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**Palaeoichnology of the terminal Proterozoic-Early  
Cambrian transition in central Australia:  
interregional correlation and palaeoecology**

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*reniforme* (after Hofmann, 1979); E. *P. curvipalmatus* (after Pollard, 1981); F. *P. auduni* (after Dam, 1990); G. *P. bromleyi* (after Dam, 1990); H. *P. ungulata* (after Fillion and Pickerill, 1990); I. *P. wabanensis* (after Fillion and Pickerill, 1990); J. *P. tempulus* (after Han and Pickerill, 1994); K. *P. coronatum* (after Crimes and Anderson, 1985).

**Figure 7.36** - Specimens of *Phycodes* from central Australia: A. *P. curvipalmatus*; B. *P. coronatum*; C. *P. palmatus*; D. Schematic reconstruction of *P. palmatus*. All specimens are preserved as convex hyporeliefs.

**Figure 7.37** - Preservational modes of *Plagiogmus arcuatus*: A. Basal ladder-like burrow; B. Middle backfilled part overlying the basal ladder-like burrow; C. Bilobate upper part lying on both the middle back-filled and basal ladder-like parts. All forms display the distinctive ladder-like transverse ridges on their basal part.

**Figure 7.38** - *Plagiogmus arcuatus*, showing morphological elements of the basal ladder-like structure.

**Figure 7.39** - Diagram showing the spacing between successive transverse ridges and their distance from an arbitrary datum point. The rhythmic variation probably is due to the peristaltic movement of the trace maker (Data from specimen illustrated in the Plate 18C).

**Figure 7.40** - Cross sections through *Plagiogmus arcuatus*: A. A longitudinal cross section through middle part of the burrow displays glauconite grains aligned along oblique laminae. The burrow has been penetrated by several vertical burrows; B. A transverse section. The upper bilobate part is deflected sediment laminae cut through by an organ of the producer. Note the marginal rim along the middle part is thicker on both sides likely due to subsequent compaction.

**Figure 7.41** - A three dimensional reconstruction of *Plagiogmus arcuatus* showing different morphological elements.

**Figure 7.42** - Reconstruction of the producer of *Plagiogmus* based on criteria gained from its burrow system.

**Figure 7.43** - *Halkieriid* body fossil: A. A specimen reported from the Early Cambrian of North Greenland (Conway Morris and Peel, 1990) showing a soft bodied animal covered by tiny sclerites. There are two large shells on either ends of the animal

which the posterior one possesses a sharp apex; **B.** The reconstruction of the of *Halkieriid* animal given by Conway Morris and Peel, 1995) resembles the producer of the *Plagiognus*.

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**Figure 7.46** - *Olivellites plummeri*: **A.** Lectotype chosen by Yochelson and Schindel (1978, after Plaziat and Mahmoudi, 1988); **B.** Three dimensional reconstruction of the burrow.

**Figure 7.47** - A block diagram illustrating the ichnogenus *Aulichnites*, characterised by a bilobate burrow preserved as an epirelief comprising lateral grooves and a lower unilobate part.

**Figure 7.48** - block diagrams showing the ichnogenus *Psammichnites*: **A.** Lower view of the burrow and its epichnial mould; **B.** Upper view of the burrow and its hypichnial mould.

**Figure 7.49** - Comparison between ichnogenera *Cylindrichnus* and *Rosselia*; **A.** In *Rosselia* laminae of sediment are V-shaped convex down and terminate at the median shaft of the burrow; **B.** *Cylindrichnus* displays sediment laminae which are concentric and parallel to the median shaft; **C.** An inclined transverse section through *Cylindrichnus* may produce a form similar to the ichnogenus *Rosselia*. However, the median shaft in this instance does not extend through the laminae.

**Figure 7.50** - Ichnospecies of *Rosselia*: **A.** *R. rotatus* vertical and horizontal cross section (after McCarthy, 1979); **B.** *R. socialis*, a reconstruction of the terminal bulbous structure (after Chamberlain, 1971); **C.** *R. chonooides* showing both vertical and horizontal cross section (after Howard and Frey, 1984).

**Figure 7.51** - **A.** *Rusophycus avalonensis* comprises two lobes covered with a set of 4-6 scratch marks. **B.** *R. bonnarensis* from central Australia is a moustache-like burrow

with longitudinal scratch marks. **C.** *R. bonnarensis* from the Uratanna Formation South Australia. Though the trace is moustche-like in outline does not show the scratch marks. **D.** *?Rusophycus* isp. B from central Australia is a small, low relief burrow with fine scratch marks. The bilobation is not clear in some specimens.

**Figure 7.52** - Associations of *Rusophycus* and *Planolites* burrows may be an indication of hunting: **A.** The *R. bonnarensis* and *P. montanus* in a close relationship. *R. bonnarensis* is indicated by the series of parallel scratch marks; **B.** Association of *Rusophycus* isp. A and numerous *Planolites* burrows. The *Rusophycus* burrow is disturbed indicating heightened activity of the producing animal probably due to its effort to catch an inhabitant of the *Planolites* burrows.

**Figure 7.53** - Ichnogenus *Saerichnites*: **A.** Reconstruction of burrow system by Tunis and Uchman (1996); **B.** The bedding plane view of the burrow comprises a double series of circular structures; **C.** *Saerichnites* isp. B from central Australia preserved in convex hyporelief; **D.** An alternative interpretation of the burrow suggests that it consists of a horizontal tunnel with paired vertical shafts which diverged from both sides of the tunnel; **E.** Bedding plane displays a series of double circular structures (scale bar = 1 cm).

**Figure 7.54** - Ichnospecies of *Skolithos*: **A.** *S. linearis*; **B.** *S. verticalis*; **C.** *S. magnus*; **D.** *S. ingens*; **E.** *S. annulatus*; **F.** *S. bulbosus* (A-F after Alpert, 1975); **G.** *S. gyratus* (after Hofmann, 1979); **H.** *S. ramosus* (after Walter and Elphinstone, 1989).

**Figure 7.55** - Transverse cross section through *Skolithos bulbosus* from the Donkey Creek Beds, Georgina Basin, shows a spherical structure at the middle of the burrow coated with clay. Note the subcircular structure on the top of the burrow not located centrally.

**Figure 7.56** - Ichnospecies of *Taenidium*: **A.** *T. serpentinum*; **B.** *T. cameronensis*; **C.** *T. satanassi* (after D'Alessandro and Bromley, 1987).

**Figure 7.57** - Three dimensional reconstruction of *Taphrhelminthoidea convoluta*. There is a transverse laminated part underneath the burrow. The median furrow is deep and extends through the overlying sediment laminae.

**Figure 7.58** - **A.** Reconstruction of *Teichichnus rectus* (after Hantzschel, 1975); **B.** *Teichichnus* isp. from central Australia.



**Figure 7.59** - Ichnospecies of *Treptichnus*: **A.** *T. bifurcatus* (after Archer and Maples 1984); **B.** *T. lublinensis* (after Paczesna, 1986); **C.** *T. triplex* (after Palij *et al.*, 1983); **D.** *T. pedum* (after Jensen, 1997).

**Figure 7.60** - Preservational variation of ichnogenus *Treptichnus*: **A.** Three dimensional reconstruction of the burrow system; **B.** bedding plane view of the burrow resembles *Saerichnites*; **C.** Common preservation of the burrow displays a bifurcating burrow system; **D.** This preservation resembles *Plangtichnus* (after Archer and Maples, 1984 and Maples and Archer, 1987).

**Figure 7.61** - Three dimensional reconstruction of *Belorhaphé zikzak* (after Seilacher, 1977) resembles *Treptichnus*. However, the former displays a meandering, zigzag burrow with vertical shafts alternating to the left and right.

**Figure 7.62**- The ichnogenus *Intexalvichnus* comprises a horizontal tunnel and funnel-shaped vertical shafts closely and alternatively located to the left and right. The burrow resembles *Treptichnus* in its general morphology (after Hantzschel, 1975).

**Figure 7.63** - Variable morphology of *Treptichnus pedum*: **A.** A curved burrow with dense branching pattern; **B.** A curved burrow with closely spaced branches; **C.** A straight to gently curved burrow in which some segments display delicate striations. All specimens are preserved as convex hyporeliefs (scale bar = 1 cm).

**Figure 7.64** - Ichnogenus *Trichophycus* is a branched burrow system in which branching starts from the distal part of the burrow and advances toward the proximal part. The limited number of branches diverge from top of the burrow and not from side or beneath the burrow as occurs in *Treptichnus pedum*.

**Figure 7.65** - Preservational variations of ichnogenus *Treptichnus pedum*: **A.** Three dimensional reconstruction of the burrow; **B.** Bedding plane view consists of a series of circular structures aligned in a straight to curved line resembling *Hormosiroidea*; **C.** Common preservation of the ichnogenus; **D.** A section through lower part of the burrow may show a series of parallel elongated elliptical structures resembling the "feather stitch" burrows of Wilson (1948). Drawn after Geyer and Uchman (1995).

**Figure 7.66** - The production of *Treptichnus pedum* burrows. The producer first excavated horizontally then moved vertically to maintain its connection to the sea water (thick arrow) next it moved backward into the horizontal position and started to repeat the procedure for the next segment of the burrow (after Geyer and Uchman, 1995).

**Figure 7.67** - *Treptichnus ?triplex* preserved as a convex hyporelief. Some segments display trilobation due to two delicate furrows (scale bar = 1 cm).

**Figure 7.68** - *?Vendichnus* isp. preserved as epirelief. Three approximately ovate shaped, roughly bilobate structures are arranged in a line (scale bar = 1 cm).

**Figure 7.69** - **A.** Ichnofossil A, vertical, branched burrow in which the main shaft branches distally in acute angles to produce side branches (scale bar = 1 cm). **B.** The ichnogenus *Fascifodina* comprises a vertical shaft which branches distally to form short, vermiform branches (after Osgood, 1970).

**Figure 7.70** - Ichnofossil B, an ovate structure preserved as convex hyporelief and comprising a middle bilobate part surrounded by an imbricate margin (scale bar = 1 cm).

**Figure 7.71** - Ichnofossil C, a straight to sinuous burrow preserved as concave epirelief. Burrow consists of a wide middle furrow with elevated margins

**Figure 7.72** - Ichnofossil D, a series of arcuate to crescent-shaped grooves arranged in a curved to winding pattern. Some burrows show an en-echelon pattern of grooves (scale bar = 1 cm).

**Figure 7.73** - **A.** Ichnofossil E, vertical, bow-shaped burrows with branches developed on one limb. Branches are concave, blade-like in outline (scale bar = 1 cm). **B.** A schematic reconstruction of the burrow system.

# Abstract

The Precambrian-Cambrian time interval in central Australia is well represented by successions of siliciclastic sediments cropping out along the northern margin of the Amadeus Basin and southwestern part of the Georgina Basin. These strata were deposited in a shallow water environment as a part of large delta system. In the Amadeus Basin, these clastic successions occur between two carbonate intervals (Julie Formation below and Todd River Dolomite and its equivalent calcareous deposition above) and are known as Arumbera Sandstone (Wells *et al.*, 1967). In its lower part, this unit includes a few simple, horizontal trace fossils such as *Cochlichmus*, *Intrites*, *Palaeophycus*, and *Planolites* along with rare occurrences of Ediacaran body fossil remains. In contrast, the lithologically similar upper part, generally considered of Early Cambrian age, yields abundant occurrences of complex and diverse trace fossils.

A substantial collection of trace fossil in the Department of Geology and Geophysics collected from the above succession provided a unique opportunity to establish the bed by bed distribution of trace fossils through the Precambrian-Cambrian transition. The significance of trace fossils in the biostratigraphy of this interval of time was emphasised when the Precambrian-Cambrian Working Group (PCCWG) decided that the first appearance of *Treptichnus pedum* indicated the base of the Cambrian System in the Global Stratotype Section and Point (GSSP) of the Precambrian-Cambrian, Newfoundland Canada. This study has resulted in the identification of about 45 ichnogenera comprising 70 ichnospecies. Several new ichnotaxa have been described for the first time from central Australia (e.g. *Asaphoidichnus ?trifidum*, *Asteriacites* isp., *Phycodes coronatum*, *?Hormosiroidea pollardi*, *Planolites bulbosus*, and *Planolites ferrovittatus*). *Hormosiroidea arumbera*, *Plagiogmus arcuatus* and *Taphrhelminthoidea convoluta* were analysed morphologically resulting in the recognition of new structural elements. Several changes regarding classification of some ichnogenera such as *Hormosiroidea*, *Phycodes*, *Plagiogmus*, and *Saerichnites* are proposed.

A new stratigraphic division is proposed for the Precambrian-Cambrian interval in the Amadeus Basin. Following Daily (1976), the Arumbera Sandstone *sensu lato*, is divided into three units comprising the Arumbera, Box Hole and Allua Formations from older to younger respectively. It is suggested that the name Arumbera Sandstone *sensu lato* to be discarded to avoid any further confusion. The Arumbera Formation (restricted) embraces Units I and II, and in some localities the lower part of Unit III of Wells *et al.* (1967). The Box Hole Formation is considered to be an equivalent of the upper part of Unit III and the Allua Formation comprises Unit IV of Wells *et al.* (1967). A regional, diachronous erosional surface separates the Box Hole Formation and the underlying Arumbera formation in all studied sections. A granular band occurring at the base of the Allua Formation in the Ross River area probably indicates another erosional surface at the base of that formation. However, the lateral extent of this surface is not established.

Three ichnozones are recognised based on the distribution of trace fossils in the studied sections: Ichnozone I contains simple horizontal burrows reported from the Arumbera Formation including *Bilinichnus*, *?Helminthoidea*, *Intrites*, *Palaeophycus*, and *Planolites*. This ichnozone is correlated with the *Harlaniella podolica* Zone of Narbonne *et al.* (1987) reported from Newfoundland. Ichnozone II comprises some complex trace fossils which commonly occur throughout the Phanerozoic including *Arenicolites*, *Curvolithus*, *Diplichnites*, *Didymaulichnus*, *Glockerichnus*, *Gyrolithes*, *Hormosiroidea*, *Laevicyclus*, *Monocraterion*, *Phycodes*, *Protopaleodictyon*, *Psammichnites*, *Rusophycus*, *Saerichnites*, *Skolithos*, and *Treptichnus*. Contrary to the situation in the Newfoundland sections, the ichnospecies *Rusophycus avalonensis* first occurs with or prior to the ichnospecies *T. pedum* in the studied sections from central Australia. Ichnozone III occurs in the Allua Formation and comprises *Asteriacites* isp., *Palaeophycus canalis*, *Palaeophycus ferrovittatus*, *Plagiogmus arcuatus*, *Rusophycus bonnarensis*, *Skolithos ramosus*, and *Taphrhelminthopsis circularis*, among which *P. arcuatus* and *T. circularis* have apparently a restricted stratigraphic range. Ichnozones II and III are correlated with the *Rusophycus avalonensis* Zone of Narbonne *et al.* (1987). It is concluded that the *Treptichnus pedum* Zone of Narbonne *et al.* (1987) is absent from the studied sections probably indicating a major hiatus prior to deposition of the Box Hole Formation.

Ichnozone I is correlated with Zone 1B of Crimes (1994) which is attributed to the post-Ediacaran pre-Cambrian and considered to be latest Vendian in age. The trace fossil *Intrites*

reported from the Arumbera Formation (McIlroy *et al.*, 1997) is apparently restricted to this Ichnozone. Ichnozones II and III are considered to be equivalent to Zone III of Crimes (1994). *Taphrhelminthopsis circularis* and *Plagiogmus arcuatus*, apparently restricted to Crimes' Zone III, are common in the studied sections from central Australia. The occurrence of *?Vendichnus* in association with other trace fossils of Cambrian aspect is significant. This ichnogenus is reported to be restricted to Zone IB of Crimes (1994) and if the identification proves true, will extend its stratigraphic range upto Zone III.

The correlation of the Box Hole and Allua Formations with the *R. avalonensis* zone indicates a middle Tommotian to Atdabanian age. However, there is no definite information as to how much of the lower portion of this zone is missing because of the erosional surface at the base of the Box Hole Formation. The appearance of *R. avalonensis* before *T. circularis* which is in contradiction to their order of appearance in the Newfoundland stratotype, is likely due to this hiatus. It is considered that the Box Hole Formation is late Tommotian.

The occurrence of Ichnozone III in the Allua Formation with its diagnostic trace fossils, *R. bonnarensis* and *P. arcuatus* correlates with the upper part of the *R. avalonensis* zone (with the exception of *T. circularis*), indicating an atdabanian age for the Allua Formation.

The correlation between the Precambrian-Cambrian successions of central and South Australia reveals that the trace fossil assemblage within the lower Uratanna Formation, Flinders Ranges (Gauld, 1976) contains *Cochlichnus*, *Curvolithus*, *Planolites*, and *Skolithos* and can be correlated with Ichnozone I. This may also be correlative with the lower part of Ichnozone II for which the basal extent is not clear in the studied sections from central Australia due to the regional erosional surface at the base of the Box Hole Formation.

The middle and upper part of the Uratanna Formation contains *Cochlichnus*, *Curvolithus*, *Didymaulichnus*, *Monocraterion*, *Neonereites*, *?Palaeophycus*, *Planolites*, *Rusophycus avalonensis*, *Skolithos*, *Treptichnus* isp., and *Treptichnus pedum* as documented by Gauld, (1976). This trace fossil assemblage is considered to be correlative with Ichnozone II in central Australia.

As recorded by Glaessner (1969), Daily (1972, 1973), and Gauld (1976), the overlying Parachilna Formation yields *Diplocraterion parallelum*, *Palaeophycus* isp., *Phycodes* isp., *Rusophycus bonnarensis*, *Plagiogmus arcuatus*, *Phycodes palmatus*, and *Treptichnus pedum*

and is correlated with the Ichnozone III in central Australia. Accordingly, the Uratanna Formation may be correlated with the upper part of the Arumbera Formation (restricted). However, the lower part of the Uratanna Formation evidently postdates the Ediacaran soft-bodied fauna reported from the Arumbera Formation. The middle and upper parts of the Uratanna Formation are correlated with the Box Hole Formation. The succeeding Parachilna Formation containing the diagnostic trace fossil, *Plagiogmus arcuatus* is considered correlative with the Allua Formation. *P. arcuatus* is restricted to Zone III of Crimes (1994) which implies an Atdabanian age for the formation.

Analysis of distribution of trace fossils in the studied sections indicates the presence of the *Cruziana* ichnofacies in alternating fine- to medium-grained sandstone and siltstone dominated by horizontal burrows such as *Palaeophycus* and *Planolites*. The *Skolithos* ichnofacies occurs in medium to coarse grained, medium to thick bedded sandstone layers with dominant *Skolithos* and *Arenicolites* burrows.

## **STATEMENT OF ORIGINALITY**

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Mohammad Hassan Baghiyan-Yazd

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## **Dedication**

*"To my beloved wife for her support and devotion"*

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# Chapter 1

## Introduction

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### 1.1. The evolution of Metazoa

The fossil record of the late Precambrian-Early Cambrian is marked by extraordinary changes much wider in their implications than might be apparent in any single geological succession. The dramatic contrast between the Proterozoic and Phanerozoic has long been recognised as a major problem in the history of life. The abrupt appearance of fossil remnants in some local areas may be still be explained by incompleteness of the stratigraphical record. However, the idea that the "Cambrian explosion" is essentially an event of biomineralization, and "explosion" of fossils rather than of organisms, has been widely disproved. The current knowledge of fossil occurrences from the late Precambrian to the Early Cambrian fully supports the view pioneered by Cloud (1948; 1968) that the biotic changes across this interval of time are indeed real, not due to artefacts of preservation.

Various hypotheses have been proposed to explain this major change in the history of life around the Precambrian-Cambrian boundary interval, but none has received widespread acceptance (Lipps *et al.*, 1992), likely due to the fact many factors were responsible simultaneously. Because of their uniqueness relative to an extraordinary narrow interval of geological time, it is difficult to interpret the overall significance of the events suggested to have involved all groups of organisms, from protists (like acritarchs) through multicellular plants and animals. The ubiquitous spurt in evolution implies profound changes in biogenic and trophic relationships.

Trace fossils found in the late Precambrian and Early Cambrian are particularly significant for the investigation of the development of metazoans of that time. They are abundant and diverse in many clastic sequences spanning this interval and have proven to be the most useful palaeontologic method for global correlation in this stratigraphic interval.

During Proterozoic time, the global environment and ecological structures of biotas were different from those of the Phanerozoic in the following ways:

- An abundance of sediment binding involving microbial mats. This could result in extraordinary kinds of preservation of biogenic or non-biogenic structures otherwise unknown from Phanerozoic. Occurrences of *Arumberia banksi* Glaessner and Walter, 1975 have been attributed to such a condition (McIlroy and Walter, 1997), hardly repeated during the Phanerozoic.
- Absence or near-absence of bioturbating organisms. Almost all reported Proterozoic trace fossils are simple horizontal burrows which did not substantially penetrate substrates. This has been considered one of the reasons for the exceptional preservation of the soft-bodied Ediacaran fauna.
- The absence or near-absence of macrophagous heterotrophs.

In addition, different global level of oxygen, carbon dioxide, and calcium may have engendered modes of life that are poorly or not at all represented today. Evolutionary patterns may also have been affected by worldwide phenomena such as the late Proterozoic glaciations and the break up of the Proterozoic supercontinent. Whatever were the reasons for the explosive evolution of organisms characterising the Precambrian-Cambrian boundary, it caused a decline in abundance and diversity of the soft-bodied, Ediacaran fauna known as the "Kotlinian Crisis" (Brasier, 1992).

The best preserved sequences spanning the Precambrian-Cambrian boundary are mostly composed of shallow-water clastic sediments, and it is precisely these lithologies in which trace fossils are most abundant. Trace fossils are common below the lowest occurrence of Cambrian skeletal fossils in a number of successions in different parts of the world varying in age from latest Precambrian to earliest Cambrian. Thus, they provide important evidence

about the evolution of metazoans and the development of their behavioural patterns during that interval of time (Signor and Lipps, 1992).

## **1.2. Significance of trace fossils relating to the Precambrian-Cambrian interval**

Trace fossils are abundant in clastic rocks with alternating sandy and shaly beds. They provide certain evidence of life on and within the sediment. Trace fossils and their associations are also of great value for sedimentology, palaeontology, palaeogeography and palaeoenvironmental studies owing to the range of facies in which they occur. Because they are, with very few exceptions, preserved *in situ*, So, they furnish direct evidence of autochthonous life in the sediment.

Trace fossils may be used to define or correlate the base of the Cambrian System (e.g. Daily, 1972; Alpert, 1977; Seilacher, 1956; Crimes 1974, 1992a, b; Crimes and Anderson, 1985). Seilacher (1956) was first to suggest that the beginning of the Cambrian System could be delineated by trace fossils which occur below the earliest trilobites. Crimes (1975a) concluded that trace fossils are more common than body fossils in many Precambrian-Early Cambrian sequences. He suggested that this, together with the rapid evolution of the animals at that time, mean that trace fossils should at least be considered in defining a base to the Cambrian System, and might be most valuable in adequately locating that base in many sections.

In the past, the main objections to using trace fossils for correlation have been their marked facies control and long-time ranges. It has, however, been shown recently that the facies control of trace fossils is much less marked in the Early Cambrian than later (e.g. Crimes and Anderson, 1985). The long-time ranges of most trace fossils limit their usefulness for correlation in Phanerozoic sequences, but the rapid evolution which took place at about the Precambrian-Cambrian boundary created a number of short-ranging forms which have good potential for correlation. Also, at about this time most of the long-ranging trace fossils evolved, and it is their initial appearance which provides a major criterion for correlation.

### 1.3. Comparative relevance of trace fossils and shelly fossils for palaeobiological studies

Trace fossils have several advantages over shelly fossils that are particularly relevant to studies in the Precambrian-Cambrian interval. The most important criteria concerning their distribution are:

- Facies Distribution. In the boundary interval, trace fossils and small shelly fossils show an almost antipathetic relationship; trace fossils are most common in clastics whereas small shelly fossils are restricted to carbonates (e.g. Narbonne *et. al.*, 1987).
- Lack of Provincialism. Marked provincialism characterises Early Cambrian shelly fossils (e.g. Cowie, 1971; Jiang, 1985) and results in problems in global correlation. This might be due to little documentaion of small shelly fossils worldwide. In contrast, late Precambrian and Early Cambrian trace fossils are well studied. They are cosmopolitan and most of the diagnostic ichnogenera have been reported from every continent except Antarctica (Crimes, 1987).
- Lack of Secondary Transport. Shelly fossils, especially small shelly fossils, are subjected to post-mortem transport. They can be reworked into younger deposits or can infiltrate into older deposits (Cowie, 1985). In contrast, trace fossils are not subjected to post-mortem transport and almost all trace fossils are preserved *in situ*, the exceptions are both obvious and rare.

Trace fossils are also useful, as:

- Many trace fossils are produced by soft-bodied organisms, and thus provide the most abundant evidence for their former existence.
- Most trace fossils are small and commonly well preserved in cores, which is specially important to petroleum geologists.

#### 1.4. Precambrian-Cambrian boundary problem in central and South Australia

There are relatively few places around the world where it is possible to establish a comprehensive relationship between bed by bed stratigraphy and their fossil content across the Precambrian-Cambrian boundary interval. One of the best examples is in central Australia where widespread clastic sediments of this interval of time preserve spectacular and diverse assemblages of trace fossils (e.g. Glaessner, 1969; Webby, 1970; Daily, 1972, 1973, 1976; Walter *et al.*, 1989; McIlroy *et al.*, 1997).

A few occurrences of body fossils, small shelly fossils and rare simple horizontal burrows have been reported from rocks of definite Precambrian age. In Australia there are no known sequences of fossiliferous carbonates at this likely boundary level, emphasising the local biostratigraphic importance of trace fossils for quantifying the Precambrian-Cambrian transition. Ichnology studies world-wide indicate an abrupt increase in the abundance and diversity of trace fossils from Precambrian through Cambrian strata, a phenomenon both confirmed in central Australia, and augmented by the variety of taxa discovered.

Collections made by the late Brian Daily and R. J. F. Jenkins in central Australia and part of the Flinders Ranges, South Australia during the 1970s and further work by several later research students (Gauld, 1976; Thomson, 1992) provided an extensive collection of trace fossil specimens. This material forms the basis for the present thesis. This study attempts to identify and formally characterise these collections, most particularly material from the Arumbera Sandstone *sensu lato* of the northern Amadeus Basin, central Australia. The tight stratigraphic control of these traces, over a supposedly continuous sequence through the Proterozoic-Cambrian interval provides a unique opportunity to test the currently proposed ichnozonal scheme for this time, and to rationalise the placement of the basal Phanerozoic boundary in Australia, and for that matter, local sections thought to have potential global significance (e.g. Daily, 1972, 1976; Walter *et al.*, 1989). Some ichnotaxa are recognised in three major intercontinental basins, the Adelaide Foldbelt, Amadeus Basin and southern Georgina Basin. A new local ichnozonal scheme is proposed leading to questioning of the continuity of the local succession.

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## Chapter 2

### Late Proterozoic - Early Cambrian Stratigraphy of central and South Australia

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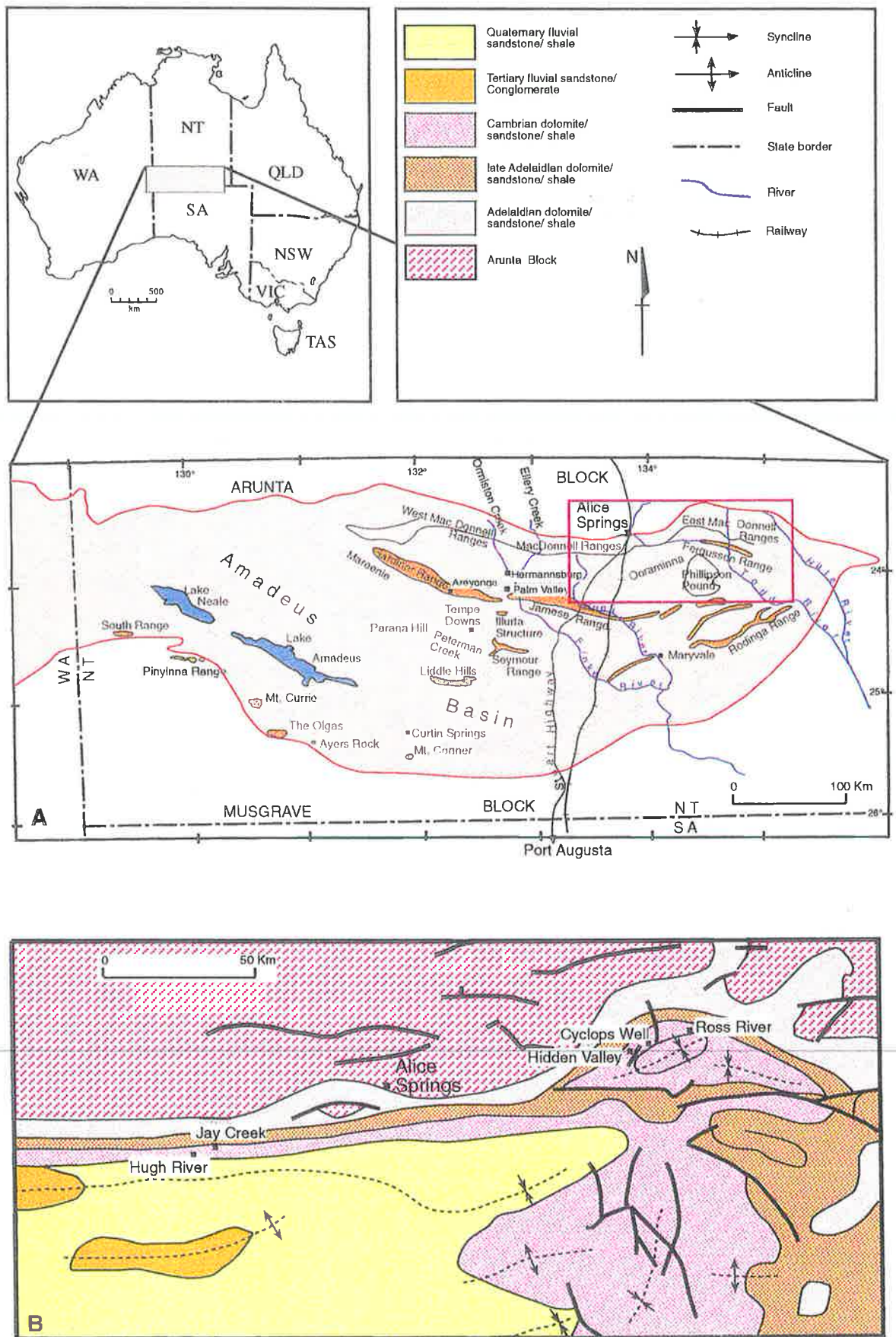
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#### 2.1. Introduction

A number of broad, shallow intracratonic depressions developed on the southeastern, central eastern and northwestern parts of the Australian shield during the late Proterozoic and early Palaeozoic. Lindsay *et al.* (1987) related the formation of these shallow basins to extension of a wider land area due likely to the break-up of a Proterozoic supercontinent. Walter *et al.* (1995) defined the term Centralian Superbasin which encompasses the Neoproterozoic fill of the Amadeus, Georgina, Ngalia, Officer and Savory Basins. They considered a swarm of dykes in the Musgrave Block, Gawler Craton and Stuart Shelf, associated with the crustal sagging to initiate the formation of the Centralian Superbasin. The superbasin was disrupted by subsequent orogenies (Petermann Ranges and Alice Springs Orogenies) to form the structural basins mentioned before. The present study involves the latest Precambrian - Early Cambrian stratigraphy within the Amadeus and Georgina Basins and is discussed below.

#### 2.2. Amadeus Basin

The Amadeus Basin is a broad intracratonic structure lying at the centre of the Australian continent (Fig. 2.1). It is some 850 km long, 250 km in width and contains perhaps 13 km of late Proterozoic to Middle Palaeozoic sedimentary rocks in several depocentres (Lindsay, 1987). The sediments are almost entirely of shallow-water origin, with common hypersaline conditions prevailing at least during the older phases of deposition.



**Figure 2.1** - Amadeus Basin, central Australia (A), and locations of the studied sections (B).



### 2.2.1. The basin fills

Along the northern margin, the older Precambrian basement consists of igneous and metamorphic rocks of the Arunta Complex and to the south, the Musgrave-Mann complex and Olia Gneiss, as well as other unnamed Precambrian rocks. A thick sequence of younger Precambrian basement metasediments and volcanic rocks rests on older Precambrian crystalline rocks in the southwest (Wells *et al.*, 1967, 1970).

The first sediments deposited in the basin were the sands of the Heavitree and Dean Quartzites followed by evaporites, penesaline sediments, and marine stromatolitic carbonate rocks and shale of the Bitter Springs Formation and equivalent Pinyinna Beds. Following deposition of the Bitter Springs Formation, the area to the south was uplifted and became the main provenance of the Proterozoic sediments during the mild tectonism described as the Areyonga and Souths Ranges Movements (Wells *et al.*, 1970). Diamicitic sediments were deposited during two periods of glaciation. Late Proterozoic sedimentation was terminated in the southwestern part of the basin during the Petermann Ranges Orogeny that folded and uplifted a large area. However, Proterozoic to Palaeozoic sedimentation appears to be more complete in some parts of the basin. The uplifted southern area formed a new margin to the basin and was a major source for the Cambrian sediments (Wells *et al.*, 1967).

The early Palaeozoic sediments are mostly fluvial in the west (Mount Currie Conglomerate and arkose at Ayers Rock), while to the east, shallow marine clastic and carbonate sediments are dominant (Cleland Sandstone and Namatjira Formation, Wells *et al.*, 1967; Bradshaw, 1988). Evaporative sediments succeeded the sediments of Arumbera Sandstone and were overlain by penesaline and marine stromatolitic carbonates rocks (Giles Creek Dolomite and Shannon Formation).

During Cambro-Ordovician times, sedimentation was initially restricted to the northern part of the basin. However, Data from McDills No. 1 well (see e.g. Gravestock, 1995, p. 41) indicate an equivalent of the Todd River Dolomite in this well which is less than 30 km north of the SA/ NT border. Thus, there may have been a Cambrian seaway between the Officer, Warburton and Amadeus Basins. The Ordovician sea gradually spread to the south. The sandstone, shale and minor carbonate rocks of the Larapinta Group conformably overlay the Pertaoorra Group in the north and occur disconformably above it in the south. Deltaic or

estuarine sand deposited subsequent to the Larapinta Group may represent the last marine deposits in the Amadeus Basin. The basin was subjected to a broad erosive event during the epirogenic uplift of the Rodingan Movement, which consequently provided the sediments of the Mereenie Sandstone during the Siluro - Devonian. The subsequent Pertnjara Movement successively uplifted a large block of sediments on the northern part of the basin. The eroded products were deposited to the south as a thick molassic wedge, represented by the Pertnjara Group. The lacustrine siltstone at the base of the Pertnjara Group deposited unconformably on the Mereenie Sandstone and, following further uplift, younger strata of the same group successively overlapped older units along the northern margin of the basin. The sedimentation in the basin was destabilised after the deposition of the Pertnjara Group and the sedimentation was brought effectively to a close by the Alice Springs Orogeny during the Carboniferous (Wells *et al.*, 1970). Figure 2.2 shows an overview of the stratigraphy and major tectonic movements of the Amadeus Basin.

### 2.2.2. Structural elements of the Basin and basin evolution

Figure 2.3 shows morphological structures of the basin based on seismic stratigraphy studies carried out by Korsch and Lindsay (1989) and Lindsay and Korsch (1991). They recognised the following main areas of tectonic significance:

1) Platform areas which are covered by thin sediments. These areas are located particularly in the south and west and form the largest area of the basin. Oaks *et al.* (1991) referred to this region as the Mount Conner Sub-basin. The average sediment thickness on platform areas is about 2 km.

2) Three depocentres have been recognised along the northern margin of the basin: the Ooraminna, Carmichael and Idirriki Sub-basins. A total succession of about 14 km thick has been indicated by seismic data within the Carmichael Sub-basin and a somewhat similar depth in the other sub-basins. Oaks *et al.* (1991) included these three depocentres in his northern sub-basin, informally called the MacDonnell Ranges Sub-basin. Two additional small sub-basins also occur within the Amadeus Basin; the Seymour Range Sub-basin in the Seymour Range area and the Mount Currie Sub-basin at the south-west margin of the basin.

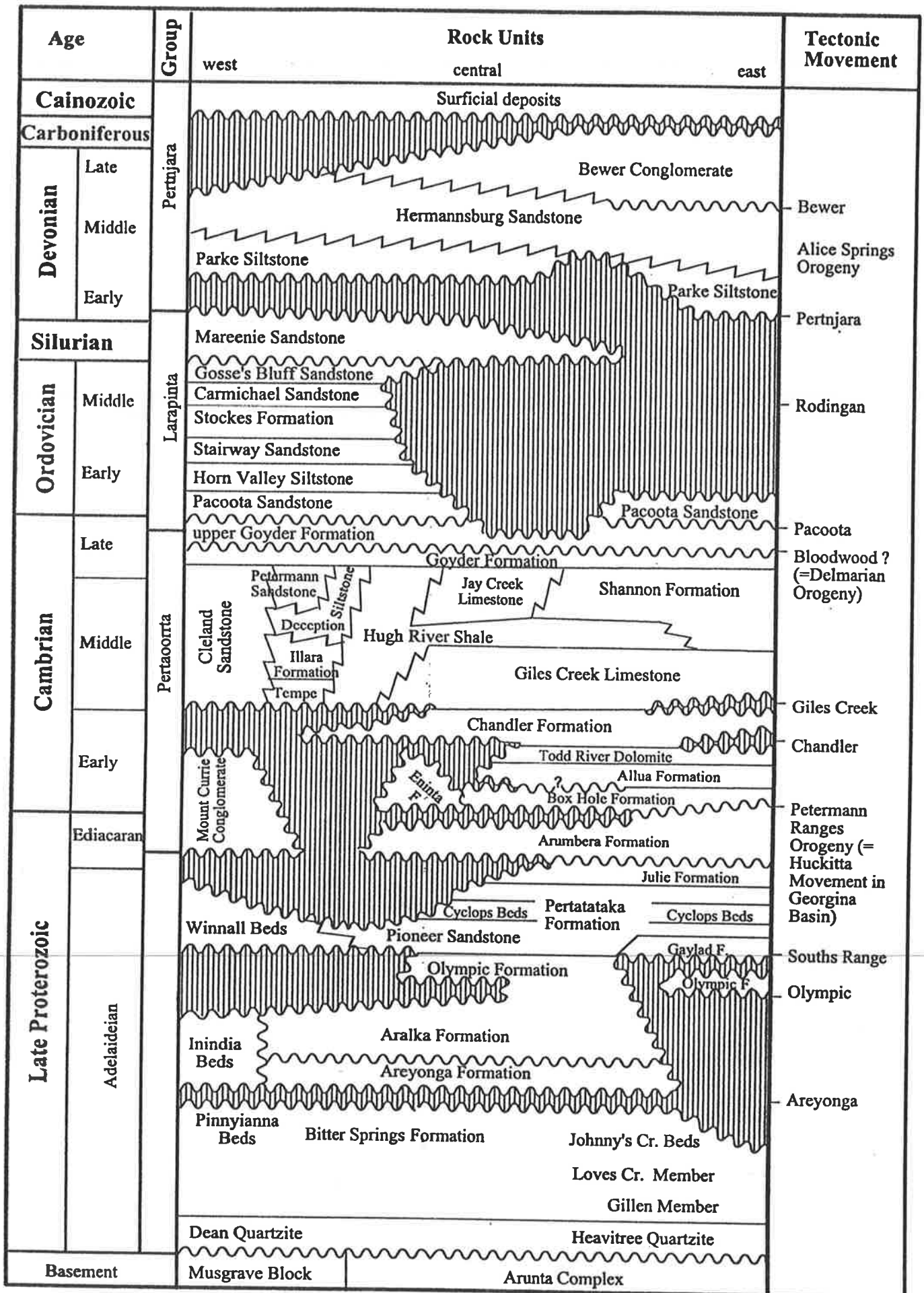
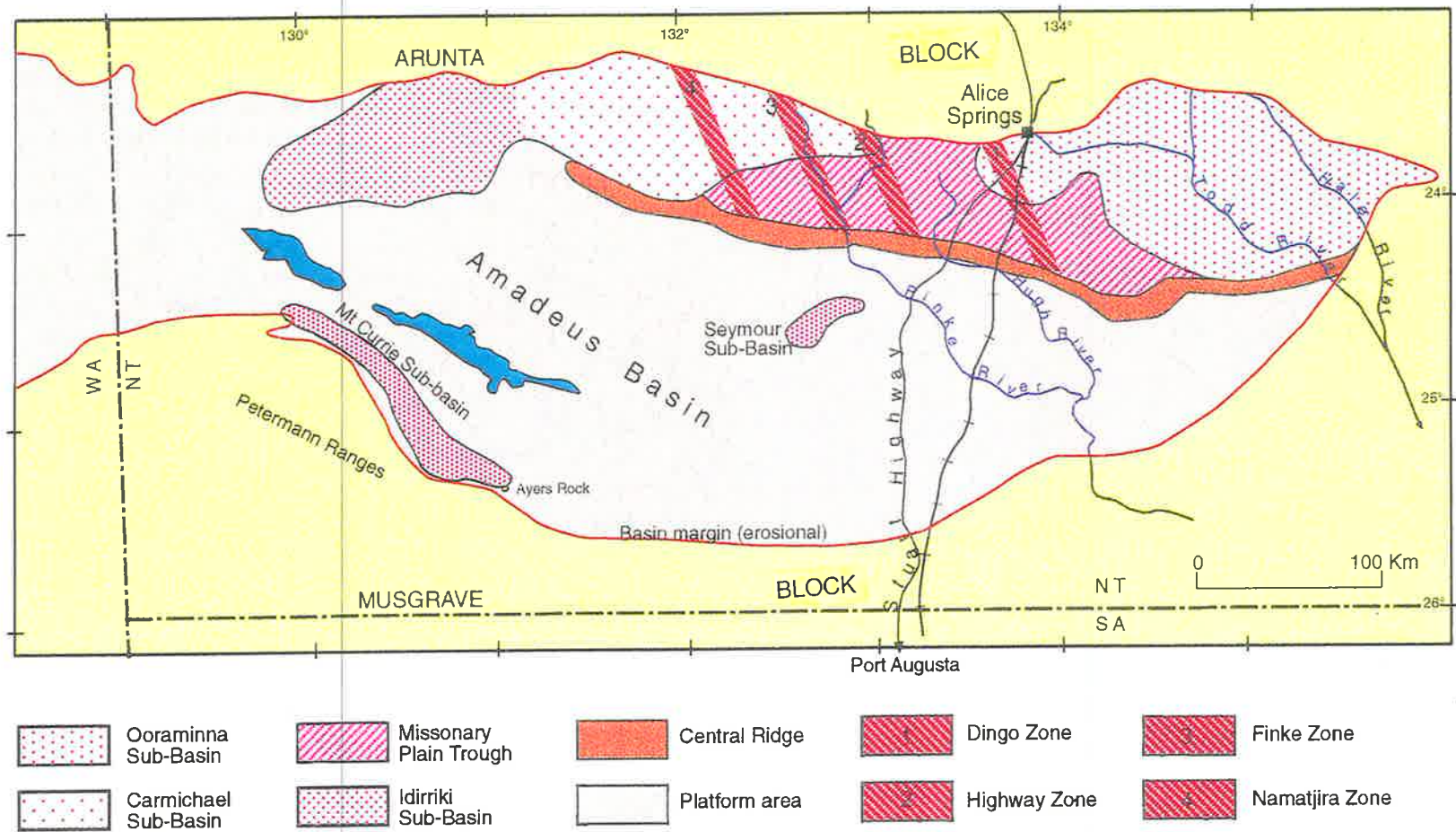


Figure 2.2. Stratigraphic correlation of the Amadeus Basin (modified after Wells *et al.*, 1967, 1970; Shergold, 1986; Oaks *et al.*, 1991).



**Figure 2.3** - Structural elements of the Amadeus Basin, central Australia (after Lindsay and Korsch, 1991; Oaks *et al*, 1991).

3) A depression termed the Missionary Plain Trough links the Carmichael and the Ooraminna Sub-basins. By comparison with the other sub-basins a relatively similar but thinner succession accumulated within this structure. A similar trough-like structure may link the Carmichael and Idirriki sub-basins as well.

4) Physiogeographic ridges surrounded the sub-basins. The Central Ridge (Lindsay, 1987) is the most significant of these ridges. It occurs along the southern margin of the Ooraminna and Carmichael Sub-basins and Missionary Plain Trough. Its later growth has been linked to the flowage of the Bitter Springs salt from the Missionary Plain Trough into the ridge (Lindsay, 1987). At times, this ridge acted as a barrier to sedimentation. Seismic data show that anticlinal structures to the north of the ridge have large salt cores but no basement involvement whereas those to the south have smaller salt cores and possibly some limited basement involvement (Korsch and Lindsay, 1989).

5) Depositional compartments superimposed on the morphological structures of the basin controlled distribution of sediment particularly during the Early Cambrian. These compartments, striking predominantly north-northwest are separated by zones of discordance. They are referred to as the Namatjira, Finke, Highway and Dingo Zones (Lindsay and Korsch, 1991).

The basin evolved in three major stages (Korsch and Lindsay, 1989; Lindsay and Korsch, 1991). The first stage began at about 900 Ma with extensional thinning of the crust and the formation of half-grabens. This stage was followed by the deposition of a rift sequence of volcanic and fluvial sediments (Mount Harris Basalt, Bloods Range Beds and Dixon Range Beds in the southwest and an unnamed succession of sedimentary rocks, basalt and dacite in the northwest) unconformably on the Arunta Block to the north and the Musgrave Block to the south. Thermal subsidence comprising stage one was continued by a long post-thermal phase of minimal subsidence during which sedimentation was probably controlled by small-scale tectonic events (Lindsay and Korsch, 1991; Shaw, 1991).

The second stage of basin evolution began in the latest Proterozoic at approximately 580 Ma and ended at approximately 450 Ma (Korsch and Lindsay, 1989). No volcanics have been reported from the basin for this stage, which suggests a lesser amount of extension than during stage one. Faulting that might be expected in the basin fill contemporary with basin

growth and sedimentation is rare because the strain associated with basin growth was taken up by salt motion.

Concurrent with the initiation of the extensional basin in the northern part of the Amadeus Basin during stage two, a compressional basin was forming to the southwest (Korsch and Lindsay, 1989). This event, referred to as the Petermann Ranges Orogeny by Forman (1966), resulted in the uplift of the south western margin of the basin. Some clastic sediments derived from this uplifted margin were transported north, by-passing the southern platform and accumulating in the central and northerly sub-basins as the Arumbera Sandstone *sensu lato* (Lindsay, 1987).

During stage three the present basin margins, which are structural and erosional rather than depositional, were produced. At this time the basin was shortened by 50-100 km (Korsch and Lindsay, 1989; Stewart *et al.*, 1991; Shaw *et al.*, 1991). Events relating to this phase of basin development are responsible for most of the obvious structural patterns visible in the present surface geology. This final stage of basin evolution resulted from the Alice Springs Orogeny producing molasse deposition (Shaw *et al.*, 1991).

During this third stage of basin development the load of major southward-directed thrust sheets caused progressive downward flexing of the northern margin of the basin, and sediments were shed from the thrust sheet into the downwarps.

### **2.2.3. Latest Proterozoic - Early Cambrian Stratigraphy of the basin**

The latest Proterozoic - Early Cambrian sediments comprising the Pertatataka Formation, Julie Formation and Pertaoorra Group are discussed below.

#### **2.2.3.1. Pertatataka Formation**

Chewings (1935) included all units between the Bitter Springs Formation and Arumbera Sandstone (*sensu lato*) in the Pertatataka Series. Prichard and Quinlan (1962) redefined this as the Pertatataka Formation and excluded the Areyonga Formation from its base. The Julie Formation was later excluded from the top by Preiss *et al.* (1978). The type section is located 5 km west of Ellery Creek.

The Pertatataka Formation consists of predominantly grey-green, thin-bedded siltstone and shale with minor fine-grained sandstones containing abundant and diverse acritarchs (Zang and Walter, 1992). It is a recessive sequence and exhibits parallel to wavy bedding, current ripples and cross-stratification.

In the north-eastern part of the Amadeus Basin the Pertatataka Formation is generally conformable above the Areyonga Formation and is succeeded by the Julie Formation. However, in some localities (e.g. Fenn Gap, west of Alice Springs) it rests on the Bitter Springs Formation. This contact may be a low-angle regional unconformity (South Ranges Movement, Oaks *et al.*, 1991). An overstep of the Arumbera Sandstone (*sensu lato*) from the Julie Formation onto the Pertatataka Formation southward within the Deep Well Range supports this interpretation (Phillips, 1986, p.35). In several places the formation is either overlain disconformably or unconformably by the Arumbera Sandstone (*sensu lato*), the Cambrian Chandler Limestone, or with an angular unconformity by the much younger Pertnjara Formation (Wells *et al.*, 1967, p.25).

Shales of the lower part of the formation in the Ooraminna No. 1 and the Mt. Charlotte Wells give Rb/Sr ages of  $760 \pm 33$  m.y. and  $822 \pm 8$  m.y. respectively (Wells *et al.*, 1967, p.25) but by comparison with other regions these nominal ages are almost certainly too old, perhaps reflecting detrital components in the sediments. A late Proterozoic age is also indicated for the formation based on its stratigraphic position beneath the Julie Formation and Arumbera Sandstone (*sensu lato*).

#### **2.2.3.2. Julie Formation**

Wells *et al.* (1967, p.30) recognised this unit as the Julie Member of the Pertatataka Formation. The unit was redefined as Julie Formation by Priess *et al.* (1978). It consists of a sequence of dolomite, limestone and siltstone, with lenses of sandstone and crops out through most of the north-eastern part of the Amadeus Basin. Wells *et al.* (1967, p.30) suggested that the formation is probably equivalent to part of the Pertatataka Formation. It conformably overlies the Pertatataka Formation and over wide areas is conformably overlain by the Arumbera Sandstone (*sensu lato*).



In a few places, poorly preserved stromatolites with an indistinct wavy bulbous outline occur in dolomites of the Julie Formation (Wells *et al.*, 1967, p.31). An upper Precambrian age is assigned to the formation based on its stratigraphic position under the Arumbera Sandstone (*sensu lato*).

### ***2.2.3.3. Pertaoorrta Group***

Prichard and Quinlan (1962) defined the Pertaoorrta Group in the Hermansburg Sheet area. Ranford *et al.* (1965) reported two new members in the group and Wells *et al.* (1967) and Ranford (1969) defined others. Relationships between lithostratigraphic units in this group and their spatial distribution are summarised in Figure 2.4.

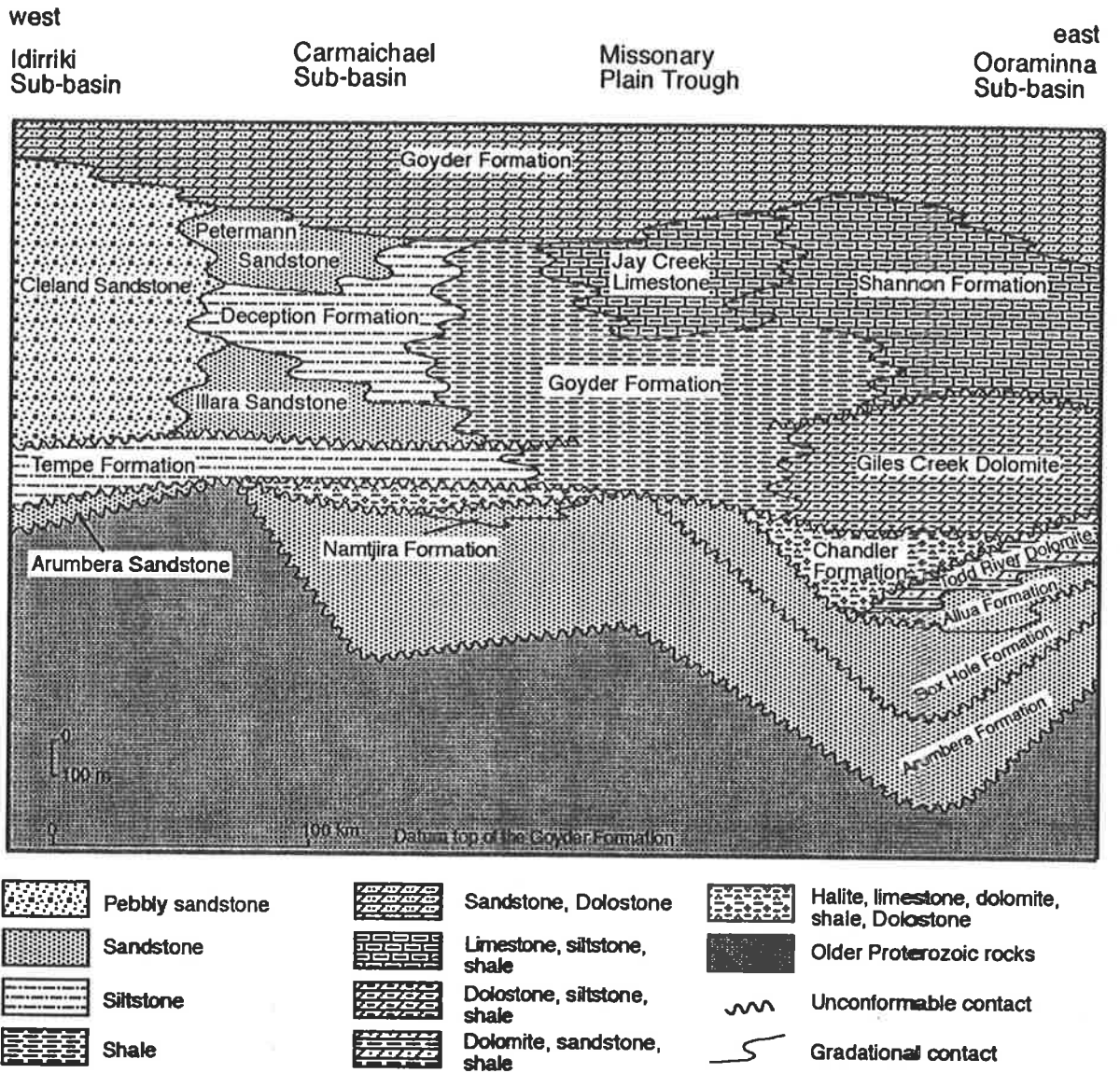
The Pertaoorrta Group comprises a wide variety of sediments varying in age from latest Proterozoic to Late Cambrian. The group has a maximum thickness of 2900 m in the northwest and more than 2100 m in the northeast of the Amadeus Basin. Deposition of the Pertaoorrta Group is considered by Kennard & Lindsay (1991) as being controlled by two major late Proterozoic events; crustal shortening followed by crustal extension in the central part of the Amadeus Basin.

The Pertaoorrta Group thins to the south and east and changes from a sandy facies in the west to a mixture of siltstone, shale and carbonate in the east (Ranford *et al.*, 1965). Discussing all formations within this group is beyond the scope of the present study. However, the following units of the Pertaoorrta Group are briefly described herein because of their relevance for this study:

#### ***Quandong Conglomerate***

The name was first defined by Ranford *et al.* (1965) for conglomerate and conglomeratic sandstones which crop out in the Henbury Sheet area. The type section is located 6 miles (10 km) northeast of 'Tempe Downs' homestead. Its thickness varies considerably over a short distance and it is considered to be equivalent to the Eninta and Arumbera Sandstones (*sensu lato*). Although it lacks fossils, the unit is assigned to the Early Cambrian as it lies conformably beneath the Middle Cambrian Tempe Formation.





**Figure 2.4.** Lithostratigraphical units of Pertooorrtta Group and their spatial relationship (after Kennard and Lindsay, 1991).

### ***Eninta Sandstone***

This was first defined by Wells *et al.* (1962) in the Gardiner Range as the Arumbera Greywacke. Wells *et al.* (1963) changed the name to the Eninta Sandstone Member of the Pertaoorra Group and Ranford *et al.* (1965) raised it to formation status.

It comprises sandstone with minor siltstone and conglomerate and crops out only in the Gardiner Range (Wells *et al.*, 1970, p. 52). The formation is considered to be contemporaneous with the Quandong Conglomerate and Arumbera Sandstone (*sensu lato*) and its age, based on its stratigraphic position, is likely Early Cambrian.

### ***Arumbera Sandstone (sensu lato)***

Due to the significance of this formation in this study the Arumbera Sandstone (*sensu lato*) will be discussed in greater detail in a separate chapter.

### ***Chandler Formation***

The name Chandler Limestone was first introduced by Ranford *et al.* (1965) for limestone, dolomite and evaporites which crop out widely in the central and eastern part of the basin. Chandler Limestone was later amended to Chandler Formation on account of the large halite volume (Bradshaw, 1991). The formation is strongly folded and its thickness varies considerably. It is variably unconformable above the Julie Formation, Pertatataka Formation, Arumbera Sandstone (*sensu lato*), Eninta Sandstone and the Todd River Dolomite and is itself overlain by the Giles Creek and Jay Creek Dolomites. Although no fossil are found in the formation, its age is considered Early Cambrian based on its stratigraphic position.

### ***Todd River Dolomite***

The unit was defined by Wells *et al.* (1967). The formation consists of pink and grey thick-bedded dolomite with thin-bedded calcareous sandstone, red-brown sandstone, siltstone and thin beds of dolomite at its lower part. The type section is in the Ross River Gorge. The Todd River Dolomite conformably overlies the Arumbera Sandstone (*sensu lato*) and is

conformably or disconformably overlain by the Giles Creek Dolomite or Chandler Limestone.

The Todd River Dolomite crops out in northeastern part of the basin. An Early Cambrian age is indicated by its fossil content which mostly comprises archaeocyathans and small shelly fossils (Wells *et al.*, 1970; Kruse and West, 1980; Shergold *et al.*, 1985).

### ***Hugh River Shale***

The Hugh River Shale was described by Prichard and Quinlan (1962). Wells *et al.* (1965) redefined the unit as a member of the Pertaoorra Group and Ranford *et al.* (1965) reinstated it as a formation. It crops out in the central north and northeastern part of the Amadeus Basin mainly along the MacDonnell Range. It comprises shale and siltstone with minor thin carbonate and sandstone beds. The formation mainly lies conformably between the Arumbera Sandstone (*sensu lato*) below and the Jay Creek Limestone above. Although not fossiliferous, it is considered to be Early Cambrian to early Middle Cambrian in age because of its stratigraphic position.

The other units within the Pertaoorra group as summarised in Figure 2.2 lie beyond the limits of the present study and are only discussed briefly below. In the west, at Petermann Creek and Para Hill anticlines, the older Bitter Springs Formation is overlain by the Tempe Formation, Illara Sandstone, Deception Formation and Petermann Sandstone which consist mainly of siltstone, dolomite and glauconitic sandstone. These divisions are considered to be of older Middle to early Late Cambrian in age based on their stratigraphic position (Wells *et al.*, 1970, Shergold *et al.*, 1985). In the far west, the Cleland Sandstone was deposited during this time, while in the northeastern part of the basin shaly and calcareous sediments accumulated (Giles Creek and Jay Creek limestones, Shannon Formation). The Goyder Formation is the youngest formation of the Pertaoorra Group and comprises sandstone, shale, dolomite and limestone with numerous halite pseudomorphs. Its age is likely middle Late Cambrian based on the occurrence of the algal stromatolites, trilobites, gastropods and hyolithids (Wells *et al.*, 1967; Shergold *et al.*, 1985).

### 2.3. Georgina Basin

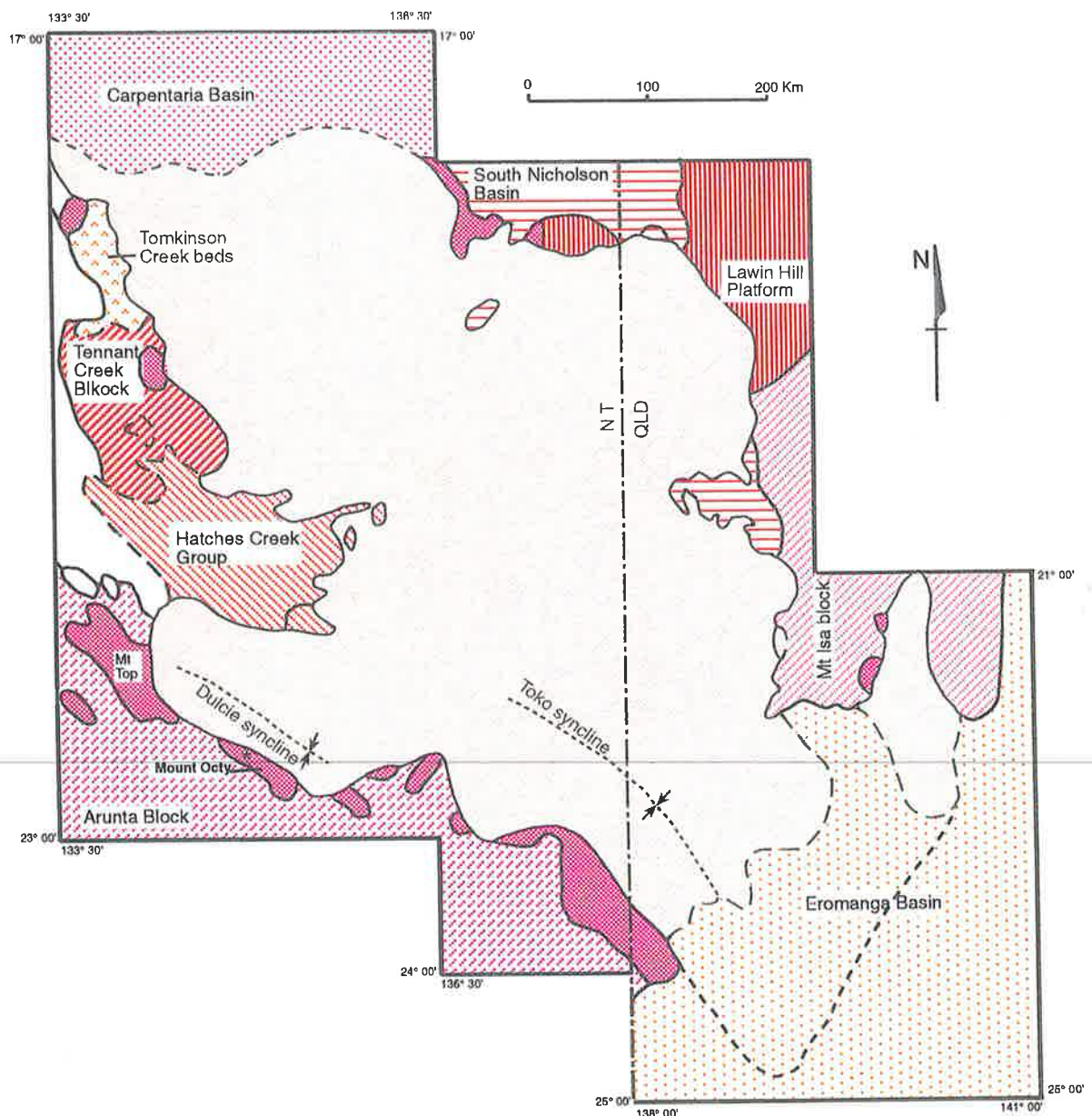
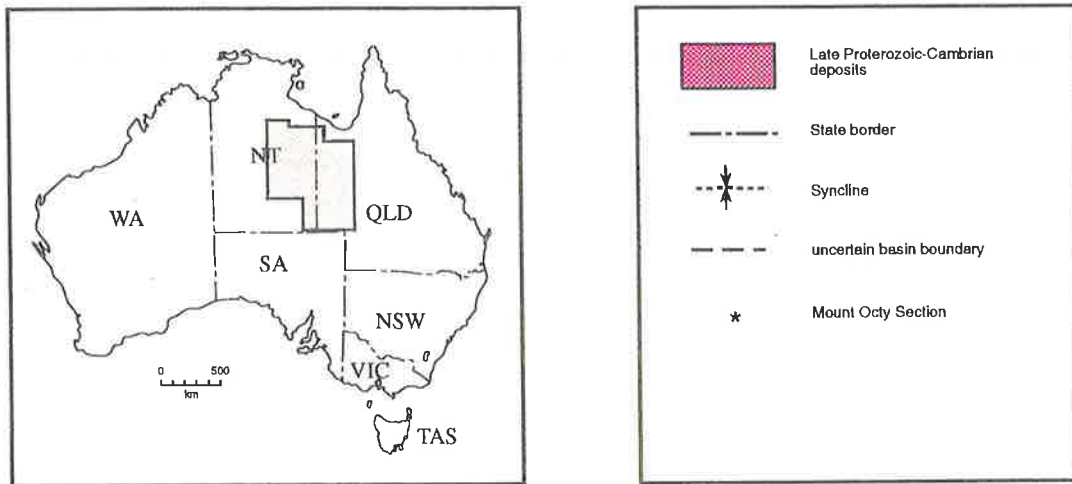
Georgina Basin includes a large expanse of intracratonic sediments extending from northwestern Queensland into the Northern Territory. It covers an area of about 325000 square kilometres. The margins of the basin are embraced by Neoproterozoic outcrops in the southeast, west, north and east but the northeastern and southeastern margins are hidden beneath Mesozoic sediments. It is separated from the Amadeus, Ngalia and Officer Basins by the Arunta and Musgrave Blocks in the southwest (Fig. 2.5). The basin comprises a sequence of sedimentary and volcanic rocks of late Proterozoic to Devonian age (Smith 1972; Shergold and Druce, 1980).

Smith (1972) regarded early Middle Cambrian sediments as basal to the sequence disconformably overlying the Proterozoic basement over a wide area. However, Bureau of Mineral Resources aeromagnetic surveys and core drilling revealed that a thick sequence of Adelaidean/ Early Cambrian sediments occurs beneath the Middle Cambrian rocks in much of the basin (Smith, 1972). These rocks are exposed in many places along the western and southwestern margins. Walter (1980) and Shergold and Druce (1980) redefined the basin to include the arkosic and glauconitic sediments of latest Proterozoic to Early Cambrian age.

In general, the earliest sediments in the basin north of latitude 21° S are represented by Middle Cambrian carbonates with a local basal clastic association which unconformably overlies the lower Proterozoic to Carpentarian metamorphics (Shergold & Druce, 1980; Eyre, 1994). The granites and metamorphic rocks of the Arunta Complex are overlain by late Proterozoic and Early Cambrian sediments south of latitude 20° S where arkose and glauconitic sediments commonly commence the sequence (Shergold & Druce, 1980; Eyre, 1994). Walter (1978) tentatively suggested that the Late Proterozoic-Cambrian sediments of the southwestern Georgina Basin are the platformal equivalents of the basinal sediments of the Amadeus Basin.

#### Late Proterozoic - Early Cambrian stratigraphy of the basin

Although the stratigraphy of the Middle Cambrian and younger rocks of the Georgina Basin is well established (Smith, 1972; Walter *et al.*, 1979; Walter, 1980; Shergold and Druce,



**Figure 2.5.** Location of main structures of the Georgina Basin (modified after Shergold and Druce, 1980; Eyre, 1994).

1980), there are different views regarding the stratigraphy of the latest Proterozoic and Early Cambrian succession (see Smith, 1972; Walter, 1980; Shergold and Druce, 1980). For the purpose of this study, the stratigraphic divisions proposed by Walter (1980) for the southwestern part of the Georgina Basin is followed (Fig. 2.6), since it applies to the present studied area (Mount Octy).

The glacial sequences of the Field River Beds and Mount Cornish Formation crop out in the west and southwest margins. The basal sequence of the Field River Beds consists of faceted and striated boulders (up to 1.3 m) of gneiss, schist, quartzite, granite, porphyry and stromatolitic dolomite lying in a green siltstone, suggesting a glacial origin for the unit. Higher in the sequence boulders occur in arkosic beds, which may represent a second period of glaciation (Smith, 1972). The basal unit was correlated with the Areyonga Formation (Prichard & Quinlan, 1962) in the Amadeus Basin.

Smith (1964, 1972) named the Mount Cornish Formation for blue-green siltstones containing cobbles and pebbles, cyclical laminated siltstone, and sandstone with minor dolomitic arkose and quartz greywacke. The formation rests unconformably on the crystalline Arunta Complex and was correlated with the Olympic Member of the Pertatataka Formation (Wells *et al.*, 1967; Walter, 1980).

The Central Mount Stuart Beds (Smith & Milligan, 1964) consist of arkose, greywacke, siltstone and dolomitic siltstone. The unit is cross-bedded and ripple-marked. The upper part comprises red and white quartz sandstone and siltstone with minor feldspathic sandstone (Smith, 1972, Shaw & Warren, 1975, Shergold & Druce, 1980. Smith (1972) considered a glacial origin for the oldest part of the unit based on the presence of boulder beds near the base in the northwest part of the 1/250,000 Alcoota Sheet. Shaw & Warren (1975) gave formation status to the unit and recorded tillite and boulder beds at its base. A few trace fossils (Walter *et al.*, 1989) and a soft bodied metazoan fauna (Wade, 1970) are reported from the Central Mount Stuart Formation. Walter *et al.* (1989, 1995) suggested the formation to be an equivalent of the lower part of the Arumbera Sandstone (*sensu lato*) of the Amadeus Basin. Walter (1980) correlated the upper Central Mount Stuart Formation with the Arumbera Sandstone 1 (*sensu* Wells *et al.*, 1967) on lithological grounds, and the common occurrence of the Mt. Skinner fauna of medusoids and coelenterates. Jenkins *et al.* (1988)



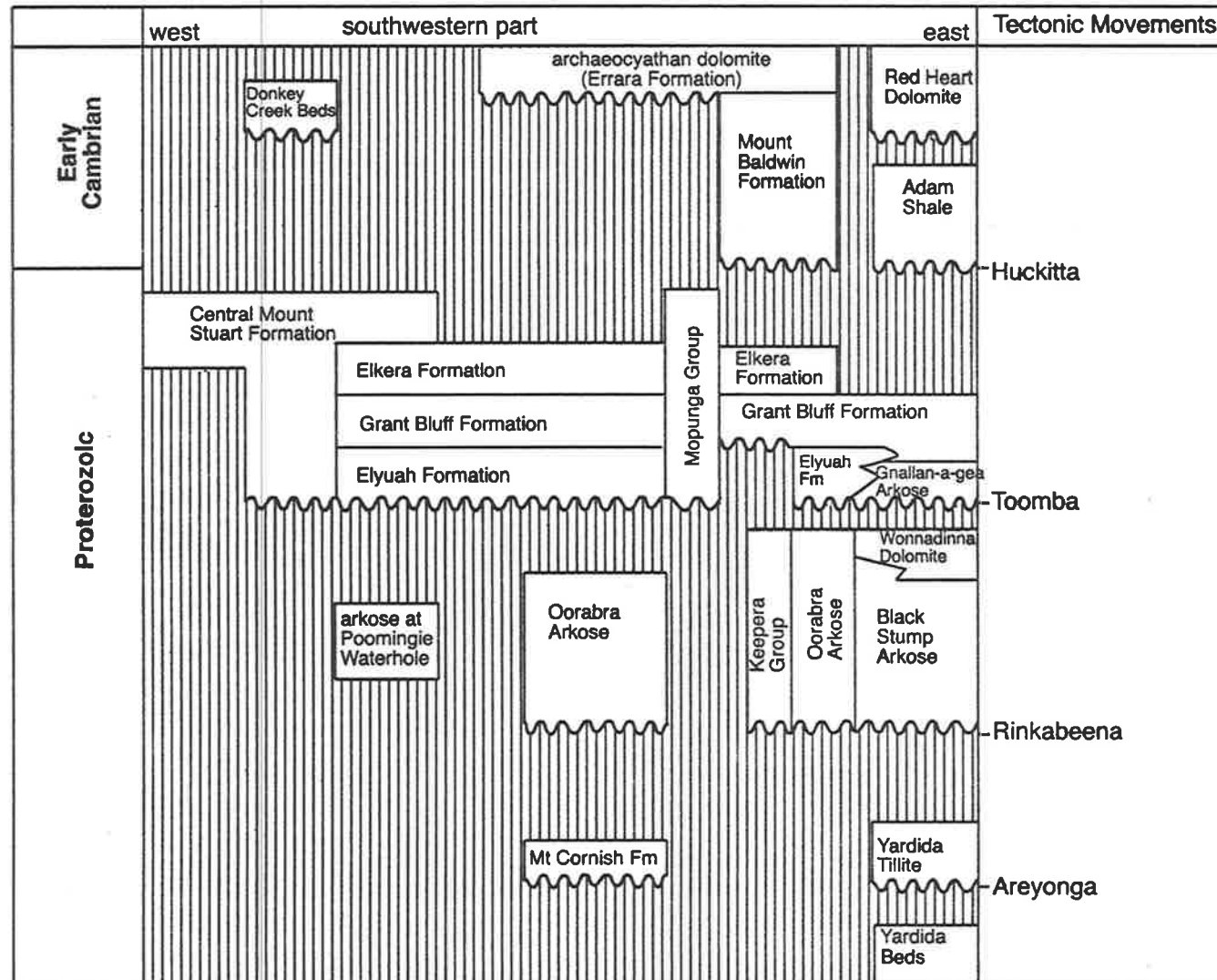


Figure 2.6 - Chronostratigraphic chart of south and south-western part of Georgina Basin (after Walter, 1979).

considered that the Central Mount Stuart Formation likely is partly a correlative of the Mt. Baldwin Formation (restricted sense) and Arumbera Sandstone (restricted). The formation rests unconformably on the Arunta Complex and Precambrian intrusive rocks on the southern part of the basin and is followed conformably by the Grant Bluff Formation of the Mopunga Group near the Barrow Creek settlement (Smith, 1972). However, Shergold in Shergold & Druce (1980) reported that the Central Mount Stuart Formation is overlain by glauconitic sandstone containing trace fossils of Early Cambrian age and the mollusc *Bemella* which was erroneously referred to the Grant Bluff Formation by previous authors. This latter fossiliferous sequence comprises the Donkey Creek Beds of Walter (1980).

The Donkey Creek Beds consist of brown and green-grey arkose, sandstone and siltstone with abundant trace fossils. A paraconformity separates this unit from the underlying Central Mount Stuart Formation near Mt. Octy in the Barrow Creek 1:250,000 Sheet area. An extensive collection of trace fossils made from these beds suggests an Early Cambrian (Atdabanian) age.

According to Smith (1964, 1972), the Mopunga Group straddles the Precambrian - Cambrian boundary and includes the Elyuah, Grant Bluff and Mount Baldwin Formations. Walter (1980) recognised unconformities between the lower member (Oorabra Arkose Member) and the upper part of the Elyuah Formation and between the upper Grant Bluff Formation and the Mount Baldwin Formation. Walter (1980) redefined the Group and excluded the Mount Baldwin Formation. According to Walter (1980) the Mopunga Group belongs to the Precambrian and comprises the Gnallan-a-gea Arkose and Elyuah, Grant Bluff, Elkeru, and Central Mount Stuart Formations in the southwestern part of the basin.

The Gnallan-a-gea Arkose consists of light brown to grey fine to very coarse grained pebbly arkose, sandstone, siltstone and shale. Its thickness varies from 10 m in the Keepera Ridges to the 1450 m in the Bat Hills. It rests disconformably on the lower dolomitic units and is overlain conformably by the Elyuah Formation in the Keepera Ridges and by Grant Bluff Formation in the Mount Winecke and Mount Barrington areas (Walter, 1980).

The Elyuah Formation comprises a basal arkose (locally named Oorabbra Arkose Member) and a younger shaly sequence. Walter (1980) excluded the basal arkose and considered it as a



formation. The base of the redefined Elyuah Formation is marked by a sandstone and pebbly arkose. It is overlain conformably by the Grant Bluff Formation.

The Grant Bluff Formation comprises grey, fine to medium-grained, thin bedded, glauconitic quartz sandstone and siltstone, shale and thin beds of stromatolitic dolomite (Smith, 1972). It conformably overlies the Field River Beds in the Hay River and Tobermory Sheet areas and on Central Mount Stuart Formation near the Barrow Creek settlement. Smith (1972) reported that the Grant Bluff Formation is diachronous and contains abundant worm trails that were identified as sinuous desiccation cracks by Walter *et al.* (1989). Smith and Milligan (1964) reported *Helcionella*, an Early Cambrian fossil from the formation. However, Walter *et al.* (1979), Burek *et al.* (1979) and Walter (1980) assigned the formation to the Proterozoic rather than Cambrian and correlated it with the Cyclops Member of the Pertatataka Formation in the Amadeus Basin. Burek *et al.* (1979) and Walter *et al.* (1979) stated that in the Hay River 1:250,000 Sheet area of the southern Georgina Basin a major break exists between the Adelaidean and Cambrian and there are no equivalents of the upper Pertatataka Formation, the Julie Formation and the lower Arumbera Sandstone. Jenkins *et al.* (1988) reported the occurrence of trace fossils *Palaeophycus tubularis* and *Planolites montanus* in the type exposure of the Grant Bluff Formation at Elyuah Range, taxa suggestive of a latest terminal Proterozoic or younger. In the Desert Syncline the Grant Bluff Formation is unconformably overlain by the Adam Shale, which mainly consists of mottled, medium green to brown mudstone and laminated shale. According to an acritarch assemblage found in the Adam Shale, it is considered to be not older than Vendian and not younger than Early Cambrian, possibly Tommotian as reported by Walter *et al.* (1979).

Smith (1964) reported that the Grant Bluff Formation is succeeded conformably by the Mount Baldwin Formation. Walter (1980) redefined the Grant Bluff Formation by excluding the upper recessively weathering sequence which was called the Elkera Formation. He mentioned that in many parts of the Huckitta 1:250000 sheet area the Elkera Formation has been mis-mapped as Mount Baldwin Formation. Walter (1980) also showed that an unconformity exists between the Elkera Formation and succeeding Mount Baldwin Formation in the Desert Syncline area.

The Elkera Formation consists of interbedded siltstone, dolomite, sandstone and shale. The lower dolomites are medium to dark brown, yellow or grey and contain the abundant columnar stromatolite *Georginia howchini*. In the Huckitta Sheet area, the boundary between Elkera Formation and the Mt Baldwin Formation or archaeocyatha bearing carbonates marks a disconformity. However, this boundary apparently is conformable at Mt. Skinner (Walter, 1980).

Smith (1972) reported that the Mopunga Group and the Mount Baldwin Formation are overlain, probably disconformably, by the lower Middle Cambrian Arthur Creek Beds. However, according to the redefinition of Walter (1980) the Mopunga Group is overlain by the Mount Baldwin Formation and archaeocyathan dolomite of the Early Cambrian.

The Mount Baldwin Formation comprises dark red glauconitic sandstone, siltstone, shale and greywacke, with minor pink and grey sandstone and brown and yellow dolomite. The dolomite beds near the top of the formation contain archaeocyathids and brachiopods of Early Cambrian age (Smith, 1972). Walter (1980) excluded the archaeocyathan dolomite and the overlying sequence from the type section and located the top of the formation at the base of the dolomite beds. Freeman *et al.* (1984) redefined the formation and excluded a conglomerate-sandstone unit under the dolomite beds. They interpreted this unit as a basal clastic sequence of the disconformably overlying Errara Formation (Shergold *et al.*, 1985).

The Mount Baldwin formation was correlated with the Adam Shale and lower Red Heart Dolomite by Walter *et al.* (1979) and Walter (1980). They considered the archaeocyathan dolomite as a correlative of the upper Red Heart Dolomite in the Desert Syncline and the Todd River Dolomite of the Amadeus Basin. An Early Cambrian age, Atdabanian, was assigned to the formation through its trace fossil content (Walter, 1980; Kruse and West, 1980; Shergold *et al.*, 1985). Shergold and Druce (1980) reported rare trace fossils of Cambrian aspect from the Mount Baldwin Formation and recorded that the formation thins to the northeast, where it is mainly arkosic. It is apparently absent from the adjacent Tobermory and Hay River Sheet areas. Eyre (1994) divided the Mount Baldwin Formation into four units and interpreted it to represent alluvial fan-delta deposits.

## 2.4. Adelaide Geosyncline

Although this study is based on the trace fossils collected from the Amadeus and Georgina Basins, many references to the equivalent sediments from the Adelaide Geosyncline have been cited within the text and hence, it is essential to give a summary of the geological history of the upper part of the Adelaide Geosyncline/ South Australia.

The Adelaide Geosyncline comprises an extremely thick succession of sediments deposited during late Precambrian to Middle Cambrian time and provides one of the most completely known sedimentary records for this time interval. The sediments deposited initially in rifted troughs and later in broad zones of regional subsidence (Preiss, 1993). A total cumulative thickness of over 40 km of sediments, including the Cambrian, is present in the Copley area (Coats, 1973, Forbes *et al.*, 1982). The latest Proterozoic is represented by the Pound Subgroup of the upper part of the Wilpena Group (Marinoan *sensu lato* in age) and the overlying oldest Early Cambrian deposits are indicated by the lower part of the Hawker Group including Uratanna and Parachilna Formations (Dalgarno, 1964) in the central Flinders Ranges, the Winulta Formation (Daily, 1963) in the far southwestern Flinders Ranges and Stansbury Basin and the lower part of the Normanville Group in the Kanmantoo Trough and Nackara Arc. A stratigraphic break has been generally conceded below the initial deposits of the Cambrian System everywhere in South Australia (i.e. Daily, 1972; Jenkins, 1981). Figure 2.7 illustrates the Late Proterozoic-Early Cambrian Succession of South Australia.

### 2.4.1. Late Proterozoic - Early Cambrian stratigraphy of the basin

The Wilpena Group overlies the Umberatana Group and represents two major post-glacial marine transgressive-regressive cycles, the younger of which contains the fossiliferous beds of the Pound Subgroup (Preiss, 1990).

The Pound Subgroup embraces sediments of the upper part of the Wilpena Group which was originally named as the Pound Quartzite by Mawson (1937). Forbes (1971) applied the name 'Bonney Sandstone Member' for the lower red part and 'Rawnsley Quartzite Member' for the fossiliferous upper white sandstone. Further studies indicate that the members show

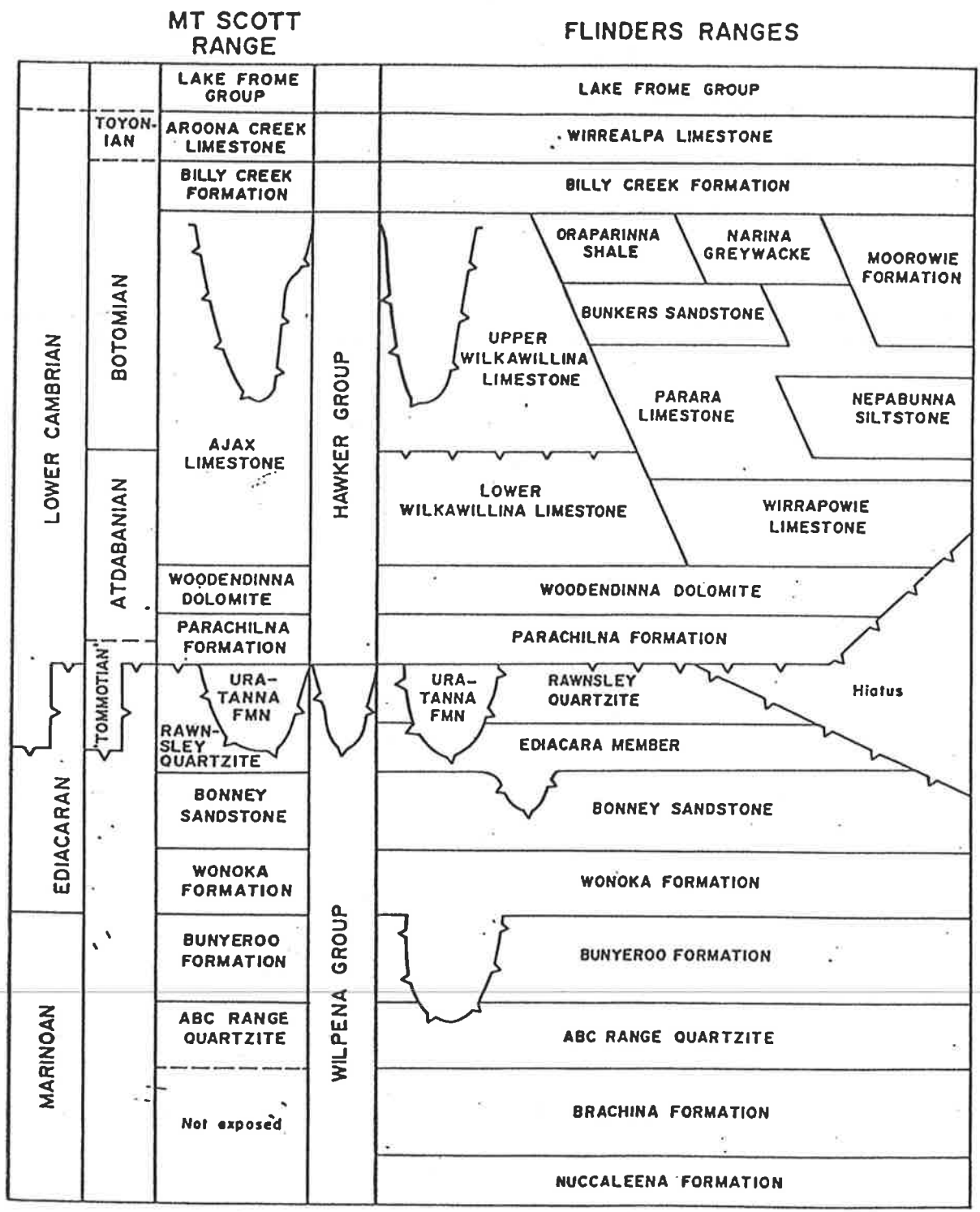


Figure 2.7 - Ediacaran and Early Cambrian succession of Flinders Ranges and Mount Scott Range, South Australia (after Jenkins, 1992).

characteristic and different lithologies and represent separate cycles of deposition (Jenkins, 1975, 1981, 1984; Jenkins *et al.*, 1983). Jenkins (1975) proposed formation status for the members of the Pound Quartzite and defined the name 'Bonney Sandstone' for the lower red sandstone and used the name 'Rawnsley Quartzite' for the upper white sandstone. Consequently the Pound Quartzite was elevated in rank to the Pound Subgroup. Jenkins *et al.* (1981, 1983) showed that an erosive surface occurs below the Rawnsley Quartzite which is irregular in form and has a relief of at least 10 metres and reported that a cross-bedded, channel-filling sandstone, containing lithified clasts of the Bonney Sandstone, occurs above the erosive surface and indicates a renewed transgression. The disconformity between the two formations was also reported by Gehling (1982).

The Bonney Sandstone comprises dominantly red, fine to very fine grained, haematite-cemented sandstone containing lenticular and wavy bedding, micro-cross-lamination, mudcracks, clay galls, well rounded granules and possible rain prints indicating subaerial exposure (Jenkins *et al.*, 1983). The sedimentary characteristics of the Bonney Sandstone suggest a shallow-water, highly oxidising environment with active currents but without separation of sands from silt. It possibly deposited in a tidally influenced marginal environment (Forbes, 1971; Jenkins *et al.*, 1983; Gehling, 1982). Wade (1970) reported a trail resembling Form "B" of Glaessner (1969) and probable medusoids from the formation at Brachina Gorge.

The Rawnsley Quartzite represents a renewed transgressive cycle of shallow marine sandy deposits. Jenkins (1975) proposed the name 'Ediacara Member' for the fossiliferous unit in the lower part of the Rawnsley Quartzite and Jenkins *et al.* (1983) used this name for several intervals of siltstone and thin to medium-bedded fossiliferous sandstone or quartzite and more massive unfossiliferous sandstone. The contact was later extended downwards by Gehling (1987, 1988).

Jenkins *et al.* (1983) identified five distinctive lithofacies within the Ediacara Member:

Facies 'A'- Siltstone and fine-grained sandstone. This comprises micaceous siltstone and fine-grained quartz arenite showing wavy-bedding. A trace fossil resembling form 'B' of Glaessner (1969) and rare, indistinct medusoids were reported from this facies. Based on common association of fine lamination or thin bedding this facies may be considered of

neritic shelf aspect. Facies 'A' tends to be more sandy and coarsens towards the medial part of the Ediacara Member representing a possible lagoonal environment, with more sandy sediments indicating tidal influence.

Facies 'B'- Heterolithic facies of laminated siltstone and interbedded orthoquartzite flags. The rocks of this facies show fine-grained partings and are commonly fossiliferous, with fossils occurring particularly on the base of the sandstone flags. This facies was deposited approximately in the same environment as the facies 'A' with a much larger, current-transported traction load.

Facies 'C'- Flaggy, wavy bedded orthoquartzite. This is the most fossiliferous part of the Ediacara Member containing sinuous mudcracks, flat-topped ripples, ladder ripples in wavy-bedded, flaggy, fine to medium-grained orthoquartzite with perfect parting. A mid intertidal sand flat environment was suggested for this facies.

Facies 'D'- Flaggy to thick-bedded orthoquartzite with silty partings. In this facies bedding surfaces were formed by silty partings and fossils are rare to quite abundant. This facies includes medium to coarse-grained feldspathic quartz arenites and possibly represents the lower part of a tidal flat sequence.

Facies 'E'- Mainly flat-stratified, thin to very thick-bedded, massive orthoquartzites. This facies consists of medium to coarse-grained quartz arenites containing typical flat clay galls and distinctive, subcircular concretionary structures. Facies 'E' represents a relatively high energy environment similar to a modern beach and barrier complex.

The vertical disposition of these facies in the Ediacara Member is generally complex. There are divergent opinions concerning inferred environments of deposition of the Ediacara Member (Preiss, 1987). Wade (1970) considered a low energy environment for the deposition of the Ediacara Member and supposed that the likely reactivation of the diapirs to the east provided a barrier to reduce wave action. However, Jenkins *et al.* (1983) considered that the role of the diapirs was merely to serve as nuclei for the formation of spits which extended to form a barrier complex.

Jenkins *et al.* (1983) considered that the fossilisation of the soft-bodied fauna was influenced by diurnal movement of sands during tidal deposition. Gehling (1983, 1987, 1988, and 1991)

considered that the depositional environment was an outer shelf setting below fair-weather wave base in which organisms were buried by storm-surge sand. Jenkins (1992) reported large polygonal desiccation cracks in highly fossiliferous parts of the section at Ediacara Range and in facies 'D' in part of the Heysen Range supporting the suggestion of deposition in tidal regimes subject to emergence. He also stated that the intense concentric crinkling of some of the remains resulted from desiccation (Jenkins, 1992). The preservation of virtually intact individuals of the community and delicate epichnial trace fossils associated with the fauna are not consistent with the initiation of the fossilisation by an energetic process such as a storm (Jenkins, 1992). Nedin and Jenkins (1991) also discussed that the presence of complete benthic communities indicated the inhabitants of a subtidal setting.

The upper part of the Rawnsley Quartzite represents transgressive, shallow tidal-shelf deposition including shore-face, barrier and migrating channel facies (Jenkins *et al.*, 1983

Gehling (1982, 1983) showed that the Ediacara Member has an erosional base cutting down some 300 m through the lower part of the Rawnsley Quartzite and he considered that only the upper part of the Ediacara Member occurs in the type and subsidiary sections of Jenkins *et al.* (1983). Gehling (1983) suggested both a eustatic and a tectonic cause for the erosional event within the Rawnsley Quartzite. Jenkins (1995) reported a new member within the lower part of the Rawnsley Quartzite from the "Nilpena" pastoral property. The new member comprises channel deposits filling erosional valleys cut down into older light coloured sandstones and contains fauna atypical of the type Ediacara assemblage present in the succeeding Ediacara Member. The channel deposits includes dark-red-brown siltstone, storm-deposited sand beds and manganese-stained, thin quartzite beds with abundant mudcracks in some parts, and represent an upward-shallowing sedimentary cycle indicative of an estuarine environment. Jenkins (1995) considered the fauna associated with the 'new member' as a *Rangeid-Hiemalora* Assemblage Zone containing the trace fossils *Helminthoidichnites tenuis*, *Planolites montanus*, *Helminthopsis*, and *Palaeopascichnus delicatus*, specimens of rangieds, *Hiemalora*, *Pteridinium ?carolinaensis* and *Kullingia* and rare samples of *Dickinsonia costata* and *Tribrachidium*. He assigned the type Ediacara assemblage to the *Dickinsonia costata* Assemblage Zone.

Trace fossils are abundant in parts of the Ediacara Member particularly in facies that initially consisted of alternating silt and sand layers (Facies B, C and D). Glaessner (1969) reported traces made by various worm-like sediment feeders and detritus feeders but there is no evidence of suspension feeding organisms. Virtually all of the bioturbation is parallel to the bedding plane and other than for escape structures, vertical burrows are absent (Jenkins *et al.*, 1983).

At the Ediacara Range an interval of sediments as narrow as 2.5-4 m in thickness separates the Ediacara Member and the surface of disconformity supposed to represent the base of the Cambrian (Glaessner and Daily, 1959; Daily, 1972, 1973, 1976; Jenkins *et al.*, 1983; Jenkins, 1995). However, this interval embraces several hundreds of metres of sediments elsewhere in the same province (Wade, 1970; Jenkins *et al.*, 1983; Jenkins, 1995; Mount, 1989, 1991, 1993a).

A complete regression of the sea occurred in the Adelaide Geosyncline at the end of the Proterozoic. A transgression recorded in the Early Cambrian led to widespread deposition of carbonates (Preiss, 1993).

The earlier, but more restricted deposition of the older Early Cambrian sediments is recorded by the Uratanna Formation in the central northern Flinders Ranges (Daily, 1973; Preiss, 1990). The sandstone of the Uratanna Formation fills basins and erosional channels cut into the underlying Pound Quartzite, sometimes to the level below that of the Ediacara fauna, and its thickness changes considerably over short distances suggesting that its base is diachronous (Daily, 1973, 1976; Daily *et al.*, 1982). Daily (1972, 1973) recorded the occurrence of the trilobite trace fossil *Rusophycus* in a thin sandstone lens 30 m below the top of the formation. It resembles *Rusophycus parallelum* from the basal Cambrian sandstone in Scania, Sweden and *Cruziana cantabrica* from the Early Cambrian Porma Sequence, Leon Province, Spain, and leading Daily to assign a Cambrian age. Daily (1973) also found the trace fossil *Curvolithus? davidis* (= *C. multiplex*) from the mid Uratanna Formation southwest of the termination of the Mount Scott Range. This ichnotaxon was reported by Webby (1970) from the Lintiss Vale Formation in western NSW, which Daily correlated with the Uratanna Formation. However, he considered that a late Proterozoic age could not be excluded. The fauna of the Lintiss Vale Formation was also correlated with the



Uratanna assemblages by Wade (1970), Webby (1984), Daily (1974, 1976, as cited by Webby, 1984), and Jenkins (1981). Daily (1973) also stated that the Camels Hump Quartzite below the Lintiss Vale Formation may indicate the transgression initiating the Cambrian sequence and is correlative with the basal quartzite of the Uratanna Formation.

In the Angepena area, Mount (1993b) recognised three units within the Uratanna Formation: a basal channel sandstone unit, a middle siltstone/sandstone unit and a succeeding cross-stratified sandstone unit. These were referred to as the lower, middle and upper members by Gauld (1976). Mount (1993b) considered the lower part of the formation to be of a Precambrian age, but, Jenkins *et al.* (1993) considered that it is difficult to give any distinct age to the lower part of the formation because of the non-occurrence of the body or trace fossils.

Mount (1993b) recorded the trace fossil *Phycodes coronatum* and unusual, organic-walled body fossils resembling *Sabellidites* from the Uratanna Formation, and considered that this forms a key biostratigraphic link between South Australia and the global stratotype for the Precambrian-Cambrian boundary in southern Newfoundland.

Based on the occurrence of trace fossils with Cambrian aspect such as *Treptichnus* (= *Phycodes*) *pedum*, and *Didymaulichnus miettensis* Jenkins *et al.* (1993) and Mount (1993b) considered a Cambrian age for the middle and upper part of the Uratanna Formation.

The Parachilna Formation contains the first abundant burrows of *Diplocraterion* (Dalgarno & Johnson, 1962, 1963,; Dalgarno, 1964; Daily, 1972, 1973, 1976, Preiss, 1987, 1990). In the area of the type section at Parachilna Gorge, it consists of white sandstone with scattered pebbles at the base overlain by 9.2 m of ferruginous weathering sandstone with numerous vertical burrows followed by sandy units, calcareous silts and shales with minor oolitic limestone (Dalgarno, 1964). The Parachilna Formation was deposited as a transgressive tidal and sand-sheet with increasing carbonate content upsection. Thomson *et al.* (1964; in Dalgarno, 1964) considered the base of the Parachilna Formation to terminate the Adelaide System.

Daily (1973) found numerous samples of *Plagiogmus* 23.5 m stratigraphically above the base of the Parachilna Formation in the Mount Scott Range. In this area, the base of the

Parachilna Formation, overlying the Uratanna Formation, is characterised by a metre-thick band of mud-cracked, rippled and heavily burrowed *Diplocraterion* sandstone (Daily, 1973). At the same locality, he also reported burrows of *Diplocraterion* penetrating the Pound Quartzite from the overlying Parachilna Formation (Daily, 1973). This phenomenon also was reported by Dalgarno and Johnson (1962) and Dalgarno (1964) from the Mount Frome, east of Reaphook Hill, leading Dalgarno (1964) to suggest a presence of a hiatus before deposition of the Parachilna Formation.

There is an assumption among many authors that a disconformity exists between the Parachilna Formation and underlying Pound Subgroup or Uratanna Formation (Daily, 1972, 1973; Daily *et al.*, 1982; Jenkins, 1975, 1981; Jenkins *et al.*, 1983, 1993; Preiss, 1987). However, Mount (1989) believed there is no significant time break at that interval. Mount (1989) reported that a locally gradational transition occurs between the Pound Subgroup and the Parachilna Formation and the top of the Pound Subgroup was penetrated by *Diplocraterion* burrows originated from the overlying Parachilna Formation. Thus, the Pound Subgroup apparently was not completely lithified prior to the deposition of the Parachilna Formation. However, lack of lithification of the Pound Subgroup does not necessarily imply continuous sedimentation between it and the Parachilna Formation. It merely implies lack of sedimentation. Mount (1989, 1991) also believed that the abrupt appearance of *Diplocraterion* within the lowermost part of the Parachilna Formation was due to facies changes favourable for the formation and/ or preservation of the *Diplocraterion*, rather than to be an indication of a stratigraphic break, an assumption strongly argued against by Nedin and Jenkins (1991).

Mount (1989) reported that the 'incisions' reported by Daily (1973) from the base of the Uratanna Formation are, in most cases, syndepositional grabens locally filled by mass-flow sands, and suggested that the some part of the Uratanna Formation may be correlative with uppermost Pound Subgroup. However, Jenkins *et al.* (1993) stated that the shales of the Uratanna Formation possibly resemble the lithology of older parts of the Ediacara Member, but certainly have a quite different vertical stratigraphic position. Mount (1989, 1991) also disputed the occurrence of an unconformity between the Uratanna Formation and Parachilna Formation and interpreted the lateral changes in the thickness of the Uratanna Formation, which had previously been used to support the existence of an unconformity (Daily, 1973),

as a product of localised syndepositional graben formation in the northern Flinders Ranges. Nedin and Jenkins (1991) argued that there is no major syndepositional faulting associated with the deposition of the Uratanna Formation.

An Early Cambrian age is assigned to the Parachilna Formation in its type section because of the occurrence of the geographically widespread U-shaped burrows of *Diplocraterion* Torell (Dalgarno, 1964; Glaessner, 1969; Daily, 1973) near base of the formation and other trace fossil of Cambrian aspect (Daily, 1963, 1972) such as: *Treptichnus (=Phycodes) pedum* and *Plagiogmus*. Daily (1973) has also reported a specimen of *Bemella* from the Parachilna Formation.

Crimes (1987) considered that the Uratanna Formation and the top of the Pound Subgroup are probably no older than upper Tommotian and might even be Atdabanian, but Glaessner (1990) argued against this notion and stated that the Ediacara fauna is stratigraphically located below any reasonable base of the Cambrian. Mount and McDonald (1992) suggested that the lack of Ediacaran-type fauna in suitable facies, within the Uratanna sequence, coincides with the notion that there is no preserved overlap between the Ediacaran and Cambrian fauna.

#### **2.4.2. Distribution of Latest Proterozoic to Early Cambrian sediments in South Australia**

Daily (1963, 1974, 1976) correlated the Parachilna Formation with part of the Winulta Formation and the upper member of the Mount Terrible Formation based on the occurrence of trace fossils and one occurrence of the gastropod *Bemella* in the Parachilna Formation. The Winulta Formation (Daily, 1974, 1976) consists of reddish and paler coloured cross-bedded sandstones, arkoses and conglomerates with minor intercalated shales and siltstone. In its type section it is 100 m in thickness. The formation rests unconformably on the older Precambrian crystalline basement and is conformably overlain by the Kulpara Formation in the Winulta district and elsewhere. Daily (1974, 1976) reported fragments of hyolithids and spicules of the sponge *Chancelloria* in well cuttings taken through a 3 metre interval of glauconitic and pyritic sandstones with grey siltstone interbeds. The sandstone commences

30 m above the base of the formation in the Stansbury West No. 1 Well. Thus, he assigned an initial Early Cambrian age to that part of the formation.

Daily (1990, actually 1974 but published posthumously in 1990) reported many characteristic trace fossils from the Winulta formation in the Winulta and Maitland district, Yorke Peninsula including *Plagiogmus arcuatus*, *Treptichnus* (= *Phycodes*) *pedum* and rare examples of *Diplocraterion*. In the Winulta area the trace fossils occur about 20 m above the base of the formation. Thus, Daily (1974, 1976) correlated the Winulta Formation with the Parachilna Formation; the Allua Formation within the Amadeus Basin; and the Grant Bluff Formation in the western Georgina Basin. Daily (1976) also suggested a correlation of the middle member of the Mount Terrible formation with the Uratanna Formation.

The Mount Terrible Formation (Daily, 1963) is the oldest unit of the Normanville Group and comprises three members in its type area near the Sellick Hill. The lowest member consists of 12 m of feldspathic sandstone and arkose. The base fills minor erosional hollows cut into the underlying Adelaidean rocks. A 60 m thick grey siltstone containing phosphate nodules in places overlies the lower part, which is followed by a 13 m thick cavernous weathering sandstone. The topmost third member is conformably overlain by carbonates of the Wangkonda Formation (Daily *et al.*, 1982).

Daily (1972) suggested that the Early Cambrian boundary should be located at the base of the Mount Terrible Formation in the Mount Lofty Ranges and at the base of the transgressive Uratanna Formation in the Flinders Ranges. The location of the Precambrian-Cambrian boundary within the Uratanna Formation was first proposed by Mount and McDonald (1992). Christie-Blick *et al.* (1995) considered the Precambrian-Cambrian boundary to be located in the lower part of the middle member of the Uratanna Formation according to the distribution of known trace fossils. Christie-Blick (1992) suggested that the incised valley at the base of the Uratanna Formation may be due to large-scale evaporitic lowering of sea level in an isolated basin.

A prolonged phase of mainly carbonate deposition followed the initial Early Cambrian sediments. The lithologies and thickness of the resulting carbonates were predominantly influenced by changes in water depth and subsidence rates (Daily, 1972). Abundant small shelly fossils (Bengtson *et al.*, 1990) and archaeocyathans (Gravestock, 1984) are reported

from these carbonates. The Early Cambrian carbonates have been studied by numerous authors (e.g. Daily, 1972; Gravestock, 1984; Alexander & Gravestock, 1990; Clarke, 1990; Bengtson *et al.*, 1990). Their occurrence and geological review are beyond the scope of the present study.

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# Chapter 3

## Arumbera Sandstone *sensu lato*

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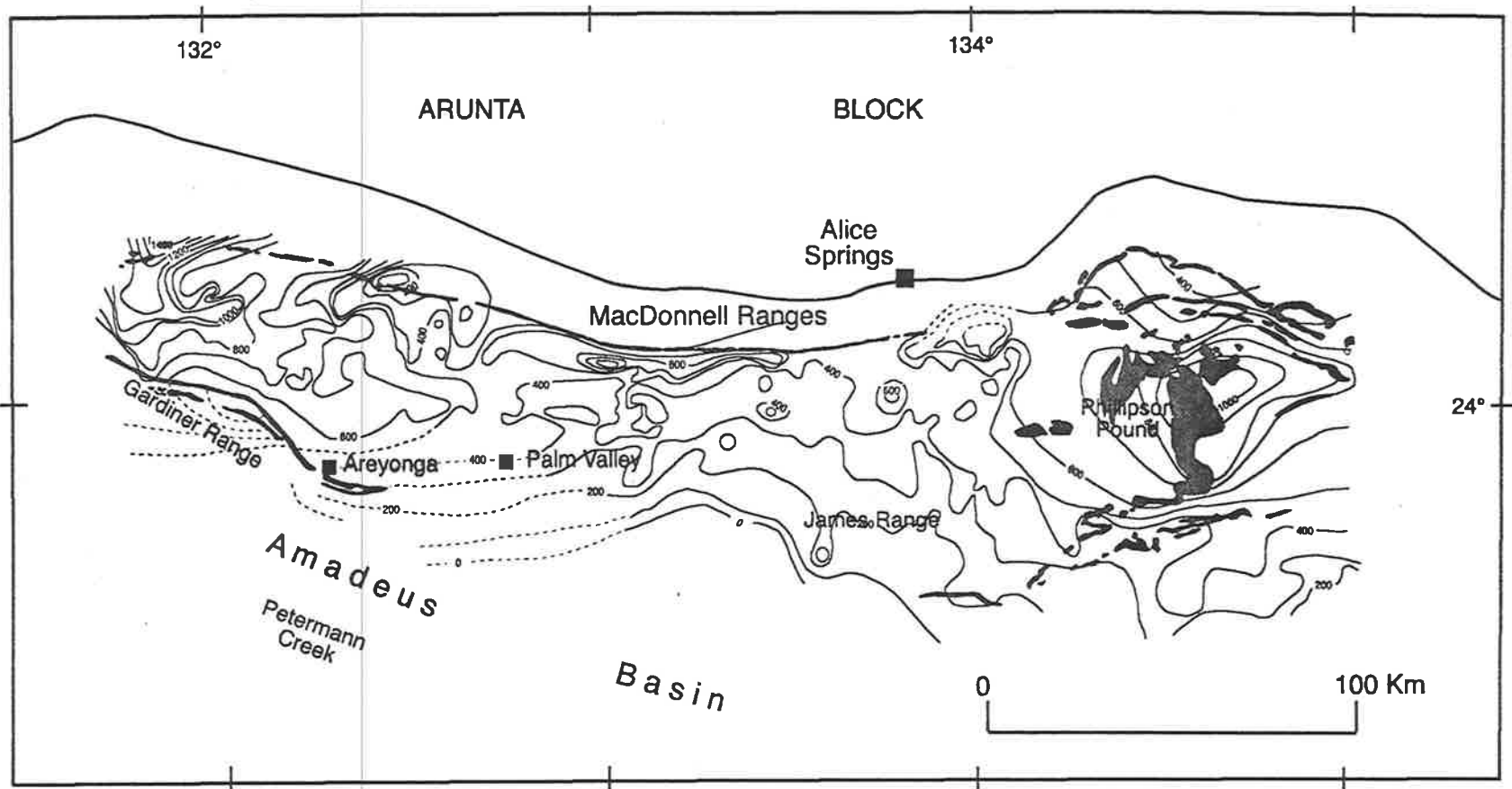
### 3.1. Introduction

The term "Arumbera Sandstone" *sensu lato* is used in this chapter as originally defined by Wells *et al.* (1967) to represent the whole sequence between the Julie Formation and the Todd River Dolomite. A new stratigraphic classification is introduced informally herein (Fig. 3.1) including the term "Arumbera Formation" which is introduced herein to refer to the lower part of the succession. The Arumbera Formation is equivalent to the Arumbera Sandstone *sensu* Daily (1976). Daily's other units (Box Hole and Allua Formations) are also adopted informally.

The Arumbera Sandstone *sensu lato* is the basal part of the Pertaoorrta Group (Fig. 2.2) and is widely distributed throughout the Amadeus Basin. Figure 3.2 shows outcrops and an isopach map of the Arumbera Sandstone *sensu lato* over the Amadeus Basin. The succession mainly crops out on the northeastern part of the basin and along the MacDonnell Ranges. It is considered to straddle the Precambrian-Cambrian Boundary based on the occurrence of rare soft bodied fossils, an excellent assemblage of trace fossils and very rare shelly fossils (Glaessner, 1969; Wells *et al.*, 1967; Daily, 1972, 1976; Walter *et al.*, 1989; Haines, 1991, McIlroy *et al.*, 1997). Because of its stratigraphic importance and hydrocarbon content it has been the subject of many studies (e.g. Gorter, 1984; Lindsay, 1987; Lindsay and Korsch, 1991; Lindsay and Gorter, 1993).

