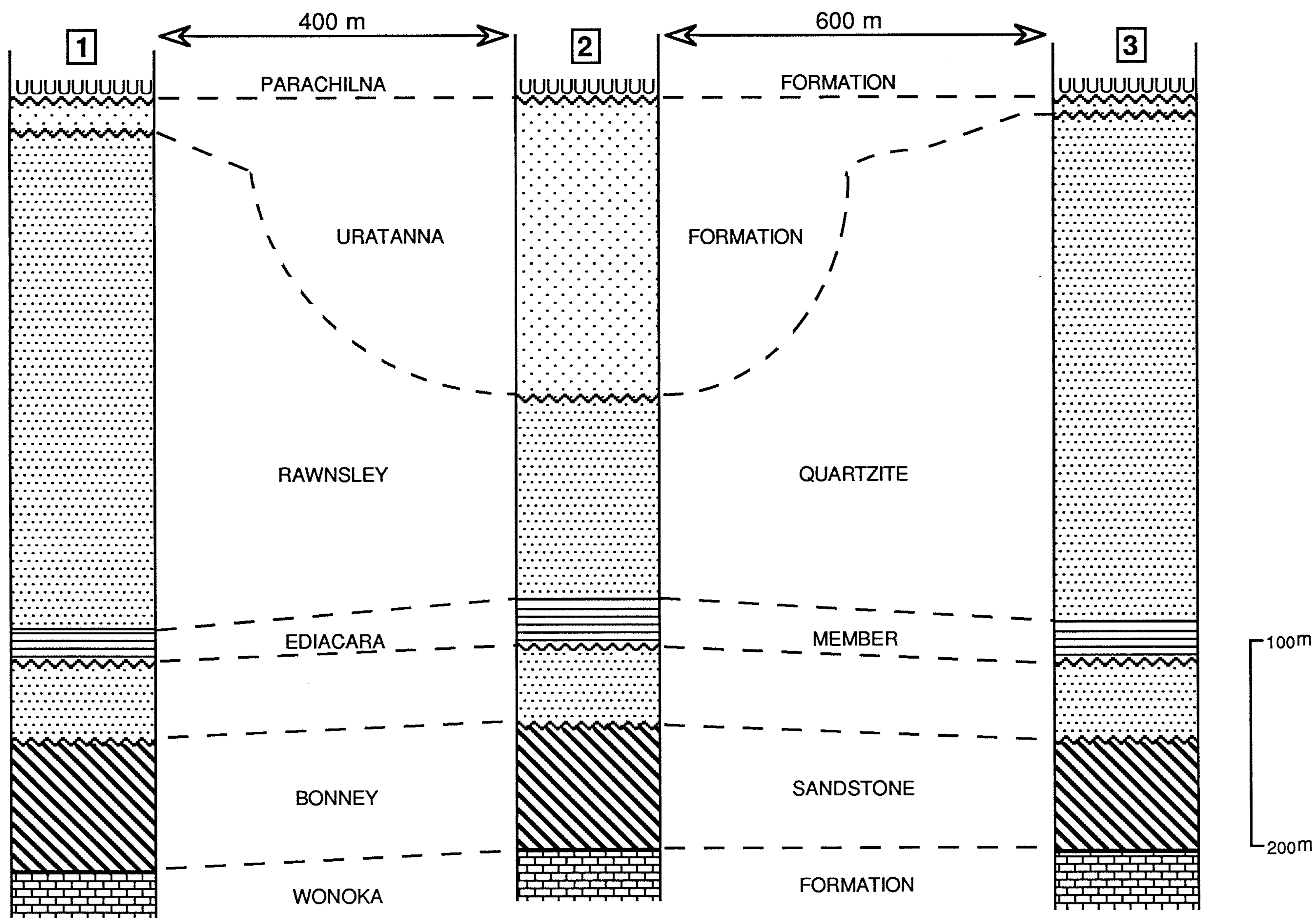


Figure 6. Measured sections across the Precambrian-Cambrian boundary, approximately 3.75 kilometres northwest of Mount Scott. Note: section 2 is 150 metres northwest of Daily's (1973) type section (See Map 2A)

Rawnsley Quartzite. Mount (1989, p 371) admits that the pebbles were derived from locally eroded Rawnsley Quartzite. Also, Jenkins *et al* (1983) indicated partial lithification of the Bonney Sandstone had occurred even before Rawnsley Quartzite deposition. It is evident that the Pound Subgroup underwent several episodes of, at least partial, lithification before the deposition of the Parachilna Formation.

Both *Diplocraterion* occurrence and lithology are controlled by the amount of energy in the environment. *Diplocraterion* is almost exclusively found in energetic, low intertidal to shallow subtidal, tide-dominated facies (Bjerstedt & Erickson 1989). It especially favours clean sands, which were seemingly mobilized by swift tidal currents on extensive, low sand flats (Fürsich 1974, Crimes *et al* 1977, Crimes & Germs 1982, Legg 1985, Cornish 1987, Bjerstedt & Erickson 1989, Dam 1990). Thus the upper Rawnsley Quartzite would have presented an ideal environment for colonization by *Diplocraterion*, if it were present. Also, since *Diplocraterion* and *Skolithos* appear to be mutually exclusive, beds where *Diplocraterion* are absent would be expected to contain *Skolithos* (Cornish 1987). No traces attributable to *Diplocraterion* or *Skolithos* have ever been found as integral elements within the Pound Subgroup, apart from the examples of *Diplocraterion* obviously penetrating shallowly down (on average 1-3 cm) from the overlying Parachilna Formation.

The unconformable nature of the contact is well demonstrated at Puttapa Syncline (Map 2B). Here the Pound Subgroup has been deformed by the Beltana Diapir. The strata are folded, faulted and even overturned close to the Precambrian-Cambrian boundary (Hull 1973), whilst the Parachilna Formation and the overlying Cambrian limestones remain undeformed. This relationship indicates that diapiric activity occurred after Rawnsley Quartzite deposition, but before deposition of the Parachilna Formation. Thus, a significant period of time must have elapsed between the two events, before the erosional surface was buried.

Elsewhere, detailed mapping across the Pound/Parachilna boundary, has shown a disconformity, marked by an angular discordance,varying from 4 degrees at Puttapa to 10-12 degrees at Red Range (Map 2C).

URATANNA/PARACHILNA BOUNDARY

Detailed remapping of Daily's (1973) subsidiary section 2, revealed a hitherto unmapped channel cut into the Uratanna Formation and filled by Parachilna strata (Map 2A). This indicates erosion occurred on the Uratanna Formation before deposition of the Parachilna Formation and is evidence for a possible hiatus between them.

Upper parts of the Uratanna Formation include a rich trace fossil assemblage (Daily 1976, Gould 1976) in the green shales of the Uratanna Middle Member (Plate 6e). This assemblage is indicative of a likely correlation with the upper Rovno Horizon of the Baltic Series of the East European Platform. With reference to Velikanov *et al* (1990), Soviet opinion favours the Rovno as pre-Tommotian (or at least overlapping the older to mid Tommotian). Therefore, in respect of the several potential Precambrian/Cambrian transition stratotypes currently under consideration in Siberia, China and Newfoundland, the Uratanna Formation may either be latest Precambrian or overlap the Early Cambrian.

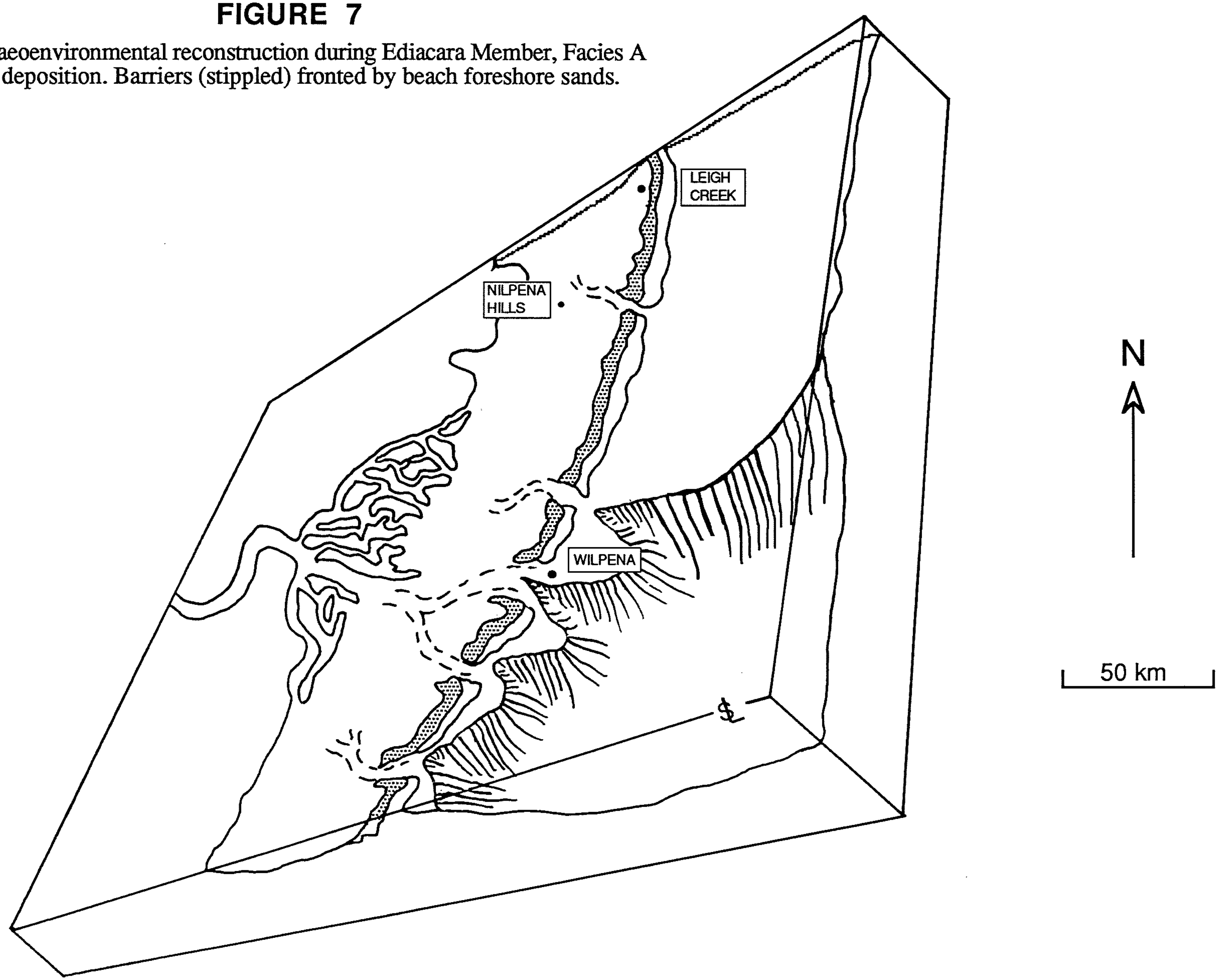
POSITION OF THE EDIACARA MEMBER

The Ediacara Member lies stratigraphically low within the Rawnsley Quartzite (Wade 1970) (Fig, 6). It is justly famous for its rich assemblage of Precambrian body fossils. The depositional history of the Ediacara Member has been viewed in two main ways, a shallow subtidal to intertidal sequence (Jenkins *et al* 1983), or as proximal turbidity grainflows, below fairweather wave base (Gehling 1982). Whilst these differing views may seem irreconcilable, this is not so. The bulk of Gehling's work centered on the palaeoshelf and palaeoshelf break environment, whilst Jenkins *et al* concentrated on the proximal inshore to intertidal environment, some 60-110 km to the north-west. It is not surprising therefore, that two differing models have been proposed. They are, in fact, each substantially correct, when applied to the appropriate environment.

The recent re-evaluation by Mount (1989) states that the preservation of fossils only occurs in the wavy bedded sandstone facies and that, therefore, the preservation is unique (Mount 1989 p 367). Both assertions are incorrect in the area of this study. Unfortunately, Mount erred in applying the deep water palaeoenvironmental interpretation of Gehling (1982) from the west-central Flinders Ranges, to the shallow subtidal-intertidal environments of the extreme western edge of the Flinders Ranges, which is more accurately described by Jenkins *et al.* Here, all facies of the Ediacara Member are fossiliferous to some degree (Jenkins *et al* 1983, p 106-107), not just the wavy-bedded sandstone facies. The preservation cannot, therefore, be unique, nor was it particularly stringent (Wade 1970). The range of the assemblage is not, as was asserted, due to the "stratigraphic distribution of critical lithofacies" (Mount 1989, p 369) especially in the shallow to intertidal environments of the Ediacara and Mount Scott Ranges. In order for the diachronous theory to be correct, the Bonney Sandstone-Rawnsley Quartzite boundary would also have to be diachronous, since the Ediacara Member retains its relative position close to the base of the Rawnsley Quartzite throughout the areas mapped. Mapping has shown that its position with regard to the top of the Rawnsley Quartzite is dependent on the extent of erosion pre-dating the Uratanna Formation (Fig. 6). In the area of interest, the top of the Rawnsley Quartzite is extensively eroded by Uratanna channels, some greater than 100m deep (Daily 1973, Fig. 2). Also, Wade (1970) and Gehling (1982) reported extensive erosion of the Rawnsley Quartzite before Cambrian deposition.

FIGURE 7

Palaeoenvironmental reconstruction during Ediacara Member, Facies A deposition. Barriers (stippled) fronted by beach foreshore sands.



Chapter 3 CONCLUSIONS

At Nilpena Hills, the depositional environment of the Ediacara Member is envisaged as one dominated by back barrier lagoonal sedimentation (Fig. 7). A rise in relative sea level was commensurate with the production of barriers, coupled with a marked decrease in arenaceous input. The area received suspension sedimentation brought in via wash load. Coarse material was confined to discrete, meandering channels - Facies A. A gradual, relative sea level fall, probably caused by filling of the back barrier lagoon, then occurred. Possible partial barrier breakdown allowed a more energetic régime to deposit sands onto subtidal to possibly intertidal mud flats, incised by tidal channels - Facies B. A further relative sea level rise then allowed lagoonal suspension sedimentation to be re-established. However, the more energetic régime continued, resulting in increased sand deposition within the lagoon - Facies C. A final relative sea level fall, caused most probably by sediment filling the lagoon and possibly combined with the final breakdown of the barrier bars then may have occurred. This allowed the intertidal sand flat environment to become re-established - Facies D. Channelized Facies E sands occurred in both Facies B and Facies D. Finally, intertidal sediments which typify the Rawnsley Quartzite were deposited.

The interpretation of a shallowing lagoonal sequence for Facies C may be supported by the benthonic bias of the Ediacaran assemblage from this facies, where the majority of forms are bottom dwellers, dominated by sessile organisms. Toward the top of Facies C, the "Dickinsonia bed" exhibits a preponderance of motile forms (*Dickinsonia*) over sessile forms. This is to be be expected if the depositional environment were shallowing to a possibly intertidal régime, since the sessile Pennatulacean-like forms which dominated the deeper water environment would not be expected to flourish in areas prone to periodic emergence.

