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THE PARACHILNA FORMATION AND ITS TRACE FOSSILS

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THE PARACHILNA FORMATION
AND ITS TRACE FOSSILS

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CONTENTS.

I. ABSTRACT.

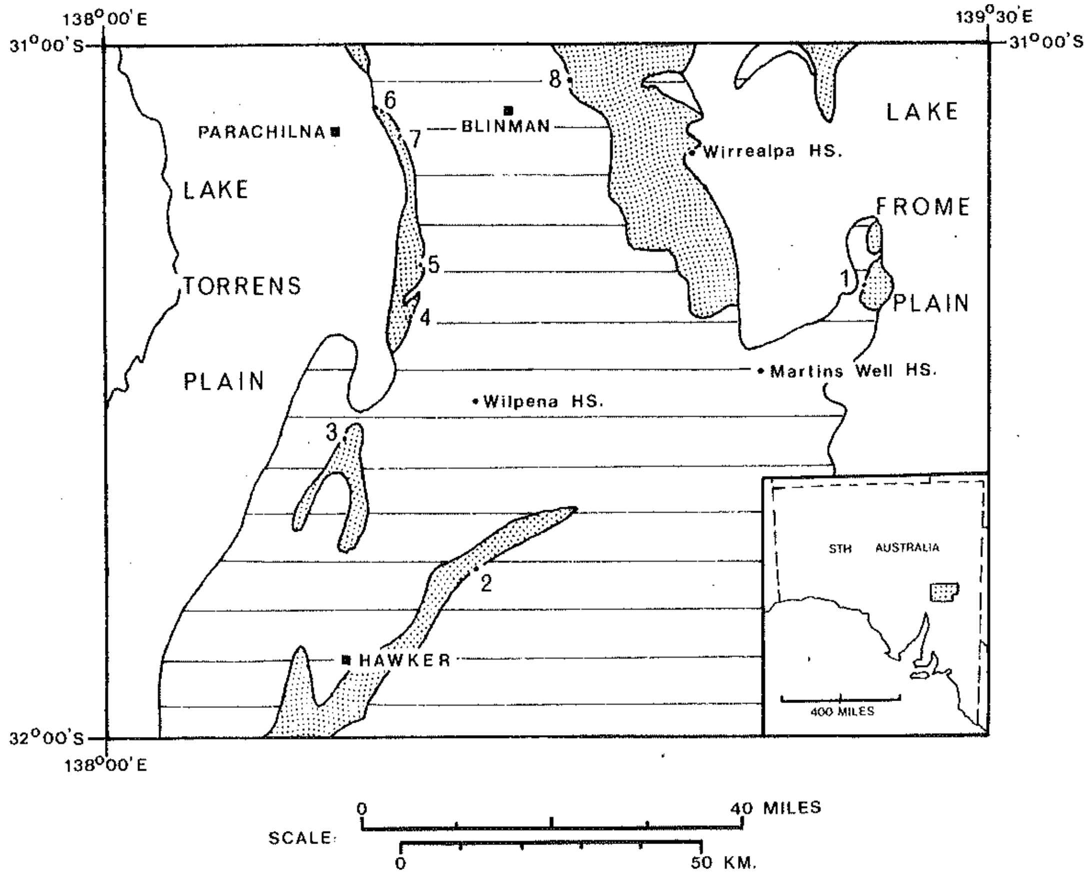
The sediments comprising the Parachilna Formation have long been regarded as "transition beds" between the regressive Pound Quartzite and the massive Lower Cambrian shelf carbonates of the Wilkawillina Limestone. This study, suggested by Professor M. F. Glaessner, is an attempt to interpret the Parachilna Formation by means of its trace fossil content. In considering the palichnology of the formation, the lithology has not been neglected, but rather is presented as a complement in palaeoenvironmental interpretation. The nature of the relationships between the Parachilna Formation and both the underlying Pound Quartzite and overlying Wilkawillina Limestone is considered in some detail, with resultant reflections on the aptness of the term "transition beds" in this instance.