		Wells <i>et al.</i> 1967	Daily 1976	Conrad 1981	Lindsay 1987	Oaks <i>et al.</i> , 1991	McIlory <i>et al.</i> , 1997	This study	
Cambrian	Todd River Dolomite								
	Arumbera Sandstone <i>sensu lato</i>	Unit IV	Allua Formation	Unit 4b Unit 4a	Sequence 2	Unit 4B Unit 4A	Member IV	Allua Formation	upper lower
		Unit III	Box Hole Formation	Unit 3		Unit 3	Member III	Box Hole Formation	upper middle lower
		Unit II	Arumbera Sandstone <i>sensu stricto</i>	Unit 2c Unit 2b Unit 2a	Sequence 1	Unit 2C Unit 2B Unit 2A	Member II	Arumbera Formation	
Unit I	Unit 1	Unit 1		Member I					
Precambrian	Julie Formation								

Figure 3.1 - Various divisions of the Arumbera Sandstone, *sensu lato*.



**Figure 3.2** - An isopach map and outcrops of Arumbera Sandstone *sensu lato* Amadeus Basin (C.I.=100 m; redrawn after Lindsay *et al.*, 1987).



### 3.2. Previous Studies

Originally referred to as the "number three Quartzite" (Madigan, 1932) the Arumbera Sandstone *sensu lato* was formally defined by Prichard & Quinlan (1962) as the 'Arumbera Greywacke'. It was redefined as the 'Arumbera Greywacke member' of the Pertaoorra Formation by Wells *et al.* (1965). Wells *et al.* (1967) changed the name to the Arumbera Sandstone.

In general, the Arumbera Sandstone *sensu lato* consists of red-brown and white sandstone with minor siltstone, shale, conglomerate and dolomite. It tends to form prominent strike ridges.

One interpretation of the Arumbera Sandstone is that it generally consists of two upward shallowing sandstone and siltstone sequences, with minor interbeds of glauconitic sandstone and mud-shale deposited along the northern and north-eastern parts of the Amadeus Basin (Lindsay, 1987). Divisions of the formation according to different authors are shown on figure 3.1 and discussed below.

Wells *et al.* (1967) divided the Arumbera Sandstone into 4 units in the northeastern part of the Amadeus Basin. Many authors followed this four-fold division of the Arumbera Sandstone in which members I and II represent sparsely fossiliferous or unfossiliferous older parts of the succession. In particular Unit I comprises thin to medium bedded siltstones and sandstones and Unit II is a thick to massive bedded, red-brown sandstone (Conrad, 1981, Lindsay, 1987). Units III and IV are commonly nominated as the trace fossil bearing Cambrian part of the succession (e.g. Wells *et al.*, 1965; Daily, 1972, 1976; Lindsay, 1987; Walter *et al.*, 1989; McIlroy *et al.*, 1997). The four-fold division of Wells *et al.* (1967) loses its definition in the platform area immediately south of the Central Ridge. Although Wells *et al.* (1967) proposed four-fold divisions for the Arumbera Sandstone *sensu lato*, they used a threefold division to draw stratigraphic columns for their sections at Ross River Gorge and the Todd River Anticline.

On the basis of lithology and a sequence of soft-bodied fossils and trace fossils, Daily (1972, 1976) introduced a threefold subdivision for the Arumbera Sandstone in which his Unit 1, informally named the "Arumbera Sandstone" (*sensu* Daily, 1976), broadly corresponds to

units I and II of others. His Unit 2, which he recognised informally as the silt rich "Box Hole Formation" (Daily, 1976), overlapped part of Unit III of Wells *et al.* (1967) and his Unit 3, informally nominated as the "Allua Formation" (Daily, 1976), is the equivalent of Unit IV of most other authors. Daily (1972) stated that an erosive surface of disconformity exists between his first and second units. The threefold division was also followed by Cowie & Glaessner (1975), Walter *et al.*, (1989) and Kruse and West (1980). Cook (1982), in a stratigraphic column for the Amadeus Basin, followed the four-fold division of Wells *et al.* (1967). However he erroneously considered his Unit II as the Box Hole Formation. He also indicated an unconformity separating Unit I and Unit II of the Arumbera Sandstone (according to his chart, below the Box Hole Formation).

Based on a detailed magnetostratigraphic study, Kirschvink (1978a, b) supported Daily's (1972) view and confirmed the existence of an unconformity within the Arumbera Sandstone *sensu lato* considered to reflect the Petermann Ranges Orogeny. This was further confirmed by additional magnetic data in Burek *et al.* (1979). The basal part of the Arumbera Sandstone predominantly shows reversed polarity and the remainder is mainly of normal polarity (Burek *et al.*, 1979). However, Walter *et al.* (1989) found no evidence of an unconformity within the formation and stated that the widely quoted intra-formational unconformity within the Arumbera Sandstone (e.g. Cowie and Glaessner, 1975 ; Kirschvink, 1978a) was the result of a misunderstanding. Walter *et al.* (1989) argued that the interpretation of the magnetostratigraphy depended on an assumption that rates of sedimentation did not vary significantly when comparing widely spaced sections representing a deltaic sequence. This latter argument is considered to be invalid for reasons given in a later chapter. Lindsay (1987) and Walter *et al.* (1989) considered that Kirschvink's (1978) data can not be fully interpreted until the magnetostratigraphic results have been carefully related to palaeoenvironmental interpretations. Walter *et al.* (1989) agreed with Hamp (1985) that Arumbera IV was eroded prior to deposition of the Middle Cambrian Hugh River Shale. These authors considered the Arumbera Sandstone to be a continuous depositional sequence spanning the Precambrian-Cambrian transition, though, they could not dispute the possibility that there might be a paraconformity within the formation. However, Jenkins *et al.* (1988) disputed the existence of a continuous succession within the Arumbera Sandstone *sensu lato*

and suggested that the failure to recognise a depositional break is evidently based on cursory examination of the unit.

Based on sequence stratigraphy, Lindsay (1987) defined two depositional sequences within the Arumbera Sandstone. The lower sequence comprises silty shale at the base with thin, fine-grained sandstone beds increasing up-section. Sequence 2 begins in fissile siltstone resembling sequence 1 and thick sandstone units appear about half way through it. As in sequence 1, the lower part of sequence 2 appears to pass upward from a basinal or pelagic facies, through a shoreface environment, to a coastal plain and deltaic association (Lindsay, 1987). Toward the top of the sequence the thicker sandstone units disappear and thinly bedded shale and carbonate dominate. This part of the section has been mapped and named the Todd River Dolomite and appears to have been deposited in a tidal flat environment (Kennard and Lindsay, 1991).

### 3.3. Lithology and facies analysis of the Arumbera Sandstone *sensu lato*

Various authors have proposed that the Arumbera Sandstone *sensu lato* be divided into different divisions which are not consistent with one another and there are many changes in the boundaries between the sub-divisions (Fig. 3.1). In this study, the lithology of the Arumbera Sandstone is described from the measured stratigraphic sections made available from the north-eastern and central western parts of the Amadeus Basin. Many authors who worked on the Amadeus Basin or other basins within central Australia, referred or compared their studies and interpretations to the studies of Wells *et al.* (1965, 1970). However, the present interpretation of the Arumbera Sandstone *sensu lato* is different from the one proposed by Wells *et al.* (1965) and similar to the classification of Daily (1972, 1976).

Following Daily (1972, 1976) the sequence between the Julie Formation and Todd River Dolomite (= Arumbera Sandstone *sensu lato*) is divided herein into three formations namely the Arumbera, Box Hole and Allua Formations. The formations are established on the basis of their lithology and fossil content. For this purpose, lithostratigraphy of the succession and the distribution of trace fossils in three sites, covering six sections, from the Amadeus Basin have been investigated including Ross River and Cyclops Bore, located on the north eastern part of the basin, and Hugh River from the central western sector. The first two comprise

representative outcrops of the Precambrian and Cambrian transitional interval with abundant trace fossils. The Hugh River section is much thinner in comparison with the other sections. The sections from the Amadeus Basin have been measured from top of the Arumbera Formation (restricted) upto the lower part of the Todd River Dolomite during two field excursions made by the late B. Daily and R. J. F. Jenkins (1972 and 1975) and an honours study undertaken by Thomson (1992). The measured sections are as follows:

- ***Cyclops Bore area.*** Three sections have been measured from the Cyclops Bore area:

- Cyclops section measured from the eastern bank of the creek, west of Cyclops Bore (Fig. 3.3).
- Cyclops West I section measured about 300 metres west of the creek. At this section numerous trace fossils were collected as float due to the topography of the area (Fig. 3.4).
- Cyclops West II section measured about 500 metres further toward the west (Fig. 3.5).



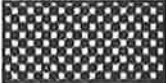



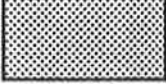





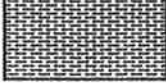

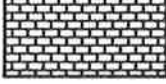

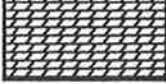



- ***Ross River area.*** Two section were measured from the Ross River area;

- The West Ross River section was measured on west bank of the Ross River, southwest of the Ross River tourist camp (Fig. 3.6).
- The East Ross River was measured on east bank of the Ross River, southwest of the Ross River tourist camp (Fig. 3.7).

- ***Hugh River.*** One section was measured from this area;

- Hugh River Section measured in a creek (0347 7366) west of Jay Creek on Hermannsburg 1:250.000 Geological Series (Fig. 3.8).

The measured sections do not cover the lower half of the Arumbera Sandstone *sensu lato* and lithostratigraphic description given for the Arumbera Formation (restricted) is based on information available from the literature.

	Rounded quartz grains		Laminated <10 mm
	Conglomerate		Thin 1 - 10 cm
	Coarse sandstone		Medium 10 - 30 cm
	Medium grained sandstone		Thick 30- 100 cm
	Siltstone with sandstone interbeds		Cross-bedded
	Siltstone		Mud cracks
	Shale		Ripple-marks, wave
	Limestone		Ripple marks, current
	Dolomite		Trace fossils
			Bioturbation
			Coarsening upward succession

Gl	Glauconitic	f	fine	0.125 - 0.25 mm
Mi	Micaceous	m	Medium	0.25 - 1.0 mm
Qz	Quartzose	c	Coarse	1.0 - 2.0 mm
Ca	Carbonaceous	vc	Very coarse	>2.0 mm
Mg	Dolomitic	o	Specimens found in float	
Fs	Feldspathic	●	Specimens found <i>in situ</i>	
Ha	Pseudomorph of Halite			
Gy	Gypsum crystals			

Key for the stratigraphic columns

# Cyclops

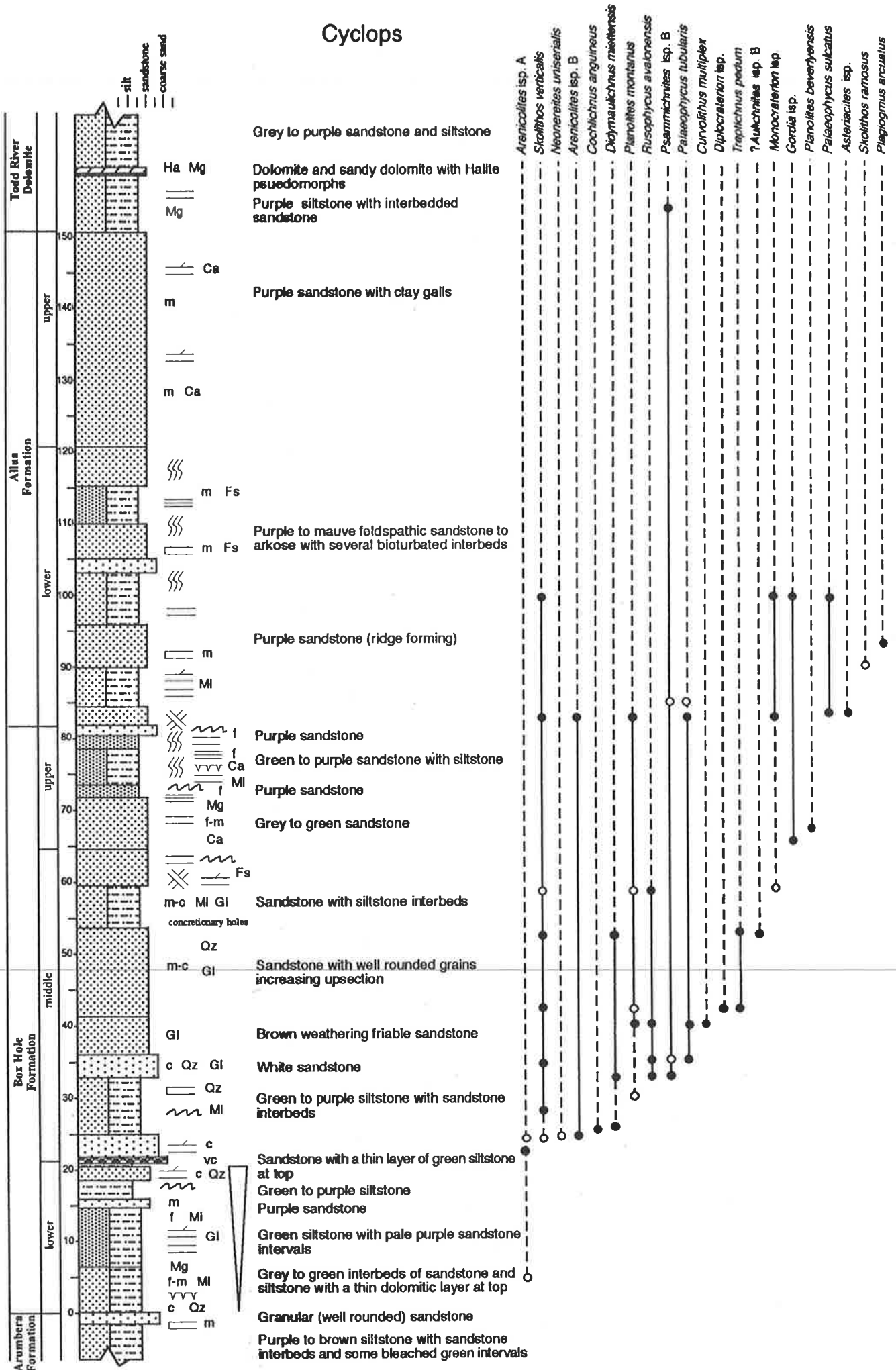
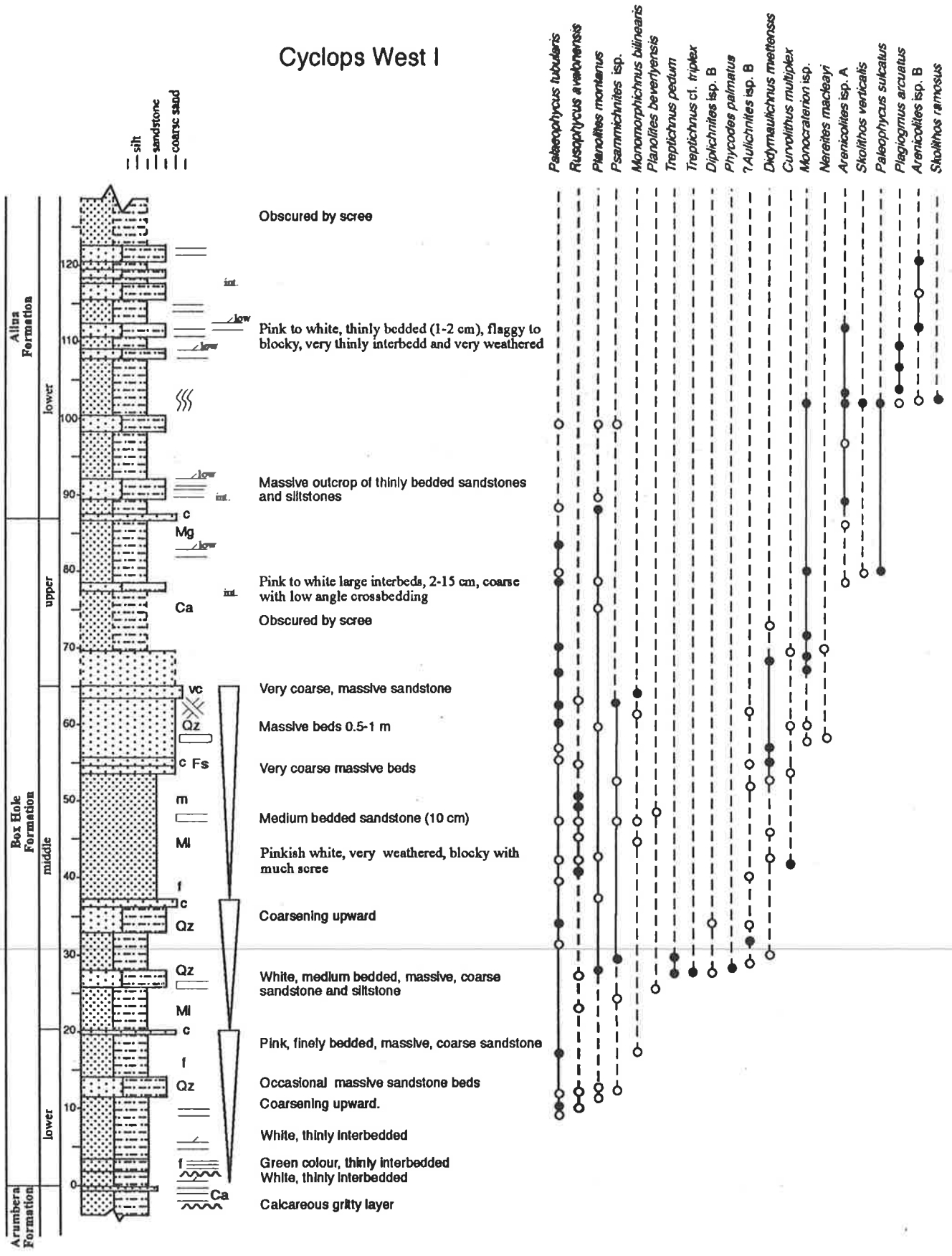


Figure 3.3 - The late Precambrian - Early Cambrian succession at Cyclops section, Cyclops Bore.

# Cyclops West I



**Figure 3.4 - The late Precambrian - Early Cambrian succession at Cyclops West I section, Cyclops Bore.**

# Cyclops West II

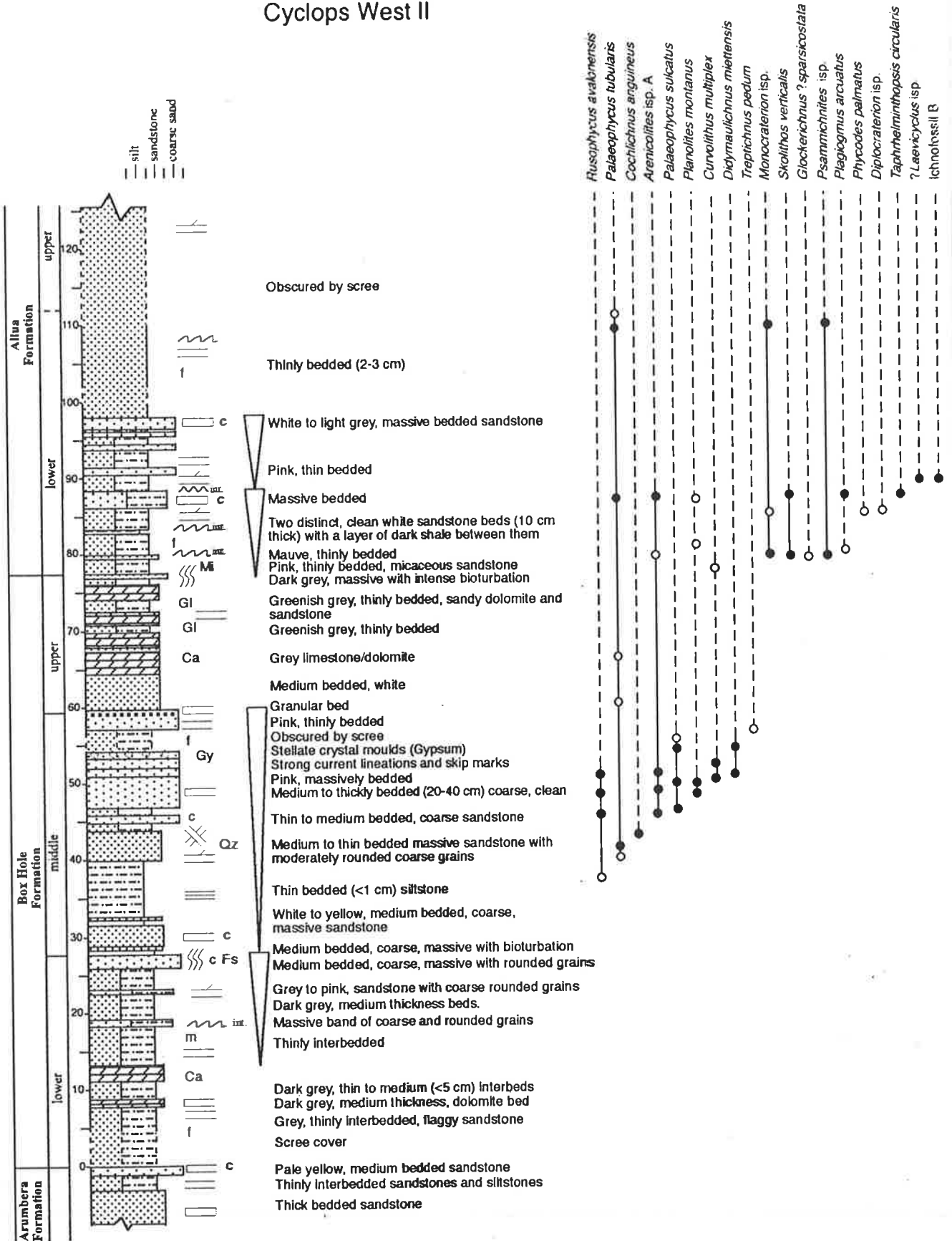


Figure 3.5 - The late Precambrian - Early Cambrian succession at Cyclops West II section, Cyclops Bore.



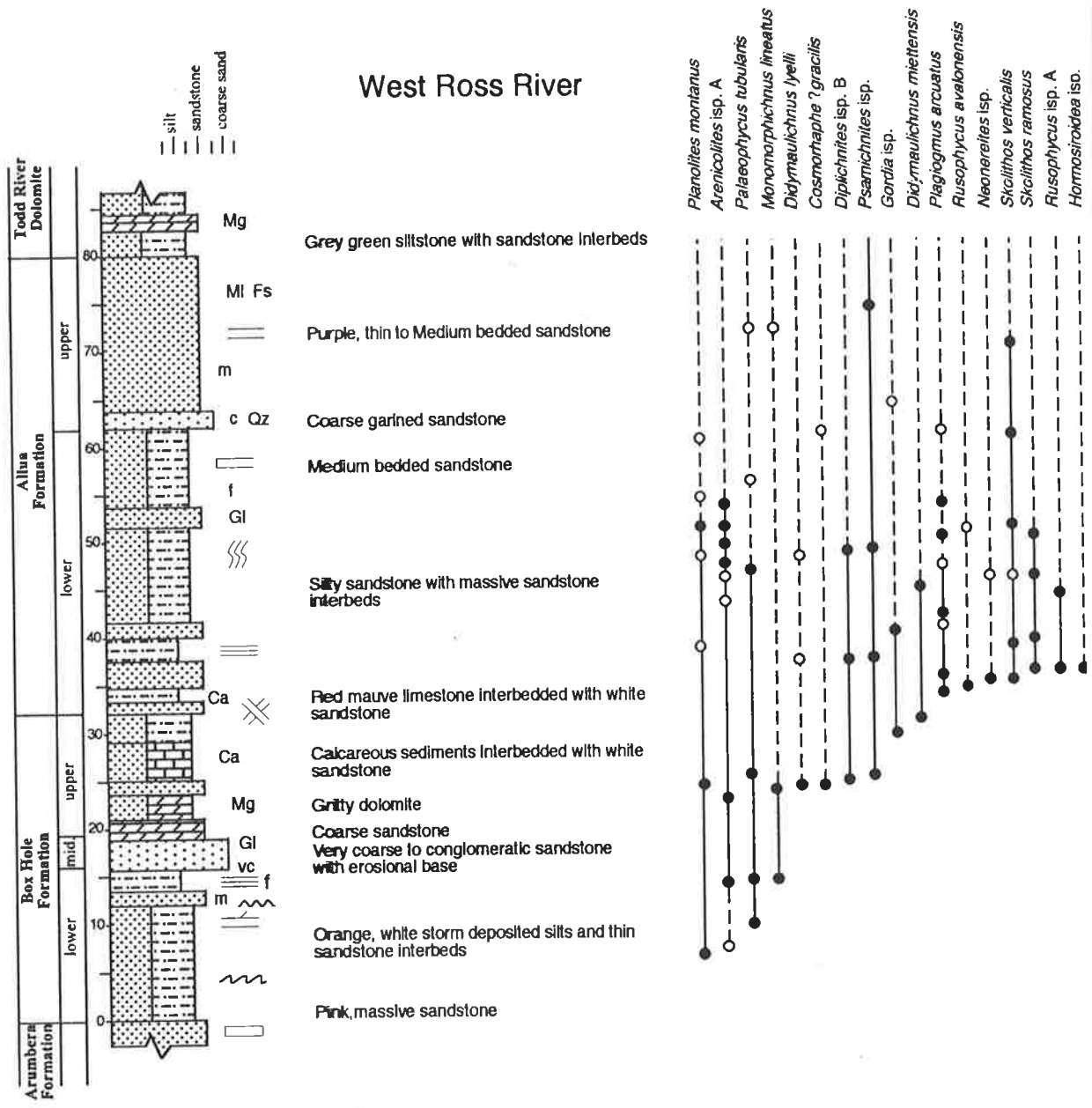


Figure 3.6 - The late Precambrian - Early Cambrian succession at West Ross River secti

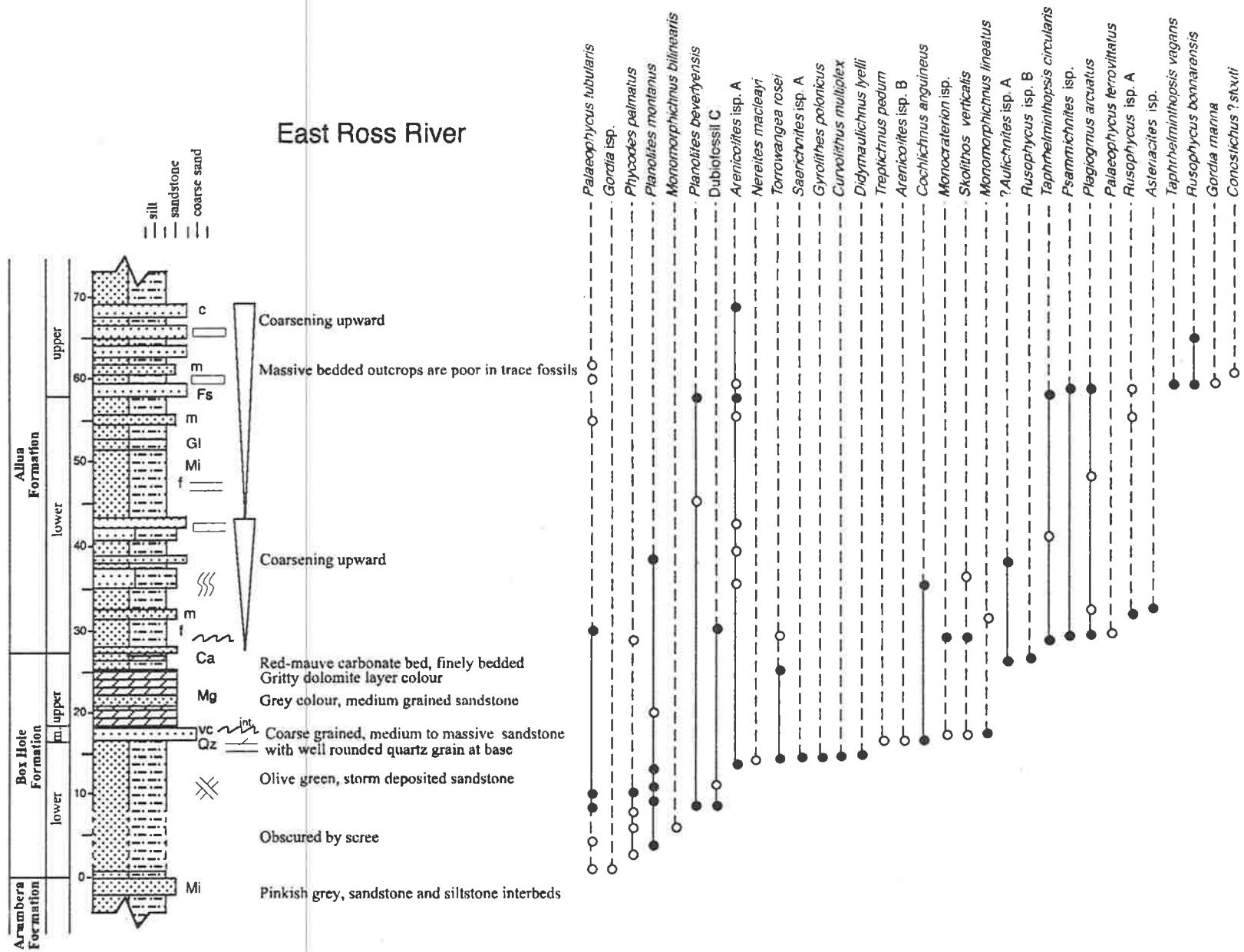


Figure 3.7 - The late Precambrian - Early Cambrian succession at East Ross River section, Ross River.

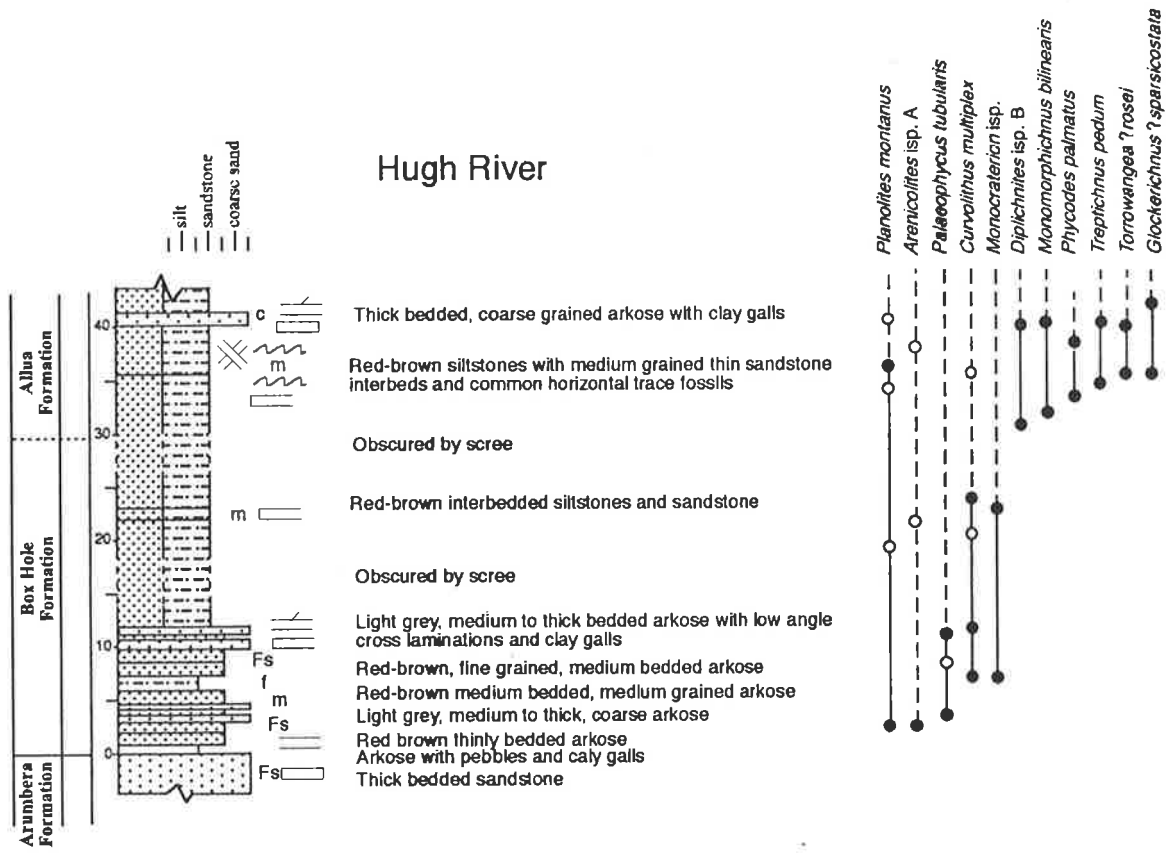


Figure 3.8 - The late Precambrian - Early Cambrian succession at Hugh River.

### 3.3.1. Arumbera Formation (restricted)

This formation includes Unit I and II and in some places (Western MacDonnell Ranges and Cyclops Bore) the lower part of Unit III of Wells *et al.* (1967).

#### 3.3.1.1. The lower contact

In general, the contact marks a distinct change in lithology in which grey-green shale with thin carbonate layers of the Pertatataka Formation or the shallow marine oolitic carbonate of the Julie Formation underlie the red-orange, lenticular, conglomeratic sandstone of the basal Arumbera Formation. The contact between the Arumbera Formation and underlying formations (Bitter Springs, Julie and Pertatataka Formations) is a regional unconformity. An angular unconformity and valley incisions of about 100 m or less occur at the southern margin of the Carmichael Sub-basin, on the margin of the Ooraminna Sub-basin, on the flanks of the Central Ridge, and over localised highs scattered within the basin. This is evidently related to movement of older salt deposits (Lindsay, 1987; Wells *et al.*, 1965; Kennard and Lindsay, 1991). The discordant relationship is clearly visible on aerial photographs of the central Gardiner Range area, where at least 60 m of the Julie Formation were eroded prior to the deposition of the Eninta Formation (= "Arumbera Sandstone" *sensu lato*, Wells *et al.*, 1965; Kennard and Lindsay, 1991). Hamp (1985, p. 23) reported on the contact between the Arumbera Formation and underlying Pertatataka Formation in the Carmichael Sub-basin, and the contact with the Julie Formation in the Missionary Plain Trough. In both areas the contact is sharp and although conformable, probably indicates a disconformity. Conrad (1981) reported that the contact with the Julie Formation is sharp at Shannon Bore. The same contact has been reported as an unconformity particularly where the Arumbera Formation onlaps the Central Ridge (e.g. Cook, 1968; Oaks *et al.*, 1991).

Conrad (1981 p.37), Lindsay (1987) and Walter *et al.* (1995) reported a gradational contact between the Arumbera Formation and the underlying Julie Formation in the north-eastern part of the basin, considered as a depocentre by many authors. Lindsay (1987) and Lindsay and Korsch (1991 p. 18) believed that this contact is conformable over most of the area especially in the deep sub-basins. However, Kennard and Lindsay (1991, fig. 2) considered an unconformity between the Arumbera Formation and the older Proterozoic sediments over

all areas of the Amadeus Basin including the sub-basins. In addition, their figure 3 shows a significant hiatus prior to the deposition of the Arumbera Formation. This contact has, alternatively also been interpreted as a paraconformity (Lindsay *et al.*, 1993).

The inferred erosional break at the base of the Arumbera Formation (restricted) has been related to the compressional Petermann Ranges Orogeny, which deformed earlier sequences at the southern margin of the basin (Wells *et al.*, 1965, 1967; Forman, 1966; Lindsay, 1987; Lindsay and Korsch, 1991; Kennard and Lindsay, 1991).

### 3.3.1.2. *Lithology of the Arumbera Formation (restricted)*

The lower part of the formation consists of fine-grained, red, highly fissile, silty shale in the greater part of the basin (western MacDonnell Ranges). Towards the west and south-west, the basal part consists dominantly of coarser conglomerate and conglomeratic sandstone variably known as the Mount Currie Conglomerate, Ayers Rock Conglomerate, Quandong Conglomerate and Eninta Sandstone, all believed to be equivalents of the "Arumbera Sandstone" *sensu lato*, deposited closer to the source area (Wells *et al.*, 1965, 1967; Lindsay, 1987; Lindsay and Korsch, 1991, Conrad, 1981; Phillips, 1986). Further to the west, at least the lower part of the Cleland Sandstone is considered to be an equivalent of the "Arumbera Sandstone" *sensu lato* (Wells *et al.*, 1965). Lindsay and Korsch (1991) considered the Cleland Sandstone to be a fluvial link between the alluvial fans of the Mount Currie Conglomerate and the coastal plain to shallow marine deposits of the "Arumbera Sandstone". However, Oaks *et al.* (1991) in a stratigraphic chart for the basin (their fig. 2), considered a higher stratigraphic position for the Cleland Sandstone, which with a significant break, rests on older formations.

Higher in the section (at Ooraminna Sub-basin), thin irregularly spaced fine-grained sandstone beds appear, with their numbers and thickness increasing upward. The sandstone beds, which are mostly 2-3 cm thick all have a sharp base and a gradational upper contact, and exhibit fine lamination and climbing ripples (Lindsay, 1987, Lindsay and Korsch, 1991). Lindsay (1987) considered these sandstone layers to be distal turbidites deposited in a pelagic environment representing divisions C-E in terms of the Bouma classification of turbidites. However, Conrad (1981) in his measured stratigraphic section of Wyeecha Spring, reported

casts of gypsum crystals in this unit associated with oscillation ripples, wedging channels 5-10 m deep and 10-15 m in lateral extent, and herringbone laminae, indicative of much shallower environments. It should be noted that Wyeecha Spring is located in the Ooraminna Sub-basin for which the contact between the Arumbera Sandstone *sensu lato* and the top of the Julie Formation is reported to be gradational (Conrad, 1981). Conrad (1981) further reported various sedimentary structures indicative of beaches within the lower part of the succession, including xi cross-stratification, truncated wave ripple laminae, planar parallel laminae and heavy mineral concentrations.

Higher in the section (at Ooraminna Sub-basin), thick arkosic sandstones appear abruptly and ultimately become the dominant lithology. These thicker sandstone beds are fine-grained and weakly laminated. They exhibit sharp lower contacts, with flute and load casts, and commonly have poorly developed hummocky cross stratification and numerous water escape structures (Kennard and Lindsay, 1991 p.176). The lower of these beds are relatively few and have a maximum thickness of 1 m. Higher in the section these sandstone layers increase in number and are up to 2-3 m thick. As the sandstone beds thicken up-section, they tend to become more massive and featureless. Lindsay (1987) reported that approximately 10% of the sandstone units are highly deformed as a result of soft-sediment failure. These sandstone beds are interpreted to have accumulated by storm or flood events in shoreface or slope environments (Lindsay, 1987). The succession from the base of the formation up to this level has been included within Unit I of Wells *et al.* (1967).

Following the deposition of the lower recessive part of the Arumbera Formation, massive, largely structureless sandstone was deposited within the Ooraminna Sub-basin. Conrad (1981) reported a sharp contact between the massive sandstone and the underlying recessive part marked by shallow scours at Bloodwood, Allambarinja and in the Wyeecha areas. Phillips (1986, p.23) also reported a sharp contact between these units and although he suggested the possible existence of a disconformity at this level, the contact was interpreted to be the result of northward migration of a fluvial distributary system. These sandstones rarely exhibit large scale channels. This part of the section is generally more varied lithologically than the lower part (Lindsay, 1987). In the Missionary Plain Trough and the Carmichael Sub-basin, this upper part is not monolithic and comprises shallowing upward cycles of predominantly massive sandstone. The sandstones are internally laminated and are

highly contorted due to both soft sediment deformation and water escape structures. The soft sediment deformation increases up-section (Lindsay, 1987).

Higher in the section, Conrad (1981, p.48) reported a sandstone and mudrock succession which is wedge-shaped in its wider distribution and possibly is a local transgressive deposit. The sandstones coarsen upward and represent small lenses of conglomerate and conglomeratic sandstone in the Bloodwood, Phillipson No. 1, Allambarinja and Brumby areas. Up-section, massive, cross-bedded sandstones which are locally intersected by large channels were deposited, with common slump folds and mud-chips within the channels. On the flanks of the Central Ridge, major cycles within this part of the Arumbera Formation terminate locally in poorly sorted conglomerate about 2 m thick, containing sub-angular to well-rounded clasts of grey, white and green chert and red-brown and white silicified sandstone (Wells *et al.*, 1965). The conglomeratic layers were interpreted as braided-stream deposits (Lindsay, 1987, p.1391). The conglomeratic nature of this part of the formation is also reported by Conrad (1981) and Wells *et al.* (1965) from the north-eastern area and by Phillips (1986) from the central part of the basin. This part of the section is absent in the Gardiner Range and the James Range 'B' anticline (Phillips, 1986), in the Shannon area (Conrad, 1981) and in the Missionary Plain Trough (Hamp, 1985, p.24). The sandstone layers within this succession form prominent strike ridges and are entirely fluvial toward the west.

The upper part of the formation crops out over a vast area and Lindsay (1987) interpreted the sandstones as part of a coastal or deltaic plain association. These massive ridge forming sandstones were grouped as Unit II in the four-fold division of Wells *et al.*, (1967).

In some areas (e.g. Cyclops Bore) fissile, grey-green, featureless siltstones represent the top of the formation. There are abundant well sorted sandstone beds within this silty succession. The sandstone layers exhibit internal lamination and climbing ripples and have sharp upper and lower contacts. A basinal or pelagic environment has been suggested for this part of the succession (Lindsay, 1987). However, desiccation mudcracks occur within this interval (sections reported in this study) and Conrad (1981) also reported rain drop-impressions, evidence obviously indicative of a shoreface setting. This part comprises the lower part of Unit III of Wells *et al.* (1967).

The Arumbera Formation has a maximum thickness of about 700 m in the Ooraminna Sub-basin and 800 m in the Carmichael Sub-basin. It is 200 - 300 m thick in the Missionary Plain Trough (calculated from data given in Wells *et al.*, 1970 and Lindsay, 1987).

### 3.3.2. The contact between the Arumbera and Box Hole Formations

A low relief surface of erosion, corresponding approximately with the appearance of trace fossils of Cambrian aspect, marks the lower boundary of the Box Hole Formation. In contradistinction to this notion, various authors assumed that the erosional break occurs between the units II and III (in the four-fold division). However, the field observations by R. Jenkins (*pers. comm.*) do not substantiate that assumption. Investigations between Ross River and Alice Springs indicate that the disconformity surface below the Box Hole Formation cuts progressively downwards towards the east as a low angle unconformity, ultimately lying close to the top of Unit II, or even cuts into the top of Unit II (four fold division). Christie-Blick *et al.*, (1995) reported a 23 m deep erosional down-cut within Arumbera II (four fold division) at the Gaylad Syncline. At Ross River on the northern flank of the Ooraminna Sub-basin, Jenkins and Walter (cited in Lindsay, 1987 p. 618) have mapped a pebbly erosion surface at the contact between the Box Hole and Arumbera Formations. Jenkins and Walter were able to trace this pebble horizon to the west. Within the Missionary Plain Trough, the basal boundary of the Box Hole Formation is commonly erosional, with the underlying succession exposed prior to and/or during deposition of the Box Hole Formation (Conrad, 1981; Lindsay, 1987). Walter *et al.* (1995) consider that an extensive regional disconformity exists under the Early Cambrian sandstones of all the northern basins. McIlroy *et al.* (1997, fig. 2) also reported a major hiatus at the basal part of Unit III (four-fold division) which is consistent with the an erosional surface at the base of the Box Hole Formation.

Although, the existence of an unconformity or a paraconformity below the recognised Cambrian level is agreed upon by almost all authors, the stratigraphic position of this erosional surface is a matter of controversy. According to available measured sections and the known occurrence of trace fossils, it is presently considered that this break is probably located somewhere above the major ridge forming sandstone of the Arumbera Formation (Unit II of Wells *et al.*, 1965) and within the lower part of the overlying recessive part (Unit



III of Wells *et al.*, 1965). This view which is consistent with Daily's interpretation (Daily, 1972, 1976) is supported here as the Arumbera Formation (restricted) is disconformably (or unconformably, Jenkins, *pers. comm.*) overlain by the succeeding Box Hole Formation. This unconformity widely cuts the underlying units because of an erosional hiatus prior to the deposition of the Box Hole Formation, the observation also reported by Conrad (1981) and Lindsay (1987).

### 3.3.3. The Box Hole Formation

The Box Hole Formation varies in thickness from about 70 to 85 m at its nominated type exposure in the Cyclops Bore area. The type section has been measured 1 km southwest of Cyclops Bore (Cyclops section, eastern bank of creek, 23° 39'S, 134° 23'E). At its type section the formation consists of three parts:

Lower Box Hole Formation (unit A). This part begins with 10-15 m of calcareous sandstone and green shales thinly interbedded with occasional medium to fine-grained massive sandstone beds (<0.5 m thick), which are finer in grain-size in the Cyclops West II section. This unit also contains some well rounded granules and mudcracks in the measured Cyclops West I section. White to green interbeds of sandstone and siltstone in the basal part of the section contain desiccation cracks and cross stratification. The boundary between the Arumbera Formation and the Box Hole Formation is marked by a white granular sandstone layer a few centimetres thick at the Cyclops section. The granules are well rounded indicating extensive reworking of the grains prior to deposition. A low relief erosional surface has also been recognised below the Box Hole Formation at this area. One or two dolomitic layers occur higher at the middle part of this unit in the Cyclops West II section.

Thinly bedded green siltstones and fine sandstones represent the top of this unit. Several coarse, pink sandstone layers occur within this succession. Trace fossils occur sparsely in this unit and mostly are represented by simple, horizontal burrows. The lower unit is more calcareous in the Cyclops West II section (Fig. 3.5) where it lacks characteristic trace fossils, though it embraces bioturbated horizons at the top of the unit. The unit is generally a coarsening upward cycle and its thickness increases from 20 m in the Cyclops section to about 28 m in the Cyclops West II section. A bed of coarse to very coarse grained sandstone

containing well rounded quartz grains separates the lower and middle units of the formation. This layer is likely associated with some erosion and can be correlated with the same horizon in the Ross River area.

Middle Box Hole Formation (Unit B). The middle unit is the most fossiliferous part of the formation and consists of grey green interbeds of siltstone and sandstone with several massive sandstone horizons. A white coarse sandstone layer occurs at the base of this unit at the type section. The grains are well rounded and become pebbly towards the Cyclops West II section. This gritty bed is also reported by Jenkins and Walter (cited in Lindsay *et al.*, 1993).

The grit is overlain by 15-20 m of thinly interbedded sandstone and shale with an increasing number of massive sandstone beds (0.5-1 m thick) up-section. Some of the thicker sandstones are highly glauconitic and much coarser in grain size. The top of this unit consists of 10-15 m of white to pale grey, coarse, massive sandstone beds with a few shale interbeds. Most shales tend to be slightly micaceous. The unit is about 40 m thick at the type section and decreases in thickness to about 32 m 0.5 km further west. The middle unit represents a shallowing upward sequence and at least two coarsening upward cycles are recognised within this unit especially in the Cyclops West I section. In Cyclops West II section, moulds of gypsum crystals occur as stellate structures at the top of this unit, indicating evaporative conditions in a restricted setting.

Upper Box Hole Formation (Unit C). The contact with the underlying Unit B is located at the top of the white, coarse, quartzose sandstone forming the upper part of Unit B. Much of the lower part of Unit C has been covered by scree due to its recessive nature. Its lower part mostly consists of interbeds of green siltstone and sandstone with occasional occurrences of thinly bedded pink sandstone. The succession becomes more calcareous at its upper part in Cyclops West II where 5 to 10 m of calcareous siltstone and sandstone with a few dolomite beds are the prominent lithology.

Thickness of the Unit C decreases from 22 m in the east to about 18 m at the west of Cyclops Bore. Its upper boundary is located at the base of first occurrence of pink to purple sandstone layers which are characteristic of the overlying Allua Formation.

In general, the Box Hole Formation represents an overall coarsening upward succession comprising 2-3 smaller shallowing upward cycles. Its thickness varies from about 70 m in the Cyclops section to about 55 m in Cyclops West II section. This is consistent with the general thinning of the formation towards the Missionary Plain Trough (Lindsay, 1987). The occurrences of mudcracks and dolomitic layers within the basal unit also indicate a very shallow environment prior to the deposition of the middle unit.

The Box Hole Formation is much thinner in the two measured Ross River sections than at Cyclops Bore 20 km west (Fig. 2.1). There is a very coarse to conglomeratic sandstone layer with an erosional base in the lower part of the formation (about 15-18 m from the base). This horizon matches well with the conglomeratic sandstone at the base of the middle unit of the Box Hole Formation in the Cyclops Bore area. A calcareous succession similar to the upper unit of the Box Hole Formation at Cyclops Bore overlies this level at the Ross River.

Comparison with the Cyclops Bore section indicates that most of the middle unit of the formation at the Ross River was never deposited or has been eroded away prior to the deposition of the upper unit. Thus the lower and upper units of the Box Hole Formation are recognised at Ross River, with a possible partial occurrence of the middle unit.

At Hugh River section, the Box Hole Formation overlies the thick to massive bedded, coarse sandstone at the top of the Arumbera Formation (restricted). It is not possible to distinguish between different units of the formation mainly due to its recessive nature and cover of scree. The formation consists of interbeds of siltstone and sandstone in which sandstone layers are mainly feldspathic. The succession is grey to green in colour at the lower part with some purplish sandstone interbeds, and becomes purplish to dark brown toward the top (Fig. 3.8)

The formation yields numerous trace fossils which occur mostly within the successions comprising interbeds of siltstone and sandstone and are absent or occur sparsely within the calcareous part of the formation. McIlroy *et al.* (1997, fig. 2) considered that a hiatus occurred within the upper part of this formation (their Member III). This is interpreted to be the same surface referred to herein as the erosional surface marking the lower boundary of the Allua Formation at the Cyclops area.

### 3.3.4. The contact between the Box Hole and Allua Formations

At Cyclops Well the upper boundary of the Box Hole Formation is located at the base of the first interval of pink to reddish sandstones and siltstones attributed to the Allua Formation. Daily stated (Jenkins *pers. comm.*) that an erosional surface occurs between the Box Hole Formation (= part of Unit III of Wells *et al.*, 1965) and the Allua Formation (Unit IV of Wells *et al.*, 1965), recognising the Box Hole Formation “an indicative of a part of Early Cambrian and the Allua Formation with its diagnostic trace fossils of *Plagiogmus* as the equivalent of higher part of the Early Cambrian” (Daily, 1976). Continued investigations have failed to define a unique lithological surface forming a well defined boundary between the Box Hole Formation and Allua Formation, though a granule bearing sandstone suggestive of condensation occurs at this level in the vicinity of Cyclops Bore. At Daily Gorge (25 km east-northeast of Cyclops Bore) an erosive surface occurs in thin to medium bedded sandstones situated basal to the Allua Formation and locally this surface erodes some tens of centimetres through individual medium bedded sandstone units resulting in a stepped truncation, suggestive of some incipient lithification before deposition of the overlying sandstone (this is likely the same surface which is reported by McIlroy *et al.* (1997, fig. 2) from top of Unit III). Kirschvink and Rozanov (1984) compared the Precambrian-Cambrian section of the Amadeus Basin with the Siberian Platform and suggested the possibility of an unrecognised disconformity at this level in Australia. Conrad (1981) also reported a sharp contact with shallow scours possibly indicating an erosional surface at this level extending over wide areas of the north-eastern part of the basin.

### 3.3.5. Allua Formation

The type section is nominated at the bluff on the southwestern side of Ross River (134° 29'E, 23° 39'S). This formation comprises two recognisable parts:

Lower Allua Formation (Unit A). This unit overlies the massive sandstone and calcareous sediments at the top of the Box Hole Formation. Lower red siltstone beds are overlain by medium bedded sandstone (20 -30 cm), which grades into thicker (40-60 cm) white to red sandstone. This unit thins to the west where its lower part is arenitic. The upper part of this unit is more sandy to the west and yields diverse ichnofossils including *Plagiogmus*. The unit

is about 40 m thick at Cyclops Bore area where it is measurable and is not covered by scree. Its thickness decreases westward to the Cyclops West II section where it represents a shallowing upward succession containing a thin layer of dark shale at its basal part. McIlroy *et al.* (1997) also reported a black shale layer from the Cyclops Bore.

Upper Allua Formation (Unit B). This unit mostly consist of medium to thick bedded sandstones with a few interbeds of siltstone. Clean sandstone beds containing large channels are a prominent lithofacies in the upper part of the formation. The contact with the underlying unit is located at the base of medium to thick bedded, medium-grained sandstone. This interval is red to purple in colour and includes rare occurrences of trace fossils.

Included channels comprise a fill 2-4 m thick which consists of well sorted, medium-grained sandstone with clay galls, ripple-marks and some glauconite. The sandstone exhibits cross-bedding and large-scale soft-sediment deformation at its base. Lindsay (1987) interpreted the facies as indicating the change from a shoreface environment to a coastal plain and deltaic association for the upper dominantly sandy part. The unit is about 30 m thick where it is measurable and is not covered by scree. At the top of the Allua Formation a thick sandstone bed occurs below the base of the Todd River Dolomite.

The Allua Formation is about 65 m thick overall as measured in the Cyclops Bore sections. It was not possible to study the lateral changes of its lithology and thickness due to lack of the suitable outcrop in the area. However, the unit is more silty to west particularly in the Cyclops West I section.

The formation varies considerably in thickness over short distances and is absent in the south. Lindsay (1987) assigned the Box Hole and Allua Formations, and the overlying Todd River Dolomite to his Sequence 2.

The Hugh River Section comprises a purplish to dark brown succession of sandstone beds toward the top similar to the Allua Formation. Nevertheless, the ichnoassemblage resembles that of the Box Hole Formation and it can be concluded that the Allua Formation does not produce a significant outcrop in the area.

### 3.3.6. Upper contact

The Arumbera Sandstone (*sensu lato*) is overlain by the Hugh River Shale in the north-west, by the Chandler Limestone in the south-west and by the Todd River Dolomite in the north-east. Wells *et al.* (1967) defined the lower boundary of Todd River Dolomite as a gradational contact and placed it where the predominantly red-brown, shaly fine-grained sandstone at the top of the Arumbera Sandstone *sensu* Wells *et al.*, 1967 (= Allua Formation) passes into the pale brown calcareous siltstone and fine to coarse-grained friable sandstone of the lower part of the Todd River Dolomite (Wells *et al.*, 1967). Conrad (1981) raised the boundary higher in the section and placed the contact at the base of the first dolomite bed, transferring thinly interbedded sandstone and siltstone with halite casts and mudcracks to the top of the underlying sequence (=Allua Formation). Herein, following many other authors (Daily, 1972; Lindsay, 1987) the definition of Wells *et al.* (1967) is applied to locate the contact between the two formations.

The Box Hole and Allua Formations pinch out toward the south on to the Central Ridge and are also absent in the MacDonnell Ranges, Gardiner Range and James Ranges Anticline. They crop out only within the north-eastern part of the basin and have been penetrated by exploration wells within the Carmichael Sub-basin (Hamp, 1985, Phillips, 1986, Lindsay, 1987).

The Chandler Formation overlies the Box Hole Formation on the flanks of the Central Ridge at Bloodwood where the Todd River Dolomite and the Allua Formation are absent. The contact between the two is an angular unconformity. In areas close to the Central Ridge, this unconformity sometimes merges with underlying unconformity surface(s); between the Allua and Box Hole Formations, between the Box Hole and Arumbera Formations, and the basal Arumbera Formation unconformity produced by the Petermann Ranges Orogeny (Oaks *et al.*, 1991, p. 83). The depth of post-depositional erosion of the Arumbera Sandstone (*sensu* Wells *et al.*, 1967) increases southward along the Deepwell Range to the James Ranges and also is generally greater in the Gardiner Range than in the western MacDonnell Ranges (Hamp, 1985; Phillips, 1986).

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# Chapter 4

## Biostratigraphy and environmental analysis of the Precambrian - Cambrian interval utilising trace fossils

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### 4.1. Introduction

This chapter comprises three parts: in the first, distribution of trace fossils through the latest Precambrian-Early Cambrian successions in selected localities from central Australia is discussed. In addition to the sections from the Amadeus Basin, a section from the Mount Octy area located in southwestern part of the Georgina Basin (Fig. 2.5) has also been investigated. In the second part, an attempt is made to establish an ichnozonation of the boundary interval using the data from this study and other available sources (e.g. Glaessner, 1969; Walter *et al.*, 1989; McIlroy *et al.*, 1997). In the last part the facial and behavioural distribution of trace fossils and their implication are discussed.

### 4.2. Biostratigraphy of the latest Proterozoic-Early Cambrian succession in central Australia

#### 4.2.1. An overview

Mawson and Madigan (1930) first confirmed Cambrian fossils from the Amadeus Basin. Madigan (1932) reported Cambrian body fossils, archaeocyaths and hyoliths. Kruse and West (1980) systematically described the archaeocyaths of the Early Cambrian. The Late Proterozoic micro biota were described by Barghoorn and Schopf (1965), Schopf (1968), Schopf and Blacic (1971) and subsequently by Knoll and Golubic (1979) and Knoll (1981).

Walter (1972) described the Proterozoic and Cambrian stromatolites. Ichnofossils and non-skeletal metazoan fossils were described by Glaessner and Wade (1966), Glaessner (1969), Wade (1970), Glaessner and Walter (1975), Walter *et al.* (1989) and Shergold *et al.* (1991). However, a detailed ichnological study of this interval has not been done yet. Opik (1970, 1979) systematically described Cambrian trilobites.

Zang (1988) and Zang and Walter (1989; 1992) described three acritarch assemblages from the Amadeus Basin. Their samples were collected from the Bitter Springs, Ediacaran Pertatataka, and Tempe Formations. They concluded that the Tempe Formation which in places overlies the Arumbera Sandstone with an unconformity, is of older Middle Cambrian age. Moderately rich assemblages of archaeocyaths reported from the carbonate rocks succeeding deposition of the Arumbera Sandstone and its equivalent sediments throughout the central Australia (e.g. Wells *et al.*, 1967; Daily, 1972; Walter *et al.*, 1979; Kruse and West, 1980; Laurie and Shergold, 1985) is considered to be of Atdabanian to Early Botomian age.

#### 4.2.2. Fossil occurrence in the Arumbera Formation (restricted)

A single specimen of a soft-bodied fossil was found by Taylor (1959) near the base of the Arumbera Formation in the Deep Well area (cited in Glaessner, 1969 and Conrad, 1981). Glaessner (1969) identified it as *Rangea cf. longa* which had been reported from south west Africa and considered it to be a component of the late Precambrian Ediacaran fauna of South Australia. The description of new specimens of *Rangea* from south west Africa showed that it had been misinterpreted and that it does not occur in Australia (Glaessner and Walter, 1981). Jenkins and Gehling (1978) reinterpreted the specimen from the central Australia and identified it as *Charniodiscus*. This has been the only such specimen found in the Arumbera Formation despite much searching (Glaessner, 1969; Jenkins, 1981; Conrad, 1981; Walter *et al.*, 1989).

Conrad (1981) reported an occurrence of simple, unbranched, horizontal, interwoven, meandering burrows within channel sandstone of the lower part of the Arumbera Formation in the Wyeecha area. He considered that the burrow is similar to *Phycodes antecedens* Webby, 1970. However, *Phycodes* is typically a branching ichnogenus and Conrad's



identification is incorrect. The trace fossil may represent horizontal burrows of *Planolites* intersecting one another. Walter *et al.* (1989) inspected the sites from which Conrad collected his specimens. They reported that the specimens occur only in float and possibly were derived from higher strata.

Hamp (1985) reported 'rare simple horizontal burrows' from this unit. However, Walter *et al.* (1989) re-examined the area from which Hamp had collected his specimens and found no trace fossils, but reported many desiccation mudcracks from the site. They considered that Hamp's specimens could be also desiccation mudcracks.

Glaessner and Walter (1975) described and illustrated *Arumberia banksi* Glaessner & Walter, 1975 from a lower part of the Arumbera Formation (Unit II of Wells *et al.*, 1967) in the Valley Dam area. Conrad (1981) also reported *A. banksi* in lower parts of the formation and mentioned that the specimens reported by Glaessner and Walter (1975) had apparently been collected from the same unit. Glaessner and Walter (1975) reconstructed *A. banksi* as a cup-shaped coelenterate-like organism of late Precambrian age. They described similar occurrences from southwest Africa and Siberia. Brasier (1979) and Jenkins (1981) considered that *A. banksi* is actually inorganic in origin and the bifurcating ribs and grooves characterising the fossil were formed by current vortices. New widespread discoveries of *A. banksi* by Daily and Jenkins (cited in Jenkins *et al.*, 1981) from central Australia supported the inorganic origin of the fossils (Jenkins *et al.*, 1981). Therefore these impressions may be pseudofossils. However, Bland (1984) reviewed the occurrences of *Arumberia* and, based on the fact that *A. banksi* has only been found in the latest Precambrian and Early Cambrian strata worldwide, considered an organic origin for the structure. He (1984 p.630) disputed Brasier's (1979) assumption about the inorganic origin of the fossil and considered *A. banksi* to be likely the impression of a colony of flexible thin-walled tubular elements. Jenkins (*pers. comm.*) has now also been convinced that the impressions have an organic origin based on his examination of some well preserved specimens from Canada. Nevertheless, McIlroy and Walter (1997) argued that *A. banksi* was inorganic based on experiments performed by Dzulynski & Walton (1965) and Allen (1982). McIlroy and Walter (1997) considered that absence of *A. banksi* in Phanerozoic strata is due to the lack of suitable highly cohesive sediment needed for the preservation of such sedimentary structures.

Wade (1969) reported *Hallidaya brueri* Wade, 1969 in the lower part of the Arumbera Formation from 23 km west of Alice Springs (south of Valley Dam). *Hallidaya* is an element of the Proterozoic Mt. Skinner fauna described by Wade (1969). Conrad (1981) reported that the stratigraphic position of *Hallidaya* at Valley Dam area is equivalent to Unit II of Wells *et al.* (1967). *H. brueri* is known only from the late Proterozoic (Wade, 1969).

Bradshaw (1988) reported trace fossils from the Namatjira Formation which is a mixed carbonate and siliciclastic unit questionably considered to be a correlative of the upper part of the Arumbera Formation (= Unit II of Wells *et al.*, 1967). However, Walter *et al.* (1989) questioned his correlation and considered the formation to be of Cambrian age.

Foyn and Glaessner (1979) reported a series of concentric rings from this unit and considered it likely to be a *Cyclomedusa*. They (1979) reported *Kullingia* aff. *concentrica* from 250 m above the base of the Arumbera Sandstone (*sensu lato*) and 63 m below a 'glaucconitic zone' in the Laura Creek area. Walter *et al.* (1989) considered the location to be very close to the same stratigraphic level as *Hallidaya brueri* (= Unit II of Wells *et al.*, 1967).

McIlroy *et al.* (1997) reported *Planolites* isp., *Bilinichnus simplex*, ?*Monomorphichnus* isp. and *Intrites* isp. in the Arumbera Formation from their "Daily Gorge" and Wyeecha sections, North western Amadeus Basin.

#### 4.2.3. Fossil occurrence in the Box Hole Formation

Abundant occurrences of trace fossils have been reported from this unit (Glaessner, 1969; Daily, 1972; Conrad, 1981; Walter *et al.*, 1989). Glaessner (1969) reported diverse occurrences of trace fossils from the upper part of the Arumbera Sandstone (*sensu lato*) which embraces Unit III and Unit IV of Wells *et al.* (1967). Conrad (1981) reported abundant and diverse occurrences of trace fossils at this level from Brumby, Ooraminna, Wyeecha, Todd River and Shannon areas. Walter *et al.* (1989) also reported diverse trace fossils from this unit. Despite the profuse occurrences of trace fossils from the Box Hole Formation (= upper part of the Unit III of Wells *et al.*, 1967), no body fossils has been reported. Appendix I shows hitherto reported ichnofossils from this unit.

Daily (1972) reported abundant occurrence of trace fossils including *Treptichnus* (= *Phycodes*) *pedum*, *Diplichnites* sp., *Rusophycus* sp. and "molluscan trails" from his Arumbera 2 or 'Box Hole Formation' (= upper part of Unit III) but mentioned rare occurrences of simple horizontal burrows from the top of his Arumbera 1 or Arumbera Formation (= the lower part of the Unit III of Wells *et al.*, 1967). Kirschvink (1978b) also reported *Rusophycus* from the Box Hole Formation.

An occurrence of *Plagiogmus arcuatus* within this level was reported by Walter *et al.* (1989). However, *Plagiogmus* has been reported to occur in higher stratigraphic level in central Australia by many authors (Glaessner, 1969; Daily, 1972; Kruse and West, 1980) and Daily (1972) considered it to be restricted to the Allua Formation (= "Unit IV of Wells *et al.*, 1967).

#### 4.2.4. Fossil occurrence in the Allua Formation

Glaessner (1969) reported *Treptichnus* (= *Phycodes*) *pedum*, *Diplichnites* isp., and a *Rusophycus*-like trace from about 50 m below the top of the Arumbera Sandstone (*sensu lato*) in Laura Creek, 25 km SW of Alice Springs. Airphoto interpretation of the locality by Walter *et al.* (1989) indicated that the trace fossils had been collected from the Allua Formation (= Unit IV of Wells *et al.*, 1967). Conrad (1981) reported rare occurrences of vertical burrows, *Plagiogmus* and *Rusophycus* associated with common *Skolithos* from this unit. *Plagiogmus* has also been reported from this level by Walter *et al.* (1989) and Kruse and West (1980) from Ross River area.

#### 4.2.5. Ichnofossil distribution of the studied Sections

##### 4.2.5.1. Amadeus Basin

**Cyclops Bore.** At Cyclops Bore the lower unit contains a few simple trace fossils including *Palaeophycus tubularis*, *Arenicolites* isp. A and *Planolites montanus*. *Rusophycus avalonensis* and *Monomorphichnus bilinearis* were found as float at this level from the Cyclops West I section but occur in higher levels in the other two sections. It is believed that these samples belong to strata located higher in this section and they slid down.

The middle unit is the most fossiliferous part of the Box Hole Formation (Fig. 3.3) and consists of grey green interbeds of siltstone and sandstone with several massive sandstone horizons. The first major appearance of trace fossils occurs within an interbedded siltstone and sandstone succession at a lower level of the unit. Trace fossils are abundant and diverse in this interval. The most significant ones are *Didymaulichnus miettensis*, *Treptichnus* (= *Phycodes*) *pedum*, *Treptichnus* cf. *triplex*, *Phycodes palmatus* and *Rusophycus avalonensis*. These traces represent complex structures and are considered to indicate an Early Cambrian age.

The upper unit yields less trace fossils than the middle unit. *Palaeophycus tubularis* is common throughout the section. *Curvolithus multiplex* and *Glockerichnus ?sparsicostata* occur at this level. A few float specimens of *Plagiogmus arcuatus* were also collected from this unit.

The lower part of the Allua Formation records the onset of some structurally complex trace fossils such as *Plagiogmus arcuatus* and *Taphrhelminthopsis circularis*, the latter only in Cyclops West II (Fig. 3.5). These two traces have not been found *in situ* within the underlying Box Hole Formation. An interesting star-like trace fossil, *Asteriacites* isp. with 10-11 rays occurs at this level. This specimen is very similar to the specimens reported from the Meishucun section, China by Crimes and Jiang Zhiwen (1986).

The upper unit of the Allua Formation yields sparse trace fossils with the common vertical burrows *Skolithos verticalis*, *Monocraterion* isp., and *Arenicolites* isp. B.

**Ross River.** The lower part of the Box Hole Formation yields some simple trace fossils including *Planolites montanus*, *Palaeophycus tubularis*, *Planolites beverlyensis*, and *Arenicolites* isp. A. *Phycodes palmatus*, a relatively more complex structure, occurs also at this level. A new group of trace fossils appearing at a stratigraphically higher level comprises *Didymaulichnus lyelli*, *?Saerichnites* isp. A, *Gyrolithes polonicus*, *Cochlichnus anguineus*, and *Treptichnus podium*. *Nereites macleayi* and *Treptichnus pedum* are the most significant traces to occur in the upper part of the formation at this site.

The Allua Formation, though thinner, is similar to its exposures in the Cyclops Bore sections and contains a relatively diverse trace fossil assemblage representing complex forms such as

*Plagiogmus arcuatus* and *Taphrhelminthopsis circularis*. Several new trace fossils also make their first appearance, including *Asteriacites* isp., *Hormosiroidea* isp., *Rusophycus avalonensis*, *Taenidium serpentinum*, and ?*Rusophycus* isp. A.

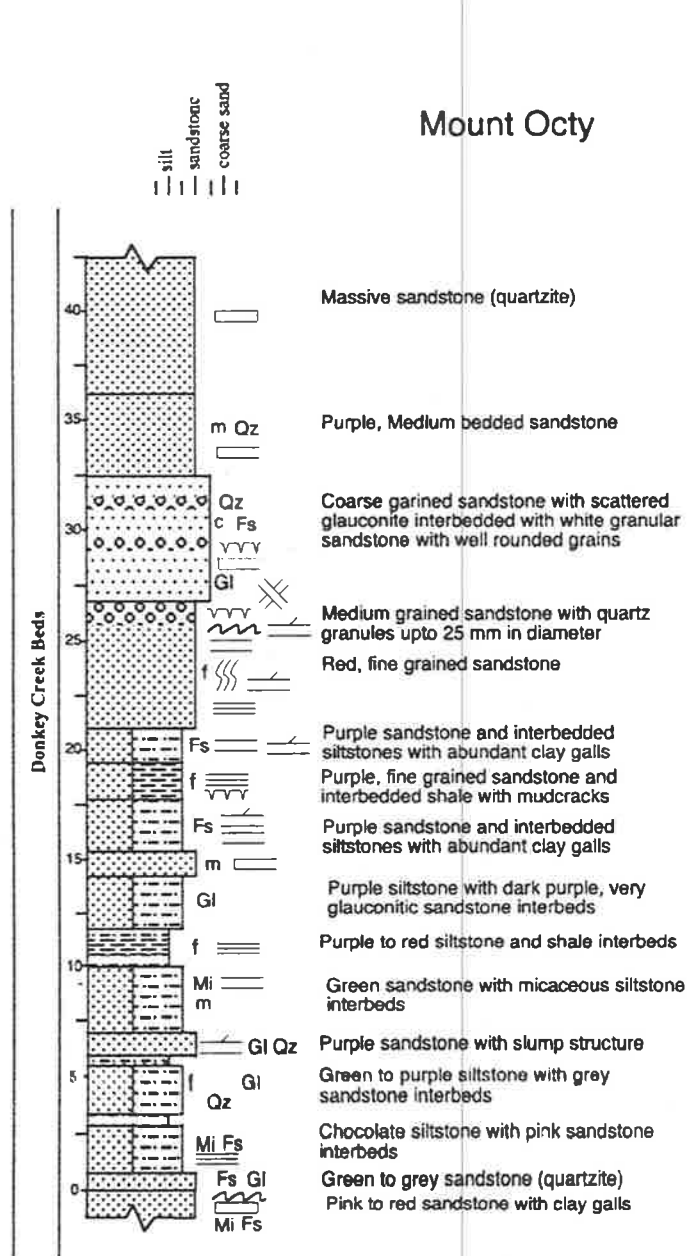
**Hugh River.** Here, the succession is substantially thinner than the other two localities. The lower part contains *Palaeophycus tubularis*, *Planolites montanus* and *Curvolithus multiplex*, forms found in the lower to upper part of the Box Hole Formation in Cyclops Bore and Ross River areas. At higher levels *Phycodes palmatus*, *Treptichnus pedum* and *Glockerichnus ?sparsicostata* are found; these are commonly occur at the upper unit of the Box Hole Formation in other localities. The typical trace fossils occurring in the Allua Formation such as *Plagiogmus arcuatus* and *Taphrhelminthopsis circularis* were not found at this locality.

#### 4.2.5.2. Mount Octy section, Georgina Basin

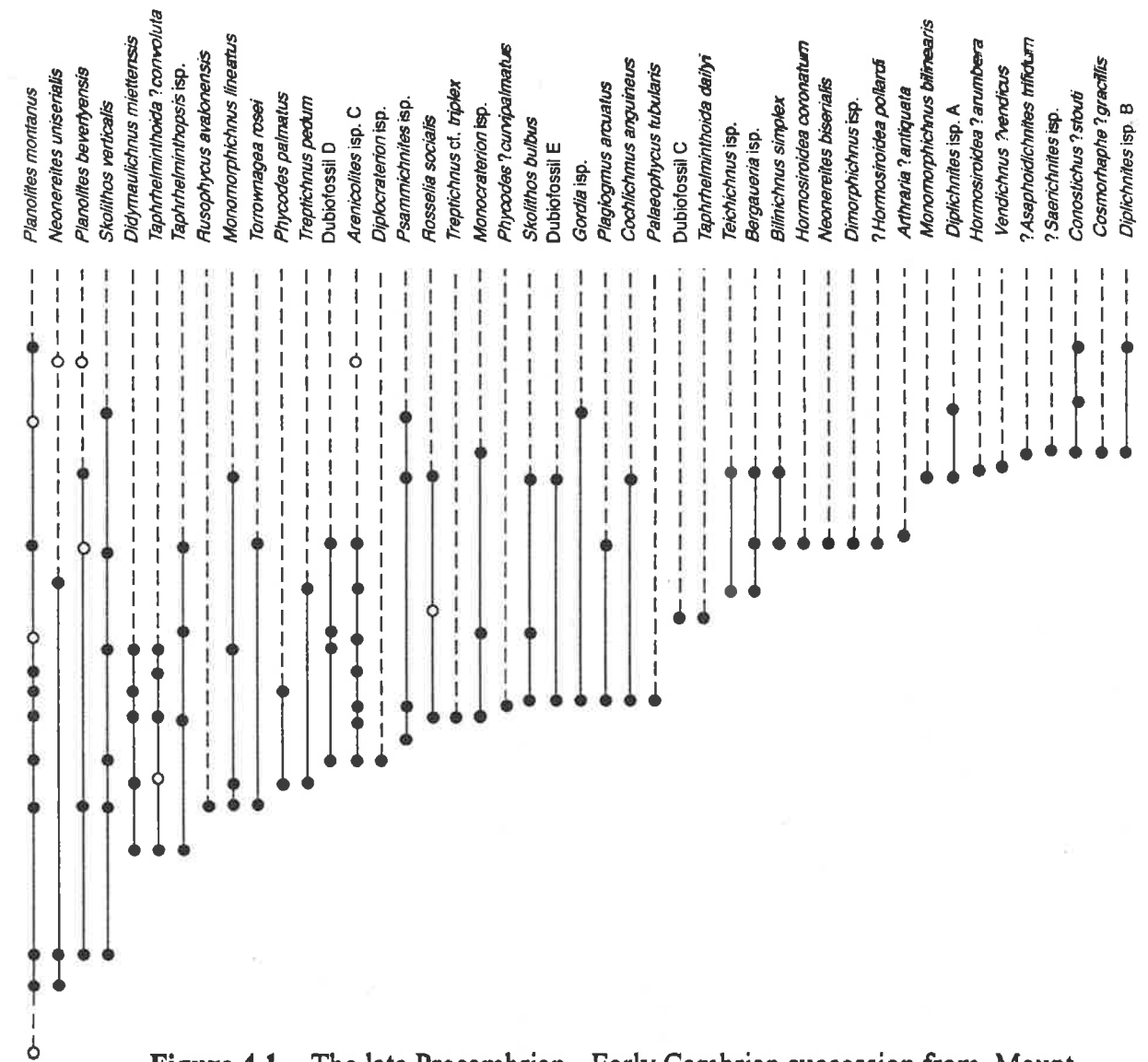
An outcrop of Precambrian-Cambrian boundary interval was investigated in the Mount Octy region, Georgina Basin (Fig. 2.5). The succession is lithologically similar to that of stratigraphically equivalent outcrops from Amadeus Basin and is referred to the Donkey Creek Beds (Walter, 1978). The interval consists of interbeds of siltstone and sandstone which are greenish in the lower part and become purplish toward the top (Fig. 4.1). The succession is glauconitic in its lower level and comprises at least one coarsening upward cycle which starts with green to purple micaceous siltstone with pink feldspathic sandstone interbeds. Some mudcrack-bearing horizons occur at the middle of the succession, which is overlain by medium to thick bedded, pink, quartzose sandstone layers containing some well rounded quartz granules indicating a high energy environment during the deposition. Abundant trace fossils have been collected from the more sandy intervals. A massive quartzite at the top of the succession yields rare trace fossils.

Walter *et al.* (1989) reported on the occurrences of trace fossils within the Donkey Creek Beds, in the southwestern part of the Georgina Basin (Appendix II). The late Precambrian strata yield a few simple horizontal traces whereas the Early Cambrian strata (Mount Baldwin Formation and Donkey Creek Beds) contain abundant and diverse trace fossils.

At a lower level the common trace fossils are *Neonereites uniserialis*, *Planolites montanus*, *Planolites beverlyensis*, and *Treptichnus pedum*. These occur continuously through the



### Mount Octy



**Figure 4.1 - The late Precambrian - Early Cambrian succession from Mount Octy, Georgina Basin.**

whole section. At the higher level some new forms such as *Taphrhelminthoida ?convoluta* and *Taphrhelminthoida dailyi* appear abundantly in the section which are not common in the sections from Amadeus Basin. A new group of trace fossils appears in the upper part of the section including: *Phycodes coronatum*, *Hormosiroidea ?arumbera* and *Plagiogmus arcuatus*.

### 4.3. Ichnozonation of the Precambrian-Cambrian succession of central Australia

According to their study of the Proterozoic and Early Cambrian trace fossil occurrences in Amadeus and Georgina Basins in central Australia, Walter *et al.* (1989) recognised four successive assemblages of trace fossils and informally designated these as Assemblages 0-3, of which the older three are Ediacaran and the fourth is Early Cambrian (Table 4.1) in age.

No distinct trace fossil occurs in the 'Assemblage' 0 and only one trace fossil, *Planolites ballandus* (= *P. montanus*) Webby, 1970 has been reported for the Assemblage 1. Their Assemblage 2 comprises several ichnospecies which are all virtually parallel to bedding.

These trace fossils have mostly been reported in association with Ediacaran soft-bodied fauna. Despite an extensive search, Walter *et al.* (1989) could not find any diagnostic and undoubted trace fossil of Assemblage 2 in the Arumbera Formation (*sensu stricto*). Their Assemblage 3 embraces all trace fossils occurring in the Box Hole and Allua Formations. Walter *et al.* (1989) also included trace fossils found in the Donkey Creek Beds, Georgina Basin within Assemblage 3. Overall, Assemblage 3 comprises about 36 ichnogenera. They concluded that abundance and diversity of trace fossils in this assemblage results from the evolutionary introduction of the originators of the traces since palaeoenvironmental differences between the Arumbera Formation (restricted) and the overlying Box Hole and Allua Formation are minor.

**Table 4.1.** Trace fossil assemblages from central Australia (Walter *et al.*, 1989)

	Assemblages			
	0	1	2	3
<i>Planolites</i>		◆		◆
<i>Neonereites</i>			◆	
<i>Corophioides</i>			◆	
<i>Gyrolithes</i>			◆	
<i>Monomorphichnus</i>			◆	◆
<i>Hormosiroidea</i>			◆	◆
? <i>Bergaueria</i>			◆	◆
<i>Gordia</i>				◆
<i>Treptichnus</i>				◆
<i>Didymaulichmus</i>				◆
<i>Curvolithus</i>				◆
<i>Helminthopsis</i>				◆
<i>Muensteria</i>				◆
<i>Palaeophycus</i>				◆
<i>Phycodes</i>				◆
<i>Torrowangea</i>				◆
<i>Arenicoloides</i>				◆
<i>Diplocraterion</i>				◆
<i>Plagiogmus</i>				◆
<i>Skolithos</i>				◆
<i>Gyrochorte</i>				◆
<i>Nereites</i>				◆
<i>Diplichnites</i>				◆



Assemblage 3 though useful for determining Early Cambrian strata, is generalised and lacks appropriate resolution for detailed biostratigraphy. Based on the studied trace fossils from the selected sections and *hitherto* reported ichnospecies from the Arumbera, Box Hole and Allua Formations, 3 ichnozones are established herein:

### **Ichnozone I**

A few trace fossils sparsely occurring in the Arumbera Formation (restricted) and consisting mostly of simple, horizontal burrows including *Bilinichnus simplex*, *Helminthopsis* isp., *Intrites* isp., *Monomorphichnus* isp., and *Palaeophycus* isp. These were reported by McIlroy *et al.* (1997) from the Arumbera Formation (restricted). This ichnozone occurs in association with elements of an Ediacaran fauna and is correlated with Assemblage 2 of Walter *et al.* (1989).

### **Ichnozone II**

Trace fossils increase both in their abundance and diversity in the Box Hole Formation. Numerous new trace fossils first appear in this formation with the most important ichnogenera *Arenicolites*, *Curvolithus*, *Diplichnites*, *Didymaulichnus*, *Glockerichnus*, *Gyrolithes*, *Hormosiroidea*, *Laevicyclus*, *Monocraterion*, *Phycodes*, *Protopaleodictyon*, *Psammichnites*, *Rusophycus*, *Saerichnites*, *Skolithos*, and *Treptichnus*.

Several diagnostic ichnospecies among these trace fossils are restricted stratigraphically and can be used for global correlation, including: *Didymaulichnus miettensis*, *Gyrolithes polonicus*, *Rusophycus avalonensis*, and *Treptichnus pedum*.

It is noteworthy to mention that trace fossils of Ichnozone II appear abruptly in many localities whereas in some places they tend to make a sequential appearance (Ross River). This may indicate a hiatus in those sections in which the Ichnozone II taxa appear abruptly.

### **Ichnozone III**

A new series of trace fossils first appears in the Allua Formation in many sections with the following assemblage considered to be the most significant: *Asteriacites* isp., *Palaeophycus canalis*, *Palaeophycus ferrovittatus*, *Plagiogmus arcuatus*, *Rusophycus bonnarensis*, *Skolithos ramosus*, and *Taphrhelminthopsis circularis*.

*Plagiogmus arcuatus* and *Taphrhelminthopsis circularis* have been reported worldwide and apparently show a very narrow stratigraphic range, emphasising their potential for international correlation. Both traces are considered to be restricted to the Allua Formation.

Ichnozones II and III are recognised in the Donkey Creek Beds, of the Mount Octy section, Georgina Basin. However, there is a slight differences in terms of the trace fossils occurring in the Amadeus and Georgina Basins; *Plagiogmus arcuatus*, *Rusophycus avalonensis*, and *Taphrhelminthopsis circularis* are common in the Amadeus Basin but occur sparsely in the Mount Octy region. Instead, the latter succession contains abundant *Rosselia socialis* and *Taphrhelminthoida convoluta* which are not found in the Amadeus Basin.

The established ichnozones I - III are approximately correlated with the trace fossil occurrences in the Arumbera Formation (restricted), Box Hole Formation, and Allua Formation respectively. They are easily differentiated according to their representative ichnospecies and have good potential for local correlation and possibly international correlation.

## **4.4. Trace fossils and paleoenvironments**

### **4.4.1. Ichnofacies**

Environmental zonations are world-wide in nature and are influenced by chemical, physical, and biological characteristics. The record of these zonations is preserved in the rock record in lithofacies and biofacies successions. The same is true of behavioural patterns among benthic organisms. Because of environmental constraints or selectivity, particular assemblages of traces tend to occur at specific depositional sites and are preserved as ichnofacies. An ichnofacies is a characteristic association of trace fossils that

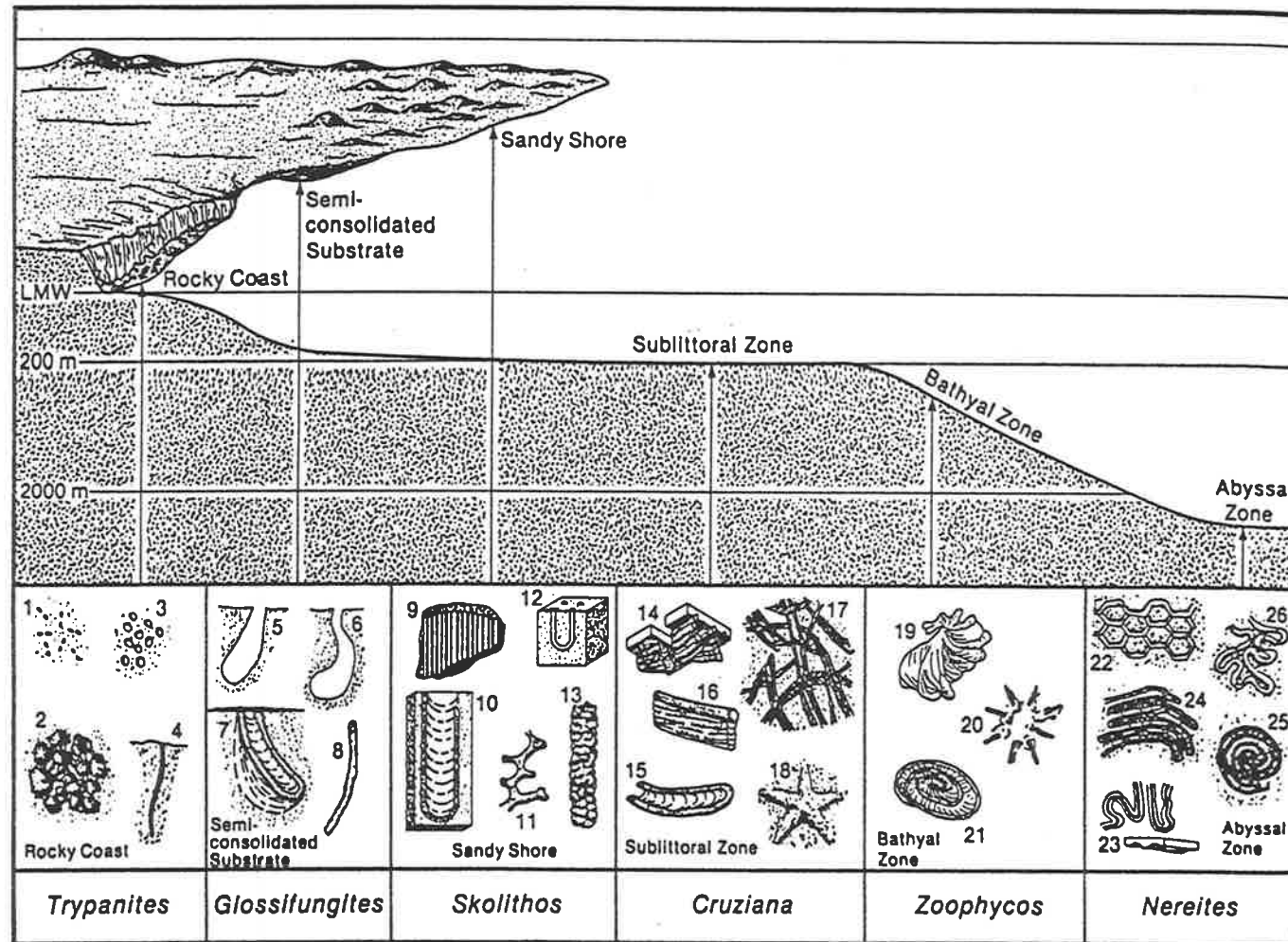
directly represents a particular kind of environment and reflects environmental conditions such as bathymetry, salinity, substrate, current energy, and so on. These characteristic assemblages recur wherever the requisite sets of parameters or environmental sites are repeated. Certain ichnofacies have proven to have marine bathymetric significance.

Seilacher (1963, 1967) was the first who appreciated the bathymetric significance of trace fossils and used them in such analyses. Trace fossils have many advantages over body fossils in paleoenvironmental studies: almost all trace fossils are autochthonous and occur in situ, and reworked examples are rare and easy to recognise. They are mostly controlled by the behavioural characteristics of the trace-maker. The anatomical structure of the producer has less effect on its trace than its behaviour. So, ichnotaxa express the response of their producers to the environmental conditions and the distribution of trace fossils depends largely on sedimentary facies. Seilacher (1963, 1967) introduced six ichnofacies from backshore to offshore environments (Fig. 4.2).

These ichnofacies have been successfully employed by ichnologists around the world for paleoenvironmental interpretation. However, some precautions must be considered. Ekdale (1988) described problems which arise when these standard ichnofacies are applied too strictly in paleoenvironmental reconstruction: The aforementioned ichnofacies do not embrace all environmental situations and many trace fossil assemblages observed in the geological record do not easily fit into any of these categories. The presence of a particular ichnogenus does not necessarily indicate the occurrence of the particular ichnofacies and sometimes a standard ichnofacies may be identified without the existence of the namesake trace fossil. Environmental shifting has been recorded for some ichnotaxa so, the paleoenvironmental significance of a particular ichnotaxon may have been changed within its stratigraphic range.

#### **4.4.2. Ichnofacies occurrence in central Australia**

The Arumbera, Box Hole Formation, and Allua Formation were deposited within the similar environmental settings with large amount of clastic input into the basin. Occasionally sediments of distributary channels dominate the lithology. These are considered to be part of a large delta system in which the lower Arumbera Formation (restricted) and the middle and



**Figure 4.2** - Recurring marine ichnofacies set in a representative, but not exclusive, suite of environmental gradients. Typical trace fossils include: 1) *Caulostrepis*; 2) *Entobia*; 3) echinoid borings, unnamed; 4) *Trypanites*; 5,6) *Gastrochaenolites* or related ichnogenera; 7) *Diplocraterion*; 8) *Psilonichnus*; 9) *Skolithos*; 10) *Diplocraterion*; 11) *Thalassinoides*; 12) *Arenicolites*; 13) *Ophiomorpha*; 14) *Phycodes*; 15) *Rhizocorallium*; 16) *Teichichnus*; 17) *Crossopodia*; 18) *Asteriacites*; 19) *Zoophycos*; 20) *Lorenzina*; 21) *Zoophycos*; 22) *Paleodictyon*; 23) *Taprhelminthopsis*; 24) *Helminthoida*; 25) *Spirorhaphe*; 26) *Cosmorhaphe*. (after Frey and Pemberton, 1984). Not to scale.

upper parts of the Box Hole Formation mostly represent basinal parts of a delta complex. However, sedimentary structures of the basal part of the Box Hole Formation indicates shallower environment. The upper part of the Arumbera Formation and Allua Formation represent the delta front and delta slope.

There is a link between lithology and trace fossil content; Horizontal burrows such as *Cochlichnus*, *Curvolithus*, *Gordia*, *Palaeophycus*, and *Planolites* tend to appear in flaggy, fine to medium grained sandstone, whereas the thicker arkosic sandstones yield vertical burrow such as *Arenicolites*, *Monocraterion* and *Skolithos*.

Though *Diplichnites* is a common trace fossil occurring in the Precambrian-Cambrian successions in central Australia, the other kinds of arthropod (particularly trilobites) burrows such as *Cruziana* and *Rusophycus* are not common, particularly the former which is the name bearing taxon of the *Cruziana* ichnofacies. Some horizons are highly bioturbated and contain abundant horizontal burrows mostly *Palaeophycus*, *Planolites* and *Psammichnites* representing the *Cruziana* ichnofacies.

Vertical burrows occur mostly in medium to thick-bedded sandstones which may contain cross bedding and slump structures indicating a shifting substrate. This can be attributed to the *Skolithos* ichnofacies. This ichnofacies is more common in the Mount Octy section where it includes *Arenicolites* isp. C.

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# Chapter 5

## Correlation of the Precambrian-Cambrian Interval Utilising Trace Fossils

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### 5.1. Introduction

Trace fossils are abundant and diverse in many clastic sequences spanning the Precambrian-Cambrian boundary and have proven themselves the most useful palaeontologic tools for global correlation of this stratigraphic interval. Many authors also realised that there is a dramatic change in their abundance, diversity and complexity in the boundary interval all around the world (e.g. Seilacher, 1956; Crimes, 1987, 1992a, b, 1994). Seilacher (1956) was first to suggest that the beginning of the Cambrian System could be delineated by trace fossils which occur below the earliest trilobites and this idea was followed by many (e.g. Daily, 1972; Alpert, 1977; Crimes 1974, 1992a; Crimes and Anderson, 1985). Crimes (1975a) concluded that trace fossils are more common than body fossils in many Precambrian-Lower Cambrian sequences. He suggested that this, together with the rapid evolution of the animals at that time, mean that trace fossils should at least be considered in defining a base to the Cambrian System, and might be valuable in adequately locating that base in many sections. Crimes (1987) also championed the notion that the first appearance of particular trace fossil species may be used for global correlation. The advantage of trace fossils over small shelly fossils for the stratigraphic correlation of this interval have been discussed by numerous workers (e.g. Crimes, 1987; Narbonne *et al.*, 1987; Narbonne and Myrow, 1988; see Chapter 1).

## 5.2. The Precambrian-Cambrian Stratotype

The selection of the Global Stratotype Section and Point (GSSP) for the Precambrian-Cambrian has been controversial and attracted wide discussion (e.g. Cowie, 1992; Brasier, *et al.*, 1994). Precambrian strata were initially assumed to be barren. The discovery of Ediacaran soft-bodied fossils in the late 1940s in the Flinders Ranges, South Australia (Sprigg, 1947, 1949) and their discovery in definite Precambrian successions around the world (see Glaessner, 1984 and Hofmann, 1987) opened a new window into Precambrian evolution. By the late 1960s the existence of a latest Precambrian fauna was widely acknowledged (e.g. Glaessner and Wade, 1966; Glaessner, 1969). An IUGS "working group on the Precambrian-Cambrian boundary" was formed to define a GSSP. They investigated several possible stratotypes around the world and eventually focused on three sections:

- Ulakhan Sulugur on the Aldan River in eastern Siberia.
- The section at Meishucun near Kunming, in the Yunnan Province of southern China.
- Several sections on the Burin Peninsula of southeastern Newfoundland, Canada.

During the early years of their investigations (1970s to mid 1980s) the group favoured the definition of the boundary by means of small shelly fossils (Cowie, 1985). Two of the mentioned sections contain calcareous rocks with abundant small shelly fossils (e.g. Rozanov *et al.*, 1969). Later, studies indicated that small shelly fossils were long ranging, highly variable, over-split taxonomically, poorly understood taphonomically and often restricted by facies and provincialism (e.g. Narbonne *et al.*, 1987). Sections in carbonate sequences, particularly phosphatic carbonates are relatively thin and commonly condensed, with possible disconformities. This led some to suggest that the boundary may be defined by trace fossils (e.g. Crimes, 1987).

Consequently the working group concentrated its focus on the dominantly siliciclastic stratigraphic succession in Newfoundland, Canada. This comprises several continuous sections over the Precambrian-Cambrian boundary interval and includes abundant trace fossils. The following observations from this region enhanced the potential of trace fossils for global correlation of this horizon:

- The stratigraphic successions at Fortune Head, Burin Peninsula shows little evidence of environmental change across the boundary.

-The range of *Harlaniella podolica* and *Treptichnus (Phycodes) pedum* do not overlap and one succeeds the other. Similar changes were reported at other localities around the world (e.g. Crimes, 1987).

After more than a quarter of a century research, field excursions and discussions the working group finalised its decision and defined the boundary in low cliffs that extended beyond "Fortune Dump" in the Burin Peninsula, southern Newfoundland. The GSSP was situated in the level marked by the lowest occurrence of *Treptichnus (Phycodes) pedum*, at the base of the Cambrian *Treptichnus pedum* Biozone.

### **5.3. The Global Stratotype Section and Point (GSSP) for the Precambrian -Cambrian boundary interval**

The oldest rocks exposed on the Burin Peninsula are mafic pillow lavas, volcanogenic sediments, shales and stromatolitic limestones of the Burin Group (Strong *et al.*, 1978). The Marystown Group unconformably overlies the Burin Group and comprises a thick succession of subaerial volcanics and related clastic deposits (Strong, 1978; Narbonne *et al.*, 1987).

In the southern part of the Burin Peninsula, the Marystown Group is disconformably overlain by a continuous, predominantly siliciclastic sequence which has been divided into three lithostratigraphic units; the Rencontre, Chapel Island and Random Formations. The Rencontre Formation was deposited in a complex of shallow marine to non-marine environments (Smith and Hiscott, 1984; Crimes and Anderson, 1985) and is conformably overlain by the Chapel Island Formation which is entirely of shallow marine origin (Anderson, 1981; Crimes and Anderson, 1985). These, in turn are overlain by the Random Formation which is disconformably succeeded by fossiliferous shales and carbonates of Early Cambrian age.

#### **5.3.1. Lithostratigraphy of the Chapel Island Formation**

The Chapel Island Formation spans the Precambrian-Cambrian boundary interval and consists of green and red siltstones and sandstones. The formation was divided into five



members by Bengtson and Fletcher (1983). The same subdivisions were also used by Crimes and Anderson (1985) who studied the trace fossil content. Narbonne *et al.* (1987) studied several sections in detail and modified this subdivision by subdividing Member 2 further into two sub-members; 2A and 2B (Fig. 5.1).

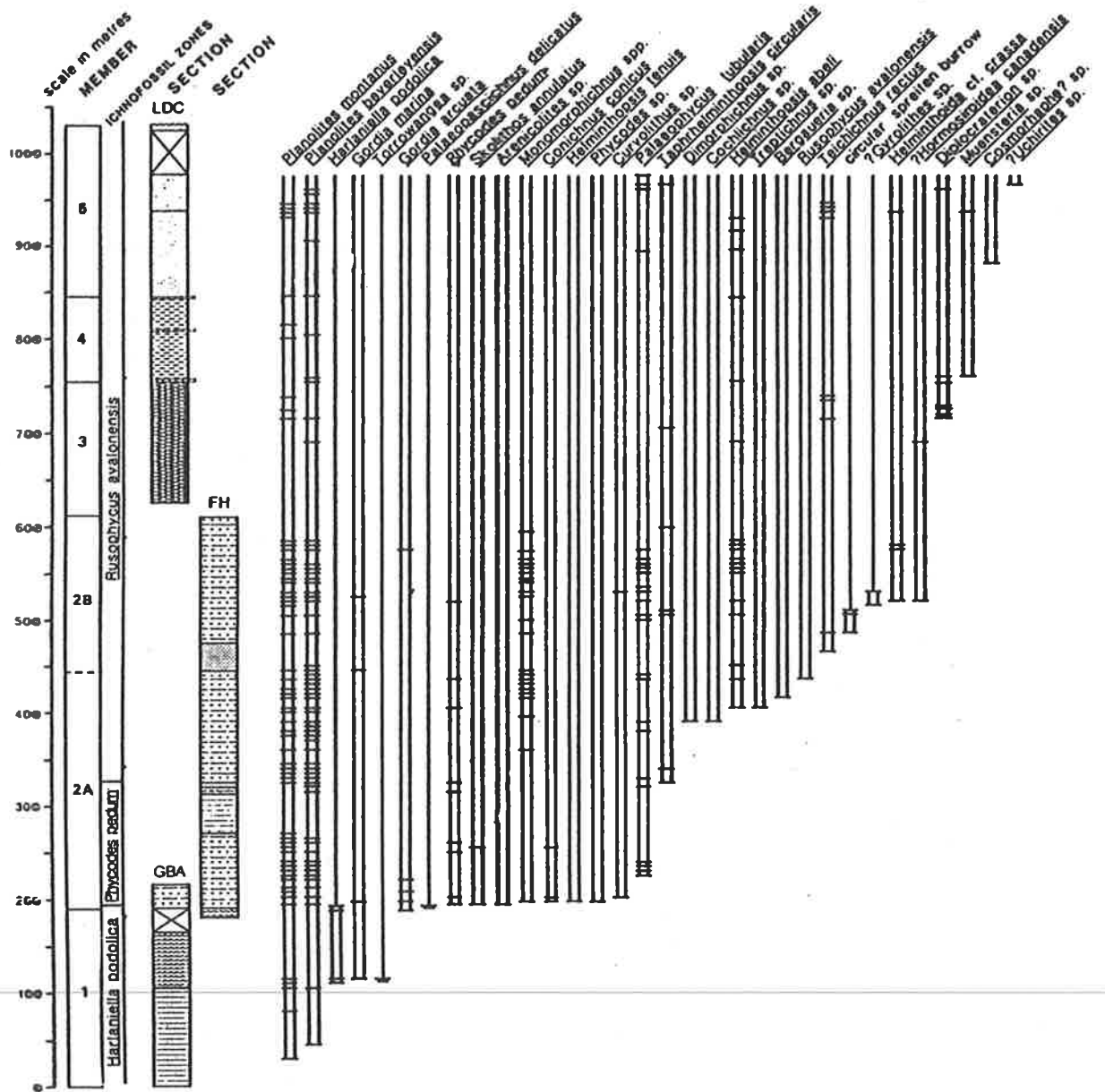
The base of the Member 1 is located between the red siltstones of the Rencontre Formation and the red and green siltstones and shales of the overlying Chapel Island Formation. The lower part of Member 2 (2A) consists of grey to grey-green interbeds of siltstone and sandstone which includes parallel lamination and current ripples with synaeresis cracks, phosphate, and pyrite nodules. The lower boundary of Member 2 is placed at the first stratigraphic occurrence of the grey-green siltstone and sandstone beds. The upper part of Member 2 (2B) consists of red and silver green siltstones. The change from Member 2 to Member 3 is highly gradational and reflects a decrease in sandstone bed thickness and a concomitant reduction in the percentage of sandstone. Member 3 comprises red, green and grey mudstone with red to white limestone. Interbedded green sandstone and siltstone of Member 4 overlies Member 3 which itself is overlain by red sandstone, minor siltstone and conglomerate forming Member 5.

The Precambrian-Cambrian boundary point was located 2.4 m above the base of Member 2 in the Chapel Island Formation, a little higher than the transition to storm influenced facies (Brasier *et al.*, 1994).

### **5.3.2. Trace fossil distribution of the Precambrian-Cambrian boundary interval**

Bengtson and Fletcher (1983) reported that trace fossils of Precambrian aspect occur within Member 1 of the Chapel Island Formation while Member 2 yields trace fossils known elsewhere from the Cambrian. The comprehensive study of Crimes and Anderson (1985) on the trace fossil distribution of the Chapel Island and Random Formations supported this view.

Narbonne *et al.* (1987) recognised three distinctive ichnozones within this interval named after a common ichnospecies restricted to or first appearing within that zone:



**Figure 5.1-** Trace fossil distribution across the Precambrian-Cambrian Stratotype, Newfoundland, Canada (after Narbonne *et al*, 1987).

-*Harlaniella podolica* zone. This embraces Member 1 and the basal 2.4 m of Member 2. Five ichnogenera comprising seven ichnospecies occur within this zone. They are all simple trails or burrows constructed at or near the sediment-water interface. Among these trace fossils, *Harlaniella podolica* and *Palaeopascichnus delicatus* are considered valuable age indicators. Both have been reported from the late Precambrian of the Eastern European Platform (Palij *et al.*, 1979; Fedonkin, 1985), Siberian Platform (Fedonkin, 1987) and in the Mackenzie Mountains (Aitken, 1984), but have not been located in Cambrian or younger strata.

-*Treptichnus (Phycodes) pedum* zone. This zone characterises the lower part of Member 2 (from 2.4 m to 133 m above its base) and contains 13 ichnospecies referable to 10 ichnogenera. A sudden increase in the number and diversity of trace fossils is evident with the first appearance of complex burrow systems. The most important trace is *Treptichnus pedum* which has widely been reported from around the world (e.g. Daily, 1972; Germs, 1972; Crimes and Anderson, 1985; Walter *et al.*, 1989; Bryant and Pickerill, 1990; Fillion and Pickerill, 1990; Geyer and Uchman, 1995; Jensen, 1997). The typical late Precambrian trace fossils such as *Harlaniella podolica* and *Palaeopascichnus delicatus* are absent.

*Rusophycus avalonensis* zone. The upper half of Member 2 and the remainder of the Chapel Island Formation and overlying Random Formation fall within this zone. The base of the zone is marked by the first appearance of *Rusophycus avalonensis* at Grand Bank Head, whereas at Fortune Head the same level contains *Taphrhelminthopsis circularis*. These two ichnotaxa are apparently restricted to this zone (Narbonne *et al.*, 1987).

#### **5.4. Correlation of the Precambrian-Cambrian transition of central Australia with the global stratotype**

Though, Jenkins (1995) reported *Harlaniella* and *Palaeopascichnus* cf. *delicatus* from the Flinders Ranges, South Australia, the typical representative of the *Harlaniella podolica* Zone of Narbonne *et al.* (1987) has not been found in the Arumbera Formation (restricted). However, the present ichnozone I is considered to be an equivalent of the *Harlaniella podolica* zone.

In the stratotype section, the ichnogenus *Treptichnus pedum* first appears in the basal part of the *Treptichnus* (=Phycodes) *pedum* zone and extends well up to the next overlying *Rusophycus avalonensis* zone. In the studied sections from central Australia, this ichnogenus occurs in close conjunction with *Rusophycus avalonensis* and even sometimes the latter occurs before the former. This may be interpreted in the following ways:

- The stratigraphic distribution of *Rusophycus avalonensis* differs in central Australia from the stratotype. Thus, this trace fossil appears in association with *Treptichnus pedum*.
- There is a stratigraphic hiatus above the Arumbera Formation (restricted) and the overlying Box Hole Formation, resulting from erosion or lack of deposition of the sediments bearing the traces of the *Treptichnus* (*Phycodes*) *pedum* zone-type traces.

The first appearance of *Rusophycus avalonensis* before *Treptichnus pedum* has been recorded from many localities worldwide (Crimes, 1987; Narbonne *et al.*, 1987) and hence, it is unlikely that the first possibility is true. The second notion is more plausible as a widely reported erosional surface marks the base of the Box Hole Formation. It is concluded that the occurrence of *Rusophycus avalonensis* before or at the same time as *Treptichnus pedum* is another criterion indicating lack of stratigraphic continuity in the Precambrian-Cambrian succession in central Australia and considered that the *Treptichnus pedum* Zone of Narbonne *et al.* (1987) is absent in the sections from central Australia due to the above mentioned erosional surface.

The *Rusophycus avalonensis* zone is well represented by trace fossils occurring in the present Ichnozones II and III which contain the diagnostic ichnospecies *Rusophycus avalonensis* and *Taphrhelminthopsis circularis* associated with *Dimorphichnus* *isp.*, *Rusophycus bonnarensis*, and *Gyrolithes polonicus*. Contrary to the situation in the stratotype, *Taphrhelminthopsis circularis* first appears after the occurrence of *R. avalonensis* and is associated with *Plagiogmus arcuatus*.

The inferred correlation between central Australia and the Global Stratotype for the Precambrian-Cambrian boundary results in the following conclusions:

- The Arumbera Formation (*sensu stricto*) belongs to the Precambrian, a notion already accepted by almost all authors.

- The sections in central Australia do not include the *Treptichnus pedum* zone and hence it can be concluded that there is no continuous deposition through the Precambrian-Cambrian interval (at least in the studied sections). This is also supported by seismic data which indicate erosion and/or onlap in the Missionary Plain Trough, Carmichael Sub-basin and locally the Ooraminna Sub-basin (Kennard and Lindsay, 1991, p.176; Lindsay *et al.*, 1993, p. 618).
- The *R. avalonensis* zone occurs in the Box Hole and Allua Formations, indicating a middle Tommotian to Atdabanian age. However, there is no definite information as to how much of the lower portion of this zone is missing because of the erosional surface at the base of the Box Hole Formation. The appearance of *R. avalonensis* before *T. circularis* is likely due to this hiatus as well. It is considered that the Box Hole Formation is late Tommotian.
- The occurrence of Ichnozone III with its diagnostic trace fossil, *R. bonnarensis* and *P. arcuatus* in the Allua Formation correlates with the upper part of the *R. avalonensis* zone (with the exception of *T. circularis*), indicating an Atdabanian age for the Allua Formation.

## 5.5 Global ichnozonation of the Precambrian-Cambrian Boundary

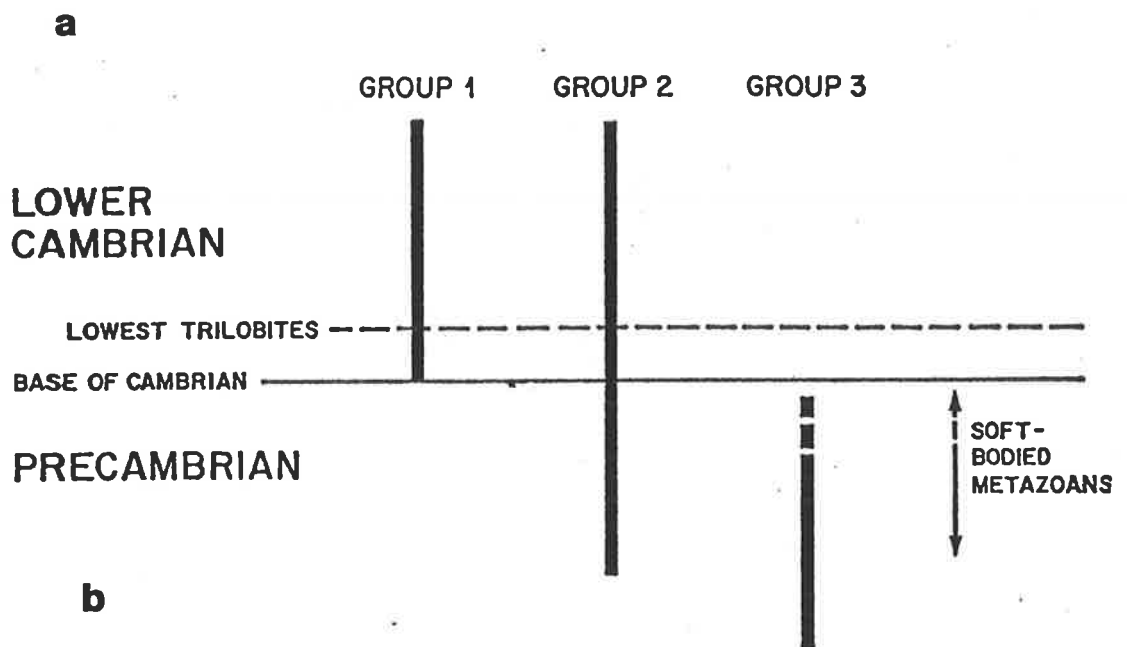
Following a comprehensive review, Alpert (1977) concluded from the occurrences of trace fossils in sections spanning the Precambrian-Cambrian boundary, that each ichnogenus falls into one of three groups (Fig. 5.2):

Group one included those whose incoming was taken to indicate an Early Cambrian age (e.g. *Cruziana*, *Diplocraterion*, *Phycodes*, *Plagiogmus*, *Rusophycus*, and *Teichichnus*).