The dominance of free living forms coupled with the decreased abundance of all faunal elements in Facies B, D and E, supports the shallow, possibly intertidal depositional environment envisaged for these facies

Although the nature of the Pound Subgroup-Parachilna Formation contact remains equivocal at Nilpena Hills, elsewhere, detailed mapping of strata adjacent to the Precambrian-Cambrian boundary at Mt. Scott range, Puttapa Syncline and Red Range, has produced ample evidence to indicate the Pound Subgroup underwent several periods of, at least partial, lithification before the deposition of the Uratanna and Parachilna Formations. This evidence includes, the presence of lithified Bonney Sandstone clasts within the basal Rawnsley Quartzite and the presence of Rawnsley Quartzite pebbles within the Upper Rawnsley Quartzite and at the base of the Parachilna Formation.

An unconformity at the Pound Subgroup-Uratanna Formation contact is evidenced by the fact that at Mount Scott Range, the Uratanna Formation terminates a small fault transecting the underlying strata.

The regional unconformity between the Pound Subgroup and the Parachilna Formation mapped at Red Range, becomes a high angle discordance adjacent to the northern part of the Beltana Diapir, Puttapa Syncline (Hull 1973, Lemon 1988).

The occurrence of time breaks between the several depositional episodes reflecting the Precambrian-Cambrian transition, is shown by erosive channel formation at Mt. Scott Range. The Rawnsley Quartzite is incised and filled with Uratanna Formation sediments. A channel cut into the Uratanna Formation is filled with beds of the Parachilna Formation. This indicates erosion of the Rawnsley Quartzite and Uratanna sediments took place prior to the deposition of Parachilna abeds.

Diplocraterion penetrate shallowly into the Rawnsley Quartzite at a number of locations in the Flinders Ranges. However, neither *Diplocraterion* or *Skolithos* have ever been found as integral elements within the Rawnsley Quartzite. Also, *Diplocraterion* is indicative of transgressive systems. These stratigraphic relationships, far from indicating a mere change in lithology, suggest an ingression of a new trace fossil assemblage coinciding with time breaks between the Pound Subgroup and the Uratanna and Parachilna Formations.

The dietary niche of the extinct Australian marsupial lion : *Thylacoleo carnifex* Owen

INTRODUCTION

When the great nineteenth century palaeontologist Sir Richard Owen made the first systematic study of the extinct Australian marsupial *Thylacoleo carnifex* in the late 1850's, he was in no doubt as to its dietary niche, calling it "the fellest and most destructive of predatory beasts" (Owen 1859). However this, and his placement of *T. carnifex* within the Diprotodonta (Owen 1866) drew immediate challenge. The taxonomy was subsequently proven correct, but the dietary niche remains contentious. The reason for the continuing debate is the unique dentition of *T. carnifex* with its huge, trenchant third premolars (Fig. 1). This led to wide ranging views on dietary intake, including; carnivorous (Finch 1982; Wells 1985), herbivorous (Flower 1868; Bensley 1903), scavenger (De Vis 1901), soft fruit (Cope 1882), Cycad pith or the fruit of the Cucurbitaceae (Anderson 1926) and even crocodile eggs (Cope 1884). More recent, excellent studies of *Thylacoleo* (Wells & Nicholl 1977, Finch 1982, Wells *et al.* 1982, Wells 1985), have tended to favour a carnivorous diet but these still rely, in the main, on dental structure and wear and the nature of the manus. This study moves away from previous methods and utilizes a totally different procedure, namely the analysis of Strontium (Sr) and Zinc (Zn) levels in bone as an indicator of dietary niche.

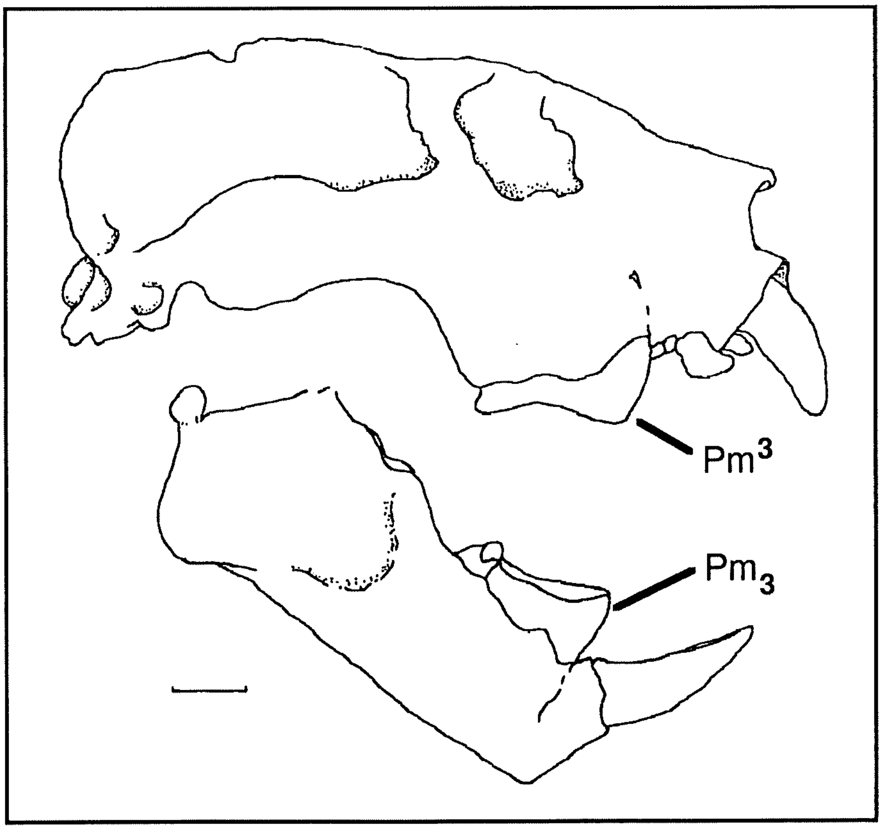


Figure 1 Expanded left lateral view of the skull of Thylacoleo carnifex, showing large third Premolars. Pm^3 = Upper Premolar 3, Pm_3 = lower Premolar 3. Scale bar 25 mm. (after Finch and Freeman 1982).

The use of Sr to establish the diet of mammals has itself been as controversial as the history of *Thylacoleo*. Since it was shown that Sr levels in bone are a consequence of Sr levels in the soil and of biologic factors (Odum 1957), they have been used to assess palaeodiet with varying degrees of success.

Strontium is discriminated against within the food chain, resulting in depletion of Sr in vertebrate tissues and organs, but incorporation into bone (Schoeninger 1979). Plants, however, do not discriminate against Sr to the same degree as vertebrates (Sillen & Kavanagh 1982) and in fact, Sr appears to be preferentially concentrated in some succulent, herbaceous vegetation to higher levels than in grasses (Bowen & Dymond 1955). This unequal distribution within the food chain means that herbivores ingest greater amounts of Sr than flesh eating carnivores, and that browsing herbivores ingest greater amounts than grazing herbivores. Since the amount of Sr taken up by bone appears to be constant, at around 20% of the amount ingested (Kshirasager *et al.* 1966), Sr found by analysis is, therefore, a function of the initial intake. These values can be used to determine diet provided the following conditions apply:

a) only bones from the same locality are compared;

b) only adult bones are used - since juveniles show markedly reduced bone Sr levels due to the very small amounts of Sr in mammalian milk - but not teeth or rib bones - Sr levels in teeth are not remodelled with growth, rib bones are more metabolically active and are therefore prone to short term resetting of bone Ca and Sr levels, especially in lactating females (Sillen & Kavanagh 1982);

c) more than one species is used for comparison.

Controversial results have been produced when one or more of these conditions was ignored, (e.g.Wyckoff & Doberenz 1967).

Recent work has suggested that the Sr levels in fossil bones may not be diet related, but an inorganic artifact (Sillen 1986) This resulted from the use of a complex analytical technique which produced atypical results. The method showed no difference between the Sr levels in the matrix and in the bones. Most analyses show a clear difference between matrix and bone Sr levels (e.g.Toots & Voorhies 1965; Wyckoff & Doberenz 1967; this study). Also, the consistent differences in Sr levels seen in other studies cannot easily be explained by purely inorganic processes.

Zinc levels in bone have also been used as a palaeodiet indicator, although in contrast to Sr, Zn levels increase through the food chain, with carnivores having higher concentrations than herbivores due to increased levels of Zn in blood and flesh compared with plants (Elias *et al.* 1982).

METHOD

Adhering to the above conditions, bones from various marsupials from the 32,000 - 40,000 year old (Pledge 1990) Henschke cave, fissure fill deposit at Naracoorte, South Australia, were taken, along with a sample of the enclosing matrix, and measured by

Atomic Absorption Spectroscopy (AAS). 1.0 g of each sample was digested with 10 ml of conc. HNO_3, evaporated, the residue taken up in 50 ml of 1.0 M HCl, made up to 100 ml in the presence of 0.2% w/v La/K, analysed for Sr using a VARIAN AA-6 Spectrophotometer with a N_2O flame and for Zn using an Air-Acetylene flame, background corrected with a Hollow H_2 lamp. Also, where amounts permited, 5 g were combined with 1.0 ml of 2.5% w/v PVA, pressed into Boric acid backed pellets and analysed by X-ray Fluorescence (XRF) using a SEIMENS SRS-1 XRF Spectrometer, with a W tube at 60 kv, 40 mA and with a LiF 220 crystal. Internal Standard MBM+BLC+Y (1345 ppm Sr). The Mass Absorption effect was calculated from the Compton Scatter peak. Analysis by XRF was used as a control, to test whether the AAS analysis was accurately measuring Sr levels.

The results from XRF closely matched those from AAS (*Macropus gigantius* Sr levels: AAS = 357 ppm , XRF = 353 ppm ; *Thylacoleo carnifex* Sr levels: AAS =183 ppm , XRF = 179 ppm) (Table 1) indicating that the AAS results were accurate.

Genus	Common Name	Bone Type	Sr ppm	Zr ppm
*Macropus giganteus**	Giant Kangaroo	Metatarsal	357 (353)	102
*Macropus giganteus**	Giant Kangaroo	Femur	373	101
Potorous tridoctylus	Rat Kangaroo	Femur	333	103
*Sthenurus sp.**	Kangaroo	Femur	516	79
Bettongia sp.	Bettong	Femur	359	106
Vombatus ursinus	Wombat	Femur	455	121
Phascolarctos cinereus	Koala	Humerus	587	61
Perameles gunii	Long Nosed Bandicoot	Femur	275	134
*Thylacinus sp.**	Thylacine	Humerus	261	141
*Thylacinus sp.**	Thylacine	Jaw Frag.	174	142
Thylacoleo carnifex *	Marsupial Lion	Ulna	183 (179)	168
Matrix	---	---	13	25

* = Extinct, ( ) = Sr values obtained by XRF.

Table 1 Strontium and Zinc levels in the bones of eleven adult marsupials from the Henschke Cave deposit, South Australia. Analysis by AAS.

DISCUSSION

The marsupials cluster into three groups. The carnivore - insectivore's *Thylacinus* and *Perameles* (Sr average 236 ppm ; Zn average 139 ppm), the grazing herbivores *Macropus, Potorous* and *Bettongia* (Sr average 355 ppm ; Zn average 103 ppm) and the browsing herbivores *Sthenurus* and *Phascolarctos* (Sr average 551 ppm; Zn average 70 ppm).

There is a close correlation between the low Sr and high Zn levels of *Thylacoleo* (183 and 168) and those of the carnivore - insectivore's, indicating a carnivorous diet for *T. carnifex.*

Since *Phascolarctos* (the Koala) is known to eat only leaves, the results indicate that *Sthenurus* is also a leaf eating browser, as suggested by its skeleton and dentition (Owen 1876; Tedford & Wells 1985).

Modern *Vombatus* is a ground dwelling grazer (Wells 1989). However, its elevated Sr and Zn levels may be explained by its burrowing habit. Breathing and ingesting fine dust would significantly increase its Sr and Zn levels (J. T. Hutton pres. comm. 1990). After plotting Sr/Zn ratios to negate the elevated values, *Vombatus* clusters with the other grazers and separate from the carnivores and browsers (Fig. 2), indicating that *Vombatus* is a grazer with elevated Sr and Zn levels.

The results obtained from the matrix sample showed a greater than ten-fold decrease in Sr levels. This discrepancy is in line with other, similar analyses, but contradicts the finding of Sillen (1986) as mentioned above. This would indicate that the use of bone Sr levels to ascertain palaeodiet is still a valid technique, especially when combined with other elements which similarly undergo concentration or reduction through the food chain

CONCLUSIONS

The results favour a carnivorous diet for *Thylacoleo carnifex*, whilst supporting the leaf eating niche of *Sthenurus*. The findings indicate that bone Sr levels can be used successfully as a valid palaeodiet indicator when the correct procedures and conditions are applied. Also, the results show that a divariate Sr and Zn analysis is a better method of establishing diet than using either element individually, since univariate analysis utilizing only Sr or Zn, would have indicated an incorrect niche for *Vombatus*.