II. INTRODUCTION

The Parachilna Formation was defined by Dalgarno (1962,1964), with the type section located in Parachilna Gorge. Dalgarno considered the formation to be a transgressive unit disconformably overlying the Uppermost Proterozoic Pound Quartzite and underlying the Lower Cambrian Wilkawillina Limestone. Consequent upon its stratigraphic position, the formation was assigned Lowermost Cambrian age. Strata now designated Parachilna Formation had been previously described by several workers, e.g. Mawson's (1937) units 28-38 in Parachilna Gorge and Segnit's (1939) unit Ela in the Mt. Scott area.

Sandstones within the formation are often conspicuously bioturbated; Dalgarno (op. cit.) noted "vertical worm burrows" and "worm castings", and Nixon (1964) utilized the basal "tubicolor" sandstone as a mapping horizon at Ediacara. The principal trace fossil, the U-burrow Diplocraterion Torell has been described briefly by Goldring and Curnow (1967) and Daily, Twidale and Alley (1969). Plagiogmus Roedel has been described from the Parachilna Formation by Glaessner (1969). Other trace fossils have been mentioned only in passing as "worm castings", but these forms generally lack the distinctive features necessary for taxonomic classification.

DISTRIBUTION OF CAMBRIAN SEDIMENTS: Central Flinders Ranges



LEGEND:

Cambrian System — Lake Frome Gp., Wirrealpa Ls., Billy Creek Fm., Hawker Gp.

Adelaide System — Wilpena Gp., Umberatana Gp.

•4 Location of measured stratigraphic sections of the Parachilna Formation (basal Cambrian).

Sections:

1	Reaphook	5	Brachina
2	Druid Range	6	Parachilna no. 1
3	Mern Merna	7	Parachilna no. 2
4	Bunyeroo	8	Nildottie

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Fig. 1

Outcrops of Parachilna Formation were studied by the author at several localities in the Central Flinders Ranges [fig. 1]. Detailed stratigraphic sections were measured on six complete sequences and two nearly-complete sequences. Trace fossil specimens were collected along the measured sections and at intermediate stations. All localities are situated within the area mapped on the Geological Survey of South Australia 1:250,000 Parachilna Sheet (Dalgarno and Johnson, 1966). Specimens pertaining to this thesis are designated by the prefix A365/.

III. STRATIGRAPHY.

1. REGIONAL GEOLOGY.

Rocks of the Parachilna Formation outcrop in the Flinders Ranges, South Australia. They overlie the dominant, ridge-forming Pound Quartzite, and underlie the massively-bedded archaeocyathid Wilkawillina Limestone. These deposits were laid down sequentially in an elongate shallow trough called the Adelaide Geosyncline. This 'geosyncline' was subject to almost continuous deposition from Upper Proterozoic to Middle Cambrian time, sediment being derived from tectonic plates to the east and west. Rates of sediment influx and floor subsidence in this depressional zone were very nearly in equilibrium for a long period of time; variations in sediment thicknesses were, on a broad scale, due to inequalities in rates of subsidence of the trough floor or penecontemporaneous erosion induced by local upwarping.

Fig. 2 illustrates stratigraphical details of the Parachilna Formation and adjacent units. The Pound Quartzite is a remarkably uniform clastic unit deposited as a blanket sand up to 9,000 feet (2,800m.) thick over earlier Adelaidean sediments. It is informally differentiated into two members - the lower 'Red' Pound and upper 'White' Pound. These sediments appear to have been deposited in a shallow water deltaic environment, under regressive conditions (Dalgarno, 1964; Goldring and Curnow, 1967; Wopfner, 1970). Representatives of the Ediacara fauna are found on bedding planes of the White Pound 60 to 300 feet (18 to 90m.) above the junction with the Red Pound (Wade,1970).