Group two included those whose range extended across the boundary, so, their occurrences could not be used for correlation (e.g. *Curvolithus*, *Didymaulichnus*, *Gordia* (= *Helminthoidichnites*), *Planolites*, *Scolicia*, and *Skolithos*).

Group three included trace fossils known only from the late Precambrian (e.g. *Buchholzbrunnichnus*).

	GROUP 1 <i>Trace fossils indicative of Early Cambrian age</i>	GROUP 2 <i>Trace fossils not useful in delineating the basal Cambrian boundary</i>	GROUP 3 <i>Trace fossils known only from the late Precambrian</i>
<b>Dwelling burrows</b>	<i>Diplocraterion</i> <i>Monocraterion</i> <i>Laevicyclus</i> <i>Dolopichnus</i> <i>Bergaueria</i>	<i>Skolithos</i>	
<b>Feeding burrows</b>	<i>Phycodes</i> <i>Rhizocorallium</i> <i>Teichichnus</i> <i>Arthropycus</i> <i>Syringomorpha</i> <i>Zoophycos</i> <i>Dictyodora</i>	<i>Planolites</i> unbranched horizontal burrows unbranched horizontal backfilled burrows	<i>Archaeichnium</i>
<b>Trails or horizontal feeding burrows</b>	<i>Plagiogmus</i> <i>Psammichnites</i> <i>Cochlichnus</i> <i>Belorhaphe</i> <i>Helminthopsis</i> <i>Astropolithon</i> <i>Dactyloidites</i> <i>Oldhamia</i>	<i>Scolicia</i> <i>Curvolithus</i> <i>Didymaulichnus</i> <i>Torrowangea</i> <i>Helminthoidichnites</i> unbranched horizontal trails	<i>Bunyerichnus</i> <i>Buchholzbrunnichnus</i>
<b>Trilobite or arthropod traces</b>	<i>Rusophycus</i> <i>Cruziana</i> <i>Diplichnites</i> <i>Protichnites</i> <i>Dimorphichnus</i> <i>Monomorphichnus</i>		



**Figure 5.2-** Trace fossil distribution (a) and stratigraphic range (b) in three groups of ichnogenera recognised relative to the base of the Cambrian (after Alpert, 1977).

Alpert (1977) therefore suggested that the basal Cambrian boundary should be placed at, or just below, the lowest horizon containing trilobite trace fossils or other trace fossils indicating a Cambrian age.

The first truly global trace fossil zonation was proposed by Crimes (1987), who recognised three zones (ichnozones) spanning the Precambrian-Cambrian boundary interval which were defined with respect to the first appearance of trace fossils:

**Zone I.** Upper Precambrian (Vendian). Simple, sub-horizontal traces. A few ichnogenera (e.g. *Harlaniella*, *Palaeopascichnus*, *Nenoxites*) are apparently restricted to this zone. Approximately 15 ichnogenera known.

**Zone II.** (Basal Early Cambrian). First appearance of complex feeding burrows (e.g. *Phycodes*, *Teichichnus*, *Treptichnus*). Approximately 25 ichnogenera known.

**Zone III.** (Early Cambrian). First appearance of arthropod burrows (e.g. *Cruziana*, *Rusophycus*) and spreiten dwelling burrows (e.g. *Diplocraterion*). Approximately 45 ichnogenera known.

Crimes (1987) proposed that these zones were globally significant. In their study of the trace fossils of the Chapel Island Formation, Narbonne *et al.* (1987) supported this view. Crimes subsequently (1994) modified his zonation and introduced five ichnozones covering the oldest appearance of trace fossils up to the level prior to the appearance of trilobite body fossils (Fig. 5.3):

**Zone 0.** This contains some simple trace fossils such as *Planolites* and *Cochlichnus* which commonly make their burrows at or near the water-sediment interface. Age: upper Riphean-lower Vendian.

**Zone IA.** This ichnozone co-occurs with Ediacaran soft-bodied fossils and shows a common increase in abundance and diversity of trace fossils. Some common ichnogenera first appear at this horizon (e.g. *Aulichnites*, *Curvolithus*, *Gordia* and *Skolithos*) along with some unusual forms which are restricted to this zone such as *Intrites*, *Medvezhichnus*, *Nenoxites*, *Suzmites* and *Vendichnus*. It is noteworthy that about 29 per cent of the ichnogenera from this zone became extinct and did not survive into the next zone. Age: Upper Vendian.

	Russian Subdivision	Biozones	Trace fossil zone	Newfoundland composite stratigraphy and trace fossil zones	Biocharacter
Cambrian	Atdabanian	Trilobite Early Cambrian	III II	Burin Peninsula Random Fm Chapel Island Fm	Trilobites
	Tommotian	Pre-trilobite Early Cambrian			Abundant and diverse Phenozoic trace fossils
Precambrian	Vendian	Post-Ediacaran Pre-Cambrian	IB	Recontre Fm	First small shelly fossils
		Ediacaran	IA	Conception Group	Soft-bodied fossils and fairly diverse traces
		Varangerian	0	Avalon Peninsula Harbour Main Group	Stromatolites
	Riphean	Riphean			

Figure 5.3- Global biozones and their relationship to trace fossil zones and Precambrian-Cambrian boundary strata in Russia and Newfoundland, Canada (after Crimes, 1994).



Zone IB. Several new ichnogenera such as *Didymaulichnus*, *Monocraterion* and *Phycodes* which first appeared at this level have been widely reported from Phanerozoic strata. Crimes (1994) reported nine ichnogenera apparently restricted to this biozone (*Beltanelliformis*, *Buchholzbrunnichnus*, *Intrites*, *Medvezhichnus*, *Nimbria*, *Suzmites*, *Vendichnus*, *Vimenites* and *Yelovichnus*) while 11 ichnogenera first appear in this biozone (*Buthotrephis*, *Chomatichnus*, *Circulichnus*, *Didymaulichnus*, *Furculosus*, *Harlaniella*, *Monocraterion*, *Olenichnus*, *Phycodes*, *Planispiralichnus*, *Protospiralichnus*). Crimes (1994) correlated this zone with the *Harlaniella podolica* zone of Narbonne *et al.* (1987). Age: Upper Vendian (post Ediacaran pre-Cambrian).

Zone II. There is a significant increase in number and diversity of trace fossils as well as their complexity at this level. About 33 new ichnogenera first appear in this zone (Crimes, 1992b, 1994) and many of them showing a complex three-dimensional structure. This biozone can be correlated with the *Treptichnus (Phycodes) pedum* zone of Narbonne *et al.* (1987). Age: Lower Tommotian.

Zone III. Many more trace fossils appear within this biozone including those attributed to arthropods, particularly trilobites (*Cruziana*, *Dimorphichnus*, *Diplichnites*, *Rusophycus*). Several characteristic trace fossils occurring at this level are likely restricted to this zone (for example, *Astropolichnus*, *Plagiogmus*, *Rusophycus avalonensis*, and *Taphrhelminthopsis circularis*). Age: Upper Tommotian to Lower Atdabanian.

Ichnozones I-III described in this study can be correlated with the above mentioned global trace fossils zonation. Ichnozone I is correlated with Zone 1B of Crimes (1994) attributed to the post-Ediacaran pre-Cambrian and evidently Vendian in age. The trace fossil *Intrites* reported from the Arumbera Formation (McIlroy *et al.*, 1997) is apparently restricted to this Ichnozone. Ichnozone II is considered to be a correlative of Zone III of Crimes (1994). The lower extent of ichnzone II in central Australia is not clear due to the erosional surface below the Box Hole Formation. Ichnozone III is also correlated with the Zone III of Crimes. *Taphrhelminthopsis circularis* and *Plagiogmus arcuatus*, apparently restricted in this Zone are common in the studied sections from central Australia.

No representative of Crimes' (1994) Zone II, which contains *Teichichnus*, *Treptichnus*, and particularly *Treptichnus pedum* but not *Rusophycus* burrows, is recognised from the studied

sections indicating either a gap in the stratigraphic record of central Australia or a different occurrence of ichnotaxa in the local section compared to the most other sections world wide.

## 5.6. Interregional Correlation of the Precambrian-Cambrian Boundary

The occurrences of trace fossils reported from the Precambrian and Cambrian rocks of South Australia can be correlated with the established ichnozones in central Australia. The lower member of the Uratanna Formation contains simple horizontal burrows, *Planolites* (Gauld, 1976; Mount, 1993b). This member does not include complex traces of Cambrian aspect. It is tentatively correlated with the Ichnozone I from the central Australia. This also may be a representative of a lower part of the Ichnozone II for which the basal extent is not clear in the studied sections from central Australia due to the regional erosional surface at the base of the Box Hole Formation.

The middle member of the Uratanna Formation contains *Gordia*, *Planolites*, and "vertical burrows" in its lower portion. An abrupt occurrence of trace fossils including *Cochlichnus*, *Phycodes coronatum*, *Nereites*, and *Skolithos* has been reported from the middle portion of the middle member (Gauld, 1976; Mount, 1993b). Several new trace fossils appear in upper layers of the middle member including *Curvolithus*, *Monomorphichnus*, *Palaeophycus*, *Rusophycus avalonensis*, *Treptichnus* isp., and *Treptichnus pedum*. This trace fossil assemblage (=ichnoassemblage) continues to occur in the upper member of the Uratanna Formation in association with new forms comprising *Didymaulichnus*, *Monocraterion*, cf. *Scolicia* and "tapering burrows" (Gauld, 1976; Jenkins *et al.*, 1993; Mount, 1993b).

The example of *T. pedum* reported from the lower part (Gauld, 1976, pl. 7.1) shows vertical offshoots on both sides of the burrow and likely represents *Saerichnites*. The trace fossil assemblage (Fig. 5.4) recorded from this interval by Gauld (1976) and Mount (1993b) resembles Ichnozone II from central Australia and is considered to be its correlative. Although, no major break has been reported between the lower and middle parts, or middle and upper parts of the Uratanna Formation, *Rusophycus avalonensis* and *Treptichnus pedum* tend to appear together and there is a little stratigraphic difference in their first occurrence.

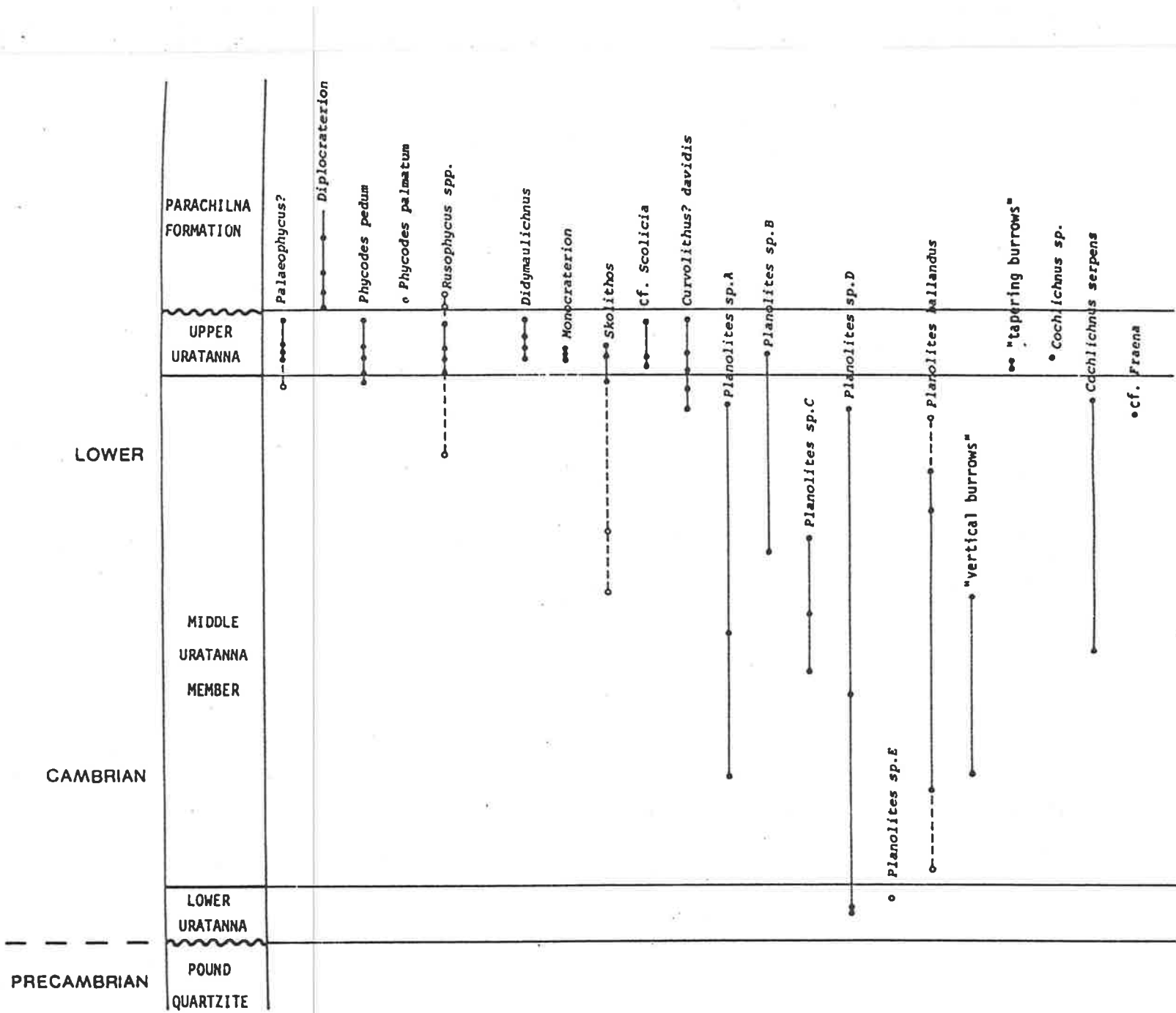


Figure 5.4- Trace fossil distribution and stratigraphic range in the Uratanna Formation, South Australia (after Gauld, 1976).

The overlying Parachilna Formation yields *Diplocraterion parallelum*, *Palaeophycus*, *Phycodes*, *Rusophycus bonnarensis* (reported by Daily, 1972, as *Cruziana cantabrica*), *Plagiogmus arcuatus*, *Phycodes palmatus*, and *Treptichnus pedum* (Glaessner, 1969; Daily, 1972, 1973; Gauld, 1976; Jenkins *et al.*, 1993; Mount, 1993b). *Diplocraterion* is found abundantly in the lower Parachilna Formation where it exhibits protrusive forms. This trace fossil assemblage is correlated with Ichnozone III in central Australia.

Based on the aforementioned correlation, the lower part of the Uratanna Formation may be correlated with the upper part of the Arumbera Formation (restricted). However, the lower part of the Uratanna Formation does not contain the Ediacaran soft-bodied fauna reported from the Arumbera Formation. The middle and upper parts of the Uratanna Formation are correlated with the Box Hole Formation from central Australia according to their trace fossils content. The succeeding Parachilna Formation, containing the diagnostic trace fossil *Plagiogmus arcuatus* is considered correlative with the Allua Formation. *P. Arcuatus* is restricted to Zone III of Crimes (1994) implying an Atdabanian age for the formation.

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# Chapter 6

## Conclusions

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The conclusions resulting from this study are:

### 6.1. Lithostratigraphic results

Based on the present information from the selected sections of the Arumbera Sandstone (*sensu lato*) from central Australia and available information from the previous work on these successions, a new stratigraphic division is proposed for this interval. Following Daily (1976), the Arumbera Sandstone is divided into three units comprising the Arumbera, Box Hole and Allua Formations from older to younger respectively. It is suggested that the name Arumbera Sandstone *sensu lato* to be discarded to avoid further confusion. The Arumbera Formation (restricted) embraces Units I, II and in some localities, the lower part of Unit III of Wells *et al.* (1967). The Box Hole Formation is considered to be an equivalent of the upper part of Unit III and the Allua Formation a correlative of Unit IV of Wells *et al.* (1967). The relationship between these formations has also been discussed. A diachronous erosional surface separates the Box Hole Formation and the underlying Arumbera Formation in all studied sections. A granular band occurs at the base of the Allua Formation at Ross River area probably indicating another erosional surface at the base of that formation. However, the lateral extent of this surface is not established.

### 6.2. Biostratigraphic results

The investigation on the distribution of trace fossils in the strata spanning the Precambrian-Cambrian boundary interval from central Australia resulted in the recognition of three

ichnozones which are correlated with the trace fossils zones proposed (Narbonne *et al.*, 1987) for the Precambrian-Cambrian Stratotype, Newfoundland:

**Ichnozone I      age: Vendian**

This ichnozone comprises simple horizontal burrows including *Bilinichnus*, ?*Helminthoida*, *Intrites*, *Palaeophycus*, and *Planolites* reported from the Arumbera Formation (restricted) by Conrad (1981) and McIlroy *et al.* (1997). This ichnozone is correlated with the *Harlaniella podolica* Zone of Narbonne *et al.* (1987) reported from Newfoundland.

**Ichnozone II      age: late Tommotian**

This ichnozone comprises some complex trace fossils which commonly occur throughout the Phanerozoic including *Arenicolites*, *Curvolithus*, *Diplichnites*, *Didymaulichnus*, *Glockerichnus*, *Gyrolithes*, *Hormosiroidea*, *Laevicyclus*, *Monocraterion*, *Phycodes*, *Protopaleodictyon*, *Psammichnites*, *Rusophycus*, *Saerichnites*, *Skolithos*, and *Treptichnus*. Contrary to the situation in the Newfoundland sections, the ichnospecies *Rusophycus avalonensis* first occurs with or prior to the ichnospecies *T. pedum* in the studied sections from central Australia.

**Ichnozone III      age: Atdabanian**

This ichnozone occurs in the Allua Formation and comprises *Asteriacites* isp., *Palaeophycus canalis*, *Palaeophycus ferrovittatus*, *Plagiogmus arcuatus*, *Rusophycus bonnarensis*, *Skolithos ramosus*, and *Taphrhelminthopsis circularis*, among which *P. arcuatus* and *T. circularis* have apparently a restricted stratigraphic range. Ichnozones II and III are correlated with the *Rusophycus avalonensis* Zone of Narbonne *et al.* (1987).

The *R. avalonensis* zone occurs in the Box Hole and Allua Formations, indicating a middle Tommotian to Atdabanian age. However, there is no definite information as to how much of the lower portion of this zone is missing because of the erosional surface at the base of the Box Hole Formation. The appearance of *R. avalonensis* before *T. circularis* which is in

contradiction to their order of appearance in the Newfoundland stratotype is likely due to this hiatus as well. It is considered that the box Hole Formation is late Tommotian.

It is concluded that the *Treptichnus pedum* Zone of Narbonne *et al.* (1987) is absent from the studied sections probably indicating a major hiatus prior to deposition of the Box Hole Formation. The occurrence of Ichnozone III with its diagnostic trace fossil, *R. bonnarensis* and *P. arcuatus* in the Allua Formation correlates with the upper part of the *R. avalonensis* zone (with the exception of *T. circularis*), indicating an Atdabanian age for the Allua Formation.

The following conclusion is also deciphered by comparing the established Ichnozones with the Global trace fossil Zones proposed by Crimes (1987; 1992a, b; 1994). Ichnozone I is correlated with Zone 1B of Crimes (1994) which is attributed to the post-Ediacaran pre-Cambrian and considered to be Vendian in age. The trace fossil *Intrites* reported from the Arumbera Formation (McIlroy *et al.*, 1997) is apparently restricted to this Ichnozone. Ichnozones II and III are considered to be equivalent to Zone III of Crimes (1994). *Taphrhelminthopsis circularis* and *Plagiogmus arcuatus*, apparently restricted in Crimes' Zone III, are common in the studied sections from central Australia. The occurrence of *Vendichnus* in association with other Cambrian-kind of trace fossils is significant. This ichnogenus is reported to be restricted to Zone IB of Crimes (1994) and if the identification is proven to be true, it will extend its stratigraphic range upto Zone III.

The established ichnozones from central Australia are used to correlate the Precambrian-Cambrian strata in South Australia with the following results:

The lower Uratanna Formation contains *Cochlichnus*, *Curvolithus*, *Planolites*, and *Skolithos* (Gauld, 1976) and is tentatively correlated with the Ichnozone I. This also can be a representative of a lower part of Ichnozone II for which the basal extent is not clear in the studied sections from central Australia due to the regional erosional surface at the base of the Box Hole Formation.

The middle (from its middle portion) and upper members of the Uratanna Formation contain *Cochlichnus*, *Curvolithus*, *Didymaulichnus*, *Phycodes coronatum*, *Monocraterion*, *Nereites*, *Palaeophycus*, *Planolites*, *Rusophycus avalonensis*, *Skolithos*, *Treptichnus* isp., and

*Treptichnus pedum* (Gauld, 1976; Jenkins *et al.*, 1993; Mount, 1993b). This trace fossil assemblage is considered to be correlative with Ichnozone II of central Australia.

The overlying Parachilna Formation yields *Diplocraterion parallelum*, *Palaeophycus*, *Phycodes*, *Rusophycus bonnarensis*, *Plagiogmus arcuatus*, *Phycodes palmatus*, and *Treptichnus pedum* (Glaessner, 1969; Daily, 1972, 1973; Gauld, 1976; Jenkins *et al.*, 1993; Mount, 1993b) which is correlated with the Ichnozone III of central Australia.

According to the aforementioned correlation, the lower part of the Uratanna Formation may be correlated with the upper part of the Arumbera Formation (restricted). In Angepena Syncline, the lower part of the Uratanna Formation does not contain the Ediacaran soft-bodied fauna reported from the Arumbera Formation. However, Gehling *et al.* (1988) have recorded "Ediacaran-type" fossils in the Uratanna sequence at the Castle Rock locality described by Mount (1993b). Thus, an Ediacaran-like fauna may be found in the lower Uratanna Formation, if appropriately preserved. The Middle and upper parts of the Uratanna Formation are correlated with the Box Hole Formation according to their trace fossil content. The succeeding Parachilna Formation containing the diagnostic trace fossil, *Plagiogmus arcuatus* is considered correlative with the Allua Formation. *P. arcuatus* is restricted to Zone III of Crimes (1994) which implies an Atdabanian age for the formation.

Analysis of the distribution of trace fossils in the studied sections indicated the presence of *Cruziana* ichnofacies in alternating fine- to medium-grained sandstone and siltstone dominated by horizontal burrows such as *Palaeophycus* and *Planolites*. The *Skolithos* ichnofacies occurs in medium to coarse grained, medium to thick bedded sandstone layers with dominant *Skolithos* and *Arenicolites* burrows.

### 6.3. Taxonomic results

An extensive collection of trace fossils has been studied resulting in identification about 45 ichnogenera which comprise 74 ichnospecies. Several ichnogenera and ichnospecies have been described for the first time from central Australia. *Hormosiroidea ?arumbera*, *Plagiogmus arcuatus* and *Taphrhelminthoida ?convoluta* were analysed morphologically and this has resulted in the recognition of new structural elements. Some new ideas regarding



classification of some ichnospecies have been applied. Following Jensen (1997), *Phycodes pedum* is considered to be an ichnospecies of *Treptichnus*. *Phycodes pollardi* is also considered to be ichnospecies of the ichnogenus *Hormosiroidea* based on its morphological similarities to the latter. An alternative interpretation of the *Saerichnites* burrow system has also been discussed.

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# Chapter 7

## Systematics:

### Trace fossil classification and Ichnotaxonomy

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#### 7.1. Trace fossil classification

Trace fossils are by their very nature sedimentary structures reflecting the relationship between the responsible organism and the enclosing substrate. There is a great diversity of trace fossils which require an efficient and generally agreed means of classification and nomenclature. Trace fossils can be principally classified in four different ways: formational, preservational, ethological, and taxonomic (Hantzschel, 1975; Ekdale *et al.*, 1984; Magwood, 1992).

Formational classifications deal with the position in which the trace was originally produced relative to the sediment surface and other stratal boundaries (Webby, 1969; Hantzschel, 1975). This is summarised in Figure 7.1.

Seilacher (1964) and Martinsson (1970) proposed a preservational classification (toponomy) which concerns the state of preservation; full or partial relief and the position of the trace with respect to the substrates in which the trace fossil is preserved (Fig. 7.2). It is important that there is no necessary correlation between formational and preservational classification (Ekdale *et al.*, 1984; Magwood, 1992).

Seilacher (1953a) proposed an ethological classification of trace fossils based on the fact that different groups of animal with similar life habits or behaviour patterns produce similar

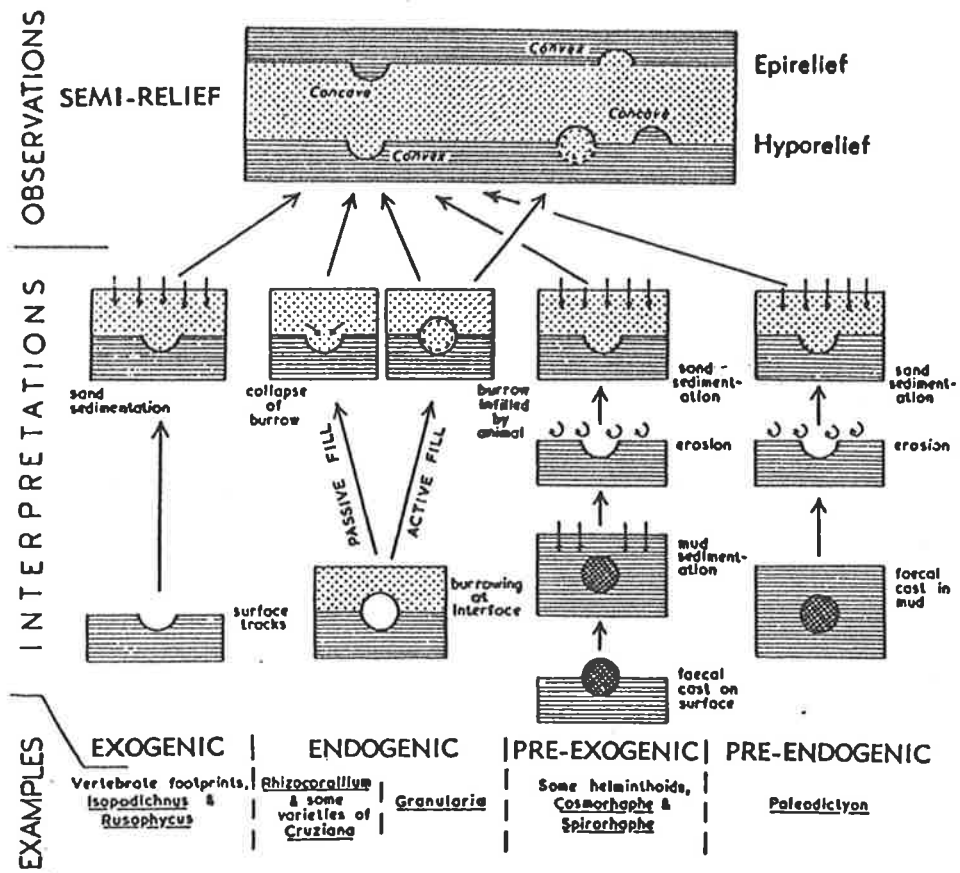


Figure 7.1 - Formational classification of trace fossils (after Webby, 1969; Häntzschel, 1975; Bromley, 1996).

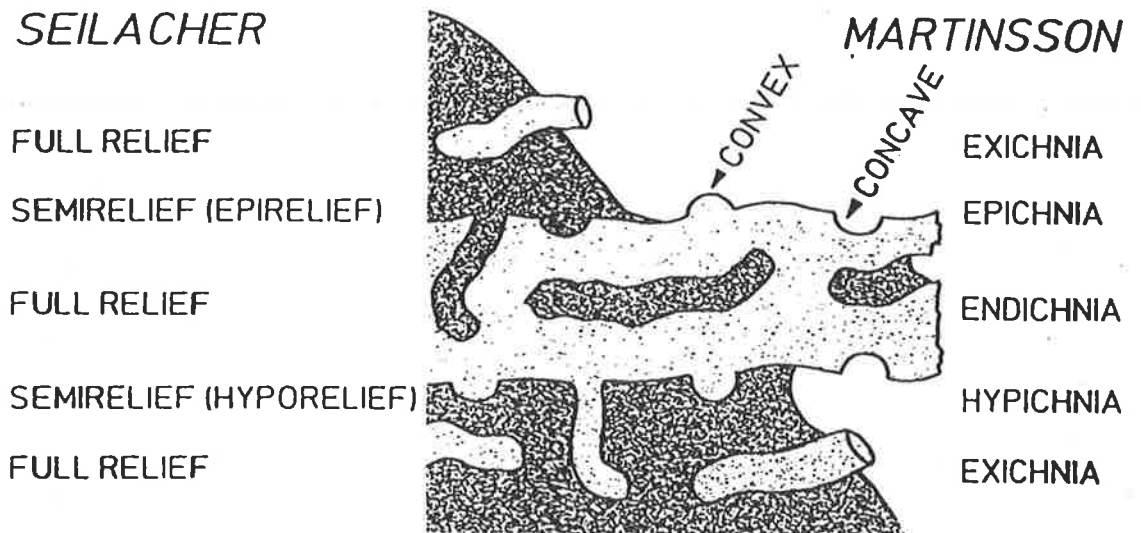


Figure 7.2- Preservational classification of trace fossils according to Seilacher (1964) and Martinsson (1970).

traces. Accordingly, several ethological classes were introduced (Fig. 7.3) to embrace different behaviour patterns (Seilacher, 1953a; Ekdale *et al.*, 1984; Frey and Pemberton, 1984).

Although the aforementioned three classifications are essential and invaluable ichnological tools, they have shortcomings regarding their application for general classification. Preservational classification is simple and not capable of distinguishing between numerous and structurally diverse ichnotaxa. Formational and ethologic classifications are subject to the interpretation of the trace and therefore rely on the opinion and viewpoints of the author, and do not provide an objective base for the classification.

The best option for the general classification of trace fossils is taxonomy (or trace fossil systematics) which is a descriptive classification based on morphology (Hantzschel, 1975; Magwood, 1992). Binomial names applied in ichnotaxonomy are similar to the genus and species names of zoological and botanical taxa. The terms ichnogenus and ichnospecies (plural ichnogenera and ichnospecies respectively) are used to clarify the different concepts applied in the two systems. These terms are usually abbreviated as igen. or isp. The International Commission of Zoological Nomenclature (ICZN) now recognises three principal levels in the ichnotaxonomic hierarchy: ichnofamily, ichnogenus, and ichnospecies as well as several intermediate levels (Rindsberg, 1990; Magwood, 1992).

As trace fossils directly reflect animal behaviour, ichnotaxonomy is based on morphological characteristics that are of behavioural significance (Fürsich, 1974b; Pemberton and Frey, 1982; Ekdale *et al.*, 1984; D'Alessandro and Bromley, 1987; Bromley, 1990, 1996). However, ichnotaxonomy can not be purely morphological and some interpretation must be involved as one must decide whether the structures in hand are biogenic, and it also assumes some level of significance to structural characteristics of the trace in order to establish a meaningful classification (Fürsich, 1973; Pemberton and Frey, 1982; Gureyev, 1985; Magwood, 1992). The observed morphology of a trace fossil may reflect the anatomy of the producer animal, preservation and diagenesis, and substrate consistency and compaction. Some of variations caused by these factors are taxonomically significant.

Definition	Characteristic Morphology	Examples
<b>Resting Traces (<i>Cubichnia</i>)</b> Shallow depressions made by animals that temporarily settle onto, or dig into, the substrate surface Emphasis is upon brief reclusion	Trough-like relief, recording to some extent the lateroventral morphology of the animal; structures are isolated, ideally, but may intergrade with crawling traces or escape structures	<i>Asteriacites</i> <i>Pelecypodichnus</i> <i>Rusophycus</i>
<b>Crawling Traces (<i>Repichnia</i>)</b> Trackways and epistratal or intrastratal trails made by organisms travelling from one place to another Emphasis is upon locomotion. Secondary activities may be involved.	Linear or sinuous overall structures, some branched; footprints or continuous grooves, commonly annulated; complete form may be preserved, or may appear as cleavage reliefs.	<i>Aulichnites</i> <i>Cruziana</i> <i>Diplichnites</i> <i>Scolicia</i>
<b>Grazing Traces (<i>Pascichnia</i>)</b> Grooves, patterned pits, and furrows, many of them discontinuous, made by mobile deposit feeders or algal grazers at or under the substrate surface Emphasis is upon feeding behaviour analogous to 'strip mining'.	Unbranched, non-overlapping, curved to tightly coiled patterns or delicately constructed spreiten dominate; patterns generally reflect maximum utilisation of food resources; complete form may be preserved	<i>Helminthoida</i> <i>Nereites</i> <i>Phycosiphon</i> <i>Zoophycos</i>
<b>Feeding Structures (<i>Fodinichnia</i>)</b> More or less temporary burrows constructed by deposit feeders: the structures also may provide shelter for the organisms. Emphasis is upon feeding behaviour analogous to 'underground mining'.	Single, branched or unbranched, cylindrical to sinuous shafts or U-shaped burrows, or complex, parallel to concentric burrow repetitions (spreiten structures); walls not commonly lined, unless by mucus Oriented at various angles with respect to bedding; complete form may be preserved.	<i>Chondrites</i> <i>Gyrophyllites</i> <i>Phycodes</i> <i>Rosselia</i>
<b>Dwelling Structures (<i>Domichnia</i>)</b> Burrows, borings, or dwelling tubes providing more or less permanent domiciles, mostly for hemisessile suspension feeders or, in some cases, carnivores Emphasis is upon habitation. Secondary activities may be discernible.	Simple, bifurcated, or U-shaped structures perpendicular or inclined at various angles to bedding, or branched burrow or boring systems having vertical and horizontal components; burrow walls typically lined Complete form may be preserved	<i>Diplocraterion</i> <i>Ophiomorpha</i> <i>Skolithos</i> <i>Trypanites</i>
<b>Escape Structures (<i>Fugichnia</i>)</b> Lebensspuren of various kinds modified or made anew by animals in direct response to substrate degradation or aggradation Emphasis is upon readjustment, or equilibrium between relative substrate position and the configuration of contained traces. Intergradational with other behavioural categories.	Vertically repetitive resting traces; biogenic laminae either in echelon or as nested funnels or chevrons; U-in-U spreiten burrows; and other structures reflecting displacement of animals upward or downward with respect to the original substrate surface Complete form may be preserved, especially in aggraded substrates	<i>Nested funnels</i> <i>U-in-U spreiten</i> <i>Down-warped laminae</i>
<b>Hunting Structures (<i>Praedichnia</i>)</b> Occurrence of two different kinds of trace fossils in close association indication a hunting relationship between the burrows.	Close association of two different trace fossils showing some sort of disturbance where they come in contact.	<i>Rusophycus</i> and <i>Planolites</i>

Figure 7.3 - Ethological classification of trace fossils (modified after Frey and Pemberton, 1984)

### Classification of structurally complex ichnotaxa

Behaviour patterns can be modified and combined with other motile habits to produce an intergradation of ichnotaxa. This creates some problems in classifying these structures which are referred to as compound or composite forms. Magwood (1992) referred to these structures as intergradational ichnotaxa.

Compound and composite specimens have been widely reported among the invertebrate ichnological literature (e.g. Fürsich, 1973; Gould, 1982; Bromley, 1990, 1996; Magwood, 1992; Pickerill and Narbonne, 1995). Composite forms are those represented by the mutual association of distinctive ichnotaxa within a single trace fossil, while a compound ichnotaxon results from the variable behaviour of an organism as it progresses on or within a given substrate (Pickerill and Narbonne, 1995).

A third category, complex forms, is proposed herein embracing those trace fossils comprising distinct structural elements. Each element has the potential to be preserved as a separate structure. Some structural elements of complex forms may be considered or mistaken as different ichnotaxa due to subsequent erosion or partial preservation of the specimen.

*Plagiogmus arcuatus* is a diagnostic example of such a complex form. The burrow system comprises three different parts each of which can be potentially preserved by itself and regarded as a distinct trace fossil (Fig. 7.41). The lower ladder-like part is the most common form and has originally been named as *P. arcuatus*. Subsequently Glaessner (1969) reported the presence of a backfilled part overlying the basal ladder-like part. The backfilled part is very similar to those referred to as *Laminites*, *Olivellites*, and *Psammichnites*. Later an upper bilobate part associated with the burrow was reported (Kruse and West, 1980; Walter *et al.*, 1989; McIlroy *et al.*, 1997) and this can be referred to as *Aulichnites* or *Psammichnites*.

There is no common approach in classifying these structures and both splitting (considering each part as separate ichnotaxon when it occurs by itself) and lumping (synonymising the available names in literature attributed to different parts) approaches have been applied by ichnologists (Chamberlain, 1971b; Chamberlain and Clark, 1973; Hofmann and Patal, 1989;

McIlroy *et al.*, 1997). A common, generally approved methodology for classification of these structures is essential, but a fundamental resolution still awaits.

## 7.2. Systematic Ichnotaxonomy

Following common ichnological procedure (Hantzschel, 1975; Crimes and Harper, 1977), and to ease reference, the ichnotaxa are arranged alphabetically. Formational and preservational terminologies of Seilacher (1964), Webby (1969), Simpson (1975) and Hantzschel (1975) have been applied in this study. The section under the heading 'occurrence' refers to material studied herein. The specimens are deposited with the Department of Geology and Geophysics, University of Adelaide.

### *Arenicolites* Salter, 1857

Type ichnospecies. *Arenicola carbonaria* Binney, 1852 page 192 by subsequent designation of Richter (1924, p.137).

Diagnosis. "Simple U-tubes without spreite, perpendicular to bedding planes; varying in size, tube diameter, distance of limbs, and depth of burrows; limbs rarely somewhat branched. Some with funnel-shaped opening" (Hantzschel, 1975, p. W38).

Preservation. Burton and Link (1991, p. 297) described *Arenicolites* as filled by sand from overlying beds and suggested that it may indicate that the burrows were open during deposition of subsequent turbidites. It is commonly preserved as full relief, but, in horizontal cross section appears on bedding planes as epireliefs. It has also been preserved as hyporelief (Corbo, 1979, p.99).

Originator. It is generally regarded as the dwelling burrow of suspension-feeders (e.g. Fürsich, 1975; Howard and Frey, 1975; Hakes, 1976, 1977; Chamberlain, 1978 Pickerel *et al.*, 1984;; Bjerstedt, 1987; Eagar *et al.*, 1985). The occurrence of a funnel-shaped aperture in some specimens of *Arenicolites* is considered to be an indicative of partial surface deposit feeding habits of the producer of the burrow (Corbo, 1979, p. 93; Eagar *et al.*, 1985, p. 131). The originator is suggested to be an annelid (Hakes, 1976; Chamberlain, 1978), particularly polychaetes (Bromley and Asgaard, 1979, p. 43; Miller, 1979, p. 120), or crustacean-like

organisms (Goldring, 1962). Bromley and Asgaard (1979, p. 43) reported that *Arenicolites* specimens occurring in the Triassic fresh water sediments of the Carlsberg Fjord/ East Greenland are very similar to the burrows that are produced today by the polychaete *Heteromastus filiformis* in conditions of rapid sedimentation alternating with non-deposition. These authors (1979) considered the burrow to be similar to the burrows of modern oligochaetes from fresh water mud.

Facies distribution. *Arenicolites* is commonly a shallow-water marine form (e.g. Pickerill *et al.*, 1984; Droser *et al.*, 1994; Narbonne, 1984), but it has been reported from non-marine (Bromley and Asgaard, 1979; Kamola, 1984) and deep-water deposits (e.g. Crimes *et al.*, 1977, 1981; Pickerill and Keppie, 1981; Savrda *et al.*, 1984; Edwards, 1985). It occurs in the *Cruziana* ichnofacies (Jansa, 1974, p. 243) and the *Glossifungites* ichnofacies (Wright and Benton, 1987). Bromley and Asgaard (1991) proposed an *Arenicolites* ichnofacies represented by opportunists creating *Arenicolites*, *Skolithos* Haldeman, 1840 and *Polycladichnus* Fürsich, 1981. Its modern analogue may be formed at depth up to and possibly exceeding 200 m (Jansa, 1974, p. 243). Generally *Arenicolites* is considered to indicate a high energy environment with shifting substrates (e.g. Hakes, 1976; Bromley and Asgaard, 1991).

Age. From the Earliest Cambrian (Narbonne and Myrow, 1988) to Holocene (Chamberlain, 1978). A probable late Precambrian occurrence of *Arenicolites* has been reported by Brasier and Hewitt (1979) from the Hartshill Formation in England and by Hofmann (1971, p.18) from Canada. Vendian occurrences of *Arenicolites* have also been reported by some other authors (e.g. Crimes and Jiang Zhiwen, 1986, p.648). However, reported Vendian occurrences are considered problematical, either because of their age or identification (Narbonne and Myrow, 1988).

Discussion. *Arenicolites* differs from *Diplocraterion* Torell, 1870, in the lack of a spreite structure developed between the limbs (e.g. Hakes, 1976). Buckman (1992) has also recorded an intermediate form between these two ichnogenera. Dam (1990, p. 124) considered that the occurrence of a thick lining in some *Arenicolites* indicates a permanent domicile. The characteristics that might be used to distinguish a particular ichnospecies of *Arenicolites* are:



**Geometry of burrow.** Although it provides a criterion for identification of different ichnospecies of *Arenicolites*, it can be unreliable as indicated by *A. carbonarius* which displays highly variable burrow morphology.

**Burrow lining.** This is highly controlled by lithology and might reflect substrate consistency.

**Size.** This has been considered to have ichnospecies-level significance. However, establishing an ichnospecies merely based on its size could be misleading unless it is supported by a strong statistical analysis.

**Aperture.** Some *Arenicolites* possess a funnel-shaped aperture. However, this can be subject to subsequent erosion and is not a reliable characteristic. The same problem exists with *Skolithos* and *Monocraterion* Torell, 1870.

**Tube cross section.** This characteristic is subject to subsequent change during compression and diagenesis of the substrate and is not visible in vertical sections of the burrow.

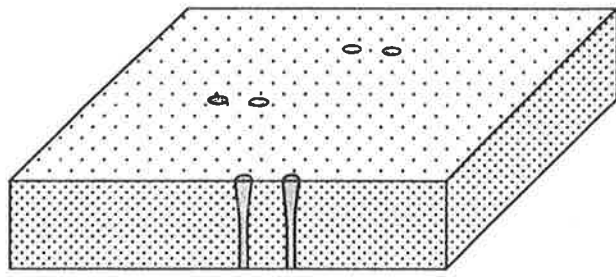
**Distance between limbs.** This can also be misleading as it may vary considerably even among the same ichnospecies.

### *Arenicolites* isp. A

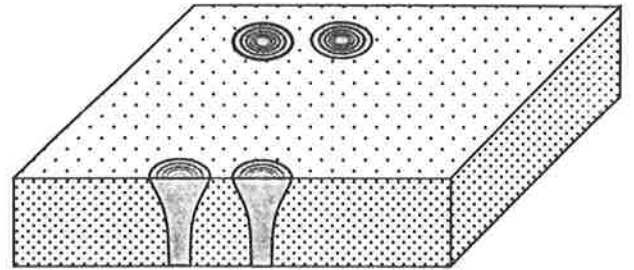
#### Plate 1A-B

Collected specimens. Eight specimens, A971-1-3, A971-1-9, A971-1-10, A971-2-21, A971-2-24, A971-3-3, A971-3-6, A971-3-8, and field photographs 1-20, 21, 22.

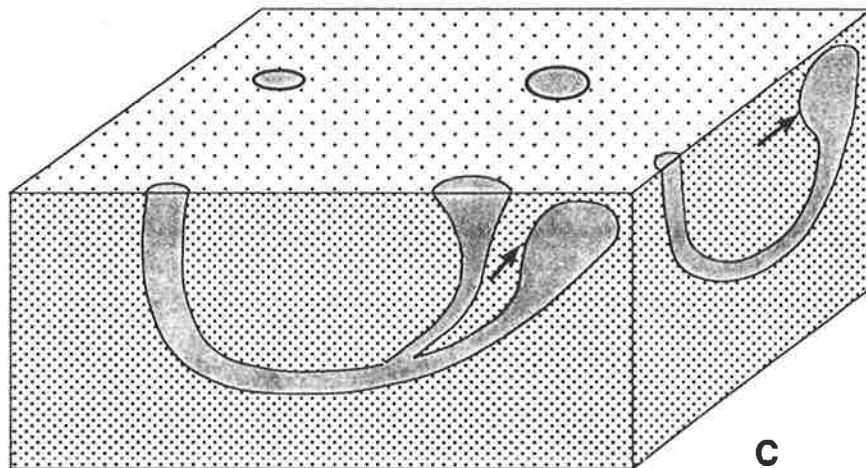
Description. Paired circular structures representing burrows perpendicular to the bedding plane with no disturbance between. Burrows are very narrow, 1-2 mm in diameter, 2-5 mm apart and abundantly cover the sandstone layer. Burrows may cut through the sandstone bed to be visible on the reverse side (sandstone slab about 5-8 mm thick) and may display a ring-shaped structure around the main shaft. Burrows have generally been preserved as concave or convex epireliefs. No complete U-shaped geometry of the burrow was observed (Fig. 7.4A).



**A**



**B**



**C**

**Figure 7.4 -** **A.** *Arenicolites* isp. A preserved as small concave epirelief or convex hyporelief circular structures. **B.** *Arenicolites* isp. B preserved as a concave epirelief and shows funnel-shaped apertures with concentric structure. **C.** *Arenicolites* isp. C, large U-shaped burrows with a bulbous termination on one end. The burrow fill is different from the host rock. Note the bulbous termination widens towards the inner side of the burrow (arrow).

Remarks. A concave ring around the structure is probably due to the wall of the burrow being altered by the organism as a lining, hence altering its lithology, which was subsequently more susceptible to erosion.

Occurrence. Box Hole Formation and Allua Formation at Ross River, Cyclops Bore and Hugh River, Amadeus Basin.

### *Arenicolites* isp. B

Plate 1C

Collected specimens. Four specimens, A971-1-11, A971-1-27, A971-1-29, and A971-3-12.

Description. Paired circular structures representing burrows perpendicular to the bedding plane with no disturbance between. Burrows are elevated and some show a conical funnel-shaped aperture with a concentric structure. They are 3-7 mm in diameter and 8-10 mm apart. Fill is coarser than the host rock (Fig. 7.4B). Burrows mostly are visible on the reverse side of the slab which is 10-15 mm thick.

Remarks. *Arenicolites* isp. B differs from *Arenicolites* isp. A in being larger and having a funnel-shaped aperture. It is much smaller than the *Arenicolites* isp. C and its limbs are closer together than the latter.

Occurrence. Box Hole Formation, Ross River and Cyclops Bore; Allua Formation, Cyclops Bore, Amadeus Basin.

### *Arenicolites* isp. C

Plate 1D, F, G

Collected specimens. Five specimens, A1035-MO47, A1035-MO47A, A1035-MO52A, A1035-MO54, and A1035-MO146.

Description. Large, vertical U-shaped burrows with a funnel-shaped aperture or bulbous termination at one or both ends. The funnel aperture is almost perpendicular to bedding and occurs mostly on one limb. However, in some specimens (A1035-MO146) both limbs

terminate to the funnel-shaped aperture in which one of the funnels is larger than the other. Some specimens (Pl. 1F) display a bulbous termination at one end instead of a funnel-shaped aperture. The limb which terminates in the bulbous structure is more oblique than the other and generally the bulbous structure is also oblique itself and seems to be a closed space. The structure is not symmetrical and widens from the inner side of the burrow producing an oval-shaped space (Fig. 7.4C). The burrow has been partly filled. The burrow fill which differs from the host rock and is darker in colour has been eroded away in most specimens due to its soft nature. One specimen displays an apparent branching (Pl. 1.G) in which one branch terminates in a funnel and the other in the bulbous structure. However, branching was not observed in other samples due to poor preservation. In burrows with bulbous terminations, the limbs do not terminate at the same sedimentary level. The limb with the bulb-shaped termination is located at lower level than the other one.

The burrow diameter changes from 10 mm at the vertical shaft to about 3-4 mm at the horizontal part. The funnel- and bulb-shaped structures vary in diameter from 15 to 23 mm. The complete burrow is about 60-80 mm deep and 70-100 mm wide.

Discussion. Occurrence of the limb with bulb-shaped structure in the *Arenicolites* isp. C is interesting as it terminates at slightly lower sedimentary level in comparison to the other limb. The bulbous termination does not seem to have been a vertical structure open to the sea floor. It is oblique or almost horizontal in some specimens and apparently is an enclosed space. If it was a closed space the burrows can not be classified as the ichnogenus *Arenicolites* which has two openings. However, both kinds of burrows (with funnel- or bulb-shaped terminations) occur together and as shown by one of the specimens (Pl. 1G), they may be part of the same burrow system. Therefore, these burrows are tentatively assigned to *Arenicolites*.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

***Arthraria*** Billings, 1872

Type ichnospecies. *A. antiquata* Billings, 1872; by monotypy (Hantzschel, 1975).

**Diagnosis.** Dumb-bell shaped trace preserved as convex hyporelief comprising a shallower stem connecting two wider and more deeply impressed terminations. Terminations vary morphologically and might not be identical. Terminations do not extend vertically (after Fillion and Pickerill, 1984).

**Discussion.** In their monograph on the ichnogenus *Arthraria*, Fillion and Pickerill (1984) elaborated the relationship between this ichnogenus and other ichnogenera which can potentially produce dumb-bell shaped structures such as; *Diplocraterion* Torell, 1870 and *Bifungites* Desio, 1940. Fillion and Pickerill (1984) considered *Arthraria* to be a distinct ichnotaxon, usually preserved as a convex hyporelief on the sole of sandstone layers. However, it is possible that some *Arthraria* represent a hypichnial cast of *Diplocraterion* or *Bifungites* burrows (Fig. 7.5) as the latter two generally are preserved as concave epireliefs. Although this may be proven to be correct, the trace should be named as *Arthraria* since it does not possess any vertical elements.

**Age.** Early Cambrian (this study); Early Ordovician (Billings, 1872; Fillion and Pickerill, 1984) and Silurian (Hantzschel, 1975).

*Arthraria antiquata* Billings, 1872

Plate 2A

1984 *A. antiquata* Billings; Fillion and Pickerill, p. 691, fig.5.

**Collected specimens.** One specimen, A1035-MO153.

**Diagnosis.** The same as ichnogenus.

**Description.** A straight burrow 2 mm wide, 14 mm long connecting two hemispherical structures 5mm wide and 6 mm long. The burrow is preserved as a convex hyporelief on sole of a sandstone layer. The hemispherical structures show shallow transverse striations (Fig. 7.6).

**Discussion.** The present material displays shallow transverse striations which *Arthraria* lacks. However, there is no vertical element in association with this burrow thus, justifying its designation to *Arthraria*.

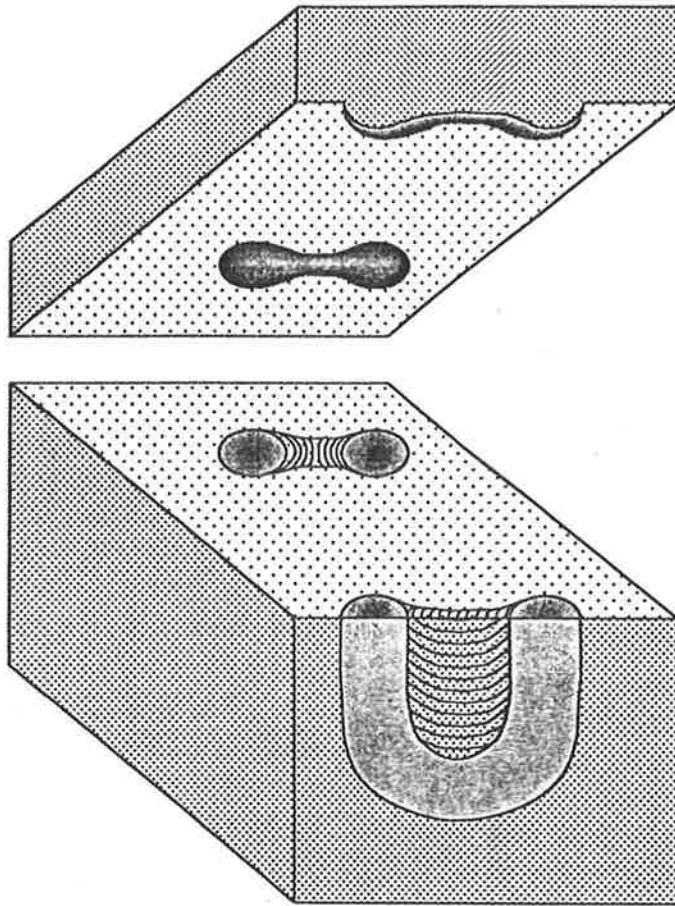


Figure 7.5 - Hypichnial cast of U-shaped spreiten bearing burrows such as *Diplocraterion*, *Corophoides* and *Bifungites*, may resemble the ichnogenus *Arthraria*.

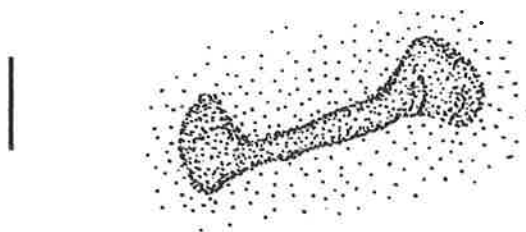


Figure 7.6 - *Arthraria antiquata* preserved as convex hyporelief. Semi-spherical terminations show faint transverse striations (scale bar = 1 cm).

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

***Asaphoidichnus* Miller (1880)**

Type ichnospecies. *Asaphoidichnus trifoldum* Miller (1880 pl. 11, fig. 6) from Cincinnati, Ohio (Osgood, 1970).

Diagnosis. "Large, trifold arthropod tracks, exhibiting both straight-ahead and oblique movement. Width of the track varies from 6.0 - 15.5 cm; number of imprints per set averages nine" (after Osgood, 1970 p. 356).

Discussion. Two ichnospecies of *Asaphoidichnus* were reported namely *A. trifoldum* and *A. dyeri*. Osgood (1970) in his review of the trace established a new ichnogenus *Allocotichnus* and considered *A. dyeri* as its type ichnospecies due to its distinct morphology which is different from other trilobite tracks.

The present specimen, though it has been preserved fairly well, is only a single trifold impression with no indication of locomotion. Hence its designation to this ichnogenus is tentative.

Age. *Asaphoidichnus* has been reported from the Early Cambrian of north western Argentina (Acenolaza and Durand, 1986) and the Cincinnati area, Ohio (Miller, 1880; Osgood, 1970).

**?*Asaphoidichnus trifoldum* Miller (1880)**

Plate 2C

Collected specimens. One specimen, A1035- MO59.

Diagnosis. Same as the ichnogenus.

Description. A trifold impression preserved as a convex hyporelief. Inner ridge is apparently branched from the middle one. Ridges are up to 18 mm long and 1 mm wide. Where ridges join together the trace is more elevated and extends a further 2 mm as a single ridge (Fig. 7.7).

Discussion. Miller (1880) reported that the trace possibly was produced by an animal lifting its feet to advance, apparently an articulated animal. He also reported that the middle ridge is a little longer than either the outer or inner ones. However, in the present material the outer ridge is the longer one, perhaps due to later erosion of the trace.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

### ***Asteriacites* von Schlotheim 1820**

Type ichnospecies. *Asteriacites lumbricalis* von Schlotheim 1820 by subsequent designation of Seilacher (1953b), from Lias of Coburg, Germany.

Diagnosis. "Stellate cubichnia of starfish which may be preserved as both concave epireliefs and convex hyporeliefs. Vertical repetition is not uncommon and some evidence of the activity of tube feet may be present" (after Osgood, 1970 p. 312).

Discussion. Seilacher (1953b) reviewed the ichnogenus, recognising two ichnospecies of *Asteriacites*, *A. lumbricalis* Schlotheim, 1820 and *A. quinquefolius* Quenstedt, 1876. The ichnospecies *A. stelliforme*, formerly *Heliophycus stelliforme* Miller and Dyer, 1878, was placed in synonymy with *A. lumbricalis* by Seilacher (1953b), but Osgood (1970) considered its rugose ornamentation to be significant at ichnospecies level and retained it as a distinct ichnospecies of *Asteriacites*.

*Asteriacites* is distinguished from other ichnogenera with stellate morphology such as *Asterosoma* von Otto, 1854, *Astropolichnus* Crimes and Anderson, 1985 and *Lorenzina* de Gabelli, 1900, by the regularity of the rays and their pointed ends.

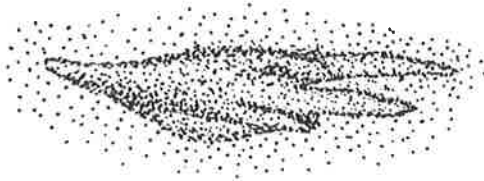
### ***Asteriacites* isp.**

Plates 1E, 2B

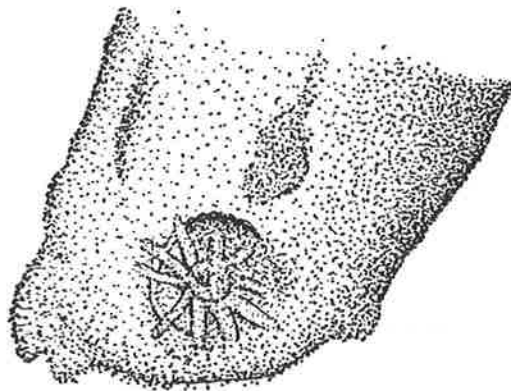
1986 *Asteriacites* sp.; Crimes and Jiang Zhiwen, fig. 3C.

Collected specimens. Two specimens, A971-1-30 and A971-2-44.





**Figure 7.7** - ?*Asaphoidichnites trifidum*, a single trifid scratchmark preserved as a convex hyporelief (scale bar = 1 cm).



**Figure 7.8** - *Asteriacites* isp. preserved as a convex hyporelief within a *Palaeophycus tubularis* burrow. It shows a central ring and a convex, ring-shaped structure close to its margin (scale bar = 1 cm).

Description. Stellate traces with about 10 relatively well-preserved, regularly spaced rays preserved as convex hyporeliefs. The impression is small about 5 mm in diameter. Rays diverge from a central circular structure and are straight to slightly curved with pointed ends. One of the traces displays a ring shaped structure close to its margin. Rays are extended slightly beyond this ring (Fig. 7.8).

Discussion. One of the specimens (Pl. 2B) has been preserved within a large burrow of *Palaeophycus tubularis*. The relationship between the present ichnotaxa and *P. tubularis* is discussed below under the latter ichnospecies. Both in size and number of rays, *Asteriacites* isp. resembles the *Asteriacites* isp. reported from the Zhongyicun Member of the Meishucun section, China by Crimes and Jiang Zhiwen (1986). *Asteriacites* isp. reported from China has an elevated knob-shaped centre and lacks the marginal ring of the present material. According to the writer's knowledge, these are the only reports of small *Asteriacites* with about ten rays and both occur in the Early Cambrian and hence may be proven to be stratigraphically significant.

An alternative interpretation of the trace is that it may represent a repetition of a 5 rayed *Asteriacites*. There is not sufficient material in the present collection to allow further study and the specimens available do not show any structure indicative of repetition. Crimes and Jiang Zhiwen (1986) also did not report any repetition structure for their specimens. The presence of marginal ring indicates that *Asteriacites* isp. is convincingly a resting trace of an asterozoan animal and not the result of burrowing activity.

It differs from other ichnospecies of *Asteriacites* in its small size and the presence of about ten rays rather than the five present in others. Although size is considered not to be significant at the ichnogenus level, it may be used in distinguishing ichnospecies (Fillion and Pickerill, 1990b p. 31). Accordingly, its size and number of rays are distinct enough to warrant a new ichnospecies name. However, following Crimes and Jiang Zhiwen (1986), a new ichnospecies is not established because of insufficient material.

Occurrence. Lower Allua Formation, Cyclops Bore and Ross River, Amadeus Basin.

### *Aulichnites* Fenton and Fenton, 1937

Type ichnospecies. *Aulichnites parkensis* Fenton and Fenton, 1937 by original designation.

Diagnosis. Preserved in convex epirelief with a bilobate upper surface. May show a unilobate, convex-downward lower surface, in which case lateral margins of both surface intersect. Upper surface may show transverse, concave-convex striation. Lobes separated by median furrow (after Hakes, 1977 and Fillion and Pickerill, 1990b).

Discussion. Fenton and Fenton (1937a) reported *Aulichnites* as a bilobate epirelief burrow. Hakes (1977) found a unilobate structure within the sediment below the upper surface of *A. parkensis* and suggested that occurrence of both structures is needed for an accurate identification. *Aulichnites* was placed in synonymy with *Scolicia* de Quatrefages, 1849, by Chamberlain (1971b) but Hantzschel (1975) retained it as a separate ichnogenus. *Aulichnites* is similar to *Didymaulichnus* Young, 1972, particularly *D. lyelli* (Rouault, 1850), *Psammichnites* Torell, 1870, and *Plagiogmus* Roedel, 1929, in being bilobate having two ridges separated by a median furrow. It differs from the *Didymaulichnus* in being preserved as a convex epirelief (upper surface) or concave hyporelief (lower surface).

*Aulichnites* differs from *Plagiogmus* in the lack of a basal ladder-like structure. Where the basal ladder-like structure is not exposed, the upper bilobate part of *Plagiogmus* might be confused with *Aulichnites*. However, the unilobate lower part of *Aulichnites* is more steep-sided than the middle oval-shaped fill of *Plagiogmus*.

The relationship between *Aulichnites* and *Psammichnites* is more confusing. *Psammichnites* is a bilobate burrow with a unilobate structure underneath, very similar to that of *Aulichnites*. However, *Psammichnites* is much larger in size with a well developed internal structure in which its lower surface may display a median ridge or furrow (Hofmann and Patel, 1989), characteristics not reported for *Aulichnites*. The present specimens are poor in both numbers and preservation which does not allow detailed study of the trace. The ichnogenus *Aulichnites* is retained herein.

Originator. *Aulichnites* has been considered as the repichnia of a gastropod (Fenton and Fenton, 1937a; Bandel, 1967), with ridges formed during peristaltic motion of the animal (Chamberlain, 1971b; Howard and Frey, 1984).

Facies distribution. *Aulichnites* is generally characteristic of shallow-water marine settings (e.g. Hakes, 1977) but has been reported from deeper marine facies (Hill, 1981) and brackish water deposits (Pollard, 1988).

Age. *Aulichnites* ranges from upper Vendian (Fedonkin, 1988) into the Palaeocene (Hill, 1981).

### ?*Aulichnites* isp. A

#### Plate 3A

Collected specimens. Two specimens, A1035-R12 and A1035-R13.

Description. Bilobate burrow with a median furrow moulded as concave hyporelief. Burrow straight to curved, parallel to bedding and 8-15 mm wide. One of the specimens (Pl. 3.A) gradually becomes less defined where it passes below a bedding horizon. At one end, the burrow becomes unilobate and shows a series of transverse annulations which are somewhat arcuate in shape (Fig. 7.9A).

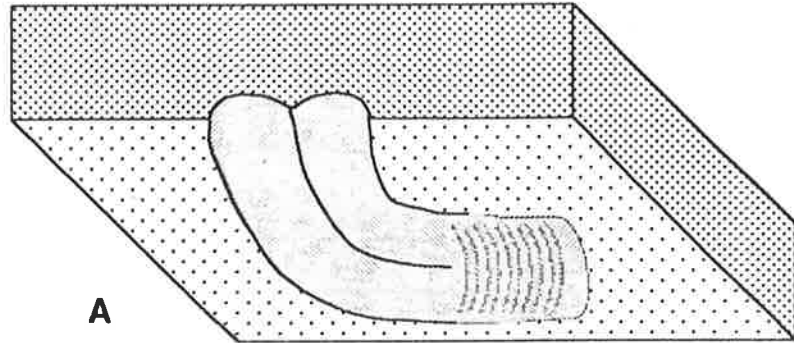
Discussion. The burrow is probably a hypichnial mould of *Aulichnites*. *Plagiogmus* also can produce such mould but the upper bilobate part in *Plagiogmus* is smooth. Since the epirelief preservation of the burrow is not available, designation to *Aulichnites* is tentative. The transverse annulations on one of the specimen (Pl. 3A) implies that nature of the locomotion by the producer animal was peristaltic.

Occurrence. Box Hole and Allua Formations, Ross River, Amadeus Basin.

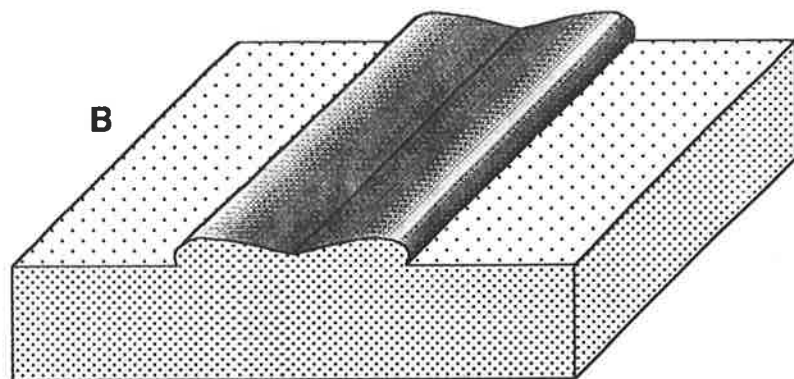
### ?*Aulichnites* isp. B

#### Plate 3B

Collected specimens. One specimen, A971-1-23A.



A



B

**Figure 7.9 - A. ?*Aulichnites* isp A**, a concave epirelief burrow possessing two lobes separated by a median ridge which has a sharp apex. At one end the burrow becomes shallower and gradually changes into a unilobate burrow showing transverse arcuate annulations which possibly reflect the peristaltic locomotion of the producer. **B. ?*Aulichnites* is B**, a large bilobate burrow preserved as convex epirelief. Lobes gently slope to the median furrow and have a raised margin.

**Description.** A large, bilobate burrow preserved as a convex epirelief. The burrow is 45 mm wide with a rather flattened lobes separated by a shallow median furrow. The lobes are more elevated at the margins and gently slope down to the median furrow. The burrow does not show a unilobate lower surface or any ornamentation on its bilobate surface (Fig. 7.9B).

**Discussion.** ?*Aulichnites* isp. B is much larger than reported range size for the ichnogenus and does not show a lower unilobate structure. This specimen is similar to that reported by Banerjee and Narain (1976) from the Jurassic, lower Tal Formation of Mossoorie, Himalayas. Their trace also is tentatively grouped within *Aulichnites*.

**Occurrence.** Box Hole Formation, Cyclops Bore, Amadeus Basin.

### ***Bergaueria* Prantl, 1945**

**Type ichnospecies.** *Bergaueria perata* Prantl, 1945; by original designation.

**Diagnosis.** One or more cylindrical to hemispherical protrusions with smooth walls, length and diameter sub-equal, lower end rounded, with a shallow depression which is sometimes surrounded by radially arranged tubercles or ledges; sediment-fill massive (after Hantzschel, 1975, p. W; Pemberton *et al.*, 1988).

**Discussion.** Pemberton *et al.* (1988) monographed the ichnogenus and recognised four ichnospecies of *Bergaueria* namely, *B. perata* Prantl, 1945, *B. radiata* Alpert, 1973, *B. hemispherica*, Crimes *et al.*, 1977 and *B. langi* (Hallam, 1960). They used wall linings and ornamentation of the distal termination as ichnospecies characteristics.

**Originator.** *Bergaueria* has been regarded as a resting trace (Cubichnia, e.g. Hantzschel, 1962, 1975; Hakes, 1976) or dwelling burrow (Domichnia, e.g. Alpert, 1973) of suspension feeding coelenterates, possibly actinian anemones. Pemberton *et al.* (1988) considered both interpretations to be correct as lined specimens represent domichnia and unlined specimens represent cubichnia.

**Facies distribution.** Although, *Bergaueria* is typical of intertidal to shoreface muddy sediments (Alpert, 1973; Crimes *et al.*, 1977; Miller and Knox, 1985), it also occurs in deep-water environments (Ksiazkiewicz, 1977; Eagar *et al.*, 1985).

Age. *Bergaueria* has been reported from the Cambrian and Ordovician (e.g. Crimes *et al.*, 1977), and the Silurian (Narbonne, 1984), Devonian (Garcia-Ramos, 1976), Carboniferous (Hakes, 1976), Permian (Muller, 1967), Jurassic (Fürsich, 1974a), Eocene (Ksiazkiewicz, 1977) and Pleistocene (Pemberton and Jones, 1988).

? *Bergaueria* isp.

Plate 2E, F

Collected specimens. Three specimens, A1035-MO106, A1035-MO117 and A1035-MO153.

Description. Smooth, semi-hemispherical vertical burrows preserved as convex hyporeliefs on sole of sandstone layers. Burrows are 5-8 mm in diameter and 3-4 mm deep. Their apex is rounded and no ornamentation was observed.

Discussion. These burrows are smaller than the reported species of *Bergaueria*, which generally show some sort of surficial ornamentation particularly at their apex. The present specimens lack this and therefore the designation to *Bergaueria* is tentative.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

***Bilinichnus* Fedonkin and Palij (in Palij *et al.*, 1979)**

Type ichnospecies. *B. simplex* Fedonkin and Palij (1979) by original monotypy, from Valdai series, River Syuzma, Ongena Peninsula, East European Platform.

Diagnosis. Straight to irregularly curved paired furrows (concave epirelief) or paired ridges (convex hyporelief) well spaced, separated by a distance considerably greater than the width of the individual furrows. Furrows are smooth and lack ornamentation. (after Fedonkin and Palij, 1979 as cited in Keighley and Pickerill, 1996).

Discussion. In their translation of the original report, Urbanek and Rozanov (1983) cited the following diagnosis after Fedonkin and Palij (1979); "two narrow shallow parallel furrows of equal width, forming gently curving trails". Keighley and Pickerill (1996) considered the

ichnogenus to embrace both paired furrows (concave epireliefs) and paired ridges (convex hyporeliefs) as illustrated in Figure 7.10.

In some aspects the ichnogenera *Archaeonassa* Fenton and Fenton, 1937 (Buckman, 1994, figs 5 and 7A-B), *Scolicia* de Quatrefages, 1849 (Tunis and Uchman, 1996, fig. 8B) and *Diplopodichnus* Brady, 1947 (Keighley and Pickerill, 1996, fig. 4) resemble *Bilinichnus*. Smooth, convex epirelief preservation of *Archaeonassa* figured by Buckman (1994, fig. 5) closely resembles *Bilinichnus* (Fig. 7.12B). However, *Bilinichnus* is reported to be preserved either as concave epirelief or convex hyporelief and not as smooth convex epirelief burrows as for *Archaeonassa*. *Bilinichnus* differs from *Diplopodichnus* in the presence of striate or punctuate ornamentation in the furrows of the latter (Fig. 7.12A). In certain preservational modes *Scolicia* may also resemble *Bilinichnus*. The central area between the ridges is disturbed in *Scolicia* but is smooth and unornamented in *Bilinichnus* (Fig. 7.12C).

Gevers (in Gevers *et al.*, 1971) introduced the ichnogenus *Arthropodichnus* from Beacon sediments (Devonian), southern Victoria Land, Antarctica. However, the name *Arthropodichnus* had previously been used by Chiplonkar and Badwe (1969; published in 1970) for arthropod tracks from the Late Cretaceous of India. Later, Gevers (1973) introduced a new name, *Beaconichnus* and considered *Arthropodichnus darwinum* (*sensu* Gevers in Gevers *et al.*, 1971) as its type ichnospecies. Hantzschel (1975) considered *Beaconichnus* a heterogeneous ichnogenus comprising different morphotypes and its re-evaluation is suggested. Among ichnospecies of *Beaconichnus*, *B. darwinum* (Gevers, 1971) is very similar to *Bilinichnus*. Some trails of *B. darwinum* end in burrow pits, which are wider than the trail itself and are elongate in the direction of prolongation of the trails. This shows the place where the producer sank into the sediment and indicates both epichnial and endichnial preservation of the burrow. The grooves in *B. darwinum* also exhibit small foot imprints. These features have not been reported for *Bilinichnus*.

Originator. Fedonkin and Palij in Palij *et al.* (1979) considered gastropods as a possible producer of the burrow. Keighley and Pickerill (1996) discussed the ethological origin of the trace and questioned its attribution to gastropods. It is reported from the Vendian and it is not clear how a soft bodied organism could produce such a marking. They also argued that the



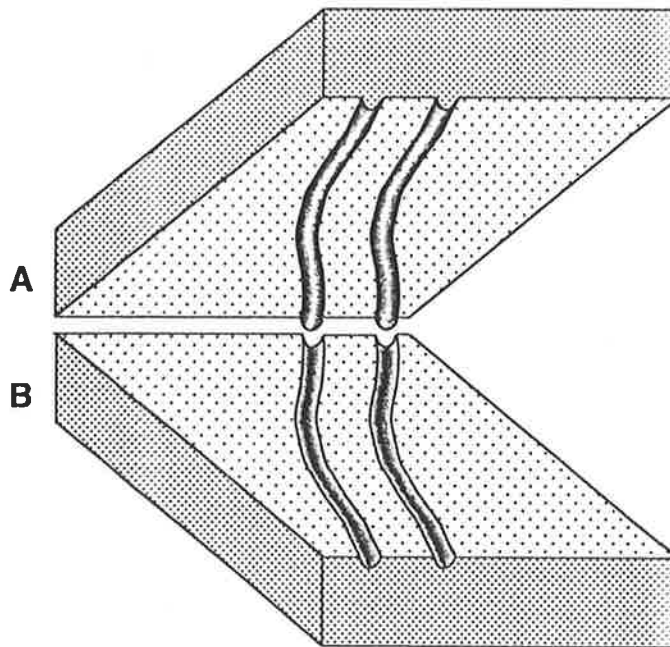


Figure 7.10 - *Bilinichnus simplex* preserved as convex hyporelief (A) and concave epirelief (B).

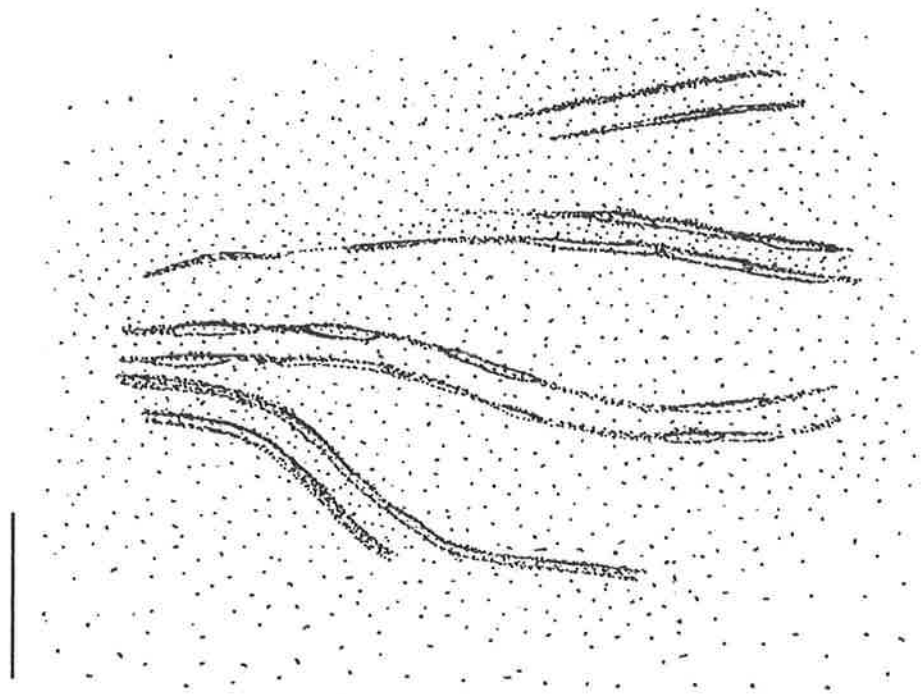
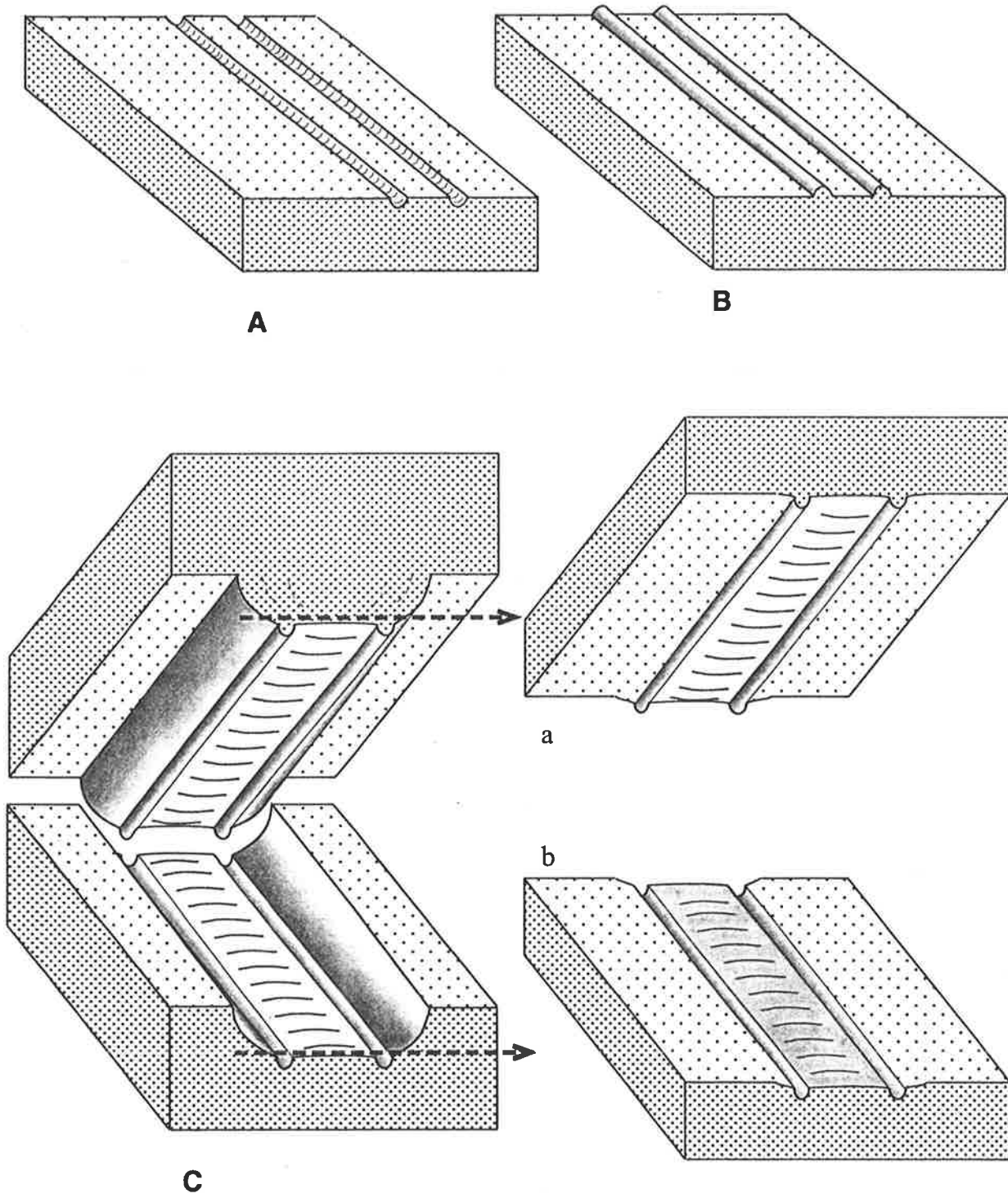


Figure 7.11 - *Bilinichnus simplex* specimens found in central Australia preserved as convex hyporeliefs. Burrows are gently curved and do not cross one another (scale bar = 1 cm).



**Figure 7.12** - Relationship between *Bilinichnus* and other ichnogenera: **A**. The ichnogenus *Diplopodichnus* comprises two parallel furrows preserved in concave epireliefs and displays a fine transverse striations; **B**. Although the shallow and smooth preservation of *Archaeonassa fossulata* may produce two parallel ridges resembling *Bilinichnus* (Buckman, 1994) they are preserved as convex epireliefs; **C**. Production of two parallel hypichnial ridges (**a**) or epichnial furrows (**b**) due to erosion of the ichnogenus *Scolicia*. The area between the ridges or furrows displays fine transverse striations.

trace may be washed out remnant of faecal sediment strings or it may even be of non-biogenic origin, specifically a tool mark.

***Bilinichnus simplex*** Fedonkin and Palij (in Palij *et al.*, 1979)

Plate 2E

1983 *Bilinichnus simplex* Fedonkin and Palij; Urbanek and Rozanov p. 87, pl. LX1-2.

1986 *Bilinichnus simplex* Fedonkin and Palij; Paczesna p.36, pl. 7 fig. 3.

Collected specimens. Two specimens, A1035-MO56 and A1035-MO172.

Diagnosis. The same as for the ichnogenus.

Description. Shallow trails preserved in low convex hyporeliefs consist of two parallel narrow ridges. The central area between the ridges is flat, smooth and undisturbed. The trail is straight to gently curved. Ridges are 0.3 to 0.5 mm thick and 2-3 mm apart. The width of the burrow and the distance between the ridges are constant along a given burrow. At least four specimens of *Bilinichnus* occur on the same slab, but do not intersect one another (Fig. 7.11).

Discussion. Although *B. simplex* reported herein displays a poor preservation, it is distinct enough to allow taxonomic identification. The trace is well accommodated within the size range given for the ichnogenus (Fedonkin and Palij in Palij *et al.*, 1979).

Occurrence. Donkey Creek Beds, Mount Octy Georgina Basin.

***Cochlichnus*** Hitchcock, 1858

Type ichnospecies. *Cochlichnus anguineus* Hitchcock, 1858; by monotypy.

Diagnosis. Meandering, smooth endichnial burrow or surficial groove with or without lateral levees, and resembling sine curve (after Hantzschel, 1975, p. W52; Buckman, 1992).

Preservation. Preserved as epireliefs and full reliefs. Full relief burrows of *Cochlichnus* are reported by Webby (1970), Elliot (1985) and Eagar *et al.* (1985).

Discussion. Fillion and Pickerill (1990b, p. 23) explained the confusion regarding the definition and differentiation of ichnospecies of *Cochlichnus*. At least six ichnospecies of *Cochlichnus* have been reported namely, *C. anguineus* Hitchcock, 1858, *C. kochi*, Ludwig, 1869, *C. antarcticus* Tasch, 1968, *C. serpens* Webby, 1970, *C. surpuliformis* Yang and Hu in Yang *et al.*, 1987 and *C. annulatus* Orłowski, 1989. Pickerill *et al.* (1987) and Fillion and Pickerill (1990b) suggested that *C. kochi* and *C. serpens* should be regarded as junior synonyms of *C. anguineus*, as the relationship between these ichnospecies is not clear and common forms occur among them. Their suggestion is followed in this study. Fillion and Pickerill (1990b) regarded *C. antarcticus* as different from *C. anguineus*, and considered *C. surpuliformis* as non-biogenic. *C. annulatus* is a distinct ichnospecies which displays transverse annulations on its outer wall and is filled by sediments different from the host rock (Orłowski, 1989).

*Cochlichnus* differs from *Belorhapse* Fuchs, 1895, in that the latter shows zigzag angular bends. Specimens of *Cochlichnus* preserved as convex hyporeliefs may resemble the ichnogenus *Cosmorhapse* Fuchs, 1895. *Cosmorhapse* is a guided meandering trace with well developed second order meandering and is generally preserved as a subcylindrical to cylindrical hypichnial burrow. Poorly preserved specimens of *Cosmorhapse* (particularly *C. gracilis*, Książkiewicz, 1977 and *C. sinuosa* (Azpeitia, 1933) in which the first order meanders are not clear might be mistaken with *Cochlichnus*.

Crimes *et al.* (1977) observed that in one of their samples, *Cochlichnus* appears to pass laterally into the median line of a specimen of *Taphrhelminthopsis circularis* Crimes *et al.*, 1977, and concluded that both ichnogenera may have been made by the same animal.

The median furrow on the upper bilobate part of the ichnogenus *Plagiogmus* (Pl. 19A) or *Psammichnites gigas* (Torell, 1868) may show a sinuous morphology similar to that of *Cochlichnus* (see Hofmann and Patel, 1989, fig. 3). The sinuous structure in *Plagiogmus* or *Psammichnites* is confined within the bilobate part of the burrow and thus is easily distinguishable from *Cochlichnus*.

Originator. Hakes (1976) and Elliot (1985) considered an annelid lacking well-developed parapodia responsible for producing *Cochlichnus*. Nematodes are also reported to make sinusoidal trails similar to *Cochlichnus* where mud is covered with a film of water not

thicker than their body (Moussa, 1970). Insect larvae can also produce similar trails under such conditions (Metz, 1987).

Facies distribution. *Cochlichnus* is eurybathic and has been reported from submarine-canyon sediments (Pickerill, 1981), flysch successions (Ksiazkiewicz, 1977), delta-slope sediments (Eagar *et al.*, 1985), tidal flat facies (Narbonne 1984; Hiscott, 1982), supersaline epeiric facies (Courel *et al.*, 1979), river flood plain sediments (Fordyce, 1980), point bars facies (Archer and Maples, 1984), proglacial lake sediments (Gibbard and Stuart, 1974; Gibbard, 1977) and bayou sediments (Chamberlain, 1975). It also has been locally used as a facies indicator (e.g. Hakes, 1976).

Age. *Cochlichnus* is of late Proterozoic to Holocene age (Fedonkin, 1988; Metz, 1987. Seilacher (1955; 1963) recorded *Sinusites* (= *Cochlichnus*) from a wide range of environments and stratigraphic horizons, including Middle Cambrian neritic sandstones of the Grand Canyon, Carboniferous fresh-water sediments of the Ruhr region and 'epicontinental' Jurassic sandstones of Wurttemberg.

***Cochlichnus anguineus* Hitchcock, 1858**

Plates 3C-E, 5A

1970 *Cochlichnus serpens* Webby, 1970, p. 97-99, fig. 16A-F.

Collected specimens. Seven specimens, A971-1-3, A971-2-53, A1035-R10, A1035-MO13, A1035 - MO100, A1035-MO116, and A1035-MO155.

Diagnosis. Smooth, unbranched sinusoidal trails or unlined burrows preserved in convex hyporeliefs or concave epireliefs (after Fillion and Pickerill, 1990b).

Description. Simple narrow (0.5-1 mm) sinuous burrows or trails parallel to bedding. They occur as epichnial grooves or hypichnial ridges. The burrow displays a short slightly variable wave length varying from 12 - 15 mm, with the amplitude of about 2-3 mm. Some burrows tend to be v-shaped in transverse section. The sinuosity of the burrow is not regular and displays variable wave lengths. Pronounced lateral ridges occur along a part of one of the specimen (Pl. 3C) which is also partly filled with a darker colour sediment. Two specimens

(Pls 3D and 5A) have been preserved in concave epireliefs and show a general curved path in which the burrow is terminated at a circular element interpreted to be a bedding preservation of an inclined burrow. One specimen, displays two curved, sinuous burrows which are approximately parallel to one another 10-12 mm apart. The area between two burrows is smooth and undisturbed (Fig. 7.13).

Discussion. Alpert (1975, p. 513) included *Cochlichnus serpens* within the ichnogenus *Planolites*. Since the distinctive sinuous pattern does not occur in *Planolites*, and *C. serpens* illustrated by Webby (1970) shows a typical sinuous pattern, it should not be included within *Planolites*. The occurrence of two curved, sinuous, concave burrows close together with almost matching curvatures poses the question as to whether they were produced by a single organism or by two moving close together. The fact that the outer trace terminates at a circular structure implies that the latter is a single trace and co-occurrence of the burrows is accidental.

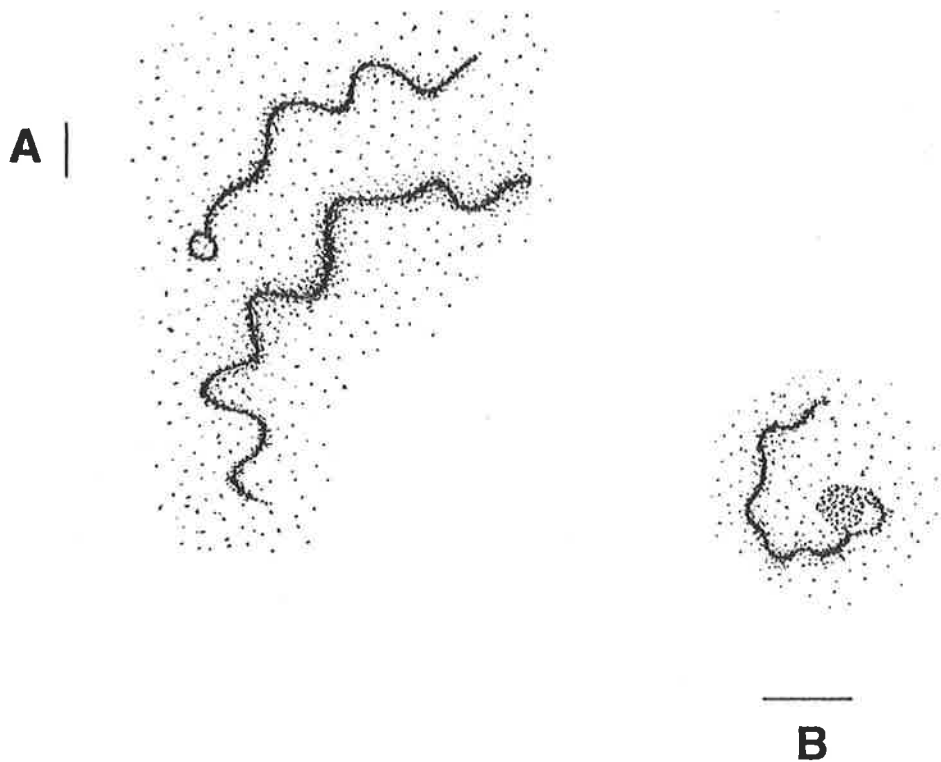
The partial preservation of the marginal ridges produces a bilobate structure similar to the ichnospecies *Didymaulichnus lyelli*. Lateral levees occur in *Cochlichnus* (Hantzschel, 1975; Dam, 1990) but they do not produce continuous ridges. The bilobate structure in *Didymaulichnus* is a continuous structure separated by a narrow furrow comparable to the width of the ridges and is a prominent characteristic of that ichnogenus. The present specimens are attributed to *Cochlichnus* based on their sinuosity and general geometry.

Occurrence. Box Hole and Allua Formations, Cyclops Bore and Ross River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

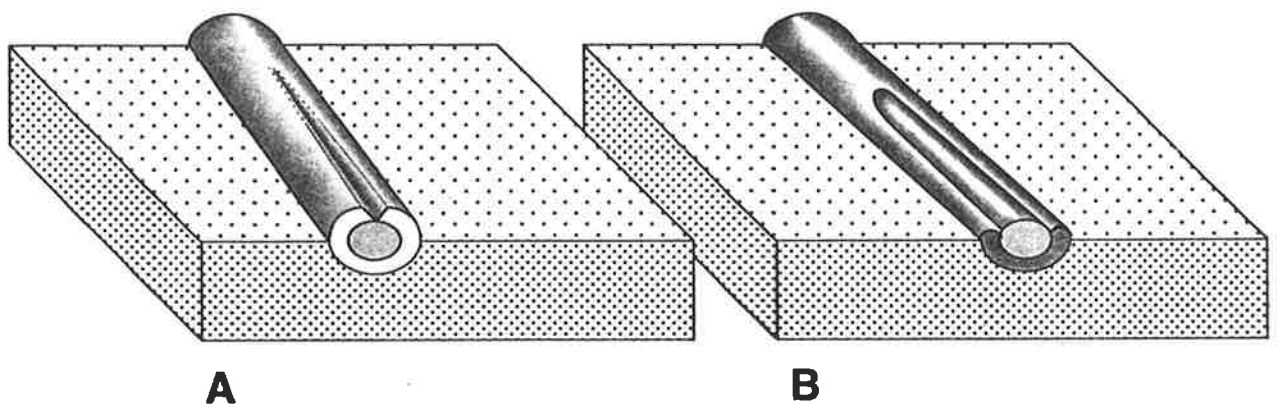
### ***Conostichus* Lesquereux, 1876**

Type ichnospecies. *Conostichus ornatus* Lesquereux, 1876, p. 201, from the Pennsylvanian of Illinois.

Diagnosis. Conical to subconical, vertical burrows, most of which display a duodecimal symmetry on the apex and sides. Most walls are fluted by transverse constrictions and longitudinal ridges and furrows. Well-developed apical disc and central subcylindrical core



**Figure 7.13** - *Cochlichnus anguineus*: **A**. Two sinuous burrows preserved as concave epireliefs. Burrows are almost parallel to one another and one of them terminates in a circular structure interpreted to be the point where animal sank into the substrate; **B**. A small convex epirelief burrow terminating in a circular structure which is much larger than the burrow width itself (scale bar = 1 cm).



**Figure 7.14** - Erosion of thick walled burrows may produce bilobate (**A**) or trilobate (**B**) structures resembling *Didymaulichnus* or *Curvolithus* respectively.

may or may not be present. Burrow fills may be structureless or composed of concentric conical or subconical laminae (after Pemberton *et al.*, 1988, p. 871).

Discussion. Pemberton *et al.* (1988) revised the ichnotaxonomy of the plug-shaped burrows and recognised five ichnogenera including *Conostichus*, *Bergaueria*, *Conichnus* Myannil, 1966, *Dolopichnus* Alpert and Moore, 1975, and *Astropolichnus* Crimes and Anderson, 1985. They also retained three other forms which appear to be distinct forms namely *Mammillichnis* Chamberlain, 1971a, *Margaritichnus* Bandel, 1973, and *Calycraterion* Karaszewski, 1971. They considered the following characteristics to be important among the plug-shaped burrows; the overall burrow geometry, wall ornamentation, and the presence of a central apical cylinder. *Conostichus* is distinguished from other plug-shaped ichnofossils in having well-developed apical disc and wall ornamentation, a diameter equal or half of its height, and the common presence of a central core. Five ichnospecies of *Conostichus* were recognised by Pemberton *et al.* (1988) based primarily on overall burrow geometry and characteristics of the apical disc.

Originator. *Conostichus* was originally interpreted as an alga or sponge (Lesquereux, 1880). Possible medusoid affinities were recognised by Fuchs (1895). Pemberton *et al.* (1988) considered that its overall geometry, duodecimal symmetry and distinct ornamentation are consistent with an actinarian dwelling burrow, an interpretation which had been briefly discussed previously by Chamberlain (1971b, pp. 220-221, figs 4A-4D).

Age. *Conostichus* has been reported from the Middle Ordovician (Fillion and Pickerill, 1984; Pickerill *et al.*, 1984) to Early Cretaceous (Imlay, 1961). If the designation of the present material to the ichnogenus *Conostichus* is correct, it constitutes a rare Early Cambrian record of this ichnogenus.

?*Conostichus* isp.

Plate 4A-C

Collected specimens. Three specimens, A971-2-44, A971-2-45, and A1035-MO180.



**Diagnosis.** Conical to subconical conostichian trace with well-developed transverse constrictions and short longitudinal furrows near the apex; the small apical disc is planar to slightly hemispherical and displays weak septation. (after Pemberton *et al.*, 1988).

**Description.** Large circular burrow preserved as concave epirelief or very low convex hyporelief. Burrow 20-25 mm in diameter and 20-28 mm in height; and consists of a central cylindrical to subcylindrical hollow structure surrounded by a thin to thick wall. A slight orientation of mica flakes occurs in the wall. The central core is about 12 to 18 mm in diameter and the wall varies from 2-6 mm. The central core filling was apparently softer than the wall and the host rock and being mostly eroded away to leave a hollow structure. This hollow central core is tapered toward its bottom to produce a conical structure. In cross section, burrow displays a structureless filling and well-developed apex. The burrow wall is irregular in cross section which it could be due to the transverse constrictions of the burrow.

**Discussion.** The outer wall morphology of the specimens found in central Australia is not known. The samples found in convex hyporeliefs possess only a small portion of the proximal part of the burrow which does not show any significant ornamentation. However, its general morphology and diameter/ height ratio is consistent with *C. stouti*. Pemberton *et al.* (1988) considered that the diameter/ height ratio is significant at the ichnogeneric-level for plug-shaped burrows.

**Occurrence.** Allua Formation, Ross River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

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### ***Cosmorhapse* Fuchs, 1895**

**Type ichnospecies.** *Helminthopsis sinusa* Azpeitia in Hantzschel, 1962.

**Diagnosis.** Composite meandering burrows consisting of first-order curves with second-order well guided sinuosity. The surface of the burrow is smooth (after Hantzschel, 1975 and Ksiazkiewicz, 1977).

**Discussion.** *Cosmorhapse* is a graphoglyptid (*sensu* Fuchs, 1895 and Seilacher, 1977) generally found on the sole of sandstones. The burrow was produced by an animal which

lived on the sea-floor or close to it and was able to burrow along the clay/ sand interface. Any worm-shaped organism or gastropod without external elaboration could produce *Cosmorhappe* (Ksiazkiewicz, 1977).

*Cosmorhappe ?gracilis* Ksiazkiewicz, 1977

Plates 4D, 6B

Collected specimens. Four specimens, A971-2-8, A971-2-31, A1035-MO177, and A1035-MO182.

Diagnosis. Hypichnial, thread-sized, subcylindrical, full burrows (?) gently meandering. The height of the second-order meanders is equal to their width (after Ksiazkiewicz, 1977 p. 152).

Description. Poorly preserved narrow, smooth, meandering burrows 0.5 mm wide and a fraction of millimetre high with second order, regularly guided curves (sinuous waves), 2 mm high and 2 mm wide. Burrows are poorly preserved on sole of the sandstone as convex hyporeliefs. The two orders of meanders, indicative of the ichnospecies, shown by the specimens are faint so that it is really difficult to show them in the photos.

Discussion. The present specimens are similar in all characteristics to *C. gracilis*, which Ksiazkiewicz (1977) erected based on its thread-like appearance. Otherwise it is very similar to *C. sinusita* (Ksiazkiewicz, 1977). Although size has been applied at ichnogenetic level to establish new ichnotaxa by some authors (e.g. *Megaplanolites* Calvo *et al.*, 1987; *Megagyrolites* Gaillard, 1980), generally it is considered as an insignificant criterion, and erecting a new ichnogenus based solely on size is not warranted. Using size at ichnospecies level is justified (e.g. Seilacher, 1977). Ksiazkiewicz (1977) clearly reported that *C. gracilis* and *C. sinusita* never occur together either on the same sole or in the same stratigraphic position. *C. gracilis* is very similar to *C. parva* Seilacher, 1977 and further study may prove that they are synonymous.

Occurrence. Upper Box Hole Formation Ross River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

## *Cruziana* d'Orbigny, 1842

Type ichnospecies. *C. rugosa* d'Orbigny, 1842 by subsequent designation of Bassler (1915). Later Seilacher (1953a) selected *C. furcifera* d'Orbigny, 1842 as the type ichnospecies. Fillion and Pickerill (1990b) considered that Miller (1889) was the first to validly designate the type ichnospecies.

Diagnosis. Elongate, band-like, bilobate burrows marked by herringbone-arrangement or transverse ridges, with or without longitudinally striated outer zones outside the V-markings, occasionally with lateral grooves and / or wisp markings (after Hantzschel, 1975 and Fillion and Pickerill, 1990b).

Discussion. Seilacher (1970) united band-like burrows and short coffee-been like excavations (= *Rusophycus*) under *Cruziana*. Although most subsequent authors recognised *Cruziana* and *Rusophycus* as separate ichnogenera (e.g. Crimes, 1970; Hantzschel, 1975; Crimes *et al.*, 1977; Fillion and Pickerill, 1990b), Seilacher (1994) continued to use *Cruziana* for both forms. Seilacher (1970, 1994) proposed that *Cruziana* may be used as a tool in Palaeozoic biostratigraphy. A revision of the ichnogenus *Cruziana* and similar forms (*Isopodichnus* Bornemann, 1889; *Fraena*, Rouault, 1850) is strongly recommended. To the writer's knowledge, about 76 ichnospecies of *Cruziana* have been reported many of which may be placed in synonymy.

*Isopodichnus* consists of two lateral lobes covered by transverse ridges and separated by a median furrow. *Isopodichnus* is differentiated from *Cruziana* in being very narrow (Hakes, 1985 p. 30) and is restricted to fresh water strata (Pollard, 1985). It is very similar to *Cruziana* and many authors considered it to be a junior synonym (Bromley and Asgaard, 1979; Fillion and Pickerill, 1990b; Keighley and Pickerill, 1996; Jensen, 1997), a notion supported herein. Though typically reported from shallow marine facies (Seilacher, 1985), *Cruziana* has also been observed in fresh water deposits (Bromley and Asgaard, 1979).

Originator. Although trilobites are commonly regarded as responsible for *Cruziana* (e.g. Seilacher, 1970), other groups of animals have been reported as a probable producer such as; notostracan branchiopods (Bromley and Asgaard, 1979); aglaspidids (Fisher, 1978); or vertebrates (Shone, 1978, 1979).

Age. The time range of *Cruziana* extends from the Early Cambrian (Crimes, 1987) to the Triassic (Bromley and Asgaard, 1979).

*Cruziana ?tenella* (Linnarsson, 1871)

Plate 5D-E

1979 *C. problematica* (Schindewolf, 1921); Bromley and Asgaard, p. 66, fig., 18.

1997 *C. tenella* (Linnarsson, 1871); Jensen, p. 46, figs 31-32

Collected specimens. One specimen, A971-B13.

Diagnosis. Small *Cruziana* having transverse to nearly transverse striae. Tendency for grouping of striae in pairs in some specimens (after Jensen, 1997).

Description. Large, band-like, bilobate burrows preserved as convex hyporeliefs comprising two lobes separated by an axial furrow. Lobes are rounded and display regular, transverse ridges about 1 mm wide and 1 mm apart. Burrows are horizontal to subhorizontal with respect to the bedding and gradually become less clear at one or both ends. Transverse ridges are more distinct close to the median furrow and less prominent on the apex of lobes which could be due to subsequent erosion. Burrows are about 10 mm wide and commonly cross or pass over or below one another.

Discussion. The present specimens are similar to *C. tenella* (Linnarsson, 1871) from the Early Cambrian Mickwitzia Sandstone of south-central Sweden (Jensen, 1997), but do not show an undulate surface or integrate into a rusiform structure. The burrows pass over one another and clearly display an endichnial origin.

Occurrence. Allua Formation, Ross River, Amadeus Basin.

*Curvolithus* Fritsch, 1908

Type ichnospecies. *Curvolithus multiplex* Fritsch, 1908 by subsequent designation of Hantzschel (1962, p. W189).

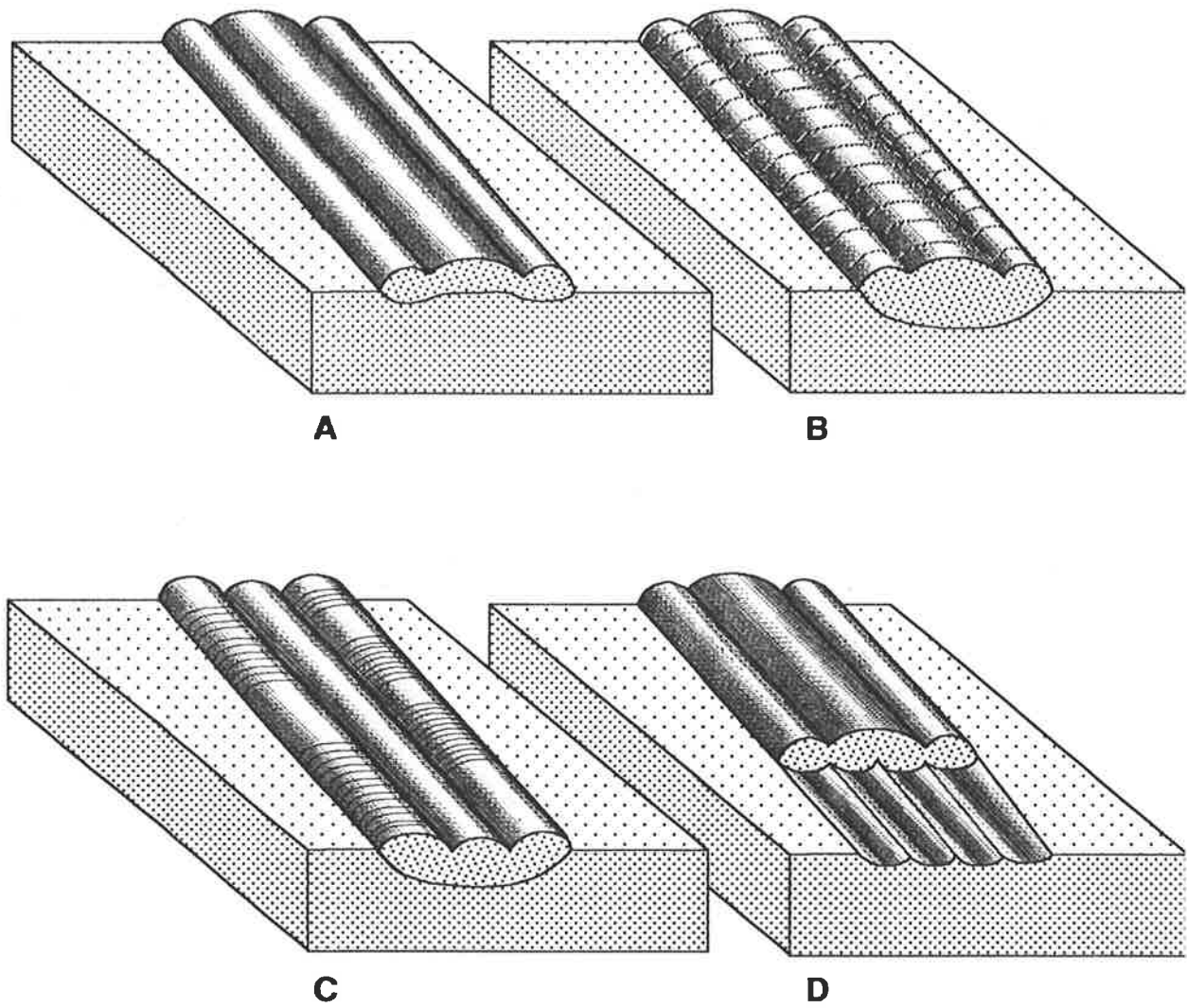
**Diagnosis.** Ribbon- or band-like trails, more or less straight, flat with trilobate upper surface consisting of a broad usually smooth central stripe and narrow lateral lobes separated by small furrows. Lower surface bilobate, comprising two small round lobes and a large median furrow. (after Heinberg, 1970; Chamberlain 1971b; Fillion and Pickerill, 1990b, p.29; Hantzschel, 1975, p. W56).

**Discussion.** Five reported ichnospecies of *Curvolithus* are briefly described in Table 7.1 and illustrated in Figure 7.15. The suggestion of Fillion and Pickerill (1990b) for a taxonomic revision of this ichnogenus is emphasised here. *C. multiplex* embraces both trilobate structures with or without a faint groove on the axial lobe. Therefore *C. ?davidis* Webby, 1970 is considered to be a junior synonym of *C. multiplex*.

**Table 7.1.** Known ichnospecies of the ichnogenus *Curvolithus*.

<i>C. multiplex</i>	Fritsch	1908	Trilobate upper surface with narrow marginal ridges separated from median lobe by furrows. Lower surface bilobate consists of two small rounded lateral lobes separated by a large median furrow or unilobate.
<i>C. ? davidis</i>	Webby	1970	Broad axial ridge and two narrower, marginal ridges separated by relatively narrow shallow grooves
<i>C. annulatus</i>	Badwe and Ghare	1978	annulated trilobate upper surface and a smooth, rounded lower surface
<i>C. aequus</i>	Walter and Elphinstone	1989	axial ridge is less convex than the marginal ridges. Ridges are almost the same width. Marginal ridges display infrequent transverse striations
<i>C. manitouensis</i>	Maples and Suttner	1990	<i>Curvolithus</i> with four furrows separated by three sharp ridges on the lower surface

If partially eroded, walled burrows such as *Palaeophycus* may produce a structure resembling the bilobate structure of *Didymaulichnus lyelli* or a trilobate structure like *Curvolithus*, particularly those which display a unilobate lower surface (Fig. 7.14 and plate



**Figure 7.15** - Ichnospecies of *Curvolithus*: **A.** *C. multiplex* (after Heinberg, 1973 and Lockley, 1987); **B.** *C. annulatus* (as described by Fillion and Pickerill, 1990); **C.** *C. aequus* (after Walter and Elphinstone, 1989); **D.** *C. manitouensis* (after Maples and Suttner, 1990).

6D). So, the true trilobate structure of the trace should be clearly proved before its designation to the ichnogenus *Curvolithus*.

Preservation. Endichnial crawling trails which pass over and under one another and cut bedding planes. (Hantzschel, 1975, p. W56).