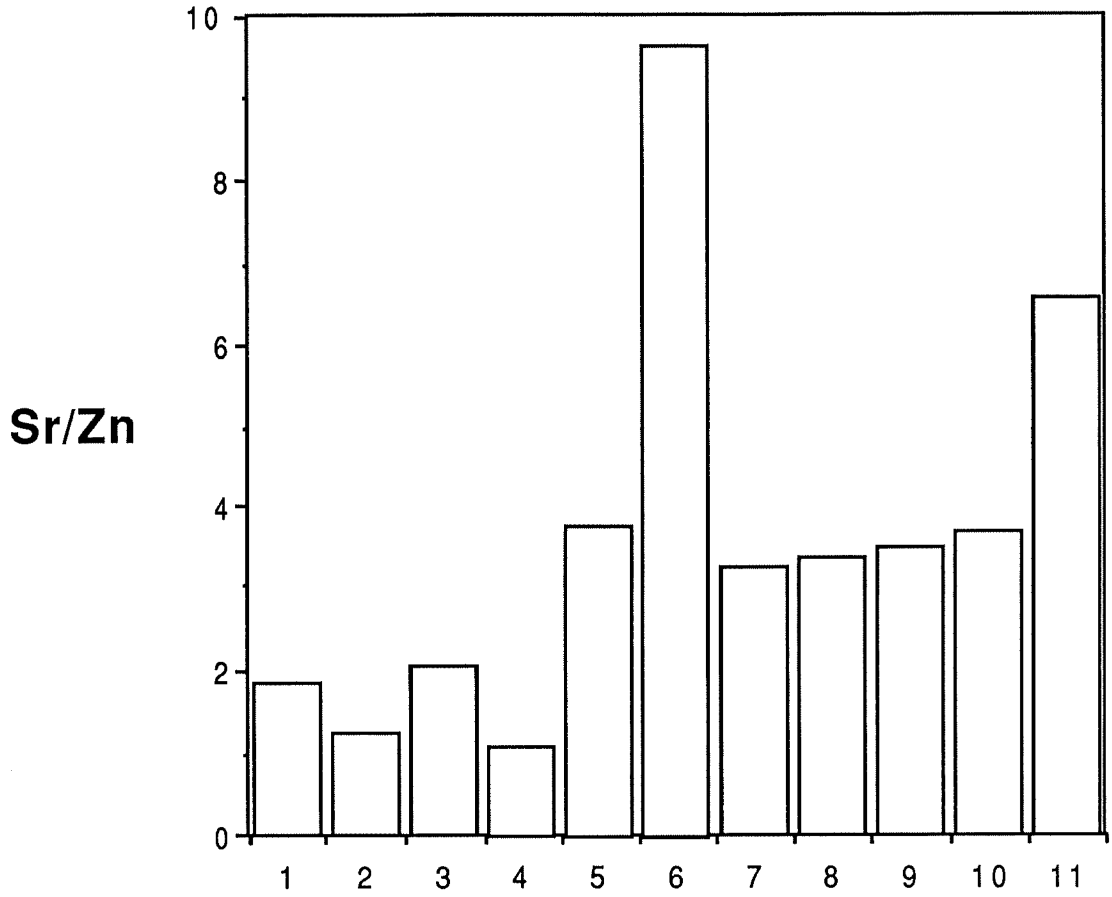


Figure 2 Sr/Zn ratios for eleven adult marsupials from the Henschke Cave deposit, South Australia. Plotted to remove the elevated Sr and Zn levels of *Vombatus*, showing that it is a grazer.
1; *Thylacinus*, 2; *Thylacinus* (Dasyuromorphia): 3; *Perameles* (Perimiliomorphia): 4; *Thylacoleo* 5; *Vombatus*, 6; *Phascolactos* (Vombatiformes): 7; *Potorous*, 8; *Bettongia*, 9; *Macropus*, 10; *Macropus*, 11; *Sthenurus* (Phalaenangeridia).

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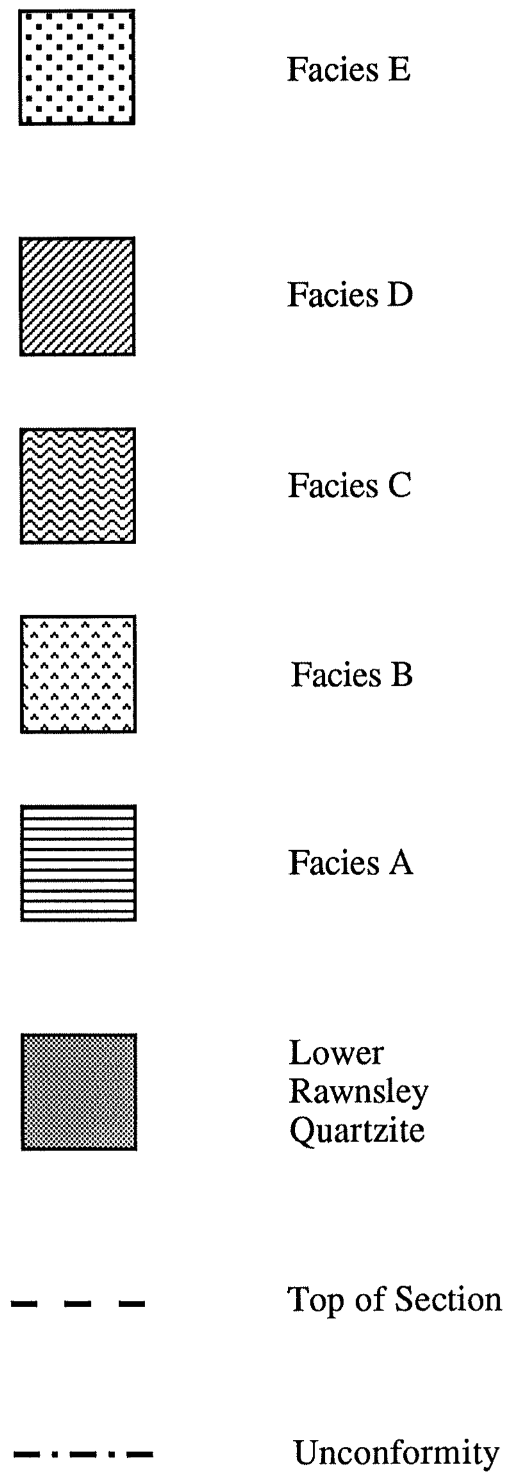
APPENDIX 1

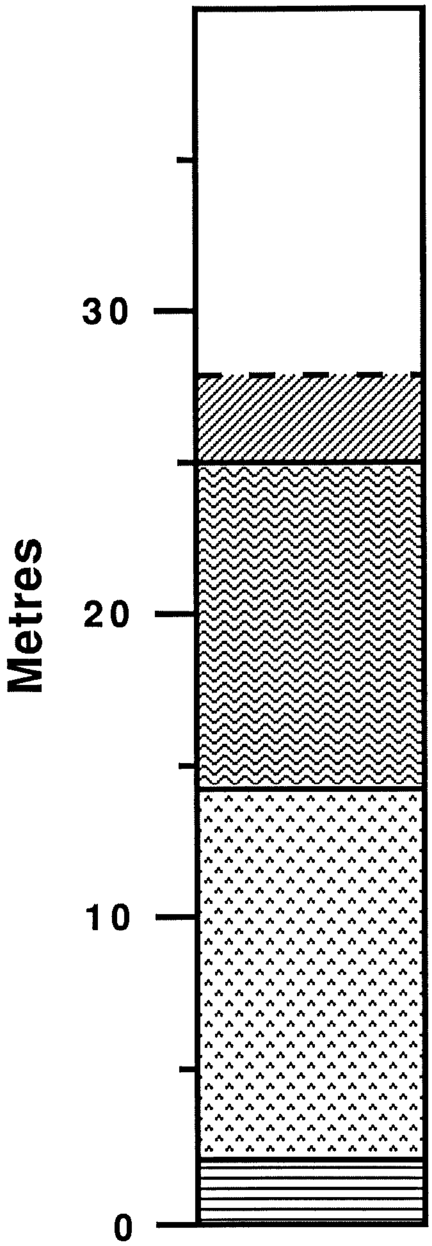
STRATIGRAPHIC SECTIONS

Stratigraphic sections of the Ediacara Member at NIlpena Hills.
Sections were constructed from 19 traverses across the Ediacara Member from two base lines. One base line orientated north-south, the other orientated west-east (see Map 1 for traverse locations). All sections are recalculated for true vertical thickness.

LEGEND


Facies E
Facies D
Facies C
Facies B
Facies A
Lower Rawnsley Quartzite
Top of Section
Unconformity

Stratigraphic Column 1



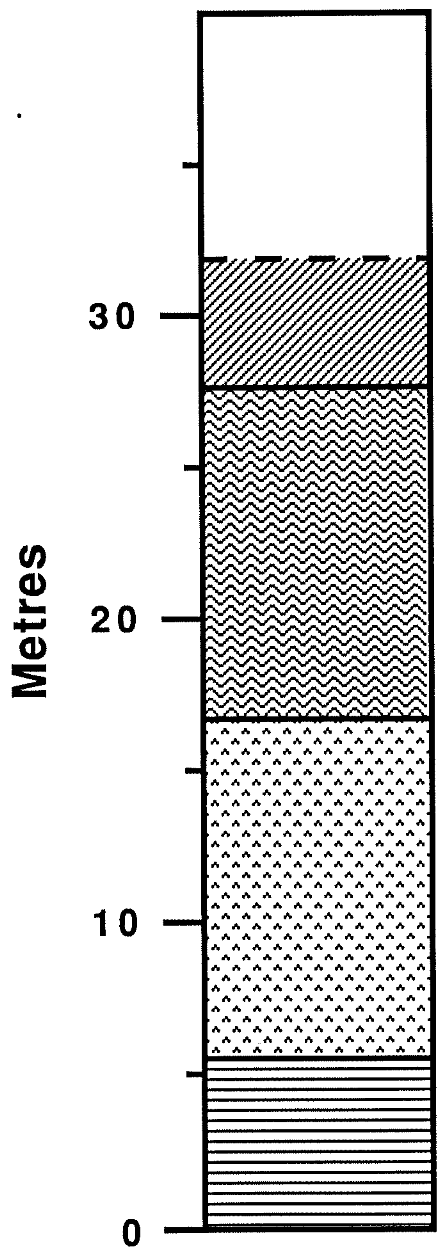
Facies D. White, medium to coarse grained, feldspathic sandstones. Low angle to trough cross bedding common. Siltstones reduced to thin silty drapes.

Facies C. White, weathering red, wavy bedded, fine to medium grained sandstones. Beds commonly graded, top surface commonly rippled, bottom surface smooth to undulatory, commonly to abundantly fossiliferous. Intercalated with thin, red siltstones.

Facies B. White fine grained, well sorted sandstones, becoming medium to rarely coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones. Fossiliferous float present.

Facies A. Red/mauve, thinly bedded, micaceous siltstones. Rarely intercalated with very fine grained sandstones.

Stratigraphic Column 2



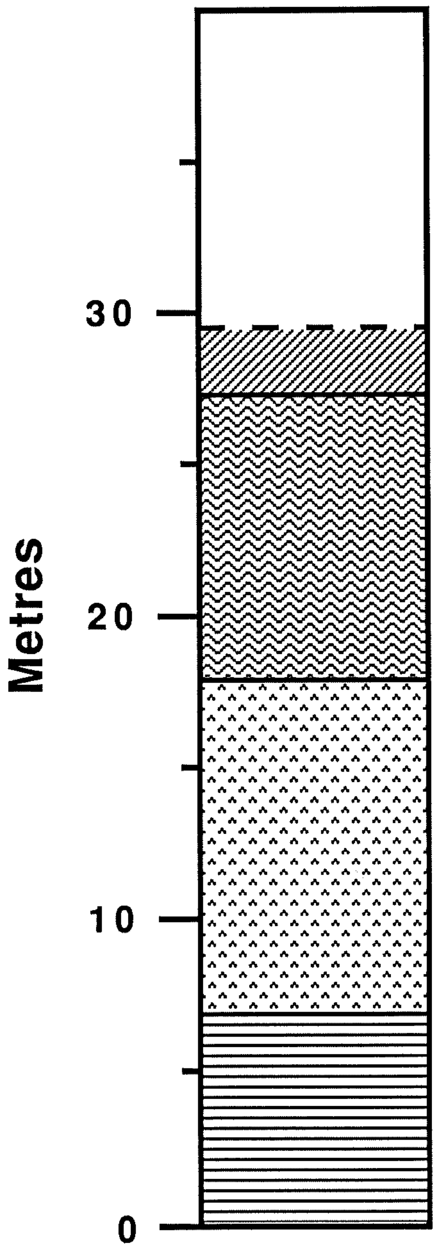
Facies D. White, medium to coarse grained, feldspathic sandstones. Low angle to trough cross bedding common. Siltstones reduced to thin silty drapes.

Facies C. White, weathering red, wavy bedded, fine to medium grained sandstones. Beds commonly graded, top surface commonly rippled, bottom surface smooth to undulatory, commonly to abundantly fossiliferous. Intercalated with thin, red siltstones.

Facies B. White fine grained, well sorted sandstones, becoming medium to rarely coarse grained toward the top of the unit. Intercalated with rare, red/mauve, micaceous siltstones. Fossiliferous float present.

Facies A. Buff, olive, very fine to fine grained, 1 to 3 cm thick sandstones, with micro cross-lamininations. Rare medium grained, 1 cm thick sandstone beds. Red/mauve silty drapes.

Stratigraphic Column 3



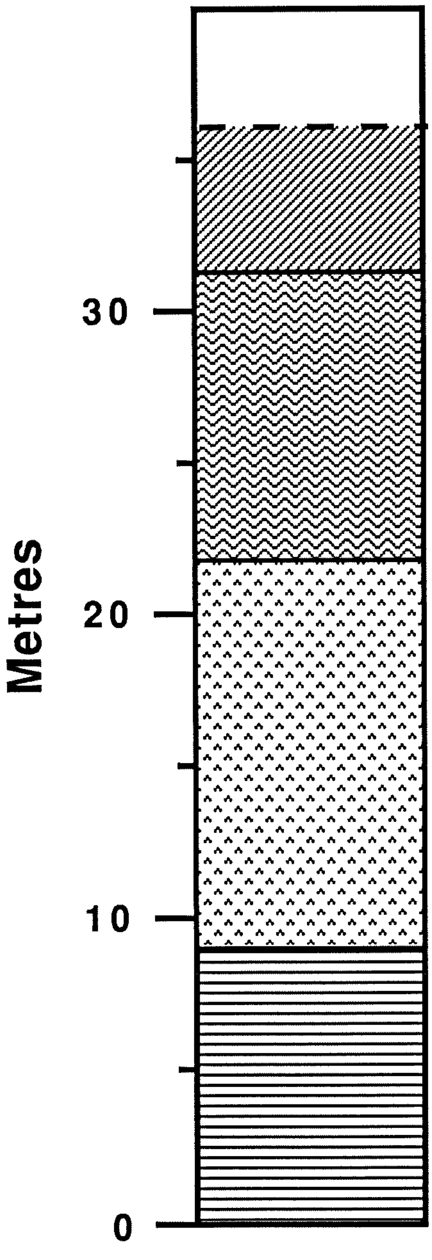
Facies D. White, medium to coarse grained, feldspathic sandstones. Low angle to trough cross bedding common. Siltstones reduced to thin silty drapes.

Facies C. White, weathering red, wavy bedded, fine to medium grained sandstones. Beds commonly graded, top surface commonly rippled, bottom surface smooth to undulatory, abundantly fossiliferous. Intercalated with thin, red siltstones.

Facies B. White fine to medium grained, well sorted sandstones, becoming rarely coarse grained toward the top of the unit. Intercalated with rare red/mauve, micaceous siltstones. Fossiliferous float present. *Rangea* fossil found 6 m below start of section.

Facies A. Buff, olive, very fine to fine, occassionally medium grained sandstones. Thin (1 to 2 cm) medium to coarse grained sandstone beds, intercalated with very thin, red, silty drapes.