Parachilna Formation and Adjacent Units

System	Series	Group	Nomenclature and Lithology	Body Fossils	Trace Fossils
CAMBRIAN SYSTEM	Lower Cambrian Series	Hawker Group	PARARA LIMESTONE Dark, flaggy and silty lime-stones, with interbedded shales.	Trilobites (Yorkella, Pararaia), gastropods, hyolithids, brachiopods, few archaeocyathids.	None known
			WILKAWILLINA LIMESTONE Massive fossiliferous lime stone, dolomitized at the base, with oölitic and sandy lenses. Overlain by thick-bedded, light-coloured pure limestone.	Archaeocyathids, phosphatic brachiopod (Micromitra sp.), sponge spicules.	Algal structures, e.g. Collenia
			PARACHILNA FORMATION Argillaceous white and grey feldspathic sandstone, often bioturbated, interbedded with white siltstone. Overlain by various coloured siltstones, with minor sandstone and carbonates. Secondary Mn-Fe capping developed extensively at the boundary with the overlying unit.	None known	Diplocraterion, Plagiogmus, various epichnial and hypichnial trails.
ADELAIDE SYSTEM	Marinoan Series	Wilpena Group	POUND QUARTZITE Upper member: Resistant, slightly feldspathic white quartzite with minor shale bands. Local channel sands at top. Lower member: Cross-bedded feldspathic red sandstone.	Medusoid and pennatulacean coelen-terates, annelids, forms of uncertain affinities of the Ediacara fauna.	Pseudorhizostomites; Forms A – F (Glaessner, 1969).
			WONOKA FORMATION Interbedded grey calcareous shales and flaggy limestones.	None known	None known

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Fig. 2

Towards the close of deposition of the White Pound, rejuvenation of the drainage of the area seems to have occurred, as local channel structures containing coarse, cross-bedded sands have been described (Goldring and Curnow, 1967). Erosion on a broader scale occurred elsewhere, as near Wirrealpa Wilkawillina Limestone lies disconformably on Red Pound. A disconformity between the Pound Quartzite and overlying Parachilna Formation has been postulated, and this view is supported by facts presented in the following text.

The Parachilna Formation overlies the Pound Quartzite with apparent structural conformity as a readily weathered feldspathic sandstone which grades upwards into pale-coloured siltstones and fine-grained sandstones (southern sections) and siltstones, limestones and minor sandstones (northern sections). Outcrop is generally subdued, with complete sections being difficult to find. Thickness of the formation varies from a few feet near Reaphook Hill to over 1,400 feet (420m.) in the Arrowie syncline (Dalgarno, 1962). Sections measured in the present study ranged from 3 to 500 feet (1 to 150m.). The coarser clastic units contain a variety of trace fossils, particularly the U-burrow Diplocraterion. Bioturbation is variable, but in several localities the top of the Pound Quartzite has been irregularly excavated by organisms burrowing through overlying Parachilna sediment. The contact with the Pound Quartzite is, in places, quite undulose (e.g. Reaphook, Parachilna No. 2), with scattered quartzite pebbles at the base of the Parachilna Formation evident particularly near Reaphook Hill. This is one factor indicative of a disconformity between the Pound Quartzite and the Parachilna Formation.

The top of the Parachilna Formation is taken as the base of the first of the massive limestone beds that form the Wilkawillina Limestone. The base of this limestone is generally oolitic and recrystallized; in places the carbonates have been dolomitized. The contact is conformable, and no time break is recognized, as minor beds of oolitic and sandy limestone appear gradationally in the northern sections of the Parachilna Formation. The invasion of a secondary mangano-ferruginous capping characterizes the Parachilna-Wilkawillina boundary, although its appearance is irregular and variable. The earliest Cambrian body fossils (archaeocyathids) appear about 160 feet (50m.) above the base of the Wilkawillina Limestone (Walter, 1967).

The above units were folded into broad anticlines and synclines during the Cambro-Ordovician Orogeny that terminated deposition in the Adelaide 'Geosyncline'. Deformation was not great in the central Flinders Ranges area, and, on the flanks of folds, beds generally dip at 30° to 60°, although the sequence is overturned on Druid Range. Diapiric piercements into zones of structural weakness and the cores of anticlines were emplaced prior to the main orogenic event (Dalgarno and Johnson, 1968). Minor faulting occurred in several localities, with more intense faulting both along and across strike near Reaphook Hill.