Originator. Its probable originator is considered to be a burrowing gastropod (Heinberg, 1973), possibly carnivorous (Heinberg and Birkelund, 1984).

Facies distribution. *Curvolithus* occurs typically in shallow-water sediments (Chamberlain, 1971b; Heinberg and Birkelund, 1984) and marginal marine or brackish facies (Hakes, 1976, 1977), but has also been reported from delta-slope deposits (Eagar *et al.*, 1985).

Age. It ranges in age from ?Precambrian (Webby, 1970; Fedonkin, 1977) to the Tertiary (Hantzschel, 1975, p. W56).

***Curvolithus multiplex* Fritsch, 1908**

Plates 3F, 5C

1976 *Curvolithus*, Hakes, p. 25, pl. 2b.

1987 *Curvolithus*, Lockley *et al.*, fig. 2d.

1989 *Curvolithus* isp., Walter and Elphinstone, p.228, fig. 7B.

Collected specimens. Two specimens, A971-1-18 and A971-2-7.

Diagnosis. Trilobate upper surface in which small, rounded marginal ridges are separated from large median lobe by shallow angular furrows. A faint central furrow may occur on the median lobe. Lower surface unilobate or bilobate. Latter consists of two small rounded lateral lobes separated by a large median furrow (after Hantzschel, 1975; Fillion and Pickerill, 1990b).

Description. Straight to gently curving trail, oblate in transverse section, parallel to the bedding plane. The burrow consists of a broad (2-6 mm) central lobe flanked by 0.5-1.5 mm deep grooves and two narrower (1-2 mm) more convex lobes. Burrows are preserved in convex hyporeliefs and sometimes exhibit rare faint transverse striations.

Discussion. The present specimens do not show the median groove preserved on the axial lobe and resemble *Curvolithus* isp. reported from central Australia by Walter and Elphinstone (in Walter *et al.*, 1989, fig. 7B).

Occurrence. Box Hole Formation, Ross River, Cyclops Bore and Hugh River, Amadeus Basin.

### ***Didymaulichnus* Young, 1972**

Type ichnospecies. *Didymaulichnus (Fraena) lyelli* (Rouault, 1850, p. 731) from the Ordovician Armorican Sandstone of western France; by original designation.

Diagnosis. "Gently curving, moderately deep, smooth, furrow-like trails which are bisected longitudinally by narrow median ridge. Trails oriented parallel to bedding planes, and may overlap and truncate one another" (Young, 1972).

Preservation. The ichnofossil is usually preserved as a convex hypichnial cast on the lower surface of beds.

Originator. It has been attributed to both molluscs (Glaessner, 1969; Vossler *et al.* 1989; Hakes, 1976), or for *D. rouaulti*, to trilobites (Crimes, 1970; Baldwin, 1977a), or other arthropods (Bradshaw, 1981).

Facies distribution. *Didymaulichnus* is a facies-crossing form (cf. Young, 1972; Hakes, 1976; Eagar *et al.*, 1985).

Age. *Didymaulichnus* has been reported from the late Vendian to Early Cambrian (Fritz and Crimes, 1985; Fedonkin, 1988; Narbonne and Myrow, 1988); Ordovician (Baldwin, 1977a; Pickerill *et al.*, 1984); Devonian (Garcia-Ramos, 1976; Bradshaw, 1981); Pennsylvanian (Hakes, 1976, 1977; Archer and Maples, 1984); and Cretaceous (Vossler *et al.*, 1989).

Discussion. Young (1972) established the ichnogenus *Didymaulichnus* in order to differentiate between several closely allied ichnogenera previously included under the heterogeneous 'trails' of *Fraena* by Rouault (1850). Although it is most commonly regarded as a surface trail (Glaessner, 1969; Young 1972; Hakes, 1976), Eagar *et al.* (1985) reported



specimens that crosscut casts of solemarks as being indicative of interstratal emplacement. So, the origin of the trace remains obscure. The geometry, size, and complexity of the trails indicate that a bilaterally symmetrical, metazoan formed them.

*Didymaulichnus* is similar to *Didymaulyponomos* Bradshaw, 1981 except that it has ideally, high steep sides. *Didymaulyponomos* is interpreted to be a true burrow equivalent of *Didymaulichnus* (Bradshaw, 1981). The ichnogenus *Taphrhelminthopsis* Sacco refers to all "freely winding and meandering" bilobate trails. However, in the original diagnosis, Sacco (1888) described a central, slightly raised thread within the median groove, unlike the plain groove of the hypichnial cast of *Didymaulichnus*. As well, *Taphrhelminthopsis* was restricted (Andrews, 1955; Hantzschel, 1962) to tightly coiled or meandering bilobate trails, also unlike the open, gentle curves displayed by *Didymaulichnus* (Young, 1972). Furrow-like varieties of *Cruziana* d'Orbigny, 1842 resemble *Didymaulichnus* except that the former exhibit V-shaped markings and fine lineations within the furrows, whereas in *Didymaulichnus* the furrows are smooth. *Aulichnites* Fenton and Fenton, 1937 is also a bilobate furrow. However, this bilobate structure forms the upper surface of a full relief burrow, roughly heart-shaped in cross section, rather than the lower surface of a bilobate trail as in *Didymaulichnus*. The bilobate trail *Gyrochorte carbonaria* Seilacher (1954) might be confused with small specimens of *Didymaulichnus*. *G. carbonaria* is much smaller than most specimens of *Didymaulichnus* and is apparently composed of two circular, curving rods parallel to and in contact with each other (Hakes, 1976).

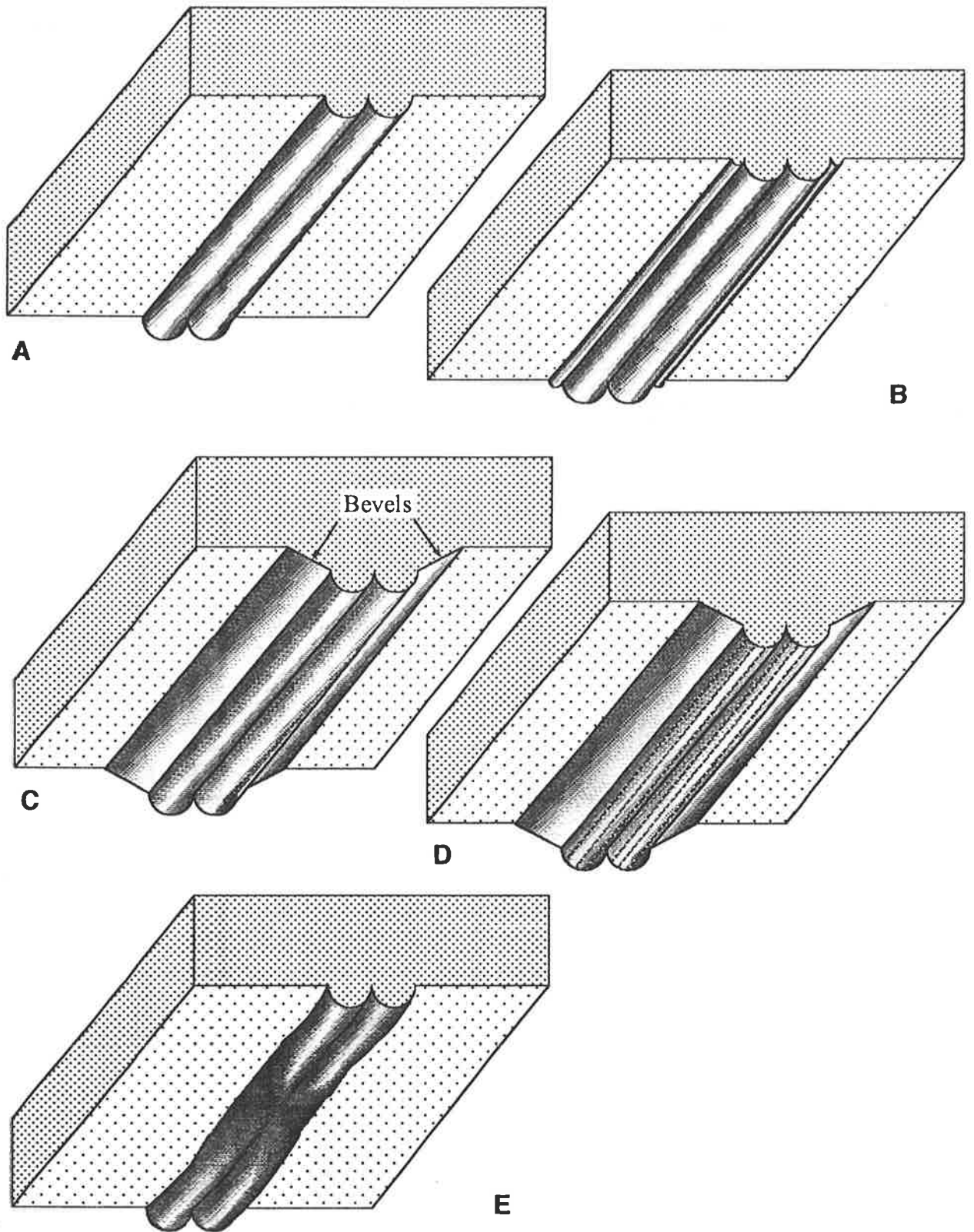
Seven ichnospecies have been assigned to the ichnogenus *Didymaulichnus* namely, *D. alternatus* Pickerill, Romano & Melendez, 1984, *D. lyelli* (Rouault, 1850), *D. rouaulti* (= *Cruziana rouaulti* Lebesconte, 1883), *D. miettensis* Young, 1972, *D. tirasensis* Palij, 1974, *D. nankervisi* Bradshaw, 1981, *D. meanderiformis* Fedonkin, 1985.

Pickerill *et al.* (1984) considered the presence or absence of the marginal ridges as important characteristics at the ichnospecies level. They assigned traces without marginal ridges or with undeveloped and subdued marginal ridges to *D. lyelli*. *D. rouaulti* is characterised by having well developed marginal ridges. *D. miettensis* and *D. tirasensis* present marginal bevels. However, the latter also has furrows along the smooth surface of the ridges.

The ichnogenus *Didymaulichnus* is not characterised by systematically meandering traces. Moreover, the Siberian ichnotaxon, *D. meanderiformis*, is not properly diagnosed according to Article 13 of the ICZN Rules (International Trust for Zoological Nomenclature, 1985), which require an accompanying description or definition that would allow it to be differentiated from other ichnotaxa. For this reason, Hofmann and Patel (1989) considered it to be synonymous with their newly established ichnospecies *Taphrhelminthoida dailyi* which is a systematically meandering bilobate trace. Designation of *D. nankervisi* to the ichnogenus *Didymaulichnus* was also questioned by Pickerill *et al.* (1984) who considered that *D. nankervisi* is more akin to a cruzianid (e.g. *Cruziana bilobata*) as it possesses transverse dig marks, which by original definition, *Didymaulichnus* lacks. Consequently, only five ichnospecies of *Didymaulichnus* are considered to be valid. These are briefly described in Table 7.2 and illustrated in Figure 7.16.

**Table 7.2.** Designated ichnospecies of *Didymaulichnus*.

<b>A- Smooth, bilobate burrows with lateral bevels:</b>	
- Large and without longitudinal furrows along the lobes	<i>D. miettensis</i> Young, 1972
- Small with longitudinal furrows along the smooth lobes	<i>D. tirasensis</i> . Palij, 1974
<b>B- Smooth bilobate burrows without lateral bevels:</b>	
- Without marginal ridges	<i>D. lyelli</i> Rouault, 1850
- With marginal ridges	<i>D. rouaulti</i> Lebesconte, 1883
- Alternative deep and shallower sections	<i>D. alternatus</i> Pickerill <i>et al.</i> , 1984



**Figure 7.16** - Ichnospecies of *Didymaulichmus*: **A.** *D. lyelli* (after Alpert, 1972); **B.** *D. rouaulti* (as described by Fillion and Pickerill, 1990); **C.** *D. miettensis* (after Alpert, 1972); **D.** *D. tirsensis* (as described by Walter and Elphinstone, 1989); **E.** *D. alternatus* (after Pickerill *et al.*, 1984).

***Didymaulichnus lyelli* (Rouault, 1850)**

Plates 5B, 6C

Collected specimens. Three specimens, A971-2-14, A971-3-13, and A1035-R1.Diagnosis. A *Didymaulichnus* without oblique scratches, lateral ridges, marginal bevels or regularly alternating, deeply impressed sections (after Young, 1972; Pickerill *et al.*, 1984; Hantzschel, 1975)Description. Curved burrows, subcylindrical to oblate, 5-10 mm wide and 2-4 mm in depth with central groove flanked by two lobes, subparallel to bedding plane with frequent intersections, rarely branched. Fill is identical to host rock.Remarks. Similar to *D. miettensis* but smaller and without the lateral bevels.Age. Hantzschel (1975) reports *D. lyelli* ranges from the latest Precambrian to the Carboniferous.Occurrence. Lower Box Hole Formation Ross River, Amadeus Basin.***Didymaulichnus miettensis* Young, 1972**

Plates 4E, 6A

1969 'molluscan trail' Glaessner, p. 389, pl. 9B-C.

1972 *Didymaulichnus miettensis* Young, p. 10-13, figs 8-10.1982 *Didymaulichnus miettensis* Young; Jiang Zhiwen *et al.*, p. 10-11, pl. 1, fig. 7, pl.1985 *Didymaulichnus miettensis* Young; Fritz & Crimes, p. 9, 11, pl. 4, figs 2-3.1985 *Didymaulichnus miettensis* Young; Crimes & Anderson, p. 319-320, fig. 5.1986 *Didymaulichnus miettensis* Young; Crimes & Jiang Zhiwen, p. 645, fig. 3d-h.1989 *Didymaulichnus miettensis* Young; Walter & Elphinstone, p. 229, fig. 8A.Collected specimens. Four specimens, A971-1-21, A971-1-22, A1035-MO46, and A1035-R3.Diagnosis. Smooth curving, hypichnial trails, each possesses a shallow median groove (on cast surface) which divides trail in two parts. Most have gently sloping peripheral bevels

which disappear in places along the trail. The central groove may be slightly meandering within the relatively straighter trail outline. The outer bevels vary in width along the length of the trail (Young, 1972, p. 12).

Description. These are straight to gently curved trails preserved as convex hyporeliefs on soles of sandstone beds. Trails consist of two parallel ridges separated by a median furrow. The ridges are flanked by lateral bevels which are less steep than the ridges (Fig. 7.16C). As suggested by Young (1972) the ichnofossil is a hypichnial cast of a double furrowed trail with a median ridge. The trails are parallel to bedding and may intersect and pass over one another. Several specimens occur together on one slab. The bevels are clear and continuous along the trail in one sample (Pl. 4E), but less clear in the other (Pl. 6A), due to apparently the nature of the substrate and mode of preservation rather than any biological difference.

*D. miettensis* is characterised by having clear bevels lateral to the ridges, which based on Young's (1972) description, may not be continuous along the trace. The ichnofossil is large and has a complex structure suggesting that it was produced by a bilaterally symmetrical metazoan. The surface of the trail is smooth and does not display any ornamentation. Both the hypichnial cast and its epichnial counterpart have been reported (Young, 1972, Walter *et al.*, 1989). However, the epirelief forms are poorly preserved and are less clear than the hyporeliefs. Young (1972) suggested that animals similar to *Parvancorina minchamia* Glaessner from the Ediacaran Assemblage, or *Cambridium*, a primitive mollusc from Siberia, could produce the trail. The 'molluscan trail' reported by Glaessner (1969, figs 9B-C) from the Arumbera Sandstone is similar to this ichnospecies.

Associated trace fossils. One sample of *D. miettensis* is penetrated by two *Skolithos* burrows which both intersect on one of the ridges. In one instance, the *Skolithos* animal produced its trace by pushing the sediments outwards to find its way through, consequently forming a lumpy structure on a ridge of a trail. Since the trail is a hypichnial cast, the burrows of *Skolithos* were produced during or after the accumulation of the upper sandstone layer and after the *Didymaulichnus* trail was filled by sediments. The preservation of the lumpy structure indicates that the filling was cohesive enough to keep the shape and the *Skolithos* organism did not excavate its burrow but simply pushed the substrate aside.

Distribution. *D. miettensis* was described by Young (1972) from material collected in the upper Miette Group of the Rocky Mountains, Canada. *D. miettensis*'s likely range is within the Early Cambrian where it has been reported by Glaessner (1969), Daily (1972) and Walter *et al.* (1989) from Australia; and by Fritz and Crimes (1983) from Cassiar Mountains, British Columbia; Crimes and Anderson (1985) and other authors indicate its occurrence in the Chapel Island and Random Formations, Newfoundland, Canada; Crimes and Jiang Zhiwen (1986) and Jiang Zhiwen *et al.* (1982) have described *D. miettensis* from Meishucun, Yunnan, China

Although the ichnogenus *Didymaulichnus* has a broad time range from the Early Cambrian to Late Cretaceous, the ichnospecies *D. miettensis* seems to be more restricted. It has only been reported from rocks belonging to the Early Cambrian strata.

Occurrence. Box Hole Formation, Cyclops Bore and Ross River, Amadeus Basin.

### ***Dimorphichnus* Seilacher, 1955**

Type ichnospecies. *Dimorphichnus obliquus* Seilacher, 1955 by monotypy.

Diagnosis. Asymmetrical trackway which consists of two sets of imprints; thin, straight or sigmoidal impressions and blunt impressions. Both sets arranged oblique to direction of movement (after Seilacher, 1955; Osgood, 1970; Fillion and Pickerill, 1990b).

Discussion. Fillion and Pickerill (1990b) have discussed in detail the distinction of *Dimorphichnus* from the morphologically similar tracks *Diplichnites* Dawson, 1873 and *Petalichnus* Miller, 1880. Seilacher (1955) considered *Dimorphichnus* to be made by a trilobite stirring up and filtering sediment, with the hood of the animal kept close to the sediment to form a filter chamber. Osgood (1970) interpreted the imprints to have been produced by a trilobite caught in oscillatory currents. Although the presence of blunt impressions is essential in differentiating *Dimorphichnus* from the similar trace *Monomorphichnus*, it might be missing in some *Dimorphichnus* specimens due to undertrack fallout (Goldring and Seilacher, 1971, p. 429, fig. 2C). *Monomorphichnus* and *Dimorphichnus* have been treated as distinct ichnogenera by many authors (e.g. Pickerill and Peel, 1990).

**Age.** Early Cambrian (Narbonne and Myrow, 1988; Jensen, 1997), Late Ordovician - Early Silurian (Pickerill *et al.*, 1987) and Devonian - Mississippian (Bjerstedt, 1987).

***Dimorphichnus* isp.**

Plate 7A, D

**Collected specimens.** Three specimens, A1035-R24, A1035-MO83 and A1035-MO84.

**Description.** Series of imprints arranged en-echelon in relation to the direction of the movement and comprising two kinds of impressions; narrow, straight to sigmoidal scratch-marks up to 18 mm long and 1-1.5 mm wide, preserved as convex hyporeliefs or concave epireliefs, and shorter push marks. In one specimen (A1035-MO83) a part of an undertrack is visible due to subsequent erosion (Fig. 7.17).

**Discussion.** Although *Dimorphichnus* is a monospecific ichnogenus, the majority of authors have recognised it at the ichnogenic level (e.g. Crimes, 1970; Baldwin, 1977a; Pickerill and Peel, 1990) perhaps due to its variable morphology. One specimen (Pl. 7D) displays sigmoidal imprints similar to that of *D. obliquus*, However, the push marks in this sample are not clear.

**Occurrence.** Donkey Creek Beds, Mount Octy, Georgina Basin; Allua Formation, Ross River, Amadeus Basin.

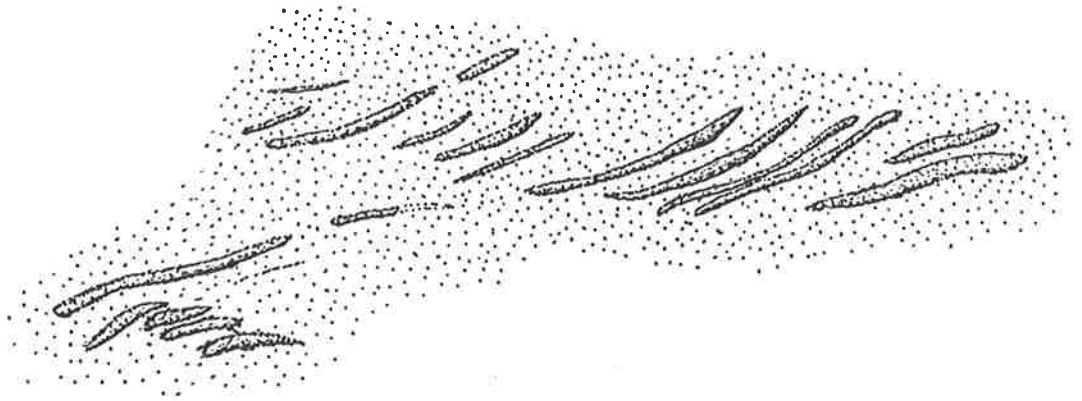
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***Diplichnites* Dawson, 1873**

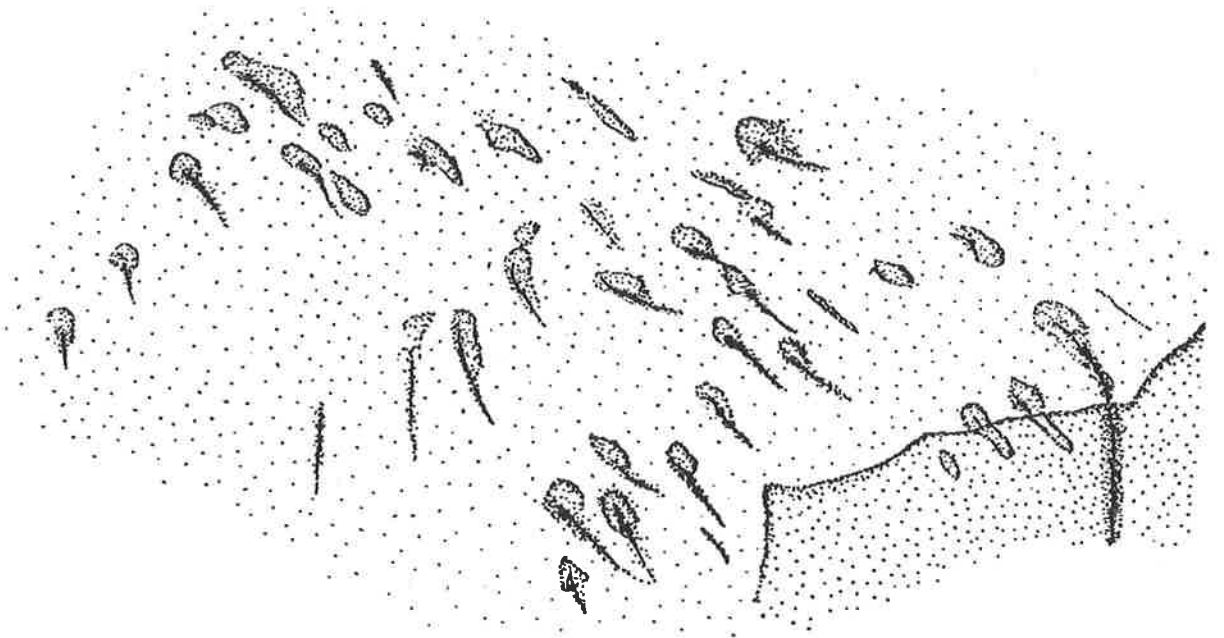
**Type ichnospecies.** *Diplichnites aenigma* Dawson, 1873; by monotypy.

**Diagnosis.** Simple tracks consisting of two parallel series of fine ridges; individual ridges arranged oblique to the track axis and sometimes apparently paired. (Hantzschel, 1975, p. W61).

**Discussion.** Crimes (1970, p. 64) considered that *Diplichnites* probably formed an end member in a continuum of trilobite locomotion which varied from the resting position (*Rusophycus*), through furrowing activity (*Cruziana*) to walking and "striding" on the



A



B

**Figure 7.17 - *Dimorphichnus* isp.:** A. A specimen preserved in convex hyporelief shows a series of parallel ridges oblique to the axis of the trace (Allua Formation, Ross River); B. A specimen preserved in concave epirelief as a series of scratch marks. There is a bulge of sediments at the end of each imprints producing a push mark. A corner of the slab has been broken off revealing the undertrack preservation of the imprints in the form of low relief ridges (scale bar = 1 cm).



substrate (*Diplichnites*). Arthropod tracks have been attributed to a variety of ichnogenera too many to name and their revision is deemed necessary. Two main kinds of *Diplichnites* occurring within the study area are discussed below. Following other authors (e.g. Pickerill and Peel, 1991), the terminology of Osgood (1970) indicated for trilobite tracks has been utilised herein to describe the traces (Fig. 7.18)

Originator. Although *Diplichnites* has been interpreted as the trail of a large crustacean or gigantic annelid or myriapod, most workers have followed Seilacher (1955) and generally interpreted it to be the locomotion track of a trilobites walking or striding in straight, forward movement across the surface of the sediment (e.g. Crimes, 1970; Hantzschel, 1975).

Facies distribution. *Diplichnites* has typically been recorded from shallow marine deposits (e.g. Crimes 1977). However, It also has been reported from deep-water facies (Pickerill, 1980, 1981).

Age. *Diplichnites* has been reported from Early Cambrian (Singh and Rai, 1983) to Triassic strata (Bromley and Asgaard, 1979).

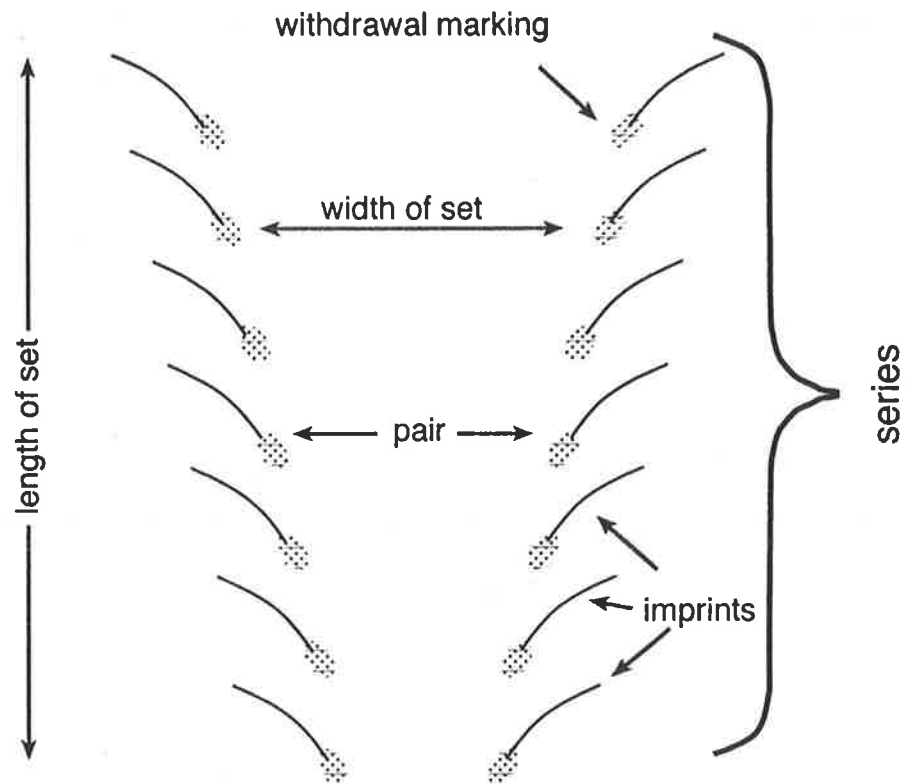
### ***Diplichnites* isp. A**

#### Plate 7B

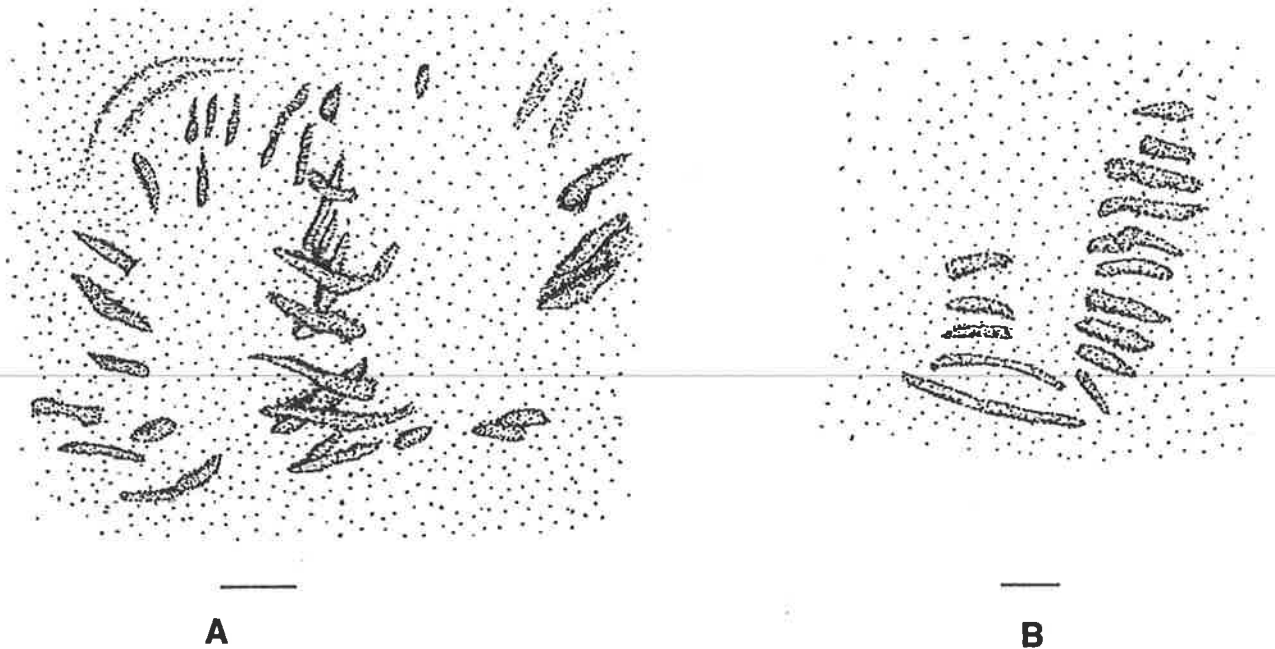
Collected specimens. One specimen, A1035-MO73.

Description. The trace comprises two series of short, nearly parallel imprints elongated oblique to the trace axis and preserved as convex hyporeliefs. The width and length of the sets are 35 and 44 mm respectively. The imprints are 2-4 mm apart, vary in length from 3 to 17 mm, and their width changes from 0.3 to 1.2 mm. The area between two series of imprints is smooth. In this specimen, the elongation of the imprints changes from oblique to parallel with the trace axis, producing a tightly arcuate arrangement of imprints (Fig. 7.19A). There is a faint curved ridge partly enclosing the arc of imprints.

Discussion. The morphology of the trace resembles that of *Diplichnites*. However, the imprints are parallel in *Diplichnites* and no arcuate arrangement of imprints has been reported. The trace displays structure indicative of resting rather than crawling, typical for



**Figure 7.18** - Terminology used in describing ichnogenus *Diplichnites* according to Osgood (1970).



**Figure 7.19** - **A.** *Diplichnites* isp. A preserved as convex hyporeliefs consisting of a series of parallel imprints arranged in a highly arcuate pattern. Imprints are mostly oblique to the axis of the trace but become parallel to the axis at the curved part of the trace. **B.** *Diplichnites* isp. B comprises two rows of parallel imprints arranged transverse to the trace axis. The two last imprints are much wider than the others (scale bar = 1 cm).

*Diplichnites*. However, the producer may have just rested on the surface for a short time without any excavation action to produce a typical resting trace (i.e. *Rusophycus*). There is another trace with larger imprints but similar morphology on the same slab. One series of imprints of this trace is superimposed on the previous mentioned trace. The curved imprint likely shows the outline of the producer which possibly was a trilobite.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

### ***Diplichnites* isp. B**

Plates 7C, 8A,D, 9D, E.

1983 *Merostomichnites*; Singh and Rai, p. 78 pl. VI, figs 46 & 47.

1991 *Diplichnites* isp.; Pickerill and Peel, p. 22, fig. 7.

Collected specimens. Five specimens, A971-2-18, A1035-MO114, A1035-R23, A1035-B2 and A1035-B9.

Description. The trace comprises two series of straight parallel imprints preserved as concave (grooves) epireliefs or convex (ridges) hyporelief which are transverse to the trace axis. Some of the imprints show double claw marks. The width of the set is 40-45 mm. The grooves are 2-5 mm apart, vary in length from 3 to 17 mm, and their width changes from 1 to 2 mm. The area between two series of imprints is smooth. In one example (Pl. 7C) the last two imprints of the set are large (24-30 mm long) and extend nearly the width of the set (Fig. 7.19B).

Discussion. The morphology of the trace resembles that of *Diplichnites*. However, the grooves are parallel and almost normal to the trace axis. There is a large specimen (Pl. 8A) which has more or less the same morphology but in which some grooves are bifurcated. The area between the series of grooves is smooth and there is a smooth margin enclosing the imprints. The general outline of the trace is oval with a slight elevation at the middle. The imprints are more separated at the middle of the trace than at either end. This specimen is tentatively attributed to *Diplichnites* isp B. Some specimens (Pl. 8D) display a faint brush-marks between the imprints representing the producer's endopodites.

Occurrence. Box Hole Formation, Ross River, Cyclops Bore, and Hugh River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

### *Diplocraterion* Torell, 1870

Type ichnospecies. *Diplocraterion parallelum* Torell, 1870 by subsequent designation of Richter (1926, p. 213) as cited by Hantzschel (1975, p. W62). However, Fillion and Pickerill (1990b) considered that the designation of the type ichnospecies was by Matthew (1891, p. 163).

Diagnosis. "U-shaped burrow with spreite, vertical to bedding plane, opening of the tubes mostly funnel-shaped, bottom of the burrow often semi-circular" (Hantzschel, 1975, p. W62).

Discussion. Fürsich (1974b) comprehensively studied *Diplocraterion* and the similar U-shaped spreiten-bearing burrows *Corophioides* Smith, 1893 and *Polyupsilon* Howell, 1957, concluding that they essentially represent the same structure. He considered the latter two as junior synonyms of *Diplocraterion*. Fürsich (1974b) proposed the concepts of "significant" and "accessory" morphological characteristics and assigned all spreite-bearing vertical U-tubes to *Diplocraterion*, considering the burrow geometry and nature of the spreite to be significant at the ichnospecies level. Several workers (i.e. Frey and Chowns, 1972; Fürsich, 1974b; Miller and Knox, 1985; Fillion and Pickerill, 1990b) have shown that specimens of *Diplocraterion* and *Corophioides* are intergradational and regarded the two as synonymous. However, some authors (e.g. Hakes, 1976; McCarthy, 1979; Durand, 1985) maintained the distinction between the two ichnogenera. *Diplocraterion* differs from *Arenicolites* in having spreiten developed between the limbs. *Diplocraterion* is reported to have funnel-shaped apertures on one or both limbs (Goldring, 1962; Cornish, 1986). Goldring (1962, p. 243, text-fig. 3) illustrated the significance of *Diplocraterion* burrows in differing environmental interpretations.

Preservation. This ichnogenus is usually reported from intertidal to shallow subtidal, high-energy facies (Fürsich, 1975; Crimes *et al.*, 1977) but examples from deep-water sediments

associated with fan (Crimes, 1977; Crimes *et al.*, 1981), distal shelf (Benton and Gray, 1981), and deltaic (Stanistreet *et al.*, 1980) deposits are also known.

Originator. *Diplocraterion* has been considered as the dwelling burrow of a polychaete annelid (Arkell, 1939), crustacean (Fürsich and Schmidt-Kittler, 1980; Runnegar, 1982) or other suspension feeding animal (Goldring, 1962; Osgood, 1970; Fürsich, 1974b).

Age. *Diplocraterion* has been reported from the Early Cambrian (Narbonne and Myrow, 1988) to the Miocene (Fleming, 1973). D'Alessandro and Bromley (1986) reported some U-shaped burrows or "equilibrium structures" from the Pleistocene similar to *Diplocraterion*.

### ***Diplocraterion* isp.**

Plates 8B-C, 9B

Collected specimens. Six specimens, A971-1-20, A971-2-20, A971-2-52, A1035-R21, A1035-MO47, and A1035-MO113.

Description. Paired vertical, circular burrows, 4-8 mm in diameter, 5-25 mm apart, jointed together resembling dumb-bell structures. Burrows are preserved as concave epireliefs and more rarely seen in vertical breaks through bedding.

Discussion. The rounded, bow-tie shaped structures seen on bedding planes are due to the spreiten between the vertical tubes being eroded. Daily (1972) stressed the value of *Diplocraterion* in determining the base of the Cambrian. Later work revealed that *Diplocraterion* is facies controlled and not quite basal Cambrian in age (Crimes and Anderson, 1985).

Occurrence. Box Hole Formation, Cyclops Bore and Ross River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

### ***Glockerichnus* Pickerill, 1982**

Type ichnospecies. *Glockeria* (= *Glockerichnus*) *glockeri* Ksiazkiewicz, 1968 by subsequent designation of Ksiazkiewicz, 1977.

**Diagnosis.** Star-shaped form consisting of ribs radiating from a centre, to which all or some of the ribs are joined; small ribs may intercalate between the main ribs; outline of the star is irregularly circular (After Ksiazkiewicz, 1970, 1977).

**Discussion.** Ksiazkiewicz (1968) established this ichnogenus for radiating ribs collected from the Moravian Carpathians. All or some of the ribs join together at the centre and may form a central knob. The ribs are of variable length and may be dichotomous. Pickerill (1982), in a taxonomic note, introduced a new name, *Glockerichnus* for the trace since the name *Glockeria* had been utilised by Wedekind in 1912 for a phacopid trilobite genus. Seilacher (1977) considered *Asterichnus* Nowak, 1961 to be a *nomen nudum* and a junior synonym of *Glockerichnus*. Seilacher (1977) also argued that the ichnogenus *Subglockeria* Ksiazkiewicz, 1975 is a preservational variant of *G. glockeri*.

Ichnospecies of *Glockerichnus* are based on the shape, dimension and density of the ribs. Six ichnospecies of *Glockerichnus* have been introduced namely, *G. glockeri* Ksiazkiewicz, 1968; *G. sparsicostata* Ksiazkiewicz, 1968; *G. disordinata* Ksiazkiewicz, 1977; *G. parvula* Ksiazkiewicz, 1970; *G. dichotoma* Seilacher, 1977; and *G. alata* Seilacher, 1977.

**Age.** Early Cambrian (Acenolaza and Toselli, 1981; this study); Ordovician (Pickerill, 1980), Late Cretaceous-Early Tertiary (Ksiazkiewicz, 1968, 1970, 1977; Tanaka, 1971; Crimes, 1977; Crimes *et al.*, 1981; Miller, 1993; Crimes and McCall, 1995).

***Glockerichnus ?sparsicostata* (Ksiazkiewicz, 1977)**

Plates 9A, C, 10C

1977 *G. sparsicostata* Ksiazkiewicz, p. 101, pl. 9 fig. 3.

1989 "Stellate Structure", Walter *et al*, 1989, p.251, fig.17C.

**Collected specimens:** Two specimens, A971-4-10, and A971-6-2.

**Diagnosis.** "Hypichnial star with ribs radiating from the centre, The ribs, few in number, are straight and pointed towards the periphery of the star. A few short ribs are intercalated between the main ribs" (Ksiazkiewicz, 1977).

Description. Rosetted burrow on a horizontal bedding plane, with 6 to 10 radial, pointed outwards ribs, 35-45 mm in total diameter with no distinct central node. The burrow is preserved in concave epirelief or convex hyporelief. Some shorter ribs intercalate between the larger one and do not reach the centre (Fig. 7.20).

Discussion. Unlike the holotype material from the flysch of the Polish Carpathians (Ksiazkiewicz, 1977), the present specimens are smaller and have been preserved commonly as concave epireliefs. It differs from *G. glockeri* in having a lesser number of both long ribs and intercalated short ribs. The "stellate structure" reported from Arumbera III (*sensu* Wells, 1967) by Walter *et al.* (1989), is similar to the present material, except for its slightly petal-shaped ribs. The ichnogenus *Glockerichnus* occurs mostly in Cretaceous to Eocene flysch deposits and has rarely been reported from Early Cambrian strata. The present report of this ichnogenus among other Early Cambrian occurrences of this ichnotaxon adds new information on the early evolution of star-shaped feeding burrows.

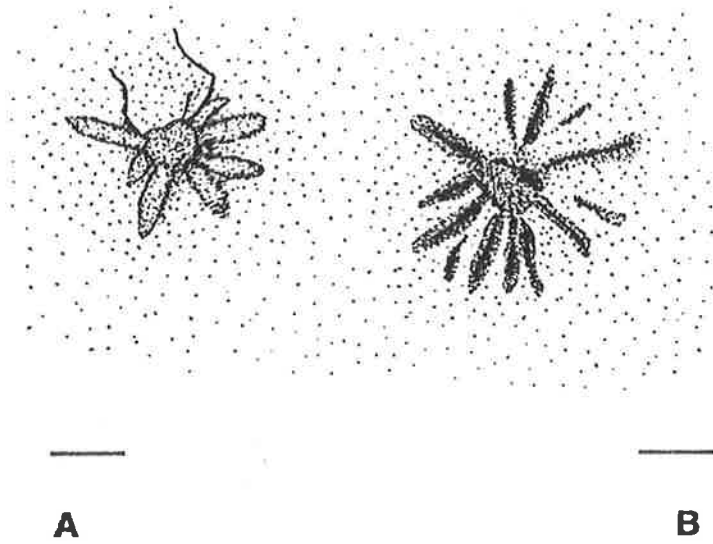
Occurrence. Allua Formation, Cyclops Bore and Hugh River, Amadeus Basin.

### ***Gordia* Emmons, 1844**

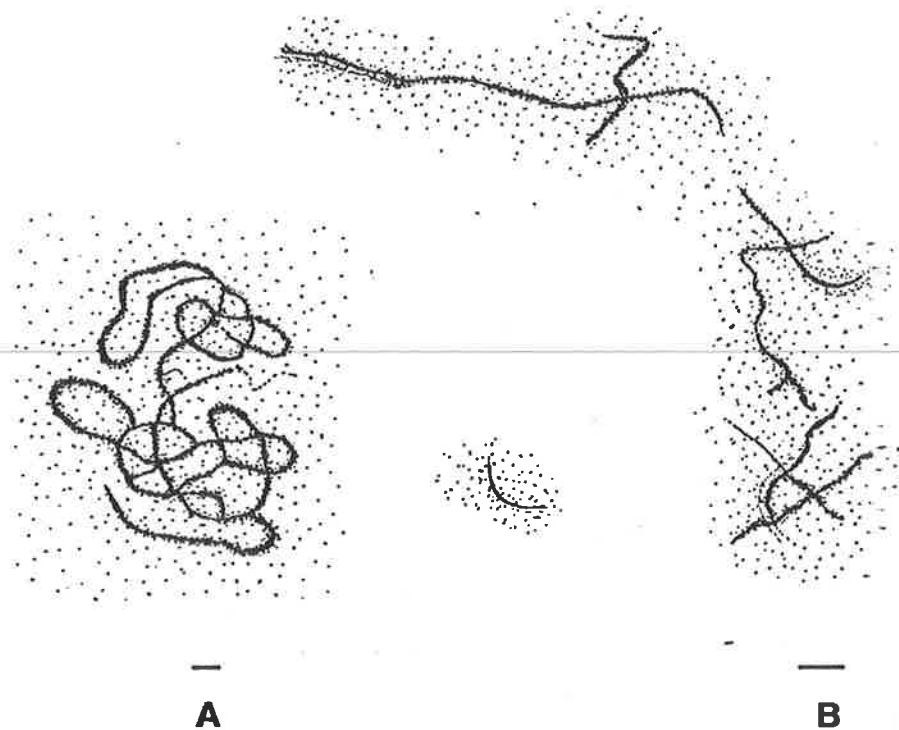
Type ichnospecies. *Gordia marina* Emmons, 1844; by monotypy.

Diagnosis. Horizontal, unbranched, smooth winding trails or burrows of uniform diameter throughout their length with a marked tendency to crossing at a given level. Burrow-fill is massive (after Hantzschel, 1975; Ksiazkiewicz, 1977).

Discussion. At least six ichnospecies of *Gordia* have been reported namely, *G. marina* Emmons, 1844, *G. molassica* (Heer, 1865), *G. arcuata* Ksiazkiewicz, 1977, *G. maeandria* Jiang in Jiang *et al.*, 1982, *G. hanyagensis* Yang and Hu in Yang *et al.*, 1987, and *G. nodosa* Pickerill and Peel, 1991. Pickerill (1981) and Narbonne and Hofmann (1987) considered *G. molassica* as junior synonym of *G. marina*. *Gordia nodosa* most likely belongs to the ichnogenus *Torrowangea* Webby, 1970, as *Gordia* is a smooth burrow and does not show annulations. Fillion and Pickerill (1990b) considered that *G. hanyagensis* is also a junior synonym of *G. marina*. *G. maeandria* has more guided meanders that results in less level crossing.



**Figure 7.20** - *Glockerichnus sparsicostata* from central Australia: **A.** A convex hyporelief; **B.** A concave epirelief (scale bar = 1 cm).



**Figure 7.21** - Ichnospecies of *Gordia* from central Australia: **A.** *G. marina*, a winding, concave burrow with frequent level crossing; **B.** *Gordia* isp. a curved to sinuous burrow. Both specimens are preserved as concave epireliefs (scale bar = 1 cm).



*Gordia* differs from *Helminthopsis* Heer, 1877 and *Planolites* Nicholson, 1873 in the presence of true level crossing in the former. *Gordia* is a facies-crossing form (Pickerill *et al.*, 1982; Narbonne, 1984).

Preservation. *Gordia* is preserved as convex hyporelief or concave epirelief.

Originator. *Gordia* is attributed to worm or worm-like organisms (Ksiazkiewicz, 1977).

Age. *Gordia* occurs in rocks from the late Vendian (Fedonkin, 1988) to Holocene (Ratcliffe and Fagerstrom, 1980, pl.1, fig. 1). *Gordia* sp. has been reported from Ediacara, South Australia by Glaessner (1969) and Jenkins (1995).

*Gordia marina* Emmons, 1844

Plate 8E

1990 *Gordia marina* Emmons; Fillion and Pickerill, p. 35, pl. 7, fig. 14.

Collected specimens. Two specimens, A971-2-49 and A1035-R15.

Diagnosis. Unguided meandering *Gordia* with frequent level-crossing (after Fillion and Pickerill, 1990b).

Description. Tightly curving to winding burrows with frequent level crossing. Burrows are 1-2 mm wide and preserved as concave epireliefs. Some burrows show more tendency to meandering and consequently display less level crossing (Fig. 7.21A).

Discussion. Fillion and Pickerill (1990b) considered that some *Gordia marina* were likely produced by a slender, bilaterally symmetrical arthropod-like or vermiform organism. The specimen illustrated in the plate 8E shows a *Gordia marina* intergraded into an irregularly meandering burrow.

occurrence. Allua Formation, Ross River, Amadeus Basin.

***Gordia* isp.**

## Plate 10A

Collected specimens. Five specimens, A971-1-17, A971-1-37, A971-2-11, A971-2-27 and A971-2-49

Description. Straight to curved burrow with level crossing. Burrow is 1-2 mm wide and preserved as concave epireliefs. Burrow displays rounded base in cross section and some of the specimens show more tendency to meandering (Fig. 7.21B).

Discussion. These burrows are similar to *G. marina* but do not show its characteristic curving and level crossing. Burrows cross one another at the same level indicating that its producer was an epifaunal animal.

occurrence. Box Hole and Allua Formations, Ross River and Cyclops Bore, Amadeus Basin.

***Gyrolithes* De Saporta, 1884**

Type ichnospecies. *Gyrolithes davreuxi* de Saporta, 1884 by subsequent designation of Hantzschel (1962, p. W200).

Diagnosis. Burrow which is coiled dextrally or sinistrally and up to several centimetres in diameter; surface of burrow with or without wall structure or scratch marks; diameter of burrow and radius of whorls almost constant; sometimes with rounded elongated processes which may branch near upper end (after Bromley and Frey, 1974; Hantzschel, 1975, p. W65).

Discussion. The suggestion of Jensen (1997) is followed that all vertical spiral burrows should be classified as *Gyrolithes* and that the size and geometry of the burrow are significant at ichnospecies level. *Gyrolithes* generally occurs in marginal marine sediments (Gernant, 1972; Bromley and Frey, 1974; Fillion and Pickerill, 1990b). Pickerill and Peel (1990) considered that the taxonomic re-evaluation of *Gyrolithes* and similar vertically coiled burrows (e.g. *Daemonehelix* Barbour, 1892; *Xenohelix* Mansfield, 1927; *Megagyrolithes* Gaillard, 1980; and *Dinocochlea* Woodward, 1922) is essential.

Originator. *Gyrolithes* has been attributed to gastropods (Woodward, 1922), rootcasts or bivalve borings (Barbour, 1892 as cited in Fillion and Pickerill, 1990b), plant fossils (Mansfield, 1927), domicnia of soft bodied invertebrates (Dryden, 1933), enteropneusts (Horst, 1940) decapod crustaceans (Hecker *et al.*, 1962; Gernant, 1972; Bromley and Frey, 1974), rodents (Schultz, 1942) and capitellid polychaetes (Powell, 1977; Fillion and Pickerill, 1990b).

Age. The ichnogenus has been reported from the Early Cambrian (Linan, 1984) to Holocene (Powell, 1977).

*Gyrolithes cf. polonicus* Fedonkin, 1981

Plate 10B

1977 ?*Gyrolithes* isp.; Fedonkin, p.187, pl. 5, figs a-b.

1997 *G. polonicus* Fedonkin; Jensen, p.51, figs 30, 34C, 36C-D, 64A-B.

Collected specimens. One specimen, A971-2-29.

Diagnosis. Sinistral or dextral vertical spiral, positive relief burrow, with diameter of whorls up to 40 mm and diameter of burrow 1 - 15 mm, but mostly less than 8 mm, Surface of the burrow smooth or with transverse ridges (after Crimes and Anderson, 1985; Jensen, 1997).

Description. Smooth vertically coiled burrow either curved dextrally or sinistrally. Diameter of the whorl 10-14 mm and of the burrow is 2-6 mm. Burrows have been preserved as convex epireliefs which represent bedding plane preservation of endichnial burrows. No complete whorl is distinguished due to poor preservation (Fig. 7.22).

Discussion. Although no complete whorl was observed, the vertical coiling of the burrow is clear from its morphology. Some of the burrows with a greater relative diameter, are very similar to *G. saxonicus* reported by Pickerill and Peel (1990, fig. 7c) from the Bastion Formation, North-East Greenland. Fillion and Pickerill (1990b) considered that *G. polonicus* may be a junior synonym of *G. saxonicus*. However, Jensen (1997) explained that *G. saxonicus* differs from *G. polonicus* in its greater size, higher ratio of spiral diameter to burrow diameter and downward expanding width of the spirals. *G. polonicus* has been

reported from Early Cambrian sediments worldwide; e.g. the Chapel Island Formation, Newfoundland, Canada (Crimes and Anderson, 1985); the Mickwitzia Sandstone, south-central Sweden (Jensen, 1997); East Poland (Fedonkin, 1977); and the Box Hole Formation, central Australia (this study). Jenkins (1981, p. 185) reported a possible occurrence of *G. polonicus* from the Precambrian? - Early Cambrian Punkerri Sandstone, Officer Basin, South Australia. Although Jenkins (1981) was not able to confirm the Ediacaran age of the Punkerri Sandstone and regarded it to be of late Proterozoic to Early Cambrian age, Walter *et al.* (1989), based on Jenkins' (1981) report, considered *Gyrolithes* to occur in their Ediacaran assemblage 2. Later Crimes (1994, p.117) quoted Walter *et al.* (1989) and reported *Gyrolithes* among his "Ediacaran biozone traces". It seems that although ichnospecies of *Gyrolithes* commonly occur in younger rocks, *G. polonicus* is restricted to the Early Cambrian strata and further study may prove its significance as an index trace fossil of that age.

Occurrence. Lower Box Hole Formation Ross River, Amadeus Basin.

### ***Hormosiroidea* Schaffer, 1928**

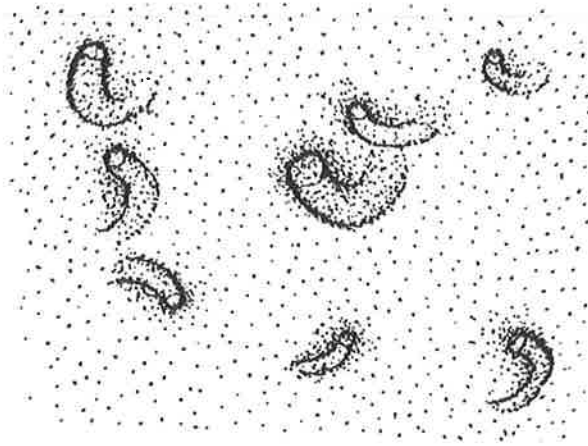
1979 "Trails of progressive motion with vertical burrows", Palić *et al.*, pl. LII, fig. 4.

1993 *Treptichnus pollardi* Buatois and Mangano, p. 221, figs 3, 5, 6A-b, 7.

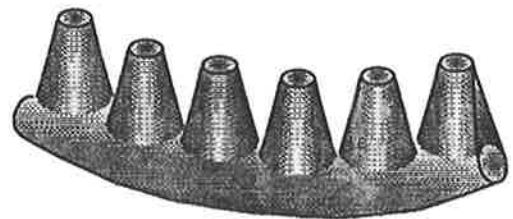
Type ichnospecies. *H. florentina* Schaffer, 1928 by original designation.

Diagnosis. A straight, curved or meandering row of circular to sub-circular pits or knobs generally jointed together as in a string of pearls (after Hantzschel, 1975; Crimes and Anderson, 1985 and Walter and Elphinstone, 1989).

Discussion. *Hormosiroidea* was erected by Schaffer (1928) for series of knobs interconnected by a horizontal burrows. Crimes and Anderson (1985) reported *H. canadensis* from the Chapel Island Formation, Newfoundland where circular to semi-circular knobs are preserved on the bedding planes. Knobs in *H. canadensis* are not joined together as they are in the type ichnospecies. Walter and Elphinstone (1989) reported a new ichnospecies *H. arumbera* from the Arumbera Sandstone of central Australia comprising circular to semi-circular deep pits arranged in curved to winding rows, interconnected by a sheet-like body



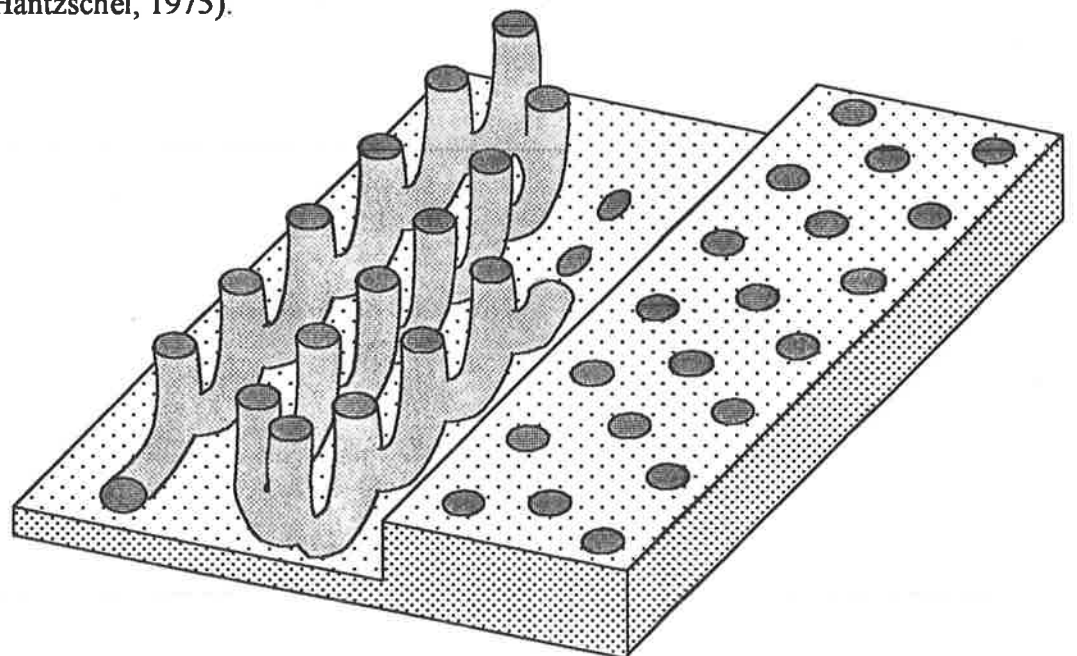
**Figure 7.22** - *Gyrolithes polonicus* preserved as convex epireliefs. Several burrows are represented by the partial preservation of the last whorl (scale bar = 1 cm).



**A**

**B**

**Figure 7.23** - **A.** *Hormosiroidea* (= *Rhabdoglyphus*) *grossheimi* is interpreted to comprise a horizontal burrow with paired vertical shafts thus can not be included within the ichnogenus *Hormosiroidea* (after Seilacher, 1977). **B.** Ichnogenus *Ctenopholeus* comprises a horizontal tunnel and vertical, conical shafts resembling *Hormosiroidea* (after Häntzschel, 1975).



**Figure 7.24** - Ichnogenus *Punctorhappe* is a tightly meandering burrow system consisting of an initial horizontal burrow with numerous vertical offshoots.

and which may coalesce to form grooves. They discussed the relationship between *H. canadensis* and *H. arumbera* and stated that further study may show that *H. arumbera* is synonymous with *H. canadensis*. *H. arumbera* is retained herein and is distinguished from other ichnospecies of *Hormosiroidea* in having pits which may join together and be interconnected by sheet-like burrows.

Tunis and Uchman (1996) referred to *H. canadensis* as *Saerichnites canadensis*. However, *H. canadensis* is a winding, single row of rounded knobs and morphologically differs from the ichnogenus *Saerichnites*, represented by a double rows of knobs or pits. *H. canadensis* is retained as a distinct ichnospecies in this study.

Seilacher (1977) considered *Saerichnites beskidensis* to be a junior synonym of *Hormosiroidea* and introduced *H. beskidensis* based on *S. beskidensis* Plicka, 1974. *Saerichnites* comprises a row of paired pits or knobs which are interpreted to be the bedding plane preservation of vertical shafts. It has been reported as a distinct ichnogenus and is retained herein.

Seilacher (1977) illustrated *Hormosiroidea* (= *Rhabdoglyphus*) *grossheimi* Vassoievitch, 1951 comprising straight burrow casts with heart-shaped expansions at regular intervals and interpreted it as a cast of a burrow in which vertical shafts stood in pairs rather than alternating (Fig. 7.23A). If this interpretation proves to be correct, the burrow should be, at best, classified as *Saerichnites grossheimi*.

The ichnogenus *Ctenopholeus* Seilacher and Hemleben, 1966, illustrated in Hantzschel (1975, fig. 35.1) is morphologically similar to *Hormosiroidea* (Fig. 7.23B). It is a poorly known ichnofossil and further study of the holotype material of *Ctenopholeus* is required to establish the relationship between the two.

The ichnogenus *Punctorhappe* Seilacher, 1977 illustrated by Seilacher (1977, fig. 6e), is morphologically similar to *Hormosiroidea*, but represents series of pits arranged in a dense first order meandering pattern lacking in the latter ichnogenus (Fig. 7.24).

Seilacher (1977) interpreted *Hormosiroidea* as an axial burrow with vertical shafts. Crimes and Anderson (1985), gave two alternative interpretations for this structure which has been illustrated in Figure 7.25. In the first, tight vertical meanders were arranged in a plane

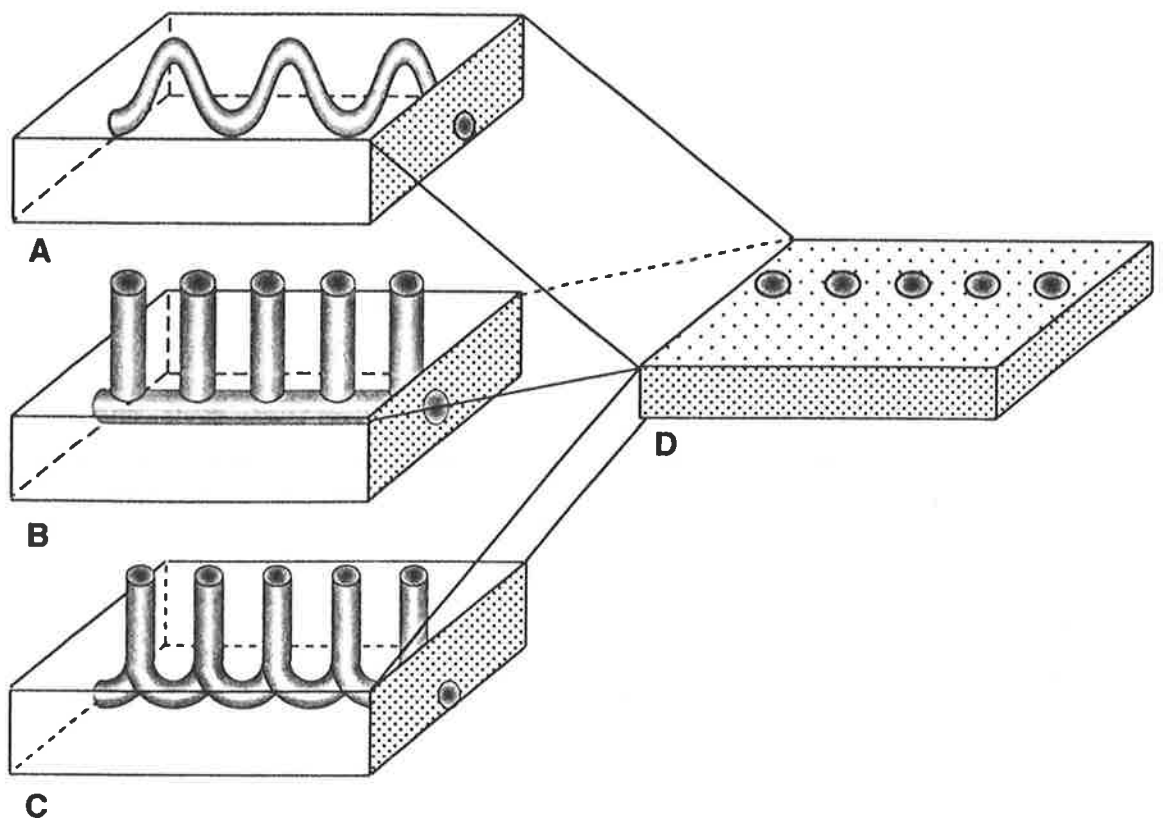
running through the line of burrow (Fig. 7.25A), while the second alternative has a lower master horizontal burrow with vertical shafts (Fig. 7.25B). Bryant and Pickerill (1990) reported *Hormosiroidea* isp. from the Early Cambrian Buen Formation, central North Greenland and favoured the first interpretation. Jensen (1997, p. 56) reported '*Hormosiroidea*' isp. from the Early Cambrian Mickwitzia Sandstone, south-central Sweden and supported the second interpretation of Crimes and Anderson (1985).

A third interpretation of the *Hormosiroidea* burrow system given here (Fig. 7.25C) is a modified form of the axial burrow with vertical shafts. In this alternative, the burrow is considered to be formed by jointed segments which curved upward distally to produce vertical shafts. The burrow is often preserved as a convex hyporelief and displays relatively regular segmentation without side projections.

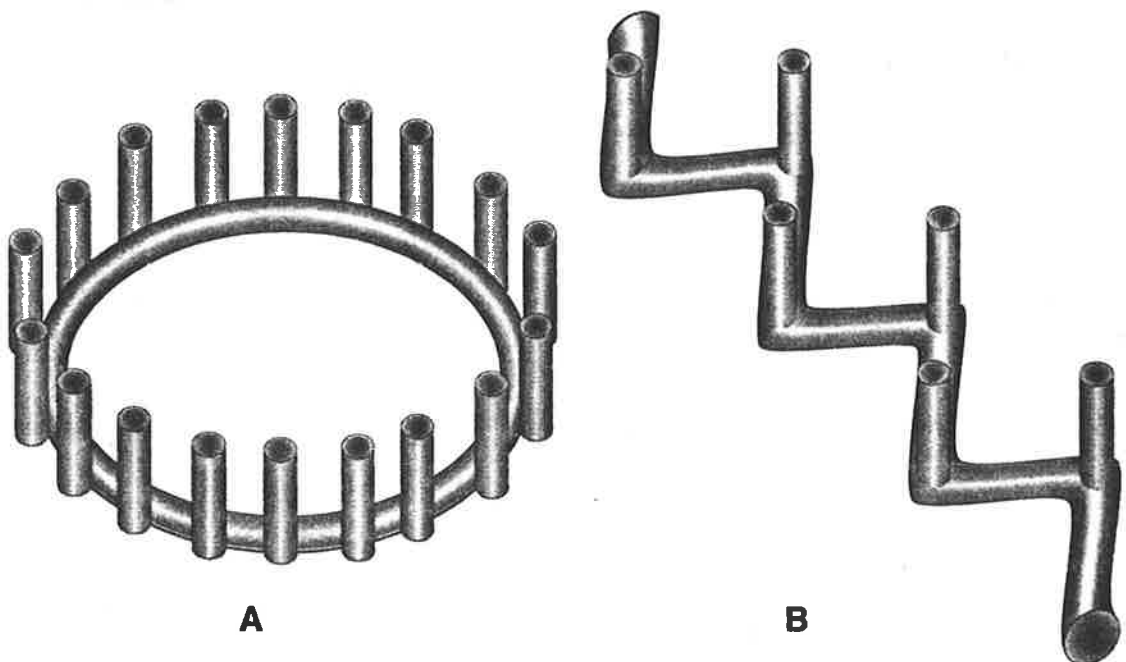
*Phycodes coronatum* reported from Newfoundland by Crimes and Anderson (1985) is a circular burrow with vertical shafts jointed to the outer margin of the burrow (Fig. 7.26A). It is generally preserved as a circular array of pits or knobs which may be interconnected and is morphologically similar to the ichnogenus *Hormosiroidea* except for the circular course of the burrow and diverging of the shafts from its outer margin. *P. coronatum* has more similarity to *Hormosiroidea* or *Treptichnus* than to *Phycodes*. Further study may prove that *P. coronatum* merits status as a distinct ichnogenus.

*Treptichnus pollardi* Buatois and Mangano, 1993, is a gently curved to zigzag burrow consisting of jointed, straight to slightly curved segments with vertical shafts diverging both from the joints or the segments themselves (Fig. 7.26B). *Treptichnus* is characterised by burrow segments, joined in a way that their distal part appears as projections. This criterion lacks in *T. pollardi*. The burrow is similar to *Hormosiroidea* and is treated as such in this study.

Although *Neonereites uniserialis* Seilacher, 1960, is very similar to *Hormosiroidea*, it represents closely spaced spherical to semi-spherical structures arranged in a straight to winding curve without any vertical extension. The distance between knobs or pits in *Hormosiroidea* is considerably greater than in *N. uniserialis* and sometimes they are interconnected by thread-like burrows. An array of pits or knobs could represent a bedding plane preservation of different burrow systems such as *Hormosiroidea*, *T. pedum* (=



**Figure 7.25** - Different interpretation of the ichnogenus *Hormosiroidea*: **A.** A horizontal burrow with vertical offshoots; **B.** A vertical sinuous burrow; **C.** A third interpretation given herein suggests that the burrow consists of segments. Each segment curves upward distally to produce vertical shaft; **D.** Bedding plain view of these burrows are similar and display series of circular structures aligned in a straight to curved line (A and B redrawn after Crimes and Anderson, 1985).



**Figure 7.26** - **A.** *Phycodes coronatum* comprises a circular burrow with vertical shafts diverging from outer rim of the burrow. It is morphologically similar to other ichnospecies of *Hormosiroidea* rather than the ichnogenus *Phycodes*. **B.** *Hormosiroidea* (= *Treptichnus*) *pollardi* consists of a curved to zigzag, horizontal burrow with vertical offshoots.



*Phycodes pedum*), *Ctenopholeus* (Figs 7.21, 7.22, 7.62). Many reported specimens of *N. uniserialis* may prove to actually be bedding plane preservation of these ichnogenera.

Age. Early Cambrian (e.g. Crimes and Anderson, 1985; Jensen, 1997; this study), Cretaceous and Eocene flysch deposits (Seilacher, 1977; Crimes and Anderson, 1985).

*Hormosiroidea ?arumbera* Walter and Elphinstone in Walter *et al.*, 1989

Plates 11D, 12B

1989 *H. arumbera* Walter and Elphinstone, p. 244, figs 14.D, 14E, 15B, 15D.

Collected specimens. Two specimens, A1035-MO160, and A1035-MO177.

Diagnosis. Uniserial chains of deep, smooth-walled pits which may coalesce to form grooves. Pits interconnected by a sheet-like body (after Walter and Elphinstone, 1989).

Description. Series of small pits arranged in a curved to winding pattern. Pits are 1-2 mm in diameter and are spaced from fraction of a millimetre to 2 mm apart. In some parts pits are interconnected by a faint burrow and at one end of the string they join together to form an almost continuous burrow which comprises a ridge with lateral grooves (Figs 7.24A-B).

Discussion. These burrows are similar to *H. arumbera* reported by Walter and Elphinstone (in Walter *et al.*, 1989) from the same formation. However, the latter displays a series of pits interconnected by a sheet-like body partially filled with glauconite, a characteristic lacking in the present material. The pits in the present specimen coalesce and form a channel as has been reported by Walter and Elphinstone (in Walter *et al.*, 1989). A specimen photographed in field (plate 11D and Fig. 7.27B) shows a closed curved pattern roughly ellipsoid in outline suggesting a close relationship between *H. arumbera* and *Phycodes coronatum* reported from Newfoundland, Canada (Crimes and Anderson, 1985).

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

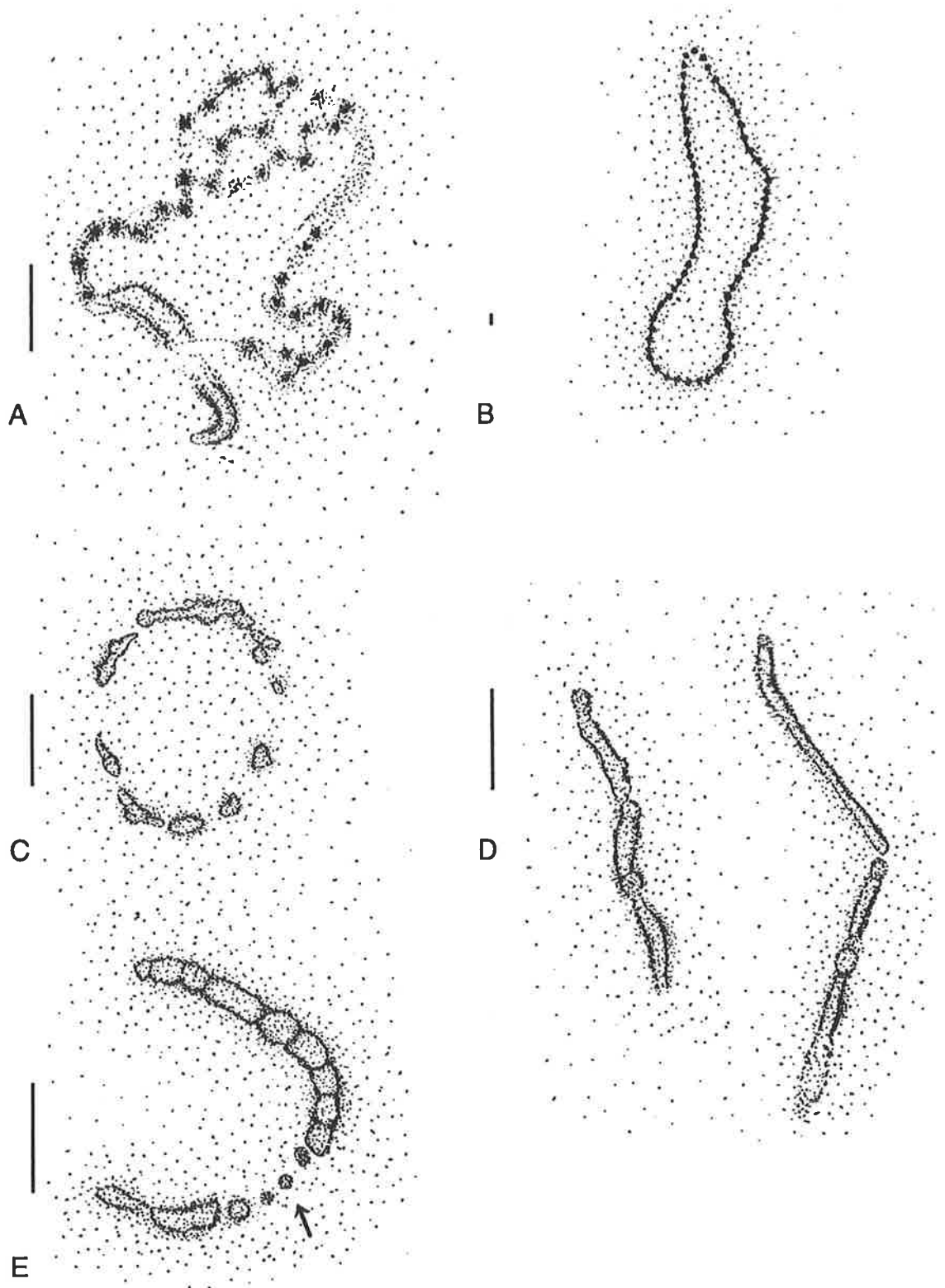
*?Hormosiroidea pollardi* (Buatois and Mangano, 1993)

Plate 11A

1993 *Treptichnus pollardi* Buatois and Mangano, p. 221, figs 3, 5, 6A-b, 7.Collected specimens. One specimen, A1035-MO159.Diagnosis. Burrows having small pits either at the angle of juncture between horizontal burrow segments or within burrow segments; pits are the bedding plane expression of vertical shafts of the burrow system (after Buatois and Mangano, 1993).Description. Zigzag, segmented burrows with small knobs or low relief pits on the joint between the segments. The knobs or pits are interpreted as bedding plane expression of vertical shafts. The burrow is 2.5 mm wide and the angle between the segments is 120-140°. The distance between the knobs or pits is 5 - 10 mm (Fig. 7.27D).Discussion. An array of pits interconnected by horizontal burrows generally narrower than the width of the pits is characteristic of the ichnogenus *Hormosiroidea*. Similar preservational expression of *Hormosiroidea* burrow systems has been reported by Jensen (1997, fig. 37B), viz. a horizontal burrow with regular to irregularly spaced knobs. *?H. pollardi* is characterised by widely spaced shafts, straight to curved horizontal burrow segments and sharp bends at the juncture between the segments. The segmentation of *?H. pollardi* supports the third alternative interpretation of *Hormosiroidea* as discussed above.Occurrence. Donkey Creek Beds, north Mount Octy, Georgina Basin.*Hormosiroidea* isp.

Plates 10D, 11B, 12A, C

1985 *Phycodes pedum* Seilacher; Fritz and Crimes, p. 15, pl. 5, fig. 1.Collected specimens. Two specimens, A971-2-1 and A1035-G1.Description. Straight to curved burrow preserved as convex hyporelief. Burrow comprises joined segments in which each segment curves upward into the sandstone layer to form a



**Figure 7.27** - Specimens of *Hormosiroidea* from central Australia: **A.** *H. ?arumberia* showing an array of small pits aligned in a winding pattern. At one end the burrow intergrades into a trilobate burrow consists of a median ridge and two lateral grooves; **B.** Drawing based on a field photograph of *H. arumberia* showing a closed curved pattern (compare with *P. coronatum* (C) represented by a circular arrangement of knobs); **D.** *?H. pollardi* comprises a zigzag burrow with vertical shafts; **E.** *Hormosiroidea* isp. is interpreted to represent a hypichnial preservation of *Hormosiroidea* burrow system showing a segmented horizontal burrow with vertical offshoots (arrow). Note the burrow fill is different from the host rock (scale bar = 1 cm).

vertical shaft. Where eroded, burrow shows the vertical shafts connected to the horizontal burrow (Fig. 7.27E). Burrows are 2-4 mm in width, parallel to bedding and seem to be annulated due to segmentation. The horizontal part of segments is 3-6 mm long. In some specimens (A1035-G1) filling of the burrow is different from that of the host rock.

Discussion. The burrow superficially resembles *Treptichnus pedum*, but, the present material does not have side projections. Burrows are considered to be a hypichnial preservation of *Hormosiroidea* according to the interpretation given for the burrow system herein (Fig. 7.25C). It is morphologically different from other reported specimens of *Hormosiroidea*, and therefore its designation to this ichnogenus is tentative. On one slab the trace occurs in association with *T. (=phycodes) pedum* and may indicate that the both traces have been produced by the same animal.

Occurrence. The Allua Formation, Ross River, Amadeus Basin.

### *Laevicyclus* Quenstedt, 1879

For the synonymy of the ichnogenus see Alpert and Moore (1975, p. 229).

Type ichnospecies. *Cyclozoon philipi* Wurm, 1912 (*partim, non* Problematicum of Philip, 1904) by subsequent designation of Alpert and Moore (1975, p.229).

Diagnosis. Vertical, cylindrical burrows with concentric tool-marks on bedding surface. The burrows may display radial imprints, particularly at its centre (after Osgood, 1970; Hantzschel, 1975; Alpert and Moore, 1975).

Discussion. Osgood (1970) discussed the ichnogenus *Laevicyclus* under the ichnogenus *Palaeoscia*, Caster, 1942. Although he mentioned the close resemblance of these two ichnogenera, he considered them to be separate forms. Alpert and Moore (1975) argued that two different *Laevicyclus*-like forms have been reported; Form A, large vertical, cylindrical burrows with a small central cylinder and Form B, vertical burrows with concentric scrape-marks on the bedding surface. Both forms have a similar appearance in bedding-plane view (Fig. 7.28). They (1975) proposed that only Form B truly represents *Laevicyclus* and regarded Form A as a new ichnogenus *Dolopichnus*. Alpert and Moore (1975 p. 229)

questionably considered *Palaeoscia* reported by Osgood (1970) from Cincinnati, to be a junior synonym of the *Laevicyclus*. The only ichnospecies of *Laevicyclus*, *L. (= Cyclozoon) philipi* was designated as type ichnospecies by Alpert and Moore (1975, p. 229). *Laevicyclus* is very similar to the Ediacaran fossil *Kullingia concentrica* Glaessner in Foyn and Glaessner, 1979 (fig. 8) which shows a series of concentric ribs without radial grooves around a central knob.

*Laevicyclus* is reported from the Late Silurian of Arctic Canada by Narbonne (1984, fig. 6D) and *Laevicyclus mongraensis* Verma, 1969, reported by Chiplonkar and Badwe (1970, pl. 3, figs 4 & 4a) from the Bagh Beds, Narbada Valley, India are believed to be specimens of *Dolopichnus*.

Originator. *Laevicyclus* is considered to be the vertical dwelling burrow of a worm, with tentacle swirl-marks around the top of the burrow (Osgood, 1970; Alpert and Moore, 1975). However, the convex hyporelief preservation of the burrow (Osgood, 1970, pl. 82, fig. 4) has been interpreted as inorganic. Jenkins (*pers. comm.*) stated that an anchored seaweed can produce circular tool-marks similar to *Laevicyclus*.

Age. Early Cambrian (Seilacher, 1955); Late Ordovician (Osgood, 1970); Early Mississippian (Bjerstedt, 1988); Jurassic (Quenstedt, 1879); and Late Cretaceous (Frey, 1970).

**?*Laevicyclus* isp.**

Plate 12E

1970 *Palaeoscia*, Osgood, 1970, pl. 82, fig. 4.

Collected specimens. One specimen, N88-A9.

Description. A vertical burrow 6 mm in diameter preserved as a convex hyporelief. The burrow is surrounded by about 14 concentric partially developed ridges and does not show radial impression. Ridges neither cross one another nor form a complete circle They produce arches from one to three quarter of a circle (Fig. 7.28C). The total structure is about 56 mm in diameter.

Discussion. The present specimen resembles closely the one figured by Osgood (1970, pl. 82, fig. 4) but has more developed concentric ridges. Osgood (1970) suggested an inorganic origin for some specimens of *Laevicyclus* including the one mentioned above. Because of insufficient number of specimens (only one) it was not possible to elaborate on the origin of the burrow. The burrow is assigned to the *Laevicyclus* for the time being.

Occurrence. Allua Formation, Ross River, Amadeus Basin.

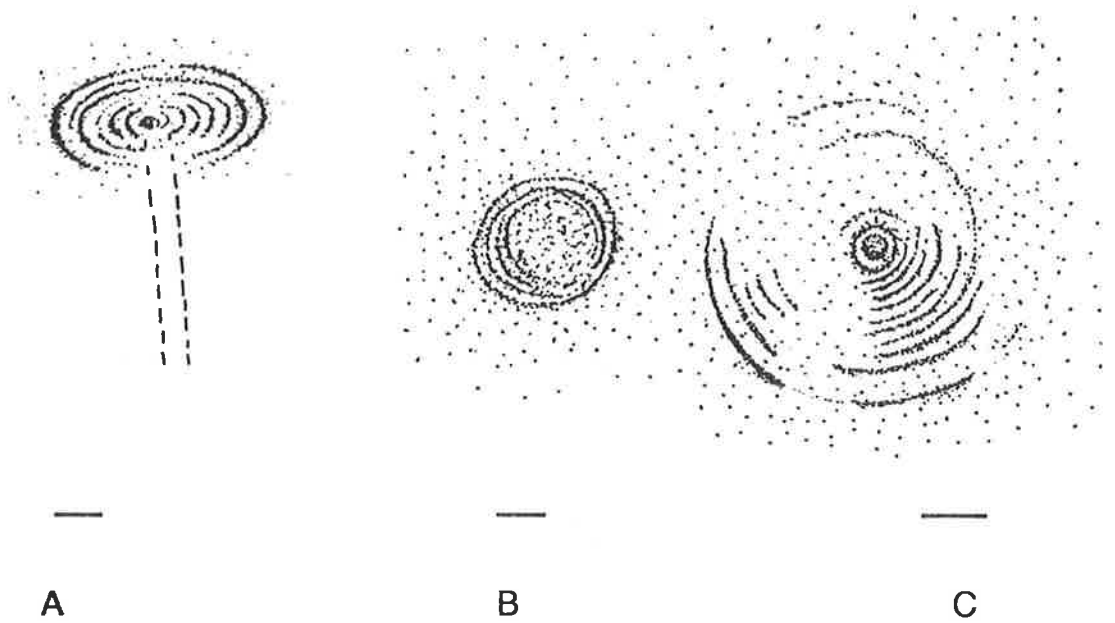
### ***Monocraterion* Torell, 1870**

Type ichnospecies. *Monocraterion tentaculatum* Torell, 1870; by monotypy.

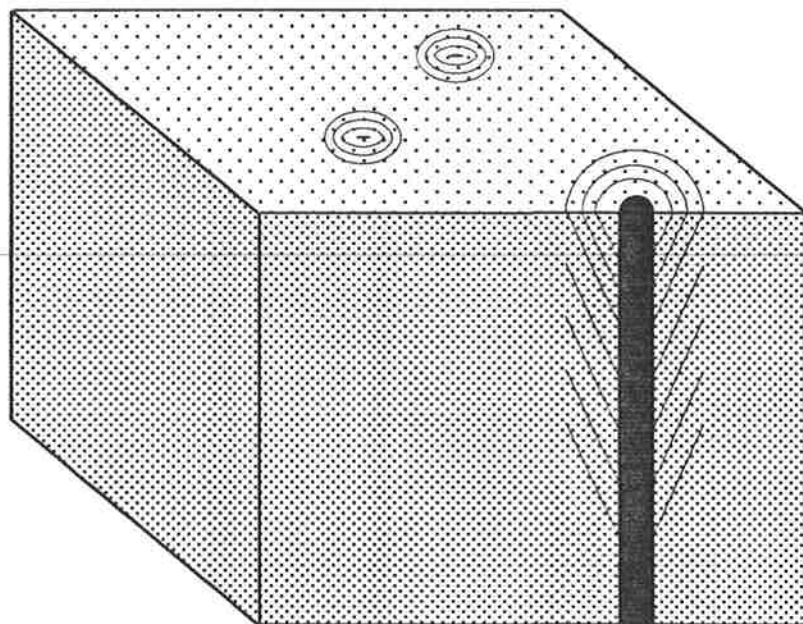
Diagnosis. Vertical funnel structure or stacked funnels penetrated by central straight or slightly curved tube, characterised by a central downward deflection of sedimentary laminae (after Hantzschel, 1975; Crimes *et al.*, 1977).

Discussion. The close association between *Monocraterion* and *Skolithos* Haldeman, 1840, led Goodwin and Anderson (1974) to interpret the former as a funnel-shaped top to the *Skolithos* burrows and conclude that the same organism was responsible for both burrows, a notion strongly disputed by Crimes *et al.* (1977) and many other authors (e.g. Fillion and Pickerill, 1990b; Jensen, 1997). Although a few authors considered forms of *Monocraterion* as ichnospecies of *Skolithos* (Frey and Howard, 1985; Clausen and Vilhjalmsson, 1986), others regarded the occurrence of the funnel-shaped aperture in *Monocraterion* to be diagnostic (e.g. Fillion and Pickerill, 1990b).

Specimens of *Monocraterion* seen in bedding plane view may be mistaken for *Rosselia* Dahmer, 1937, *Dolopichnus* Alpert and Moore, 1975 or *Cylindrichnus*, Toots in Howard, 1966. They all represent a circular to subcircular structure with concentric striations due to the internal structure of the burrows which is characteristic for each ichnogenus. Crimes (1975b) and Crimes *et al.* (1977) assigned stacks of upwardly concave funnels to *Monocraterion*, although the funnels have no attached tube. Jensen (1997, fig. 41) has illustrated semi-hemispherical structures and described them as the conical part of *Monocraterion* cf. *tentaculatum*. This structure apparently was also found as loose individuals. The *Monocraterion* funnel-shaped structure is conical due to the alteration of



**Figure 7.28-** A. *?Laevicyclus isp* (after Hantzschel, 1975). B. *Dolopichmus gulosus* (after Alpert and Moore, 1975). C. *Laevicyclus isp* from central Australia preserved in convex hyporelief (scale bar = 1 cm).



**Figure 7.29** - A vertical section through *Monocraterion* burrow showing conical laminations.

sediment laminae as a result of animal activity (Fig. 7.29). Jensen's specimens, particularly those preserved in convex hyporeliefs, are more rounded with a sharp margin, and closely resemble *Calycraterion* Karaszewski, 1971 (as figured by Fillion and Pickerill, 1990b, pl. 1, fig. 18) or the upper part of the ichnogenus *Rosselia*.

At least four ichnospecies of *Monocraterion* have been formally reported, namely: *M. tentaculatum* Torell, 1870, *M. magnificum* Matthew, 1891, *M. clintonense* Howell, 1946 and *M. rajnathi* Badwe and Ghare, 1978. Fillion and Pickerill (1990b) considered *M. clintonense* to be a junior synonym of *M. tentaculatum*. *M. rajnathi* is characterised as having "a very thin wall and wider central tube" (Badwe and Ghare 1978). *M. magnificum* is similar to *M. tentaculatum* but is larger in size.

Originator. *Monocraterion* is considered to be the dwelling structure of a small worm-like organism, possibly a polychaete. The tubes of *Diopatra cuprea* (Barwis, 1985) or *Cerianthus lloydi* (Hallam and Swett, 1966) may be a modern analogue of *Monocraterion*.

Facies distribution. The ichnogenus is typical of shallow-water settings (Hallam and Swett, 1966; Goodwin and Anderson, 1974) but doubtful examples have been reported from deep-water environments (Jordan, 1981; MacDonald, 1982).

Age. Late Precambrian (Crimes, 1994), to the Early Cretaceous (Wightman *et al.*, 1987).

### ***Monocraterion* isp.**

Plates 12D, 13A-B, 16A, 17A, 26D

Collected specimens. Ten specimens, A971-1-27, A971-1-28, A971-1-29, A971-1-31, A971-1-32, A971-1-37, A971-2-27, A1035-MO47A, A1035-MO62, and A1035-MO103.

Description. Vertical burrow with funnel shaped aperture. Burrow straight and unbranched. The funnel part is 6-12 mm and the main shaft 2-5 mm in diameter. These are preserved as convex circular structures some of which show concentric elements. The upper funnel-shaped part of the burrow displays cone-shaped laminae of fine-grained sediment which is darkened in colour (Fig. 7.29).



Discussion. Each burrow displays a vertically repeated conical structure. Jensen (1997) reported that *M. tentaculatum* displays radial furrows interpreted to be the result of the surficialsurficial feeding activity of the producer. The present material lacks any radial impressions.

Occurrence. Box Hole and Allua Formations, Ross River and Cyclops Bore, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

### ***Monomorphichnus* Crimes, 1970**

Type ichnospecies. *Monomorphichnus bilinearis* Crimes, 1970; by monotypy.

Diagnosis. "A series of straight or slightly sigmoidal ridges sometimes repeated laterally and produced by a number of clawed limbs" (Crimes, 1970, p. 57).

Discussion. Crimes (1970) introduced *Monomorphichnus* for markings formed by trilobites, caught in a current and raking the surface of the sediment with their endopodite claws. Crimes (1970) and Crimes *et al.* (1977) suggested that the traces may have been produced as swimming grazing traces. Osgood (1970) argued that this method of feeding would be insufficient and instead suggested the trace to have been made by a trilobite that lashed out to control its movement as it was swept by a current. Although this latter explanation may be correct for the majority of specimens of *Monomorphichnus* as they generally occur with tool marks and are parallel to the current (Crimes, 1970; Crimes *et al.*, 1977), Fillion and Pickerill (1990b) found some specimens associated with many other well-preserved traces, but without current-produced structures, hence suggesting them to be grazing traces. Fillion and Pickerill (1990b, p. 40-41) comprehensively reviewed the taxonomy of *Monomorphichnus* and consequently consolidated the use of this ichnogenus. At least seven ichnospecies of *Monomorphichnus* have been reported, based on the number and geometry of the ridges (Table 7.3).

Fillion and Pickerill (1990b) described two additional ichnospecies, *Monomorphichnus* ichnos. A and *M. ichnos. B*, but they did not formally erect a new ichnospecies. Crimes *et al.* (1977) erected a new ichnovariant *M. lineatus* var. *giganticus* to embrace the large specimens

of *M. lineatus*. The idea of introducing ichnovariants has not generally been accepted among ichnologists.

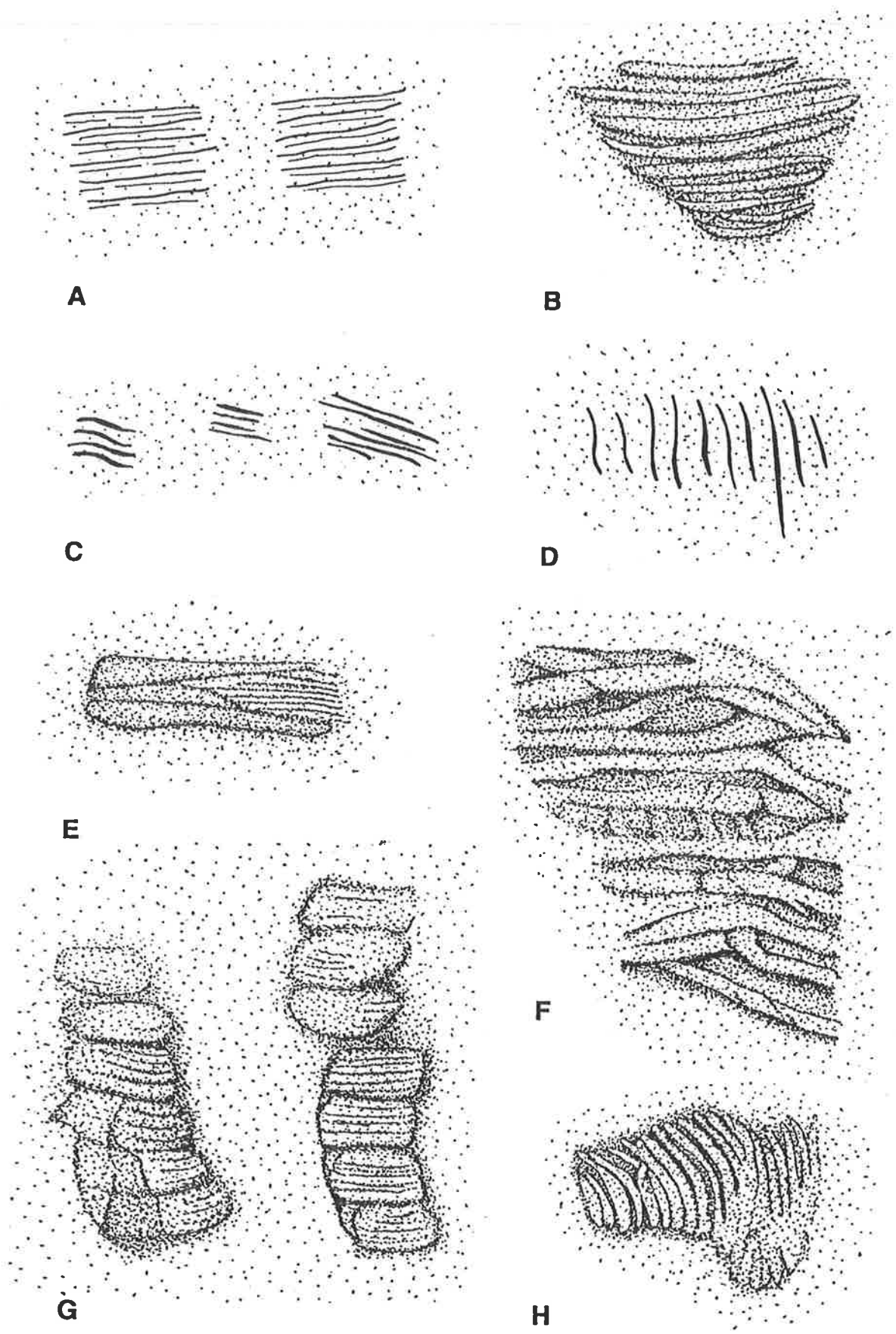
Fillion and Pickerill (1990b) considered *M. cretacea* from the Late Cretaceous of India to be inorganic. *M. monolinearis* from the Cambrian of Kashmir (Shah and Sudan, 1983) consists of a series of single ridges and is considered to be a junior synonym of *M. lineatus*. Figure 7.30 shows various ichnospecies of *Monomorphichnus*.

Originator. *Monomorphichnus* has been generally attributed to trilobite swimming-grazing trails. Other arthropods have also been potentially considered as responsible (Romano and Melendez, 1985).

**Table 7.3** - Reported ichnospecies of *Monomorphichnus*.

<i>M. bilinearis</i>	Crimes	1970	paired parallel striae with one stria of each pair typically more prominent than the other
<i>M. multilineatus</i>	Alpert	1976	set of scratch marks in which the central marks are deeper than the outer marks
<i>M. lineatus</i>	Crimes, Marcos Arboleya	Legg, and 1977	parallel, isolated, straight to slightly sigmoidal striae, which may be repeated laterally
<i>M. cretacea</i>	Badwe and Ghare	1980	inorganic in origin
<i>M. monolinearis</i>	Shah and Sudan	1983	junior synonym of <i>M. lineatus</i> .
<i>M. pectenensis</i>	Legg	1985	is a set of paired straight ridges with intervening fine, comb-like striations
<i>M. intersectus</i>	Fillion and Pickerill	1990	intersecting dig marks, as a rule highly convex in hyporelief

Facies, distribution. *Monomorphichnus* occurs in shallow marine (Baldwin, 1977b) to estuarine (Fisher, 1978) and fluvial (Shone, 1979) deposits.



**Figure 7.30** - Ichnospecies of *Monomorphichnus*: A. *M. bilinearis* (after Crimes, 1970); B. *M. multilineatus* (after Alpert, 1976); C. *M. lineatus*; D. *M. lineatus* var. *giganticus* (C-D after crimes et al., 1977); E. *M. pectenensis* (after Legg, 1985); F. *M. intersectus*; G. *Monomorphichnus* isp. A; H. *Monomorphichnus* isp. B (F-H after Fillion and Pickerill, 1990).

Age. The ichnogenus has been recorded from the oldest Early Cambrian (Narbonne and Myrow, 1988) to the Triassic (Shone, 1979). Jenkins *et al.* (1983) and Jenkins (1995) described a possible Precambrian occurrence of *Monomorphichnus*. However, Fillion and Pickerill (1990b) suggested that it may not be a *Monomorphichnus* though, they believed it to indicate arthropod scratch marks. Jenkins (1995, fig. 1C) illustrated doubled clawed scratch-marks considered as *Monomorphichnus* from the Rawnsley Quartzite, Adelaide Geosyncline.

***Monomorphichnus bilinearis* Crimes, 1970**

Plate 14B

1970 *Monomorphichnus bilinearis* Crimes, p. 57-58, pl. 12C.

Collected specimens. Seven specimens, A971-3-8, A971-4-3, A971-4-7, A1035-MO183 and A1035-B6.

Diagnosis. As for the ichnogenus, but the ridges are grouped in pairs. One ridge of each pair is typically more prominent than the other (Crimes, 1970, p. 57).

Description. Sets of parallel paired narrow ridges, 0.3-0.5 mm wide, gently curving and parallel to the bedding, which may repeat. The trace has been preserved in convex hyporelief. In some of them one ridge of each pair is slightly larger and more distinct than the other. One specimen displays fine brush-marks between the ridges.

Discussion. Some specimens within the present material possess double ridges with the occasional occurrence of brush-like scratch marks between the ridges; they differ from *M. pectenensis* in the double ridges being especially narrow.

Occurrence. Box Hole Formation, Ross River and Cyclops Bore; ? Allua Formation, Hugh River, Amadeus Basin.

***Monomorphichnus lineatus* Crimes, Legg, Marcos, & Arboleya, 1977**

Plates 12F, 13C, E, 14A, C

Collected specimens. Six specimens, A971-2-7, A971-2-13, A1035-MO87, A1035-MO96, A1035-MO102, and A1035-R25.

Diagnosis. "Parallel, isolated, straight to slightly sigmoidal striae, which may repeated laterally" (after Crimes *et al.*, 1977).

Description. Long, parallel, narrow ridges, 0.2-0.4 mm wide and variable in length, straight to slightly curved in sets parallel to the bedding, preserved as convex hyporeliefs or concave epireliefs. In one specimen (A1035-R25) the trace has been repeated up to three times. In some specimens (A1035-MO102, A1035-MO87) the ridges has been repeated on both sides of a *Palaeophycus* burrow and the general geometry resembles a cat-moustache-like structure in which the ridges have a slight tendency to converge toward the *Palaeophycus* burrow (Fig. 7.31).

Discussion. The specimens of *M. lineatus* show different overall lengths but they commonly display a series of narrow ridges which may repeat laterally. The occurrence of several cat-moustache-like *M. lineatus* in close association with *P. tubularis* burrows may indicate a praedichnial origin for this ichnospecies. However, no disturbance of the *Palaeophycus* burrow was observed where it occurs with *Monomorphichnus*.

Occurrence. The Box Hole Formation, Ross River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

### *Neonereites* Seilacher, 1960

Type ichnospecies. *Neonereites biserialis* Seilacher, 1960 by original designation.

Emended Diagnosis. Smooth-walled dimples or knobs arranged in an irregularly curved chain which may be flanked by bioturbation halos. Dimples or knobs are not interconnected by any kind of burrow and do not display any vertical extension.

Discussion. An emendation of the diagnosis is suggested herein to exclude chains of knobs or dimples which sometimes are interconnected by a string-like burrow, and represent the bedding-plane view of vertical shafts (*Hormosiroidea*). The ichnogenus *Microspherichnus* Hakes, 1976 consists of chains of small spheres preserved as convex epireliefs. Fillion and

Pickerill (1990b) retained both traces and elaborated on their differentiation. They (1990b) suggested that; a chain of hypichnial dimples could represent *Microspherichnus* or *Neonereites*, but should be regarded as *Neonereites* since this has priority over *Microspherichnus*; a chain of hypichnial knobs or epichnial dimples signifies *Neonereites* according to the original diagnosis; a chain of epichnial knobs could be *Neonereites* if they are hemispheres or *Microspherichnus* if spherical. The original diagnosis of *Neonereites* does not embrace epichnial knobs, and while supporting other recommendations of Fillion and Pickerill (1990b), it is suggested that all epichnial knobs should be excluded from *Neonereites*. Seilacher and Meischner (1964) grouped *Neonereites*, *Scalarituba* and *Nereites* together as behavioural variants. Chamberlain (1971b) placed *Neonereites* in synonymy with *Scalarituba missouriensis* Weller, 1899, and expanded the latter to include a "*Nereites* view" in convex hyporelief and a "*Phyllodocites* view" in concave epirelief. Many authors (e.g. Hakes, 1976; Pickerill, 1980; Crimes and Germs, 1982) retain *Neonereites* as a distinct ichnogenus. At least four ichnospecies of *Neonereites* have been reported namely, *N. uniserialis* Seilacher, 1960, *N. biserialis* Seilacher, 1960, *N. renarius* Fedonkin, 1980 and *N. multiserialis* Pickerill and Harland, 1988.

Originator. *Neonereites* is interpreted to be an endogenic burrow (Seilacher, 1960) or trail of a vagile benthic animal (Hantzschel and Reineck, 1968), particularly an annelid (Hakes, 1976).

Facies distribution. *Neonereites* is considered to be a facies-crossing form (Tanaka, 1971; Hakes, 1976).

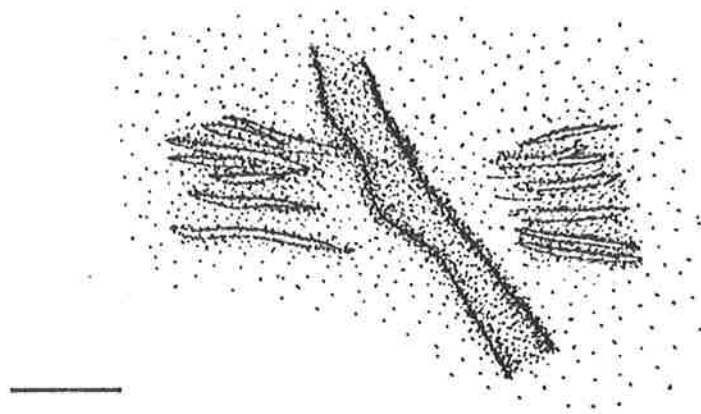
Age. Latest Precambrian (Fedonkin, 1988) to Eocene (Crimes *et al.*, 1981).

*Neonereites biserialis* Seilacher, 1960

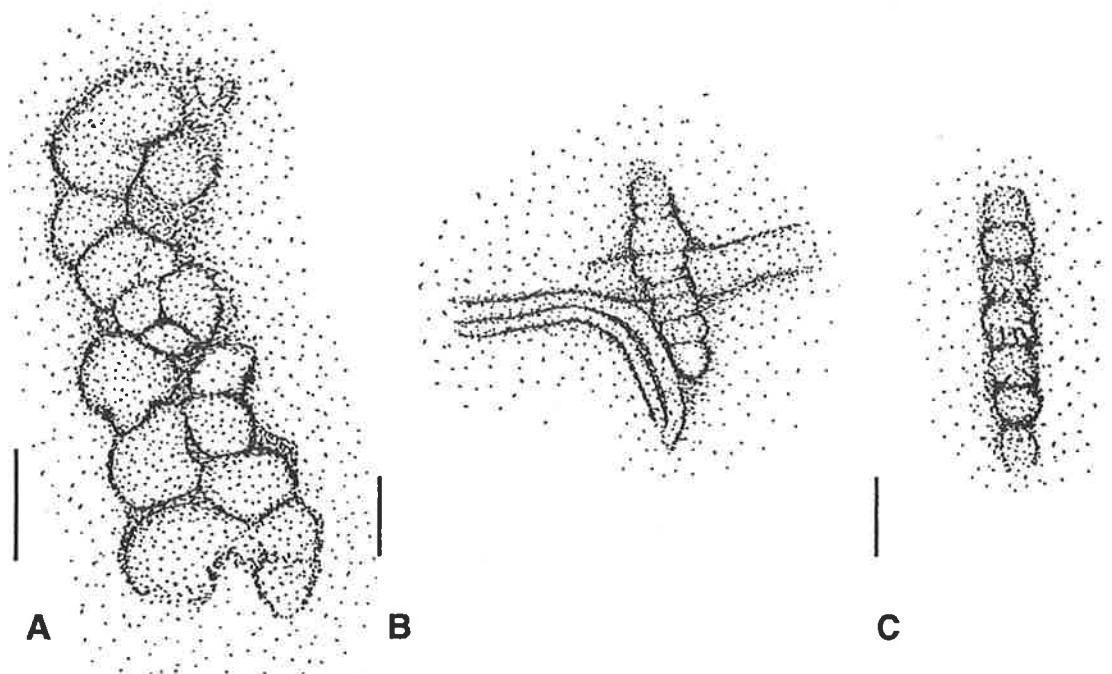
Plate 14D

Collected specimens. One specimen, A1035-MO112.

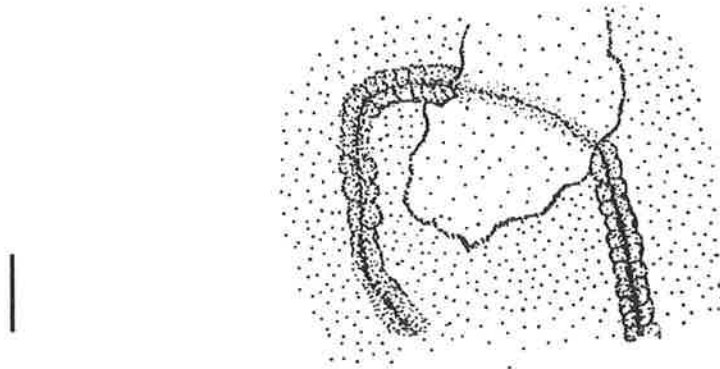
Diagnosis. Biserial *Neonereites*.



**Figure 7.31** - Relationship between *Monomorphichnus lineatus* and *Palaeophycus tubularis* burrows. The former occurs as series of parallel ridges on both sides of the later (scale bar = 1 cm).



**Figure 7.32** - Ichnogenus *Neonereites* from central Australia: **A.** *N. biserialis* comprises a double row of spherical to semispherical structures; **B.** *N. uniserialis* consists of a row of semispherical structures and often occurs in association with other ichnogenera such as *Planolites*; **C.** *Neonereites* isp. is similar to *N. uniserialis* but displays delicate striations on each knob (scale bar = 1 cm).



**Figure 7.33** - *Nereites macleayi* preserved as a concave epirelief. The burrow is parallel to the bedding plane and does not cross sedimentary laminae. It consists of a median furrow with marginal lobate ridges which is poorly preserved in some places (scale bar = 1 cm).

Description. A gently curving burrow with wavy margins, poorly preserved as convex hyporelief comprising two series of subspherical knobs (Fig. 7.32A). The knobs, 4-6 mm in diameter, are located close to or overlap each other. The total width of the burrow is 15 mm.

Discussion. The quality of the specimen is poor due to subsequent erosion of the burrow. It differs from *N. uniserialis* in having knobs arranged in double rows.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

*Neonereites uniserialis* Seilacher, 1960

Plate 13D

Collected specimens. Three specimens, A971-1-2, A1035-MO56 and A1035-MO167.

Diagnosis. *Neonereites* burrow comprising a series of spherical knobs or dimples.

Description. Circular knobs arranged in a slightly curved to straight chain. Individual knobs are 2-6 mm wide and closely spaced. The width of the knobs changes slightly along a given burrow and is more variable in specimen A1035-MO167 (Fig. 7.32B).

Discussion. *N. uniserialis* differs from other ichnospecies of *Neonereites* in being uniserial, and from *Microspherichnus linearis* Hakes, 1976 in being preserved in convex hyporelief.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

*Neonereites* isp.

Plate 14E-F

Collected specimens. One specimen, A1035-MO183.

Description. Circular knobs arranged in a straight chain. Individual knobs 4-6 mm in diameter and closely spaced. This specimen is larger than the *N. uniserialis* and has shallow longitudinal furrows on each knob.



Discussion. *N. uniserialis* generally comprises smooth knobs. Knobs in the present specimen display furrows which become closer together toward the centre of the knob (Fig. 7.32C). Crimes and Germs (1982) reported the preservation of striations in some specimens of *Neonereites* occurring in the Nama Group, Namibia. Although preservation of the ornamentation depends on the substrate consistency and is also subject to the subsequent erosion, it may be used for ichnospecies differentiation.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

### *Nereites* Macleay, 1839

Type ichnospecies. *Nereites cambrensis* Murchison, 1839; subsequent designation by Hantzschel (1962, p. W205).

Diagnosis. "Meandering trails consisting of narrow median furrow, flanked on both sides by regularly spaced, leaf-shaped, ovate, or pinnate lobes. closely spaced; commonly finely striated" (Hantzschel, 1975, p. W84).

Preservation. *Nereites* occurs on top surface of thin turbidites, and thus most probably was produced in a deep water environment. It is regarded as an internal meandering grazing trail (Seilacher and Meischner, 1964, p. 615).