Stratigraphic Column 4



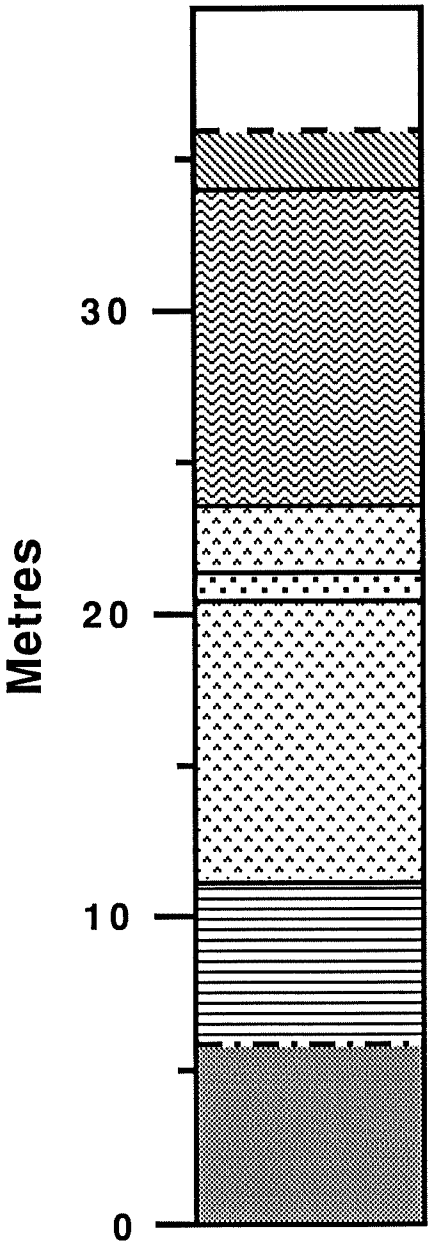
Facies D. White, medium to coarse grained, feldspathic sandstones. Low angle to trough cross bedding common. Siltstones reduced to thin silty drapes.

Facies C. White, weathering red, wavy bedded, fine to medium grained sandstones. Beds commonly graded, top surface commonly rippled, bottom surface smooth to undulatory, commonly to abundantly fossiliferous. Intercalated with thin, red siltstones.

Facies B. White fine grained, well sorted sandstones, becoming medium to rarely coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones. Abundant fossiliferous float present.

Facies A. Buff, olive, thin (>10 cm) units which grade up from red siltstone drapes, through very fine to fine grained, thinly laminated sandstones and topped by medium to coarse grained sandstone beds.

Stratigraphic Column 5



Facies D. White, medium to coarse grained, feldspathic sandstones. Low angle to trough cross bedding common. Siltstones reduced to thin silty drapes.

Facies C. White, weathering red, wavy bedded, fine to medium grained sandstones. Beds commonly graded, top surface commonly rippled, bottom surface smooth to undulatory, commonly to abundantly fossiliferous. Intercalated with thin, red siltstones.

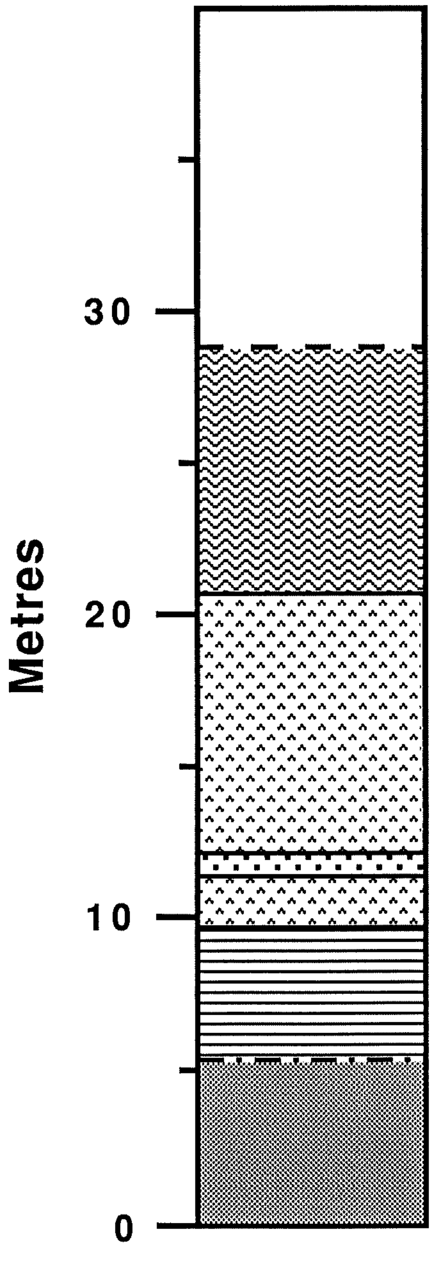
Facies E. White, medium to coarse grained, unbedded sandstones. Clay galls common near base. Base sharp and erosive, indicating scour fill.

Facies B. White fine grained, well sorted sandstones, becoming medium to coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones. Fossiliferous float present.

Facies A. Red/mauve, thinly bedded, micaceous siltstones. Rarely intercalated with very fine grained sandstones. Grades upward into buff, olive, very fine to fine sandstones.

Lower Rawnsley Quartzite. White, fine to medium grained sandstones, graded beds often present. Beds thick to thin, occasionally ripple topped, commonly disrupted.

Stratigraphic Column 6



Facies C. White, weathering red, wavy bedded, fine to medium grained sandstones. Beds commonly graded, top surface commonly rippled, bottom surface smooth to undulatory, commonly to abundantly fossiliferous. Intercalated with thin, red siltstones. *Dickinsonia* rich bed south east of traverse ('*Dickinsonia* bed').

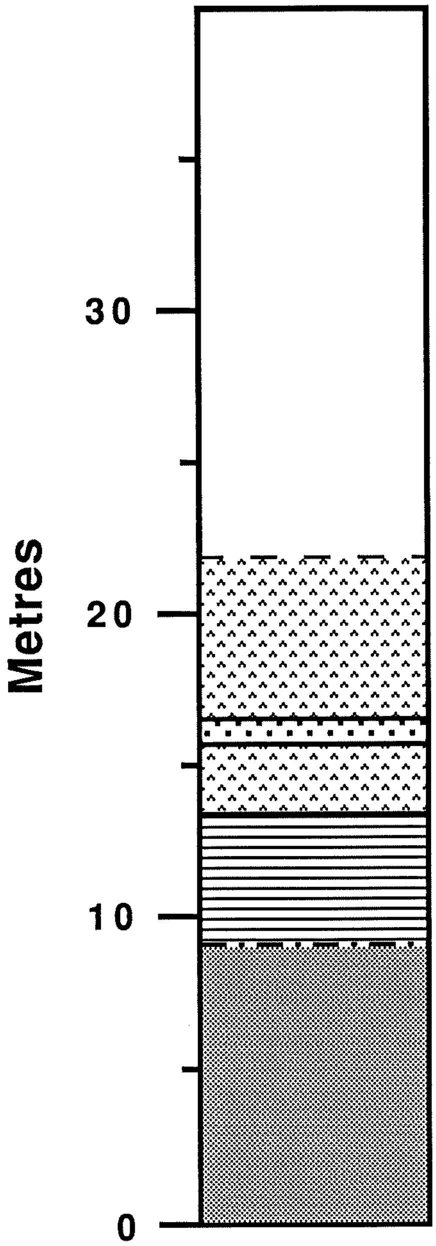
Facies B. White fine grained, well sorted sandstones, becoming medium to rarely coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones. Fossiliferous float present.

Facies E. White, medium to coarse grained, unbedded sandstones. Clay galls common near base. Base sharp and erosive, indicating scour fill.

Facies A. Red/mauve, thinly bedded, micaceous siltstones. Rarely intercalated with very fine grained sandstones towards the top of the sequence.

Lower Rawnsley Quartzite. White, fine to medium grained sandstones, graded beds often present. Beds thick to thin, occasionally ripple topped, commonly disrupted.

Stratigraphic Column 7



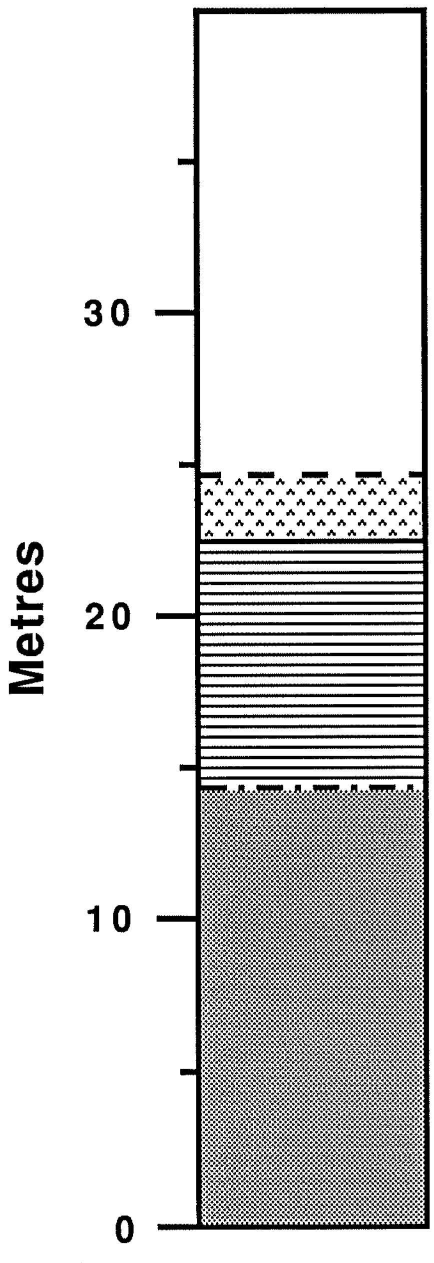
Facies B. White fine grained, well sorted sandstones, becomming medium to rarely coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones. Fossiliferous float present.

Facies E. White, medium to coarse grained, unbedded sandstones. Clay galls common near base. Base sharp and erosive, indicating scour fill. Rarely fossiliferous.

Facies A. Red/mauve, thinly bedded, micaceous siltstones. Rarely intercalated with very fine grained sandstones.

Lower Rawnsley Quartzite. White, fine to medium grained sandstones, graded beds often present. Beds thick to thin, occasionally ripple topped, commonly disrupted.

Stratigraphic Column 8

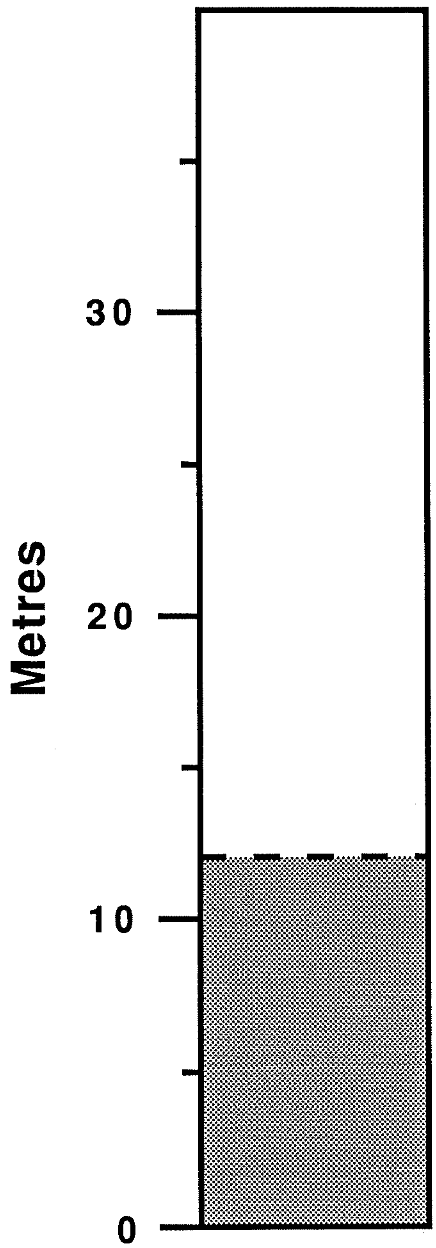


Facies B. White fine grained, well sorted sandstones, becomming medium to rarely coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones. Fossiliferous float present.

Facies A. Red/mauve, thinly bedded, micaceous siltstones. intercalated with very fine grained sandstones towards the top of the sequence.

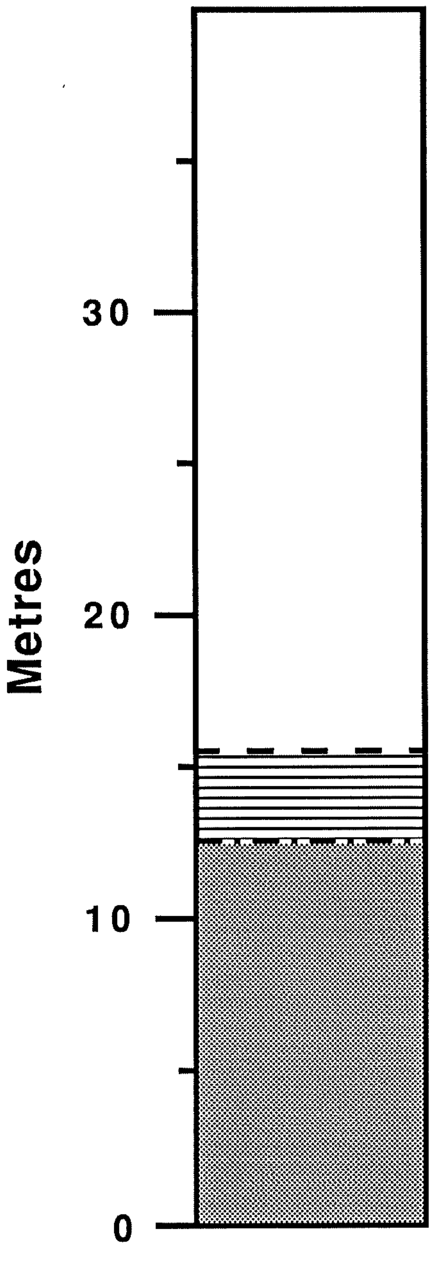
Lower Rawnsley Quartzite. White, fine grained, sub angular to sub round, friable sandstones interbedded with white, fine to medium, rarely coarse grained, cross bedded sandstones. Dish structures and sand volcanoes common in some beds.

Stratigraphic Column 9



Lower Rawnsley Quartzite. White, fine to medium grained sandstones, graded beds often present. Beds thick to thin, occasionally ripple topped, commonly disrupted.