2. STRATIGRAPHY OF THE PARACHILNA FORMATION.

The stratigraphy of the Parachilna Formation in the Central Flinders Ranges is outlined in the enclosure [fig. 3], in the pocket inside the back cover. It has been noted previously (e.g. Daily, Twidale and Alley, 1969) that the Parachilna Formation has considerable lithological variation within a single section. This study, whilst supporting the above fact, has shown that a relatively uniform lithological variation is reflected over the area studied, and, as a consequence, the Parachilna Formation has been tentatively subdivided into three constituent members on the basis of lithological differentiation. These members are described in detail below.

MEMBER 1. This, the lowermost member, consists predominantly of fine to coarse-grained sandstones with few minor intercalations of siltstone. The sandstones generally contain a pervasive matrix of white kaolinite, suggesting either a high initial feldspar content, or a disproportionately high percentage of transported clay in the sediment. Grains of clear, subangular to rounded quartz are often isolated in the floury clay matrix, giving the rock a white appearance. Diplocraterion burrows are common in less clayey sandstones, which tend to be grey or yellow in appearance. Bioturbation has destroyed many of the inorganic sedimentary structures of the basal sands, although at Reaphook and Parachilna No. 1 cross-bedding is discernible. The siltstone interbeds are composed of white, homogeneous fine-grained material which lacks bedding features and fractures conchoidally. This rock weathers into fine chips, and

Lithostratigraphic Variation — Parachilna Fm.