Discussion. Benton (1982) reviewed the ichnogenus *Nereites* and considered that four ichnospecies are represented namely, *N. macleayi* (Murchison, 1839); *N. cambrensis* Murchison, 1839; *N. jacksoni* Emmons, 1844 and *N. pugnus*, Emmons, 1844. They can be distinguished easily on the basis of size and shape of the lateral lobes. Crimes and McCall (1995) argued that Benton (1982) did not place existing ichnospecies of *Nereites* in synonymy with those he deemed to have priority, and suggested a revision of the ichnogenus. Seilacher (1974, 1983) claimed that *Nereites* shows an evolutionary trend towards more complicated and smaller forms. Crimes and Crossley (1991) suggested that this is not true everywhere, although closely spaced meanders may be more common in Mesozoic and Tertiary flysches, they are present in rocks at least as old as the Lower Silurian. *Nereites* is typical of Seilacher's (1967) *Nereites* ichnofacies characterising deep water flysch sediments,

but has been reported from shallow water environments as well (Hakes, 1976; Crimes and Germs, 1982).

Originator. Various producer animals have been suggested; worms (e.g. Richter, 1928, p. 241), gastropods (e.g. Raymond, 1931, p. 191), and crustaceans (Fraipont, 1915, p. 449). Chamberlain (1971b) considered the originator was a worm-like animal excavating lobes ahead of itself and backfilling them as it moved forward.

Age. *Nereites* is relatively a common ichnogenus (Crimes and McCall, 1995) and has been reported from late Precambrian - Early Cambrian sequences (Acenolaza and Durand, 1973; Crimes and Germs, 1982; Walter *et al.*, 1989) to Tertiary (Hantzschel, 1975, p. W84).

*Nereites macleayi* (Murchison, 1839)

Plate 15A

Collected specimens. One specimen, A971-2-27 and field photos 2-18, 2-19.

Description. Narrow, gently curving to winding burrow preserved as concave epirelief 1-2 mm wide. Burrow comprises a broad axial groove with lateral pinnate to ovate annulated lobes (Fig. 7.33). Annulations are fine and 1 mm wide. An individual burrow does not cross different sediment laminae indicating its surficial nature. No branching or cross cutting was observed.

Discussion. The present specimen is smaller than the size that Hantzschel (1975) has quoted (10-12 mm) but does match those of Crimes and Germs (1982), Benton (1982), as well as Crimes and Anderson (1985). *Nereites* is a rare fossil in the region.

Occurrence. The Box Hole Formation West Cyclops Bore and Ross River, Amadeus Basin.

*Palaeophycus* Hall, 1847

Type ichnospecies. *P. tubularis* Hall, 1847 from the "Calciferos Sandstone" (Beekmanton, Lower Ordovician), Mohawk Valley, New York State; subsequent designation by Bassler (1915, p. 939) (After Pemberton and Frey, 1982). Fillion and Pickerill (1990b) believed that

Miller (1889, p. 130) was the first who validly designated *P. tubularis* Hall, 1847 as the type ichnospecies.

Diagnosis. The diagnosis given by Pemberton and Frey (1982, p. 852) has been emended by Fillion and Pickerill (1990b) to exclude systematic and non-systematic winding and/or meandering burrows (e.g. *Gordia*, *Cochlichnus*); systematic branching burrows (e.g. *Phycodes pedum*, *Chondrites*) and burrows in which bifurcation results in swelling at the sites of branching (e.g. *Thalassinoides*). Their emended diagnosis is as follows: "Straight to slightly curved to slightly undulose or flexuous, smooth or ornamented, typically lined, essentially cylindrical, predominantly horizontal structures interpreted as originally open burrows; burrow-fill typically massive, similar to host rock; where present, bifurcation is not systematic, nor does it result in swelling at the site of branching".

Discussion. Alpert (1975) concluded that the presence or absence of branching may be used to differentiate *Planolites* from *Palaeophycus*. Branching burrows represent the latter and unbranched burrows the former. This notion was followed by numerous authors (Benton and Trewin, 1978; McCarthy, 1979; Miller, 1979; Pickerill and Forbes, 1979; Ratcliffe and Fagerstrom, 1980). In their comprehensive study of these ichnogenera Pemberton and Frey (1982) stated that Alpert's approach was not consistent with the original description of these ichnogenera. The internal fill of the burrow and burrow wall are important and can provide good criteria for differentiating these ichnogenera (Osgood, 1970, p. 375; Frey and Chowns, 1972, p. 32; Hantzschel, 1975, p. W88-W89; Pemberton and Frey, 1982, p. 849; Keighley and Pickerill, 1995). Pemberton and Frey (1982) concluded that *Palaeophycus* is a domicile and is not actively filled by the trace-maker. Re-examination of Hall's type material (Osgood, 1970; Pemberton and Frey, 1982) clearly showed that the material infilling the burrows is identical to the matrix of the host rock. Frey and Chowns (1972, p. 32) considered that burrow-collapse structures and distinctly lined but irregular burrow walls accompanying *Palaeophycus* indicate formerly open burrows which have been subsequently filled passively with sediment and deformed by compaction.

In contrast, Pemberton and Frey (1982) considered *Planolites* as an actively back-filled burrow produced by a mobile deposit-feeding organism. The sediments infilling the burrows is lithologically different from the matrix of the host rock (Benton and Trewin, 1978,

Pemberton and Frey, 1982) which in association with other morphological characteristics of *Planolites* such as the smooth burrow surface and lack of collapse-structures indicates actively filled feeding burrows (Frey and Chowns, 1972, p.33; Benton and Trewin, 1978, p. 6; Pemberton and Frey, 1982, p. 850).

Keighley and Pickerill (1995) elaborated on the problems concerning differentiation between *Palaeophycus* and *Planolites* and suggested that the burrow lining should be considered significant at the ichnogenic level. They assigned burrows without lining into *Planolites* and those with lining into *Palaeophycus* if they have been filled passively, and into *Macaronichnus* if filled actively.

Pemberton and Frey (1982, p.853) recognised five ichnospecies of *Palaeophycus*, based primarily on wall lining and burrow sculpture. They (1982, p. 853) also anticipated a sixth ichnospecies of *Palaeophycus* which they informally called it as *Palaeophycus* "annulatus" and suggested it to show repeated annulations.

Fillion and Pickerill (1988) reported *P. annulatus* from the Ordovician of Newfoundland, fulfilling the anticipation of Pemberton and Frey (1982). Later, Fillion and Pickerill (1990b, p. 49) deduced that *P. annulatus* is a primary junior homonym of *Palaeophycus annulatus* Badwe, 1987 and is thus invalid. McCann (1993) discussed the matter and because of the problem associated with the name *P. annulatus* introduced a new ichnospecies *P. serratus* from the Aberystwyth Grits Formation of the Welsh Basin, west Wales, for *Palaeophycus* burrows with transverse ribbing due to annulation. Buckman (1992) discussed the ichnotaxonomic status of continuously annulated forms of *Palaeophycus* and suggested that previously reported forms such as *P. annulatus* and *P. serratus* should be considered *nomina dubia* as their annulations may be of an origin other than ethological, or reflect an active mode of backfill. Buckman (1995) introduced a new ichnospecies *P. crenulatus* based on material from the Carboniferous of northwest Ireland and the Jurassic of Greenland, for continuously annulated forms of *Palaeophycus* with distinct wall lining.

At least three more ichnospecies of *Palaeophycus* were introduced later. Hofmann (1983) established *P. ferrovittatus* for thickly walled burrows with an iron oxide axis. Walter and Elphinstone (in Walter *et al.*, 1989) introduced *Palaeophycus canalis*, which is similar to *P. striatus* but instead of striae has 1-4 longitudinal canals. Nevertheless, it displays striations

on some parts where canals are absent. Pemberton and Frey (1982) included the ichnogenus *Fucusopsis Pabilin* (in Vassoevich, 1932) as part of the ichnogenus *Palaeophycus* and considered *F. angulatus* as a synonym of *P. sulcatus*. Crimes and McCall (1995) reported a specimen from Miocene sediments of Makran Range, Iran which is similar to material described by Ksiazkiewicz (1977) as *Fucusopsis angulata*. Crimes and McCall (1995) argued that the ornamentation in *F. angulatus* is wrinkle-like rather than thread-like and not continuous but terminates at a short distance to be replaced by other wrinkles. Although they (1995) supported the inclusion of *Fucusopsis* within *Palaeophycus* by Pemberton and Frey (1982), Crimes and McCall retained *Palaeophycus (Fucusopsis) angulata*. The ichnospecies of *Palaeophycus* have briefly been described in Table 7.4 and illustrated in Figure 7.34.

**Table 7.4** - Brief classification of ichnospecies included within *Palaeophycus*.

<b>I - Distinctly lined, smooth walled, unornamented:</b>	
- Thickly walled:	<i>P. heberti</i> (Saporta, 1872)
- Thinly walled	<i>P. tubularis</i> Hall, 1847
- Thickly walled with iron oxide axis	<i>P. ferrovittatus</i> Hofmann, 1983
<b>II - Very thinly lined with longitudinal or transverse ornamentation:</b>	
- continuous parallel striae	<i>P. striatus</i> Hall, 1852
- irregular, anastomosing striae	<i>P. sulcatus</i> (Miller & Dyer, 1878)
- wrinkle-like short striae	<i>P. angulata</i> Pabilin in Vassoevich, 1932
- Alternatively striated and annulated	<i>P. alternatus</i> Pemberton & Frey, 1982
- Transversely annulated	<i>P. annulatus</i> Badwe, 1987
- Transverse annulations	<i>P. annulatus</i> Pickerill & Fillion, 1988 (invalid)
- continuous parallel canals	<i>P. canalis</i> Walter & Elphinstone, 1989
- transverse ribbing	<i>P. serratus</i> McCann, 1993
- Continuously annulated	<i>P. crenulatus</i> Buckman, 1995

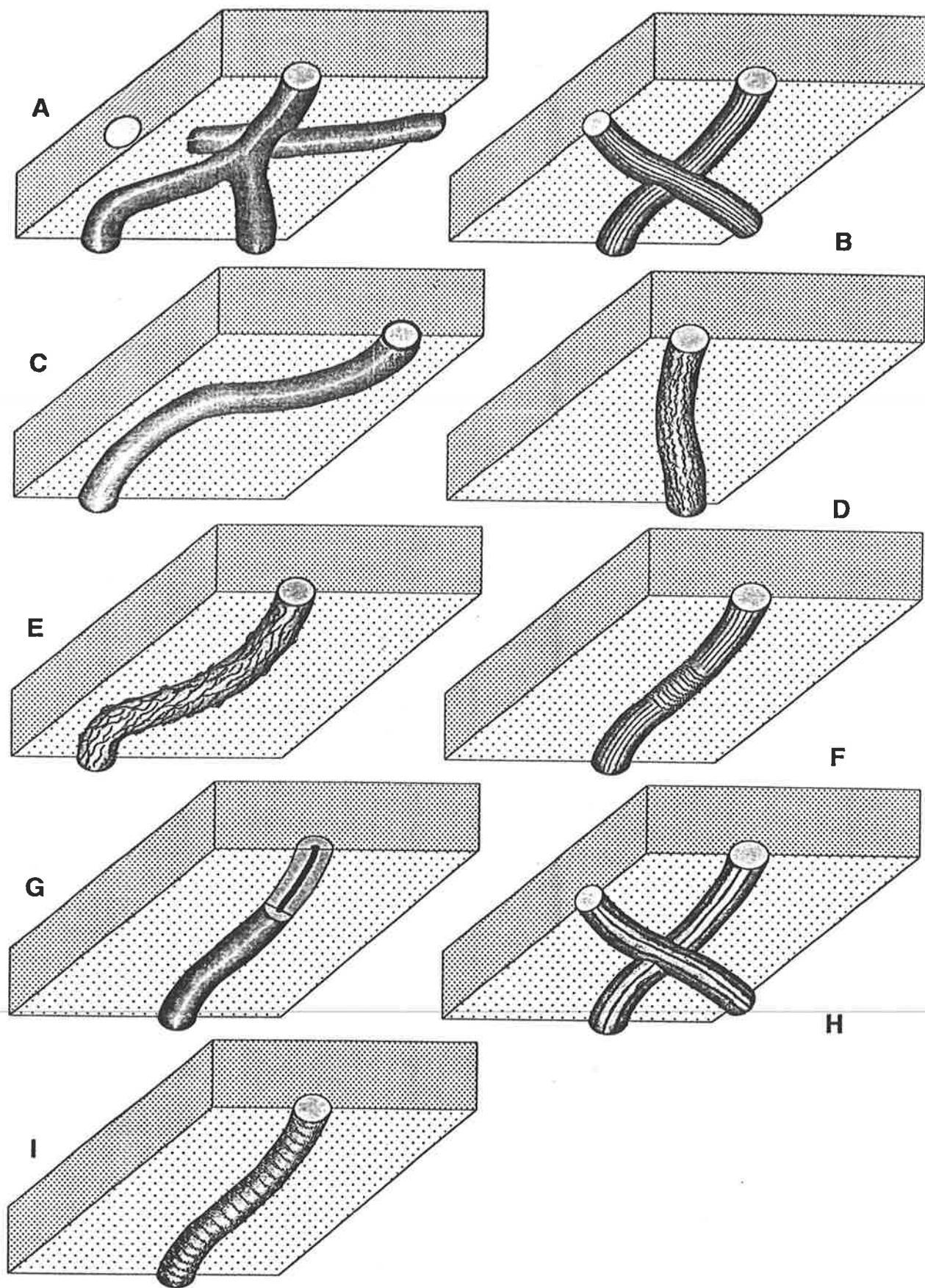


Figure 7.34 - Ichnospecies of *Palaeophycus*: A. *P. tubularis* (after Pemberton and Frey, 1982); B. *P. striatus* (after Pemberton and Frey, 1982); C. *P. heberti* (after Pemberton and Frey, 1982); D. *P. sulcatus* (after Pemberton and Frey, 1982); E. *P. angulata* (after Crimes and MacCall, 1995); F. *P. alternatus* (after Pemberton and Frey, 1982); G. *P. ferrovittatus* (after Hofmann, 1983); H. *P. canalis* (after Walter and Elphinstone, 1989); I. *P. crenulatus* (after Buckman, 1995).

Facies distribution. *Palaeophycus* is considered to be an eurybathic form (Fillion and Pickerill, 1990b).

Age. Latest Precambrian (Narbonne and Hofmann, 1987) to the Pleistocene (D'Alessandro and Bromley, 1986).

*Palaeophycus canalis* Walter and Elphinstone in Walter *et al.*, 1989

Plate 15B

1989 *Palaeophycus canalis* Walter and Elphinstone, p. 234-236, fig. 10A.

Collected specimens. One specimen, A971-3-2.

Description. Gently curved, cylindrical burrows preserved as hyporeliefs on sole of sandstones. Burrows 4-9 mm in diameter and show distinct longitudinal canals. Burrows are subparallel to the bedding and intersect or pass over one another. Some burrows also show branching.

Discussion. Burrows resemble the type material described by Walter *et al.* (1989) from the Arumbera Sandstone (*sensu lato*). However, the canals in described specimen are not necessarily parallel to one another.

Occurrence. Lower Allua Formation, Ross River, Amadeus Basin.

*Palaeophycus ferrovittatus* Hofmann, 1983

Plate 15C

Collected specimens. One specimen, A971-3-7.

Diagnosis. Straight to curved burrow composed of central axis of iron oxide surrounded by a smooth, generally thick pelletal envelope; the contact between axis and envelope has fine sculpture (after Hofmann, 1983).

Description. Straight to curved burrow preserved as endorelief visible on sole of a medium grained sandstone slab 35 mm thick. The burrow comprises a central iron oxide axis dark red

in colour enveloped by a fairly thick wall. The surface of the axis shows very fine ornamentation likely due to subsequent erosion. The wall has partially been eroded exposing the axis which is 3-4 mm wide. Overall, the burrow is 6-8 mm wide, but its elliptical cross section could be due to the subsequent compression of the sediments during diagenesis. There are two similar burrows on the same slab. One shows a longitudinal median joint believed to have formed during weathering and is not a primary structure.

Discussion. Hofmann (1983) reported *P. ferrovittatus* from the Early Cambrian of the Mackenzie Mountains, N.W.T, Canada. It differs from other ichnospecies of *Palaeophycus* in the presence of an iron oxide axis.

Occurrence. Lower Allua Formation, Ross River, Amadeus Basin.

*Palaeophycus sulcatus* (Miller and Dyer, 1878)

Plate 16A, 17A

1995 *P. sulcatus* (Miller and Dyer); Crimes and McCall, p. 241, fig. 4C.

Collected specimens. Four specimens, A971-1-28, A971-1-29, A971-1-31, and A971-1-37.

Diagnosis. *Palaeophycus* which is irregularly subcylindrical, thinly, or rarely thickly lined and ornamented with anastomosing, threadlike striae (after Pemberton and Frey, 1982; Fillion and Pickerill, 1990b).

Description. Straight to curved burrows with anastomosing longitudinal striations. Burrows are 3-8 mm wide and subparallel to bedding. They display a distinct wall 0.5 to 1 mm thick and commonly anastomose. Collapsing occurs commonly along the burrows, indicating they were originally hollow and filled passively by sediments. Some of the material represented herein shows annulations along the burrows visible on inner parts of the lining where it has been eroded.

Discussion. Some of the slabs on which trace fossils are preserved (A971-1-28; A971-1-37) show ripple-marks that indicate a shallow marine environment influenced by waves. There are some circular burrows in association believed to be cross-sections of oblique burrows of *P. sulcatus* made when they entered the sediment at steep angle to the bedding.



Associations. *Skolithos* and *Monocraterion* burrows occur on the same slab with these traces.

Occurrence. Middle Box Hole Formation to Lower Allua Formation, Cyclops Bore, Amadeus Basin.

*Palaeophycus tubularis* Hall, 1847

Plates 13C, 16B-C, 23B

Collected specimens. Eighteen specimens, A971-1-13, A971-1-14, A971-1-19, A971-1-30, A971-1-32A, A971-2-2, A971-2-6, A971-2-12, A971-2-23, A971-2-25, A971-2-28, A971-2-32, A971-2-38, A971-2-43, A971-2-44, A971-3-4, A971-4-3, and A1035-MO115.

Diagnosis. "Smooth, unornamented burrows of variable diameter, thinly but distinctly lined" (Pemberton and Frey, 1982, p. 859).

Description. Branched, gently curved, cylindrical burrows preserved as convex hyporeliefs. Burrows are 4-15 mm in width and frequently intersect and pass over one another. They are subparallel to the bedding plane and display thin but conspicuous lining. Burrows are mostly smooth. However, there are some faint longitudinal striations and transverse annulations on some parts. Branches separate at a wide angle and produce a U-shaped outline. In spite of their size, the branching pattern seems to be alike in all specimens.

Discussion. Pemberton and Frey (1982, p. 853) discussed the nomenclatural history of *Palaeophycus* and concluded that the correct spelling of this ichnospecies is *P. tubularis* rather than *P. tubulare* as mentioned by Miller (1889) and Bassler (1915).

One sample from central Australia (A971-2-47, Pl.2B) shows a small impression of a star-like trace (*Asteriacites*) preserved on the wall of a large *Palaeophycus* burrow. The impression is 5 mm across and is preserved as a convex hyporelief. This indicates that the *Palaeophycus* burrow was originally a hollow subsequently filled passively by sediment. This conclusion is consistent with the hypothesis already accepted by many authors (e.g. Pemberton and Frey, 1982). It also shows that the burrows of *Palaeophycus* were connected to the sea floor. So, the organism responsible for *Asteriacites* was able to enter the hollow

burrow of *Palaeophycus* and used it as a shelter or probably to feed on the organic material trapped on the mucus secreted by the *Palaeophycus* animal. Since the impression was produced within the substrate inside a *Palaeophycus* tube, it had a chance to be preserved.

Occurrence. Ichnospecies occurs Extensively in the Box Hole Formation and lower Allua Formation at Ross River, Cyclops Bore, Hugh River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

### ***Phycodes* Richter, 1850**

For synonymy of the ichnogenus see Osgood, 1970

Type ichnospecies. *P. circinatum* Richter, 1853, p. 30 from the Ordovician "*Phycodes* Beds" of Thuringia by monotypy (Fillion and Pickerill, 1990b).

Emended diagnosis. Bundled burrows with an overall flabellate, reniform, fasciculate or palmate pattern but not radial form, consisting of sub-horizontal burrows branching from almost the same point proximally and divided at acute angles into several free cylindrical to sub-cylindrical burrows. The distal end of burrows may grade into the host rock or may terminate in a reniform structure. Burrows are smooth or may exhibit fine annulation or longitudinal scratch marks. The proximal part of the burrows may exhibit a spreiten structure. The general geometry of the trace displays a significant three dimensional distribution of the burrows juxtaposing each other.

Discussion. As Hantzschel (1975) reported, the morphology of the specimens assigned to this ichnogenus varies considerably and the ichnogenus needs to be reassessed. An emended diagnosis is proposed herein to simplify the complex status of the ichnogenus. The following characteristics are considered to be significant in *Phycodes*;

Geometry of the burrow. Branches in *Phycodes* generally have a three dimensional distribution producing a broad U-shaped structure. This configuration of the burrow in *Phycodes* distinguishes it from other branching burrows which have a planar two-dimensional distribution (e.g. *Oldhamia* Forbes, 1849). *Phycodes* does not include any prominent vertical structures.

**Branching.** In *Phycodes*, burrows diverge from a main, parallel to sub-parallel burrow at an acute angle and may branch off from almost the same point and to curve up into the host rock. The branches produce a variety of patterns but they are not distributed radially through 360°.

**Spreite structure.** Some *Phycodes* may display a spreiten structure often at or close to their proximal part.

**Ornamentation.** Some *Phycodes* may show fine annulations and/or longitudinal striae.

Branching from the same point and general geometry of the burrow are considered to be significant at ichnogenic level. Various ichnospecies of *Phycodes* have been recognised based on their geometry, size, style and degree of branching, presence or absence of spreiten and ornamentation, as listed in Table 7.5 and illustrated in Figure 7.35.

### **Intraspecific variation**

*P. ?initium* Webby, 1970 has been utilised only in the figure caption (Webby, 1970, p.102, fig. 20). It is considered a *nomen nudum* and actually should be referred to *P. ?antecedens* Webby as described in the main text of his paper.

The pattern of branching in *P. coronatum*, *P. pedum*, *P. ?antecedens* and *P. tempulus* differ from that of the other ichnospecies of *Phycodes* in which branches diverge from approximately the same point. *P. antecedens* is larger, but morphologically similar to *P. pedum*, and following Han and Pickerill (1994) is considered to be its junior synonym. *P. pedum* consists of a main burrow with branches generally offset from one side of the burrow. Jensen (1997) found specimens of *P. pedum* grading into *Treptichnus* and considered *P. pedum* to belong to the latter. *P. pedum* is morphologically different from other ichnospecies of *Phycodes* and its exclusion from the ichnogenus *Phycodes* has been recommended (e.g. Osgood, 1970). Following Jensen (1997), it is considered that *P. pedum* is an ichnospecies of *Treptichnus* in this study and is discussed under the latter ichnogenus.

**Table 7.5** - Reported ichnospecies of the ichnogenus *Phycodes*.

<i>P. harlani</i>	Hall	1843	= <i>Arthropycus harlani</i> following Osgood (1970)
<i>P. palmatus</i>	Hall	1852	A <i>Phycodes</i> with palmate arrangement of branches
<i>P. circinatus</i>	Richter	1853	Circular burrow with vertical shafts branched from outer side of the burrow
<i>P. flabellum</i>	Miller & Dyer	1878	Small flabellate-shaped <i>Phycodes</i>
<i>P. pedum</i>	Seilacher	1955	= <i>Treptichnus pedum</i>
<i>P. gregarius</i>	Chiplonkar & Badwe	1969	<i>nomen dubium</i> according to Han & Pickerill (1994) who considered it to be ? <i>P. circinatus</i>
<i>P. antecedens</i>	Webby	1970	= <i>Treptichnus pedum</i>
<i>P. initium</i>	Webby	1970	<i>nomen nudum</i>
<i>P. reniforme</i>	Hofmann	1979	<i>Phycodes</i> in which branches terminate into reniform structures
<i>P. curvipalmatus</i>	Pollard	1981	Cylindrical burrows with dichotomous or palmate branches which curve upward
<i>P. coronatum</i>	Crimes & Anderson	1985	Circular burrows with vertical shafts branching from the outer side of the main burrow
<i>P. auduni</i>	Dam	1990	Infaunal bundled burrows branched from a centre point
<i>P. bromleyi</i>	Dam	1990	Infaunal bundled burrows arranged in flabellate pattern with short annulated tunnels
<i>P. ungolatus</i>	Fillion and Pickerill	1990	A proximal tube distally bifurcated to short cylindrical branches that abruptly angle upward
<i>P. wabanensis</i>	Fillion and Pickerill	1990	<i>Phycodes</i> in which a master tunnel branches at a very acute angle to form a broom-like burrow
<i>P. tempulus</i>	Han and Pickerill	1994	Displays interconnected bundled sets

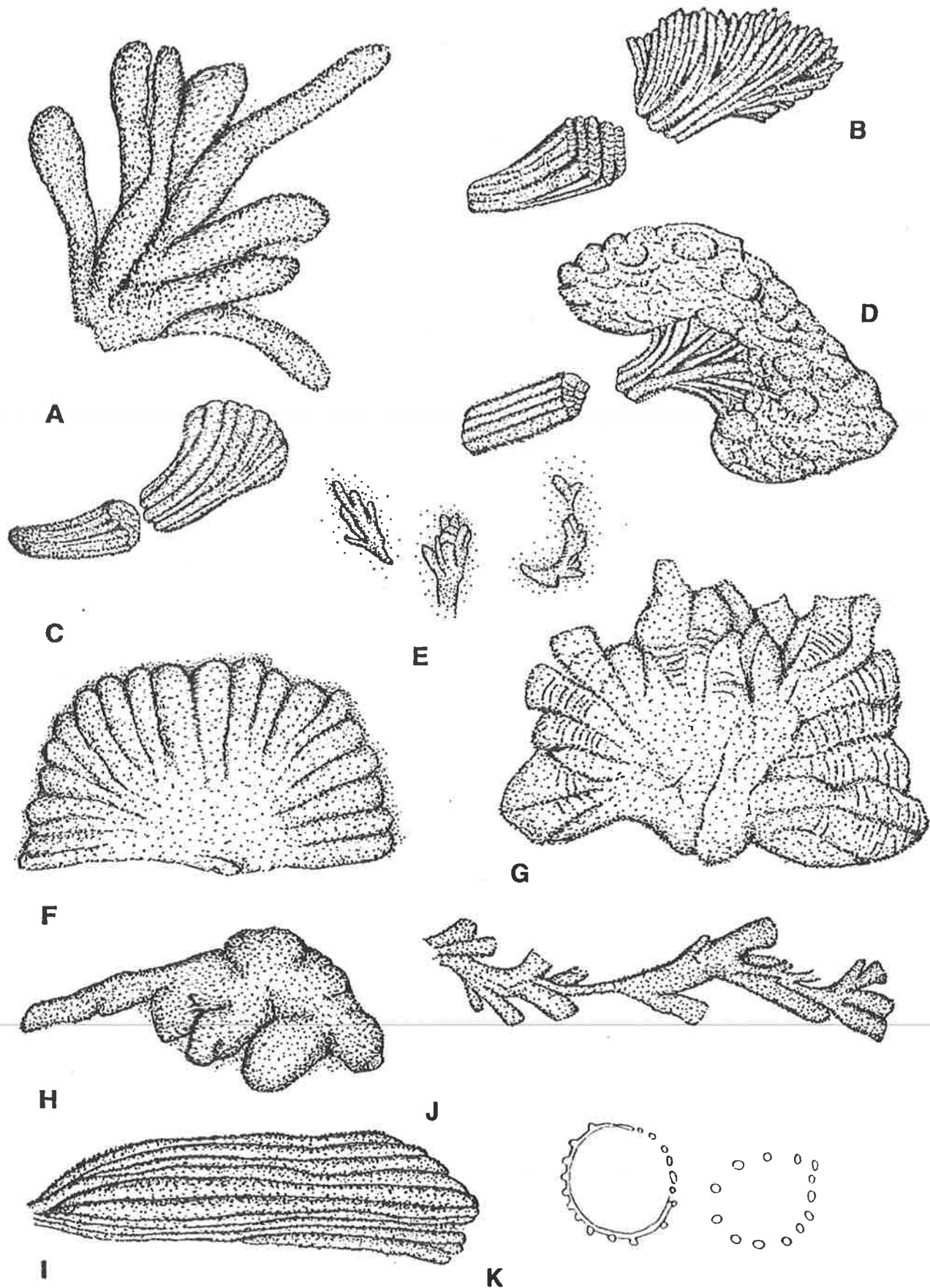


Figure 7.35 - Ichnospecies of *Phycodes*: A. *P. palmatus* (after Han and Pickerill, 1994), B. *P. circinatus* (after Seilacher, 1995); C. *P. flabellum* (after Osgood, 1970); D. *P. reniforme* (after Hofmann, 1979); E. *P. curvipalmatus* (after Pollard, 1981); F. *P. auduni* (after Dam, 1990); G. *P. bromleyi* (after Dam, 1990); H. *P. unguolata* (after Fillion and Pickerill, 1990); I. *P. wabanensis* (after Fillion and Pickerill, 1990); J. *P. tempulus* (after Han and Pickerill, 1994); K. *P. coronatum* (after Crimes and Anderson, 1985).

*P. coronatum* consists of a circular burrow with vertical shafts branching from the outer side of the main burrow. This contradicts the original diagnosis of *Phycodes*. Its geometry is morphologically similar to that of *Treptichnus* (*Phycodes*) *pedum* or even ichnogenus *Hormosiroidea* which comprises a main horizontal tunnel with vertical shafts branched from the roof of the tunnel. *P. coronatum* could be attributed to the ichnogenus *Hormosiroidea* or *Treptichnus*. However, if the circular course of the burrow is considered to be more important than the other characteristics, *P. coronatum* should be assigned to a new ichnogenus.

*P. tempulus* is more complex and possesses two or more horizontally interconnected broom-like or flabellate bundles. Each bundle set consists of 3 to 7 straight to slightly curved burrows (Han and Pickerill, 1994). Individual bundle sets are morphologically similar to *P. curvipalmatus*. However, the latter is larger in size and possesses straight branches widening distally. Although the general morphology of *P. tempulus* differs from other ichnospecies of *Phycodes*, each individual bundle set fulfils the diagnosis for *Phycodes*. *P. tempulus* is thus validly assigned to the ichnogenus.

Dam (1990) tentatively assigned *P. bromleyi* and *P. auduni* to *Phycodes* and suggested that probably a new ichnogenus should be established to accommodate a flabelliform burrow with a distinct central "radiation point".

Seilacher (1955) regarded *Arthropycus* Hall, 1852 as a junior synonym of *Phycodes*. Most subsequent authors (e.g. Hantzschel, 1962, 1975; Osgood, 1970; Pickerill *et al.*, 1991; Han and Pickerill, 1994) retain these two ichnotaxa. Thus *P. harlani* (Hall, 1843) should more appropriately be regarded as *A. harlani* Hall, 1852 which was considered by Hantzschel (1975) as the nomenclatural type.

Interpretation of the burrow. *Phycodes* is considered to be a fodinichnia where the organism systematically mined a nutrient-rich layer along a silt-mud interface (Seilacher, 1955; Osgood, 1970). The animal first burrowed down through the silt, then moved horizontally along the interface, before withdrawing from the distal portion of the burrow. It repeated the action to produce a new burrow adjacent to the old one. When a given area was mined out, the organism moved to a new location and repeated the action to produce a new burrow set.

Originator. Although, the producer is generally considered to be a worm-like organism (Hantzschel, 1975, p. W94, Dam, 1990, p. 140) as pointed out by Osgood (1970, p. 343), different organisms are capable of producing *Phycodes*-like burrows. Bradley (1980, 1981) suggested sea-pens as a probable producer, But the material which he assigned to the *Phycodes* is not exactly consistent with the description given for this ichnogenus in the literature. Bradley's specimens do not have a U-shaped outline open directly to sea floor at least from one end and branches are not divergent from the same point. Hence, it seems unlikely that sea-pens were the producers of *Phycodes*.

Facies distribution. *Phycodes* is commonly reported from shallow-water environments and was previously thought to be a reliable indicator of such conditions. It also has been recorded from brackish (Hakes, 1985) and deep-water (Narbonne, 1984) deposits.

Age. Earliest Cambrian *Treptichnus (Phycodes) pedum* Zone (Narbonne *et al.*, 1987) to the ?Miocene (Bradley, 1981).

*Phycodes coronatum* Crimes and Anderson, 1985

Plate 11C

1985 *Phycodes coronatum* Crimes and Anderson, p. 329, figs 10.5, 10.6, 11.

Collected specimens. One specimen, A1035-MO153.

Diagnosis. "Burrow circular, parallel to bedding with vertical branches from outer margin of the circle" (after Crimes and Anderson, 1985).

Description. A circular to oval burrow 1.5 mm wide including 14-16 knobs. Knobs are generally located on the outer side of the circle. The diameter of the complete system is 30 mm. The burrow has been preserved as convex hyporelief on the sole of the bed. There is another partially preserved specimen of similar structure on the same slab. Knobs are interpreted to represent bedding plane preservation of vertical shafts (Fig. 7.36B).

Discussion. *P. coronatum* differs from other species of *Phycodes* mostly in its circular course. Two different preservational variations of the burrow system have been illustrated by Crimes and Anderson (1985, fig. 11). The first is an array of small knobs arranged in a

circular pattern and the second is a circular burrow connecting a series of knobs located on its outer margin. *P. coronatum* is similar to the *Treptichnus* (*Phycodes*) *pedum* but differs from the rest of *Phycodes*' ichnospecies. Other than for its circular course, it is also similar to the ichnogenus *Hormosiroidea*. Since *T. pedum* has been transferred from the ichnogenus *Phycodes* into the ichnogenus *Treptichnus* (Jensen, 1997) and *P. coronatum* is more similar to the *T. pedum*, it is suggested that *P. coronatum* also be assigned to the ichnogenus *Treptichnus*.

Interpretation. In *P. coronatum* the organism moved in a circular path, so probably the burrow was not excavated just for feeding purposes and likely it acted as a domicile and belongs to the domichnia or even agrichnia (such as network of *Paleodictyon* Meneghini in Murchison, 1850) rather than the fodinichnia. *P. coronatum* is morphologically comparable to *P. pedum*, but the burrow does not make a complete circle, and in the latter the vertical shafts branch off below and twist around beneath burrow.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

*Phycodes* cf. *curvipalmatus* Pollard, 1981

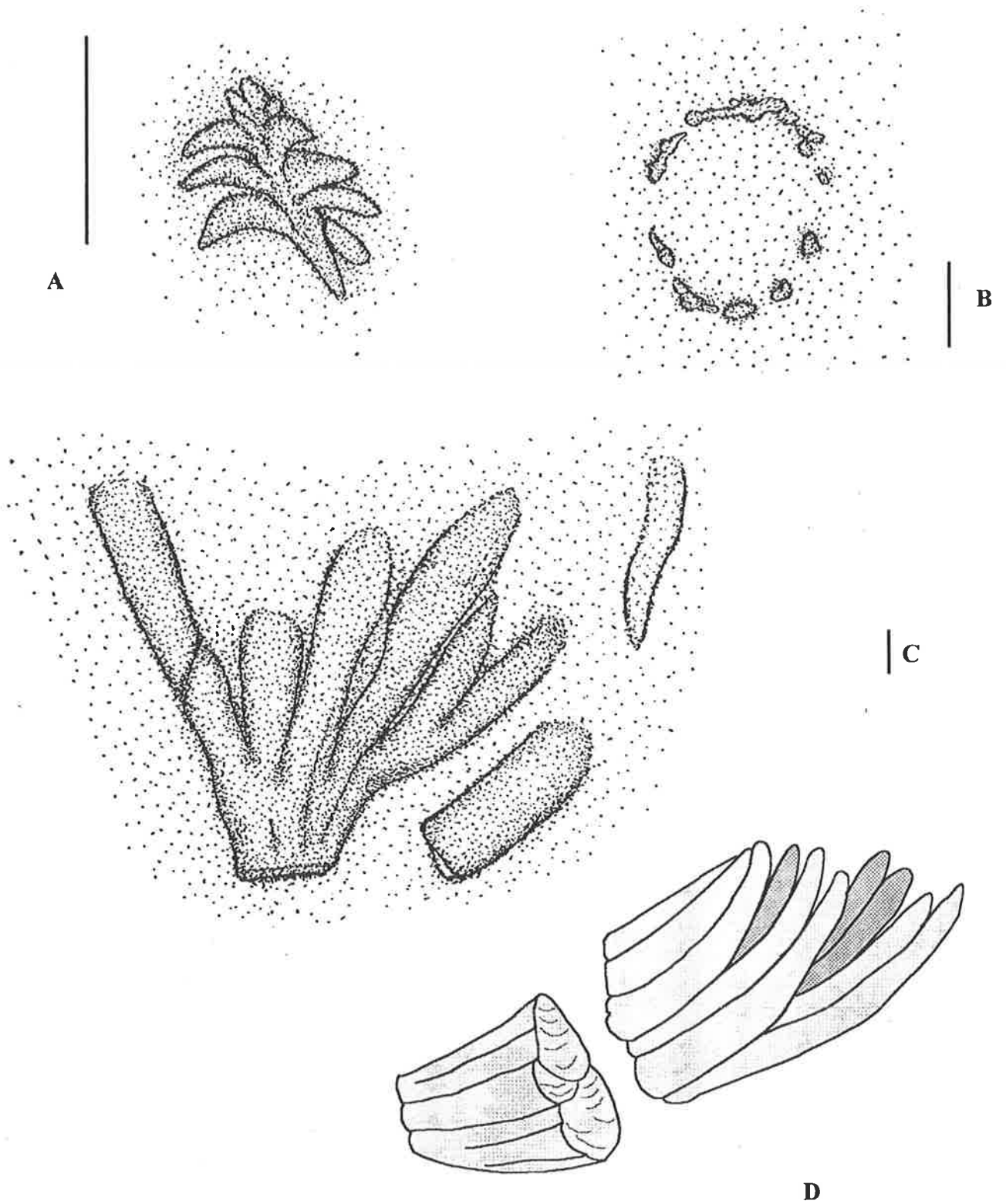
Plate 15E

Collected specimens. One specimen, A1035-MO38.

Description. Endogenic full relief small burrow observed as a convex hyporelief. It consists of about 10 distally tapering branches diverging from main burrow on both sides in a Christmas-tree pattern. The burrow decreases in dimension toward its preserved distal part. Branches which are close to the main burrow, display a curvature towards the preserved proximal part (Fig. 7.36A). The burrow system is 9 mm long and 6 mm wide with individual branches up to 1.5 mm in width. There is no ornamentation visible.

Remarks. Though the writer's knowledge about the Latin grammar is poor but according to the etymological discussion given for *Phycodes palmatus* by Fillion and Pickerill (1990b, p. 47), *Phycodes curvipalmatum* should be correctly spelt *P. curvipalmatus*.





**Figure 7.36** - Specimens of *Phycodes* from central Australia: **A.** *P. curvipalmatus*; **B.** *P. coronatum*; **C.** *P. palmatus*; **D.** Schematic reconstruction of *P. palmatus*. All specimens are preserved as convex hyporeliefs.

Discussion. According to a description given for *Phycodes* (Hantzschel, 1975) this specimen is convincingly classified under this ichnogenus. Although the branches in *P. curvipalmatus* angle up to 90 from the main burrow, they do not curve back toward the proximal part of the burrow as they do in the present specimen. Nevertheless, the burrow is morphologically similar to the *P. curvipalmatus* and is classified as such.

Occurrence. Donkey Creek beds, Mount Octy, Georgina Basin.

*Phycodes palmatus* Hall, 1852

Plates 15D, 16D, 18A

1970 *Phycodes palmatum* (Hall); Banks, p. 30.

1977 *Phycodes* aff. *palmatum* (Hall); Crimes, Legg, Marcos, Arboleya, p. 121, fig. 5i.

1983 *Phycodes* aff. *palmatum* (Hall); Turner & Benton, p. 455, fig. 4G.

1983 *Phycodes palmatum* (Hall); Shah & Sudan, p. 197, pl. II a, b, c, d.

1984 *Phycodes palmatum* (Hall); Pickerill and Fillion, p. 275

1985 *Phycodes (Buthotrephis) palmatum* (Hall); Crimes & Anderson, p. 330, figs 6.15, 6.17.

1985 *Phycodes (Buthotrephis) palmatum* (Hall); Eagar, *et al.*, p. 142, pl. 10B-a; pl. 13G.

1986 *Buthotrephis palmata* (Hall); Clausen & Vilhjalmsen, p. 53, fig. 3, pl. 1, A-C.

1989 *Phycodes palmatum* (Hall); Orłowski, p. 220, pl. 16-2.

1990 *Phycodes palmatus* (Hall); Fillion and Pickerill, p. 47, pl. 11, figs 11, 14.

Collected specimens. Four specimens, A971-1-9, A971-2-16, A971-2-17 and A1035-MO78.

Diagnosis. *Phycodes* branching in a palmate form with thick and rounded branches diverging from nearly the same point (After Osgood, 1970; Fillion and Pickerill, 1990b).

Description. A series of cylindrical, oblate burrows radiating endichnially in a palmate pattern and sub-parallel to bedding. Burrow diameter varies from 4-10 mm. The width varies slightly along a given burrow. Burrows diverge from approximately the same point decreasing in height towards their distal end and grade into the sandstone at an acute angle. Some burrows exhibit fine longitudinal scratch marks (Pl. 18a). In almost all samples only the distal part of the burrows has been preserved completely and the proximal section has been eroded. The broken proximal part does not show spreiten structure. Burrows occur at

different levels vertically and clearly demonstrate a three-dimensional distribution (Figs 7.36C-D).

Discussion. Seilacher (1955) assigned *Buthotrephis palmata* Hall (1852) to *Phycodes* as *P. palmatum*. Fillion and Pickerill (1990b) argued that according to Latin grammar the correct form is *P. palmatus*. Although Osgood (1970, p. 342) agreed that *B. palmata* differs from other ichnospecies of *Buthotrephis* figured by Hall (1847, 1852) (Osgood, 1970, considered that they are all Chondritids), he questioned its designation to *Phycodes*.

Osgood (1970) pointed out that the type species of *Phycodes* is different from *B. palmata*, with the branches more abundant, rougher and smaller. The branches in *B. palmata* are up to 20 mm in diameter. While Crimes *et al.* (1977, p. 121) found the similarities sufficient to place *Buthotrephis* in synonymy with *Phycodes*, Clausen and Vilhjalmsen (1986, p. 53) suggested the retention of *B. palmata*.

Fillion and Pickerill (1990a) discussed this issue comprehensively. Originally, five ichnospecies had been included by Hall (1847) within the ichnogenus *Buthotrephis*, namely, *B. antiquata*, *B. gracilis*, *B. succulens*, *B. flexuosa*, and *B. subnodosa*, all of which can be assigned to *Chondrites* (e.g. Osgood, 1970). Fillion and Pickerill (1990a) believed that no matter which of the original five ichnospecies is regarded as its type for the ichnogenus, *Buthotrephis* was a junior synonym of *Chondrites*. When Hall (1852) erected *B. ramosa*, *B. impudica* and *B. palmata* the name *Buthotrephis*, although available, was already in synonymy. They also reported that specimens illustrated by Hall (1852) as *B. palmata* are discordant in nature. Some exhibit branches diverging from nearly the same point, a typical characteristic of *Phycodes*. Others show branches that separate at different distances from the base, a character clearly referable to *Chondrites*. The third figure (Hall, 1852, pl. VII, fig. 1b) displays several species of doubtful affinity (Fillion and Pickerill, 1990a, p. 346). Since both *Chondrites* and *Phycodes* are older than *Buthotrephis*, Fillion and Pickerill (1990a) regarded *Buthotrephis* as a *taxon rejectum*.

Fillion and Pickerill (1990a, b) included Hall's specimens resembling *Phycodes* within this ichnogenus. Although Fillion and Pickerill (1990a) considered *Phycodes palmatus* to be valid, and distinguishable by its incipient 'spreite' and the characteristic palmate pattern, they considered that Seilacher's material is not consistent with specimens typically assigned to

this ichnospecies. It displays a more complex burrow system with well defined 'spreite' and clearly is not a *P. palmatus*. Thus, they informally erected a new ichnospecies, *P. wabanensis* to accommodate Seilacher's material from Pakistan and similar burrows found in the Early Ordovician of Bell Island, eastern Newfoundland, Canada. Fillion and Pickerill (1990b) formally published *P. wabanensis* as a new ichnospecies.

A re-examination of Hall's material of *Buthotrephis* has been suggested by many authors (Osgood, 1970; Crimes *et al.*, 1977; Clausen and Vilhjalmsen, 1986).

Occurrence. The Box Hole Formation and lower Allua Formation, Ross River, Cyclops Bore, and Hugh River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

### *Plagiogmus* Roedel, 1929

Type ichnospecies. *Plagiogmus arcuatus* Roedel, 1929 by subsequent designation of Hantzschel (1962, p. W210).

Emended Diagnosis. A burrow consisting of three components: a concave, smooth, straight to curved lower part with transverse ridges, not extending to the margin, with or without marginal bevels; a transversely laminated, back-filled middle part, oval in cross section with convex downward, arch shaped, oblique laminae; and a convex bilobate upper part with a straight to sinuous median furrow.

Discussion. The ichnogenus *Plagiogmus* (Roedel, 1929) is reported worldwide by many authors (e.g. Roedel, 1929; Glaessner, 1969; Walter *et al.*, 1989). A ladder-like trace fossil with transverse ridges from a glacial erratic found near Roholla in Glomminge on Oland, Sweden was described by Nathorst (1897) as an epichnial groove. Another specimen collected by Gerhard Holm at Storo Ror in Hogsrum was figured by Høgbom (1925, fig. 3: cited by Jaeger and Martinsson, 1980). Roedel (1926, 1929) reported further erratics with the same trace fossil which he regarded as a polychaete locomotion trail. Roedel introduced the generic name *Plagiogmus* for the trail which showed furrow-like interspaces identified as the suction marks made by an animal during its movement (Roedel 1929, p. 51).

The genus was defined as comprising two species; *P. simplex*, and *P. arcuatus* characterised by arcuate lines on the transversal furrows. Hantzschel (1962, P. W210) followed up the nomenclatural formalities by designating *P. arcuatus* as the type ichnospecies.

*Plagiogmus* was described from the basal Cambrian sediments of South Australia by Glaessner (1969). He showed that it was an endichnial burrow and not an epichnial groove as previously supposed (Glaessner 1969, p. 385). Kowalski (1978) established a new ichnospecies for samples collected from the Swietokrzyskie Mountains, Poland, analysing the number of transverse ridges along a five centimetre long trace. His study classified the traces as three different kinds;

- A- Number of ridges less than 10;
- B- Number of ridges between 10 and 16;
- C- Number of ridges more than 16.

The traces from group B were assigned to *Plagiogmus arcuatus*. He also established a new ichnogeneric name *Arcuatichnus wimani* for group A. Subsequent studies suggest that the number of ridges is variable and hence inappropriate as an ichnogeneric characteristic.

Jaeger and Martinsson (1980, pl.126) found examples of *Plagiogmus* with both dorsal and ventral parts and gave a new generic diagnosis. Well preserved specimens of *Plagiogmus* found in central Australia (Walter *et al.*, 1989; McIlroy and Heys, 1997; this study) showed *Plagiogmus* had three components; a ladder-like basal part, a middle back-filled part and a bilobed part on top. These are assigned to different ichnotaxa in the literature, a problem discussed later.

The ichnogenus *Plagiogmus* has been compared to many other traces by different authors. Glaessner (1969) compared it with *Climatichnites* Logan, 1860; *Scolicia* de Quatrefages, 1849; *Olivellites* Fenton and Fenton, 1937b and *Psammichnites* Torell, 1870. *Plagiogmus* clearly differs from *Climatichnites* in its size, shape and the arrangement of ridges. It also differs from *Scolicia* in the form of the transverse ridges and the nature of the axial zone (Kowalski, 1978). *Plagiogmus* is similar to the Precambrian putative ichnogenus *Bunyerichnus* (see Glaessner 1969), differing in the presence of an axial ridge as well as in the development of the marginal zone with ridges not reaching the margins of the trail. The biogenicity of *Bunyerichnus* has also been questioned (Jenkins *et al.*, 1983). Glaessner

(1969) first described the backfill in *Plagiogmus* specimens collected in the Early Cambrian Parachilna Formation in South Australia

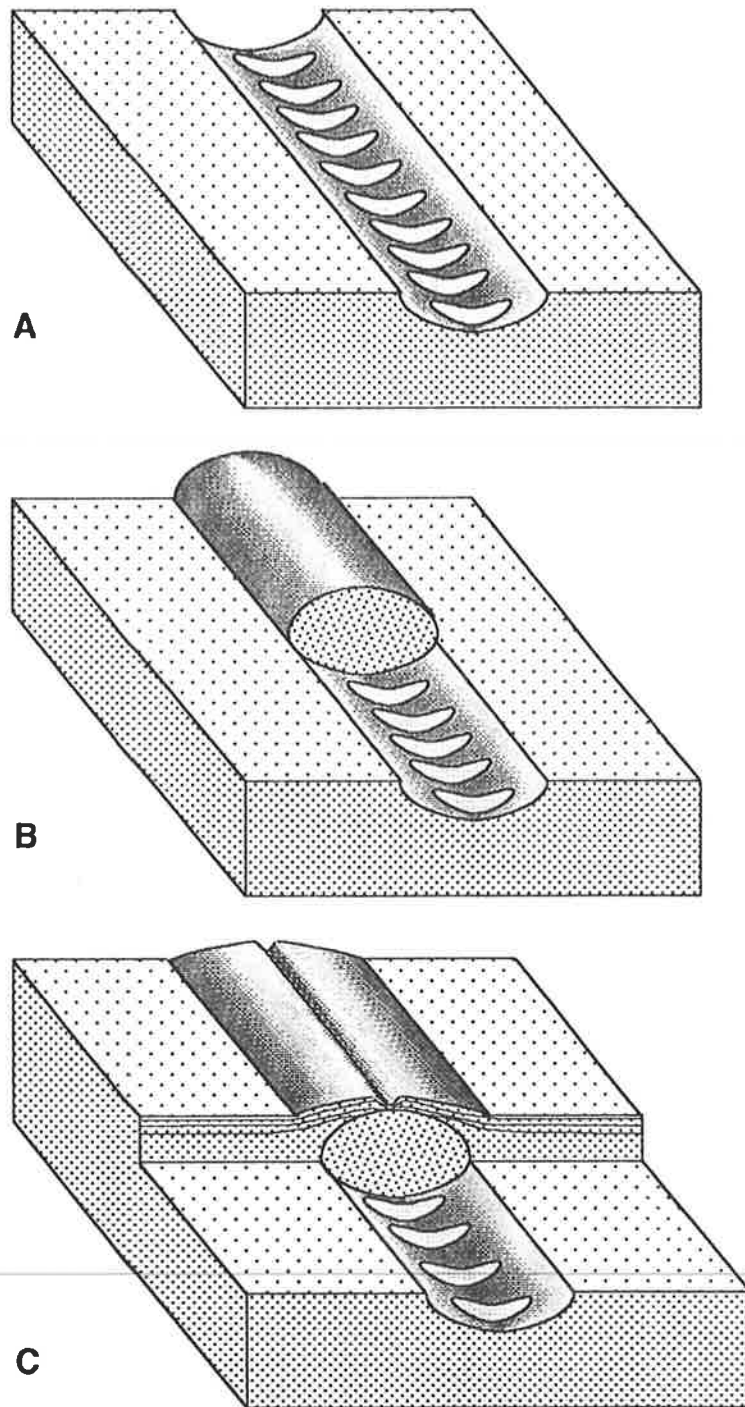
The relationship between *Plagiogmus*, *Aulichnites* and *Psammichnites* is confusing. This is discussed under the ichnogenus *Psammichnites*. It is suggested that the occurrence of transverse ridges on the basal part of the burrow (ladder-like structure) should be considered significant as an ichnogenic characteristic useful for distinguishing *Plagiogmus* from other similar burrows. Accordingly, all following preservational forms have been assigned to *Plagiogmus* in this study (Fig. 7.37):

- Burrows preserved as concave epireliefs with transverse ridges which do not reach the margins of the burrow. Burrows may display lateral bevels.
- Large unilobate burrows which may show transverse backfilled laminae and overlie a concave burrow with transverse ridges.
- Large burrows with bilobate upper surface covering a unilobate transverse backfilled laminae and overlying a concave burrow displaying transverse ridges.

***Plagiogmus arcuatus* Roedel 1929**

Plates 17B-D, 18B-C, 19A-C, E-F

- 1897 "Spar" Nathorst, PP. 361-365.
- 1925 "Fossil" Hogbom, pp. 220-221, fig. 3.
- 1926 "Problematischen Spuren" Roedel, pp. 22-26, text-fig.
- 1929 *Plagiogmus simplex* Roedel, pp. 48-52.
- 1929 *Plagiogmus arcuatus* Roedel p. 49.
- 1962 *P. arcuatus* Roedel; Hantzschel, p. W210, fig. 128,6.
- 1969 *Plagiogmus arcuatus* Roedel; Glaessner, pp. 383, 385-390, figs 7a-h.
- 1970 *Plagiogmus* isp.; Banks, p. 30, pl. 3a.
- 1970 *Plagiogmus* isp.; Cowie and Spencer, pp. 96, 98, pl. 1b, 2g.
- 1973 *Plagiogmus* isp.; Cloud and Bever, pp. 884-885, figs 1-4.
- 1973 *Plagiogmus* cf. *arcuatus*; Cloud and Bever, pp. 884-885, figs 1-4.
- 1974 *Plagiogmus arcuatus* Roedel; Peterson and Clark, pp. 767-768.
- 1974 *Plagiogmus*; Wyatt, p. 170



**Figure 7.37** - Preservational modes of *Plagiogmus arcuatus*: **A.** Basal ladder-like burrow; **B.** Middle backfilled part overlying the basal ladder-like burrow; **C.** Bilobate upper part lying on both the middle back-filled and basal ladder-like parts. All forms display the distinctive ladder-like transverse ridges on their basal part.

- 1975 *P. arcuatus* Roedel; Hantzschel, p. W95, fig. 59, 4b.  
non 1977 *Plagiogmus* isp.; Crimes *et al.*, pp. 122, 124, pls 7c, 8f.  
1978 *Arcuatichnus wimani* Kowalski, p. 339-344, pl. I figs 1-3  
1978 *Plagiogmus* isp. Kowalski, p.337.  
1980 *Plagiogmus* isp., Jaeger and Martinsson, p. 117-126, figs 1-6.  
1980 *Plagiogmus* isp., Kruse and West, p. 168, fig. 4.  
1985 *Plagiogmus* isp., Fritz and Crimes, p. 15, pl. 5, fig. 2.  
1989 *Plagiogmus arcuatus* Roedel; Walter *et al.*, p. 237-239, fig. 11a-f.  
1997 *Plagiogmus arcuatus* Roedel; McIlroy and Hays, figs 1-7.

Collected specimens. Seven specimens, A971-1-36, A971-2-10, A971-2-35, A971-2-36, A971-2-46, A1035-MO23, and A1035-MO61A.

Diagnosis. As for the ichnogenus.

Description. *Plagiogmus* consists of three distinct parts; a ladder-like trail at the base, a central back-filled burrow, and a large bilobed part at the top. These parts are discussed below.

### **Morphological analysis of the ichnogenus *Plagiogmus***

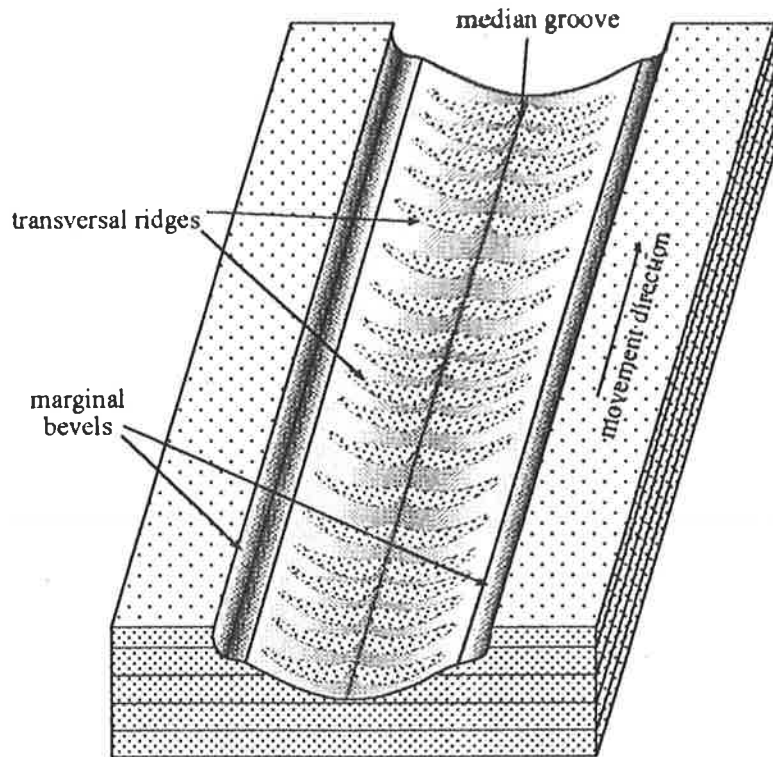
#### **Ladder-like trail**

This part is preserved as concave, straight to gently curved burrows which intersect and overlap one another. The trail is about 16-20 mm wide, 5 mm deep and comprises the following structures (Fig. 7.38):

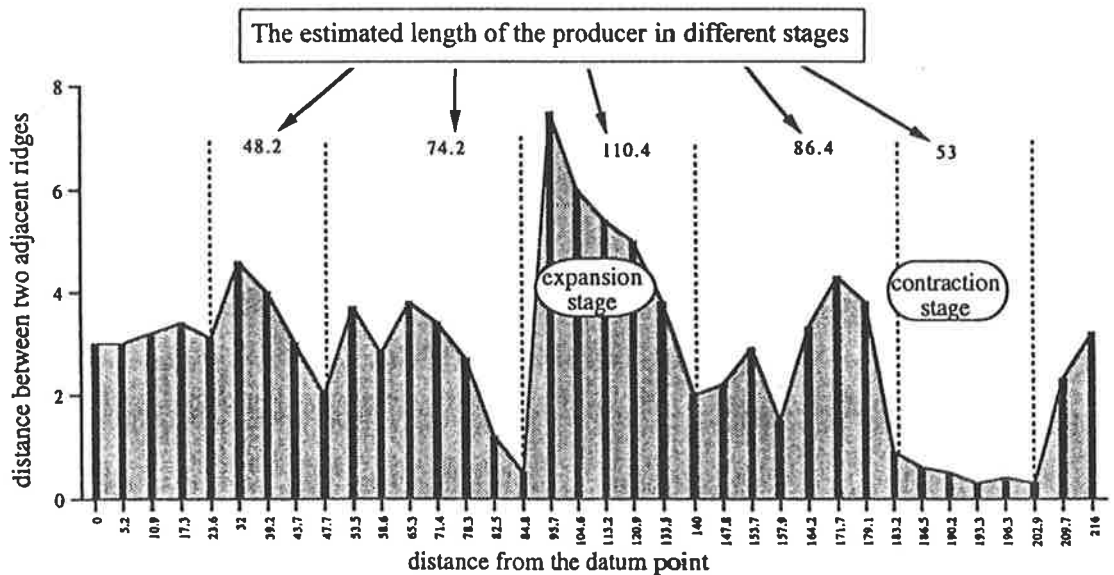
Marginal bevel. There are bevels at both margins of the trail with their inner edge about 2-3 mm lower than their outer edge. Transverse ridges of the middle part never reach the bevels.

Ladder-like structure. This part is located between the two marginal bevels (if bevels are present). It is concave and comprises transverse ridges which are separated from the edges by a smooth rim. Sometimes the ends of transverse ridges have been tapered or even bent. Figure 7.39 shows a graph displaying a patterned change of spacing between sequential ridges suggesting longitudinal constriction and expansion along the body of the producer animal likely indicative of peristaltic movement. In some specimens transverse ridges





**Figure 7.38** - *Plagiogmus arcuatus*, showing morphological elements of the basal ladder-like structure.



**Figure 7.39** - Diagram showing the spacing between successive transverse ridges and their distance from an arbitrary datum point. The rhythmic variation probably is due to the peristaltic movement of the trace maker (Data from specimen illustrated in the Plate 18C).

overlap one another or are flattened (Pl. 18B). The area where the transverse ridges are located is smooth and has no ornamentation. The width of the transverse ridges is not constant and changes from 1 to 7 mm in some specimens and their thickness is less than 1 mm. Their shape is not everywhere the same but in general they are straight to arcuate with tapering ends which are firmly attached to the base of the trail.

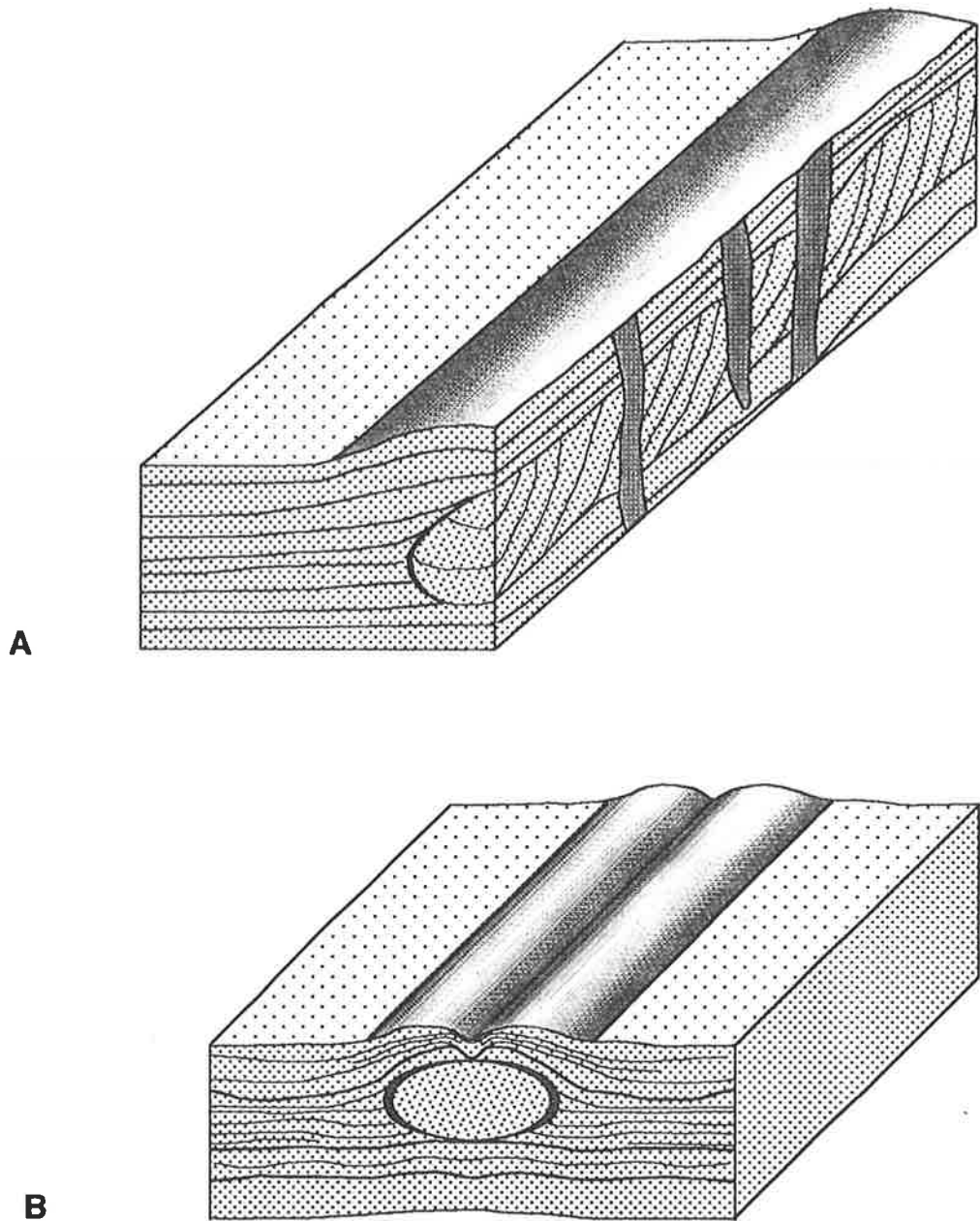
Median groove. There is a longitudinal groove in the middle of the trail in some specimens (e.g. Pl. 18B). It may cut the transverse ridges and the area between them, but often it just cuts through the transverse ridges. Where this happens it cuts one side of the ridges more than the other and bends the ridges where they are truncated. This likely shows the movement direction of the originator.

Longitudinal ripples. There are longitudinal ripples along the trail in some specimens (Pl. 18C), especially where the trail turns.

Transverse ripples. There are also weak arcuate annulations 3 to 6 mm wide and 2-4 mm apart on which the transverse ridges are superimposed. This characteristic is not clear on the present material but is well shown in a specimen figured by Glaessner (1969, fig. 7G).

#### Middle back-filled burrow

This part is located on the ladder-like base and it is up to 22 mm wide, 8 mm thick and elliptical in cross section. It consists of fine oblique laminae which are sigmoidal in shape and not related to the transverse ridges on the basal ladder-like trail. Spacing between laminae is variable. Laminae are much more visible in weathered specimens which do not show an upper bilobed part. In one specimen, (A971-2-46) the middle part has a marginal rim which is distinguished by a different colour (Fig. 7.40A). This rim is thicker at its lateral sides possibly because of compaction during diagenesis which is also likely to be responsible for the general ovate shape of the middle part. In some specimens (e.g. A1035-R5), the middle part is glauconite rich in comparison to the host rock. Glauconite grains are aligned along the oblique backfilled laminae (Fig. 7.40B).



**Figure 7.40** - Cross sections through *Plagiogmus arcuatus*: **A.** A longitudinal cross section through middle part of the burrow displays glauconite grains aligned along oblique laminae. The burrow has been penetrated by several vertical burrows; **B.** A transverse section. The upper bilobate part is deflected sediment laminae cut through by an organ of the producer. Note the marginal rim along the middle part is thicker on both sides likely due to subsequent compaction.

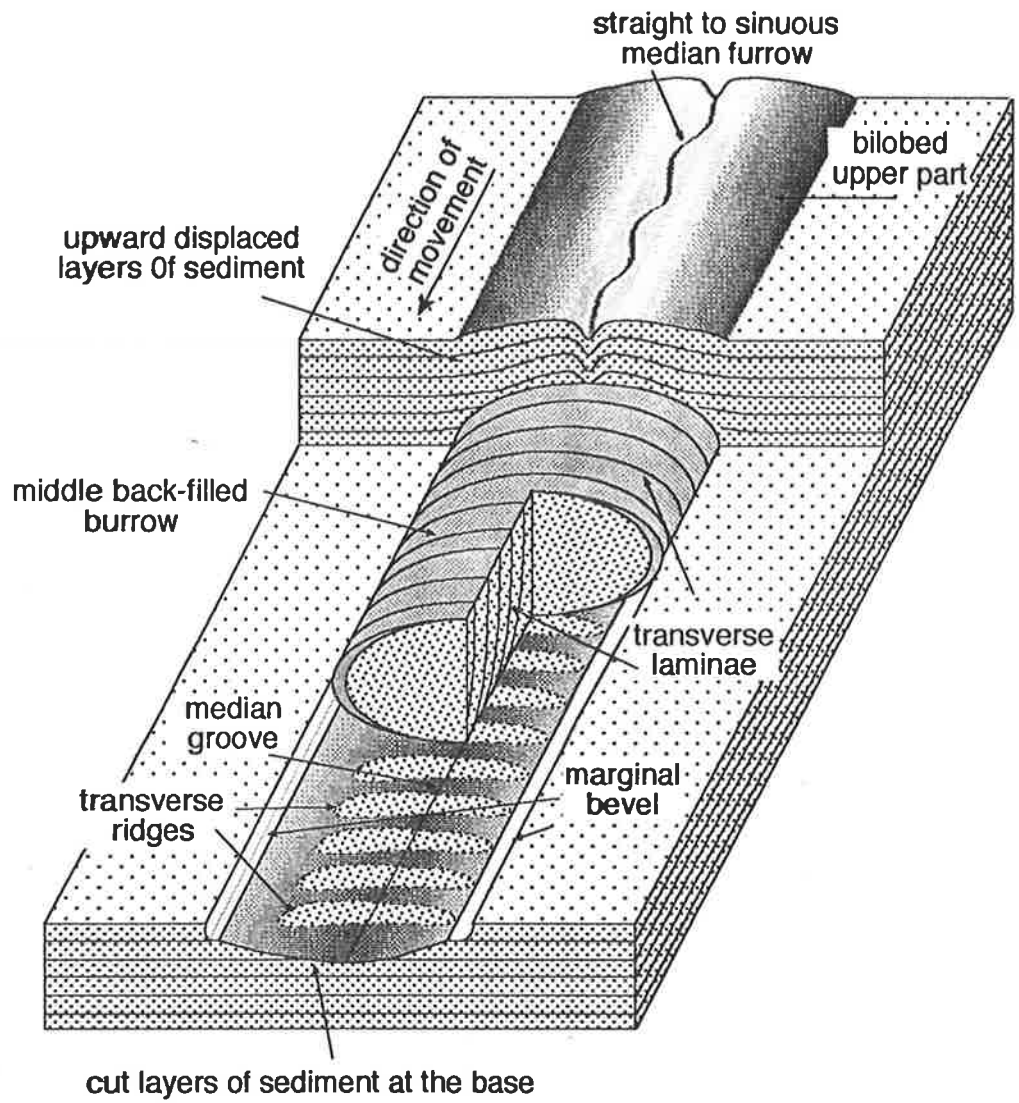
### Bilobate upper part

This part is straight to gently curved, large and bilobed about 20-25 mm wide and preserved in convex epirelief. There is a furrow in the middle. This furrow is fairly deep in some specimens to very shallow in others. The furrow is straight to curved or even sinuous (Pl. 19A). It is noteworthy that the median furrow shape does not follow the burrow's general shape and even when the median groove is strongly sinuous the edges of the burrow are straight or swell slightly. The width of the bilobate part is nearly constant along a single specimen. In one specimen (Pl. 19B) the width of the burrow changes in a regular manner which suggests a probable peristaltic movement along the body of the originator. Sometimes the two lobes of this part are located at different levels and the oblique laminae of the middle part are visible at its sides. The bilobed part does not surround the middle back-filled part of the burrow and is just a cover of sediment as is shown in the cross section (Fig. 7.37A).

*Plagiogmus* is generally an endichnial burrow, as mentioned by Glaessner (1969). However, while the burrow producer could probably move freely through sediments, it moved nearly horizontally at all times and never changed its direction to a steep angle. So far no oblique burrows of this kind have been recorded. Figure 7.41 shows a three-dimensional reconstruction of the burrow.

Interpretation. The ichnogenus *Plagiogmus* is assigned to different kinds of animals such as molluscs (Glaessner, 1969) or an annelid (McIlroy and Hays, 1997). According to the following facts which are decipherable from the trace one can schematically reconstruct the producer outline:

- The transverse ridges and fine oblique laminae from the middle part are separate rather than related to each other. Their spacing was effected by the locomotive style of the producer. This was mentioned by McIlroy and Hays (1997) as well.
- The transverse ridges are generally arcuate and are considered to be animal faeces excreted from an slit-like anus. McIlroy and Hays (1997) suggested that the transverse ridges were formed by a slit-like sucker used by the animal to anchor itself during locomotion. This interpretation was also mentioned by Roedel (1929, p. 51).



**Figure 7.41** - A three dimensional reconstruction of *Plagiogmus arcuatus* showing different morphological elements.

- If an imaginary horizontal plane considered to pass through middle of the burrow, the sediment laminae above this plane were pushed upward by the originator of *Plagiogmus* and the sediments below this plane were cut through as it is shown in the cross section. Likely the animal's mouth was located in the lower side of the body and the *Plagiogmus*-maker just cut through the sediments of the lower side and pushed the upper laminae upward during its movement. So it is likely to have a tough skin on its back.
- The marginal bevels lateral to the ladder-like part have been produced by a tough object such as a primitive shell or very tough skin which covered the back of the animal, and had distinct edges which could cut sediment. This opinion is incorporated in making a reconstruction of the producer.
- Spacing between the transverse ridges on the basal ladder-like part suggest a probable peristaltic movement so the producer should have a coelomate segmented body such as annelid worms.
- The transverse annulations on the basal ladder-like part suggest a peristaltic movement and also their shape were affected by the shape of the producer's posterior part.
- The median furrow on the upper bilobate part has been produced by a vertical, tough, blade-shaped object, likely by 'chitinoid' material or even perhaps a primitive shell. The blade could oscillate freely resulting in the occasional sinuous pattern of the furrow. McIlroy and Hays (1997) suggested that this furrow was produced by the animal's siphon extended to the surface to gather food.
- Regular changes in the width of upper bilobed part along one of the specimens suggest a peristaltic movement.
- The median longitudinal groove in the ladder-like part has probably been produced by a projection trailing the excretive slot. Thus, the producer of the burrow had a small tail (or an extension of primitive shell) at the end of its body. This tail cut through the transverse ridges and because they were not hard they were both split apart and dragged toward the movement direction. Sometimes the tail cut through both the underlying sediment and the transverse ridges.

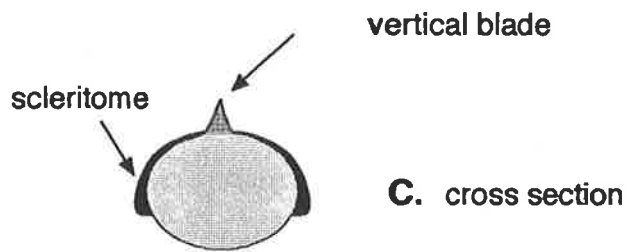
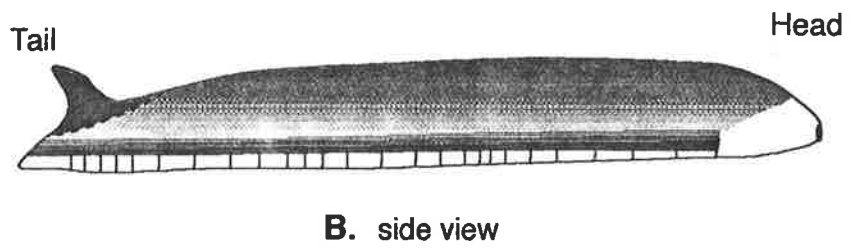
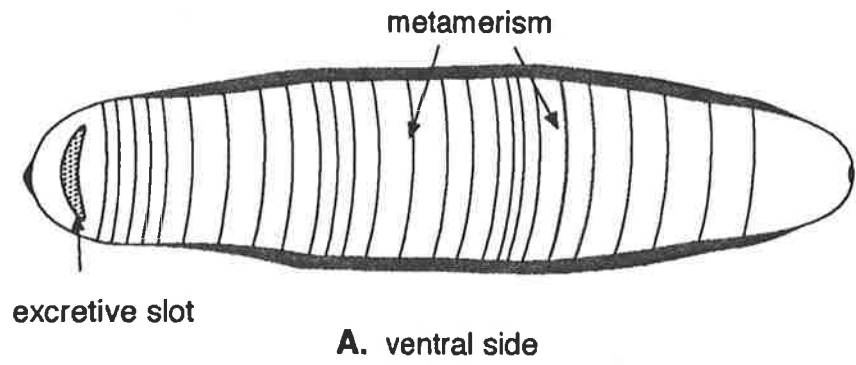
- Because the longitudinal ripples of the ladder-like part were made by the ventral side of the animal, the producer should have a soft ventral side.

It seems that the producer of *Plagiogmus* had a fairly hard, vertical blade-shaped 'fin' on its back. The blade was directed upward and cut sediments above the animal during movement, producing an empty furrow behind that was later filled by an influx of sediment. The shape of the remaining structure strongly depends on the sediment grain size and compaction.

The producer of *Plagiogmus* could possibly to have been a kind of annelid worm with a fairly hard skin covering its back and a vertical blade-shaped object on its head or tail or a siphon-bearing primitive mollusc with an early cap-shaped shell.

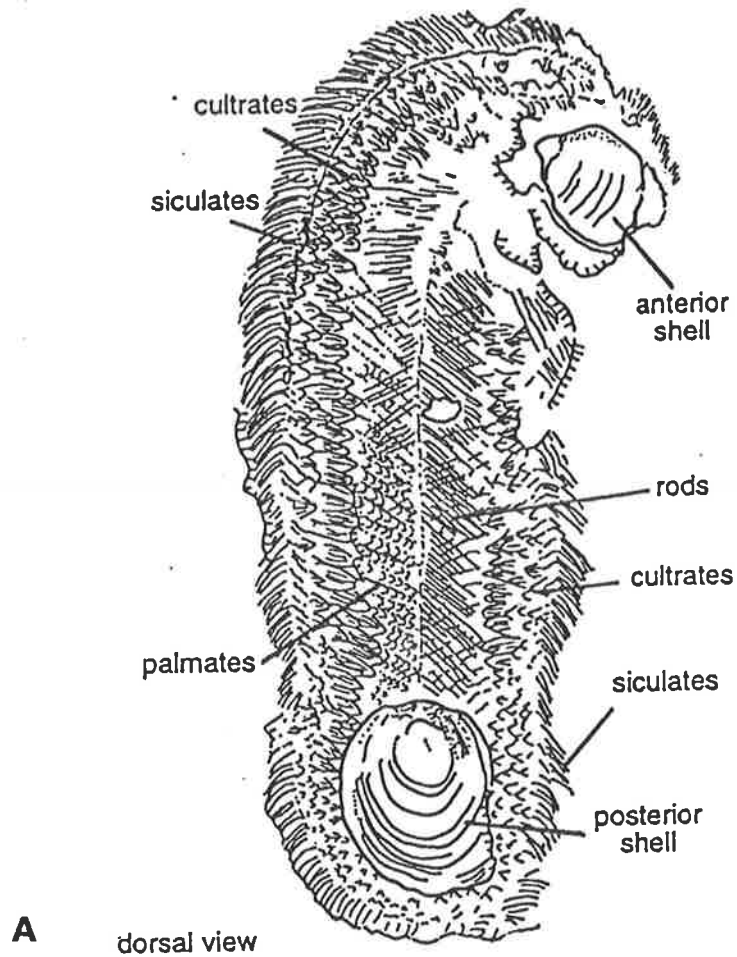
Based on the above, the schematic shape of the producer has been reconstructed as shown in Figure 7.42. This reconstruction resembles the halkieriid reported from the Early Cambrian Buen Formation of North Greenland (Conway Morris and Peel, 1990, 1995). The back of halkieriids was covered by tiny plates (sclerites) and presumably the animal had a soft, muscular ventral side or foot. There are two shells on either end of the animal and the posterior one has a sharp apex which may have covered the gills (Fig. 7.43). The width of the Greenland specimens is about 13-18 mm approximately the same as for the producer of *Plagiogmus*. Possibly, the posterior shell was attached to the body of animal along part of one edge only, thus allowing it to oscillate towards either side during locomotion so that its sharp apex cut the sinuous median furrow of the upper bilobed trace. The scleritome helped the animal to push sediments upward during locomotion and its lateral edges cut through the sediment to produce the marginal bevels. According to McIlroy and Hays (1997) the animal could have a long siphon extending upto the sea floor for seeking food and its movement produce an open space behind causing influx of sediment layers and production of the median furrow.

*Plagiogmus* occurs in a restricted stratigraphic interval of the older Early Cambrian in Australia where it is represented in sandstones containing *Diplocraterion*, *Monocraterion*, *Cochlichnus*, and *Skolithos*. Similar trace associations seem to characterise the same approximate stratigraphic level world-wide (e.g. Banks, 1970; Cloud and Bever, 1973; Crimes and Jiang Zhiwen, 1986). The local appearance of *Plagiogmus* near the first occurrence of skeletal fossil remains is perhaps late Tommotian or early Atdabanian (Daily,



**Figure 7.42** - Reconstruction of the producer of *Plagiognus* based on criteria gained from its burrow system.





**B**

**Figure 7.43** - *Halkieriid* body fossil: **A.** A specimen reported from the Early Cambrian of North Greenland (Conway Morris and Peel, 1990) showing a soft bodied animal covered by tiny sclerites. There are two large shells on either ends of the animal of which the posterior one possesses a sharp apex; **B.** The reconstruction of the *Halkieriid* animal given by Conway Morris and Peel, 1995) resembles the producer of the *Plagiogmus*.

1972; Haines, 1991). The known global distribution of halkieriid sclerites principally in the Tommotian and Atdabanian (Bengtson *et al.*, 1990; Conway Morris and Peel, 1990, 1995) is indicative of their likely time overlap with *Plagiogmus*. The characteristics of the creature which made the trace are comparable with the overall body-form and dimensions of halkieriids and are consistent with such an animal as the probable producer.

Stratigraphic distribution. Cowie and Spencer (1970) reported *Plagiogmus* from the Early Cambrian Ella Island Formation, East Greenland; and Banks (1970) noted it from the Lower Duolbasgaissa Formation, Finmark, Norway. *Plagiogmus* has been reported from the late Precambrian (rare and poorly preserved) into the Early Cambrian of *Vevadella* zone, California (Wyatt, 1974); it has also been noted from the Early Cambrian Meishucun section, Yunnan, China (Xing Yusheng *et al.*, 1984; and Crimes and Jiang Zhiwen, 1986); Alpert (1976) reported ?*Plagiogmus* in the Deep Spring Formation, of the White-Inyo Mountains, California; and Cloud & Bever (1973) mentioned it from the probable Middle Cambrian Flathead Sandstone, Wyoming, USA. *Plagiogmus arcuatus* has been recorded from Arumbera Sandstone, central Australia by Glaessner (1969), Kruse & West (1980), Walter *et al.* (1989) and McIlroy and Hays (1997). *Plagiogmus* has also been reported from the Parachilna Formation, in the Adelaide Geosyncline, Australia (Jenkins 1981). Crimes *et al.* (1977) noted *Plagiogmus* from the Herreria Sandstone, Spain; and Peterson & Clark (1974) depicted it from the Tintic Quartzite (Middle Cambrian) of Utah. It has been noted from Early Cambrian (*Protolenus* zone) Ocreseki Sandstone Formation, Swietoktzyckie Mts., Widelki (Lapigrosz) by Kowalski (1978); and Jaeger & Martinsson (1980) reported it from the Early Cambrian of the Kalmarsund area, Sweden.

Age. It apparently occurs only in Early Cambrian strata and has been reported world wide (e.g. Roedel, 1929; Glaessner, 1969; this study).

Occurrence. Lower Allua Formation at Ross River and Cyclops Bore, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

### ***Planolites* Nicholson, 1873**

? 1977 *Sabularia* Ksiazkiewicz, p. 68.

Type ichnospecies. *Planolites vulgaris* Nicholson and Hinde, 1875 = *Palaeophycus beverlyensis* Billings, 1862; subsequent designation by Alpert (1975). Fillion and Pickerill (1990b, p. 48) considered *Planolites vulgaris* Nicholson and Hinde, 1874, by subsequent designation of Miller (1889, p. 520) as the type ichnospecies.

Diagnosis. The diagnosis proposed by Pemberton and Frey (1982, p.865) was emended by Fillion and Pickerill (1990b) in order to better differentiate *Planolites* from other similar ichnogenera. Their emended diagnosis is: "Unlined, rarely branched, straight to tortuous, smooth to irregularly walled or ornamented, horizontal to slightly inclined burrows, circular to elliptical in cross-section, of variable dimensions and configurations; burrow-fill biogenic, essentially massive, differing from host rock; where present, bifurcation is not systematic, nor does it result in swelling at the sites of branching". The suggestion of Keighley and Pickerill (1995) was found to be more practical in assigning un-lined burrows to *Planolites* and lined burrows into *Palaeophycus* or *Macaronichnus* Clifton and Thompson, 1978 according to their infills.

Preservation. *Planolites* is preserved as endichnial, hypichnial ridges and epichnial grooves (Pemberton and Frey, 1982, p. 865).

Originator. It is commonly considered as reflecting the activity of vagile, vermiform deposit feeders (Alpert, 1975; Pemberton and Frey, 1982), though several phyla may be responsible.

Facies distribution. *Planolites* is considered to be an eurybathic form (Fillion and Pickerill, 1990b).

Discussion. *Planolites* differs from *Palaeophycus* in its actively filled burrow and lack of lining. Burrows which are actively filled, but lined have been included within *Macaronichnus* by many authors (e.g. Clifton and Thompson, 1978; Curran, 1985; Fillion, 1989; Fillion and Pickerill, 1990b; Keighley and Pickerill, 1995). It should be noted that although *Planolites* burrows have been actively filled, they do not display a meniscate structure typical of meniscus burrows and may only show an incipient backfill (Fillion and Pickerill, 1990b).

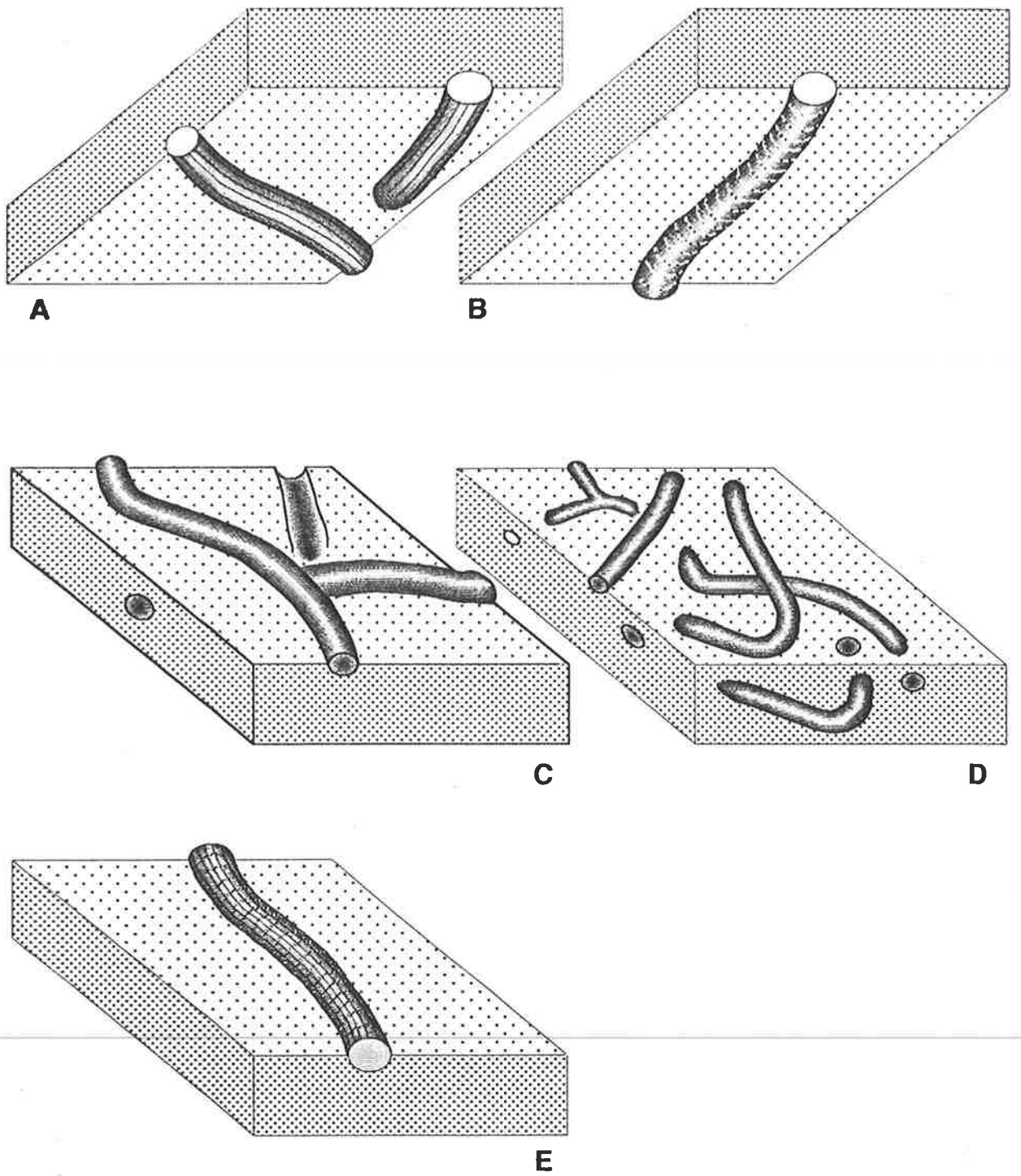
**Table 7.6** - Recognised ichnospecies of *Planolites*.

<i>P. beverlyensis</i>	(Billings)	1862	Large, straight to gently curved burrows
<i>P. annularius</i>	Walcott	1890	Transversely annulated burrows
<i>P. montanus</i>	Richter	1937	Small, curved to tortuous burrows
<i>P. terraenovae</i>	Fillion & Pickerill	1990	Longitudinally striated burrows
<i>P. constriannulatus</i>	Stanley & Pickerill	1994	Transverse annulations and longitudinal striations

Pemberton and Frey (1982) recognised three ichnospecies of *Planolites* primarily based upon the size, curvature, and burrow ornamentation. Since their comprehensive review, at least two more ichnospecies of *Planolites* have been erected. Fillion and Pickerill (1990b) nominated *P. terraenovae* for unlined burrows with longitudinal striation, an analogue of *Palaeophycus striatus* without a burrow lining. Stanley and Pickerill (1994) introduced *P. constriannulatus* from the late Ordovician, Georgian Bay Formation of southern Ontario, eastern Canada. It displays both transverse annulations and longitudinal striations. *P. renecki* Ksiazkiewicz, 1977, which displays both longitudinal and transverse striations, was considered to be a *Palaeophycus* by Pemberton and Frey (1982). However, Ksiazkiewicz (1977, p. 64) did not mention a wall lining for his specimens and apparently the burrow lacks a lining. So, the designation to *Planolites* by Ksiazkiewicz is considered to be correct. *P. renecki* resembles *P. constriannulatus* and if re-study of the holotype materials of both ichnospecies proves that they are similar, then *P. constriannulatus* becomes a junior synonymy of *P. renecki*.

Pemberton and Frey (1982) synonymised *Planolites ballandus* with *P. montanus* but Walter and Elphinstone (in Walter *et al.*, 1989) supported its retention. However, *p. ballandus* is well accommodated within the size range given for the *P. montanus* (though at its lower range) and the designation of Pemberton and Frey (1982) is followed herein. The ichnospecies of *Planolites* are briefly described in Table 7.6 and illustrated in Figure 7.44.

The ichnogenus *Sabularia* Ksiazkiewicz, 1977 was erected for horizontal, oblique or vertical, cylindrical full burrows which are straight or feebly curved and show rare



**Figure 7.44** - Ichnospecies of *Planolites*: **A.** *P. terranova* (after Fillion and Pickerill, 1990); **B.** *P. annularis*; **C.** *P. beverlyensis*; **D.** *P. montanus* (B-D after Pemberton and Frey, 1982); **E.** *P. constriannulatus* (after Stanley and Pickerill, 1994).

ramification. Książkiewicz (1977) erected four ichnospecies of *Sabularia* namely, *S. simplex*, *S. rudis*, *S. tenuis* and *S. ramosa*. Although in his description of the burrows he did not mention the wall structure, he described them as actively filled burrows which do not show any impression of backfilling on their surface. These characteristics are consistent with that of *Planolites* if the burrows are unlined and with *Macaronichnus* if they display lining. Therefore, it is suggested that *Sabularia* may be considered as a junior synonym of these ichnotaxa.

Fillion and Pickerill (1990b) elaborated on the etymology of *P. annularis* (as applied by Pemberton and Frey, 1982 and Crimes and Anderson, 1985) and stated that the proper spelling should be *P. annularius* according to Latin grammar, as it was published by the original author.

Age. *Planolites* occurs in late Precambrian strata (Narbonne and Hofmann, 1987) and as young as Pleistocene (Wetzel, 1983; Pemberton and Jones, 1988).

*Planolites beverlyensis* (Billings, 1862),

Plates 19D, 20A

*non* 1982 *P. beverlyensis* (Billings); Pemberton and Frey, pl. 1, fig. 7. (= ?*Phycodes palmatus*).

Collected specimens. Seven specimens, A971-2-13, A1035-MO40, A1035-MO41, A1035-MO86, A1035-MO108, A1035-MO168, and A1035-R6.

Diagnosis. "Relatively large, smooth, straight to gently curved or undulose cylindrical burrows" (after Pemberton and Frey, 1982)

Description. Straight to gently curved, smooth burrows preserved as convex hyporeliefs on sole of sandstone. They are 5 to 10 mm wide, subhorizontal to the bedding and intersect and/or pass over one another. Some show ramifications (A1035-MO115). The filling is slightly coarser than the host rock.

Discussion. *P. beverlyensis* is differentiated from *P. montanus* based on its larger diameter (>5 mm) and its greater length. Although these criteria are conventional and intergradational

forms also exist, they provide a practical base for classification which has been followed by many authors (e.g. Fillion and Pickerill, 1990b).

Occurrence. Box Hole and Allua Formations, Cyclops Bore and Ross River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

*Planolites montanus* Richter, 1937

Plates 12E, 13D, 14A,C,E, 19G, 20B, 21A,C, 23D

Collected specimens. Twenty nine specimens, A971-1- 2, A971-1- 8, A971-1-16, A971-1-26, A971-1-30, A971-1-32, A971-2-17, A971-2-31, A971-2-40, A971-3- 8, A971-4- 2, A971-4- 7, A971-5-1, A1035-B10, A1035-MO5, A1035-MO9, A1035-Mo47A, A1035-MO53, A1035-MO67, A1035-MO68, A1035-MO70, A1035-MO71, A1035-MO74, A1035-MO93, A1035-MO97, A1035-MO108, A1035-MO121, A1035-MO123, and A1035-MO173.

Diagnosis. Relatively small, curved to contorted burrows, less than 5 mm in diameter (after Pemberton and Frey, 1982, p. 870).

Description. Simple unbranched straight to gently curved burrows, smooth and cylindrical, parallel or sub-parallel to bedding plane, diameter 0.5-4 mm, preserved as convex hyporelief. Fill is coarser than host rock lithology. Burrows are short and commonly intersect.

Discussion. *P. montanus* is a common trace fossil in the area of study. One sample (Pl. 21A) from Ross River area is smaller than the others and occurs both as convex and concave epireliefs. It resembles specimens of *P. ballandus* (= *P. montanus*) illustrated by Webby (1970) from the Lintiss Vale Formation, New South Wales.

Occurrence. Box Hole Formation and lower Allua Formation, Ross River, Cyclops Bore, and Hugh River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

### *Psammichnites* Torell, 1870

Type ichnospecies. *Arenicolites gigas* Torell, 1868, p. 34; subsequent designation by Fischer and Paulus (1969, p. 91).

Diagnosis. Horizontal burrows, straight to curved, displaying unilobate or bilobate upper surface divided by a median furrow and may bear transverse striations. The lower surface unilobate, ornamented with a medial ridge or groove and/or with transverse striations (after Hofmann and Patel, 1989; Fillion and Pickerill, 1990b; Pickerill and Peel, 1990).

Discussion. *Psammichnites gigas* Torell, illustrated by Hantzschel (1975), shows a distinct median ridge. It is not clear that whether Torell's illustration represents the hypichnial or epichnial view of the burrow. Seilacher (1955) grouped *Psammichnites* with *Scolicia* de Quatrefages, 1849. However, subsequent authors followed Hantzschel (1975) and treated it as a distinct ichnotaxon. Hofmann and Patel (1989) reported specimens of *P. gigas* from the Early Cambrian Ratcliffe Formation, New Brunswick, Canada. Their specimens display a bilobate upper view with an axial groove and unilobate, transversely striated lower view. The upper view of the specimens reported by them closely resembles that of *Plagiogmus* from central Australia (compare their fig.3 to fig. 11C of Walter *et al.*, 1989 and plate 17B-C of this study). Hofmann and Patel (1989) schematically reconstructed the morphology of the burrow. The similarity between their reconstruction of the *Psammichnites* with that of *Plagiogmus* is striking (compare Hofmann and Patel, 1989, fig. 5 with McIlroy and Hays, 1997, fig. 7 and Fig. 7.41 of this study). To the writer's knowledge, a deep sinuous median furrow has not been reported by others author as occurring in *Psammichnites*, whereas it is a common characteristic associated with the ichnogenus *Plagiogmus*. However, Hofmann and Patel's (1989) specimens do not show the distinct backfilled middle part and ladder-like structure of the *Plagiogmus*.

*Plagiogmus*, *Aulichnites* and *Psammichnites* all possess an upper bilobate part preserved as a convex hyporelief, superimposed on a unilobate part. Although differences exist, these ichnogenera are morphologically similar. Their structure is complex and several ichnogenera have been reported as likely to represent preservational variations of these structures. *Olivellites* Fenton and Fenton, 1937b and *Laminites* Ghent and Henderson, 1966 are considered to represent the middle, unilobate, backfilled part. The median furrow on the



bilobate part is similar to the ichnogenus *Cochlichnus* (McIlroy and Hays, 1997). *Bichordites* Plaziat and Mahmoudi, 1988 also resembles the middle unilobate part.

Plaziat and Mahmoudi (1988) retained *Laminites* for large cylindrical to subcylindrical burrows with transverse, backfilled laminae. The type material of the burrow nominated by Ghent and Henderson (1966, as illustrated by Plaziat and Mahmoudi, 1988, fig. 2) is similar to weathered out specimens of *Psammichnites* and considered to be its junior synonym (Fig. 7.45).

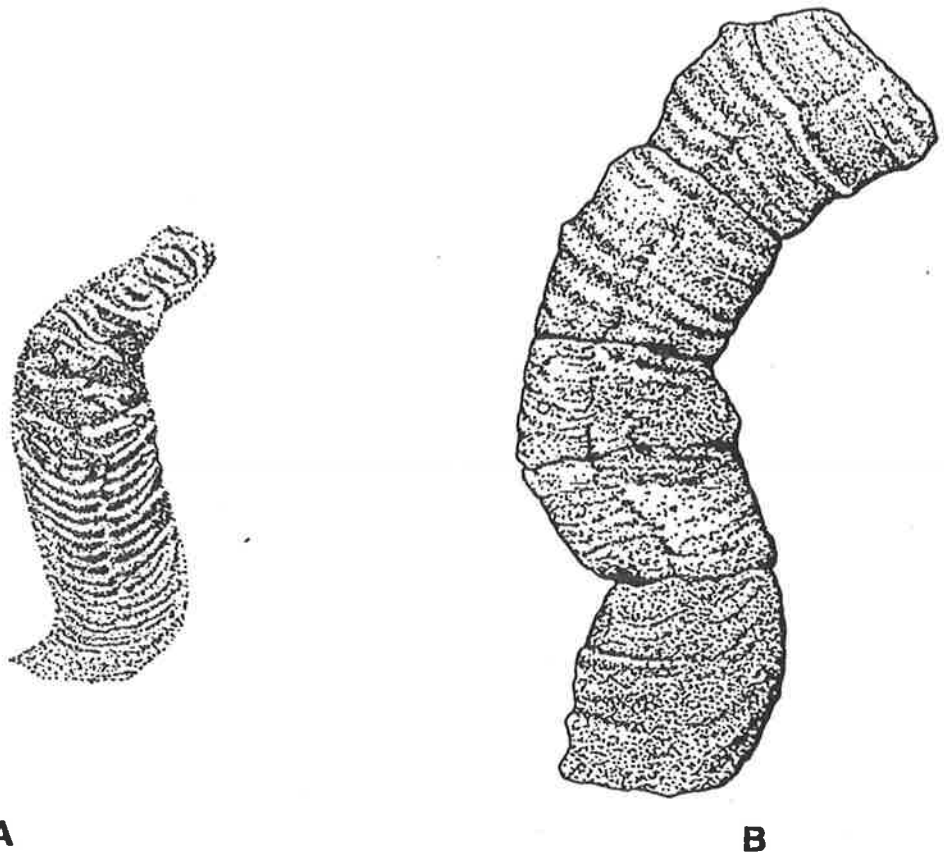
Chamberlain (1971b) and Chamberlain and Clark (1973) considered *Olivellites* Fenton and Fenton, 1937 as a junior synonym of *Psammichnites*. D'Alessandro and Bromley (1987) regarded *Olivellites*, *Aulichnites* and possibly *Laminites* as junior synonyms of *Psammichnites*.

Yochelson and Schindel (1978) redescribed *Olivellites*. It is a large ellipsoid burrow exhibiting transverse backfilled lamination bearing a distinct medial ridge on its upper surface (Fig. 7.46). They retained it as a distinct ichnogenus, the practice supported in this study. To the writer's knowledge, *Olivellites* has been reported undoubtedly from Carboniferous rocks hitherto (e.g. Chamberlain, 1971b; Chamberlain and Clark, 1973; Yochelson and Schindel, 1978; Eagar *et al.*, 1985) and apparently is restricted to the rocks of that age.

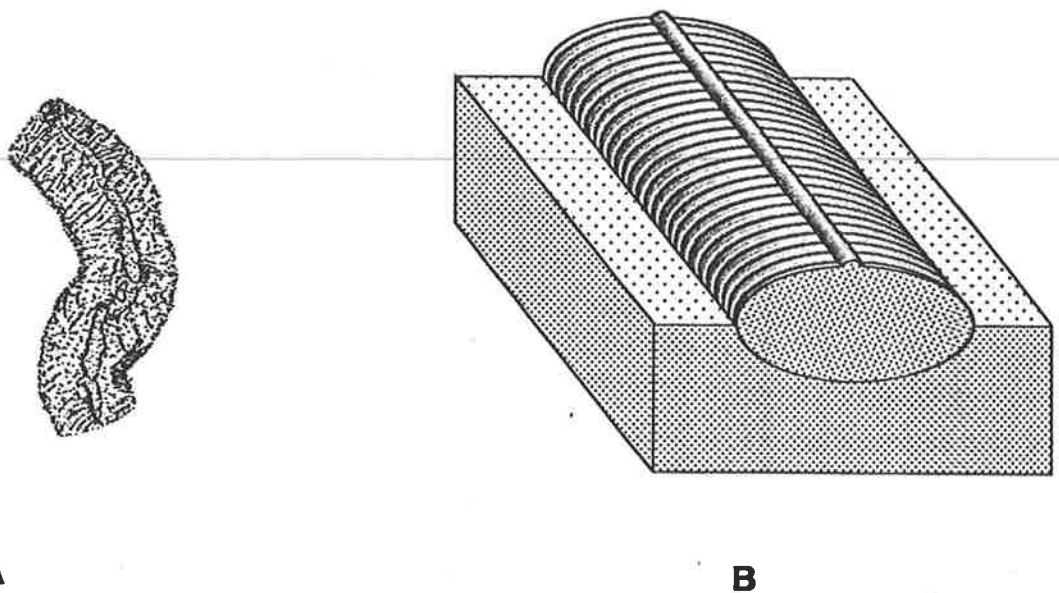
Re-evaluation of *Psammichnites* and other morphologically similar burrows (*Plagiogmus*, *Aulichnites*, *Laminites*, *Olivellites*) has been recommended by many authors (e.g. Fillion and Pickerill, 1990b). Some recommendations suggested here may be found helpful to differentiate these burrows.

The following characteristics are considered important at the ichnogenic level:

- A bilobate structure covering a unilobate burrow.
- Presence or absence of transverse ridges preserved on the basal part of the burrow.
- Presence or absence of transverse lamination within the unilobate part.
- Presence or absence of furrows lateral to the bilobate part.
- The kind of preservation as hypichnial or epichnial.



**Figure 7.45** - Specimens of ichnogenus *Laminites* as illustrated by Plaziat and Mahmoudi (1988) are similar to the ichnogenus *Psammichnites*: **A.** *L. kaitiensis*, Ghent and Henderson, 1966; **B.** A specimen reported from the late Oligocene of New Zealand by Ward and Lewis (1975).



**Figure 7.46** - *Olivellites plummeri*: **A.** Lectotype chosen by Yochelson and Schindel (1978, after Plaziat and Mahmoudi, 1988); **B.** Three dimensional reconstruction of the burrow.

It is suggested that *Plagiogmus* be restricted to those structures associated with the basal ladder-like structure with transverse ridges.

The burrows without the ladder-like transverse ridges on their basal part are:

-*Aulichnites* if the middle unilobate part does not show any structure (Fillion and Pickerill, 1990b) and is roughly heart-shaped in transverse section. It also displays grooves lateral to the bilobate upper surface (Hakes, 1976) (Fig. 7.47).

-*Psammichnites*, if they exhibit a transversely striated unilobate or bilobate upper part with a median furrow and a unilobate lower surface which may display a median ridge or furrow (Fig. 7.48).

Originator. *Psammichnites* has been attributed to worms (Torell, 1868; Matthew, 1888, 1890), crustaceans (Torell, 1870) and molluscs (Torell, 1870; Glaessner, 1969), particularly gastropods (Hantzschel, 1975). Hofmann and Patel (1989) argued that a worm-like organism does not appear to be a likely originator, considering the short wave-length sinuosity of the furrow and the alternating swelling and deflation of the burrow. They favoured a gastropod origin but considered other groups of organisms to be potential candidates.

Facies distribution. *Psammichnites* is typically reported from shallow-water, high-energy deposits. (Singh and Rai, 1983; Hofmann and Patel, 1989).

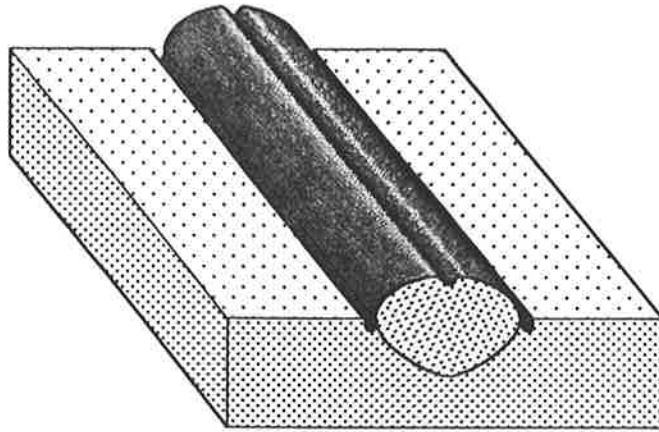
Age. *Psammichnites* occurs in strata belong to the Early Cambrian (Singh and Rai, 1983; Hofmann and Patel, 1989), upper Tremadoc (Fillion and Pickerill, 1990b), and possibly the Carboniferous (Torell, 1870; Hantzschel, 1975).

### ***Psammichnites* isp.**

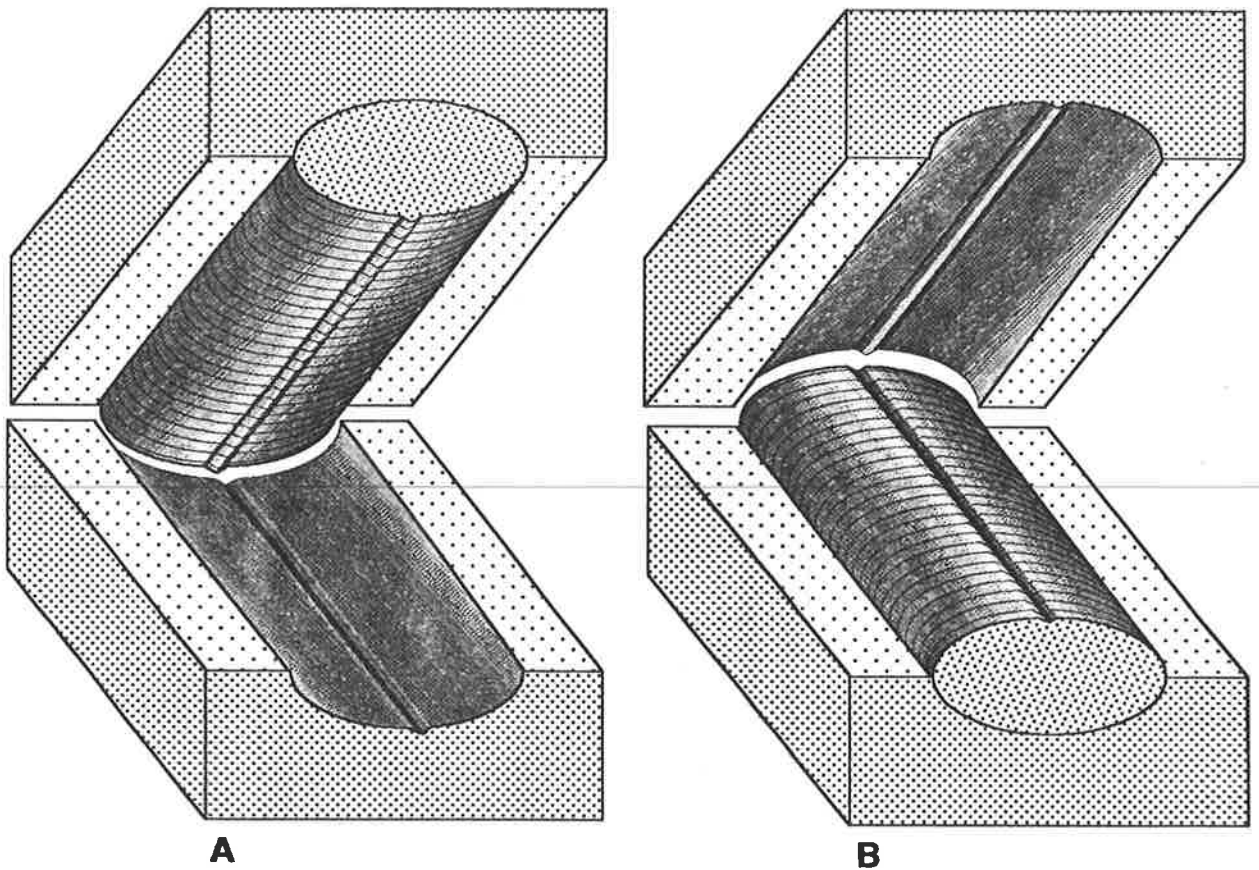
Plates 20C-D, 21B, 22A-B, 23B,E

1990 *Psammichnites gigas* (Torell); Pickerill and Peel, p. 26, fig. 11a-c.