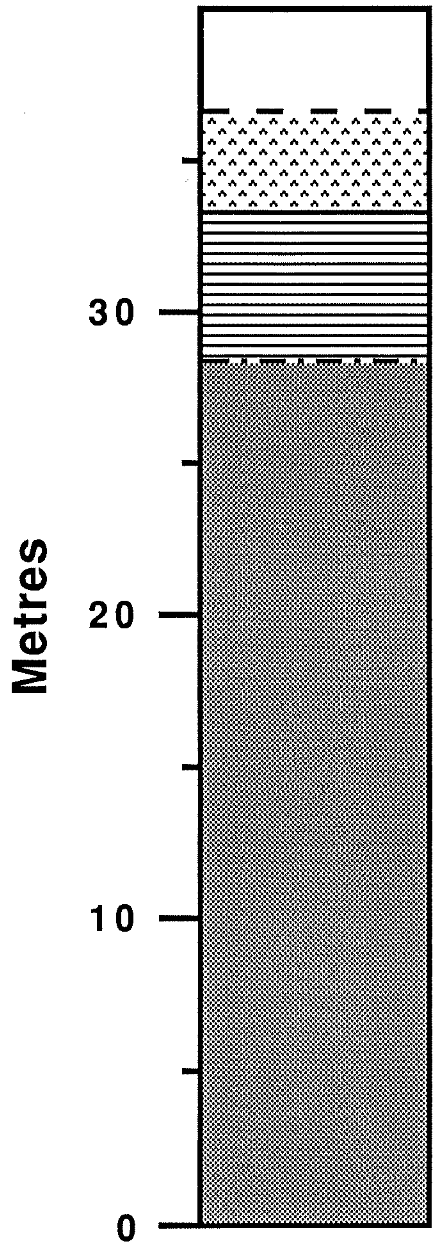
Stratigraphic Column 10



Facies A. Red/mauve,thinly bedded, micaceous siltstones.

Lower Rawnsley Quartzite. White, fine to medium grained sandstones, graded beds often present. Beds thick to thin, occasionally ripple topped, commonly disrupted. Interbedded with white, fine to medium grained sandstones with well rounded quartz grains. Beds flat laminated and commonly ripple topped (ripples orientated 114 degrees).

Stratigraphic Column 11

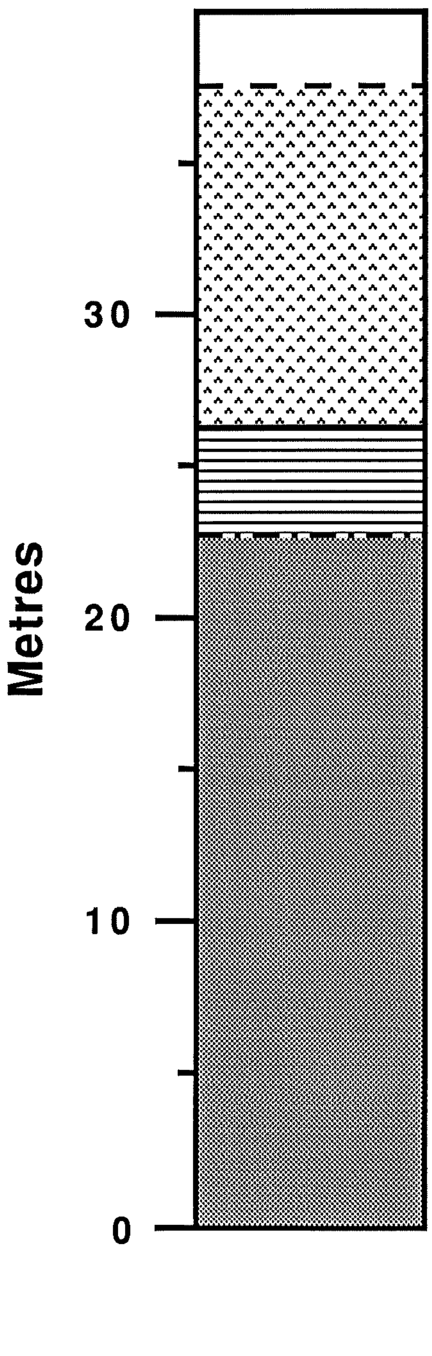


Facies B. White fine grained, well sorted sandstones; becoming medium to coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones.

Facies A. Red/mauve, thinly bedded, micaceous siltstones. Rarely intercalated with very fine grained sandstones. Grades upward into buff, olive, very fine to fine grained sandstones.

Lower Rawnsley Quartzite. White, fine to medium grained sandstones, graded beds often present. Beds thick to thin, occasionally ripple topped, commonly disrupted. Interbedded with white, fine to medium grained sandstones with well rounded quartz grains. Beds flat laminated and commonly ripple topped (ripples orientated 121 degrees).

Stratigraphic Column 12

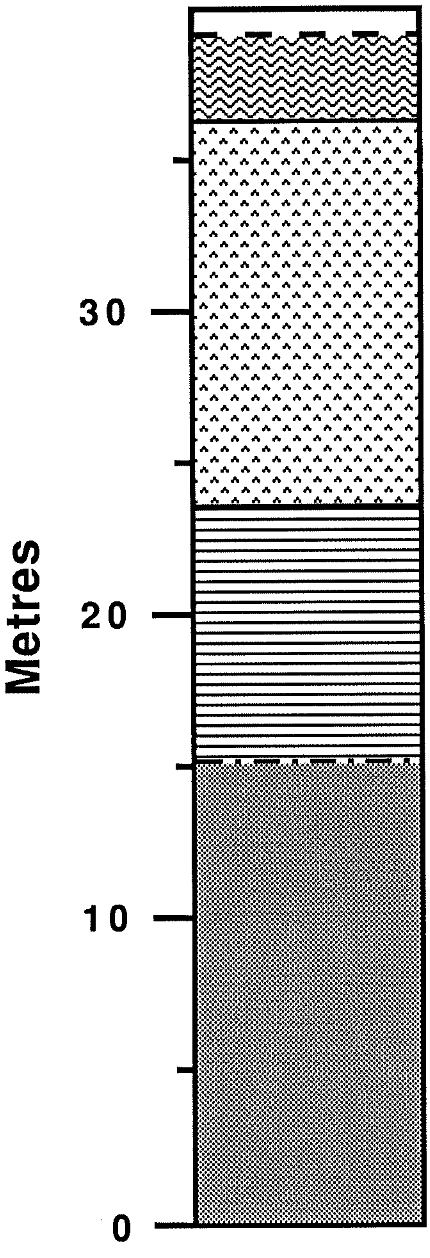


Facies B. White fine grained, well sorted sandstones, becoming medium to coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones.

Facies A. Red/mauve, thinly bedded, micaceous siltstones. Rarely intercalated with very fine grained sandstones. Grades upward into buff, olive, very fine to fine sandstones.

Lower Rawnsley Quartzite. White, fine to medium grained sandstones, graded beds often present. Beds thick to thin, occasionally ripple topped, commonly disrupted. Interbedded with white, fine to medium grained sandstones with well rounded quartz grains. Beds flat laminated and commonly ripple topped (ripples orientated 121 degrees).

Stratigraphic Column 13



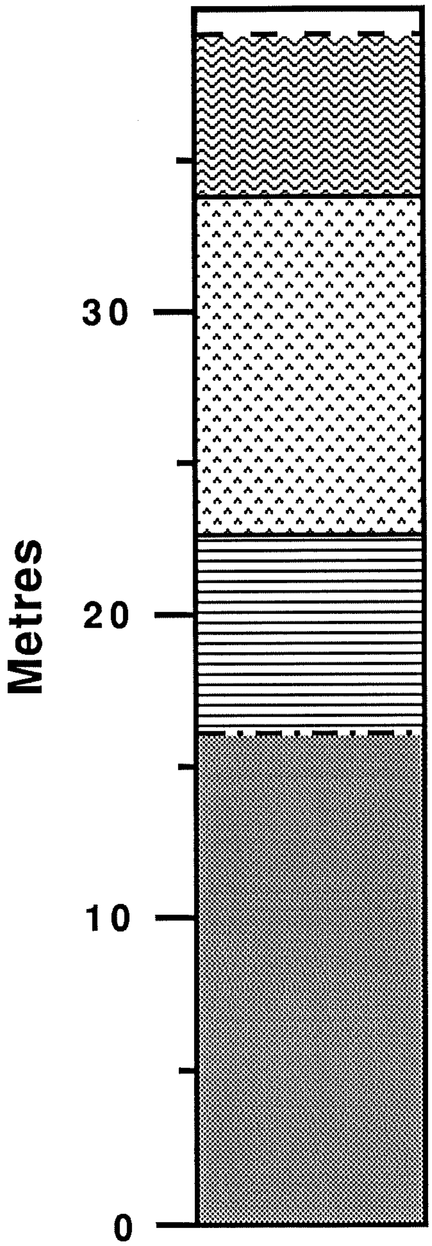
Facies C. White, weathering red, wavy bedded, fine to medium grained sandstones. Beds commonly graded, top surface commonly rippled, bottom surface smooth to undulatory, commonly to abundantly fossiliferous. Intercalated with thin, red siltstones. *Dickinsonia* rich bed south of section ('*Dickinsonia* bed').

Facies B. White fine grained, well sorted sandstones, becoming medium to coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones. Fossiliferous float present.

Facies A. Red/mauve, thinly bedded, micaceous siltstones, intercalated with very fine grained sandstones. Channel deepens to the east.

Lower Rawnsley Quartzite. White, fine to medium grained sandstones, graded beds often present. Beds thick to thin, occasionally ripple topped, commonly disrupted. Interbedded with white, fine to medium grained sandstones with well rounded quartz grains. Beds flat laminated and commonly ripple topped (ripples orientated 110-121 degrees).

Stratigraphic Column 14



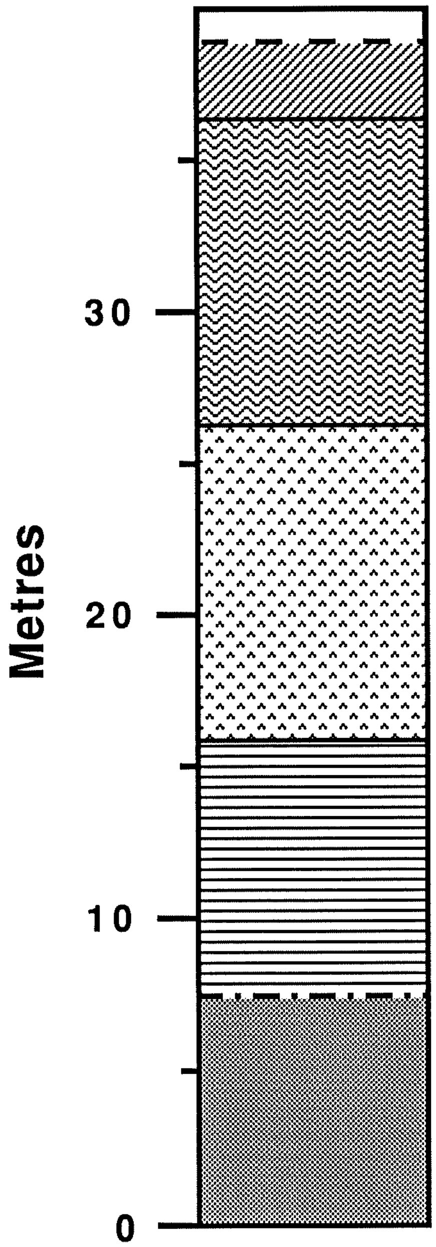
Facies C. White, weathering red, wavy bedded, fine to medium grained sandstones. Beds commonly graded, top surface commonly rippled, bottom surface smooth to undulatory, commonly to abundantly fossiliferous. Intercalated with thin, red siltstones. *Dickinsonia* rich bed south of section ('*Dickinsonia* bed').

Facies B. White fine grained, well sorted sandstones, becoming medium to coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones. Fossiliferous float present.

Facies A. Red/mauve, thinly bedded, micaceous siltstones. Rarely intercalated with very fine grained sandstones. Grades upward into buff, olive, very fine to fine sandstones.

Lower Rawnsley Quartzite. White, fine to medium grained sandstones, graded beds often present. Beds thick to thin, occasionally ripple topped, commonly disrupted. Interbedded with white, fine to medium grained sandstones with well rounded quartz grains. Beds flat laminated and commonly ripple topped (ripples orientated 110-121 degrees).

Stratigraphic Column 15



Facies D. White, medium to coarse grained, feldspathic sandstones. Low angle to trough cross bedding common. Siltstones reduced to thin silty drapes.

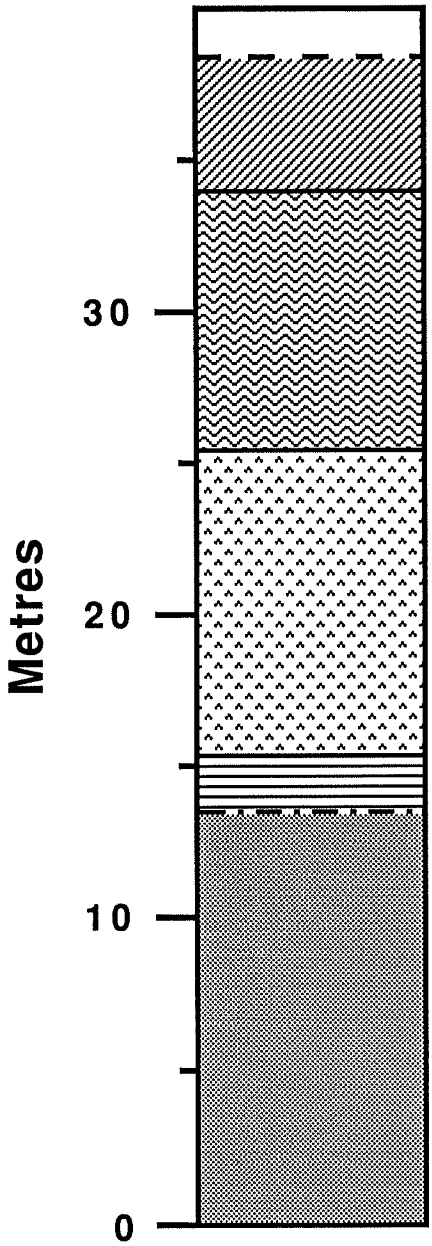
Facies C. White, weathering red, wavy bedded, fine to medium grained sandstones. Beds commonly graded, top surface commonly rippled, bottom surface smooth to undulatory, commonly to abundantly fossiliferous. Intercalated with thin, red siltstones.

Facies B. White fine grained, well sorted sandstones, becoming medium to coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones. Fossiliferous float present.

Facies A. Red/mauve, thinly bedded, claystones, grading upward into red, micaceous siltstones. Towards the top of of the channel sequence, red, micaceous, coarse siltstones intercalate with very fine grained sandstones.

Lower Rawnsley Quartzite. White, fine to medium grained sandstones, graded beds often present. Beds thick to thin, occasionally ripple topped, commonly disrupted.

Stratigraphic Column 16



Facies D. White, medium to coarse grained, feldspathic sandstones. Low angle to trough cross bedding common. Silty drapes present.

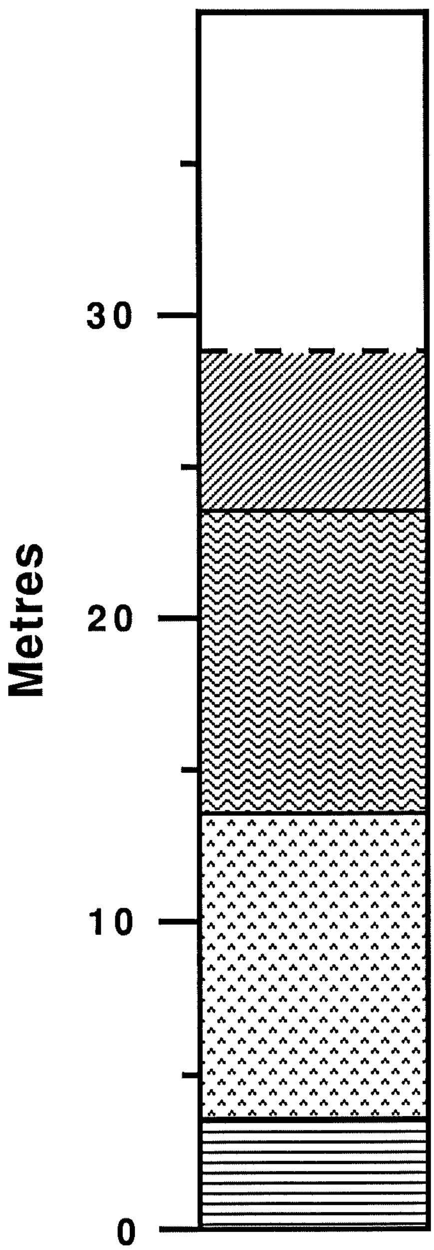
Facies C. White, weathering red, wavy bedded, fine to medium grained sandstones. Beds commonly graded, top surface commonly rippled, bottom surface smooth to undulatory, becoming uncommonly fossiliferous. Intercalated with thin, red siltstones.

Facies B. White fine grained, well sorted sandstones, becoming medium to coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones. Rare Fossiliferous float present.

Facies A. Red/mauve, thinly bedded, micaceous siltstones. intercalated with very fine grained sandstones.

Lower Rawnsley Quartzite. White, fine to medium grained sandstones, graded beds often present. Beds thick to thin, occasionally ripple topped, commonly disrupted.

Stratigraphic Column 17



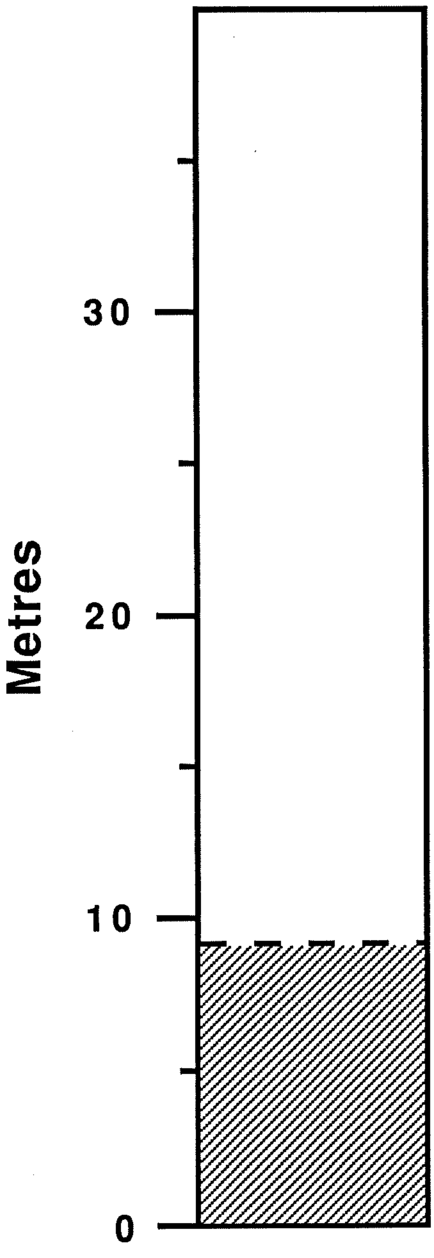
Facies D. White, medium to coarse grained, feldspathic sandstones. Low angle to trough cross bedding common. Siltstones reduced to thin silty drapes.

Facies C. White, weathering red, wavy bedded, fine to medium grained sandstones. Beds commonly graded, top surface commonly rippled, bottom surface smooth to undulatory, commonly to abundantly fossiliferous. Intercalated with thin, red siltstones.

Facies B. White fine grained, well sorted sandstones, becoming medium to coarse grained toward the top of the unit. Intercalated with red/mauve, micaceous siltstones. Fossiliferous float present.

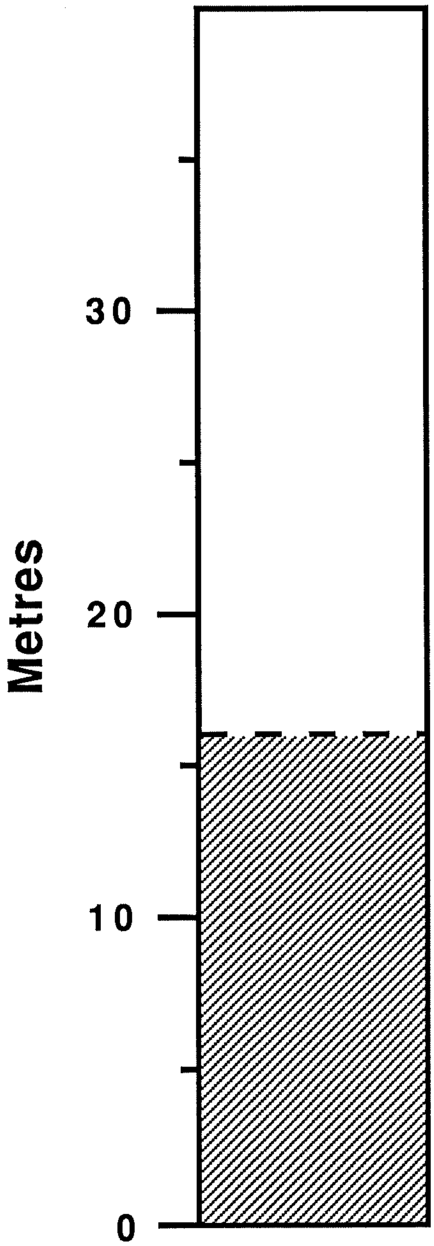
Facies A. Red/mauve, thinly bedded, micaceous siltstones. Rarely intercalated with very fine grained sandstones.

Stratigraphic Column 18



Facies D. White, medium to coarse grained, feldspathic sandstones. Low angle to trough cross bedding common. Siltstones reduced to thin silty drapes.

Stratigraphic Column 19



Facies D. White, medium to coarse grained, feldspathic sandstones. Low angle to trough cross bedding common. Siltstones reduced to thin silty drapes.

APPENDIX 2

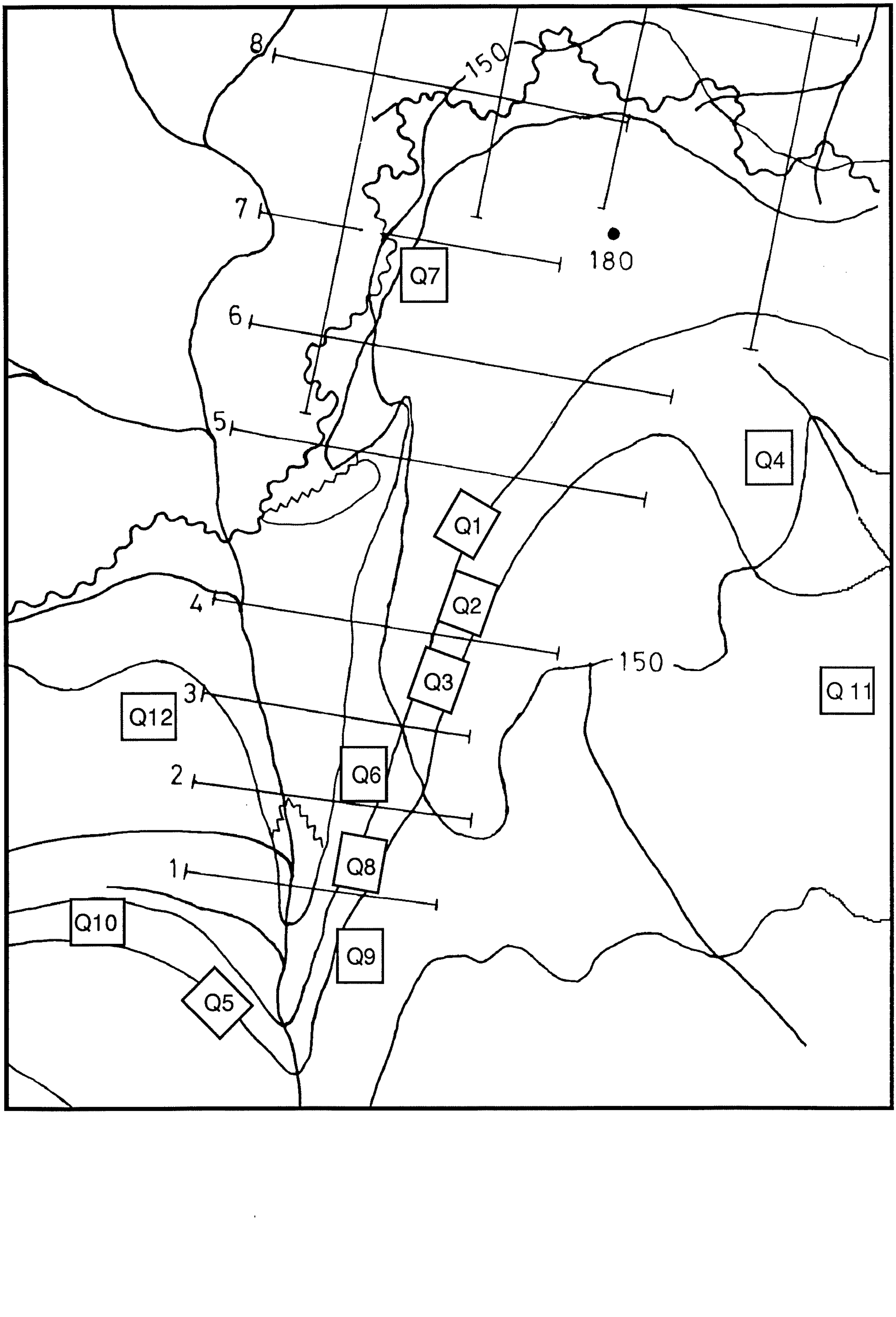
Analysis of the individual abundance of fossil forms from the Ediacara Member at Nilpena Hills.

50mx50m quadrats were selected on a random basis and abundance of forms counted within the quadrats.

Virtually all individuals originated from Facies C except where noted.

Quadrats within and below Facies C were generally rich in fossils, quadrats above Facies C were generally poor in fossil numbers e.g. quadrat 11 and quadrat 5 (straddling Facies D-Facies C contact).

APPENDIX 2 DIAGRAM 1 Location map for quadrats sampled at Nilpena Hills. See Map 1 for legend



Name	Q 1	Q 2	Q 3	Q 4	Q 5	Q6	Total
Cyclomedusa sp.	15	21	23	1	2	17	81
Conomedusites lobatus.	2	1	-	-	-	1	3
Medusina filamentis	2	1	1	-	-	-	4
Ediacara sp.	1	-	1	-	-	-	2
medusoids	3	7	6	-	1	1	18
stem impressions	4	4	3	-	-	2	13
Tribrachidium heraldicum	-	-	-	-	-	1	1
Dickinsonia costata	5	9	10	15	4	6	47
Dickinsonia lissa	-	1	2	2	-	2	5
Spriggina floundersi.	-	-	1	-	-	1	2
Parvancorina minchami	2	1	2	1	1	2	9
Rugoconites enigmaticus	1	-	1	-	-	1	3
Trace Fossils							
Intrites	12	30	26	-	-	12	80
Condrites	2	2	1	-	-	1	6
Arthropod scratch marks	1	1	3	1	-	3	9
Form B	11	25	24	10	-	21	91
Form D	2	7	8	7	-	8	32
Total	63	110	112	37	8	80	

Table 1 Analysis of individual abundances from Quadrats 1 to 6 at Nilpena Hills. Note: Quadrat 4 samples 'Dickinsonia bed'

Name	Q 7	Q 8	Q 9	Q 10	Q 11	Q 12	Total
Cyclomedusa sp.	4	18	-	21	2	1	49
Conomedusites lobatus.	-	1	-	1	-	-	3
Medusina filamentis	-	-	-	1	-	-	4
Ediacara sp.	-	-	-	1	-	-	2
medusoids	-	1	-	3	-	-	16
stem impressions	-	1	-	2	2	-	11
Tribrachidium heraldicum	-	-	-	1	-	-	0
Dickinsonia costata	2	10	2	10	2	1	24
Dickinsonia lissa	1	3	-	2	-	-	3
Spriggina floundersi.	-	-	-	-	-	-	1
Parvancorina minchami	-	1	1	2	-	-	5
Rugoconites enigmaticus	-	-	-	1	-	-	2
Trace Fossils							
Intrites	2	20	-	23	-	-	68
Condrites	-	-	-	-	-	-	5
Arthropod scratch marks	-	2	1	3	-	-	5
Form B	8	21	8	14	-	2	60
Form D	1	8	1	7	-	-	17
Total	18	86	13	92	6	4	

Table 2 Analysis of individual abundances from 50mx50m quadrats, Ediacara member, Nilpina Hills. Note: quadrat 11 samples Facies D, quadrat 12 samples Facies B

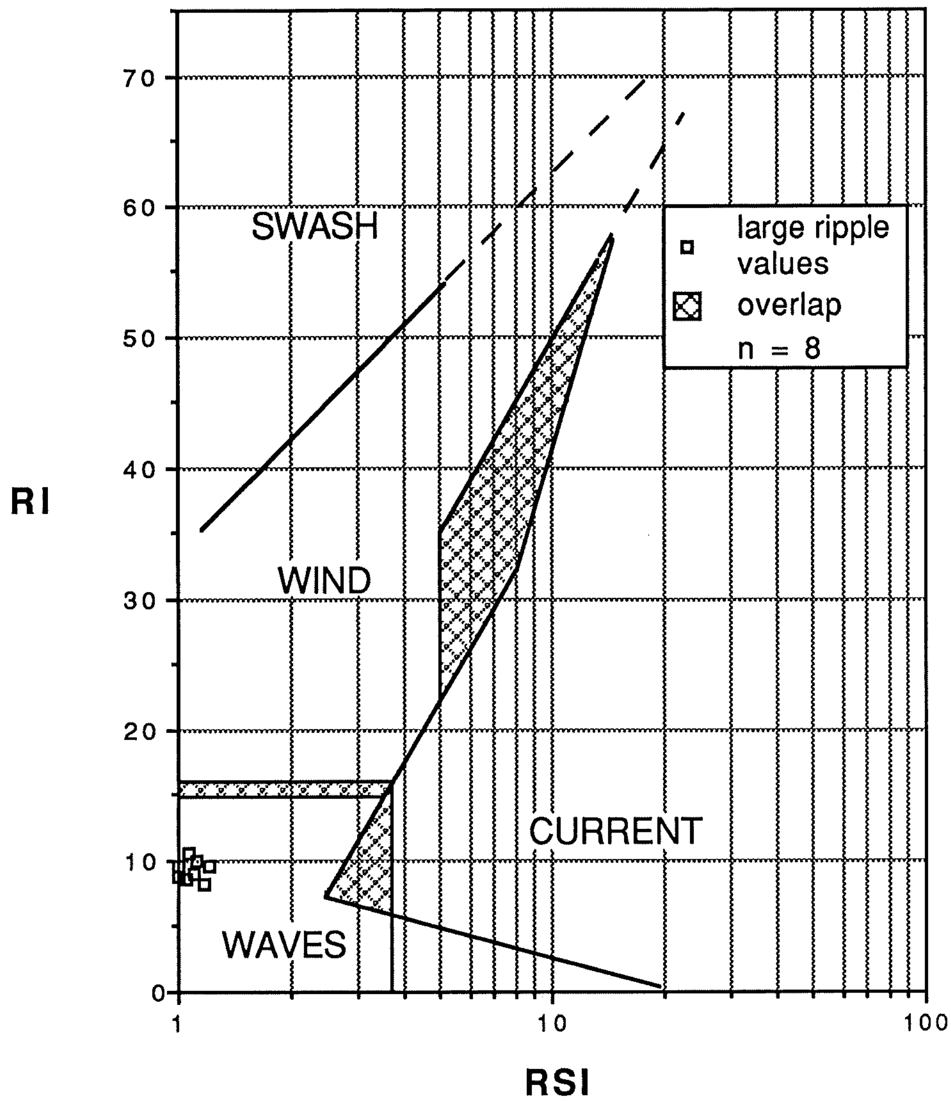
APPENDIX 3

Using the dimentionless parameters listed below, on plots constructed after Tanner (1967), ripples can be analysed in order to ascertain the environment in which they formed. Ripples formed by the action of wind, current, waves and swash can be recognised depending on where they plot using various index combinations. Various indices were measured on a slab collected from the Ediacara Member, Facies C, sample A-932-101 (Plate 2c).