Collected specimens. Ten specimens, A971-1-23, A971-2-3, A971-2-4, A971-2-34, A971-2-48, A1035-MO61, A1035-MO63, A1035-MO107, A1035-MO110, and A1035-MO119.



**Figure 7.47** - A block diagram illustrating the ichnogenus *Aulichnites*, characterised by a bilobate burrow preserved as an epirelief comprising lateral grooves and a lower unilobate part.



**Figure 7.48** - block diagrams showing the ichnogenus *Psammichnites*: **A.** Lower view of the burrow and its epichnial mould; **B.** Upper view of the burrow and its hypichnial mould.

Description. Large gently curving burrows, never branching, with common intersections, 15-40 mm wide, 10-15 mm deep, ovate in cross-section with narrow axial groove/ ridge. Burrows display fine transverse ridges and are preserved in concave epirelief or convex hyporelief or epirelief. Burrows intersect one another at different levels indicating their endichnial origin. Some specimens (e.g. Pl. 20D) preserved in concave epirelief show a longitudinal shallow groove along the burrow. Transverse striations of the backfilled laminae are more visible in some (A1035-MO61). Samples collected from stratigraphically higher position within the Todd River Dolomite are much larger in size (plate 22) and have been preserved in yellowish green, calcareous sandstone; These burrows are ellipsoid in cross section with their upper surface flatter than the lower surface and exhibiting a median groove (A971-2-4 and A971-2-3). Transverse arcuate shaped annulations have also been observed on some specimens (Pl. 21B).

Discussion. The present specimens do not display an upper bilobate part as described by Hofmann and Patel (1989). They are more similar to that reported by Pickerill and Peel (1990, fig. 11) from the Early Cambrian Bastion Formation of North-East Greenland. The epichnial (concave epirelief) or hypichnial (concave hyporelief) moulds of the burrows (Fig. 7.48) are common at the appropriate stratigraphic level within the study areas.

Occurrence. Box Hole and Allua Formations, Ross River and Cyclops Bore, and lower Todd River Dolomite, Ross River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

### *Rosselia* Dahmer, 1937

Type ichnospecies. *Rosselia socialis* Dahmer, 1937; by monotypy.

Diagnosis. Conical to irregularly funnel-shaped vertical to horizontal burrows comprising concentric layers of fine sediments surrounding a vertical shaft, or spreite-like helicoid swirls surrounding a cone, both tapering downward to a concentrically walled, subcylindrical stem (after McCarthy, 1979; Howard and Frey, 1984; Fillion and Pickerill, 1990b).

Discussion. Intergradations among specimens individually referable to *Cylindrichnus*, *Skolithos*, *Monocraterion* and *Rosselia* have been reported by several authors (Frey and

Howard, 1982b, 1985; Howard and Frey, 1984; Frey and Bromley, 1985). The lower stem of *Rosselia* is morphologically similar to *Cylindrichnus concentricus* (Pickerill and Peel, 1990; Uchman and Krenmayer, 1995) and if *Rosselia* is incomplete, the two forms may be confused. However, the internal concentric structure of both differs from that of *Skolithos* (Frey and Howard, 1985) and *Monocraterion* (Pickerill and Peel, 1990).

Sediment laminae display a set of parallel lines in longitudinal cross section in *Cylindrichnus* whereas they are convex down, V-shaped in *Rosselia*, which is easily identifiable if the funnel-shaped upper portion of the burrow is preserved. The inclined cross section of *Cylindrichnus* may be mistaken for the lower part of *Rosselia* (Fig. 7.49).

Many authors pointed out the similarity between *Rosselia* and the ichnogenus *Asterosoma* von Otto, 1854 (e.g. Chamberlain, 1971b; Howard and Frey, 1984; D'Alessandro and Bromley, 1986; Uchman and Krenmayer, 1995). Although *Rosselia* has been suggested to be synonymous with *Asterosoma* (Seilacher in Hantzschel, 1975), subsequent authors retained both as distinct ichnogenera (e.g. Howard and Frey, 1984; Miller and Knox, 1985; Uchman and Krenmayer, 1995). *Asterosoma* should only be applied to star-shaped, branched, concentrically lined and longitudinally ornamented burrows (Fillion and Pickerill, 1990b). Uchman and Krenmayer (1995) reviewed *Rosselia* and considered that *Polycylindrichnus* Fournier *et al.*, 1980 and *Anemonichnus* Chamberlain and Clark, 1973 to be junior synonyms.

Although *Rosselia* is commonly reported from shallow marine sediments (McCarthy, 1979; Pickerill and Peel, 1990), it also occurs in deep water flysch deposits (Ksiazkiewicz, 1977). At least three ichnospecies of *Rosselia* have been reported, based on the internal structure of the burrow (Table 7.7; Fig. 7.50).

**Originator.** *Rosselia* has been attributed to annelids (Chamberlain, 1971b), crustaceans (Frey, 1970) or sea anemones (Chamberlain and Clark, 1973; Uchman and Krenmayer, 1995).

**Age.** *Rosselia* has been reported from the Early Cambrian (Seilacher, 1955; Pickerill and Peel, 1990), to Pleistocene (D'Alessandro and Bromley, 1986).

**Table 7.7** - Reported ichnospecies of *Rosselia*.

<i>R. socialis</i>	Dahmer	1937	a shaft surrounded by concentric, funnel-like laminae, nested convex downward joining to a concentric layered stem
<i>R. rotatus</i>	McCarthy	1979	Funnel-shaped structure showing highly developed crescentic backfill structure formed by rotary movement of the tube within the funnel
<i>R. chonoides</i>	Howard and Frey	1984	large, vertical, bulbous to funnel-shaped burrows consisting of helicoid swirls of reworked sediments

***Rosselia socialis*** Dahmer, 1937

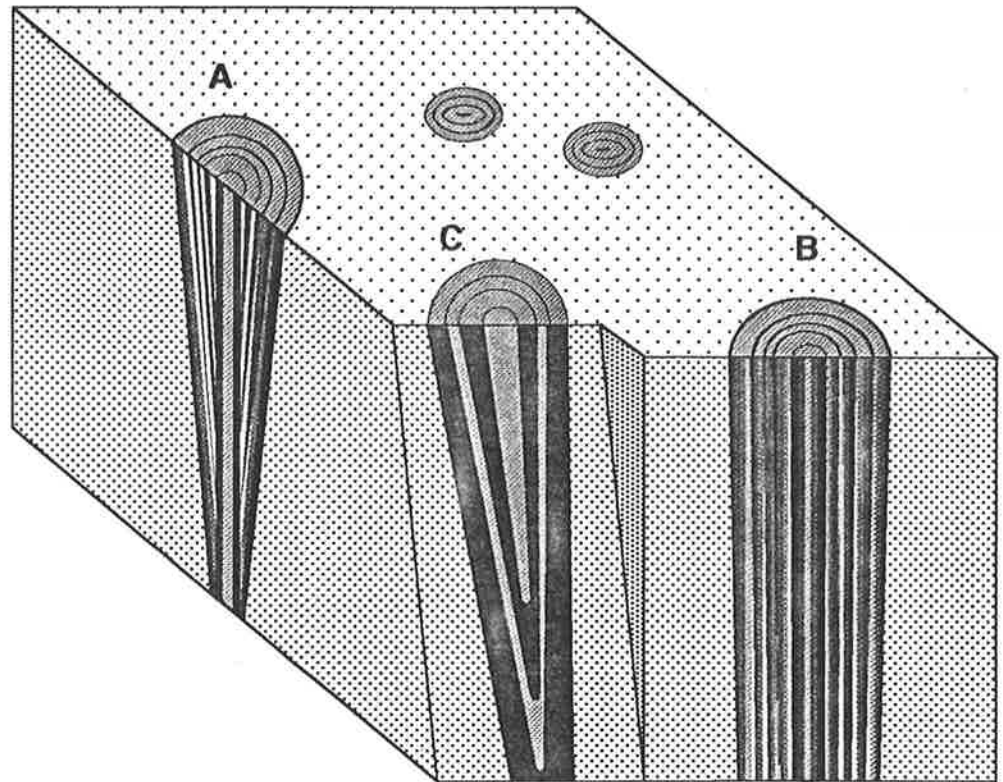
Plates 13A-B, 21D, 23C

For the synonymy list see Uchman and Krenmayer, 1995.

Collected specimens. Two specimens, A1035-MO62 and A1035-MO166.

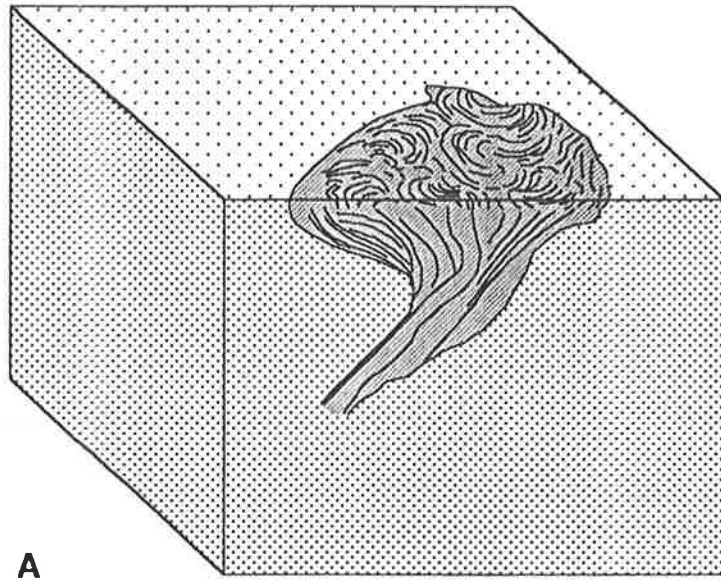
Description. Vertical to inclined burrows comprising a central shaft surrounded by concentric laminae of fine grained sediments and displaying a funnel-shaped or bulbous structure at the top. Burrows are preserved as circular to subcircular structures on bedding planes. In cross section, convex downward, V-shaped concentric layers of sediments surround an axial shaft filled with a coarser grained sediment; burrows are 2-4 mm wide at their lower stem, increasing to about 10 mm at the upper funnel-shaped opening.

Discussion. *R. socialis* differs from *R. chonoides* and *R. rotatus* in having concentric laminae and lacking helicoid swirl or crescentic backfill structures formed by rotary repositioning of the tube within the funnel-shaped part. Uchman and Krenmayer (1995) reviewed the ichnotaxonomy of *Rosselia* and considered *R. rotatus* and *R. chonoides* as junior synonyms of *R. socialis*. They (1995 p. 510) opined that the spreite-like internal lamination seen in *R. rotatus* is an intraspecies variation and is related to higher energy facies. Uchman and Krenmayer (1995 p. 508) also discussed the possibility that forms lacking concentric

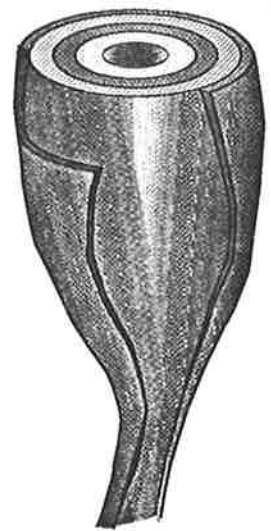


**Figure 7.49** - Comparison between ichnogenes *Cylindrichnus* and *Rosselia*; **A.** In *Rosselia* laminae of sediment are V-shaped convex down and terminate at the median shaft of the burrow; **B.** *Cylindrichnus* displays sediment laminae which are concentric and parallel to the median shaft; **C.** An inclined transverse section through *Cylindrichnus* may produce a form similar to the ichnogenus *Rosselia*. However, the median shaft in this instance does not extend through the laminae.

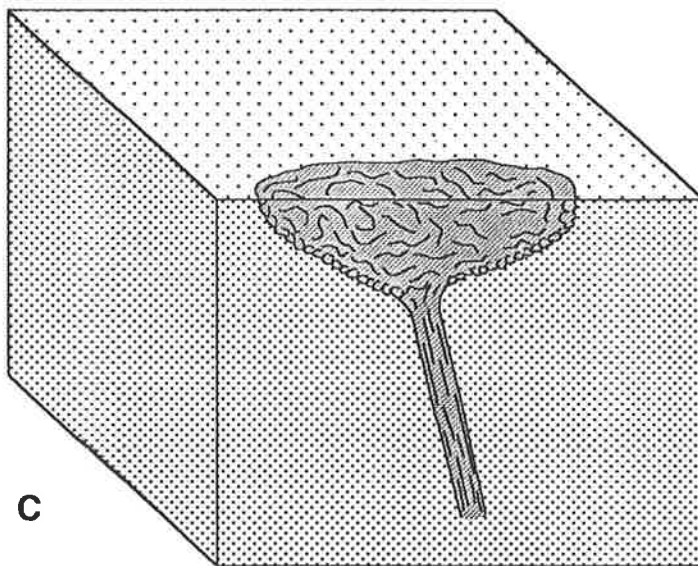




A



B



C

**Figure 7.50** - Ichnospecies of *Rosselia*: **A.** *R. rotatus* vertical and horizontal cross section (after McCarthy, 1979); **B.** *R. socialis*, a reconstruction of the terminal bulbous structure (after Chamberlain, 1971); **C.** *R. chonoides* showing both vertical and horizontal cross section (after Howard and Frey, 1984).

laminae, described as *R. chonoides* (Howard and Frey, 1984) represent probably either *R. socialis* reworked by secondary small burrows or should be excluded from this ichnogenus.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

### ***Rusophycus* Hall, 1852**

Type ichnospecies. Many authors designated *R. clavatus* as the type ichnospecies (e.g. Miller, 1889; Hakes, 1976, p. 32). *Fucoides biloba* Vanuxem, 1842, p. 79 has also been considered to be the type ichnospecies by some authors (e.g. Osgood, 1970; Hantzschel, 1975; Alpert, 1976). Fillion and Pickerill (1990b) elaborated on the issue and concluded that for nomenclatural stability, *Fucoides biloba* should be regarded as the type ichnospecies but, nevertheless, they continued to use *R. clavatus* as the type ichnospecies (Fillion and Pickerill, 1990b, p. 52).

Diagnosis. "Short bilobate buckle-like forms resembling shape of coffee beans; preserved in convex hyporelief. Lobes are parallel or merging posteriorly, and transversely wrinkled by anterolaterally directed coarse or fine striae; deep median furrow, outline mostly elliptical. Coxal, exopodal, spinal, cephalic and pygidial markings may be present (after Osgood, 1970; Hantzschel, 1975, p. W101; Alpert, 1976).

Discussion. Although Seilacher (1970) considered *Rusophycus* as a junior synonym of *Cruziana*, almost all other authors have considered them to be distinct ichnogenera (e.g. Osgood, 1970, Crimes *et al.*, 1977). Osgood (1970) comprehensively discussed the nomenclatural history of the ichnogenus and reported samples intermediate between *Rusophycus* and *Cruziana* stating that sometimes it is not easy to draw a line between the two. Numerous ichnospecies of *Rusophycus* (At least 70, including different forms) have been erected based on their geometry, kinds of scratch-marks, and preservation of other characteristics such as cephalic imprints, etc. Re-evaluation of this ichnogenus is recommended.

Originator. The ethology of *Rusophycus* has been discussed by many authors (e.g. Seilacher, 1970; Osgood, 1970). They are considered to be resting burrows made by trilobites digging into sediment for temporary settlement. However, there are other groups of organisms such

as marine polychaete *Aphrodite* capable of excavating burrows similar to those of trilobites (Osgood, 1970). Some authors suggested that it could be a feeding burrow (Glaessner, 1957) or represent an egg depository (Fenton and Fenton, 1937a). Some evidence for hunting of soft-bodied animals by the producer of *Rusophycus* has also been found (Bergstrom, 1973; Jensen, 1997; this study, Pl. 23B, Fig. 7.52).

**Facies Distribution.** Although *Rusophycus* is characteristic of the *Cruziana* ichnofacies of Seilacher (1967), it has also been reported from intertidal (Narbonne, 1984; Legg, 1985), non-marine (Helwig, 1972; Bromley and Asgaard, 1979) and slope (Pickerill *et al.*, 1987) settings.

**Age.** It ranges in age from the Early Cambrian (Narbonne and Myrow, 1988) to the latest Triassic (Wright and Benton, 1987).

***Rusophycus avalonensis* Crimes and Anderson, 1985**

Plate 21E

1976 *Rusophycus* isp.; Alpert, pl. 2, fig. 7.

1985 *R. avalonensis* Crimes and Anderson, p. 331, figs 5.2-3, 12.2.

? 1985 *Rusophycus* isp.; Nowlan *et al.*, fig. 4D.

1987 *R. avalonensis* Crimes & Anderson; Narbonne *et al.*, fig. 6G & I.

**Collected specimens.** Four specimens, A971-1-12, A971-1-18, A971-2-28 and A1035-B11.

**Diagnosis.** "*Rusophycus* consisting of fine scratch marks in bundles of five or more, arranged obliquely or transversely to median line" (Crimes and Anderson, 1985, p. 331).

**Description.** Transverse scratch marks in two discrete sets, 5 or more pronounced scratch-marks per set, individual sets elliptical to coffee bean shaped. Complete trace 30-50 mm wide and 3-8 mm deep. Preserved as convex hyporelief (Fig. 7.51 A).

**Discussion.** Crimes and Anderson (1985) separated the *Rusophycus* form of *Cruziana fasciculata* Seilacher, 1970 and attributed it to a new ichnospecies *Rusophycus avalonensis*. The scratch-marks in the present material are not fine as explained by Crimes and Anderson

(1985, p. 331), but otherwise closely resemble those reported from Newfoundland, Canada by these authors and Narbonne *et al.* (1987).

Occurrence. Allua Formation, Cyclops Bore and Ross River, Amadeus Basin.

*Rusophycus bonnarensis* Crimes, Legg, Marcos and Arboleya, 1977

Plates 23A, 23D, 25A

*partim* 1970 *Cruziana cantabrica*, Seilacher, p.456, fig. 7.1-2.

1977 *R. bonnarensis*, Crimes *et al.*, p. 105, pl. 3d,e.

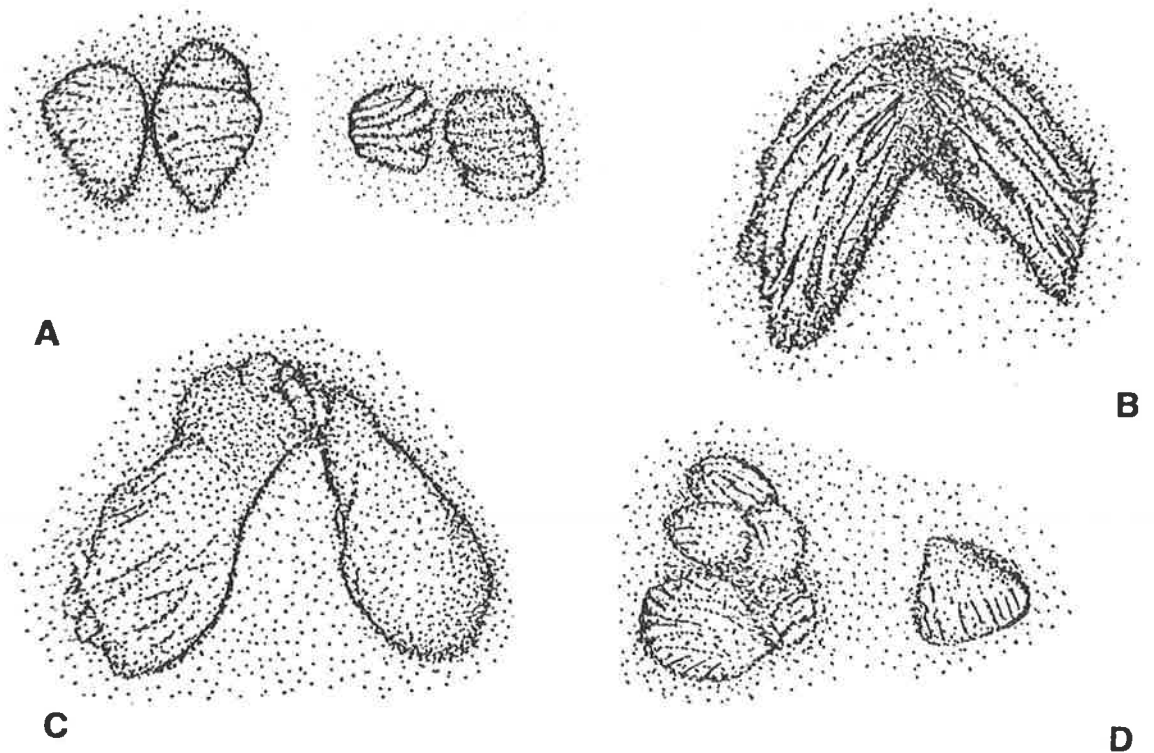
1985 *R. bonnarensis* Crimes *et al.*; Crimes and Anderson, p. 333, fig. 12.3.

Collected specimens. Four specimens, A1035-B1, A1035-B5, A1035-B6, and A1035-B10.

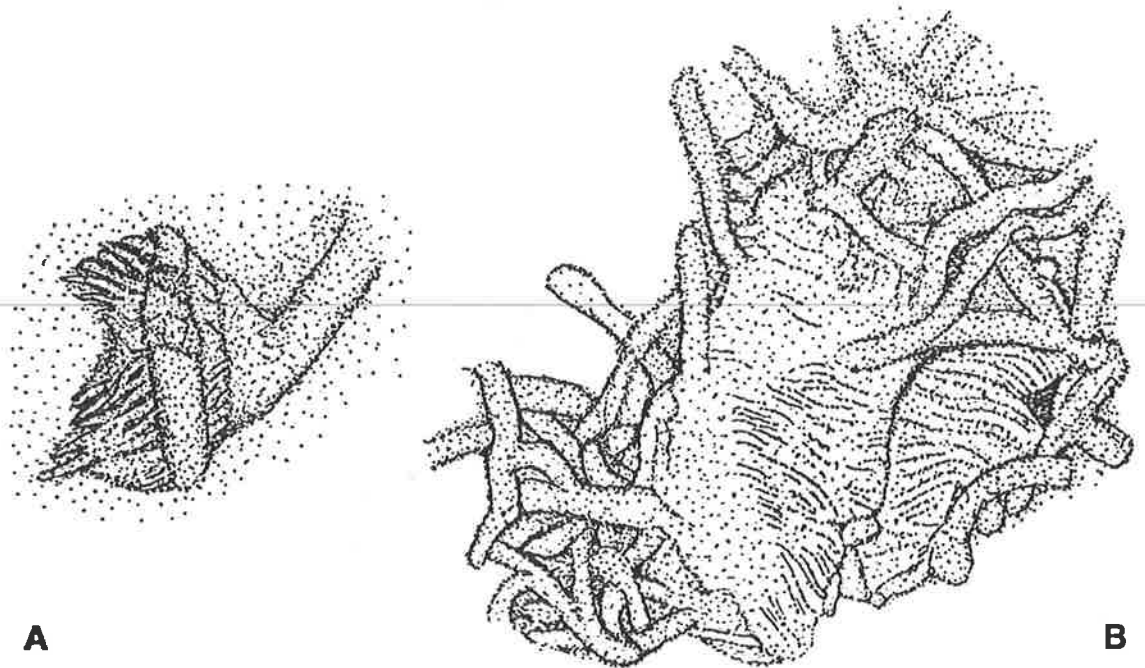
Diagnosis. Large, deeply excavated, moustache-like markings having 6 or more scratches running parallel to the anterior margin of the trace (after Crimes *et al.*, 1977; Crimes and Anderson, 1985).

Description. Bilobate burrows preserved as convex hyporeliefs with moustache-like outline. Burrows possess 5-6 parallel to subparallel scratch-marks running along each lobe. Some scratch-marks show a double clawed impression, particularly close to the anterior side of the burrow. Lobes are 7-13 mm wide and up to 40 mm long. The bilobate structure is 18-26 mm and 40-56 mm wide at the anterior and posterior respectively (Fig. 7.51 B).

Discussion. Seilacher (1970) united both *Rusophycus*- and *Cruziana*-form traces under *Cruziana cantabrica*. Crimes *et al.* (1977) supported the retention of both ichnogenera and introduced the new name *R. bonnarensis* for *Rusophycus*-like burrows. *R. bonnarensis* is a distinctive trace produced by the front limbs of the producer (most likely a trilobite) and distinguished from other *Rusophycus* in its great width and moustache-like outline. All samples of *R. bonnarensis* found by Crimes *et al.* (1977) were from medium to coarse grained, thick-bedded sandstone and led them to suggest a preferential colonisation of high energy environment. The present samples collected from Allua Formation also occur in medium-grained, thick-bedded sandstone and support the conclusion of Crimes *et al.* (1977). *R. bonnarensis* specimens from central Australia are smaller than those reported by Crimes *et al.* (1977) and Crimes and Anderson (1985). The samples from Mount Scott, Adelaide



**Figure 7.51** - **A.** *Rusophycus avalonensis* comprises two lobes covered with a set of 4-6 scratch marks. **B.** *R. bonnarensis* from central Australia is a moustache-like burrow with longitudinal scratch marks. **C.** *R. bonnarensis* from the Uratanna Formation South Australia. Though the trace is moustache-like in outline does not show the scratch marks. **D.** *?Rusophycus* isp. B from central Australia is a small, low relief burrow with fine scratch marks. The bilobation is not clear in some specimens.



**Figure 7.52** - Associations of *Rusophycus* and *Planolites* burrows may be an indication of hunting: **A.** The *R. bonnarensis* and *P. montanus* in a close relationship. *R. bonnarensis* is indicated by the series of parallel scratch marks; **B.** Association of *Rusophycus* isp. A and numerous *Planolites* burrows. The *Rusophycus* burrow is disturbed indicating heightened activity of the producing animal probably due to its effort to catch an inhabitant of the *Planolites* burrows.

Geosyncline, are larger in size and do not show parallel scratch-marks (Fig. 7.51 C). They are tentatively assigned to *R. bonnarensis* based on their moustache-like morphology. Daily (1972) also reported *Rusophycus* burrows similar to this ichnospecies from Uratanna Formation, Adelaide Geosyncline.

One specimen shows an occurrence of poorly preserved *R. bonnarensis* with *Planolites beverlyensis*. The *Rusophycus* animal apparently dug down into sediments to reach to the *Planolites* burrow and feed on its producer (Fig. 7.52 A, plate 24C).

Seilacher (1970) considered *R. bonnarensis* to occur stratigraphically lower than *R. avalonensis*. Crimes and Anderson (1985) stated that, although in the Random Formation, Newfoundland, *R. bonnarensis* is stratigraphically lower than *R. avalonensis* this is not always true. The authors (1985) suggested that *R. bonnarensis* is apparently restricted to the Early Cambrian.

Occurrence. The Allua Formation, Ross River, Amadeus Basin.

### ?*Rusophycus* isp. A

#### Plate 23B

1990 *Rusophycus dispar* Linnarsson; Pickerill and Peel, p. 30, fig.12C.

Collected specimens. Four specimens, A971-2-6, A971-2-44, A971-2-38, and A1035-B12.

Description. Large, oval burrows preserved as convex hyporeliefs, 10-15 mm deep. 40-60 mm wide and 70-90 mm long, showing transverse scratch-marks (Fig. 7.52 B). One specimen (A971-2-38) displays scratch-marks in the opposite direction (proverse and retroverse scratch-marks) with some scratch-marks showing a delicate bifurcation. Burrows do not show a clear bilobate structure.

Discussion. These burrows do not show the diagnostic bilobate structure of *Rusophycus*. However, their general geometry is similar to this ichnogenus and resemble *Rusophycus dispar* reported from the Early Cambrian Bastion Formation, north-east Greenland (Pickerill and Peel, 1990). Burrows occur in close association with abundant *Palaeophycus tubularis*, suggesting a hunting relationship between the two with the *Rusophycus*-animal excavating

the sediment to reach a soft-bodied animal living there. As the specimens show, the substrate was abundantly populated by infaunal organisms of different kinds (Fig. 7.52 B).

Occurrence. The Allua Formation, Ross River, Amadeus Basin

### ?*Rusophycus* isp. B

Plate 23F

1977 *Rusophycus* isp., Crimes *et al.*, p.110, pl. 4d, fig. 6.

Collected specimens. One specimen, A971-2-15.

Description. Small, shallow bilobate burrows preserved as convex hyporeliefs. Burrows are poorly preserved and comprise two circular to subcircular lobes separated by a furrow. Lobes possess scratch-marks displaying a radial pattern particularly around their outer margin. Scratch-marks are not clear on top of the lobes (Fig. 7.51 D).

Occurrence. The poor preservation and insufficient number of specimen does not allow detailed study. They superficially resemble *Rusophycus* isp. reported by Crimes *et al.* (1977) from the Early Cambrian of Spain, but are much smaller.

Occurrence. Allua Formation, Ross River, Amadeus Basin.

### *Saerichnites* Billings, 1866

? 1977 *Tuberculichnus bulbosus* Ksiazkiewicz, p. 142, pl. 13 fig. 7, text-fig. 27h.

1979 *Treptichnus* isp.2, Palij *et al.*, p. 83, pl. LII, fig. 5.

Type ichnospecies. *Saerichnites abruptus*, Billings, 1866; by monotypy (Hantzschel, 1975).

Diagnosis. Two parallel rows of circular to semi-circular pits or knobs alternating with each other uniformly. The pits or knobs have been interpreted as the bedding plane preservation of vertical paired burrows (after, Hantzschel, 1975; Seilacher, 1977; Crimes *et al.*, 1981).

Discussion. Seilacher (1977) placed *Saerichnites* tentatively in *Hormosiroidea* and included *Saerichnites beskidensis* within the latter ichnogenus as *Hormosiroidea beskidensis*. Crimes

*et al.* (1981) argued that *Saerichnites abruptus*, the type ichnospecies, has two distinct parallel rows of closely spaced knobs contrary to the ichnogenus *Hormosiroidea* which is characterised by a single row of circular knobs or pits.

One of the interpretations for the ichnogenus *Saerichnites* is that the double row of knobs or pits is the bedding plane preservation of vertical shafts (Crimes, 1977; Seilacher, 1977). Tunis and Uchman (1996, p. 9, fig. 10) illustrated *Saerichnites* as the impression of shafts which may meet the sea-floor as vertical extensions of a horizontal burrow system. The reconstruction of the *Saerichnites* by Tunis and Uchman (1996, p.9, fig. 10) based on this interpretation resembles that of *Treptichnus* (Figs 7.53A,B). Inclusion of *Treptichnus*-like burrows within *Saerichnites* is not warranted and both ichnogenera are suggested to be distinct forms. Another alternative interpretation for the burrow is proposed herein based on material found in the Allua Formation at Ross River (Pl. 24.A) and is discussed under the *Saerichnites* isp. B below.

Ichnogenus *Tuberculichnus* Ksiazkiewicz, 1977 comprises tubercles of various shapes aligned on a straight to winding line. Ksiazkiewicz (1977) stated that they might have been formed by the filling of pre-existing holes. Ksiazkiewicz (1977) introduced three kinds of *Tuberculichnus* based on the shape and alignment of tubercles namely, *T. vagans*, *T. meanderinus* and *T. bulbosus*. Of these, *T. vagans* and *T. meanderinus* resemble the ichnogenus *Hormosiroidea* in bedding plane view. *T. bulbosus* consists of knobs arranged in two almost parallel rows. The knobs are 40-50 mm wide at base and 10-30 mm high. *T. bulbosus* is morphologically similar to *Saerichnites* and likely a junior synonym of the latter.

The main characteristic of *Saerichnites* is considered to be a row of paired knobs or pits which clearly represent the bedding plane preservation of vertical shafts. The angle between an imaginary line connecting each pair and the burrow path is considered to have secondary importance at ichnospecies level.

Originator. Plicka (1974) reported *S. beskidensis* from the Late Cretaceous of Czechoslovakia and suggested it was produced by an animal walking on the sea bottom. Crimes (1977), Seilacher (1977) and Crimes *et al* (1981) attributed it to the burrowing activity of an organism.



Age. *Saerichnites* has been reported from the Early Cambrian (Crimes and Germs, 1982), Ordovician (Billing, 1866), Late Cretaceous (Plicka, 1974) and Eocene (Crimes, 1977).

**?*Saerichnites* isp. A**

Plate 25D

?1982 *Diplichnites* isp., Crimes and Germs, p.896, pl. 1-5.

Collected specimens. One specimen, A971-2-37.

Description. Poorly preserved circular tubercles arranged in two parallel rows and preserved as low convex epireliefs. The tubercles are closely spaced and are interpreted to be the bedding plane preservation of paired vertical shafts. An imaginary line connecting the tubercles of each pair is normal to the main course of the burrow. Tubercles are 1.5 mm in diameter and are preserved on top of a ripple marked sandstone.

Discussion. In *Saerichnites* the imaginary line connecting each pair of tubercles is reported to be oblique to the burrow path. The present material is smaller than the *Saerichnites abruptus* and *Saerichnites beskidensis*. Crimes and Germs (1982, pl. 1-5) reported similar trace fossil from the Nama Group, Namibia as *?Diplichnites* isp. The latter consists of a winding row of marks, each consisting of two imprints which could be followed on the immediately overlying lamina. The imprints are similar in size to the specimens reported herein, but preservation of the Namibia specimen is as a concave epirelief and there is a greater distance between the pairs.

Occurrence. Box Hole Formation, Ross River, Amadeus Basin.

***Saerichnites* isp. B.**

Plate 24A

? 1989 *Phycodes pedum*, Seilacher; Walter and Elphinstone, fig. 9-B.

Collected specimens. One specimen, A1035-B30.

Description. Straight to gently curving burrow 3-5 mm wide preserved as convex hyporelief. The burrow displays projections on both sides 1.5-2.5 mm across and located 1-3 mm apart. Projections do not alternate and occur as pairs. The burrow shows annulation due to these side projections and grades into a smooth, annulated trace without projections at one end. The projections are interpreted as the hypichnial preservation of vertical shafts ascending to the overlying sandstone (Fig. 7.53C).

Discussion. The relationship between the vertical shafts and the horizontal burrow in the present specimen is similar to that of *Phycodes coronatum* reported by Crimes and Anderson (1985) from Newfoundland. However, the vertical offshoots are paired and occur on both sides of a straight to curved burrow in the Australian specimens. Although the present specimen differs morphologically from *Saerichnites* it is regarded as a hyporelief preservation of that ichnogenus. The trace is considered to consist of a horizontal burrow with regular to irregularly spaced paired vertical shafts (Fig. 7.53D). Because of the single specimen no new name is proposed here and it is tentatively assigned to *Saerichnites*.

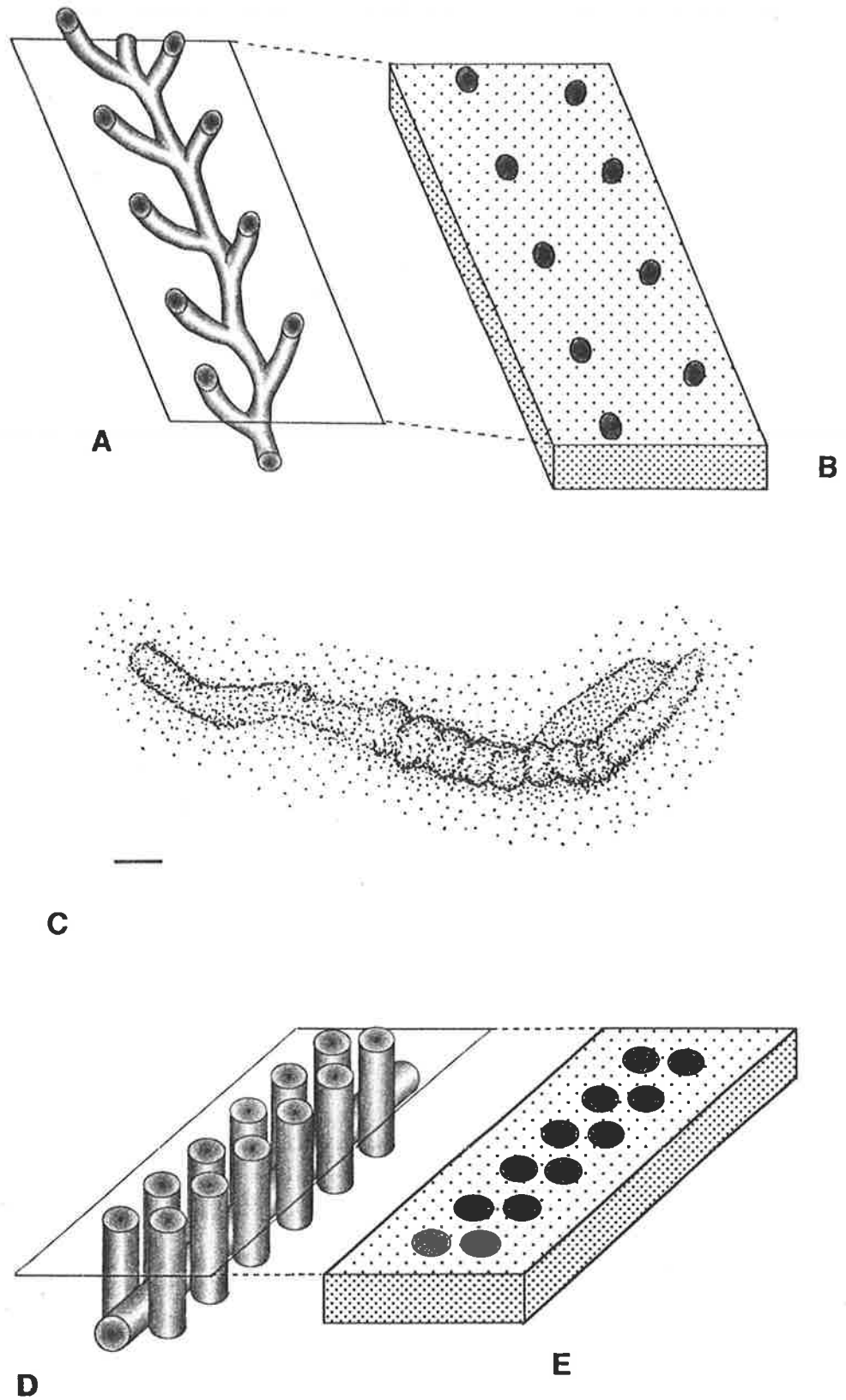
Occurrence. Allua Formation, Ross River, Amadeus Basin.

### ***Skolithos* Haldeman, 1840**

Type ichnospecies. *Fucoides? lineatus* Haldeman, 1840, p. 3 by monotypy (Hantzschel, 1975, p. W106)

Diagnosis. Perpendicular or steeply inclined, unbranched, cylindrical to subcylindrical burrow with or without lining, and with massive fillings. Burrow diameter may vary slightly along its length. When found in abundance it is sometimes referred to as "pipe rocks" (after Alpert, 1974; Hantzschel, 1975, p. W107).

Originator. Interpreted to be dwelling and feeding burrows made by unspecified marine worms (MacCulloch, 1814, p. 461), annelids (e.g., Nicholson, 1873, p. 288), brachiopods (Perry, 1872) or phoronids (Fenton and Fenton, 1934, p. 348). Barwis (1985) and Skoog *et al.* (1994) reported on the distribution of the tubes of *Diopatra cuprea* and considered it as a modern analogue of *Skolithos*.



**Figure 7.53 - Ichnogenus *Saerichnites*:** **A.** Reconstruction of burrow system by Tunis and Uchman (1996); **B.** The bedding plane view of the burrow comprises a double series of circular structures; **C.** *Saerichnites* isp. B from central Australia preserved in convex hyporelief; **D.** An alternative interpretation of the burrow suggests that it consists of a horizontal tunnel with paired vertical shafts which diverged from both sides of the tunnel; **E.** Bedding plane displays a series of double circular structures (scale bar = 1 cm).

Facies distribution. *Skolithos* occurs in different environments, but it is typical of high-energy marine conditions, particularly in nearshore shallow-water where it is diagnostic of the *Skolithos* ichnofacies of Seilacher (1967). It has also been reported from deep-water submarine channels and canyons (Seilacher, 1967; Fürsich, 1974b; Alpert, 1974; Crimes, 1977; Pickerill, 1981) and flood plain and dune environments (Ahlbrandt *et al.*, 1978; Curran and White, 1987).

Age. Late Precambrian (Fedonkin, 1985) to Pleistocene (Pemberton and Jones, 1988). Cloud and Glaessner (1982) considered it to be indicative of an Early Cambrian or younger age.

Discussion. Alpert (1974) reviewed the ichnogenus *Skolithos* conducted solely on literature research and concluded that ichnogenera such as *Tigillites* Rouault, 1850 (partim), *Stipsellus* Howell, 1957, *Sabellarifex* Richter, 1921, and *Asabellarifex* Klahn, 1932 can be confidently put in synonymy with *Skolithos*. Alpert (1974) recognised five ichnospecies of *Skolithos* (Table 7.8 and Fig. 7.54) and later proposed a sixth, *Skolithos bulbosus* Alpert, 1975. Subsequently, several other ichnospecies of *Skolithos* have been introduced; Hofmann (1979) proposed *Skolithos gyratus* from Ordovician of Ottawa. Fillion and Pickerill (1990b) considered *Skolithos lianhuashanensis* Yang, 1983 a junior synonym of *Skolithos linearis*. Walter and Elphinstone (in Walter *et al.*, 1989) reported *Skolithos ramosus* from the Early Cambrian of central Australia. They (1989) stated that *Skolithos ramosus* displays both branched and unbranched forms. The ichnogenus *Skolithos* does not include vertical branched burrows (Alpert, 1974, p. 662) and vertically branched forms are best assigned to other available ichnogenera (e.g. *Chondrites* von Sternberg, 1833; *Fascifodina* Osgood, 1970).

Although Alpert (1974) considered that the generic description of *Tigillites* agrees with that of *Skolithos*, he considered that several ichnospecies assigned to *Tigillites* can not be transferred to *Skolithos* for morphological reasons.

Alpert (1974) considered that large vertical burrows with a diameter greater than 15 mm should be assigned to other ichnogenera (e.g. *Pilichnia* Chamberlain, 1971b). However, erecting a new ichnogenus solely based on size is not warranted unless it has been associated with a statistical analysis.

**Table 7.8** - Reported ichnospecies of *Skolithos*.

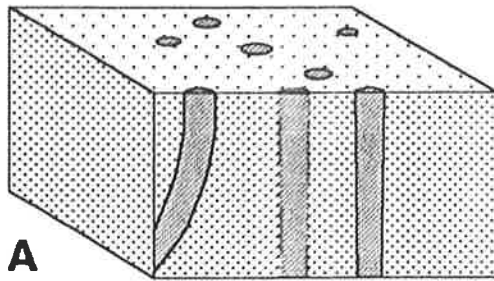
<i>S. linearis</i>	Haldeman	1840	vertical to slightly inclined, 3-12 mm in diameter and up to a meter long, wall distinct to indistinct and may be annulate.
<i>S. verticalis</i>	(Hall	1843)	straight to curved, vertical to inclined, 1-4 mm in diameter, wall smooth, rarely corrugated
<i>S. magnus</i>	Howell	1944	vertical may curve slightly, 6-12 mm in diameter, wall distinct somewhat irregular
<i>S. ingens</i>	Howell	1945	vertical, 7-9 mm in diameter, wall distinct, shows slight bulges at irregular intervals.
<i>S. annulatus</i>	(Howell)	1957	Vertical, straight, about 12 mm in diameter, wall distinct, smooth with ring-like annulations
<i>S. bulbus</i>	Alpert	1975	Vertical to inclined, straight, or undulate, wall distinct and smooth, with widely spaced spherical expansions and slight bulge along the length.
<i>S. gyratus</i>	Hofmann	1979	Straight vertical burrows having a screw-like filling of sand.
<i>S. lianhuashanensis</i>	Yang	1983	= <i>S. linearis</i>
<i>S. ramosus</i>	Walter & Elphinstone	1989	Vertical, 1-3 mm in diameter, having a bulbous base, branched or unbranched.

***Skolithos bulbus* Alpert 1975**

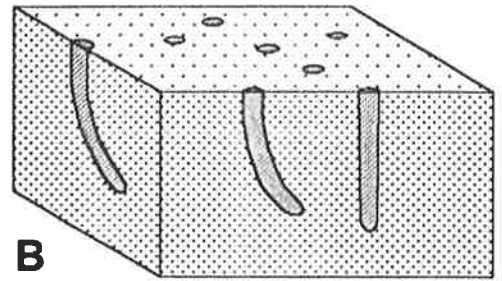
Plates 13B, 26D

Collected specimens. One specimen, A1035-MO62.

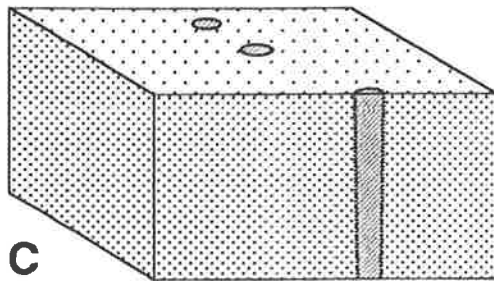
Diagnosis. Cylindrical to sub-cylindrical, vertical to inclined (rarely up to 45°), straight, curved, or undulate. Burrows comprise a distinct, smooth wall and are characterised by widely spaced spherical to subspherical expansions and slight bulge along the length (after Alpert, 1975).



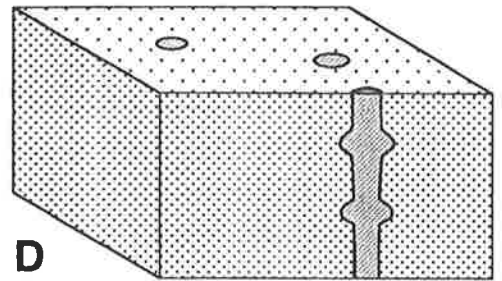
**A**  
Diameter= 3-7 upto 12 mm  
Length upto 1 metre  
with or without wall



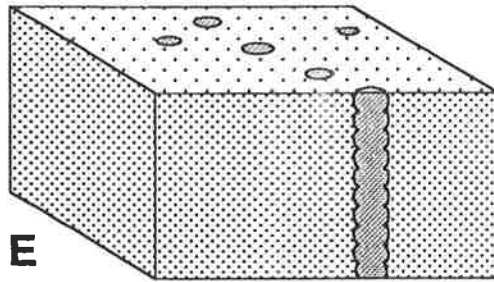
**B**  
Diameter= 1-4 mm  
Length =2-15 mm  
wall smooth, commonly inclined and curved



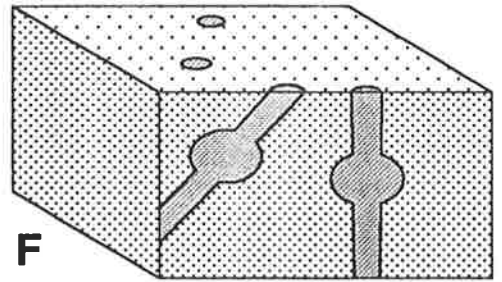
**C**  
Diameter= 6-12 mm  
Length upto 20 cm  
wall distinct but irregular



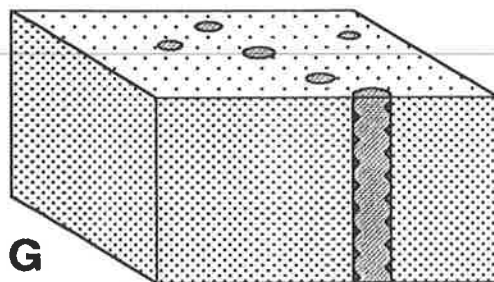
**D**  
Diameter= 7-9 mm  
wall distinct, bulges spaced irregularly



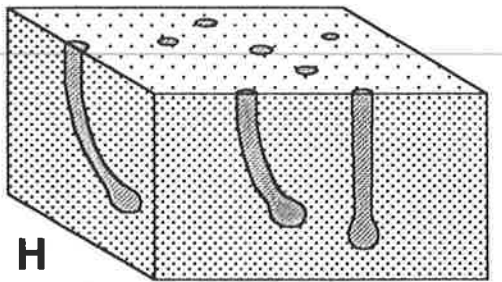
**E**  
Diameter=12 mm  
Length upto 15 cm  
wall distinct with ring-like annulations



**F**  
Diameter= 4-15 commonly 7-11 mm  
vertical to inclined upto 45



**G**  
Diameter= 5-25 mm



**H**  
Diameter= 1-3 mm  
vertical to steeply inclined  
bulbous at end

**Figure 7.54** - Ichnospecies of *Skolithos*: **A.** *S. linearis*; **B.** *S. verticalis*; **C.** *S. magnus*; **D.** *S. ingens*; **E.** *S. annulatus*; **F.** *S. bulbosus* (A-F after Alpert, 1975); **G.** *S. gyratus* (after Hofmann, 1979); **H.** *S. ramosus* (after Walter and Elphinstone, 1989).

Description. A circular burrow, slightly inclined to the bedding plane, 3 mm in diameter. Burrow shows a thin lining and filling which is finer than the host rock. A spherical structure occurs along length of the burrow 6 mm in diameter and coated with fine sediment darker in colour than the fillings or the host rock. The upper bedding plane view displays a large circular structure 14 mm in diameter positioned uncentred over the burrow (Fig. 7.55).

Discussion. This burrow is smaller in diameter than the type material. The significance of the large circular structure above the burrow is not clear and likely it indicates a wide and shallow funnel at the burrow aperture. It is noteworthy that the structure is not located central to the burrow. Since the bedding plane views of *Skolithos* burrows may be similar to one another and vertical sectioning is required for their identification, a number of this ichnospecies may exist within the present collection.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

*Skolithos ramosus* Walter and Elphinstone in Walter *et al.*, 1989

Plates 24E, 25C

1989 *S. ramosus* Walter and Elphinstone, p. 246, fig., 15C.

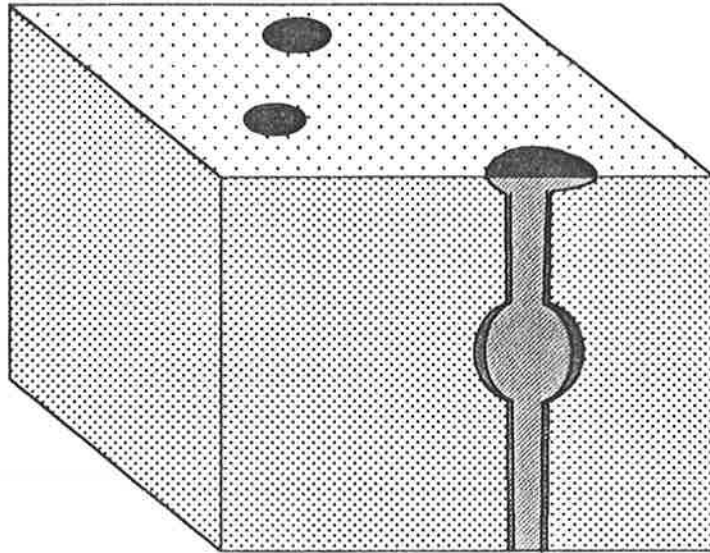
Collected specimens. Three specimens, A971-1-35, A1035-R30, and field photograph 1-7.

Diagnosis. "Vertical burrows 1-3 mm in diameter, constant width throughout except for their bulbous bases. Burrows may be branched or unbranched" (Walter and Elphinstone in Walter *et al.*, 1989, p.247).

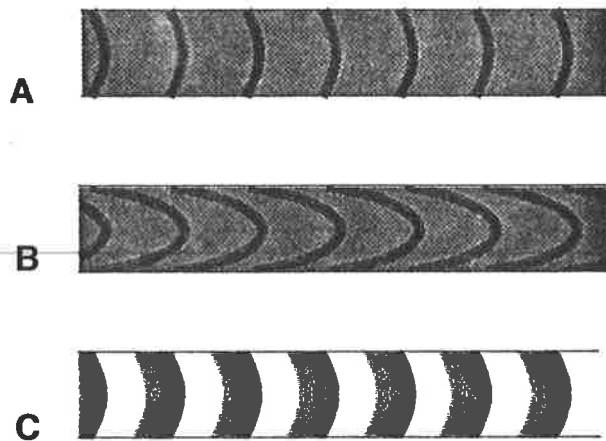
Description. Circular tubes or pipes, perpendicular to the bedding plane, 1-2 mm in diameter and 40-150 mm long; fill is commonly finer than the host rock which may have been eroded off. Burrows display a bulbous structure at their distal part with a rounded base slightly wider than the main tube.

Discussion. The present material closely resembles *S. ramosus* reported by Walter and Elphinstone (in Walter *et al.*, 1989).

Occurrence. The Allua Formation, Ross River and Cyclops Bore, Amadeus Basin.



**Figure 7.55** - Transverse cross section through *Skolithos bulbus* from the Donkey Creek Beds, Georgina Basin, shows a spherical structure at the middle of the burrow coated with clay. Note the subcircular structure on the top of the burrow not located centrally.



**Figure 7.56** - Ichnospecies of *Taenidium*: **A.** *T. serpentinum*; **B.** *T. cameronensis*; **C.** *T. satanassi* (after D'Alessandro and Bromley, 1987).



***Skolithos verticalis* Hall, 1843**

Plates 15A, 17A, 24B,D, 25B,E, 28F

Collected specimens. Thirteen specimens, A971-1-2, A971-1-13, A971-1-20, A971-2-45, A971-4-7, A1035-MO6, A1035-MO75, A1035-MO84, A1035-MO88, A1035-MO109, A1035-R4, A1035-R5, and A1035-R13.

Diagnosis. Cylindrical, straight to curved, vertical to inclined burrows 1-4 mm in diameter with a smooth wall which is rarely corrugated (After Alpert, 1974).

Description. Circular burrows, straight to curved, perpendicular or inclined to the bedding plane, 1-5 mm in diameter. Burrows cut through different layers of sediment and no complete burrow is observed. They occur sparsely or in dense groups. Fill is the same or finer than the host rock.

Discussion. *S. verticalis* differs from other forms of *Skolithos* in being generally smaller, and more commonly inclined and curved (Alpert, 1974).

Occurrence. Box Hole and Allua Formations, Ross River and Cyclops Bore, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

***Taenidium* Heer, 1877**

Type ichnospecies. *T. serpentinum* Heer, 1877 by subsequent designation of Hantzschel, 1962.

Diagnosis. The diagnosis for the ichnogenus has been emended by D'Alessandro and Bromley (1987, p. 751) as follows: "Unlined or very thinly lined, unbranched, straight or sinuous cylindrical burrows containing a segmented fill articulated by meniscus-shaped partings".

Discussion. The ichnogenus *Taenidium* has been extensively reviewed by D'Alessandro and Bromley (1987). Their study is considered fundamental for detailed discussion of the relationship between *Taenidium* and other backfilled burrows. Various names have been

applied to classify meniscus burrows including *Muensteria* Sternberg, 1833; *Taenidium* Heer, 1877; *Scalarituba* Weller, 1899 and *Ancorichnus* Heinberg, 1974)

*Muensteria* is commonly used for unbranched, unlined burrows with meniscate fills. D'Alessandro and Bromley (1987) reviewed the type material of *Muensteria* and concluded that as a trace fossil, *Muensteria* is an unavailable ichnotaxon.

Heinberg (1974) introduced the name *Ancorichnus* for the meniscate backfilled burrows in which the meniscus fills are separated from the host rock by a very well developed thick wall. Later, Frey *et al.* (1984) and Howard and Frey (1984) introduced new ichnospecies of *Ancorichnus*, *A. coronus* and *A. capronus* respectively. D'Alessandro and Bromley (1987) considered that only *A. ancorichnus* is a distinct ichnospecies and the other two should be transferred to *Taenidium*, though they did not include these ichnogenera in their synonymy table for *Taenidium*. Three ichnospecies of *Taenidium* were reported by D'Alessandro and Bromley (1987) (Table 7.9, Fig. 7.56).

**Table 7.9** - Reported ichnospecies of *Taenidium*.

<i>T. serpentinum</i>	Heer	1877	well-spaced arcuate menisci, their external mould may show slight annulation due to menisci. it has a sharp boundary without or with insignificant lining.
<i>T. cameronensis</i>	(Brady	1947)	deeply concave menisci with intermeniscate segments generally longer than wide with secondary successive branching and intersection
<i>T. satanassi</i>	D'Alessandro and Bromley	1987	alternating meniscus-shaped packets of sediment, the darker one considered to be pellets. The menisci are equal in thickness and shorter than wide

Originator. Heinberg (1974) considered sipunculids or priapulids as likely organisms responsible for *A. ancorichnus*. Frey *et al.* (1984) did not find any evidence of hydrostatic anchor in *A. coronus* hence, excluding the mentioned groups of animals as potential

producers of this ichnotaxon. Frey *et al.* (1984) concluded that the prominent internal meniscus layers of *A. coronus* and lack of collapse structure along the burrow suggest that the trace maker was an infaunal deposit feeder that actively filled its burrow (e.g. polychaetes and crustaceans). The concave sides of the menisci indicate the direction of movement (Frey *et al.*, 1984). Marine decapods are considered to be likely producers of *A. capronus* (Howard and Frey, 1984).

### *Taenidium serpentinum* Heer 1877

#### Plate 26A,B

1984 *A. coronus* Frey *et al.*, 1984; P. 516, figs 1D-E & fig. 3.

Collected specimens. One specimen, A1035-R28.

Diagnosis. D'Alessandro and Bromley (1987) emended the original diagnosis as follows: "Serpentiform *Taenidium* having well-spaced, arcuate menisci; distance between menisci about equal to or little less than burrow width. External mould may show slight annulations corresponding to menisci, or line transverse wrinkling. Secondary subsequent branching and intersections occur. Boundary sharp, lining lacking or insignificant".

Description. Straight to curved, lined, burrows, 6-8 mm wide and distinctly displaying meniscate fill. The burrows are predominantly horizontal. The wall lining is about 0.5 mm wide. The burrow fill consists of menisci of alternating dark and light coloured arcuate-shaped structures consisting of fine and coarse grained sediments respectively. The slightly darker fine-grained menisci are generally thinner than the broader coarse-grained ones. The distal parts of the menisci merge with the outer wall of the burrow. Fine grained menisci are 0.3 to 0.6 mm wide and are spaced 1-3 mm apart. Well preserved specimens display a smooth, unornamented annulated outer wall. The burrows are not branched. However, they illustrate crossing, which occurs at the same level.

Preservation. Both endichnial and hypichnial burrows have been reported (Frey *et al.* 1984). The studied specimens are preserved as low relief, convex hypichnial burrows on soles of sandstone layers.

Discussion. The present specimens are similar to the original material of *A. coronus* reported by Frey *et al.* (1984), but are larger and display broader spaces between the fine-grained menisci. Frey *et al.* (1984) reported that although the width of fine-grained menisci is almost the same for all of their specimens, the distance between them increases in larger specimens. This is also shown by the present specimens which are larger (6-8mm compare to 3-4 mm) and represent broader spaces between the fine-grained menisci (1-3 mm).

Occurrence. The Allua Formation, Ross River, Amadeus Basin.

### ***Taphrhelminthoida* Ksiazkiewicz, 1977**

Type ichnospecies. *Taphrhelminthoida convoluta* Ksiazkiewicz, 1977, p. 168.

Diagnosis. "Bilobate, guided meandering trace with a tendency to coiling" (after Ksiazkiewicz, 1977).

Discussion. *Taphrhelminthopsis* is characterised by the freely winding and non guided meandering course of the burrow. Ksiazkiewicz (1977) erected the ichnogenus *Taphrhelminthoida* for bilobate, guided meandering burrows (see the discussion under *Taphrhelminthopsis*). Most specimens from the Carpathian flysch showed obliquely laminated sand in the burrow fill, but in a few instances the burrow intersects flute casts. Ksiazkiewicz (1977) concluded that the burrow could be both pre- or post-depositional in origin. Hofmann and Patel (1989) discussed the endogenic origin for *T. dailyi* in the Early Cambrian sediments of New Brunswick, Canada. The authors (1989) also argued that *Didymaulichnus meandriformis* Fedonkin, 1985 reported from the Early Cambrian of the Olenyok River, Siberia should be transferred into this ichnogenus because *Didymaulichnus* does not include guided meandering burrows.

Originator. The producer was considered to be probably amphineuran molluscs or solenogasters (Ksiazkiewicz, 1977).

Age. *Taphrhelminthoida* occurs in Early Cambrian (Hofmann and Patel, 1989; this study) to Cretaceous - Tertiary sediments (Ksiazkiewicz, 1977).

*Taphrhelminthoida ?convoluta* Ksiazkiewicz, 1977

Plates 27B-F, 28A

Collected specimens. Four specimens, A1035-MO51A, A1035-MO64, A1035-MO65, and A1035-MO164.

Diagnosis. "Hypichnial rope-sized groove cast; bilobate meanders closely spaced, commonly coiled. Median groove concave, fairly deep, the marginal ridges large and rounded (after Ksiazkiewicz, 1977).

Description. Large bilobate burrows 25-30 mm wide comprising two marginal, rounded lobes separated by a deep median furrow 2-3 mm wide. Lobes are elevated close to the median furrow, producing levees in some places. The lobes may exhibit transverse striations or faint annulations (Pl. 28A). The burrow has been preserved as endoreliefs in which the convex bilobate structure is located on the sole of the burrow.

The median furrow is deep and reaches to the other side (upper side) of the burrow. It has been filled with sediments displaying faint transverse striations. Specimen A1035-MO65 (Pl. 27D) has been broken along the median furrow exposing the internal structure of the burrow at its axial section. The median furrow has a smooth wall extending up into the overlying sediment. This wall shows fine annulations and apparently had been covered by mucus. The same specimen as well as another specimen from Mount Octy (Pl. 27B) show a structure consisting of transversely striated, fine-grained sediment located under the bilobate part and separating it from the host rock (plate 27B, D). The striations are located 1-1.5 mm apart, oblique to the burrow making an angle of about 45°.

Discussion. Ksiazkiewicz (1970, p. 300) considered *Cylindrites convoluta* Heer, 1876 to be an ichnospecies of *Taphrhelminthopsis* based on the illustration of a specimen by Vassoevich (1932). Later, Ksiazkiewicz (1977) stated that he could not find any bilobate structure under that name in Heer's paper and Heer's *C. convoluta* represents a unilobate cylindrical burrow probably a *Helminthopsis*. Accordingly, Ksiazkiewicz (1977) introduced a new ichnospecies *Taphrhelminthoida convoluta* based on specimens found in the Carpathian flysch.

Ksiazkiewicz (1977) reported a likely endogenic origin for this ichnospecies. *T. dailyi* is also considered to be an endogenic burrow. The present specimens do not display closely spaced, coiled meanders and consequently have been tentatively assigned to *T. convoluta*. *T. ? convoluta* from central Australia has been preserved as an endorelief and displays a complex structure. The lower side of the burrow rests on an obliquely striated blanket of sediments which extends under the lobes and median furrow. The producer probably moved sediment in front along its ventral side and packed it behind. The median furrow is deep and extends into the overlying sediments (plate 27C). Its wall shows vertical annulations indicating movement of a vertical object (likely a siphon) extended to the surface to maintain a connection to the sea floor. Figure 7.57 shows a three dimensional reconstruction of the burrow. Where preserved, the basal obliquely laminated backfill of the burrow forms a unilobate convex hyporelief, superficially resembling *Psammichnites*. However, the upper surface of the burrow in the former is not clearly preserved and is not bilobate and transversely striated.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

*Taphrhelminthoida dailyi* Hofmann and Patel, 1989.

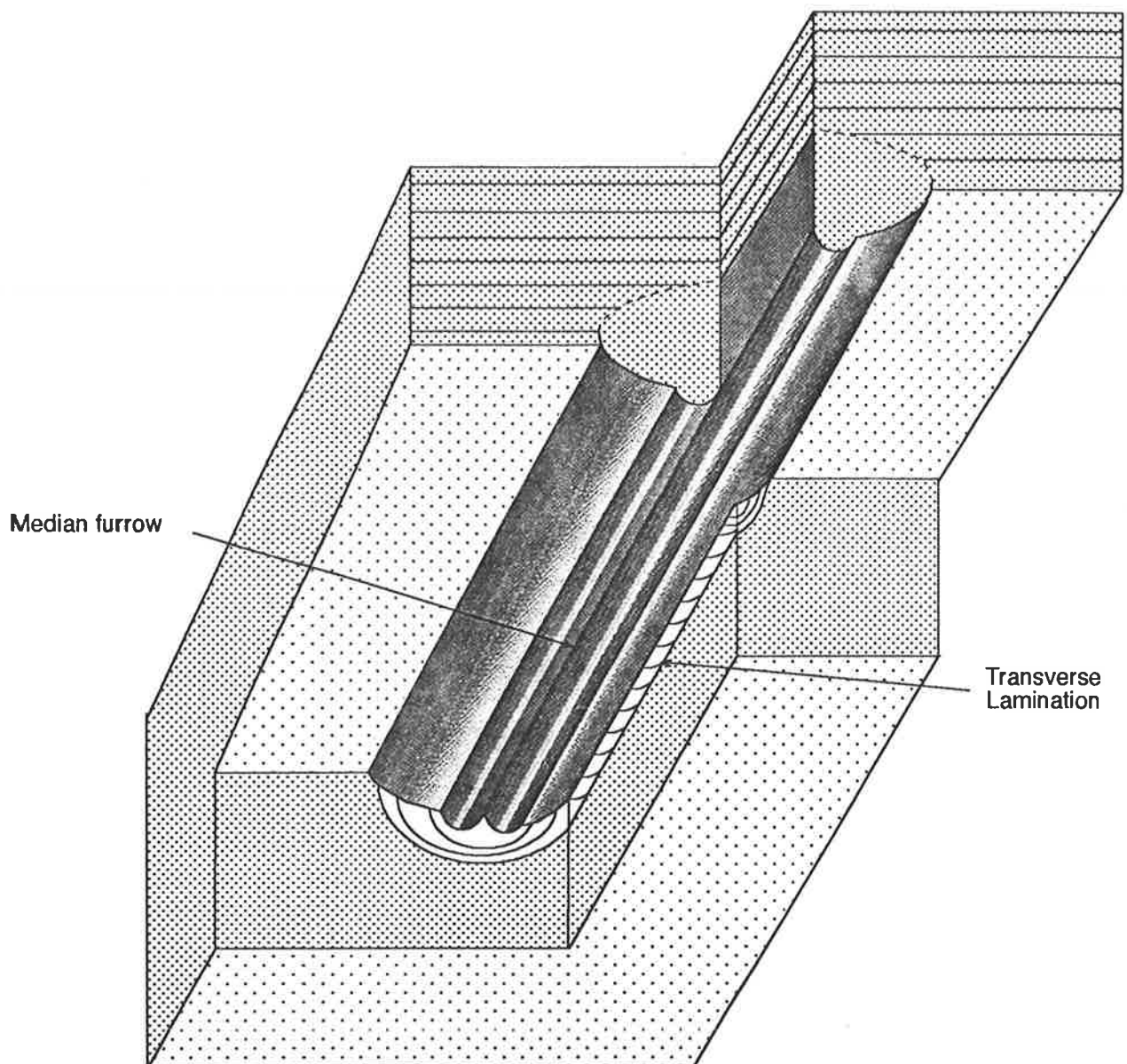
Plate 26C

1989 *T. dailyi* Hofmann and Patel, p. 148, figs 4f, 6-12.

Collected specimens. One specimen, A1035-MO201.

Diagnosis. Bilobate, regularly meandering subsurface trail with openly subparallel meander limbs displaying a sinusoidal axial groove (after Hofmann and Patel, 1989).

Description. A large meandering burrow preserved as concave epirelief on a medium grained sandstone layer. The burrow is 12-15 mm wide and shows regular meanders with almost parallel, elongate limbs. Meanders are up to 14-18 cm long and 4-6 cm wide. The burrow shows some partial filling, which is the same as host rock but, does not show a clear bilobate structure. The burrow is floored by a thin film of fine grained sediment which is darker in colour than the host rock.



**Figure 7.57** - Three dimensional reconstruction of *Taphrhelminthoidea convoluta*. There is a transverse laminated part underneath the burrow. The median furrow is deep and extends through the overlying sediment laminae.

Discussion. The present material closely resembles *T. dailyi* illustrated in Hofmann and Patel (1989, fig. 7) from the Early Cambrian Ratcliffe Brook Formation, New Brunswick, Canada. Since it is an epichnial preservation, it does not show the typical bilobate structure of the ichnogenus.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

### *Taphrhelminthopsis* Sacco 1888

Type ichnospecies. *Taphrhelminthopsis auricularis* Sacco, 1888; by subsequent designation of Andrew (1955 as cited in McCann & Pickerill (1988) and Hantzschel (1962, p. W218).

Diagnosis. Bilobate, freely winding burrows generally preserved as hypichnial casts comprising two lateral lobes separated by a distinct median furrow (after Ksiazkiewicz, 1977).

Preservation. *Taphrhelminthopsis* is commonly preserved as hypichnial casts indicated by a filling with much coarser material than the host rock, or with oblique laminated sand. Seilacher (1962 cited in Ksiazkiewicz, 1977) considered *Taphrhelminthopsis* as an excavated burrow, suggesting that after the production of the trace in muddy substrate, currents removed the soft infill of the burrow and filled it with sand. Ksiazkiewicz (1977) found some full relief bilobate traces and assigned them questionably to this ichnogenus, showing that the Seilacher's interpretation may be correct in some instances. Smith and Crimes (1983) considered *Taphrhelminthopsis* to be a washed out predepositional *Subphyllochora*. Plaziat and Mahmoudi (1988) disputed this interpretation based on a specimen of *Taphrhelminthopsis* found conjoined to the base of an endogenic *Laminites* burrow. Crimes and McCall (1995) reported *T. auricularis* and *T. vagans* from the Makran Ranges, Iran and considered a predepositional origin (in terms of turbidite deposition) for the traces. They (1995) found that the trace was affected by erosion and did not have a distinct outline. Smith and Crimes (1983) gave a similar predepositional origin for the trace.

Discussion. Bilobate, irregularly winding traces with a distinct median furrow were grouped under the name *Taphrhelminthopsis* by Sacco (1888). Later Andrew (1955; cited in McCann & Pickerill, 1988 p. 342) and Hantzschel (1962, 1965, p 91) chose *T. auricularis* Sacco,



1888 as the type ichnospecies. Książkiewicz (1977) could not find any intermediate form between non-meandering and guided meandering forms among his extensive collection of *Taphrhelminthopsis* from the Carpathian Series in Poland. Since, the original description of the trace did not embrace guided meandering forms, he (1977) excluded all bilobate, guided meandering traces with a distinct median furrow and classified them as a new ichnogenus *Taphrhelminthoida*. Plicka (1987) suggested that the meandering criterion should be used at ichnospecies level. He erected a new species *Taphrhelminthopsis maeandriiformis* and considered the ichnogenus *Taphrhelminthoida* as its synonym. Many authors (e.g. Hofmann and Patel, 1989; Crimes, 1994) continued to use *Taphrhelminthoida* as a distinct ichnogenus, a practice which is followed in this study.

*Taphrhelminthopsis* is similar to *Didymaulichnus*, but has a wider median furrow and flatter ridges and also shows less tendency to cross and a greater propensity to meander. The former sometimes shows longitudinal striations along the median furrow or transverse striations on the lateral lobes.

At least nine ichnospecies of *Taphrhelminthopsis* have been reported (Table 7.10). Of these, *T. plana* has been transferred into the ichnogenus *Taphrhelminthoida* because of its guided meandering course (Książkiewicz, 1977). *T. maeandriiformis* has a wide median furrow separating narrow lobes, it is similar to *T. podhalensis*, but shows a meandering course. It is best attributed to *Taphrhelminthoida*. It should be noted that it is difficult practically to differentiate between ichnospecies of *Taphrhelminthopsis* (except *T. circularis*) as a number of intermediate forms have also been found. A revision of the ichnogenus is suggested.

**Originator.** Książkiewicz (1977) considered that the presence of the longitudinal furrow along the trace indicates that the animal responsible had a furrow along its ventral side which produced a ridge along the under mould as it crept over the sediment surface. Subsequently the mould was filled by deposited sands and the ridge appeared as a furrow on the cast. The same author (1977) considered that *Solenogaster* could potentially produce the trace since it has a longitudinal furrow on its ventral side. Some *Solenogaster* live on the muddy bottom of bathyal deeps. Książkiewicz (1977) also postulated another alternative that the trace was an excavated burrow, following the previous opinion of Seilacher (1962 cited in Książkiewicz, 1977). For this, Książkiewicz (1977) considered that the producer was a fairly large animal

with a cylindrical body, perhaps an acorn worm. Plaziat and Mahmoudi (1988) compared *T. auricularis* with *Subphyllochora*, principally its prominent median cord which is biseriate and inflated and divided by a deep median groove. They attributed the trace to a burrowing echinoid.

**Table 7.10** - Reported ichnospecies of *Taphrhelminthopsis*.

<i>T. auricularis</i>	Sacco	1888	characterised by its ear-shaped course
<i>T. recta</i>	Sacco	1888	has longitudinal striations along median furrow
<i>T. convoluta</i>	(Heer)	1932	non <i>Taphrhelminthopsis</i> as cited in Ksiazkiewicz, 1977, p. 169
<i>T. subauricularis</i>	Chiplonkar & Badwe	1969	lobes displaying gill-like furrows
<i>T. plana</i>	Ksiazkiewicz	1970	= <i>Taphrhelminthoida</i>
<i>T. circularis</i>	Crimes <i>et al.</i>	1977	irregularly circling habit
<i>T. vagans</i>	Ksiazkiewicz	1977	straight to feebly winding bilobate burrow with rounded ridges
<i>T. podhalensis</i>	Roniewicz & Pienkowski	1977	two parallel ridges separated by a semicircular furrow and often situated on a trapezoidal ridge
<i>T. maeandriiformis</i>	Plicka	1987	= <i>Taphrhelminthoida</i>

Age. Early Cambrian (Crimes *et al.*, 1977; Bhargava and Srikantia, 1982; Kumar *et al.*, 1983; this study) to Cretaceous-Eocene (Crimes, 1970; Ksiazkiewicz, 1970, 1977).

*Taphrhelminthopsis circularis* Crimes, Legg, Marcos and Arboleya, 1977

Plates 27A, 28B,D

1977 *T. circularis* Crimes *et al.*, p. 125, pl. 8a-e.

1982 *T. circularis* Crimes *et al.*; Bhargava and Srikantia, p. 406, fig. 2.

1983 *T. cf. circularis* Crimes *et al.*; Kumar *et al.*, p. 109, pl. I-6.

1985 *T. circularis* Crimes *et al.*; Crimes and Anderson, p. 334, figs 12.6-7.

1985 *T. circularis* Crimes *et al.*; Fritz and Crimes, p. 16, pl. 5, fig. 4.

1986 *T. circularis* Crimes *et al.*; Crimes and Jiang Zhiwen, p. 645, figs 4.d-e.

1987 *T. circularis* Crimes *et al.*; Narbonne *et al.*, p. 1286, fig. 6f.

Collected specimens. Three specimens, A971-2-49, A971-2-50, A1035-B15, and field photos 1-5,6.

Diagnosis. "Bilobate trace with narrow but well defined central furrow and exhibiting an irregularly circling habit. With or without transverse or oblique striations" (after Crimes *et al.*, 1977).

Description Circular bilobate burrows preserved as convex hyporeliefs or epireliefs and comprising two rounded, convex lobes separated by a median furrow. Burrows are 8-12 mm wide and the median furrow is 2-3 mm in width. The circular structure varies from 18 to 50 mm in diameter. Burrows are preserved on thinly bedded, fine- to medium-grained sandstones and are visible on both sides of slabs. A specimen photographed in the field shows an outline similar to a figure 8 (Plate 28D).

Discussion. *T. circularis* has been reported widely from Early Cambrian deposits and is apparently restricted to that age (Table 7.11). Crimes and Jiang Zhiwen (1986) suggested that *T. circularis* may be proven as an index ichnotaxon for the older Early Cambrian.

The burrow illustrated by Cowie and Spencer (1970, pl. 2, fig. c) as an "organic mark" was attributed to *T. circularis* by Crimes *et al.* (1977). Although Pickerill and Peel (1990) agreed that this trace can be assigned to *Taphrhelminthopsis*, they questioned its attribution to *T. circularis* and stated that the specimen is best identified only at the ichnogeneric level. Some of the present specimens show pattern similar to a figure 8 and are similar to those previously reported by Crimes and Jiang Zhiwen (1986) from Meishucun, Yunnan, China.

Occurrence. Lower Allua Formation, Cyclops Bore and Ross River, Amadeus Basin.

**Table 7.11** - Reported occurrences of *T. circularis*.

Crimes <i>et al.</i>	1977	p. 125, pl. 8a-e	older Early Cambrian	Cayetano Beds of Candana Quartzite	North Spain
Bhargava and Srikantia	1982	p. 406, fig. 2	basal part of the Cambro-Ordovician	Kashmir valley	India
Kumar <i>et al.</i>	1983	p. 109, pl. I-6.	Early Cambrian	Tal Formation	Garhwal Synform, Uttar Pradesh, India
Crimes and Anderson	1985	p. 334, figs 12.6-7	Early Cambrian	Chapel Island Formation	Newfoundland, Eastern Canada
Fritz and Crimes	1985	p. 16, pl. 5, fig. 4	Early Cambrian	Stelkuz Formation	Cassiar Mountains, Canada
Crimes and Jiang Zhiwen	1986	p. 645, figs 4.d-e	Early Cambrian	Badaowan Member,	Meishucun, Yunnan, China
Narbonne <i>et al.</i>	1987	p. 1286, fig. 6f	Early Cambrian	Member 2a, Chapel Island Formation	Burin Peninsula, Newfoundland, Canada

***Taphrhelminthopsis vagans*. Ksiazkiewicz, 1977****Plate 28F**

1986 *Taphrhelminthopsis* isp.; Crimes and Jiang Zhiwen, p. 645, fig. 4. f.

**Collected specimens.** One specimen, A1035-R5.

**Diagnosis.** " Hypichnial ridge-like cast, bilobate, almost straight or feebly winding, with median concave trough bordered by round ridges"(after Ksiazkiewicz, 1977).

**Description.** A large, gently curved, bilobate burrow comprising two convex lobes separated by a wide median furrow 4-6 mm wide. The width of the lobes and furrow changes slightly

along the burrow. The burrow is 45-50 mm wide and has been preserved as a convex hyporelief.

Discussion. The burrow has been penetrated by numerous vertical burrows (*Skolithos*). It is similar to the specimen trace from the Makran Range, Iran described by Crimes and McCall (1995) but is larger. It is well accommodated within the size range given for the trace by the original author (Ksiazkiewicz, 1977 p. 138).

Occurrence. Lower Allua Formation, Ross River, Amadeus Basin.

### ***Taphrhelminthopsis* isp.**

Plate 28C,E

Collected specimens. Five specimens, A1035-MO58, A1035-MO111, A1035-MO148, A1035-MO149, and A1035-MO150.

Description. Large, straight to curved, bilobate burrows preserved as convex hyporeliefs with a distinct, wide, deep median furrow. Lobes are convex and sometimes show faint transverse striations. Burrows are 16-24 mm wide and the median furrow is about 2-4 mm broad.

Discussion. Some of these burrows similar to *Taphrhelminthoida convoluta* do not display a meandering course, and therefore, they are included within *Taphrhelminthopsis*. The median furrow is deep and sometimes has been filled with sediment. The lobes are sometimes more elevated close to the median part of the burrow, producing ridges lateral to the median furrow.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

### ***Teichichnus* Seilacher, 1955**

Type ichnospecies. *Teichichnus rectus* Seilacher, 1955; by monotypy, from the Early Cambrian *Neobolus* Sandstone of the Salt Range, Pakistan.

Diagnosis. Long, wall-like burrows formed by vertical displacement of horizontal or oblique tubes (after Seilacher, 1955; Hantzschel, 1975).

Discussion. The *Teichichnus*-like structure has been reported to occur within different ichnogenera (e.g. *Ophiomorpha nodosa*, *Phycodes*, *Thalassinoides*) indicating reworking of sediments by the originator of the burrow (Fig. 7.58A). The burrow has been interpreted to be an equilibrium structure as a result of the animal's response to sediment fluctuations. *Teichichnus* differs from the proximal part of *Phycodes* mostly by its lack of branching

Age. *Teichichnus* has been reported from sediments of Early Cambrian to Tertiary age (Hantzschel, 1975).

*Teichichnus* isp.

Plate 29A

Collected specimens. One specimen, A1035-MO25.

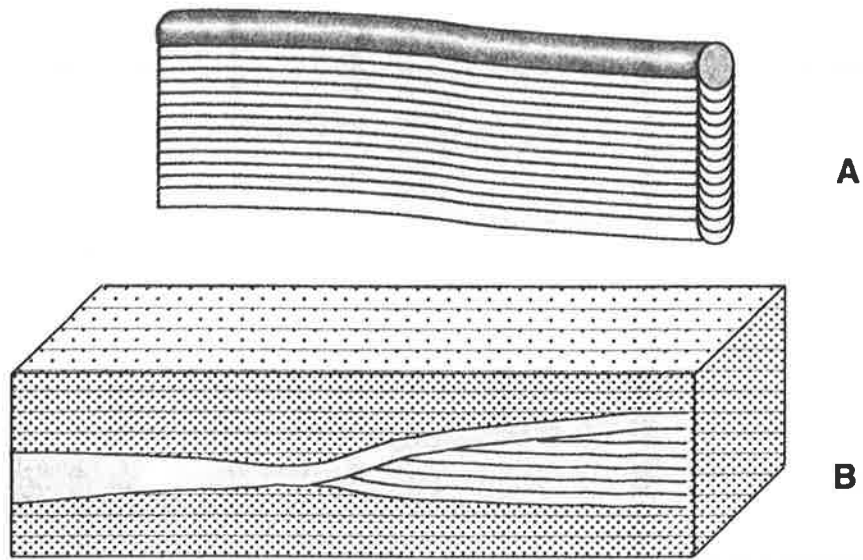
Description. A straight burrow preserved as an endorelief visible on the side of a sandstone slab. The burrow is 3–4 mm wide and widens into a vertical retrusive spreiten structure. The spreiten structure has been developed on one side and is 24 mm thick.

Discussion. *T. rectus* was diagnosed to be a straight, unbranched burrow with retrusive spreiten. The present material displays a spreiten structure similar to that illustrated in Howard and Frey (1984, fig. 21), probably indicating deposit feeding behaviour. The burrow differs from *T. rectus* as the spreiten structure is only developed on part of the burrow (Fig. 7.58B).

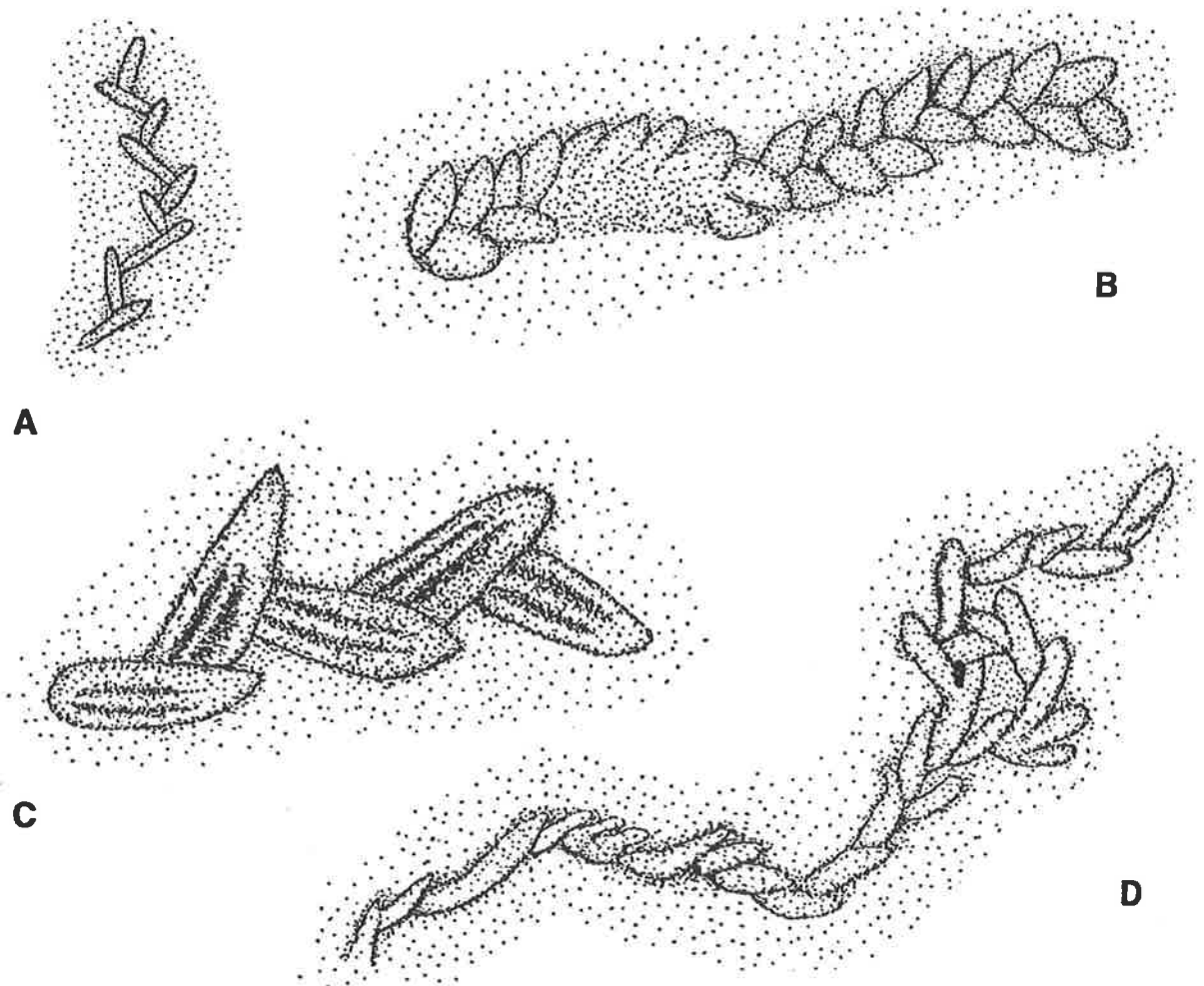
Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

*Torrowangea* Webby, 1970

Type ichnospecies. *Torrowangea rosei* Webby, 1970; by original designation.



**Figure 7.58** - A. Reconstruction of *Teichichnus rectus* (after Häntzschel, 1975). B. *Teichichnus* isp. from central Australia.



**Figure 7.59** - Ichnospecies of *Treptichnus*: A. *T. bifurcatus* (after Archer and Maples 1984); B. *T. lublinensis* (after Paczesna, 1986); C. *T. triplex* (after Palij et al., 1983); D. *T. pedum* (after Jensen, 1997).

Diagnosis. "Random, sinuous to meandering trails, from 1-2 mm wide, with irregularly spaced transverse constrictions" (Webby, 1970, p. 101).

Discussion. *Gordia nodosa* Pickerill and Peel, 1991 is morphologically similar to *T. rosei*. Pickerill and Peel (1991) distinguished the two by the tendency of the former for level crossing. However, the holotype of *G. nodosa* (Pickerill and Peel, 1991 fig. 4) clearly shows burrows passing over or under pre-existing ones and purposefully avoiding level crossings, the phenomenon also observed by the original authors. Additionally, *Gordia* represents burrows with a smooth surface unlike that of *G. nodosa*. It is considered that the similarities between the two ichnogenera are sufficient to consider *G. nodosa* as a junior synonym of *T. rosei*.

Originator. *Torrowangea* represents the feeding burrow of a worm-like organism, likely an annelid and occurs in both shallow- and deep-water deposits (Narbonne and Aitken, 1990). Webby (1970) favoured the postdepositional origin of the burrow due to its termination or offset by current markings.

Age. *T. rosei* was originally described from the Lintiss Vale Formation of New South Wales, Australia (Webby, 1970). Although the age of this unit is controversial, the occurrence of complex burrows suggests an Early Cambrian age (Walter *et al.*, 1989). *T. rosei* has apparently been reported only from Latest Precambrian (Paczesna, 1985, 1986; Narbonne and Aitken, 1990; Geyer and Uchman, 1995) and Early Cambrian sediments (Walter *et al.*, 1989)

*Torrowangea ?rosei* Webby, 1970

Plate 29B

Collected specimens. Four specimens, A971-2-49, A1035-MO54A, A1035-MO70, A1035-MO153 and field photographs, 1-24, 2-3.

Diagnosis. Same as the ichnogenus.



Description. Meandering to tightly curved unbranched trails, parallel to bedding with regular constrictions causing transverse annulations at 2-4 mm intervals or closely spaced, diameter 0.5-2 mm. Preserved in convex hyporelief.

Discussion. The annulated appearance of *Torrowangea* was interpreted by Webby (1970) as a backfill structure. Narbonne and Aitken (1990) showed that in longitudinal thin section the burrow does not show internal structure and concluded that the annulation most likely represent peristalsis.

Occurrence. Lower Allua Formation, Cyclops Bore and Hugh River, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

### *Treptichnus* Miller, 1889

Type ichnospecies. *Treptichnus bifurcus* Miller, 1889; by original designation (Hantzschel, 1975, p. W117).

Diagnosis. Trace consisting of segments of curved burrows joining each other at low angles and intersecting to form projections on one or both sides of burrow. The burrow may exhibit striations or longitudinal furrows. The trace is straight to winding and has been preserved as convex hyporeliefs or concave epireliefs (after Hantzschel, 1975; Maples and Archer, 1987; Jensen, 1997).

Discussion. The most important characteristic of the ichnogenus *Treptichnus* is the presence of a series of more or less straight segments joined to each other at an angle, generally intersecting some distance from the end of the previous segment to form projections. Projections are hyporelief preservation of vertical shafts extending into the overlying sediments. Other characteristics such as the thickness of the segments, course of the burrow, surficial surficial striations or furrows, occurrence of projections on one or both sides of the burrow and spacing of the segments are considered to have ichnospecies-level significance.

**Table 7.12** - Reported ichnospecies of *Treptichnus*.

<i>T. bifurcus</i>	Miller, 1889	A delicate, zigzag burrow comprising short projections on both sides of the burrow.
<i>T. lublinensis</i>	Paczesna, 1986	Densely and irregularly arranged short segments at angle to the long axis of the burrow.
<i>T. triplex</i>	Palij, 1976	Characterised by the presence of two grooves that subdivide individual segments into three ridges.
<i>T. pedum</i>	(Seilacher, 1955)	Short burrows arranged obliquely on one side of the main burrow.
<i>T. pollardi</i>	Buatois and Mangano, 1993	Straight, curved to zigzag burrows having pits or knobs representing vertical shafts (= ? <i>Hormosiroidea pollardi</i> ).

As cited by Maples and Archer (1987, p. 893) and Jensen (1997) the specimen of *Treptichnus* figured by the original author (Miller, 1889, Fig. 1895) consists of an irregularly running burrow with short projections. Where the course of the burrow is straight, projections are situated alternatively to the left and right. Where the course is curved the projections all occur on the outside of the curve. Despite Miller's (1889) description and illustration (cited in Jensen, 1997), *Treptichnus* has been used generally for traces with a straight zigzag course and with segments regularly alternating in direction (e.g. Hantzschel, 1975).

Five ichnospecies of *Treptichnus* reported hitherto which are listed in Table 7.12. *T. pollardi* possesses a straight to curved burrow with vertical tubes and does not display projections. Beside its occasional zigzag course and sharp bends, it is morphologically similar to the ichnogenus *Hormosiroidea* and is included within the latter as ?*H. pollardi* in this study.

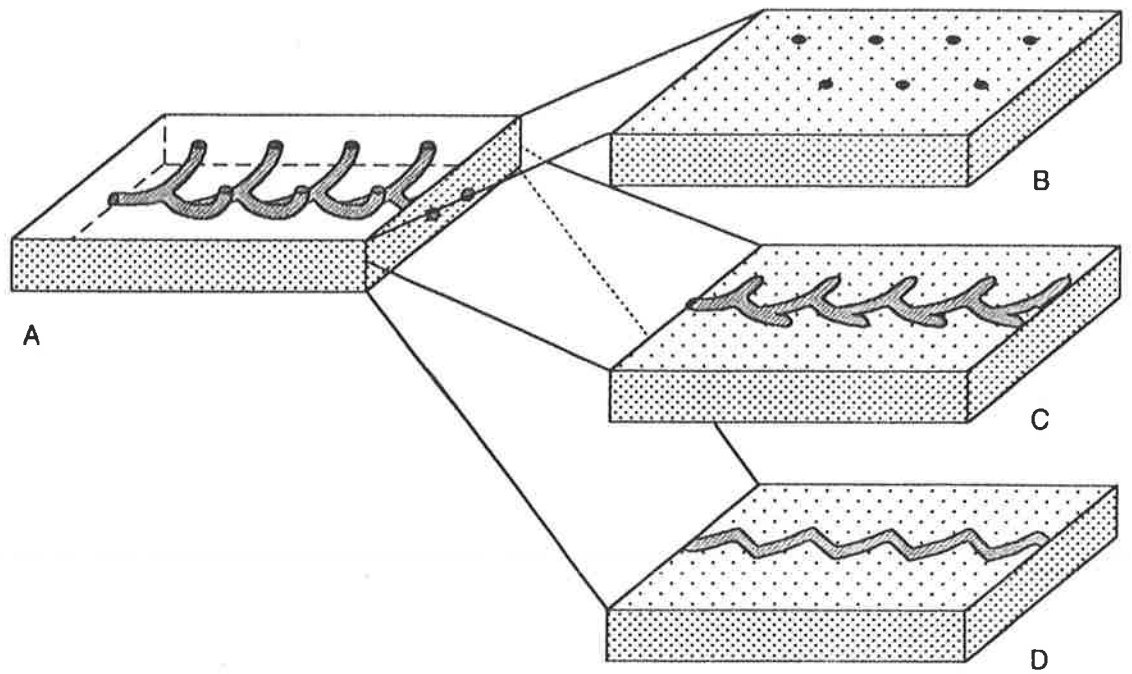
*T. bifurcus* is a delicate burrow system with short terminations projecting from a thin zigzag burrow (Archer and Maples, 1984). *T. lublinensis* comprises densely and irregularly arranged short segments at an acute angle to the long axis of the burrow. *T. triplex* is characterised by the presence of two grooves that subdivide individual segments into three ridges (Palij *et al.*, in Urbanek and Rozanov (Trans.), 1983). *T. pedum* is distinguished by the presence of the

projections generally on one side of the burrow. Figure 7.59 illustrates the various ichnospecies.

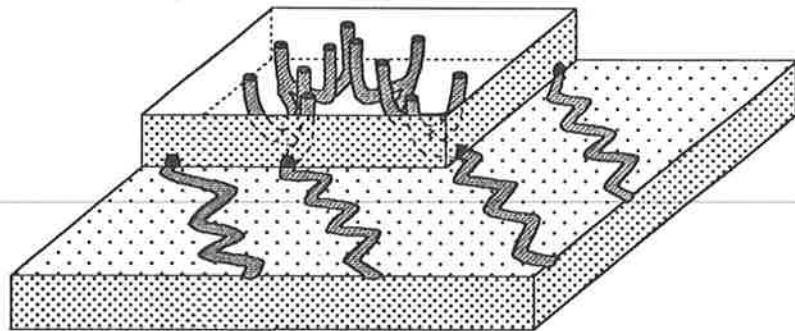
As illustrated in Figure 7.60 different erosional expressions of the *T. bifurcus* burrow system result in different morphology. These morphotypes have been treated and named separately in the literature as distinct ichnogenera, namely; *Saerichnites* Billings 1866, *Treptichnus* and *Plangtichnus* Miller, 1889. *Saerichnites* represents a double rows of circular to oval hypichnial mounds located in alternating position. It has been interpreted as a cast of part of a branched burrow system (Crimes and Anderson, 1985; Tunis and Uchman, 1996). The schematic illustration of *Saerichnites abruptus* Billings, 1866 given in Tunis and Uchman (1996, fig. 10) is similar to that of *T. bifurcus*. Although their interpretation of the burrow system may be proven to be true, *Saerichnites* and *Treptichnus* represent two distinct morphologies and should be considered as separate ichnotaxa. *Saerichnites* is retained herein for double rows of circular to subcircular pits or mounds which may represent a bedding plain preservation of the *Treptichnus* burrow system. An alternative interpretation of the *Saerichnites* burrow system has been previously discussed.

Archer and Maples (1984) and Maples and Archer (1987) explained the relationship between *Plangtichnus* and *Treptichnus* by considering them as different expressions of a single three-dimensional burrow system (Fig. 7.60). They retained both forms as distinct ichnogenera. Buatois and Mangano (1993) and Jensen (1997) confirmed the relationship between the two ichnogenera illustrated by the above mentioned authors, but they considered *Plangtichnus* and *Treptichnus* as synonyms. The continuation of the segments as projections is regarded as significant in *Treptichnus* at ichnogenic-level. Therefore, the application of the former authors is followed herein and both forms are retained as distinct ichnogenera.

Seilacher's (1977, fig. 6a) interpretation and illustration of the *Belorhapse zickzack* (Heer, 1877) is somewhat similar to that of *Plangtichnus* and *Treptichnus* (compare Buatois and Mangano, 1993 fig. 3 to Seilacher, 1977, fig. 6a). *B. zickzack* is considered to be a preservational expression of a zigzag burrow system with vertical shafts arranged alternatively to the left and right (Fig. 7.61). *B. zickzack* is generally smaller than *Plangtichnus* and displays a meandering course. It is also more restricted in flysch



**Figure 7.60** - Preservational variation of ichnogenus *Treptichnus*: **A**. Three dimensional reconstruction of the burrow system; **B**. bedding plane view of the burrow resembles *Saerichnites*; **C**. Common preservation of the burrow displays a bifurcating burrow system; **D**. This preservation resembles *Plangtichnus* (after Archer and Maples, 1984 and Maples and Archer, 1987).



**Figure 7.61** - Three dimensional reconstruction of *Belorhappe zikzak* (after Seilacher, 1977) resembles *Treptichnus*. However, the former displays a meandering, zigzag burrow with vertical shafts alternating to the left and right.

environments. The possibility that *Plangtichnus* should be considered as a junior synonym of *B. zickzack* depends on re-investigation of the holotypes of both ichnogenra.

*Intexalvichnus magnus* Buckman, 1997 consists of a main gallery with recurved, conical-shaped shafts occurring on both sides of the gallery (Fig. 7.62). *I. magnus* is morphologically similar to *Treptichnus* but differs from it in having funnel-shaped, closely spaced vertical shafts.

Age. *Treptichnus* ranges in age from the Early Cambrian (e.g. Paczesna, 1989; this study) to the Eocene (Crimes *et al.*, 1981).

### *Treptichnus pedum* (Seilacher, 1955)

Plates 29C-D, 31B

1969 *Phycodes pedum* Seilacher; Glaessner, p. 383, fig. 6c-e.

1970 *Phycodes pedum* Seilacher; Banks, p.28, pl. 2a.

1970 *Phycodes pedum* Seilacher; Crimes, pl. 13c.

1972 *Phycodes* aff. *pedum* Seilacher; Germs, p. 869, pl. 2, figs 7, 8.

1972 *Phycodes pedum* Seilacher; Daily, p. 19.

1975 *Phycodes pedum* Seilacher; Hantzschel, p. W95, fig. 59, 2c.

1977 *Phycodes pedum* Seilacher; Crimes, Legg, Marcos & Arboleya, p.121-122, pl.7a, b.

1982 *Phycodes* cf. *pedum* Seilacher; Crimes & Germs, p. 901, pl. 2, fig. 9.

1983 *Phycodes pedum* Seilacher; Fritz, Narbonne & Gordey, p. 371, pl. 44.1, fig. 1.

1985 *Phycodes* cf. *pedum* Seilacher; Crimes & Anderson, p. 330-331.

1985 *Phycodes pedum* Seilacher; Nowlan, Narbonne & Fritz, p. 239, fig. 5A.

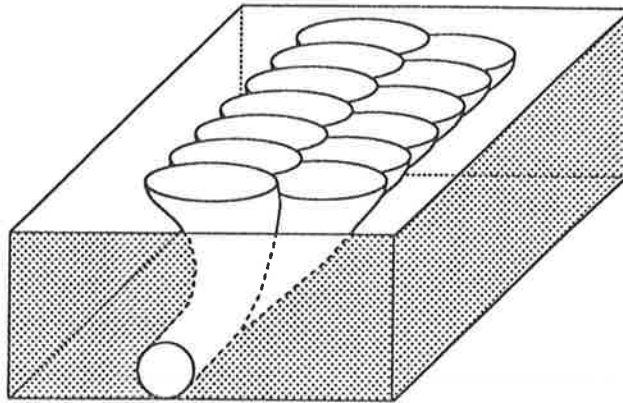
1989 *Phycodes pedum* Seilacher; Walter, Elphinstone, p. 236-237, fig. 9B-C.

1995 *Trichophycus pedum* Seilacher; Geyer and Uchman, pp. 185-191 figs 5.3-5, 6 & 7.

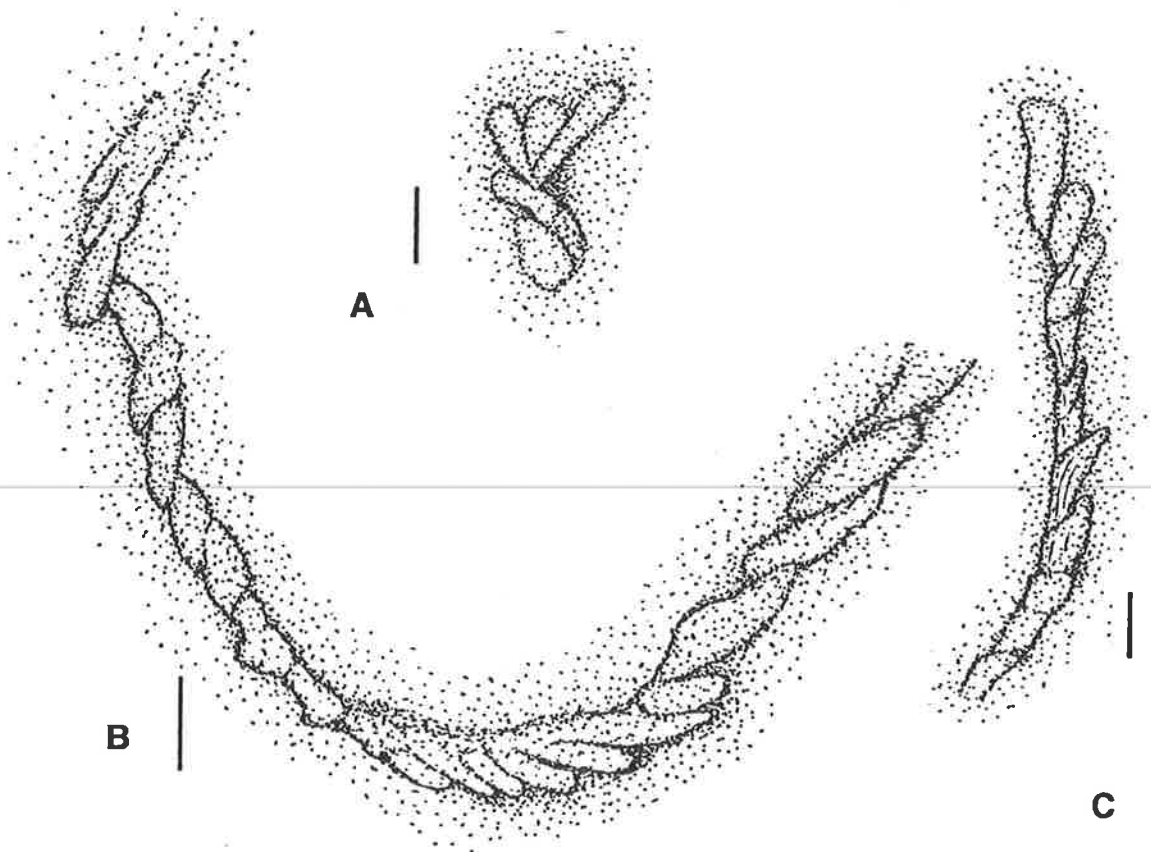
1997 *Treptichnus pedum* Seilacher; Jensen, pp. 91-93 fig. 62.

Collected specimens. Five specimens, A971-2-1, A971-4-2, A1035-MO66, A1035-MO106, A1035-MO167, and field photos 1-16, 1-17.

Diagnosis. Burrows consisting of a subhorizontal, straight to curving master tunnel bifurcating at relatively constant intervals, usually from one side, to produce short branches (after Seilacher, 1955; Fillion and Pickerill, 1990b).



**Figure 7.62-** The ichnogenus *Intexalvichnus* comprises a horizontal tunnel and funnel-shaped vertical shafts closely and alternatively located to the left and right. The burrow resembles *Treptichnus* in its general morphology (after Häntzschel, 1975).



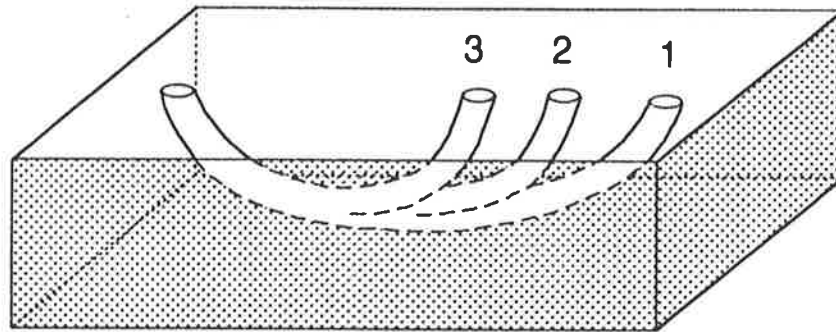
**Figure 7.63 -** Variable morphology of *Treptichnus pedum*: **A.** A curved burrow with dense branching pattern; **B.** A curved burrow with closely spaced branches; **C.** A straight to gently curved burrow in which some segments display delicate striations. All specimen are preserved as convex hyporeliefs (scale bar = 1 cm).

Description. Gently curved to coiled burrow without any particular pattern which are preserved in positive relief (convex hyporelief). Burrow possesses short segments jointed together at an angle and bending upward distally through the sediment, producing projections mostly on one side of the burrow. Some specimens have an annulated appearance due to the segmentation and exhibit fine longitudinal ridges in places. Burrows truncate one other or themselves. The burrow width varies from 3-5 mm and changes slightly along individual burrows. The interval between the projections is not constant and changes randomly. In one specimen (Pl. 29C) the side branches are densely located.

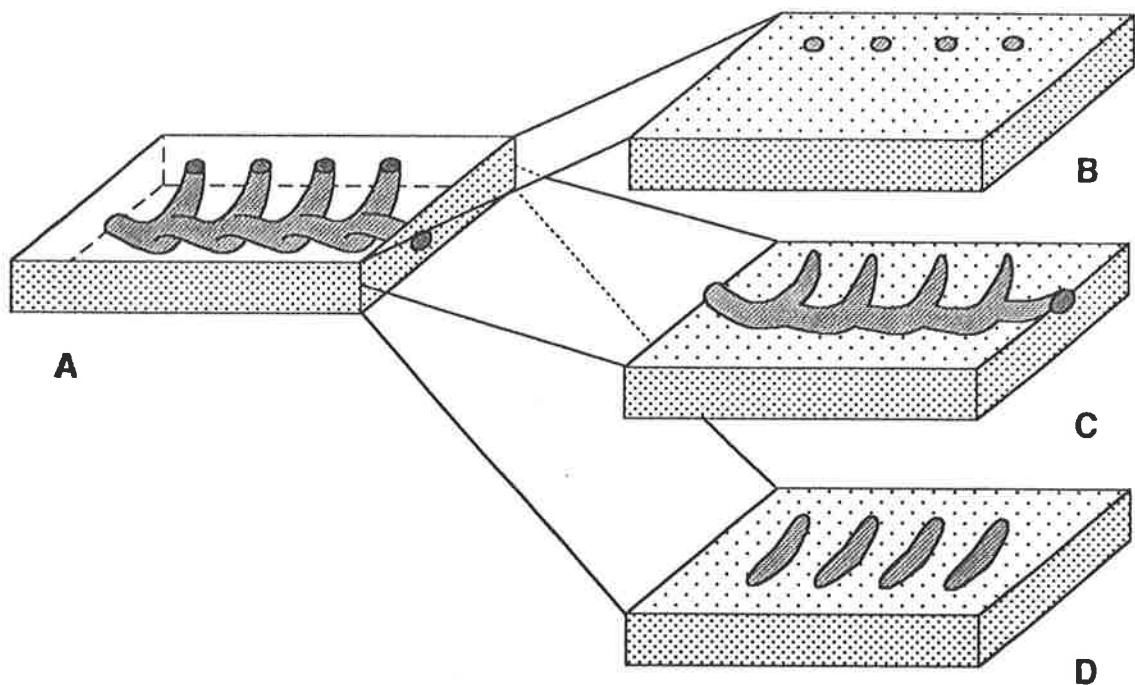
Description. The trace seems to be formed by jointed segments rather than being a continuous tunnel with side branches. The segmentation of the burrow is clear in the present material and almost all reported specimen of *T. pedum* (e.g. Banks, 1970; Fillion and Pickerill, 1990b; Bryant and Pickerill, 1990; Jensen, 1997). Figure 7.63 shows various morphologies assigned to the ichnospecies *T. pedum*.

Discussion. *Phycodes pedum* which Seilacher (1955) described from the Early Cambrian of the Salt Range, Pakistan is considerably different from other kinds of *Phycodes*. Osgood (1970, p. 342) proposed the exclusion of *P. pedum* from the ichnogenus *Phycodes*. Since the introduction of *P. pedum* by Seilacher, numerous occurrences of this ichnospecies have been reported from Early Cambrian sediments worldwide (e.g. Glaessner, 1969; Banks, 1970; Fritz and Crimes, 1985; Crimes and Anderson, 1985). Geyer and Uchman (1995) reported a *Teichichnus*-like structure within the basal part of the vertical shafts and considered it as a proof of its feeding origin. They (1995) included *Phycodes pedum* within the ichnogenus *Trichophycus*, which is a cylindrical, gently U-shaped burrow with a small number of vertically directed secondary branches (Osgood, 1970). Branching in *Trichophycus* starts from the distal part and advances to the proximal part of the burrow (figure 16 of Osgood, 1970) where each branch covers part of the previous branch and then curves upward (Fig. 7.64). Therefore, it is considered that the two ichnogenera are different and inclusion of *P. pedum* within *Trichophycus* is not warranted.

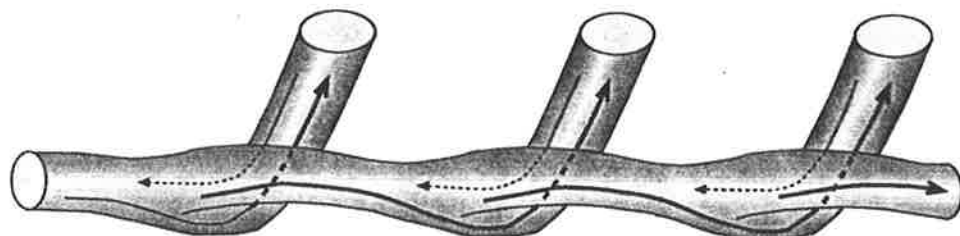
Jensen (1997) reported on the type ichnospecies of *Treptichnus* and stated that both *Phycodes pedum*- and *Treptichnus*-like burrows occur together in the original specimens figured by Miller (1889, fig. 1095), consequently including *Phycodes pedum* within the



**Figure 7.64** - Ichnogenus *Trichophycus* is a branched burrow system in which branching starts from the distal part of the burrow and advances toward the proximal part. The limited number of branches diverge from top of the burrow and not from side or beneath the burrow as occurs in *Treptichnus pedum*.



**Figure 7.65** - Preservational variations of ichnogenus *Treptichnus pedum*: **A**. Three dimensional reconstruction of the burrow; **B**. Bedding plane view consists of a series of circular structures aligned in a straight to curved line resembling *Hormosiroidea*; **C**. Common preservation of the ichnogenus; **D**. A section through lower part of the burrow may show a series of parallel elongated elliptical structures resembling the "feather stitch" burrows of Wilson (1948). Drawn after Geyer and Uchman(1995).



**Figure 7.66** - The production of *Treptichnus pedum* burrows. The producer first excavated horizontally then moved vertically to maintain its connection to the sea water (thick arrow) next it moved backward into the horizontal position and started to repeat the procedure for the next segment of the burrow (after Geyer and Uchman, 1995).



ichnogenus *Treptichnus* as *T. pedum*. Several other authors have also observed that *T. (Phycodes) pedum* may have portions of the *Treptichnus*-kind (e.g. Crimes *et al.*, 1977; Fritz and Crimes, 1985; Bryant and Pickerill, 1990). Nevertheless, *T. bifurcus* has been utilised only for relatively straight, zigzag burrows with alternative projections on both sides of the burrow (e.g. Hantzschel, 1975). Since *Treptichnus* has been utilised widely based on this concept, it is suggested that the same practice should be continued to support ichnotaxonomic stability. Following Jensen (1997), *T. pedum* is applied to treptichnian burrows with projections generally on one side of the burrow though with occasional occurrences of projections on both sides.

Geyer and Uchman (1995) illustrated different preservational variants of *T. pedum* (Fig. 7.65). The upper surface preservation of the burrow produces a series of circular structures similar to that of the ichnogenus *Hormosiroidea*. The expression represented by a plane taken through the middle of the burrow has been commonly reported as *Phycodes pedum* (= *Treptichnus pedum*). The third variant represents a series of short burrows parallel to each other and resembles the "Feather stitch trail" of Wilson (1948).

Interpretation of the burrow. *T. pedum* specimens collected from central Australia show that the organism was continuously moving through the substrate and never withdrew completely to the beginning of its burrow (Fig. 7.66). Also, the organism apparently did not interrupt its continuous burrowing to move to a new location in the search for fresh food resources. The faint longitudinal ridges preserved along some parts of the burrow may result from its appendages using for excavation. A similar method of burrowing has been suggested for the originator of *Treptichnus triplex* by Geyer and Uchman (1995, their *Trichophycus tripleurum*).

Age. Basal Early Cambrian up into the Early Ordovician (Germs, 1972; Hantzschel, 1975; Baldwin, 1977b; Crimes *et al.*, 1977). Seilacher (1955) first suggested that this ichnospecies has a potential to serve as a Cambrian index fossil of world-wide importance. Narbonne *et al.* (1987) proposed that the lower limit of *Phycodes pedum* Zone be considered as the base of the Cambrian and this has been adopted in the recognition of the present basal Cambrian GSSP in Newfoundland (e.g. Brasier, *et al.*, 1994). This view was supported by the

Precambrian-Cambrian Working Group who selected this ichnofossil as an index for determining the Precambrian-Cambrian Boundary.

Occurrence. Lower to upper Box Hole Formation, Ross River, Cyclops Bore, Jay, Creek Hugh River, Amadeus Basin; Donkey Creek beds, Mount Octy, Georgina Basin.

*Treptichnus* cf. *triplex* Palij, 1976

Plate 29F

1979 *Treptichnus* isp. 1, Palij *et al.*, p. 82, pl. LI, fig. 7.

1995 *Trichophycus tripleurum* Geyer and Uchman, pp. 191-193, figs 8.1-8, 9.

Collected specimens. Two specimens, A1035-MO170 and A1035-R31.

Diagnosis. A treptichnian burrow comprising thick burrow segments subdivided into three ridges by two shallow furrows (after Palij *et al.*, 1979, Buatois and Mangano, 1993)

Description. A series of short, thick burrow segments jointed together to the left and right alternatively. Segments intersect previous segment some distance from its end to leave short projections. Each segment tapers distally and produces a more or less pointed end. A few of these segments display two shallow parallel furrows on their surface particularly where they intersect the previous segment (Plate 29F; Fig. 7.67). The burrow segments are 2 to 4 mm thick and 10-14 mm long. The thickness is greatest in the middle of the segment and decreases toward its distal part. The burrow course is straight to gently curved and is preserved as a convex hyporelief.

Discussion. The burrow morphology is similar to *Treptichnus* isp. 1 and *Treptichnus triplex* reported by Palij *et al.* (1979) from the East-European Platform. *T. triplex* is distinguished by having two distinct furrows (three ridges) on its burrow segments. The specimens reported herein display faint furrows which are not as prominent and distinct as in *T. triplex*. *T. cf. triplex* may represent a form intermediate between the *T. triplex* and *T. isp. 1* of the Palij *et al.* (1979).

Geyer and Uchman (1995) introduced the new ichnotaxon *Trichophycus tripleurum* from the Nama Group. It possesses subangular intersected segments with upward-curved distal parts

where their lower side is delicately trilobate. They distinguished it from *Treptichnus triplex* by the regularly arranged probes of the latter. However, as discussed before, *Treptichnus* embraces both one- or two-sided projection bearing burrows and therefore, *T. tripleurum* is considered to be junior synonym of *T. triplex*.

Occurrence. Box Hole Formation, Cyclops Bore, Amadeus Basin; Donkey Creek Beds, Mount Octy, Georgina Basin.

### *Vendichnus* Fedonkin, 1979

Type ichnospecies. *V. vendicus* Fedonkin, 1979; by original designation.

Diagnosis. "Short bilaterally symmetrical resting trace subdivided into two by an uneven ridge. On both sides of the ridge, over its full length, there are elongated shallow wing-shaped depressions with transverse ridges and furrows" (after Fedonkin in Palij *et al.*, 1979).

Preservation. Trace preserved in positive hyporelief as irregular convex burrows with a median furrow.

Discussion. Fedonkin (1977, pl. 2, fig. e) first reported this ichnogenus as the "resting trail of a small bilateral animal" from the Valdai Series, East European Platform. Later Fedonkin (1979; translated into English by Urbanek and Rozanov, 1983) erected a new ichnogenus, *Vendichnus*, based on the same specimen. It is noteworthy that the scale of the photograph in Fedonkin (1979) is double that in the previous report (in Fedonkin 1977).

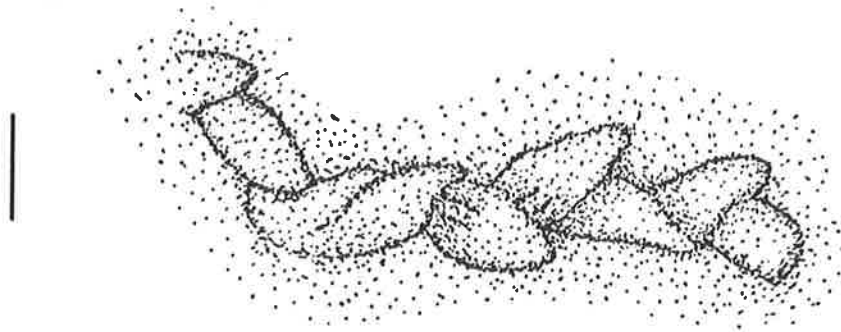
Originator. Fedonkin (in Palij *et al.*, 1979) suggested that the trace has been produced by a bilaterally symmetrical animal representing a nektonic faunal element.

Age. Late Proterozoic (Fedonkin in Palij *et al.*, 1979) to Early Cambrian (this study).

?*Vendichnus* isp.

Plate 30B

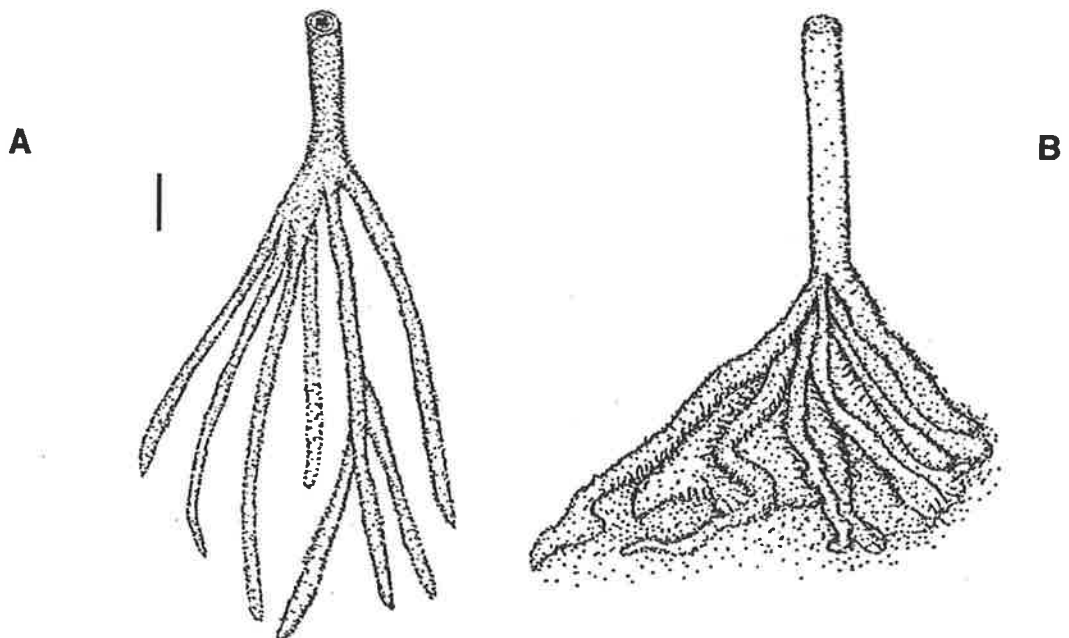
1977 "Resting trail of a small bilateral animal", Fedonkin pl. 2 fig. e.



**Figure 7.67** - *Treptichnus ?triplex* preserved as a convex hyporelief. Some segments display trilobation due to two delicate furrows (scale bar = 1 cm).



**Figure 7.68** - *?Vendichnus* isp. preserved as epirelief. Three approximately ovate shaped, roughly bilobate structures are arranged in a line (scale bar = 1 cm).



**Figure 7.69** - **A.** Ichnofossil A, vertical, branched burrow in which the main shaft branches distally in acute angles to produce side branches (scale bar = 1 cm). **B.** The ichnogenus *Fascifodina* comprises a vertical shaft which branches distally to form short, vermiform branches (after Osgood, 1970).

1979 *Vendichnus vendicus* Fedonkin in Palić *et al.* (English translation by Urbanek and Rozanov (1983), p. 92, pl. LXII, fig. 5)

? 1987 Dubiofossil B Narbonne and Hofmann; p. 671, Text-fig. 10h.

Collected specimens. Two specimens, A1035-MO72 and A1035-MO91.

Diagnosis. Same as the ichnogenus.

Description. Ovoid burrow in section preserved as convex hyporeliefs. Burrow bilobate with two lateral lobes separated by a median furrow. Lobes are cut by transverse, arcuate furrows. Burrows are 10 to 18 mm long and 8-10 mm wide. Specimen A1035-MO72 shows three burrows aligned 8 to 15 mm apart.

Discussion. Although, the present specimens do not clearly show the bilateral symmetry mentioned by the original author, they are similar to the type ichnospecies both in size and sectioned outline. The fine striations on the lateral lobes reported by Fedonkin (1979) are absent in the present material. They are similar to the specimen reported from the Wernecke Mountains, Yukon, Canada by Narbonne and Hofmann (1987) as Dubiofossil B, though, the latter show a sub-hexagonal outline with an outer rim not observed in the present material.

Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

## **Ichnofossil A**

Plates 30A

Collected specimens. One specimen, A971-2-42.

Description. Straight to curved burrows 4-6 mm in diameter which are vertical to inclined relative to the bedding plane. Burrow fill is different from the host rock in being finer and less resistant to weathering. Burrows are preserved as concave structures due to subsequent erosion and branch off distally producing many curved and inclined branches 2-4 mm in diameter. The plane view of the primary burrow shows a circular structure preserved as a concave epirelief. Burrows show a concentric structure at their aperture (Fig. 7.69).

Discussion. The plane view of the present sample is similar to that reported by Walter and Elphinstone (in Walter *et al.*, 1989) from central Australia as *Skolithos ramosus*. However, *Skolithos* does not include vertically branched burrows and it is suggested that the branched form of *S. ramosus* may be attributable to other ichnogenera. The ichnogenus *Fascifodina* is a vertically branched ichnotaxon reported from Cincinnati area (Osgood, 1970) and resembles the present specimen (Fig. 7.69). The distal branches in *Fascifodina* commonly occur as short vermiform concave epireliefs.

Occurrence. Allua Formation, Ross River, Amadeus Basin.

## **Ichnofossil B**

Plate 31C

Collected specimens. One specimen, A1035-B4.

Description. A circular structure preserved in convex hyporelief. It possess a bilobate mid part divided by a median ridge. The mid part is surrounded by an imbricate ring-like ridge and has an elevated margin. The diameter of the trace is about 30 mm. The middle bilobate part is about 20mm in diameter (Fig. 7.70).

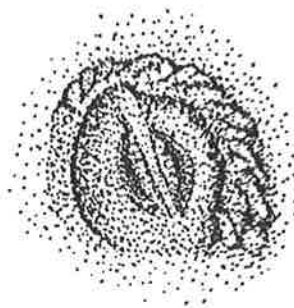
Discussion. This structure superficially resembles Tal-Ichnogenus K reported from the Vendian-Early Cambrian of the Lesser Himalayas (Singh and Rai, 1983). Tal-Ichnogenus K occurs as a convex epirelief whereas the present material has been preserved as a convex hyporelief. This impression occurs in association with *?Laevicyclus* isp. and *Planolites montanus* on the sole of a medium-grained sandstone layer, 3-5 cm thick.

Occurrence. Allua Formation, Ross River, Amadeus Basin.

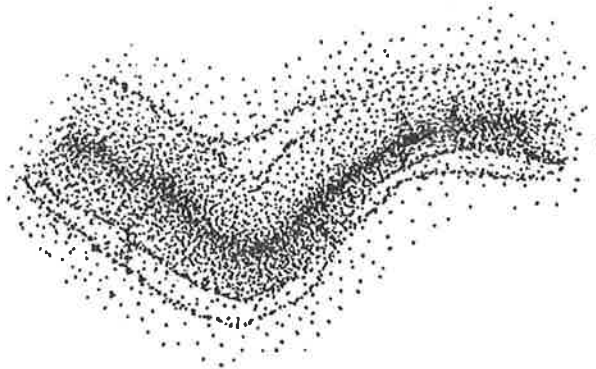
## **Ichnofossil C**

Plate 30C,E

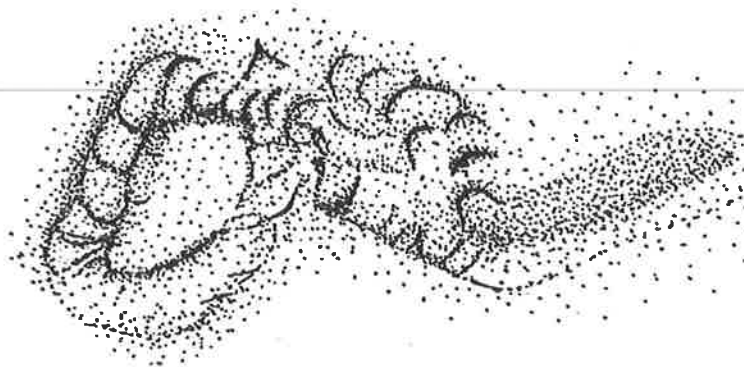
Collected specimens. Two specimens, A971-2-30 and A1035-MO169.



**Figure 7.70** - Ichnofossil B, an ovate structure preserved as convex hyporelief and comprising a middle bilobate part surrounded by an imbricate margin (scale bar = 1 cm).



**Figure 7.71** - Ichnofossil C, a straight to sinuous burrow preserved as concave epirelief. Burrow consists of a wide middle furrow with elevated margins



**Figure 7.72** - Ichnofossil D, a series of arcuate to crescent-shaped grooves arranged in a curved to winding pattern. Some burrows show an en-echelon pattern of grooves (scale bar = 1 cm).

Description. Large, gently curved to sinuous burrows pressured as concave epireliefs. Burrows comprise a wide furrow with low relief marginal levees. They are 8-12 mm wide and some show widely spaced fine, transverse grooves on the furrow (Fig. 7.71).

Discussion. Burrows are similar to the ichnogenus *Herpystezoum* Hitchcock, 1848 described by Buckman, 1992. *Herpystezoum* is a bedding-parallel, concave epirelief burrow which could be either V-shaped or U-shaped in cross section and may or may not possess lateral levees.

Occurrence. Lower Box Hole Formation Ross River, Amadeus Basin; Donkey Creek Beds, Georgina Basin.

## **Ichnofossil D**

Plate 30D

Collected specimens. Five specimens, A1035-MO55, A1035-MO109, A1035-MO145, A1035-MO161 and A1035-MO179.

Description. Curved to winding burrows preserved as either convex or concave epireliefs. Burrows look annulated due to the presence of arcuate to crescent shaped grooves, 3-6 mm apart (Fig. 7.72). The burrow width is 8-10 mm and changes slightly along an individual burrow. Burrows lack any distinct wall structure.

Discussion. These burrows resemble the ichnogenus *Taenidium*, which, however displays a distinct wall structure lacking in the present material.

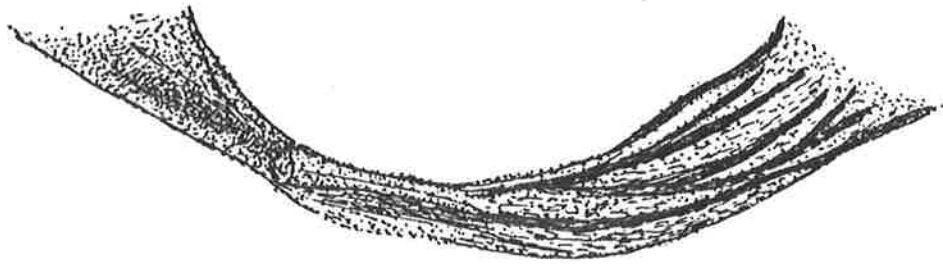
Occurrence. Donkey Creek Beds, Mount Octy, Georgina Basin.

## **Ichnofossil E**

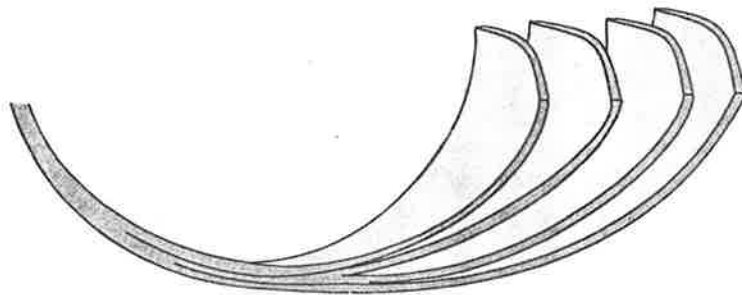
Plate 31D

Collected specimens. Two specimens, A1035-MO50A and A1035-MO162.





**A**



**B**

**Figure 7.73 - A.** Ichnofossil E, vertical, bow-shaped burrows with branches developed on one limb. Branches are concave, blade-like in outline (scale bar = 1 cm). **B.** A schematic reconstruction of the burrow system.

Description. Burrows are wide, U-shaped in overall outline. They are preserved as endoreliefs and are visible on sides of broken slabs. The main burrow is 4-6 mm wide and branches at one point producing gently upward-curving branches. The branches are concave and blade-shaped varying in width from a few millimetres to a few centimetres. The burrow filling is different from the host rock (Fig. 7.73).

Discussion. This form is morphologically similar to the ichnogenus *Phycodes* but, has blade-shaped branches. The producer likely mined sediments horizontally for some span before commencing to produce a new branch. This kind of mining is more sophisticated than *Phycodes* burrows and allows the producer to excavat sediment more efficiently.

Occurrence. Allua Formation, Ross River, Amadeus Basin.

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Ichnofossils and other fossils	Author(s)	Year	lower part		upper part	
			Arumbera Formation		Box Hole Fm	Allua Fm
			Lower(=Unit I)	upper(=Unit II and lower Unit III)		
<i>Rangea cf. longea</i>	Glaessner	1969	*			
simple horizontal burrows	Conrad	1981	*			
<i>Arumberia banksi</i>	Glaessner & Walter	1975		*		
<i>Arumberia banksi</i>	Conrad	1981		*		
<i>Hallidaya brueri</i>	Wade	1969		*		
<i>Hallidaya brueri</i>	Conrad	1981		*		
<i>Kullingia aff. concentrica</i>	Føyn and Glaessenr	1979		*		
<i>Bilinichnus simplex</i>	McIlroy <i>et al.</i>	1997		*		
Serial pimples	McIlroy <i>et al.</i>	1997		*		
? <i>Monomorphichnus isp</i>	McIlroy <i>et al.</i>	1997		*		
<i>Palaeophycus isp.</i>	McIlroy <i>et al.</i>	1997		*		
<i>Intrites isp.</i>	McIlroy <i>et al.</i>	1997		*		
? <i>Helminthoida isp.</i>	McIlroy <i>et al.</i>	1997		*		
<i>Planolites isp.</i>	McIlroy <i>et al.</i>	1997		*	*	
<i>Didymaulichnus miettensis</i>	Glaessner	1969			*	
<i>Phycodes pedum</i>	Daily	1972			*	
<i>Rusophycus</i>	Daily	1972			*	
<i>Diplichnites</i>	Conrad	1981			*	

**Appendix I.** Reported trace fossils and other fossils from Arumbera Sandstone (*sensu lato*), Amadeus Basin.

Ichnofossils and other fossils	Author(s)	Year	Arumbera Formation		Box Hole Fm	Allua Fm
			Lower (=Unit I,) <i>sensu</i> Well, et al, 1967)	upper (=Unit II & lower III) <i>sensu</i> Well, et al, 1967		
<i>Laevicyclus</i>	Conrad	1981			*	
<i>Phycodes pedum</i>	Conrad	1981			*	
<i>Psammichnites</i>	Conrad	1981			*	
<i>Skolithos</i>	Conrad	1981			*	
<i>Skolithos</i>	Hamp	1985			*	
<i>Diplichnites</i>	Hamp	1985			*	
<i>Monomorphichnus</i>	Hamp	1985			*	
<i>Phycodes pedum</i>	Hamp	1985			*	
<i>Curvolithus sp.</i>	Walter <i>et al.</i>	1989			*	
<i>Nereites sp.</i>	Walter <i>et al.</i>	1989			*	
<i>Torrowangea rosei</i>	Walter <i>et al.</i>	1989			*	
<i>Hormosiroidea arumbera</i>	Walter <i>et al.</i>	1989			*	
<i>Diplichnites</i>	Walter <i>et al.</i>	1989			*	
<i>Monomorphichnus lineatus</i>	Walter <i>et al.</i>	1989			*	
<i>Transversely annulated trail</i>	Walter <i>et al.</i>	1989			*	
Stellate structure	Walter <i>et al.</i>	1989			*	
Small filled burrows	Walter <i>et al.</i>	1989			*	
<i>Saerichnites canadensis</i>	McIlroy <i>et al.</i>	1997			*	
<i>Didymaulichnus lyelli</i>	McIlroy <i>et al.</i>	1997			*	
? <i>Helminthoida isp.</i>	McIlroy <i>et al.</i>	1997			*	
<i>Curvolithus isp.</i>	McIlroy <i>et al.</i>	1997			*	

Ichnofossils and other fossils	Author(s)	Year	Arumbera Formation		Box Hole Fm	Allua Fm
			Lower (=Unit I,) <i>sensu</i> Well, et al, 1967)	upper (=Unit II & lower III) <i>sensu</i> Well, et al, 1967		
<i>?Plagiogmus arcuatus</i>	Mellroy <i>et al.</i>	1997			*	
<i>Gyrolithes polonicus</i>	Mellroy <i>et al.</i>	1997			*	
<i>?Arenicolites isp.</i>	Mellroy <i>et al.</i>	1997			*	
<i>Rusophycus cf. avalonensis</i>	Mellroy <i>et al.</i>	1997			*	
<i>Bergaueria perata</i>	Mellroy <i>et al.</i>	1997			*	
<i>Teichichnus rectus</i>	Mellroy <i>et al.</i>	1997			*	
<i>Protopaleodictyon</i>	Mellroy <i>et al.</i>	1997			*	
<i>Glockerichnus isp.</i>	Mellroy <i>et al.</i>	1997			*	
<i>Didymaulichnus miettensis</i>	Mellroy <i>et al.</i>	1997			*	
<i>Graphogyptid indet.</i>	Mellroy <i>et al.</i>	1997			*	
<i>Trichophycus</i>	Mellroy <i>et al.</i>	1997			*	
<i>Monocraterion</i>	Mellroy <i>et al.</i>	1997			*	
<i>Palaeophycus</i>	Mellroy <i>et al.</i>	1997			*	
<i>Glockerichnus isp. B</i>	Mellroy <i>et al.</i>	1997			*	
<i>Nereites isp.</i>	Mellroy <i>et al.</i>	1997			*	
<i>Plagiogmus var. A</i>	Mellroy <i>et al.</i>	1997			*	
<i>?Squamodictyon</i>	Mellroy <i>et al.</i>	1997			*	
<i>Cochlichnus</i>	Mellroy <i>et al.</i>	1997			*	
<i>?Pseudilyella</i>	Mellroy <i>et al.</i>	1997			*	
<i>Belorhaphe</i>	Mellroy <i>et al.</i>	1997			*	
<i>Curvolithus aequus</i>	Mellroy <i>et al.</i>	1997			*	

Ichnofossils and other fossils	Author(s)	Year	Arumbera Formation		Box Hole Fm	Allua Fm
			Lower (=Unit I,) <i>sensu</i> Well, et al, 1967)	upper (=Unit II & lower III) <i>sensu</i> Well, et al, 1967		
<i>Taenidium isp.</i>	McIlroy <i>et al.</i>	1997			*	
<i>Monomorphichnus lineatus</i>	McIlroy <i>et al.</i>	1997			*	
<i>Diplichnites isp.</i>	McIlroy <i>et al.</i>	1997			*	
<i>Treptichnus isp.</i>	McIlroy <i>et al.</i>	1997			*	
<i>Phycodes anticedes</i>	McIlroy <i>et al.</i>	1997			*	
<i>Plagiogmus</i>	Cowie & Glaessner	1975			*	*
<i>Psammichnites</i>	Cowie & Glaessner	1975			*	*
<i>Phycodes</i>	Cowie & Glaessner	1975			*	*
arthropods tracks	Cowie & Glaessner	1975			*	*
sinusoidal curvature	Glaessner	1969			*	*
<i>Didymaulichnus lyelli</i>	Walter <i>et al.</i>	1989			*	*
<i>Didymaulichnus miettensis</i>	Walter <i>et al.</i>	1989			*	*
<i>Gordia arcuata</i>	Walter <i>et al.</i>	1989			*	*
<i>Gordia sp.</i>	Walter <i>et al.</i>	1989			*	*
<i>Monomorphichnus bilinearis</i>	Walter <i>et al.</i>	1989			*	*
Crescent-shaped grooves	Walter <i>et al.</i>	1989			*	*
<i>Palaeophycus alternatus</i>	Walter <i>et al.</i>	1989			*	*
<i>Palaeophycus tubularis</i>	Walter <i>et al.</i>	1989			*	*
<i>Plagiogmus arcuatus</i>	Walter <i>et al.</i>	1989			*	*
<i>Scolicia</i> -like traces	Glaessner	1969				*
<i>Planolites</i>	Glaessner	1969				*

Ichnofossils and other fossils	Author(s)	Year	Arumbera Formation		Box Hole Fm	Allua Fm
			Lower (=Unit I,) <i>sensu</i> Well, et al. 1967)	upper (=Unit II & lower III) <i>sensu</i> Well, et al. 1967		
<i>T. (=Phycodes) pedum</i>	Glaessner	1969				*
<i>Rusophycus</i> -like	Glaessner	1969				*
<i>Diplichnites sp.</i>	Glaessner	1969				*
<i>Plagiogmus</i>	Daily	1972				*
vertical burrows	Conrad	1981				*
<i>Plagiogmus</i>	Conrad	1981				*
<i>Skolithos</i>	Conrad	1981				*
<i>Plagiogmus</i>	Kruse and West	1980				*
<i>Plagiogmus</i>	Kirschvinck	1978				*
<i>Diplocraterion</i>	Kirschvinck	1978				*
Radial hyporelief	Walter <i>et al.</i>	1989				*
<i>Skolithos verticalis</i>	Walter <i>et al.</i>	1989				*
<i>Skolithos ramosus</i>	Walter <i>et al.</i>	1989				*
<i>Planolites beverlyensis</i>	Walter <i>et al.</i>	1989				*
<i>Palaeophycus canalis</i>	Walter <i>et al.</i>	1989				*
<i>Gyrochorte</i>	Walter <i>et al.</i>	1989				*
<i>Muensteria</i>	Walter <i>et al.</i>	1989				*
<i>Phycodes pedum</i>	Walter <i>et al.</i>	1989				*
<i>Didymaulichnus miettensis</i>	Shergold <i>et al.</i>	1986				*
<i>Cochlichnus serpens</i>	Shergold <i>et al.</i>	1986				*
<i>Gordia sp.</i>	Shergold <i>et al.</i>	1986				*

Ichnofossils and other fossils	Author(s)	Year	Arumbera Formation		Box Hole Fm	Allua Fm
			Lower (=Unit I,) <i>sensu</i> Well, et al, 1967)	upper (=Unit II & lower III) <i>sensu</i> Well, et al, 1967		
<i>Gyrochorte</i>	Shergold <i>et al.</i>	1986				*
<i>Laminites</i>	Shergold <i>et al.</i>	1986				*
<i>Margaritichnus</i>	Shergold <i>et al.</i>	1986				*
<i>Monocraterion</i>	Shergold <i>et al.</i>	1986				*
<i>Monomorphichnus</i>	Shergold <i>et al.</i>	1986				*
<i>Phycodes pedum</i>	Shergold <i>et al.</i>	1986				*
<i>Plagiogmus arcuatus</i>	Shergold <i>et al.</i>	1986				*
<i>Planolites sp.</i>	Shergold <i>et al.</i>	1986				*
<i>Psammichnites</i>	Shergold <i>et al.</i>	1986				*
<i>Rusophycus</i> -like marks	Shergold <i>et al.</i>	1986				*
<i>Skolithos sp.</i>	Shergold <i>et al.</i>	1986				*
<i>Taphrhelminthopsis</i>	Shergold <i>et al.</i>	1986				*
<i>Rusophycus</i>	Conrad	1981				*
Rare <i>Skolithos</i>	Conrad	1981				*
<i>Plagiogmus</i>	Haines	1991				*
Orthothecimorph hyolith	Haines	1991				*
<i>Monomorphichnus bilinearis</i>	McIlroy <i>et al.</i>	1997				*
<i>Helminthoida isp.</i>	McIlroy <i>et al.</i>	1997				*
<i>Asteriacites isp.</i>	McIlroy <i>et al.</i>	1997				*
? <i>Belorhapse isp.</i>	McIlroy <i>et al.</i>	1997				*
<i>Helminthopsis abali</i>	McIlroy <i>et al.</i>	1997				*

Ichnofossils and other fossils	Author(s)	Year	Arumbera Formation		Box Hole Fm	Allua Fm
			Lower (=Unit I,) <i>sensu</i> Well, et al, 1967)	upper (=Unit II & lower III) <i>sensu</i> Well, et al, 1967		
<i>?Rhizocorallium isp.</i>	McIlroy <i>et al.</i>	1997				*
<i>Gyrolithes isp.</i>	McIlroy <i>et al.</i>	1997				*
<i>Taenidium cameronensis</i>	McIlroy <i>et al.</i>	1997				*
<i>Palaeophycus canalis</i>	McIlroy <i>et al.</i>	1997				*
<i>?Treptichnus pedum</i>	McIlroy <i>et al.</i>	1997				*
<i>Hormosiroidea arumbera</i>	McIlroy <i>et al.</i>	1997				*
<i>Skolithus ramosus</i>	McIlroy <i>et al.</i>	1997				*
<i>Taphrhelminthopsis circularis</i>	McIlroy <i>et al.</i>	1997				*
<i>Monocraterion cf. tentaculum</i>	McIlroy <i>et al.</i>	1997				*
<i>Phycodes circinatum</i>	McIlroy <i>et al.</i>	1997				*
<i>Trichophycus venosus</i>	McIlroy <i>et al.</i>	1997				*
<i>Cruziana isp.</i>	McIlroy <i>et al.</i>	1997				*
<i>Saerichnites arumberia</i>	McIlroy <i>et al.</i>	1997				*
<i>Rhizocorallium irregulare</i>	McIlroy <i>et al.</i>	1997				*
<i>Psammichnites</i>	McIlroy <i>et al.</i>	1997				*

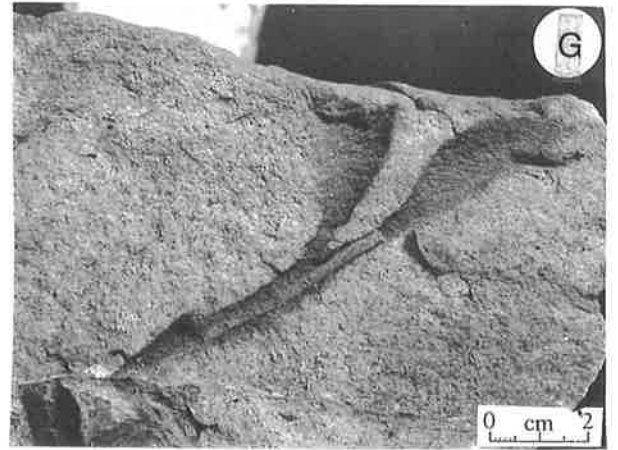
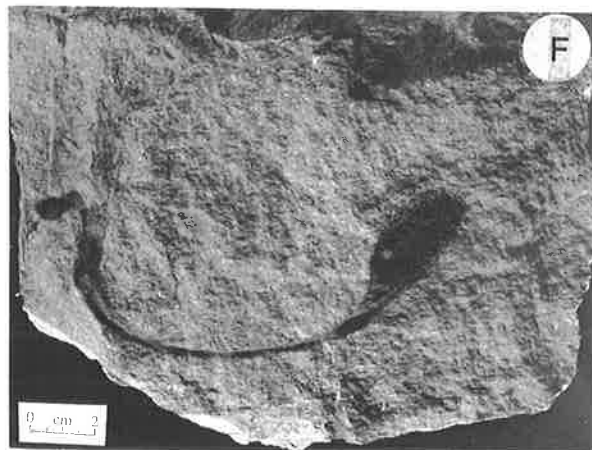
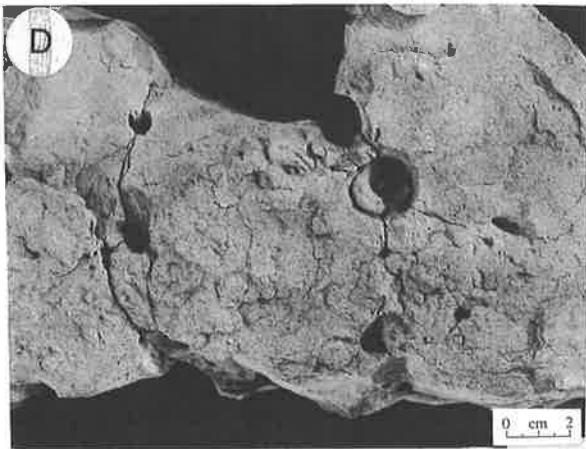
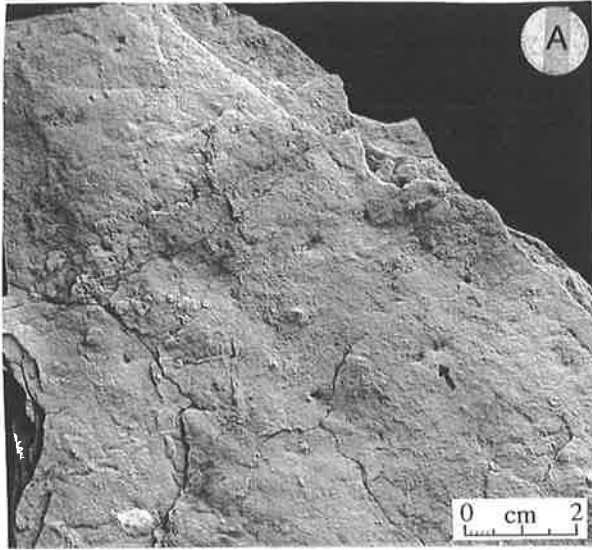


Ichnofossils and other fossils	Author(s)	Year	Elkara Formation	Central Mount Stuart Fm.	Mount Baldwin Fm.	Donkey Creek Beds	Red Heart Dolomite
Dubiofossil	Walter <i>et al.</i>	1989		*		*	
<i>Hormosiroidea arumbera</i>	Walter <i>et al.</i>	1989		*		*	
<i>Planolites beverlyensis</i>	Walter <i>et al.</i>	1989			*		
<i>Treptichnus isp</i>	Walter <i>et al.</i>	1989			*		
<i>Gordia arcuata</i>	Walter <i>et al.</i>	1989			*	*	
<i>Gordia isp.</i>	Walter <i>et al.</i>	1989			*	*	
<i>Palaeophycus tubularis</i>	Walter <i>et al.</i>	1989			*	*	
<i>Palaeophycus alternatus</i>	Walter <i>et al.</i>	1989			*	*	*
? <i>Diplocraterion isp.</i>	Walter <i>et al.</i>	1989				*	*
<i>Didymaulichnus lyelli</i>	Walter <i>et al.</i>	1989				*	
Crescent-shaped grooves	Walter <i>et al.</i>	1989				*	
Large burrow	Walter <i>et al.</i>	1989				*	
<i>Skolithos ramosus</i>	Walter <i>et al.</i>	1989				*	
<i>Skolithos verticalis</i>	Walter <i>et al.</i>	1989				*	
Petal-shaped depressions	Walter <i>et al.</i>	1989				*	
<i>Helminthopsis irregularis</i>	Walter <i>et al.</i>	1989				*	
<i>Muensteria isp.</i>	Walter <i>et al.</i>	1989				*	
<i>Treptichnus(Phycodes) pedum</i>	Walter <i>et al.</i>	1989				*	
<i>Plagiogmus arcuatus</i>	Walter <i>et al.</i>	1989				*	
<i>Torrowangea rosei</i>	Walter <i>et al.</i>	1989				*	

Ichnofossils and other fossils	Author(s)	Year	Elkara Formation	Central Mount Stuart Fm.	Mount Baldwin Fm.	Donkey Creek Beds	Red Heart Dolomite
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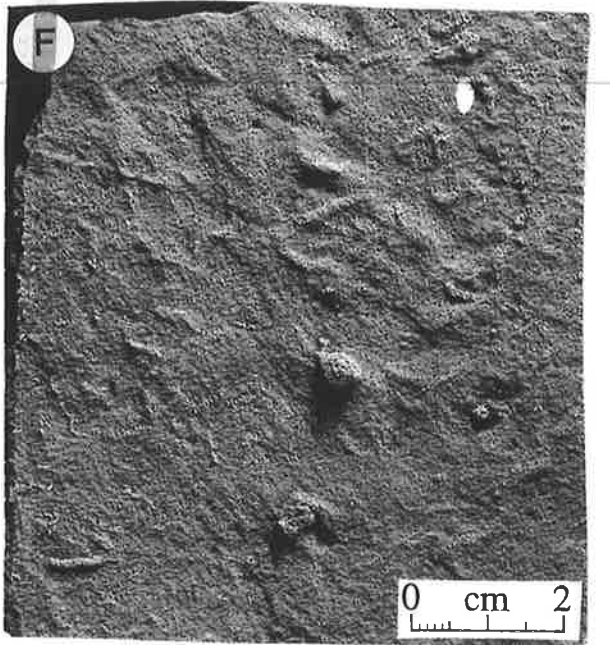
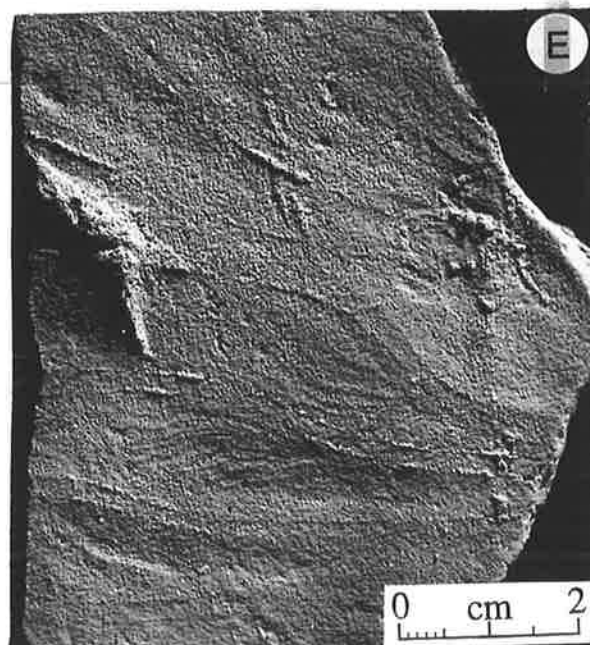
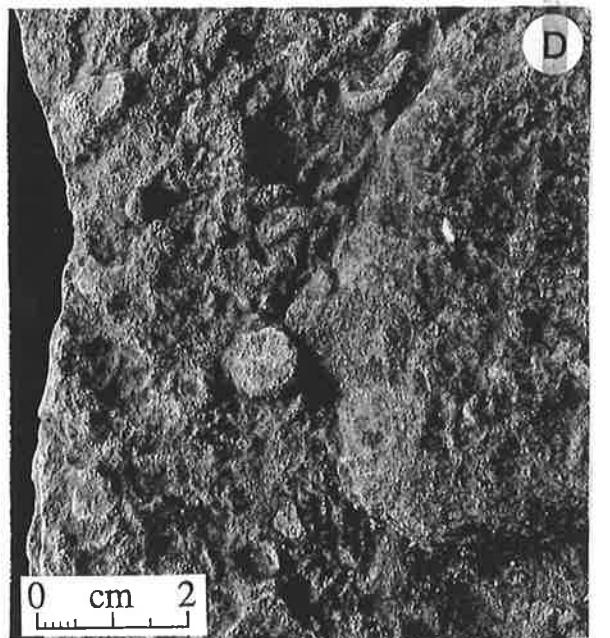
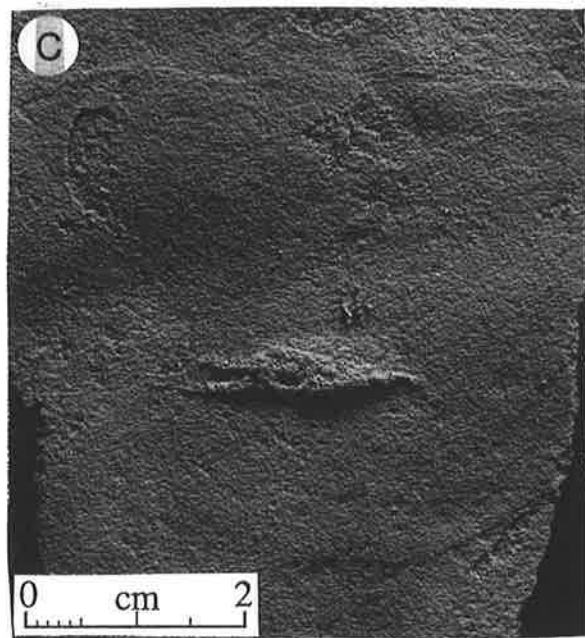
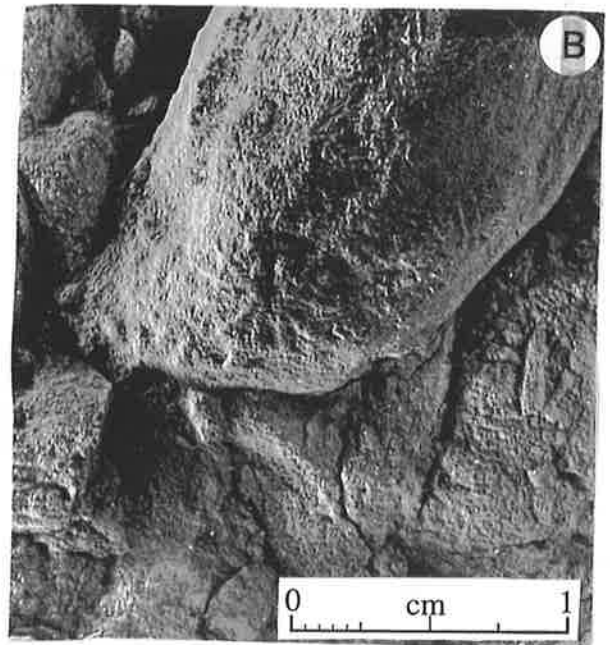
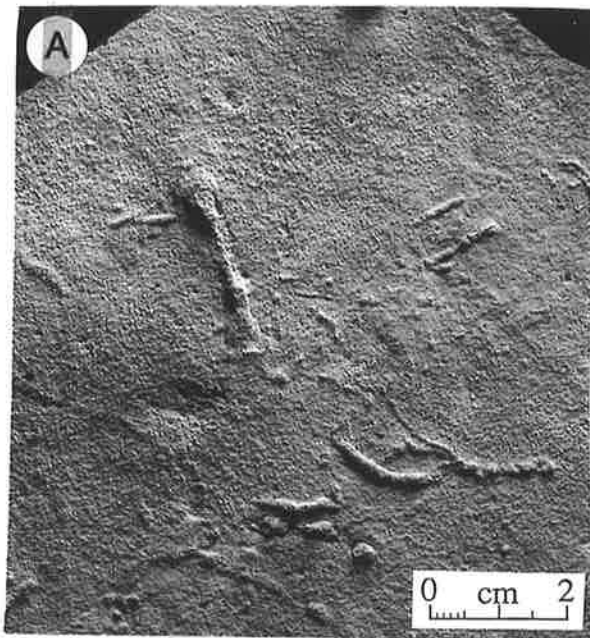
## Plate 1

- A. *Arenicolites* isp. A, concave epirelief, Allua Formation, Ross River, A971-3-8.
- B. *Arenicolites* isp. A, concave or low relief convex epireliefs, Box Hole Formation, Cyclops Bore, A971-1-4.
- C. *Arenicolites* isp. B, concave epirelief, some show concentric structure, Box Hole Formation, Cyclops Bore, A971-1-37.
- D. *Arenicolites* isp. C, bedding plane view, concave epirelief, Donkey Creek Beds, Mount Octy, A1035-MO146.
- E. *Asteriacites* isp. poorly preserved specimen, convex epirelief, Allua Formation, Ross River, A971-2-44.
- F. *Arenicolites* isp. C, Side view showing a U-shaped burrow with a bulb-like structure at on end, Donkey Creek Beds, Mount Octy, A1035-MO54.
- G. *Arenicolites* isp. C, side view of figure 1D showing a branched specimen with bulbous or funnel terminations. Donkey Creek Beds, Mount Octy, A1035-MO146.



## Plate 2

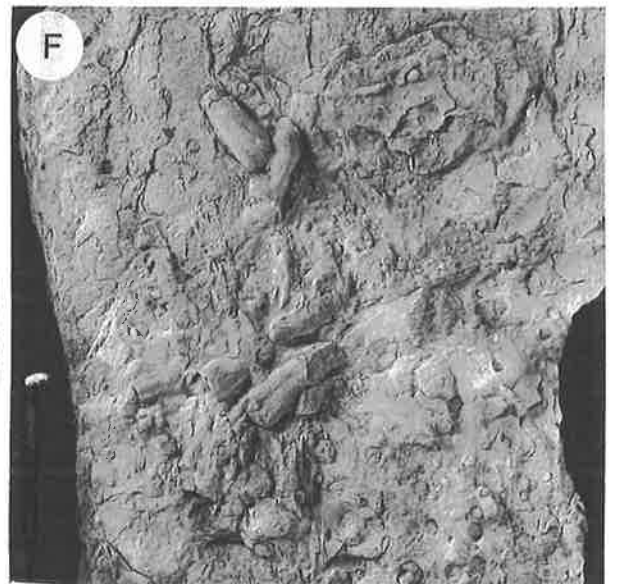
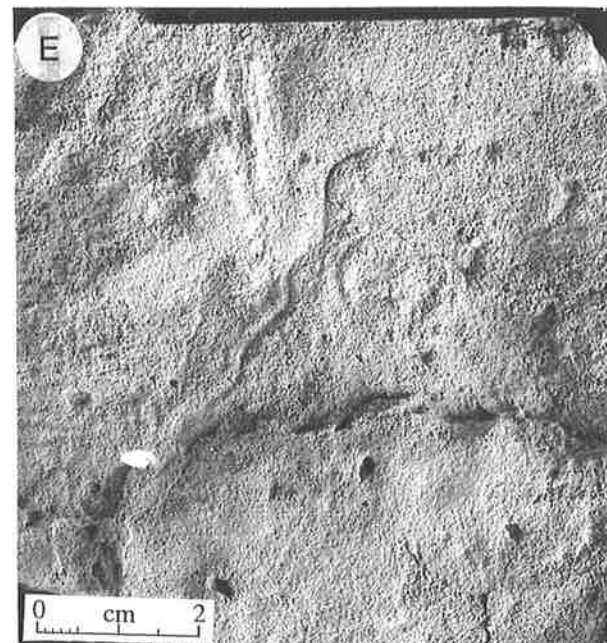
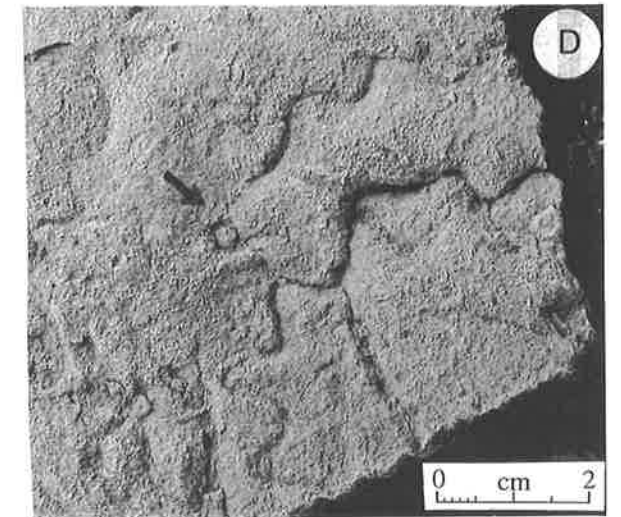
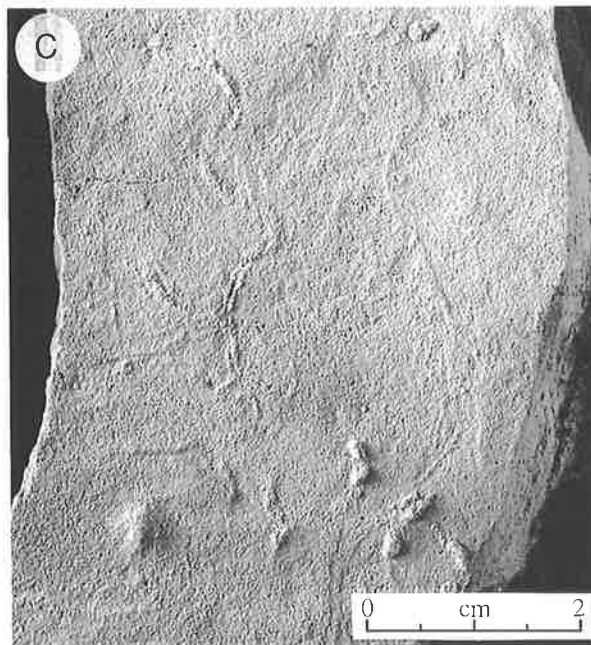
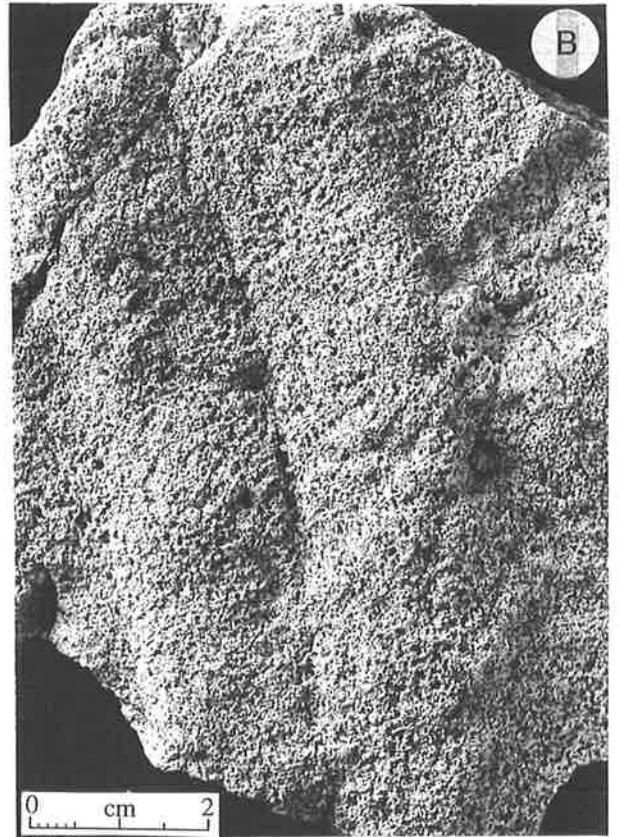
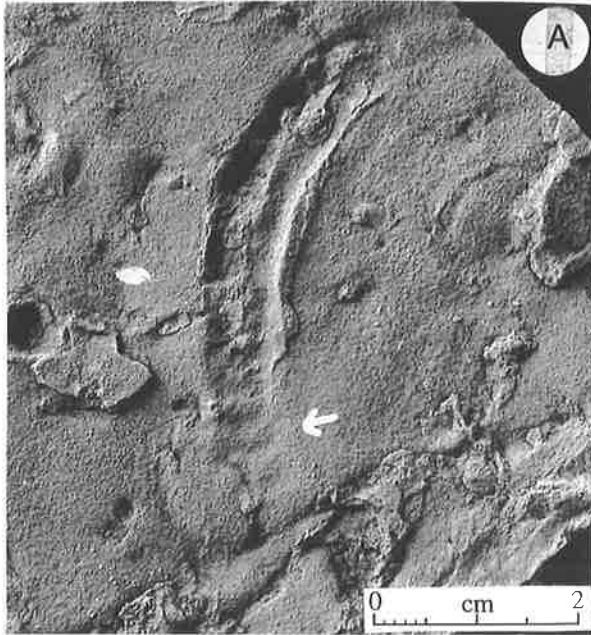
- A.** *Arthraria antiquata*, convex hyporelief, Donkey Creek Beds, Mount Octy, A1035-MO53.
- B.** *Asteriacites* isp., convex hyporelief, preserved on lower surface of a *Palaeophycus tubularis* burrow. Note the circular ring close to the margin of the trace, Cyclops Bore, A971-1-30.
- C.** ?*Asaphoidichnus trifidum*, Single set of trifold arthropod scratch marks preserved as convex hyporelief. Donkey Creek Beds, Mount Octy, A1035-MO59.
- D.** ?*Bergaueria* isp., convex hyporelief, Donkey Creek Beds, Mount Octy, A1035-MO106.
- E.** *Bilinichnus simplex*, convex hyporelief, poorly preserved material showing several specimens, Donkey Creek Beds, Mount Octy.
- F.** ?*Bergaueria* isp., convex hyporelief, Donkey Creek Beds, Mount Octy, A1035-MO153.



### Plate 3

- A.** *?Aulichnites* isp. A, concave hyporelief, a bilobate burrow with two concave lobes separated by a median ridge. Note the transverse annulations at one side of the burrow where the bilobation is lacking, Box Hole Formation, Ross River, A1035-R12.
- B.** *?Aulichnites* isp. B, convex epirelief, Box Hole Formation, Cyclops Bore, A971-1-23A
- C.** *Cochlichnus anguineus*, concave epirelief, the burrow shows partly elevated margin producing superficial bilobation, Donkey Creek Beds, Mount Octy, A1035-MO100.
- D.** *Cochlichnus anguineus*, concave epirelief, the specimen shows two burrows which are almost parallel to one another and one of them apparently terminates at a circular structure (arrow). Allua Formation, Ross River, A971-2-53.
- E.** *Cochlichnus anguineus*, concave epirelief, displays an irregular sinuous pattern, Donkey Creek Beds, Mount Octy, A1035-MO55.
- F.** *Curvolithus multiplex*, convex epirelief, short trilobate burrows possessing two lateral ridges separated from a median ridge by two narrow furrows. *Skolithos verticalis*, concave or convex epireliefs, burrows display different diameters, Box Hole Formation, Cyclops Bore, A971-2-7.

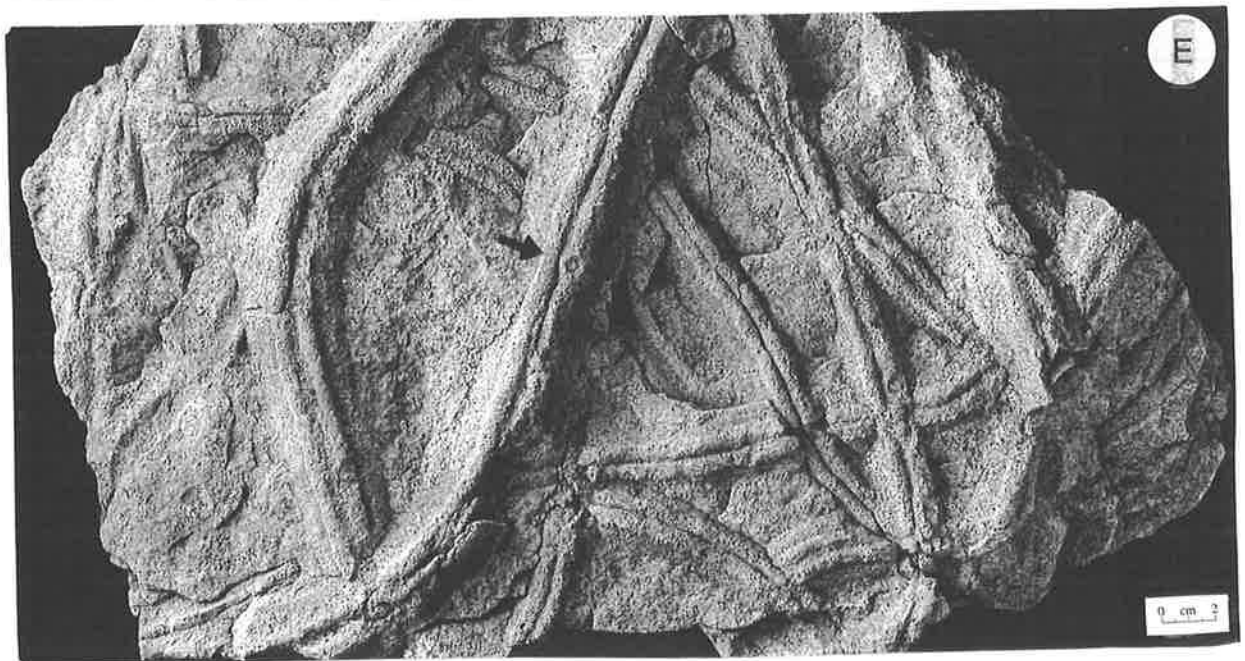
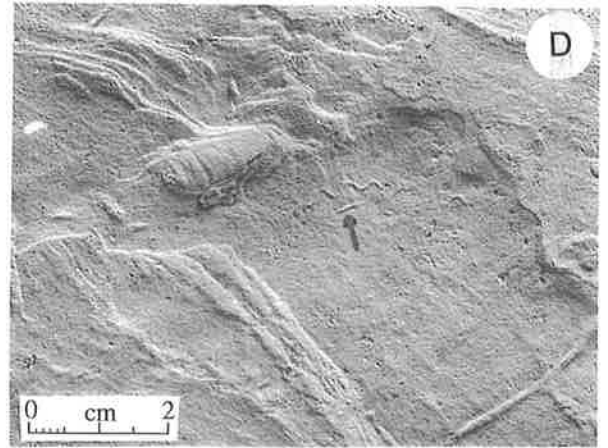
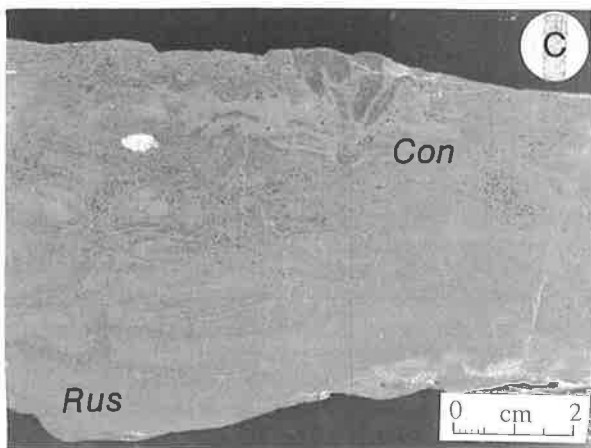
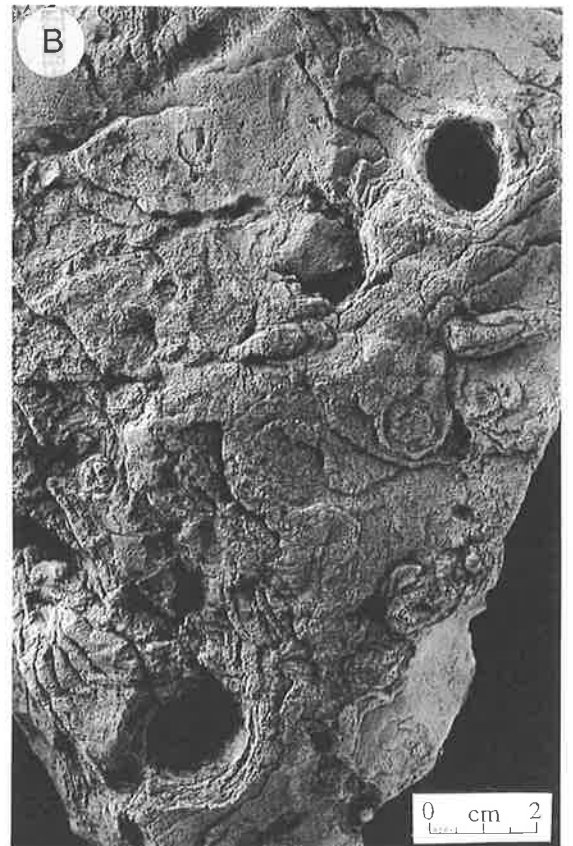






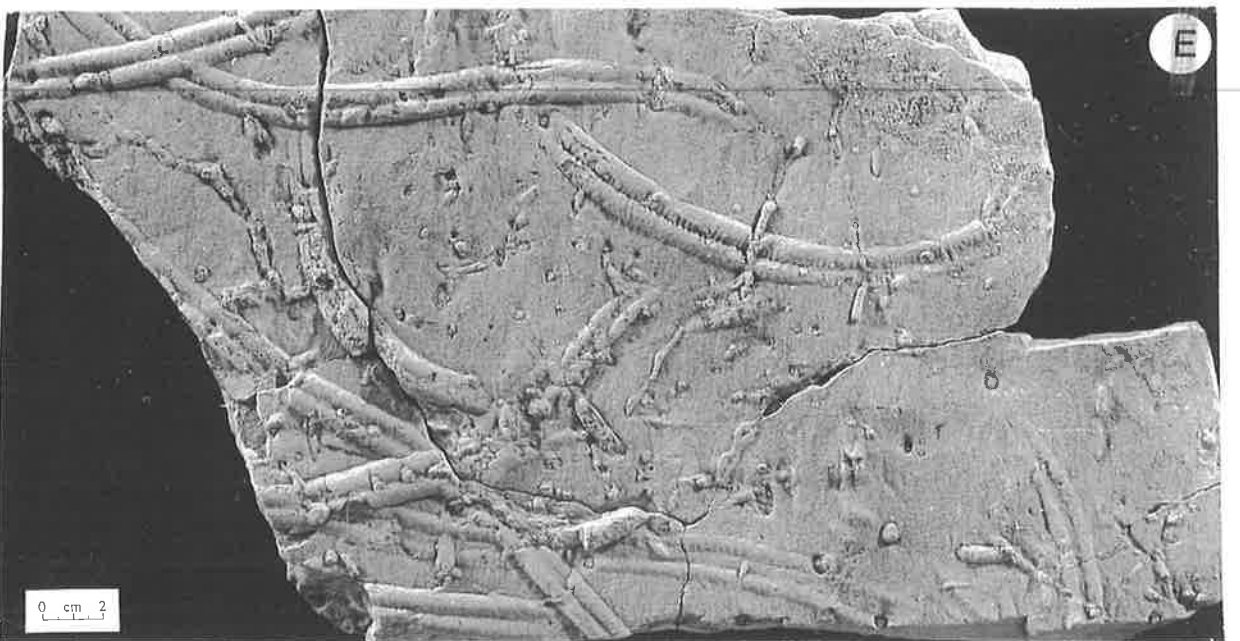
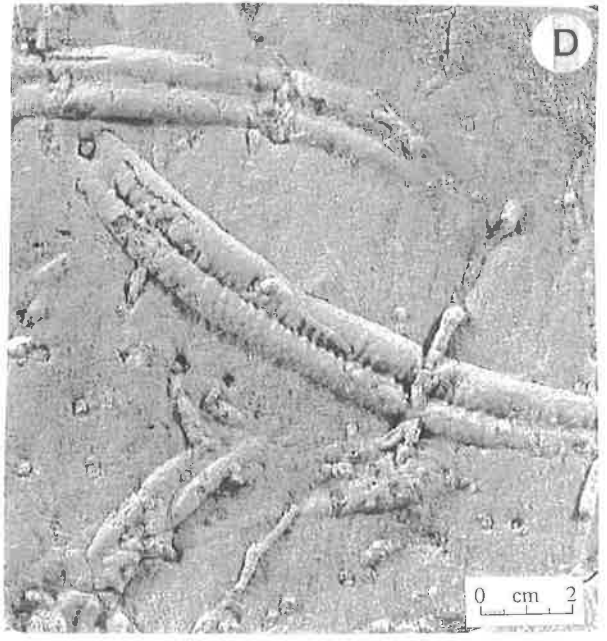
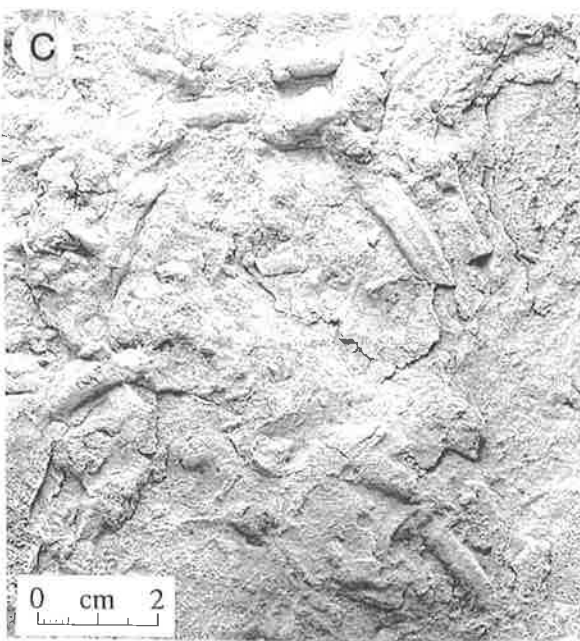
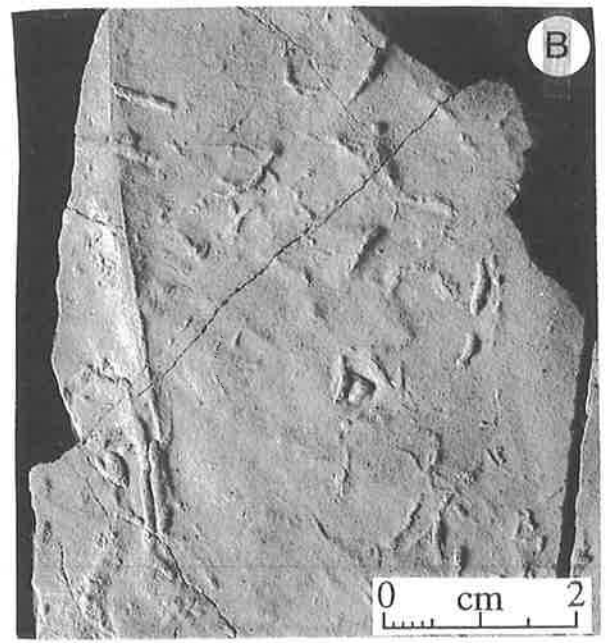
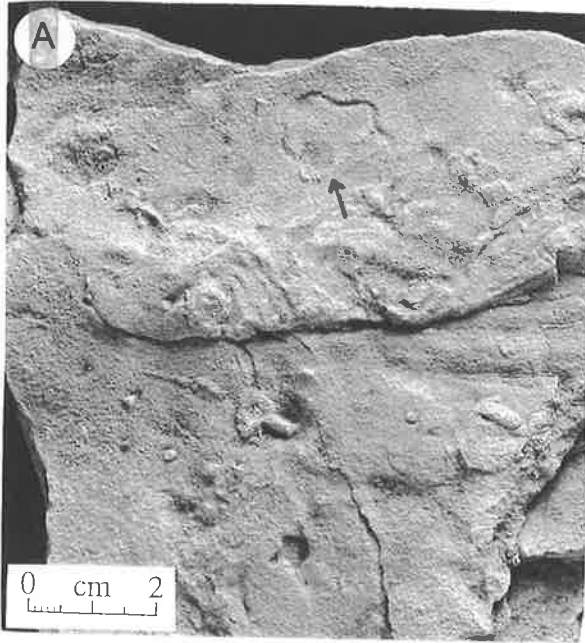
## Plate 4

- A. ?*Conostichus* isp., concave epirelief, Note the *Asteriacites* isp. at the middle of the photo (arrow, see figure 1E for enlargement), Allua Formation, Ross River, A971-2-44.
- B. ?*Conostichus* isp., concave epirelief, the burrow shows a faint concentric structure around its margin, Allua Formation, Ross River, A971-2-45.
- C. ?*Conostichus* isp., (Con), side view of a polished transverse section of the same specimen as in Pl.4A showing a cone shaped burrow which has a different filling from that of host rock. There is also a slight concentration of mica flakes around the margin of the burrow. *Rusophycus* isp. A (Rus) is seen in transverse section on the lower part of the photo.
- D. *Cosmorhapha* ?*gracilis*, poorly preserved specimen, convex epirelief. An undetermined annulated burrow also has been preserved as convex hyporelief, upper Box Hole Formation, Ross River, A971-2-7.
- E. *Didymaulichnus miettensis*, convex hyporelief, one of the burrows has been penetrated by *Skollithos* causing swelling of the *D. miettensis* (arrow), Box Hole Formation, Cyclops Well, A971-1-21.



## Plate 5

- A. *Cochlichnus anguineus*, concave epirelief, the burrow terminates in a circular structure (arrow) much larger in diameter, Donkey Creek Beds, Mount Octy, A1035-MO116.
- B. *Didymaulichnus lyelli* and *Torrowangea rosei*, convex hyporelief, Box Hole Formation, Ross River, A1035-R1.
- C. *Curvolithus multiplex*, convex epirelief, upper Box Hole Formation, Ross River, A971-2-7.
- D. *Cruziana ?tenella*, enlargement of specimen in plate 5E showing transverse ridges.
- E. *Cruziana ?tenella*, convex hyporelief, burrows are subparallel to bedding plane and tend to pass over or under one another indicating their endichnial origin of the burrow; *Skolithos verticalis*, convex or concave hyporeliefs, Allua Formation, Ross River, A971-3-13.



## Plate 6

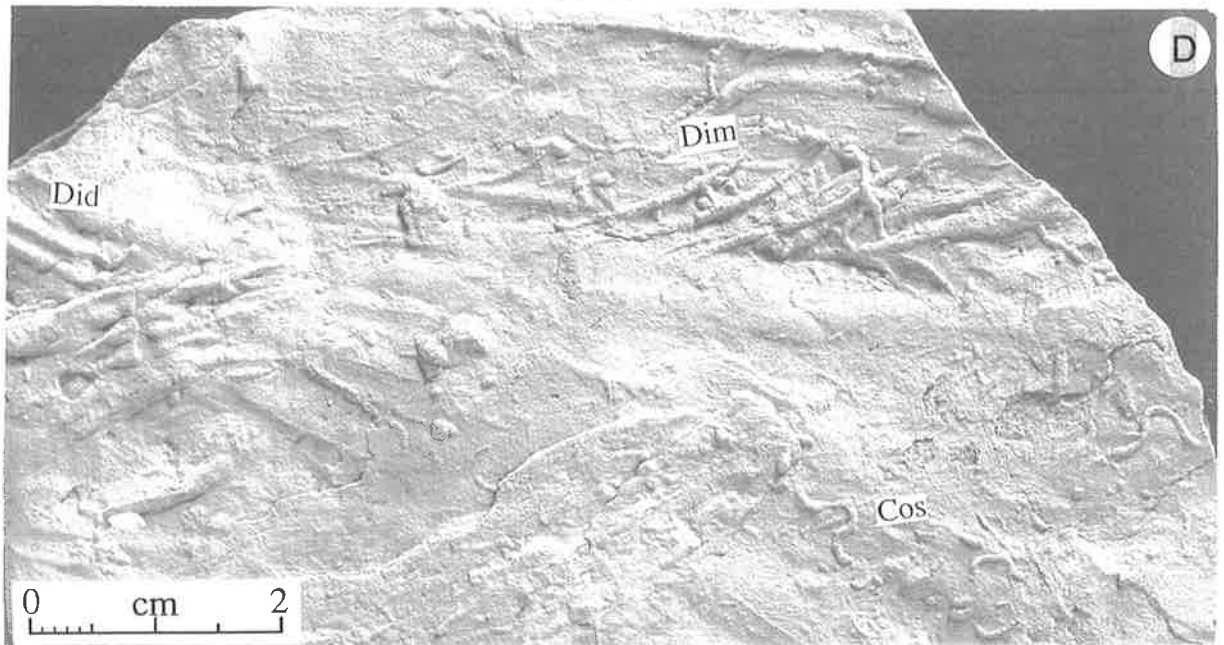
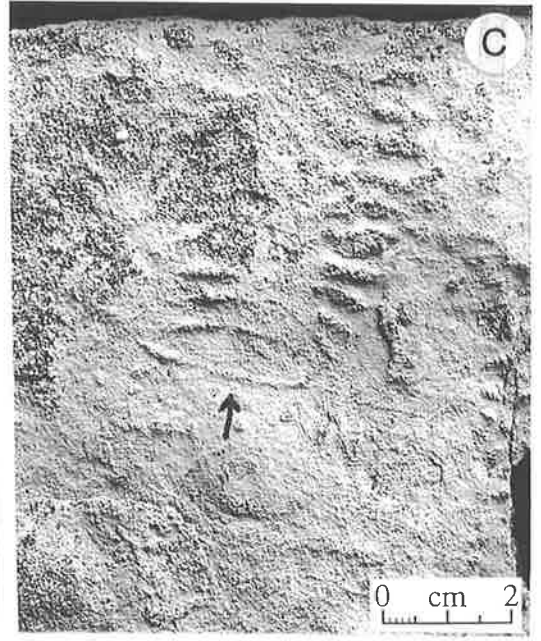
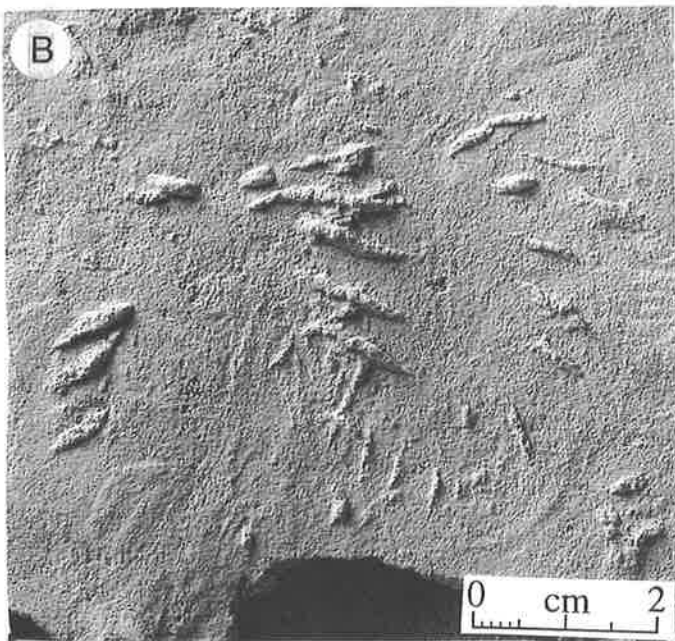
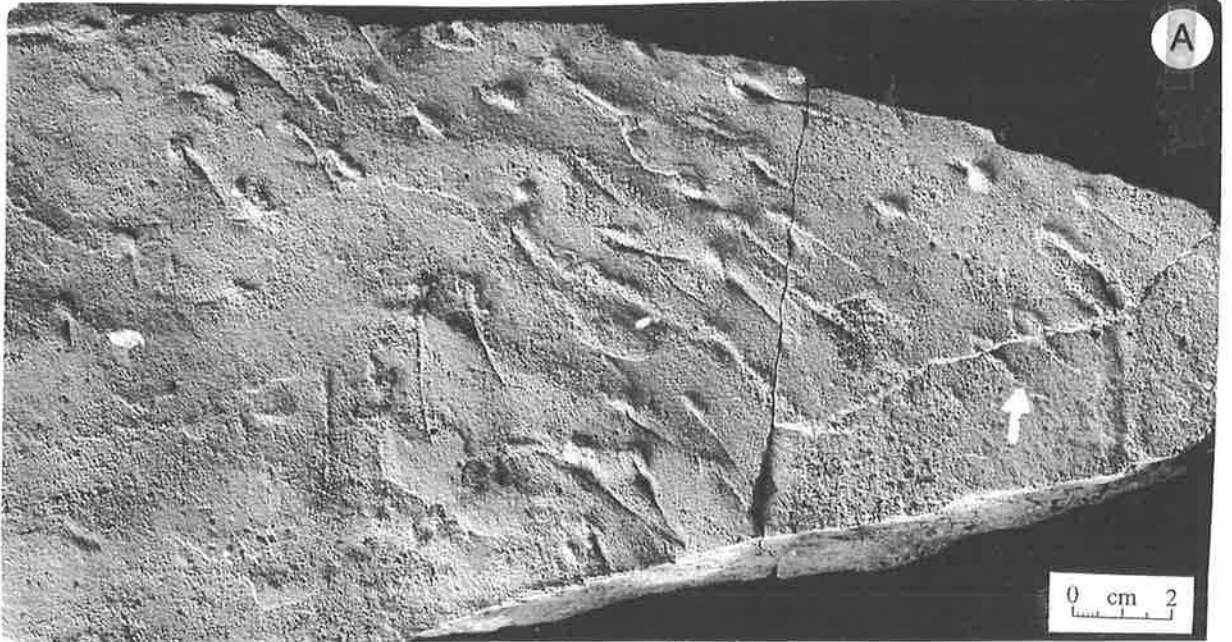
- A.** *Didymaulichnus miettensis*, convex hyporelief, burrows cross or pass over one another, Box Hole Formation, Cyclopes Bore, A971-1-22.
- B.** *Cosmorhapha ?gracilis*, convex epireliefs, poorly preserved specimen showing small sinuous burrows, Box Hole Formation, Ross River, A971-2-31.
- C.** *Didymaulichnus lyelli*, convex hyporelief, Box Hole Formation, Ross River, A971-2-14.
- D.** Erosion of walled burrows may produce false lobation. Arrows show false trilobation of a *Palaeophycus tubularis* burrows, note that the furrows produced due to erosion are not parallel and meet each other, upper Box Hole Formation, Ross River, A971-2-31.





## Plate 7

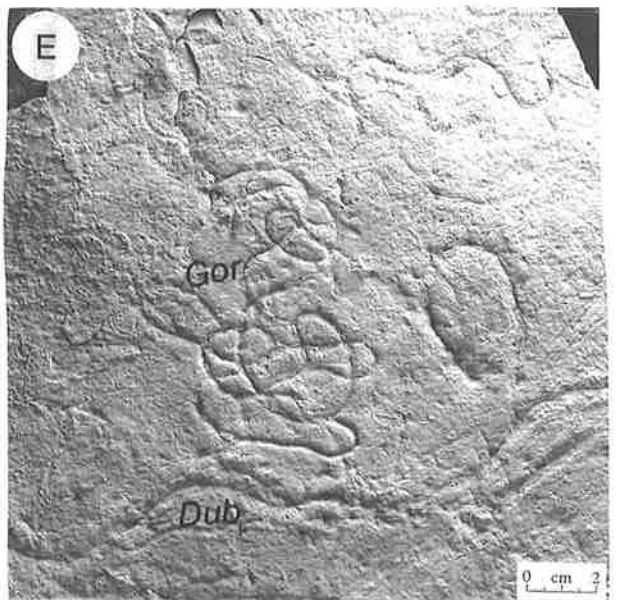
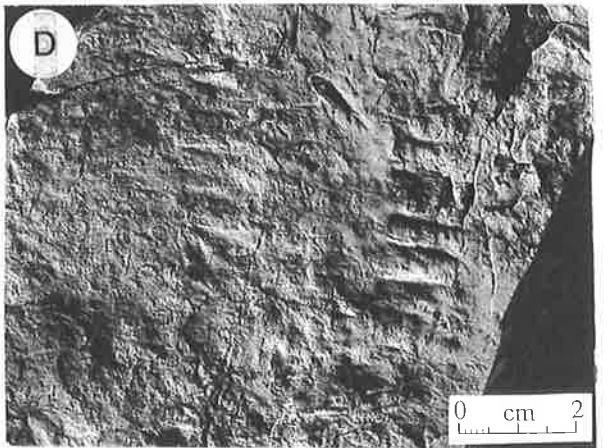
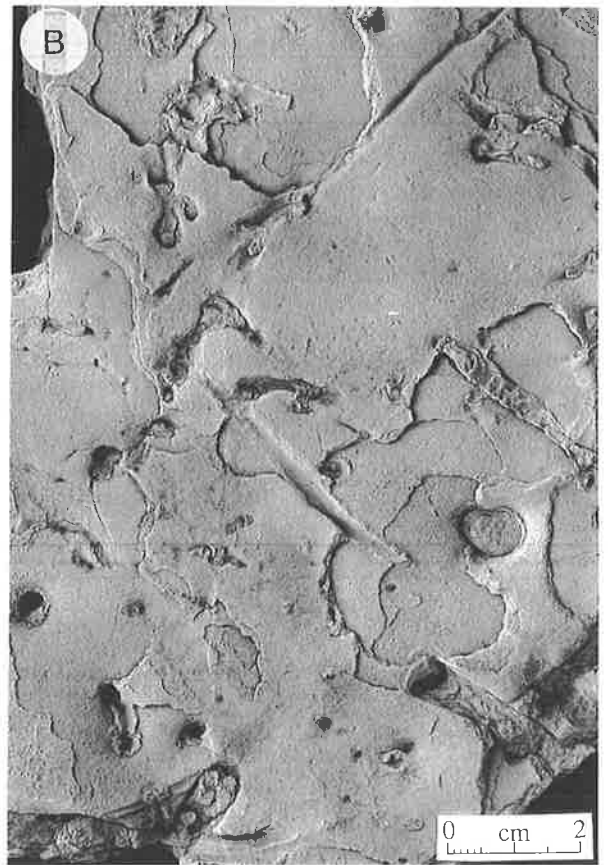
- A.** *Dimorphichnus* isp., concave epirelief, series of parallel scratch marks of which some show bulge of sediment at one end (push marks), Donkey Creek Beds, Mount Octy, A1035-MO84.
- B.** *Diplichnites* isp. A, series of parallel ridges preserved as convex hyporeliefs and arranged in a tight arcuate pattern. Note that elongation of imprints changes from transverse to parallel with the axis of the trace, Donkey Creek Beds, Mount Octy, A1035-MO73.
- C.** *Diplichnites* isp. B, concave epirelief, the last two imprints (arrow) are longer and extend beneath both sets of imprints, Box Hole Formation, Ross River, A1035-R23.
- D.** *Dimorphichnus* isp. (Dim), *Cosmorhaphe ?gracilis* (Cos) and *Didymaulichnus lyelli* (Did), convex hyporeliefs, Allua Formation, Ross River, A1035-R24.





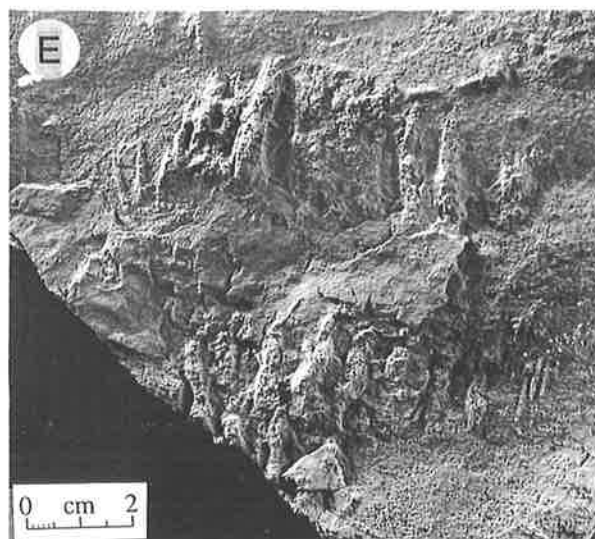
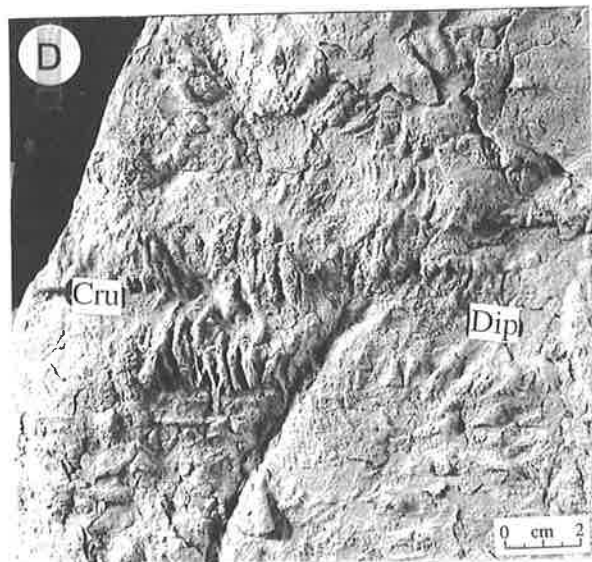
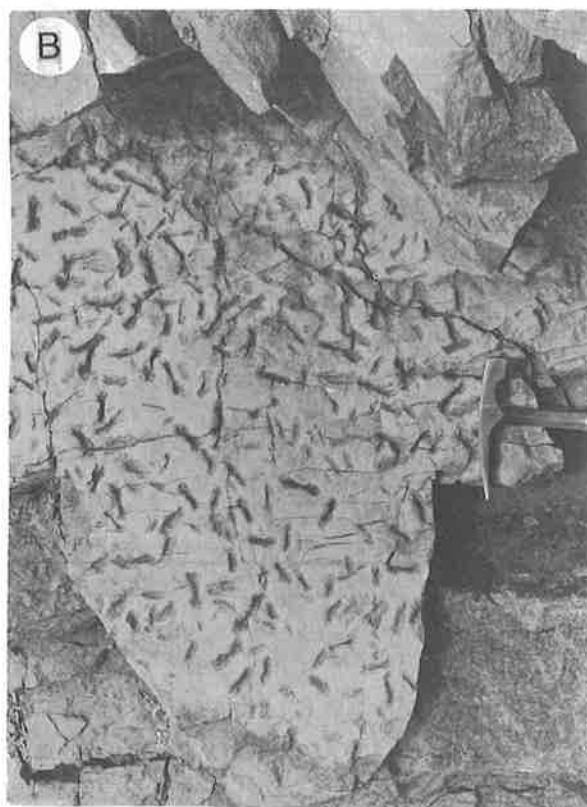
## Plate 8

- A.** *Diplichnites* isp. B, concave epirelief, a large burrow comprising two series of imprints arranged in an ovate pattern. The trace shows an elevated axial area. Donkey Creek Beds, Mount Octy, A1035-MO114.
- B.** *Diplocraterion* isp., concave epirelief, paired vertical burrows with a disturbed zone between, Box Hole Formation, Cyclops Bore, A971-1-34.
- C.** *Diplocraterion* isp., concave epirelief, filling of the burrow has been eroded away by subsequent weathering, Box Hole Formation, Ross River, A971-2-52.
- D.** *Diplichnites* isp. B, concave epirelief, two series of imprints almost perpendicular to axis of the trace. The area between the two series is smooth with no ornamentation, Box Hole Formation, Ross River, A1035-B2.
- E.** *Gordia marina* (Gor), narrow burrows with tendency to level crossing; Dubiofossil C(Dub), a large sinuous furrow with elevated margins, concave epireliefs, Allua Formation, Ross River, A971-2-49.



## Plate 9

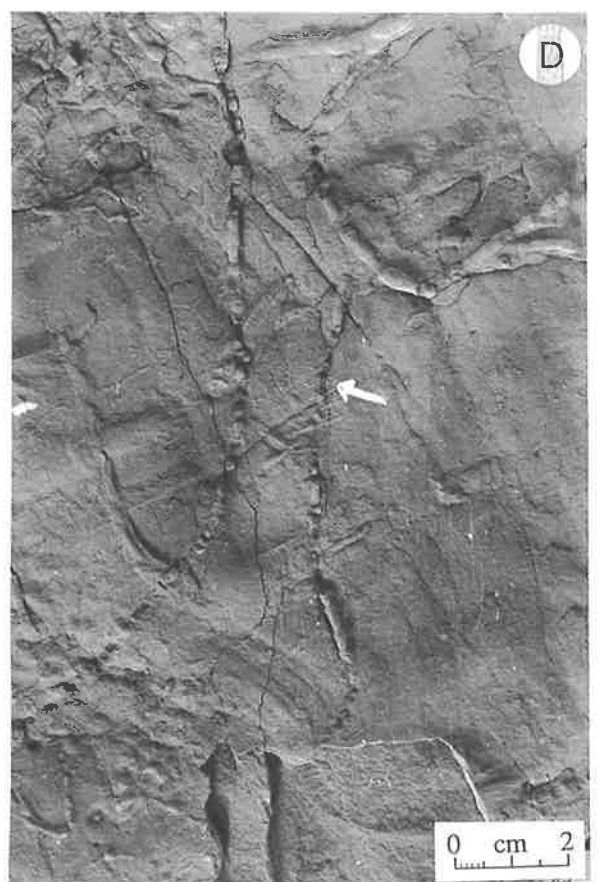
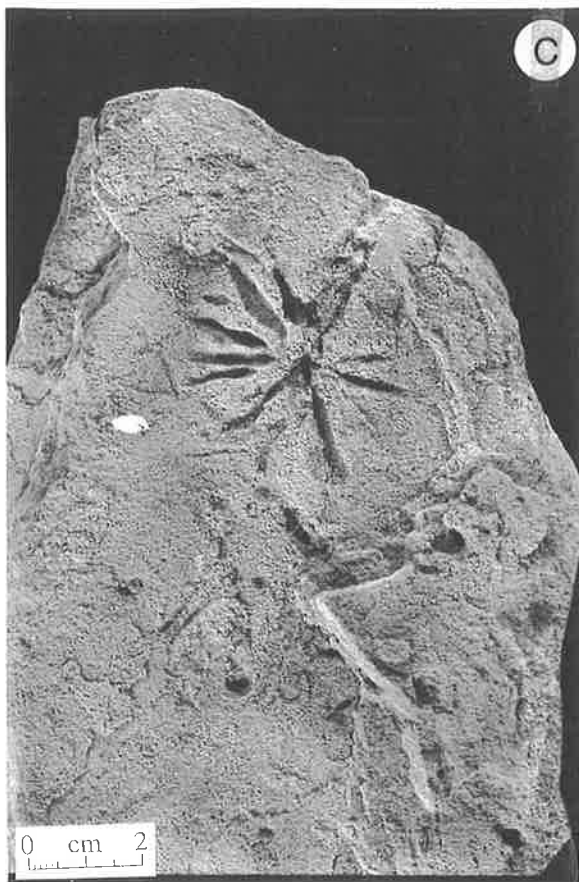
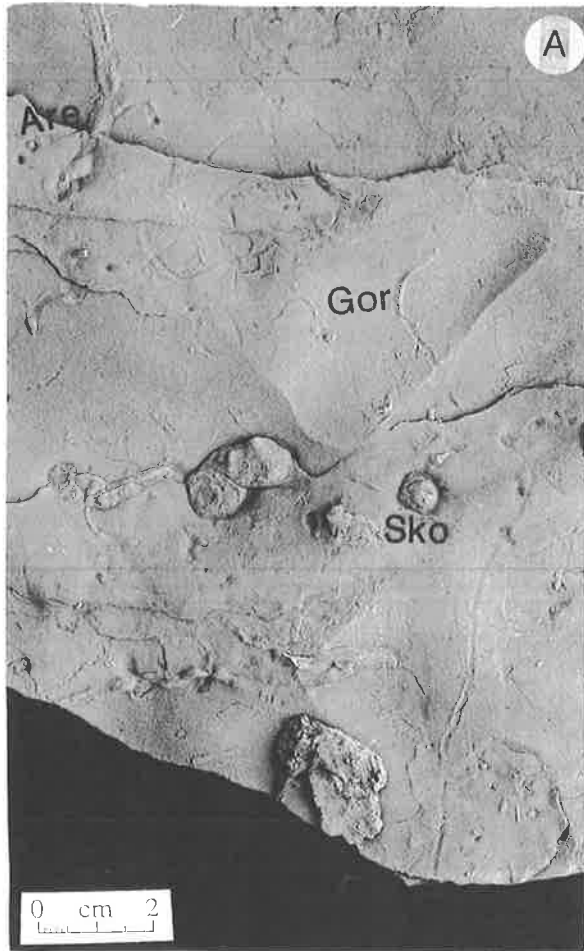
- A.** *Glockerichnus ?sparsicostata*, stellate structures preserved as convex hyporeliefs, there are one well preserved and several poorly preserved specimens (arrow), Allua Formation, Hugh River, A971-4-10.
- B.** *Diplocraterion* isp., concave epireliefs, a field photo showing densely populated specimen.
- C.** *Glockerichnus ?sparsicostata*, concave epirelief; this is the epichnial view of specimen in plate 9A.
- D.** *Diplichnites* isp. B (Dip) intergrades into a *cruziana*-like burrow (Cru), convex hyporelief, Box Hole Formation, Ross River, A1035-B9.
- E.** *Diplichnites* isp. B, convex hyporelief, Box Hole Formation, Ross River, A1035-R23.



## Plate 10

- A.** *Gordia* isp. (Gor), *Arenicolites* isp. A (Are) and *Skolithos verticalis* (Sko), concave epireliefs, Box Hole Formation, Ross River, A971-2-27.
- B.** *Gyrolithes* cf. *polonicus*, curved burrows preserved as convex epireliefs representing the last whorl of spiral burrows, Box Hole Formation, Ross River, A971-2-29.
- C.** *Glockerichnus* ?*sparsicostata*, concave epirelief, Allua Formation, Cyclops Bore, A971-6-2.
- D.** *Hormosiroidea* isp. Preserved as convex epireliefs showing a straight to curved burrow with vertical shafts (arrow), Allua Formation, Ross River, A1035-G1.





## Plate 11

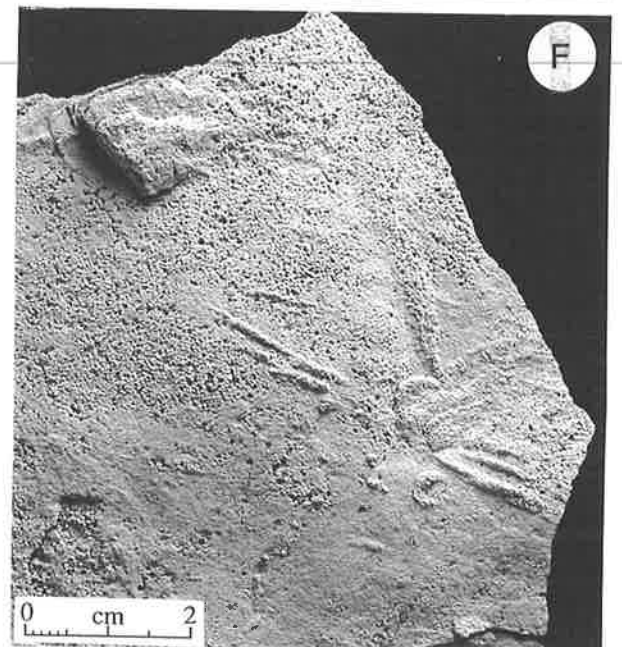
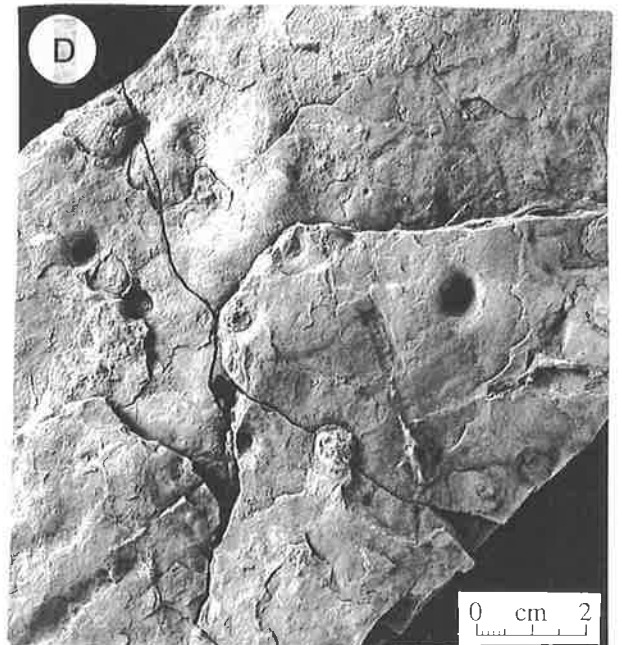
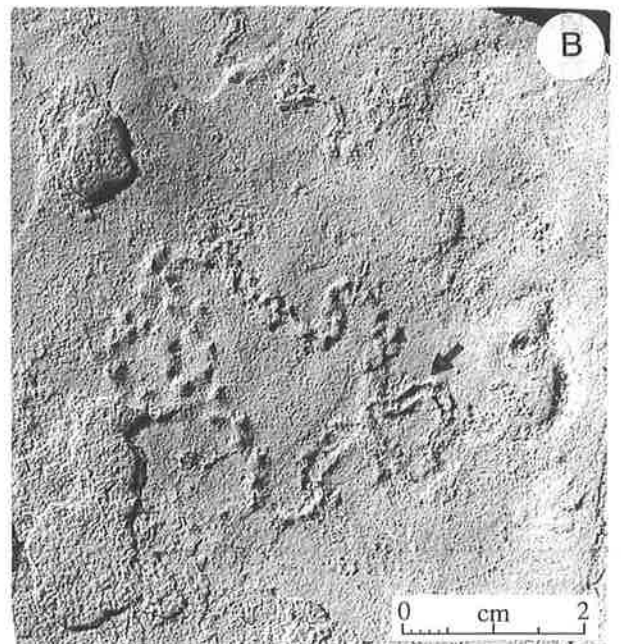
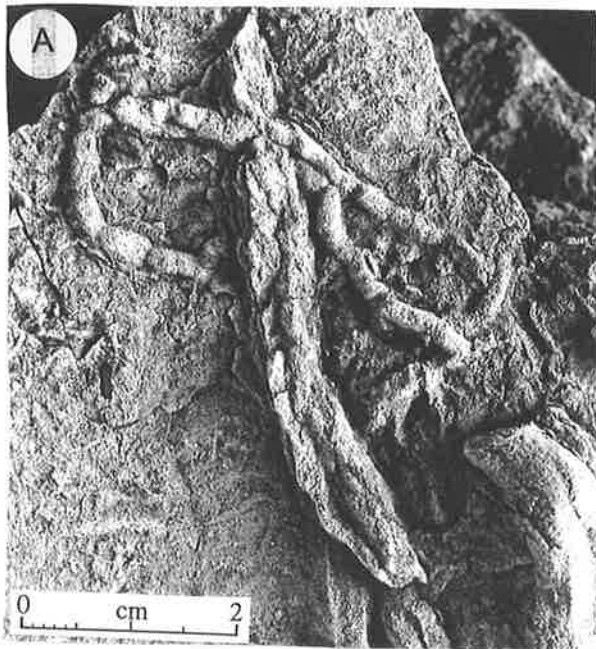
- A.** *?Hormosiroidea pollardi*, convex epirelief, vertical burrows with vertical extensions, Donkey Creek Beds, Mount Octy, A1035-MO159.
- B.** *Hormosiroidea* isp., an enlargement of figure 12C showing a horizontal burrow annulated due to vertical extensions (sh). Note the difference between the filling of the shafts and the host rock. Allua formation, Ross River, A1035-G1.
- C.** *Phycodes coronatum*, convex epirelief, Donkey Creek Beds, Mount Octy, A1035-MO153.
- D.** *Hormosiroidea ?arumbera*, a field photo showing irregular pattern of the burrow system. One of the burrows (arrow) displays a closed curve. Note the vertical shafts are connected together, Allua Formation, Cyclops Bore.





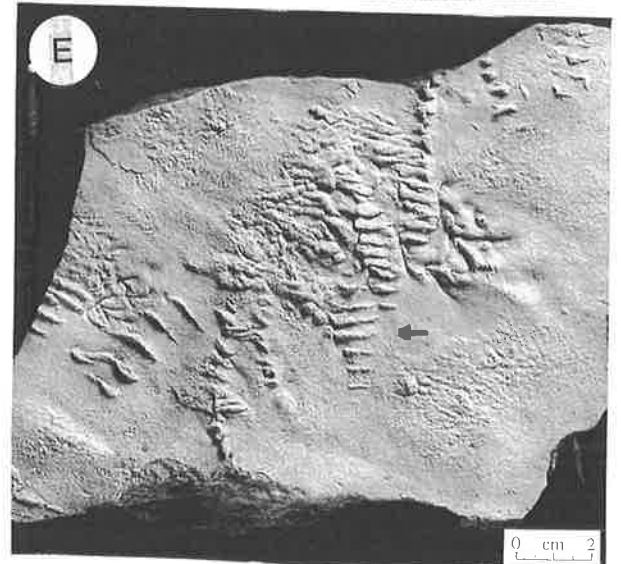
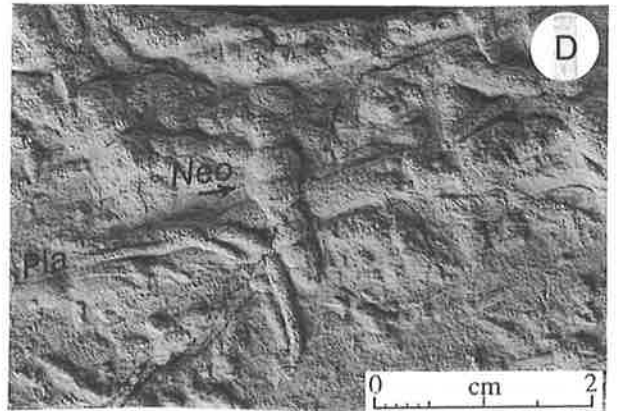
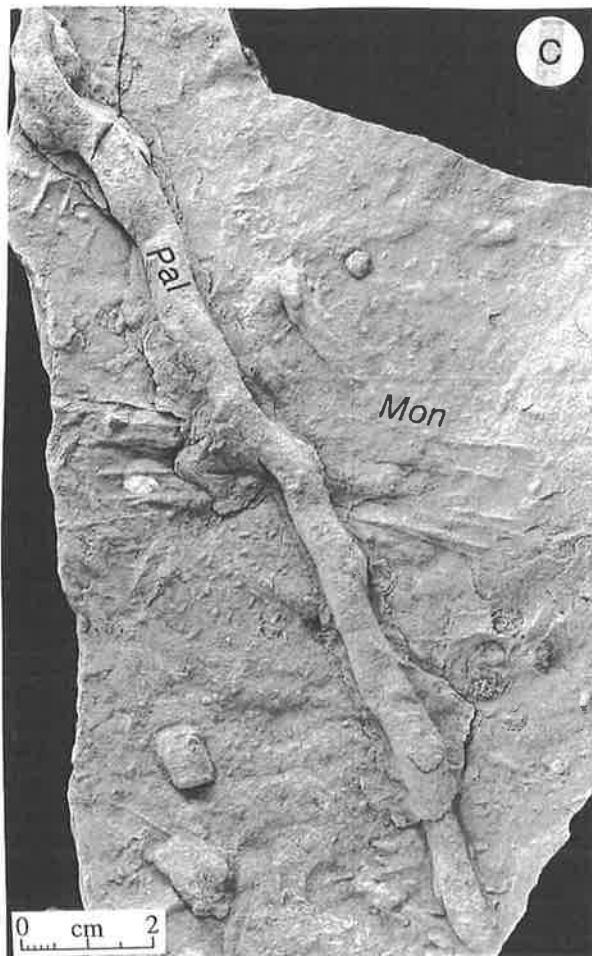
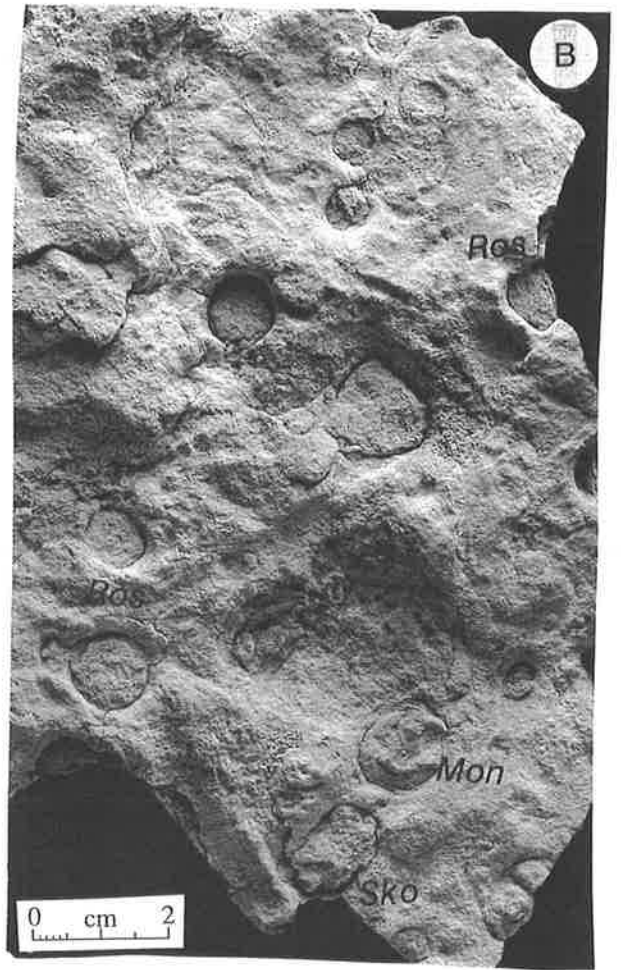
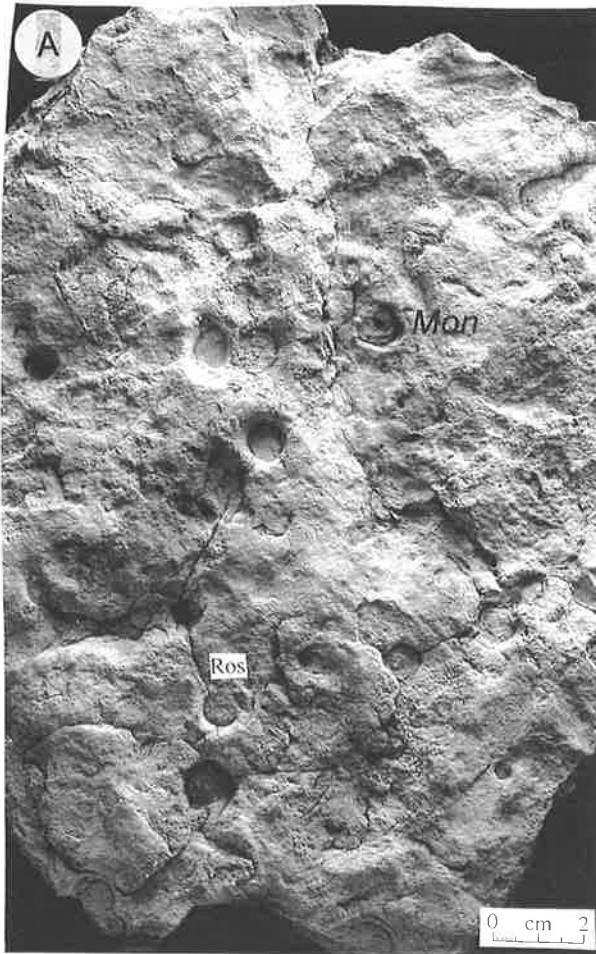
## Plate 12

- A. *Hormosiroidea* isp., annulated burrow preserved as convex hyporelief, annulation is likely due to vertical extension of each segment, Allua Formation, Ross River, A1035-R15.
- B. *Hormosiroidea* ?*arumbera*, concave epirelief, series of pits arranged in a winding pattern, Donkey Creek Beds, Mount Octy, A1035-MO160.
- C. *Hormosiroidea* isp., convex hyporelief, several specimens cross one another. Burrows display annulations due to the vertical offshoots. Allua Formation, Ross River, A1035-G1.
- D. *Monocraterion* isp., concave epirelief, large circular burrow with funnel-shaped aperture, Box Hole Formation, Cyclops Bore, A971-1-27.
- E. ?*Laevicyclus* isp. (Lae), concentric circular ridges surrounding a vertical element, *Planolites montanus* (Pla), short burrows with coarser filling than the host rock, convex hyporeliefs, Allua Formation, Allua Formation, A1035-B4.
- F. *Monomorphichnus lineatus*, convex hyporelief, straight ridges arranged in a cat-moustache-like pattern, Donkey Creek Beds, Mount Octy, A1035-MO102.