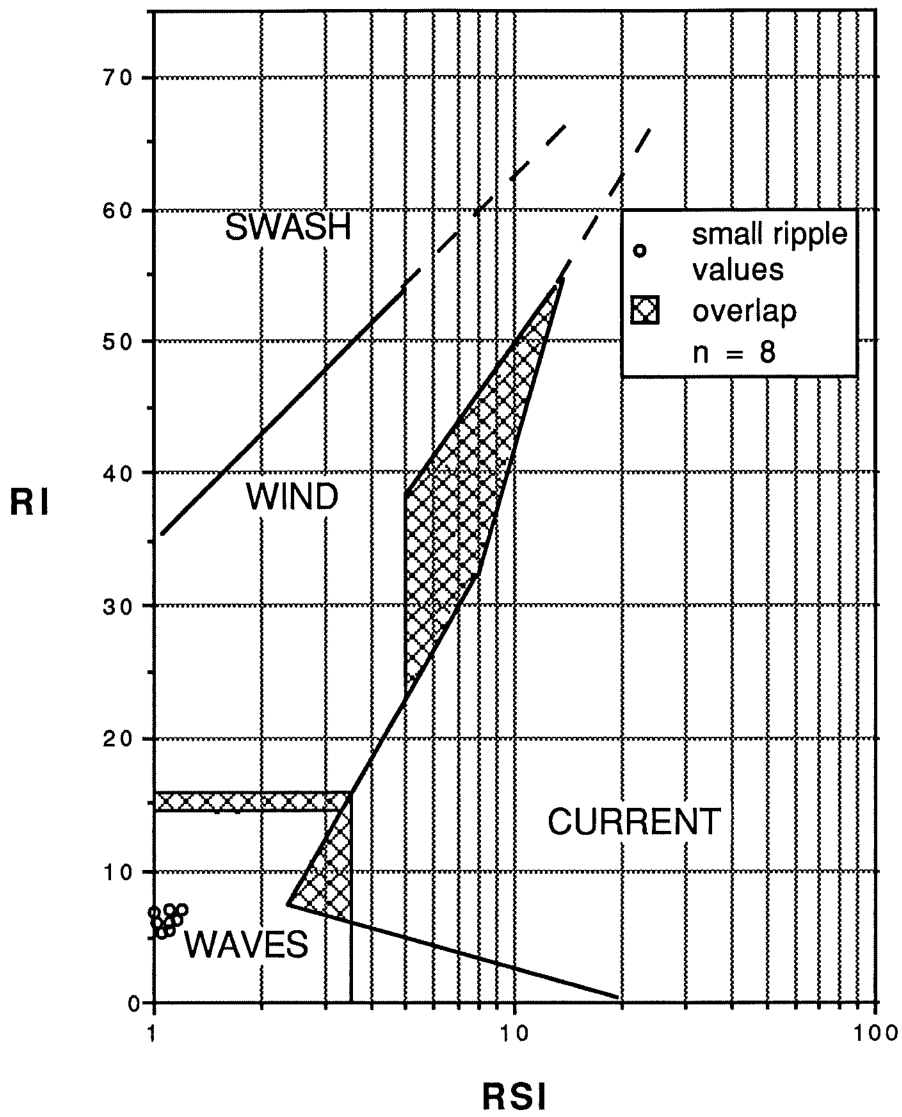
RIPPLE INDEX (RI)	Wave length divided by the height.
RIPPLE SYMMETRY INDEX (RSI)	Horizontal distance between crest and trough on both sides of ripple (larger value divided by smaller value).
STRAIGHTNESS INDEX (SI)	Distance, parallel with crest, along which curvature can be seen, divided by the maximum departure of the crest from a straight line.
PARALLELISM INDEX No.1 (PI1)	Distance, parallel with crest, along which curvature can be seen, divided by (mean spacing between crests multiplied by maximum crest spacing divided by minimum crest spacing).

Large RI	Large SI	Large RSI	Small RI	Small PI1	Small SI	Small RSI
9	1.1	5.8	5.6	1.1	8.5	1.1
9.5	1.1	6	7	1.1	14.4	1.5
8.8	1	4.9	6.8	1	12	1
10.1	1.1	5.3	6.1	1.1	10.8	0.9
9.5	1	5.7	6.9	1.2	11	0.9
9.5	1.2	5.3	6.6	1.2	9.8	1.1
9.8	1	5.4	5.9	1.1	9	1
9.2	1.1	5.8	6.2	1.1	9.9	1.3

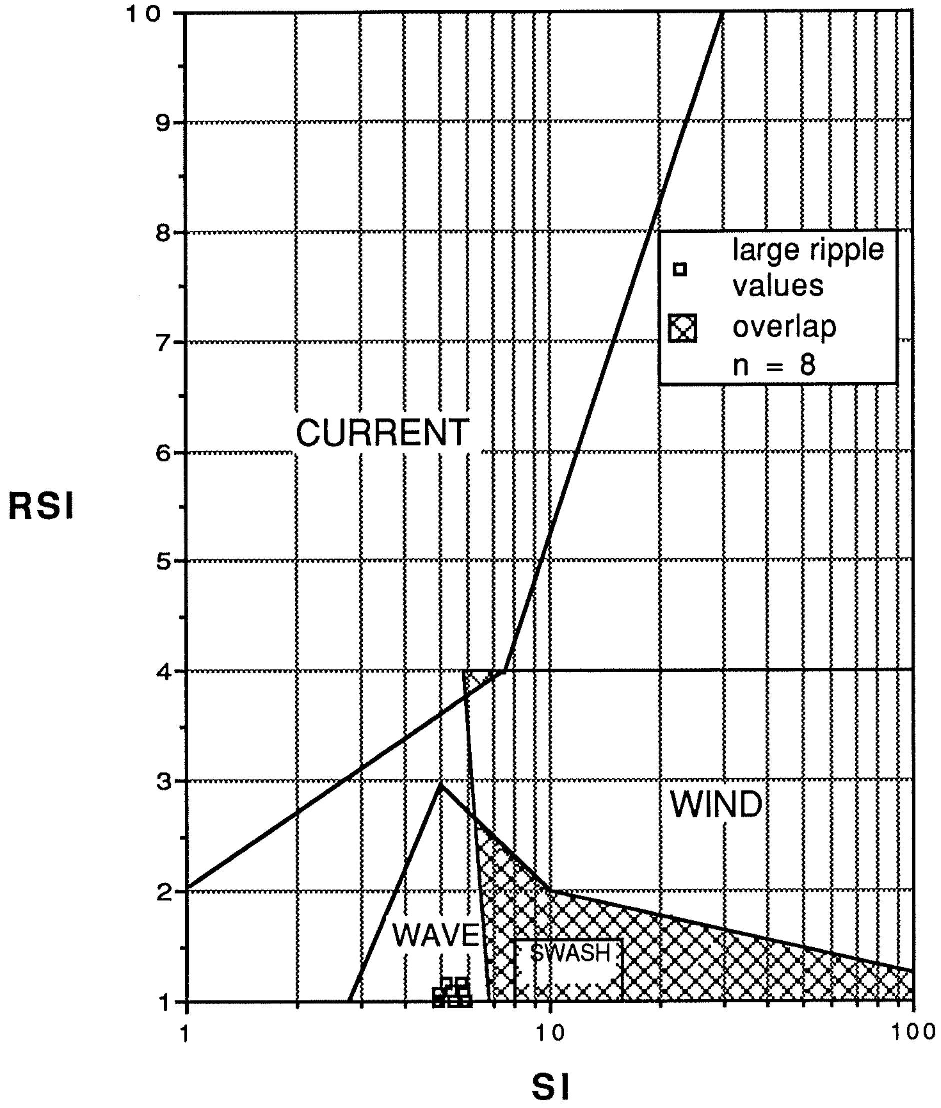
Table 1 Results obtained for various ripple indices measured from sample A-932-101 and plotted on Graphes 1-5.



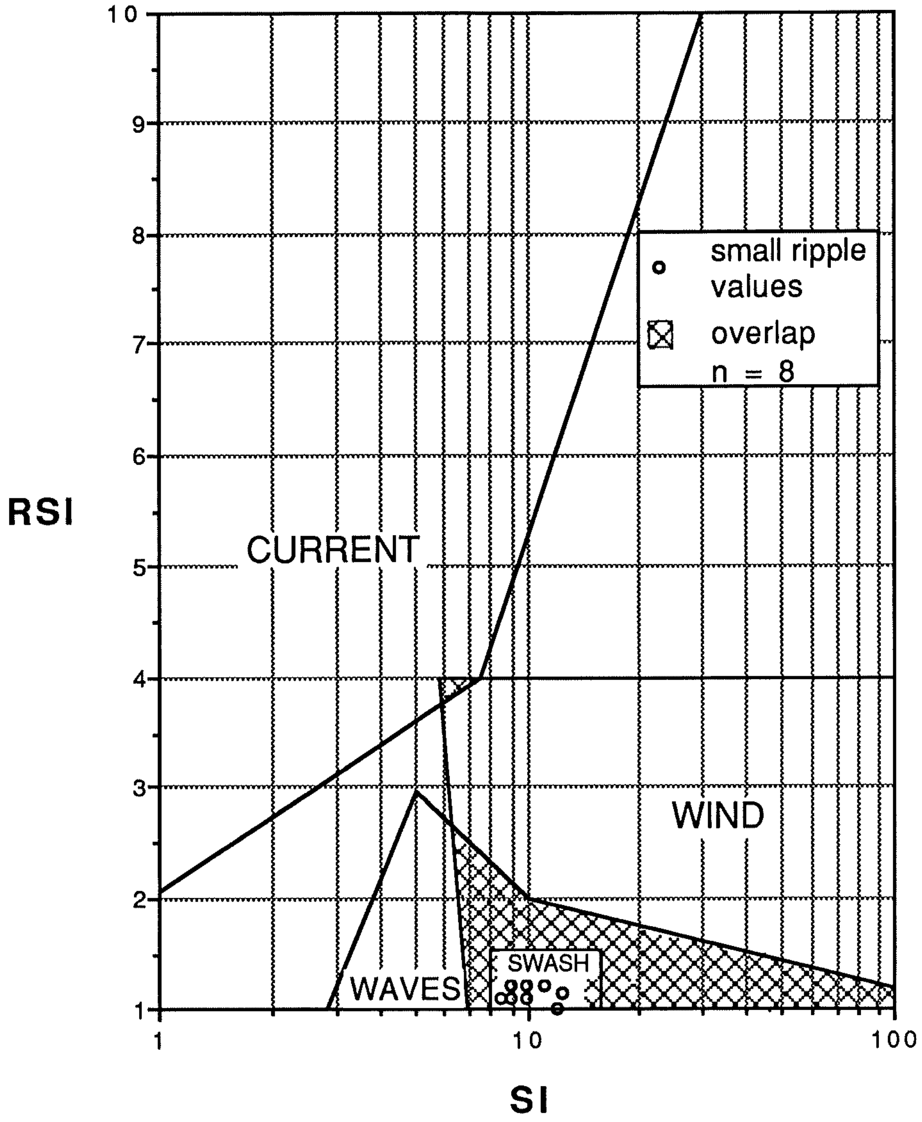
Graph 1 Ripple Index (RI) against Ripple Symmetry Index (RSI) for large ripples on sample A-932-101.



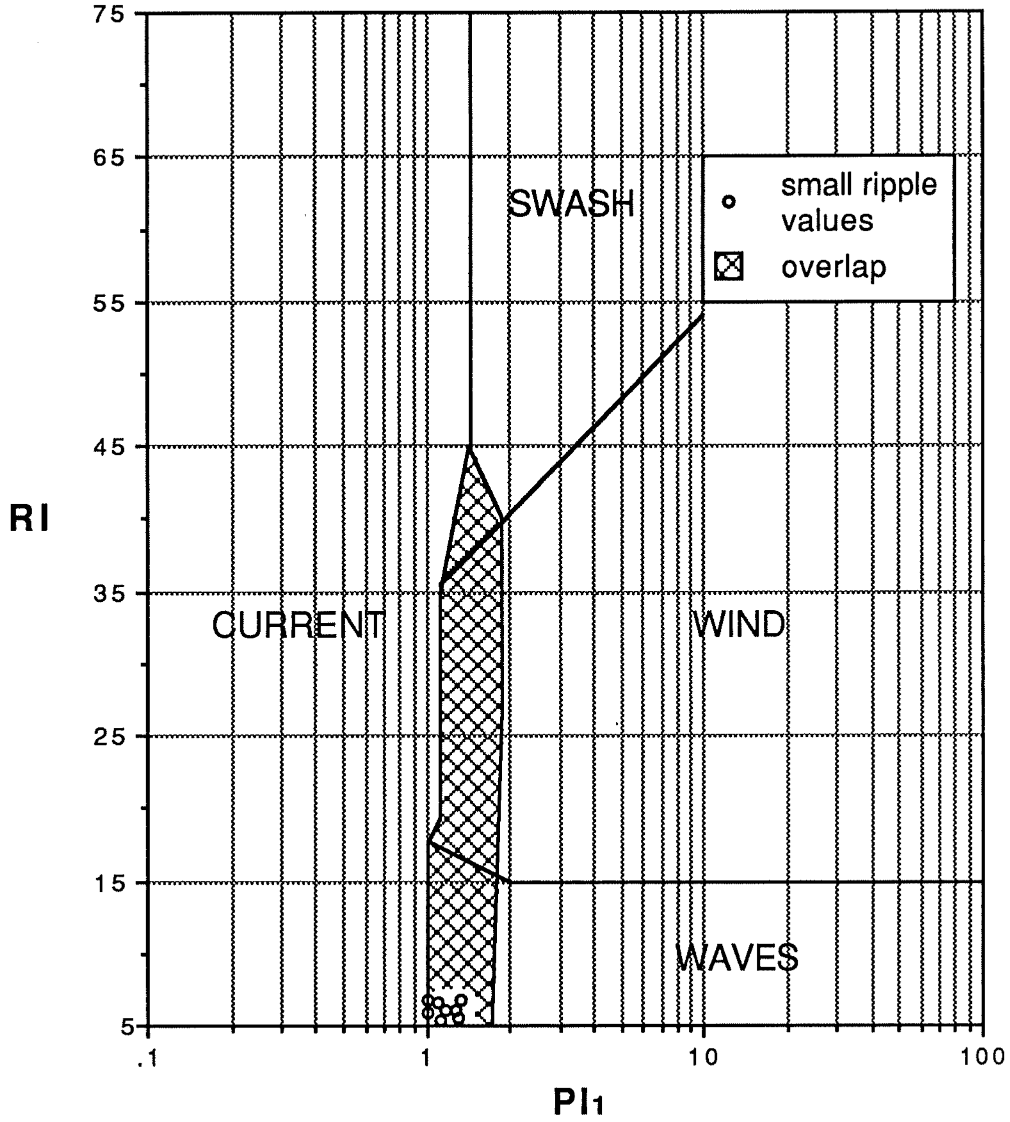
Graph 2 Ripple Index (RI) against Ripple Symmetry Index (RSI) for small ripples on sample A-932-101.



Graph 3 Ripple Symmetry Index (RSI) against Straightness Index (SI) for large ripples from sample A-932-101.



Graph 4 Ripple Symmetry Index (RSI) against Straightness Index (SI) for small ripples from sample A-932-101.



Graph 5 Ripple Index (RI) against Parallelism Index No.1 (PI1) for small ripples on sample A-932-101.

APPENDIX 4

SYSTEMATIC PALAEONTOLOGY

PHYLUM: Annelida
CLASS: Polychaeta
ORDER Uncertain
FAMILY: Sprigginidae

Spriggina floundersi Glaessner
(Plate 3f)

Diagnosis

Prostomium horeshoe-shaped, strongly sclerotized, with a sharp medio-posterior semicircular impression on its margin; no external segmentation; body flexable, up to approximately 42 segments; neuropodia with either acicular setae or resilient, blade-like elements; sagittal groove separates a double series of medio-dorsal paired convexities.

PHYLUM: Annelida
CLASS: Polychaeta
ORDER Uncertain
FAMILY: Dickinsoniidae

Dickinsonia costata Sprigg
Dickinsonia lissa Wade
(Plate 2d; 3d, 3e)
(Plate 3c)

Diagnosis

Broad, flat with numerous segments; anterior body segments fused pre-orally along the median line; segment furrows depressed dorsally and ventrally; notopodial-elytral ridges well developed; filled intestine, or intestinal caeca rarely preserved.

PHYLUM Arthropoda (?)
CLASS Branchiopoda (?)
ORDER Uncertain (?)
FAMILY Parvancorinidae

Parvancorina minchami Glaessner
(Plate 5h)

Diagnosis

Shieldlike carapace elongate, with faint marginal raised rim and distinctly elevated, smooth dorsal ridges, about five pairs of anterior appendages, about twenty filiform, undiferentiated posterior appendages. Although this genus has been placed within the Arthropoda, its classification remains equivocal as no specimen has been found with antenna.

PHYLUM: Cnidaria
CLASS: Conulata
ORDER: Conulariida
FAMILY: Conchopeltidae

Conomedusites lobatus Glaessner & Wade
(Plate 5a,b)

Diagnosis

Theca forming low cone, divided by four deep radial grooves; further lobes may be intercalated peripherally, between the main lobes; fringe of thick tenticles may be preserved around peripheral margin.

PHYLUM: Cnidaria
CLASS: Anthozoa
ORDER: Pennatulacea
FAMILY: Charniidae

Gen. et sp. indet.
(Plate 3g, 3h)

Diagnosis

Fragment of leaf-like frond, rhachis apparently narrow. Individual branches inflated, prominent grooves between primary branches, particularly deep near rhachis, individual branches apparently sinuous, secondary grooves visible on some branches (Fused polyp anthosteles?). Unusual preservation in 3 dimentions, within Facies E sandstone. The specimen possibly represents a new species, however, insufficient material is available to make this unequivocal.

PHYLUM: Cnidaria
CLASS: Anthozoa
ORDER: Rangeomorpha
FAMILY: Rangeidae

Rangea schneiderhoehni Gürich
(Plate 5e, f)

Diagnosis

Composed of several, serially repeated, foliate elements, elements fusiform and tapering, divided into small, chevron-shaped secondary branches, also very fine third order division present in well preserved specimens.

ICHNOFOSSILS

Diplocraterion parallelum Torell
(Plate 3b)

Diagnosis

U-shaped burrow with spreiten, always perpendicular to bedding, tubes end in large funnels often not preserved, arms of burrow parallel, spreiten can be protrusive, retrusive or retrusive-protrusive.

Form B Glaessner

Diagnosis

Concave exogene semireliefs or epichnial grooves, invariably sinuous, occasionally branching, both sides distinctly raised as levees. Generally 3 to 4 millimetres wide.

Form D Gleassner
(Plate 5h)

Diagnosis

Large, slightly to markedly sinusoidal trails, up to several centimeters wide, occur either as hypichnial casts or in full relief, some show wrinkling.

Chondrites Type C(?) Sternberg
(Plate 5g)

Diagnosis

Small, thin (less than 2 mm) wide, branching burrows, radiate out from central, main burrow, preserved on sole of bed.

Intrites punctataus(?) Fedonkin
(Plate 5a)

Diagnosis

Small (< 1cm) rounded forms, with central depression, may exhibit ribbing, can occur in abundance on bedding surfaces.

INFORMAL GROUPS

Medusina filamentis Sprigg
(Plate 5c, d)

Diagnisis

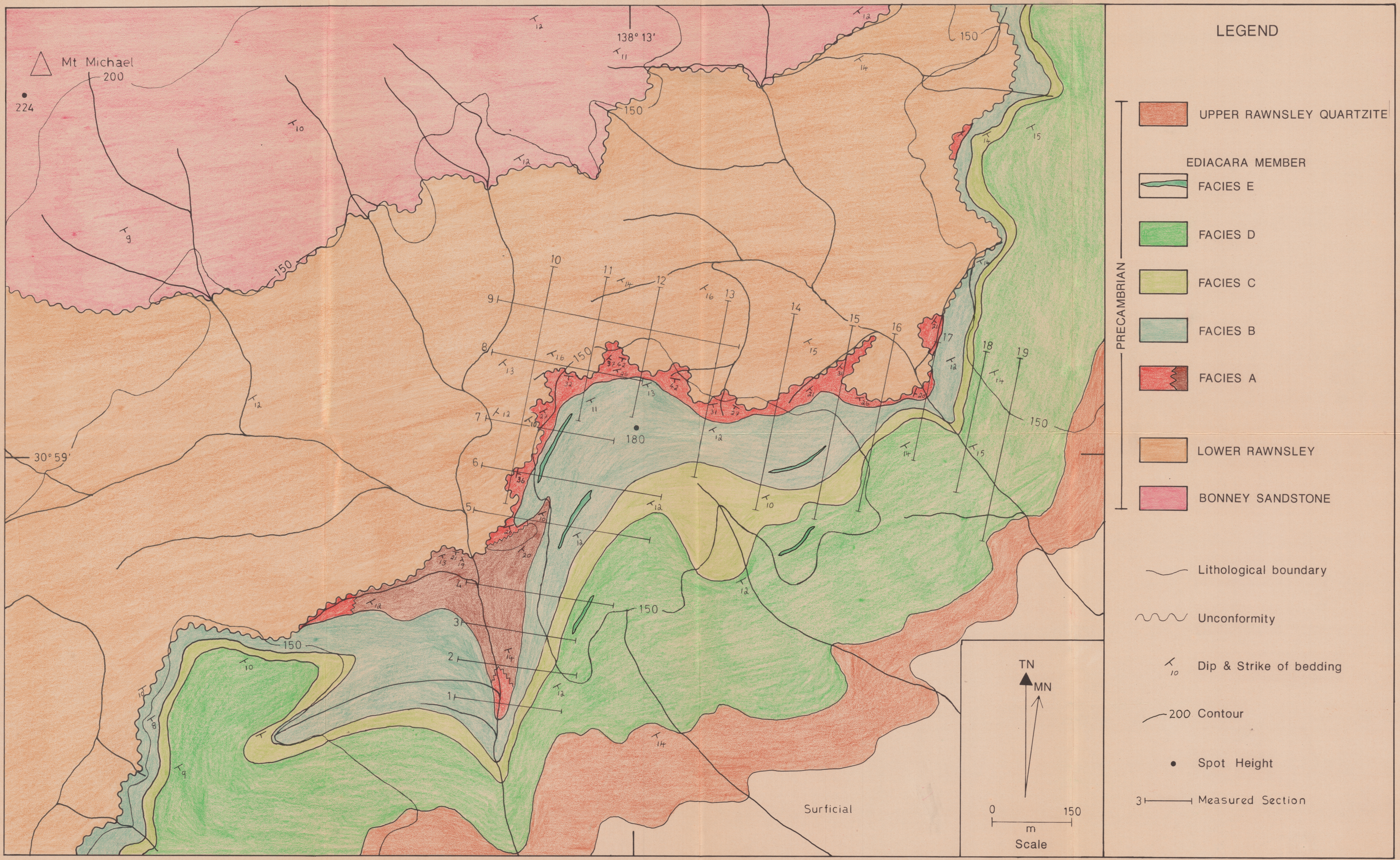
Oval; furrows radiating outward from well difined, disrupted central region; periferal margin may be present; central region passes upward through the sand bed, with expression on the overlying bedding plane.

Cyclomedusa Sprigg
(Plate 4a-e)

Diagnosis

Outline subcircular; surface of disc with several slightly elevated areas; many specimens show fine, straight, radial grooves.

MAP 1 GEOLOGICAL MAP OF THE EDIACARA MEMBER AT NILPENA HILLS



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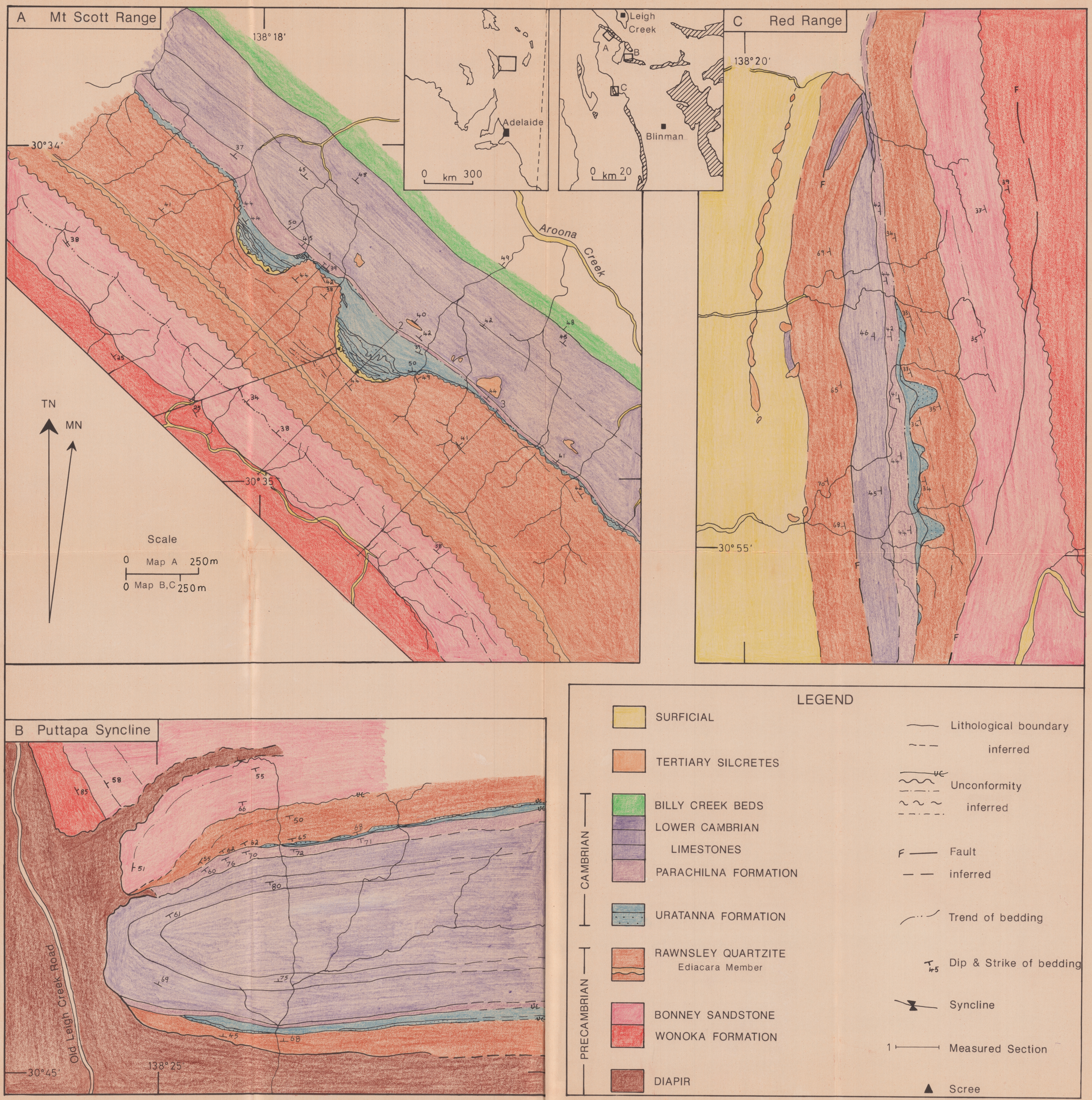
MAP 2



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