## Plate 13

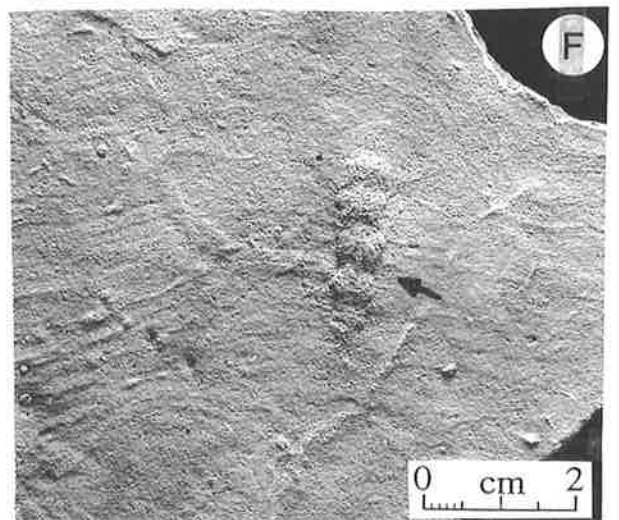
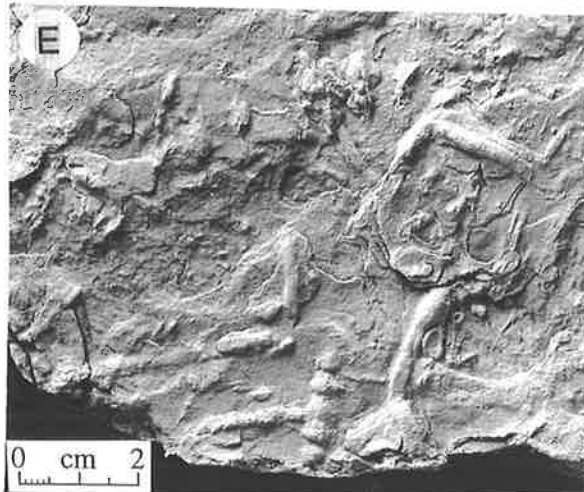
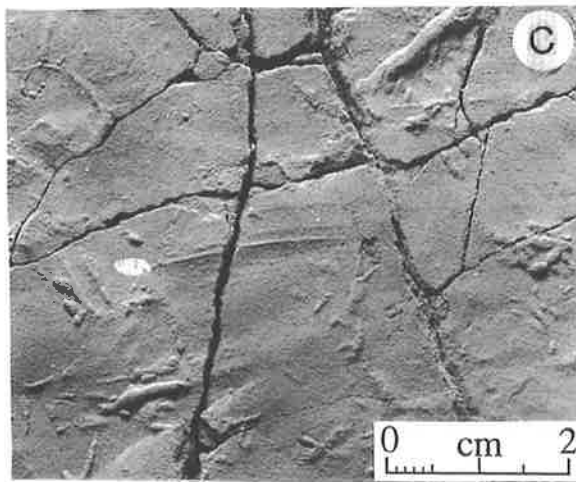
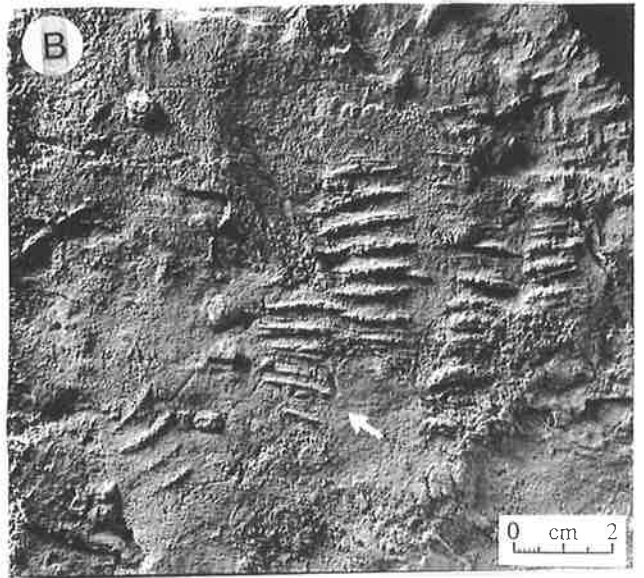
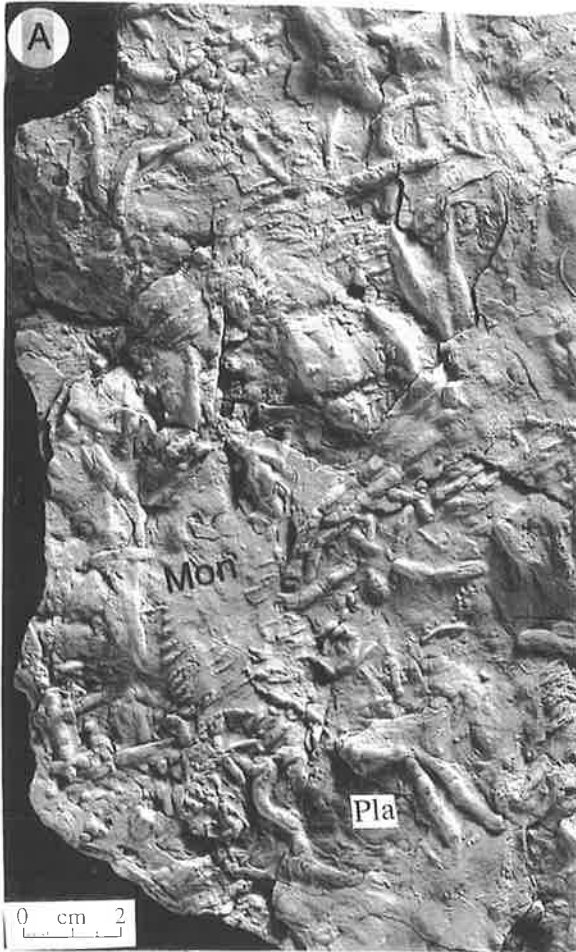
- A. *Monocraterion* isp. (Mon) and *Rosselia socialis* (Ros) burrows preserved as convex and concave epireliefs, Donkey Creek Beds, Mount Octy, A1035-MO47A.
- B. *Monocraterion* isp. (Mon), *Skolithos bulbosus* (Sko) and *Rosselia socialis* (Ros) burrows preserved as convex and concave epireliefs. *R. socialis* burrows are more circular and display a faint concentric structure, Donkey Creek Beds, Mount Octy, A1035-MO62.
- C. *Monomorphichnus lineatus* (Mon) and *Palaeophycus tubularis* (Pal) preserved in convex hyporeliefs. The *M. lineatus* shows a cat-moustache pattern on both sides of the *P. tubularis* burrow. Allua Formation, Ross River, A971-2-13.
- D. *Neonereites uniserialis* (Neo) and *Planolites montanus* (Pla), convex hyporeliefs, Box Hole Formation, Cyclops Bore, A971-1-2.
- E. *Monomorphichnus lineatus*, convex hyporelief. Soft sediment deformation has obliterated part of the impressions. Some specimens (arrow) show more prominent imprints at the middle portion and resemble *M. multilineatus*, Box Hole Formation, Ross River, A1035-G2.



## Plate 14

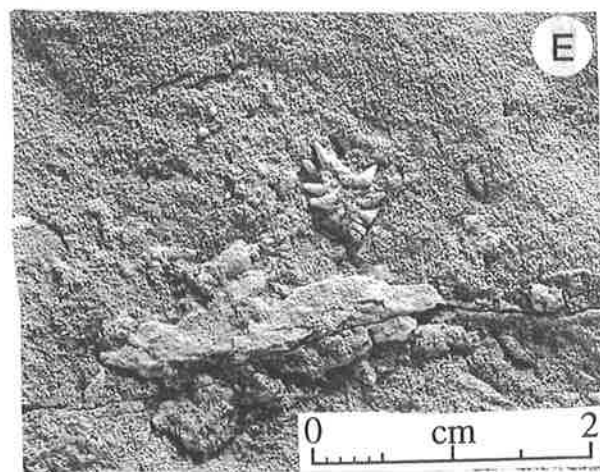
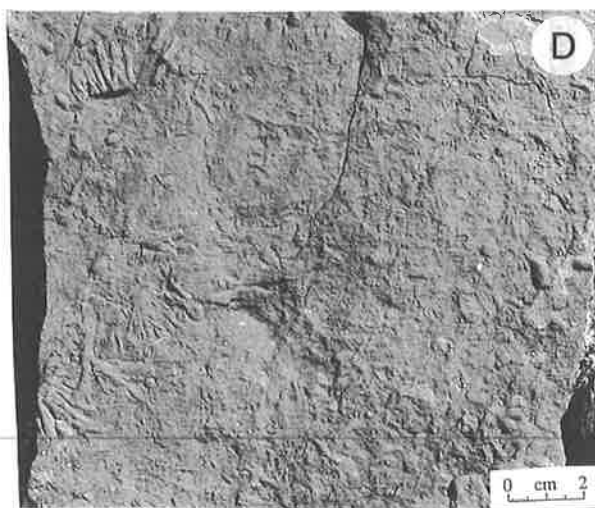
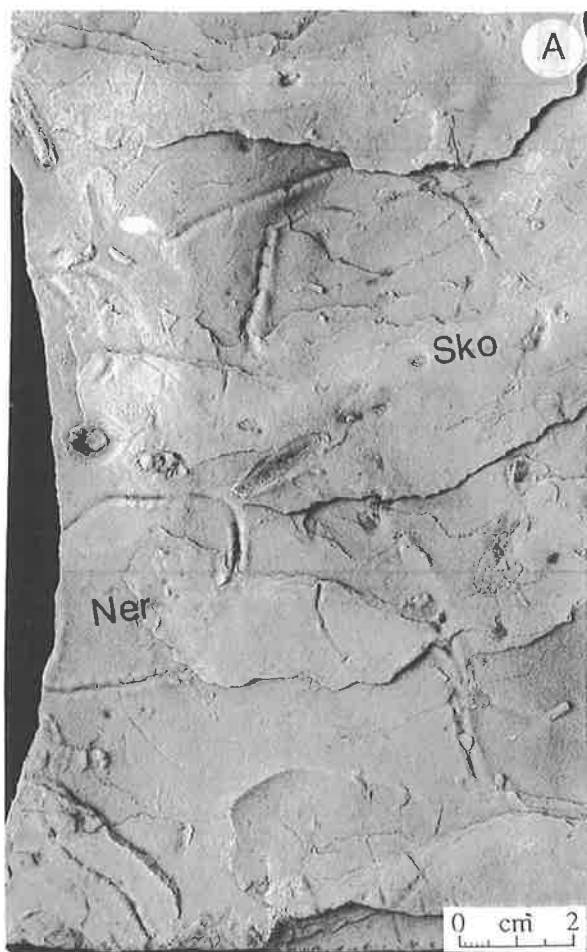
- A. *Monomorphichnus lineatus* (Mon) and *Planolites montanus* (Pla), convex hyporeliefs, Box Hole Formation, Ross River, A1035-R25.
- B. *Monomorphichnus bilinearis*, convex epirelief, note the brush marks between some imprints (arrow), Box Hole formation, Ross River, A1035-B7.
- C. *Monomorphichnus lineatus* and *Planolites montanus*, convex hyporeliefs, Box Hole Formation, Ross River, A971-2-13.
- D. *Neonereites biserialis*, convex hyporelief, Donkey Creek Beds, Mount Octy, A1035-MO112.
- E. *Neonereites* isp., convex hyporelief, comprising spherical structures displaying faint striations; *Planolites montanus*, convex hyporelief, Box Hole Formation, Cyclops Bore, A1035-R42
- F. *Neonereites* isp., convex hyporelief, several spherical structures aligned in a straight line displaying faint striations, Donkey Creek Beds, Mount Octy, A1035-MO183.





## Plate 15

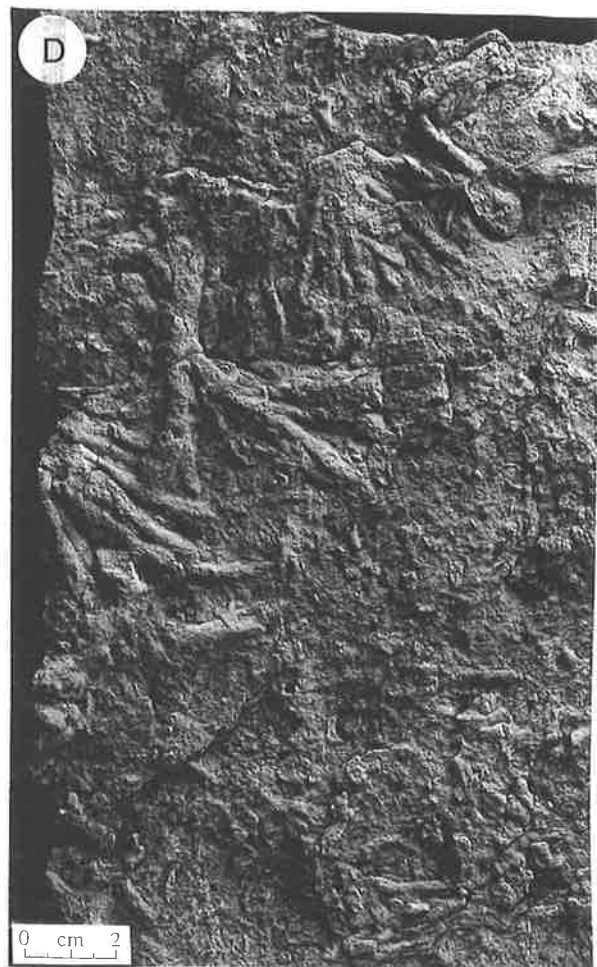
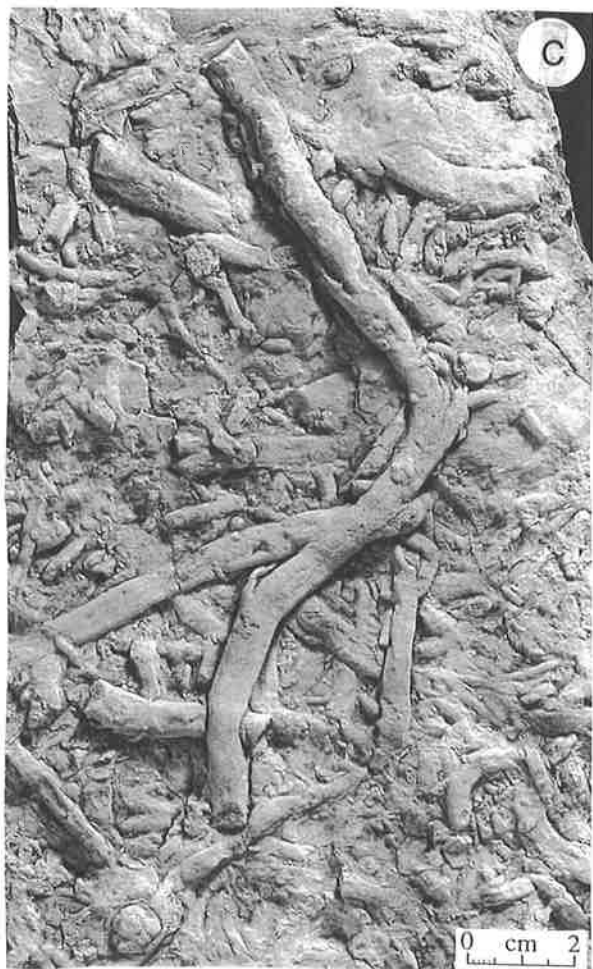
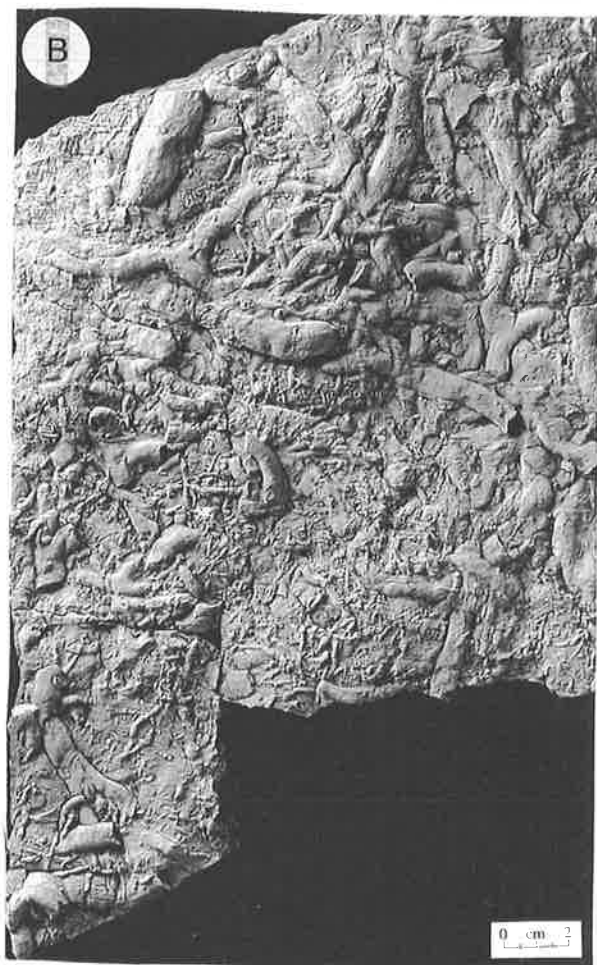
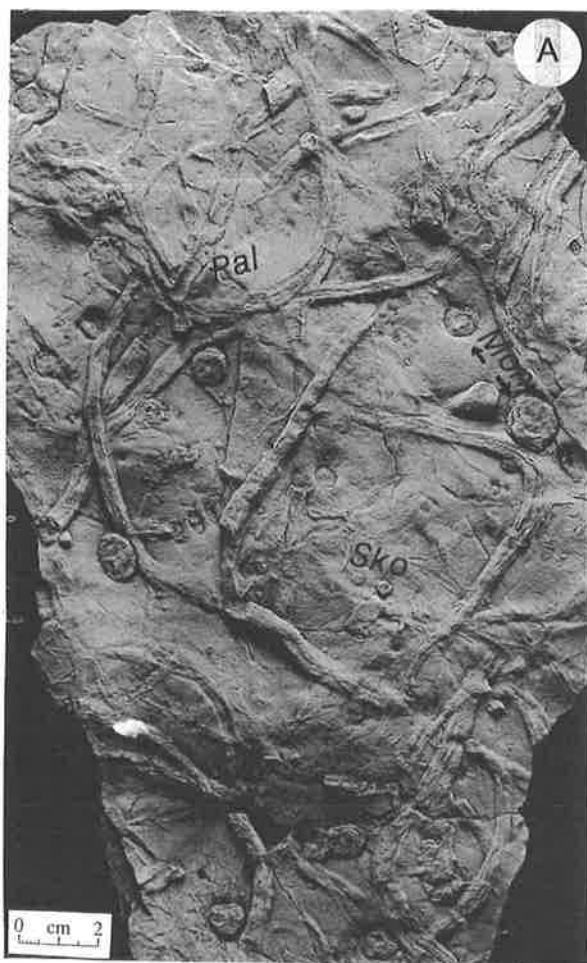
- A. *Nereites Macleayi* (Ner) and *Skolithos verticalis* (Sko), concave epireliefs, Box Hole Formation, Ross River, A971-2-27.
- B. *Palaeophycus canalis*, convex hyporeliefs, burrows display longitudinal canals which are almost parallel to one another, Allua Formation, Ross River, A971-3-2.
- C. *Palaeophycus ferrovittatus*, convex hyporeliefs, the arrow shows the ferroginous axial zone which has been exposed due to erosion, Allua Formation, Ross River, A971-3-7.
- D. *Phycodes palmatus*, convex hyporeliefs, a field photo showing several specimens, Allua Formation, Ross River.
- E. *Phycodes* cf. *curvipalmatus*, convex hyporeliefs, Donkey Creek Beds, Mount Octy, A1035-MO38.





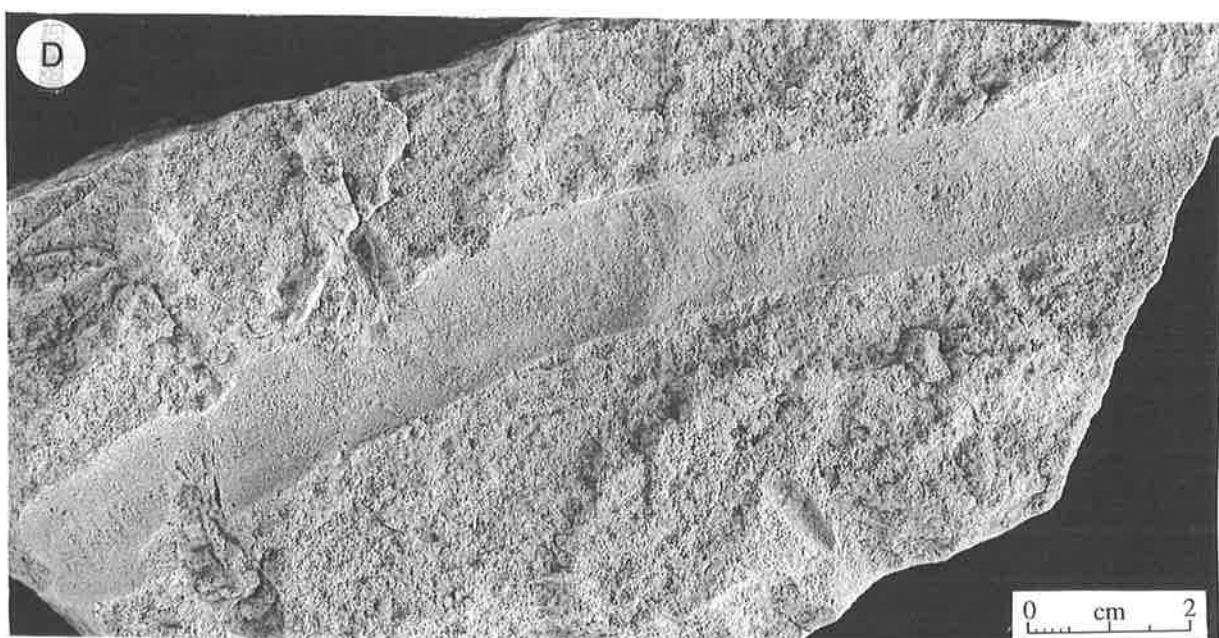
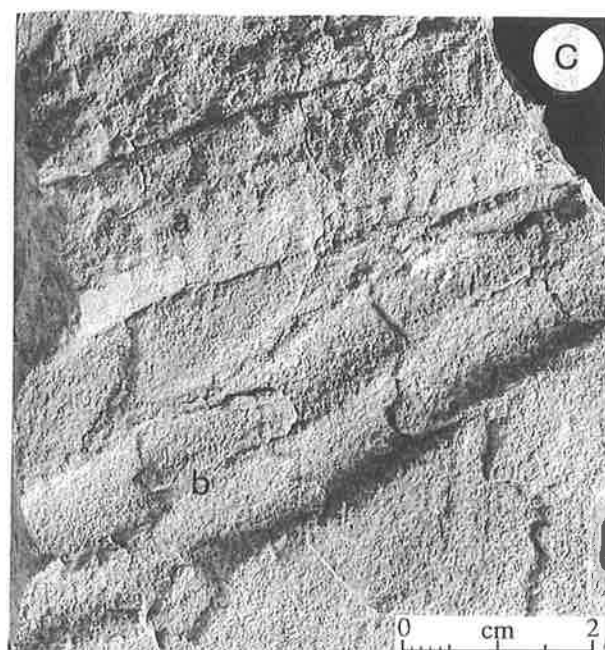
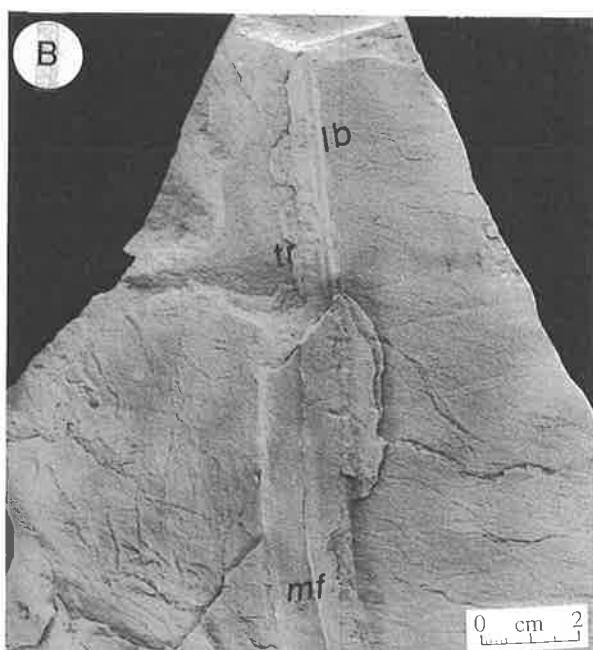
## **Plate 16**

- A.** *Palaeophycus sulcatus* (Pal), *Monocraterion* isp. (Mon) and *Skolithos verticalis* (Sko), convex epireliefs, Allua Formation, Cyclops Bore, A971-1-29.
- B.** *Palaeophycus tubularis*, convex hyporelief, Box Hole Formation, Cyclops Bore, A971-1-30.
- C.** *Palaeophycus tubularis*, convex hyporelief, Allua Formation, Ross River, A971-2-47.
- D.** *Palaeophycus palmatus*, convex hyporelief, a well preserved specimen showing the distal, palmate-shaped part of the burrow, Allua Formation, Ross River, A971-2-16.



## Plate 17

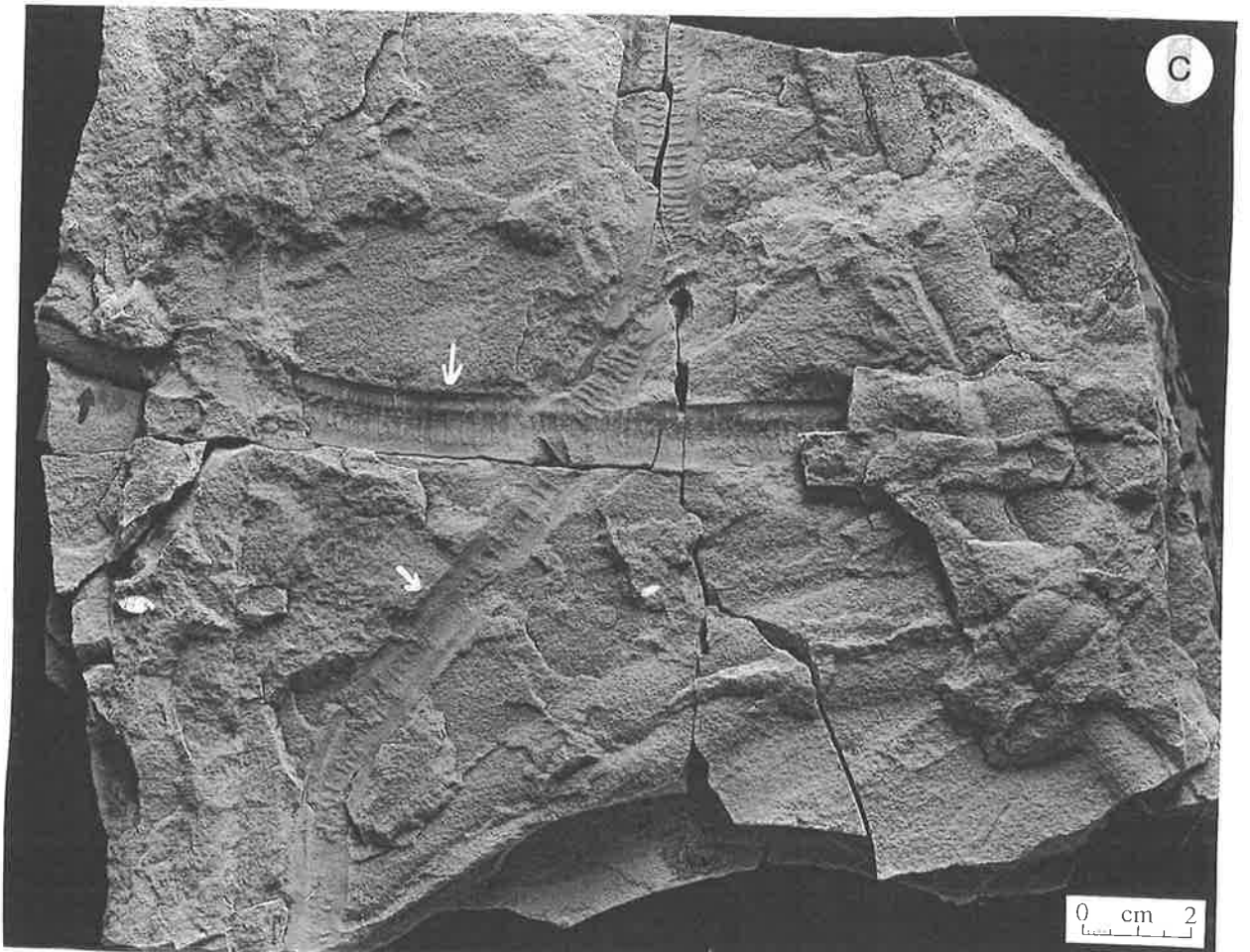
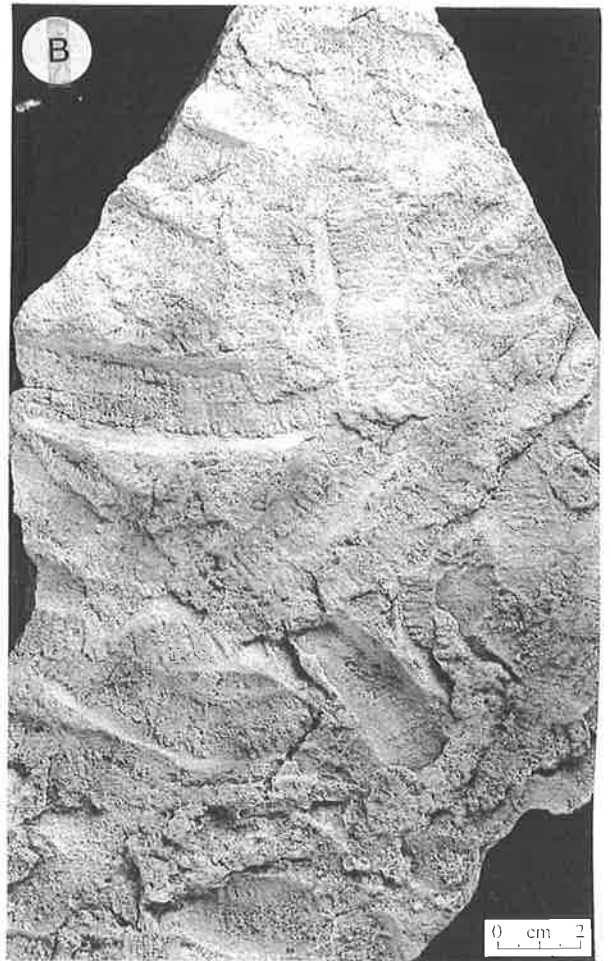
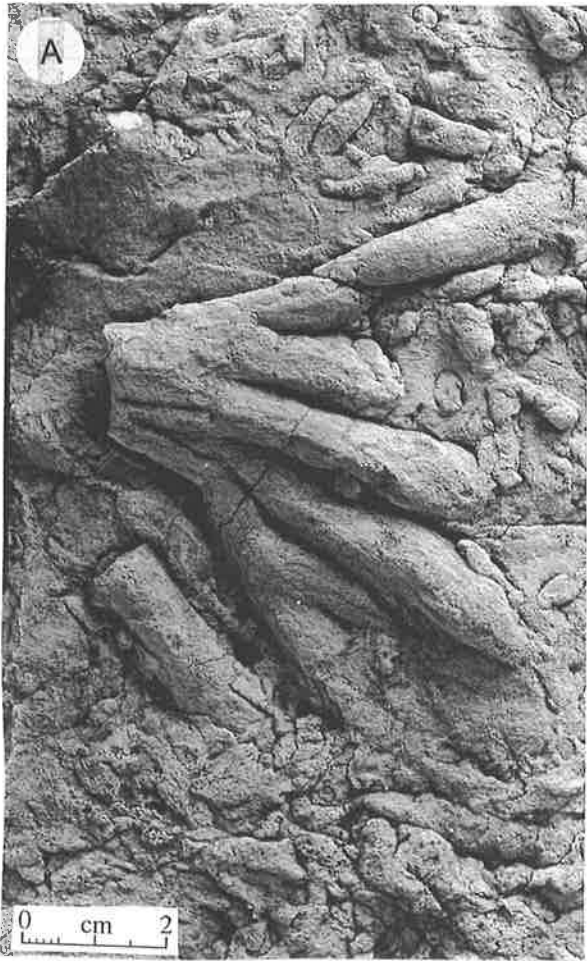
- A. *Palaeophycus sulcatus* (Pal), *Monocraterion* isp. (Mon) and *Skolithos verticalis* (Sko), concave and convex epireliefs, Allua Formation, Cyclops Bore, A971-1-28.
- B. *Plagiogmus arcuatus*, convex epirelief, showing bilobate upper part and the basal ladder-shaped part. The median furrow (mf), lateral bevels (lb) and transverse ridges (tr) are marked on the photograph, Allua Formation, Ross River, A971-2-46.
- C. *Plagiogmus arcuatus*, two specimens preserved on sole of a sandstone layer. a. transversely annulated convex fill represents the middle part of the burrow. b. a concave bilobate structure represents mould of the upper bilobate part of the *Plagiogmus*, Allua Formation, Mount Shannon Bore, A1035-RS1.
- D. *Plagiogmus arcuatus*, concave epirelief, the basal ladder-shaped part of the burrow. Transverse ridges are poorly preserved and do not reach the margin of the burrow, Allua Formation, Cyclops Bore, A971-1-36.



## Plate 18

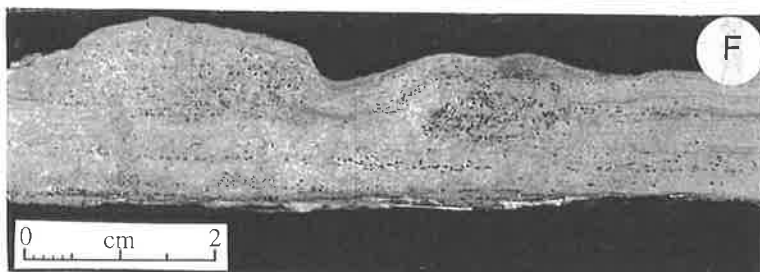
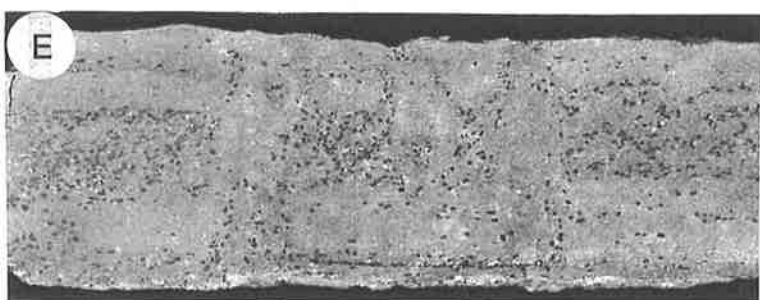
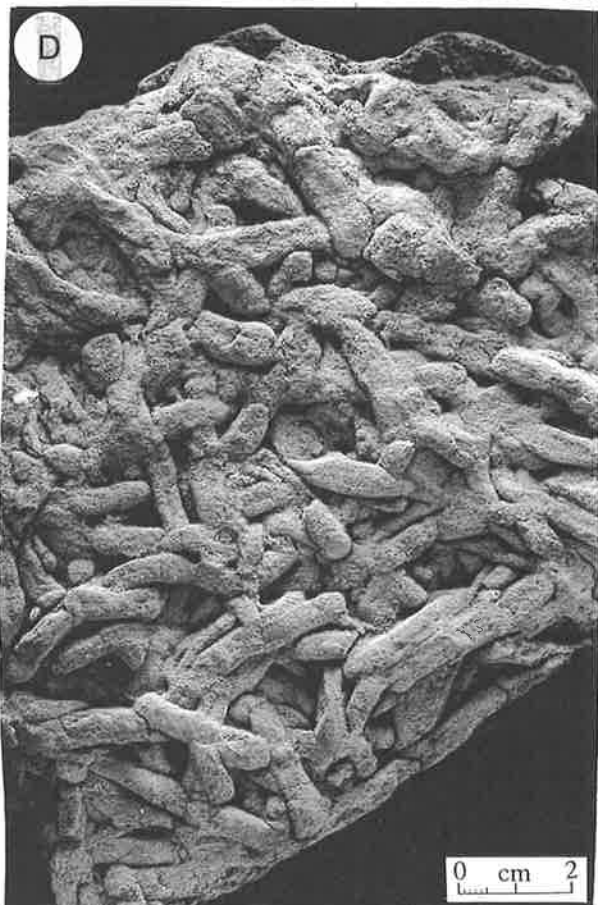
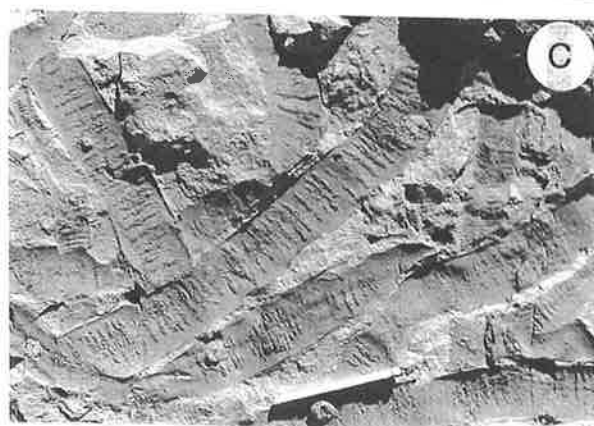
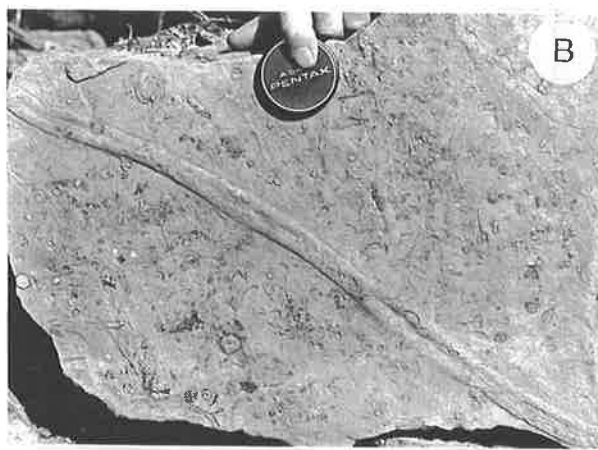
- A. *Phycodes palmatus*, Convex hyporelief, Donkey Creek Beds, Mount Octy, A1035-MO78.
- B. *Plagiogmus arcuatus*, concave epireliefs, display densely arranged transverse ridges on the basal ladder-shaped part, Allua Formation, Mount Shannon Bore, A1035-RS2.
- C. *Plagiogmus arcuatus*, concave and convex epireliefs, display upper bilobate and basal ladder-shaped part, longitudinal annulations are shown by an arrow, Allua Formation, Mount Shannon Bore, A1035-RS3.





## Plate 19

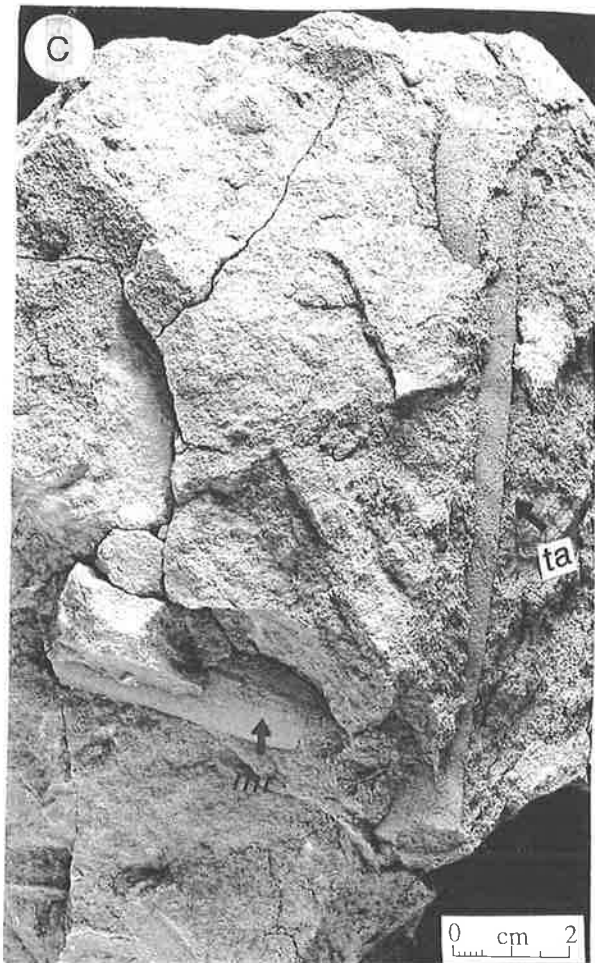
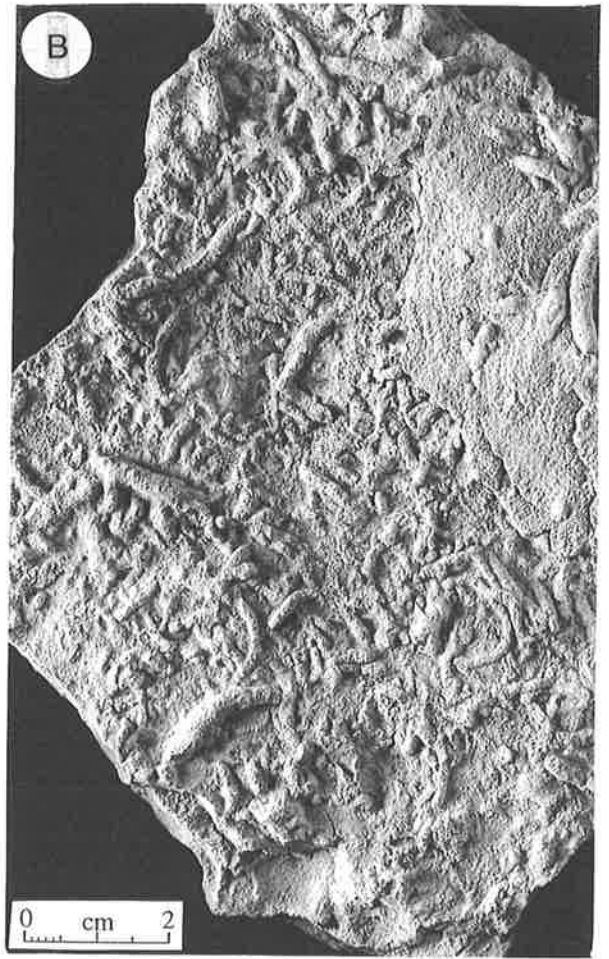
- A. *Plagiogmus arcuatus*, convex epirelief, upper bilobate part with a sinuous median furrow which indicates that the part responsible for creating this could freely oscillate side to side, Allua Formation, Mount Shannon Bore, A1035-RS4.
- B. *Plagiogmus arcuatus*, convex epirelief, a field photo displaying the upper bilobate part. Note the rhythmic change of the burrow thickness, Allua Formation, Ross River.
- C. *Plagiogmus arcuatus*, concave epireliefs, a field photo displaying the basal ladder part of the burrow. The density of transverse ridges changes in a rhythmic pattern. Allua Formation, Cyclops Bore, the match stick is 5 cm long.
- D. *Planolites beverlyensis*, convex hyporeliefs, Donkey Creek Beds, Mount Octy, A1035-MO89.
- E. *Plagiogmus arcuatus*, polished longitudinal section of the burrow showing the oblique laminations of the middle part of the burrow which is enhanced by concentrated glauconite grains. The burrow has been penetrated by three vertical burrows, Allua Formation, Ross River, A1035-R5.
- F. *Plagiogmus arcuatus*, polished transverse section of the burrow. A concentration of glauconite grains occurs in the middle part of the burrow, Allua Formation, Ross River, A1035-R5.
- G. *Planolites montanus*, convex hyporeliefs, burrow filling is coarser than the host rock, Allua Formation, Ross River, A1035-B10.





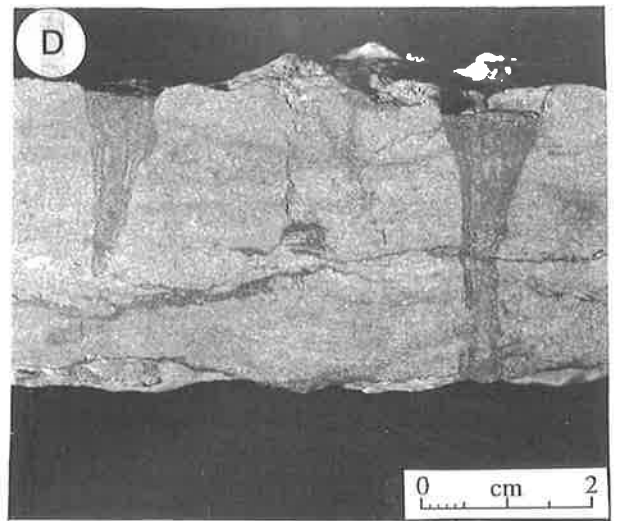
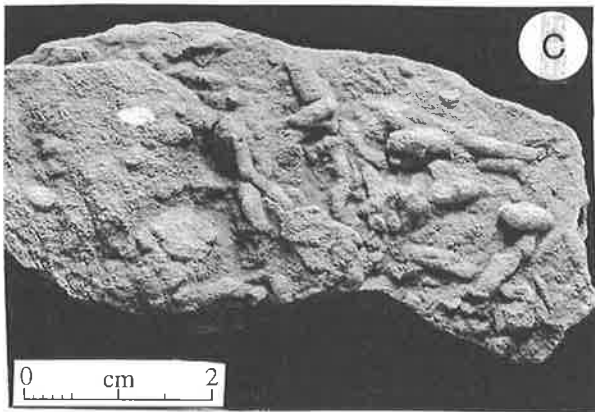
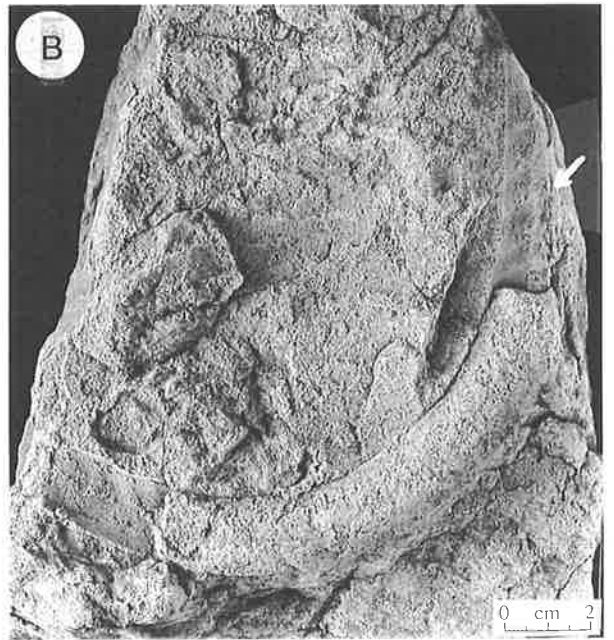
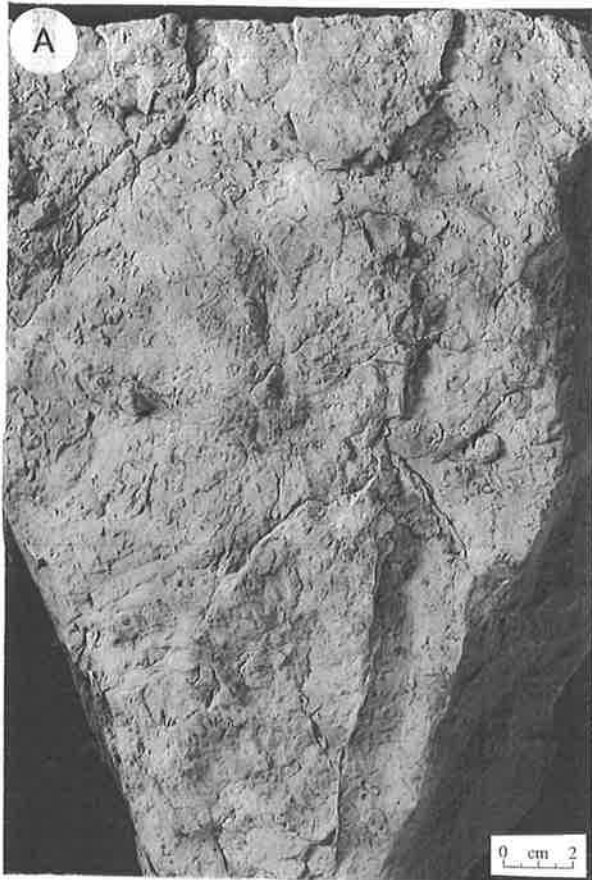
## Plate 20

- A.** *Planolites beverlyensis*, convex hyporeliefs, Donkey Creek Beds, Mount Octy, A1035-MO80.
- B.** *Planolites montanus*, convex hyporeliefs, Donkey Creek Beds, Mount Octy, A1035-MO70.
- C.** *Psammichnites* isp., convex hyporeliefs, showing two specimens which display a median ridge (mr) and transverse annulations (ta), Donkey Creek Beds, Mount Octy, A1035-MO63.
- D.** *Psammichnites* isp., convex and concave epireliefs, displaying transversely laminated middle part and the basal part of the burrow which lacks transverse ridges, Donkey Creek Beds, Mount Octy, A1035-MO61.



## Plate 21

- A.** *Planolites montanus*, concave and convex epireliefs, numerous short burrows parallel to or inclined to the bedding; most of the circular structures represent the place where the horizontal burrows enter the host rock, Box Hole Formation, Ross River, A1035-R40.
- B.** *Psammichnites* isp., convex hyporelief, showing the middle part and the basal part of the burrow. The basal part displays transverse annulations, Donkey Creek Beds, Mount Octy, A1035-MO52.
- C.** *Planolites montanus*, convex hyporeliefs, Donkey Creek Beds, Mount Octy, A1035-MO97.
- D.** *Rosselia socialis*, polished transverse section showing two specimens, Donkey Creek Beds, Mount Octy, A035-MO62.
- E.** *Rusophycus avalonensis*, convex hyporelief, Box Hole Formation, Cyclops Bore, A971-1-12.

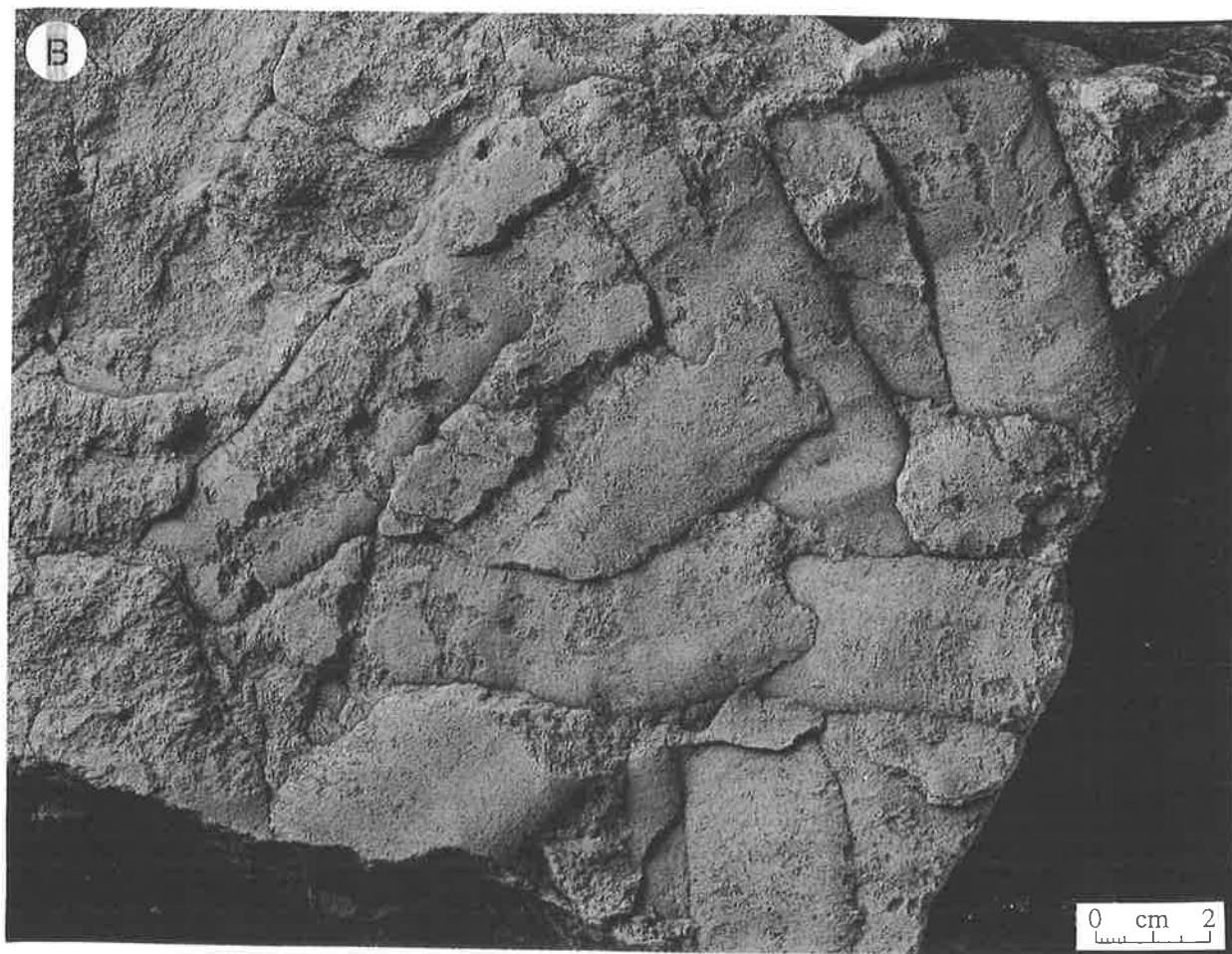
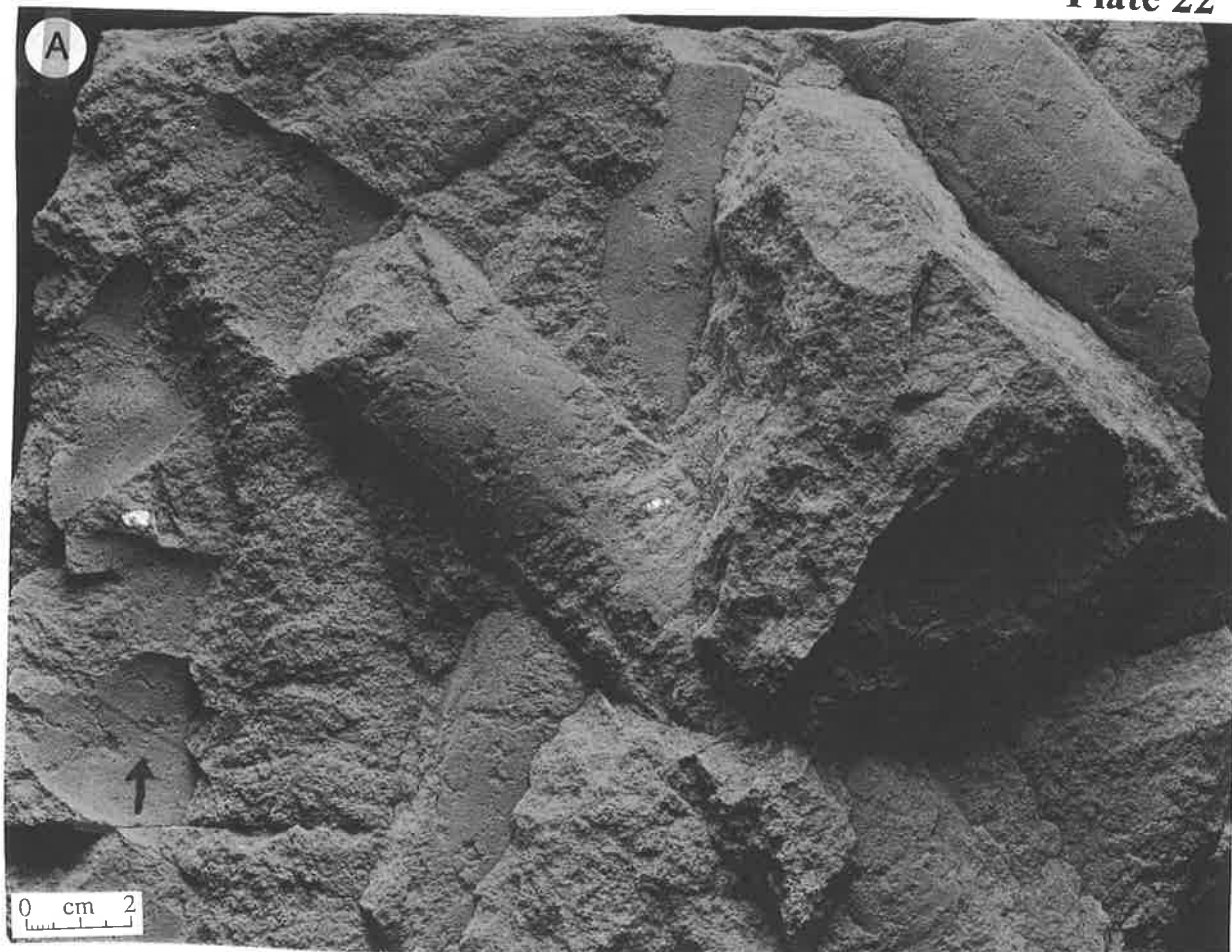


## Plate 22

**A.** *Psammichnites* isp., convex epireliefs, showing the transversely laminated middle part. There is a median groove on the basal part of the burrow (arrow), Todd River Dolomite, Ross River, A971-2-3.

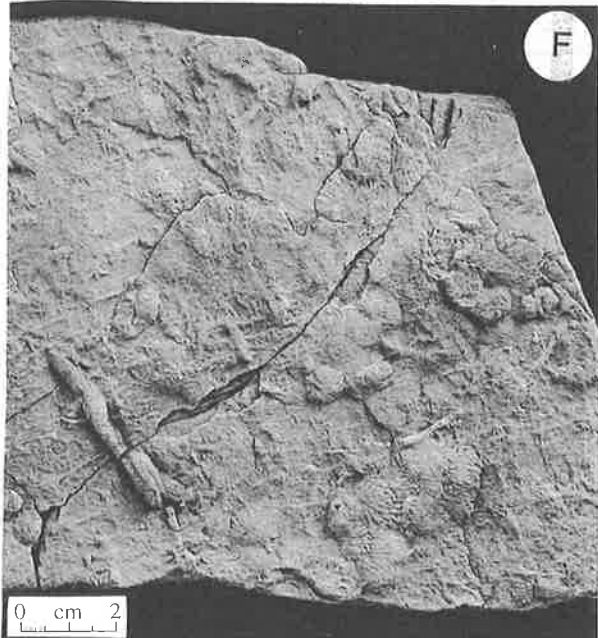
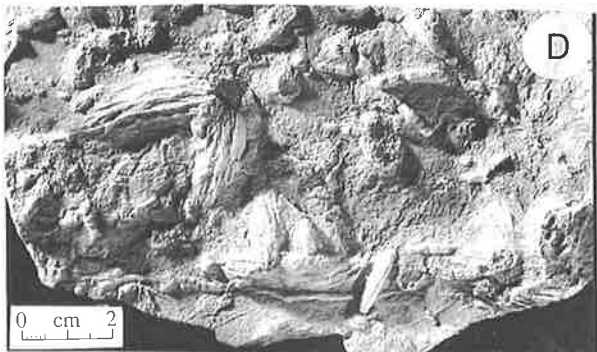
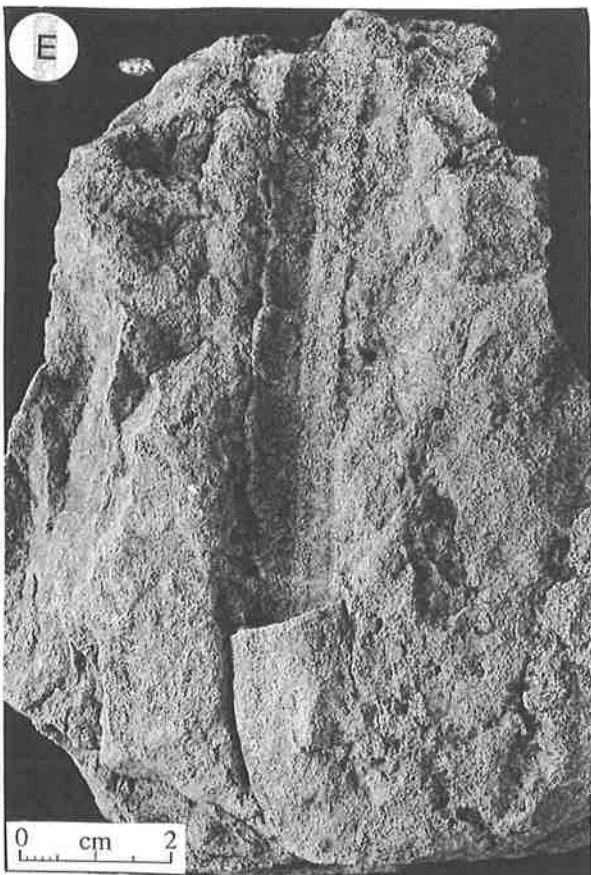
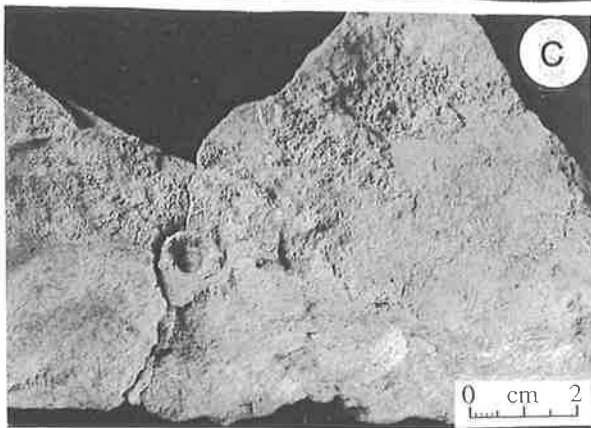
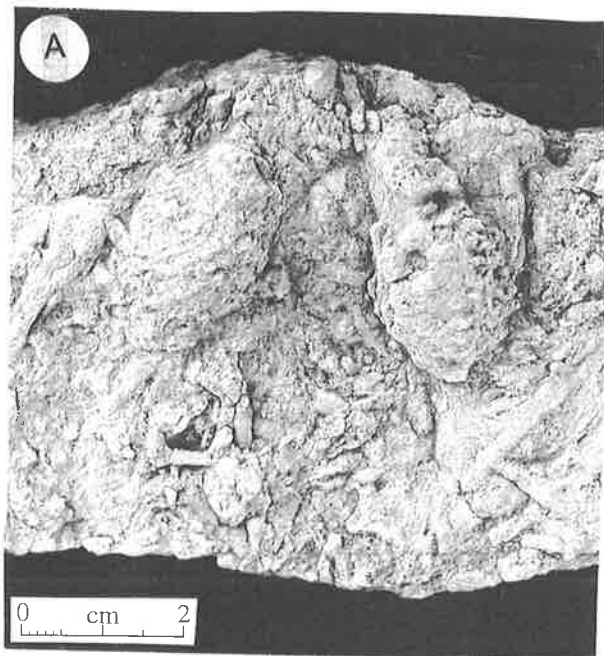
**B.** *Psammichnites* isp., convex hyporeliefs, This the same specimen as in 22A showing the faintly bilobate upper part of the burrow. transverse lamination is visible on some part of the burrows, Todd River Dolomite, Ross River, A971-2-3.





## Plate 23

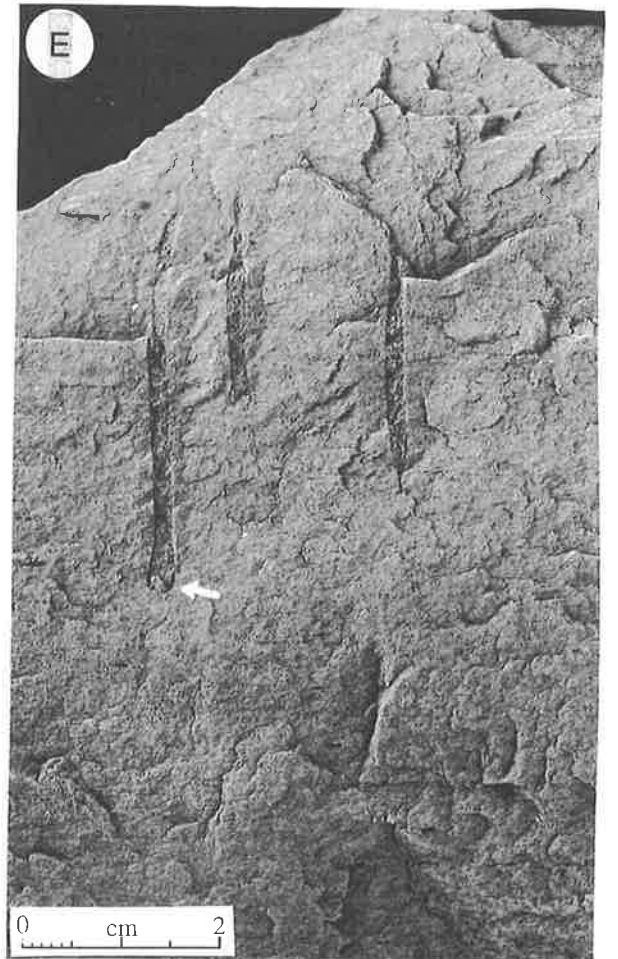
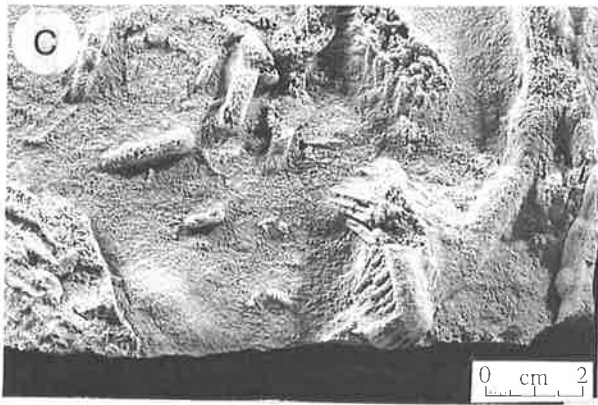
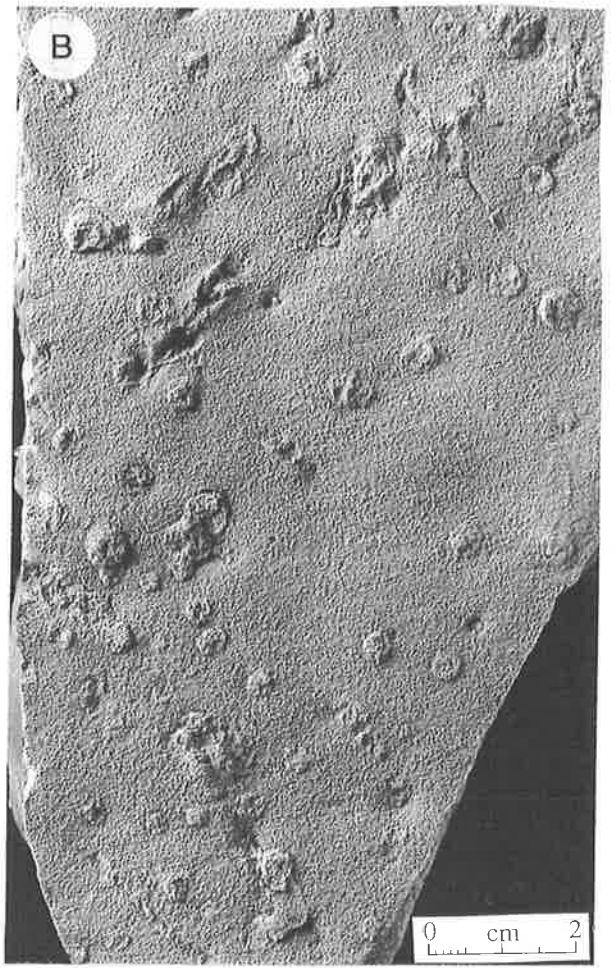
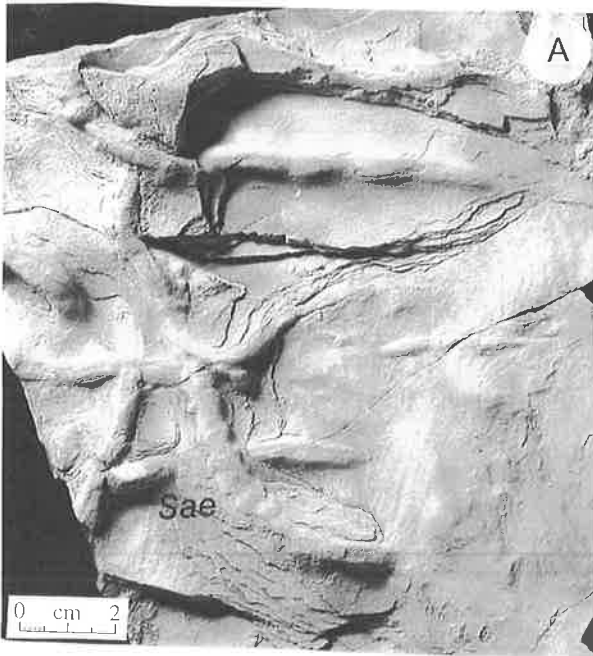
- A. *Rusophycus bonnarensis*, convex hyporelief, Uratanna Formation, Mount Scott, A1035-RS10.
- B. ?*Rusophycus* isp. A (Rus), *Palaeophycus tubularis* (Pal), *Psammichnites* isp. (Psa) and *Skolithos verticalis* (Sko), convex hyporeliefs, Allua Formation, Ross River, A971-2-6.
- C. *Rosselia socialis*, side view showing an inclined burrow with a bulbous termination at its top, Donkey Creek Beds, Mount Octy, A1035-MO166.
- D. *Rusophycus bonnarensis* and *Planolites montanus*, convex hyporeliefs; some of the scratch marks on *R. bonnarensis* display a double claw marks, Allua Formation, Ross River, A1035-B1.
- E. *Psammichnites* isp., convex epirelief, showing the transverse laminations and the middle furrow of the basal part, Donkey Creek Beds, Mount Octy, A1035-MO107.
- F. ?*Rusophycus* isp. B, convex hyporeliefs, Allua Formation, Ross River, A971-2-15.





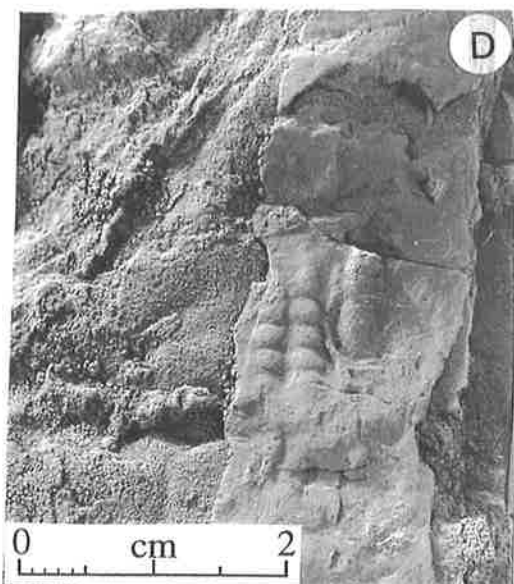
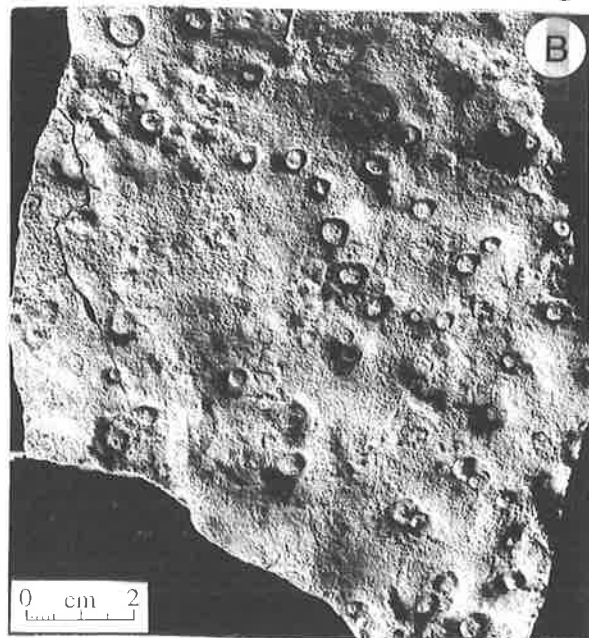
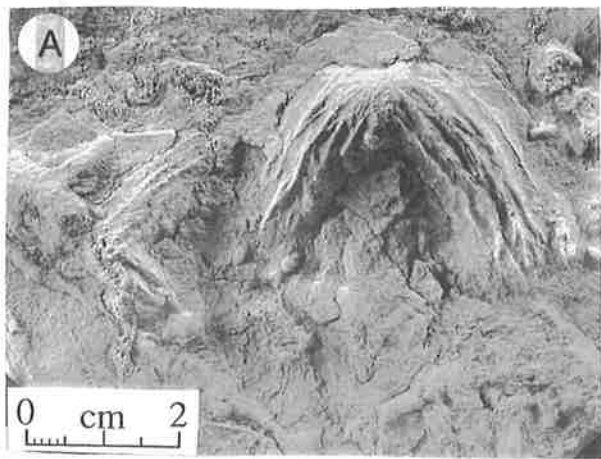
## Plate 24

- A. *Saerichnites* isp B. (Sae), hypichnial view, the burrow displays annulations due to vertical shafts, Allua Formation, Ross River, A1035-R41.
- B. *Skolithos verticalis*, convex epireliefs, Allua Formation, Ross River, A1035-R3.
- C. *Planolites montanus* in close relationship with *Rusophycus bonnarensis* which may indicate a predatore-pray relationship between the producers of the burrows, Allua Formation, Ross River, A1035-B1.
- D. *Skolithos verticalis*, convex epireliefs, Allua Formation, Ross River, A1035-R10.
- E. *Skolithos ramosus*, side view, vertical burrows with a bulbous termination; the filling is different from the host rock, Allua Formation, Ross River, A971-1-35.



## Plate 25

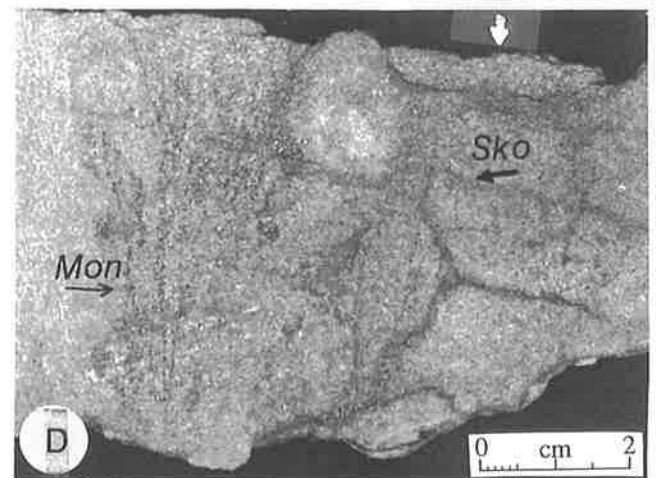
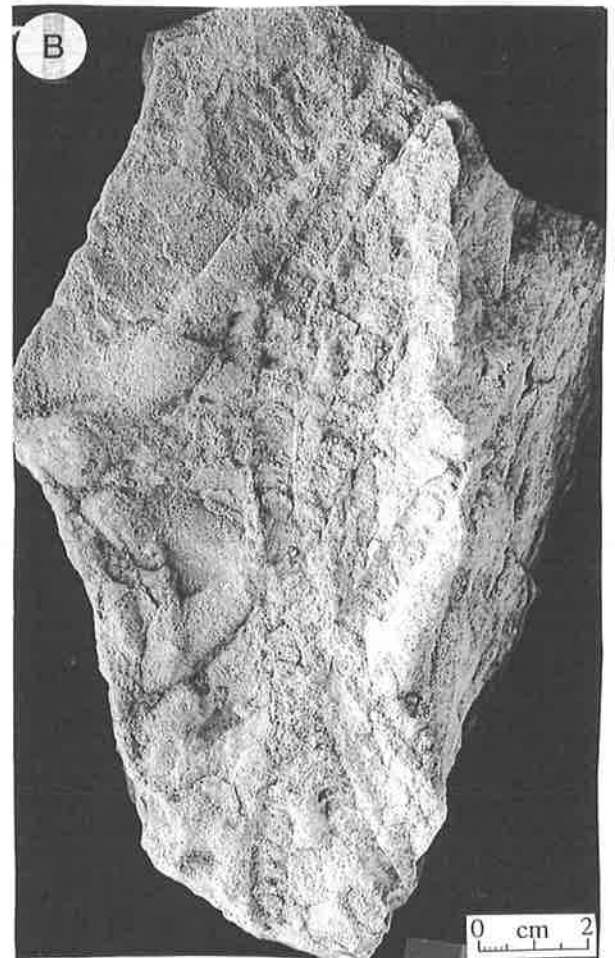
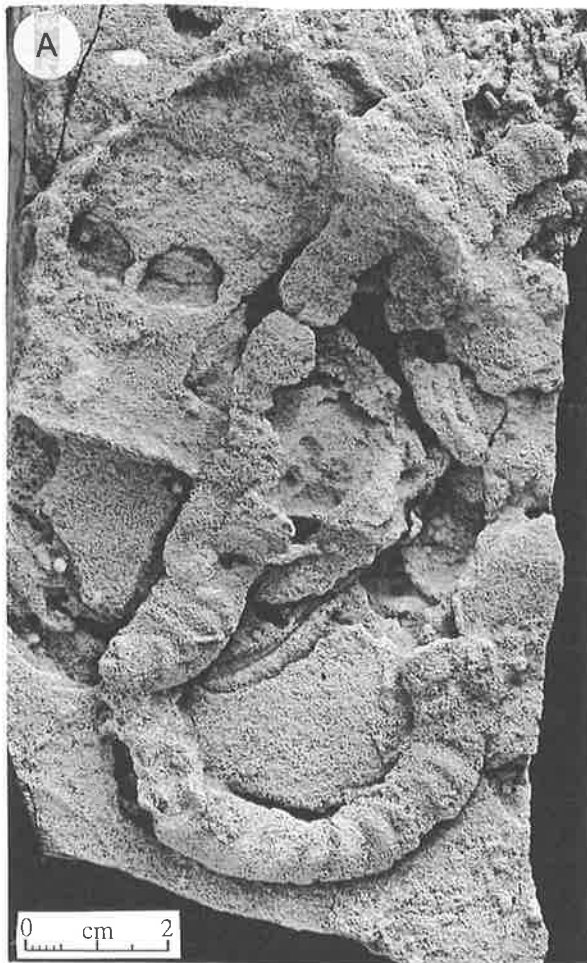
- A. *Rusophycus bonnarensis*, Preserved as convex hyporelief, Allua Formation, Ross River, A1035-B5.
- B. *Skolithos verticalis*, convex epireliefs, a concave ring around the burrow aperture indicates wall of the burrow which has been eroded away, Box Hole Formation, Ross River A971-4-7.
- C. *Skolithos ramosus*, a field photo displaying side view of vertical burrows with a bulbous termination, filling is different from the host rock, Allua Formation, Ross River,.
- D. ?*Saerichnites* isp. A, convex epirelief, series of paired knots interpreted to represent vertical shafts, Box Hole Formation, Ross River, A971-2-37.
- E. *Skolithos verticalis*, side view of the burrow showing several inclined specimens, Donkey Creek Beds, Mount Octy, A1035-MO75.



## Plate 26

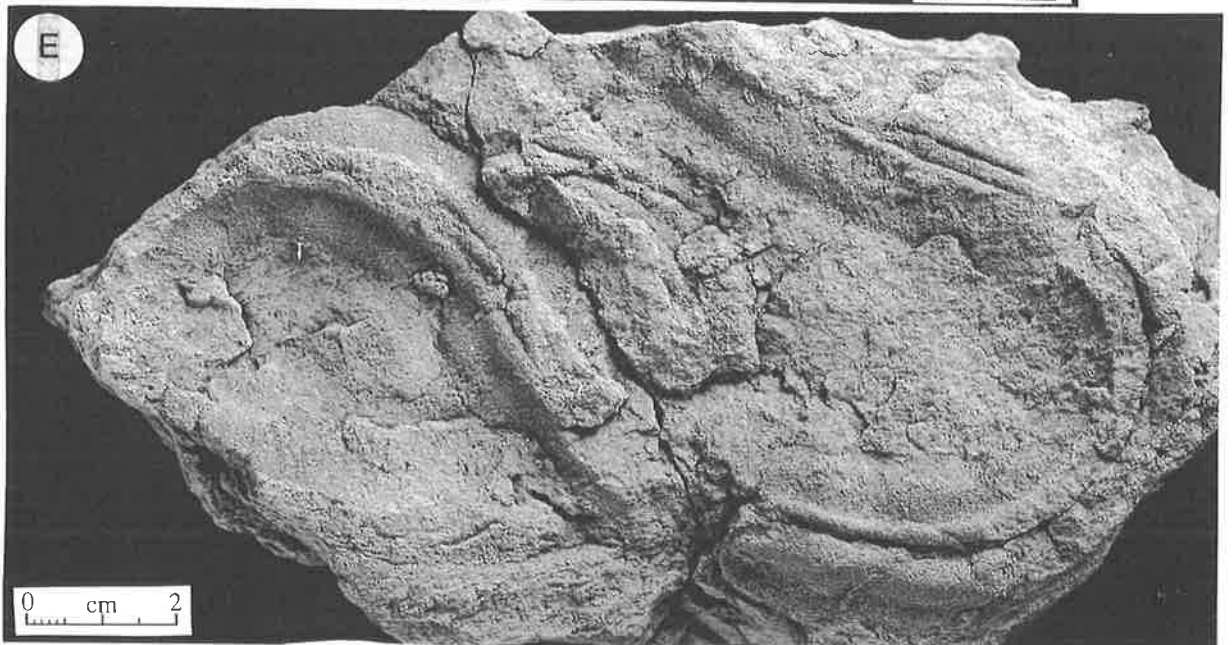
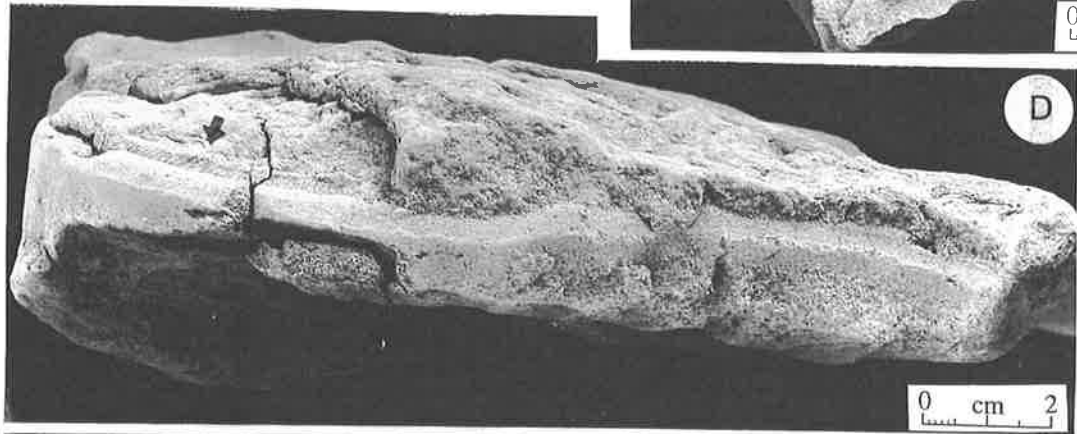
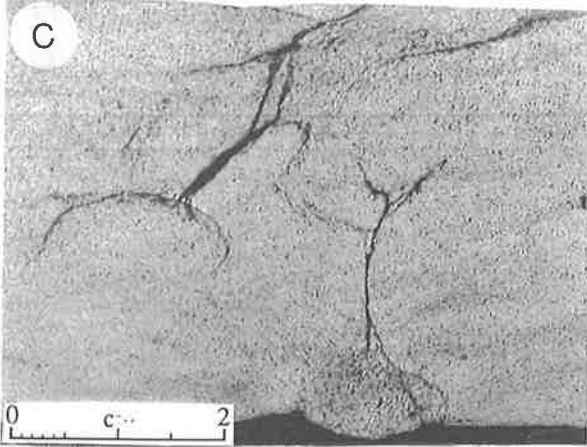
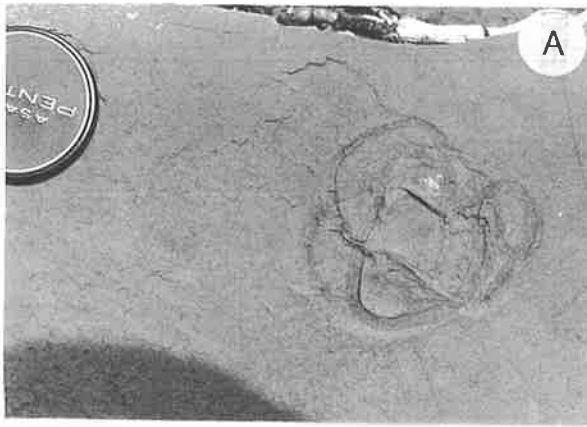
- A.** *Taenidium serpentinum*, convex epirelief, the burrow displays arcuate transverse annulations. The burrow wall has been eroded away, Donkey Creek Beds, Mount Octy, A1035-MO212A.
- B.** *Taenidium serpentinum*, convex epirelief, Allua Formation, Ross River, A1035-R28
- C.** *Taphrhelminthoidea dailyi*, a meandering burrow preserved as convex and concave epireliefs, Donkey Creek Beds, Mount Octy, A1035-MO201.
- D.** *Skolithos bulbosus* (Sko), a vertical burrow with a spherical structure at the middle. The burrow displays a thin wall which is thicker around the spherical structure. On top, burrow possesses a large and flat aperture which is not central to the burrow axis (white arrow). *Monocraterion* isp. (Mon), showing inclined pattern of sediment laminae, polished transverse section, Donkey Creek Beds, Mount Octy, A1035-MO62.





## Plate 27

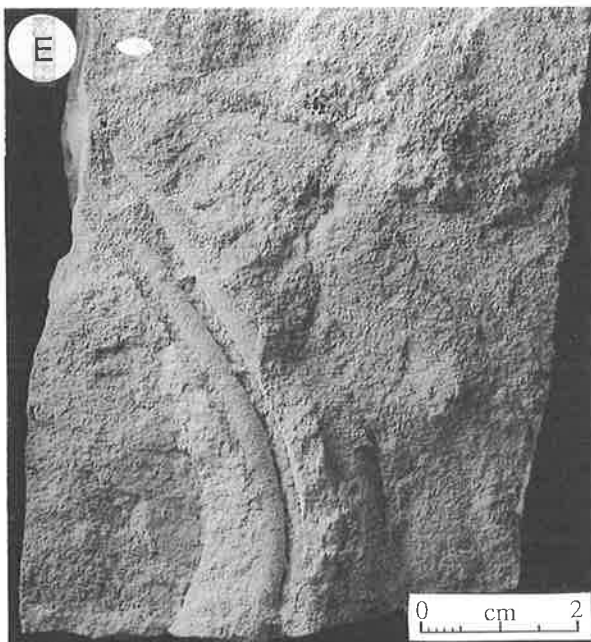
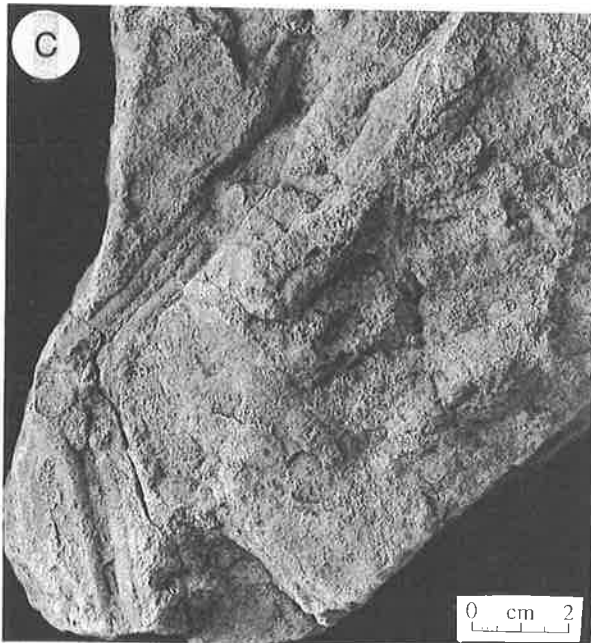
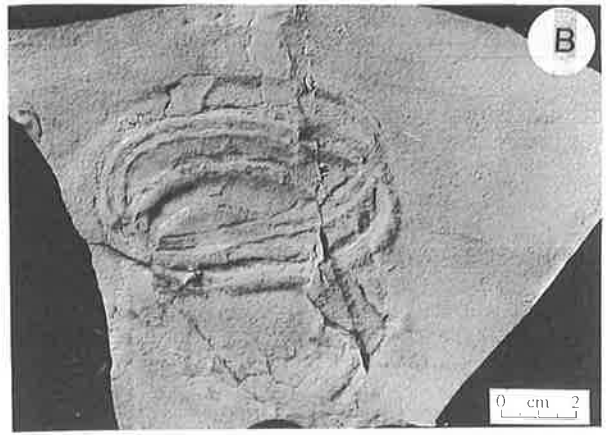
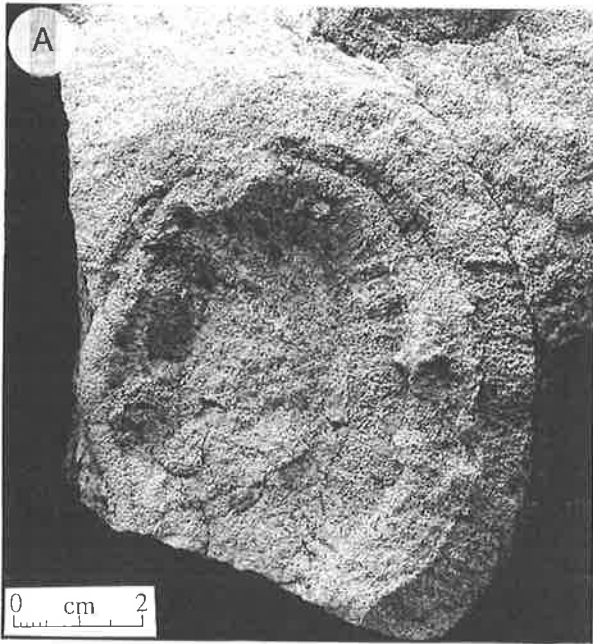
- A. *Taphrhelminthopsis circularis*, epirelief, a field photo (1-11) showing a winding bilobate burrow, lower Allua Formation, Cyclops Bore.
- B. *Taphrhelminthoida ?convoluta*, convex hyporelief, a meandering bilobate burrow possessing two lobes separated by a median furrow. There are partially preserved ridges lateral to the median furrow. Arrow shows transversely laminated sediments adjacent to the lobes, Donkey Creek Beds, Mount Octy, A1035-MO64.
- C. *Taphrhelminthoida ?convoluta*, polished transverse section showing a structure produced by movement of animal's siphon through the sediments. The burrow filling is different from the host rock, Donkey Creek Beds, Mount Octy, A1035-MO163.
- D. *Taphrhelminthoida ?convoluta*, side view of the burrow showing it broken off from its median furrow. The median furrow is deep and has smooth walls interpreted to be produced by the movement of animal's siphon through the sediments. The specimen is photographed upside down (upper side represents sole of the layer) to show the obliquely laminated sediments adjacent to the burrow (arrow). Donkey Creek Beds, Mount Octy, A1035-MO65.
- E. *Taphrhelminthoida ?convoluta*, convex hyporelief, showing a meandering burrow, Donkey Creek Beds, Mount Octy, A1035-MO164.





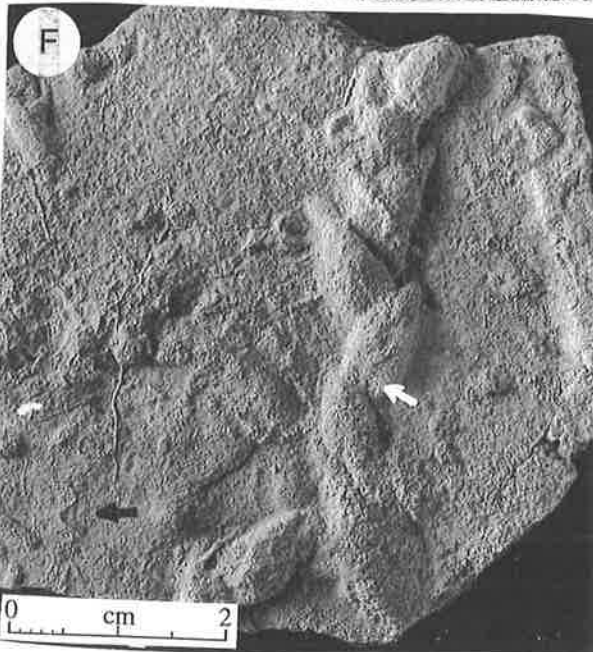
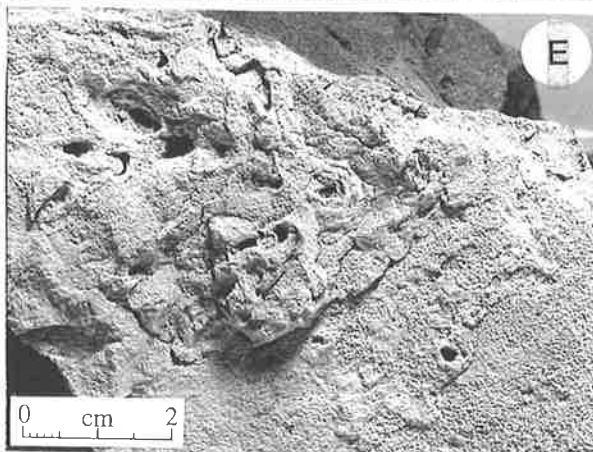
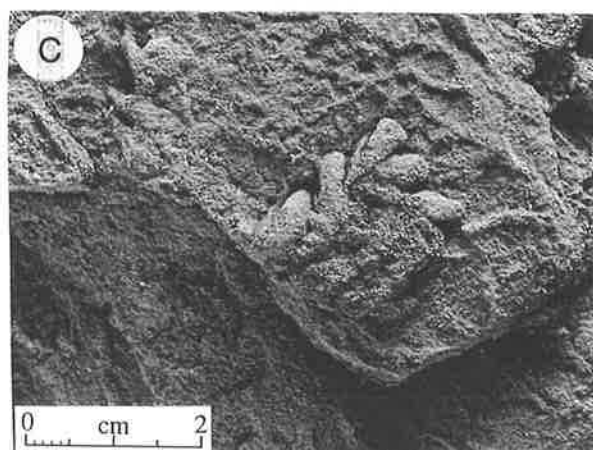
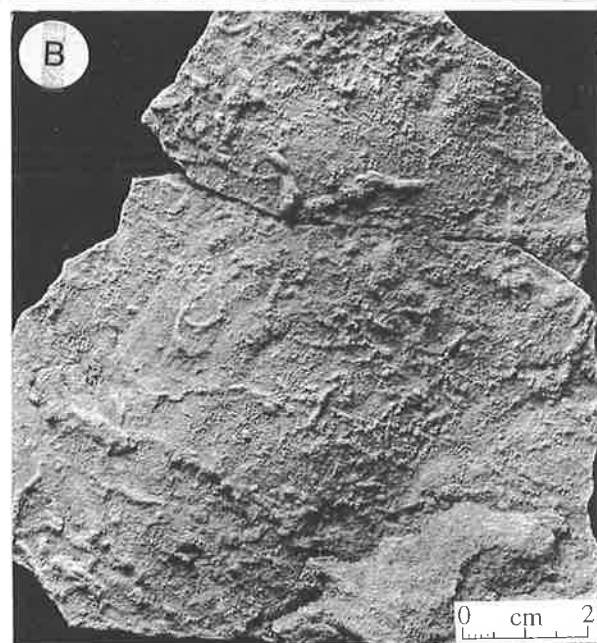
## Plate 28

- A. *Taphrhelminthoida ?convoluta*, convex hyporelief, a portion of meandering bilobate burrow shows transverse striations, Donkey Creek Beds, Mount Octy, A1035-MO51A.
- B. *Taphrhelminthopsis circularis*, convex hyporelief, illustrating a circular, bilobate burrow, Allua Formation, Ross River, A971-2-50.
- C. *Taphrhelminthopsis* isp., convex hyporelief, Donkey Creek Beds, Mount Octy, A1035-MO154.
- D. *Taphrhelminthopsis circularis*, convex hyporeliefs, a field photo (1-12) displaying several specimens. Some of them show a figure 8 pattern, Allua Formation, Ross River.
- E. *Taphrhelminthopsis* isp., convex hyporelief, Donkey Creek Beds, Mount Octy, A1035-MO58.
- F. *Taphrhelminthopsis vagans* and *Skolithos verticalis*, convex hyporeliefs, Allua Formation, Ross River, A1035-R5.



## Plate 29

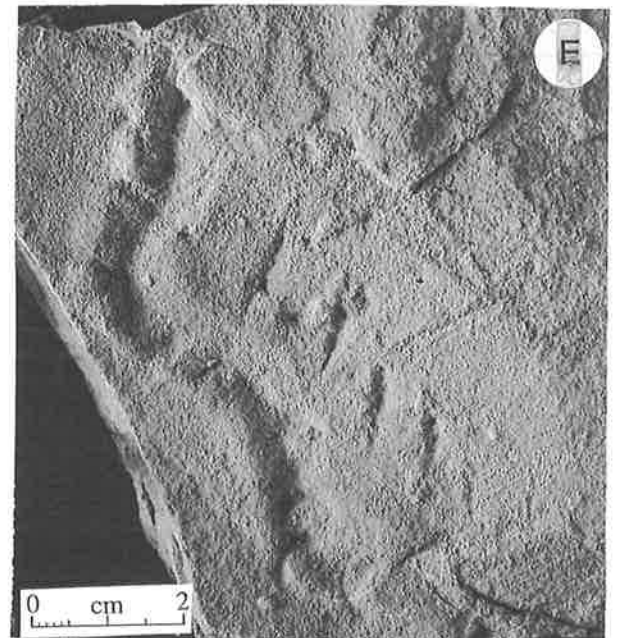
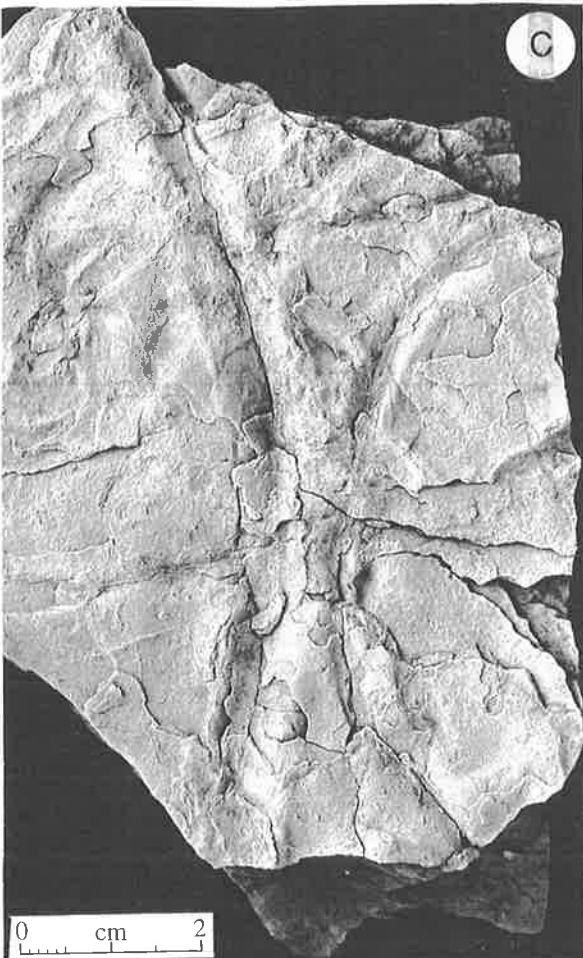
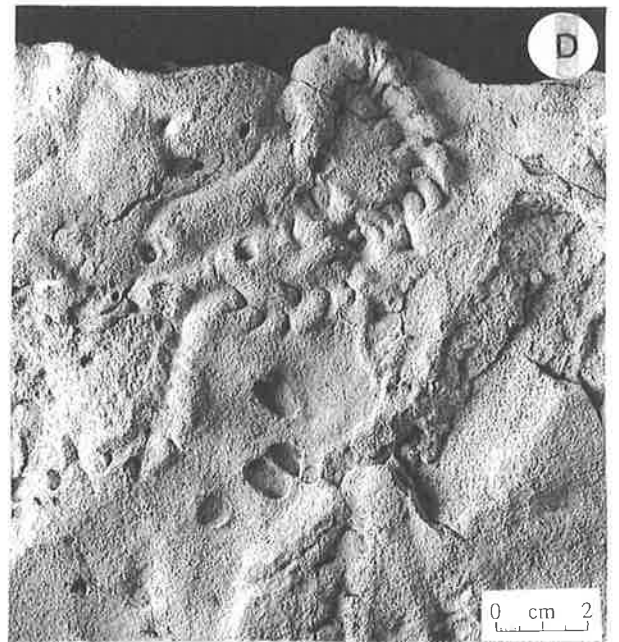
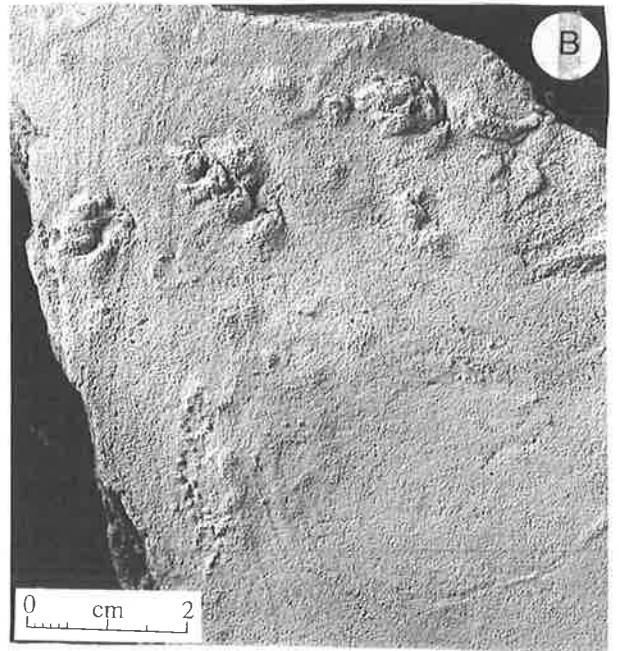
- A. *Teichichnus* isp., side view, Donkey Creek Beds, Mount Octy, A1035-MO25.
- B. *Torrowangea ?rosei*, convex hyporelief, Donkey Creek Beds, Mount Octy, A1035-MO54.
- C. *Treptichnus pedum*, convex hyporelief, Donkey Creek Beds, Mount Octy, A1035-MO106.  
F. *Treptichnus* cf. *triplex*, convex hyporelief, some segments show faint furrows (arrow), Donkey Creek Beds, Mount Octy, A1035-MO70.
- D. *Treptichnus pedum*, convex hyporeliefs, Donkey Creek Beds, Mount Octy, A1035-MO66.
- E. Ichnofossil A, concave epirelief, vertical burrows with concentric circular structure, each burrow leads to a vertically branching burrow system, Allua Formation, Ross River, A971-2-42.



## Plate 30

- A. Ichnofossil A, side view of the specimen in 29E showing a branched vertical burrow in which branches diverge almost from the same point. The burrow filling is different from the host rock. Allua Formation, Ross River, A971-2-42.
- B. ?*Vendichnus* isp., convex hyporelief, Donkey Creek Beds, Mount Octy, A1035-MO72.
- C. Ichnofossil C, concave epirelief, large concave burrows display elevated margins, lower Box Hole Formation, Ross River, A971-2-30.
- D. Ichnofossil D, concave epirelief, a winding burrow displaying lobations due to transverse, arcuate grooves, Donkey Creek Beds, Mount Octy, A1035-MO161.
- E. Ichnofossil C, concave epirelief, a large sinuous, concave burrow with elevated margins; *Monomorphichnus lineatus*, concave epirelief, Donkey Creek Beds, Mount Octy, A1035-MO169.





## Plate 31

- A.** Ichnofossil D, convex epirelief, a winding burrow displaying lobations due to transverse, arcuate grooves, Donkey Creek Beds, Mount Octy, A1035-MO109.
- B.** *Treptichnus pedum*, convex hyporelief, ?lower Allua Formation, Hugh River, A1035-B3.
- C.** Ichnofossil B, Convex hyporelief, a bilobate burrow comprising a middle ridge separating two arcuate lobes and surrounded by an imbricated circular ridge, Allua Formation, Ross River, A1035-B4.
- D.** Ichnofossil E, side view, a bow shaped burrow which is branched at one end. The burrow filling is different from the host rock. Donkey Creek Beds, Mount Octy, A1035-MO162.