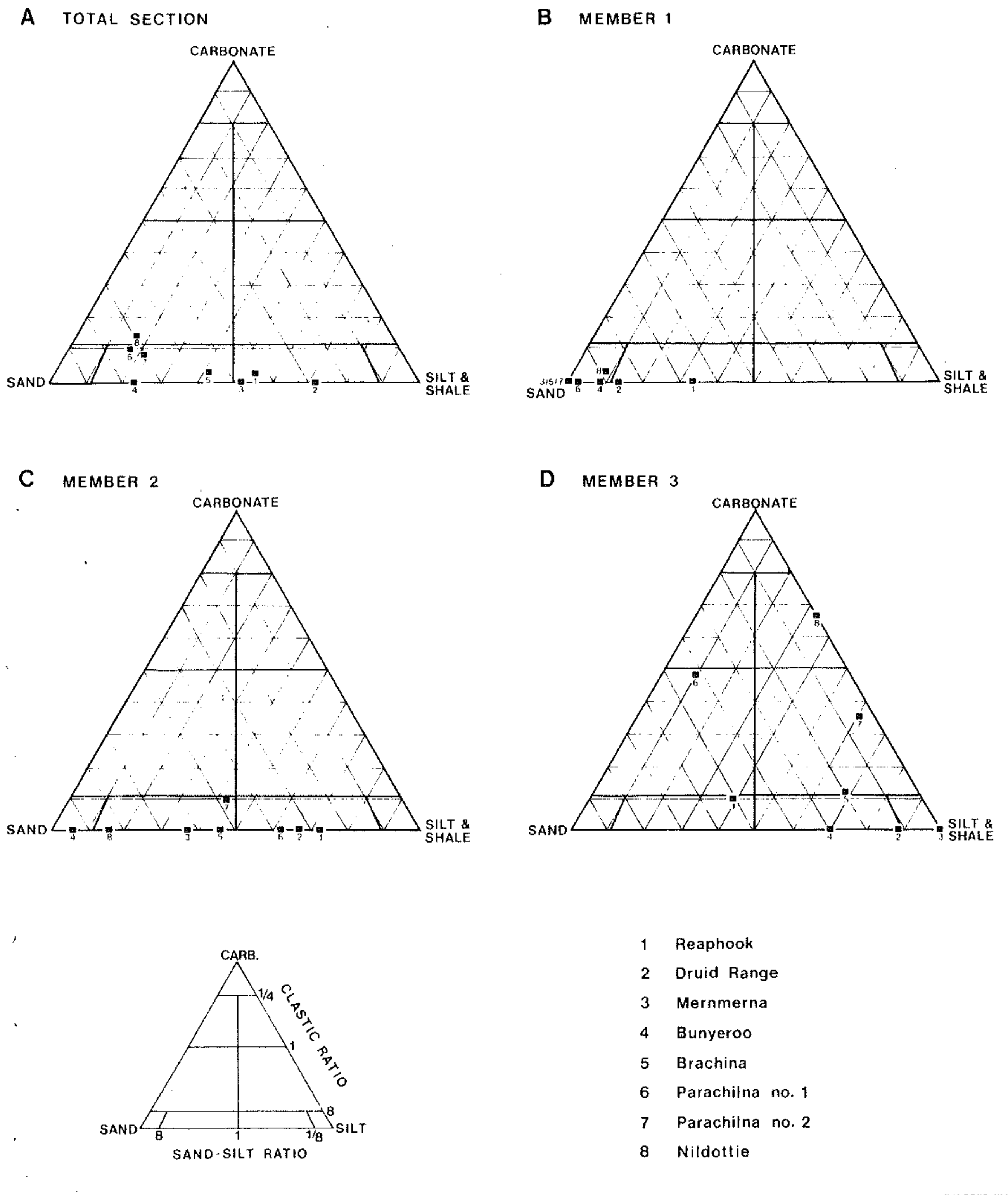

Fig. 4

is generally of subdued outcrop. Thickness of Member 1 varies from 12 feet (3.8m.) [Druid Range and Mernmerna] to 116 feet (35m.) [Parachilna No. 2]. Siltstones are developed in four sections (Reaphook, Druid Range, Bunyeroo and Nildottie); the siltstones at Nildottie tend to shale and revert to a 4 feet (1.2m.) thick limestone bed, the lowermost carbonate seen in the formation. Fig. 4B illustrates the high sand percentage of Member 1 in all sections, with the increased silt content of the most easterly section (Reaphook) being explicable in terms of a westerly sediment source [see Section VI].

<u>MEMBER 2</u> is a fine-grained clastic unit, consisting of alternating white siltstone and greyish sandstone interbeds. The best development of this member is seen at Mernmerna, where white clayey siltstone beds 1 to 2 feet (0.3 to 0.6m.) thick intercalate with fine to medium-grained sandstones with a clay matrix. Incorporated in this sequence are bioturbated medium-grained purplish sandstones, which have a lower clay content and outcrop strongly in beds 6 in. to 2 feet 6 in. (0.15 to 0.8m.) thick. Elsewhere the sediment variation is less regular, but sandstone-siltstone intercalations occur in all sections except Bunyeroo, in which Member 2 consists of a very fine-grained white sandstone with a clay matrix, capped by an 8 feet (2.5m.) thick bed of strongly jointed greyish fine-grained quartzite. Parachilna No. 2 (the type section) contains two carbonate beds in Member 2, the lower being a pisolitic calcareous siltstone and the upper a soft, fine-grained grey-green limestone with manganese dendrites. As can be seen from fig. 4C, Member 2 contains a wide variation in sand-silt ratio, although the percentage of fine material is again greatest in the easternmost sections (Reaphook and Druid Range).

<u>MEMBER 3.</u> This, the uppermost member, again shows a wide range in lithology, but a trend in composition can be seen from studying the sections in fig. 3. The southerly sections (Druid Range, Mernmerna and Bunyeroo) consist almost entirely of siltstones with only very minor incursions of sand. These siltstones, which tend to shales in places, are initially white or pale grey, but towards the top of the sequence are strongly coloured - yellow, brown, purple and red - probably relating to the Mn-Fe capping that is characteristic of the Parachilna-Wilkawillina contact and is discussed in Section IV. The only trace fossils

Panel Diagram of the Parachilna Formation, Central Flinders Ranges

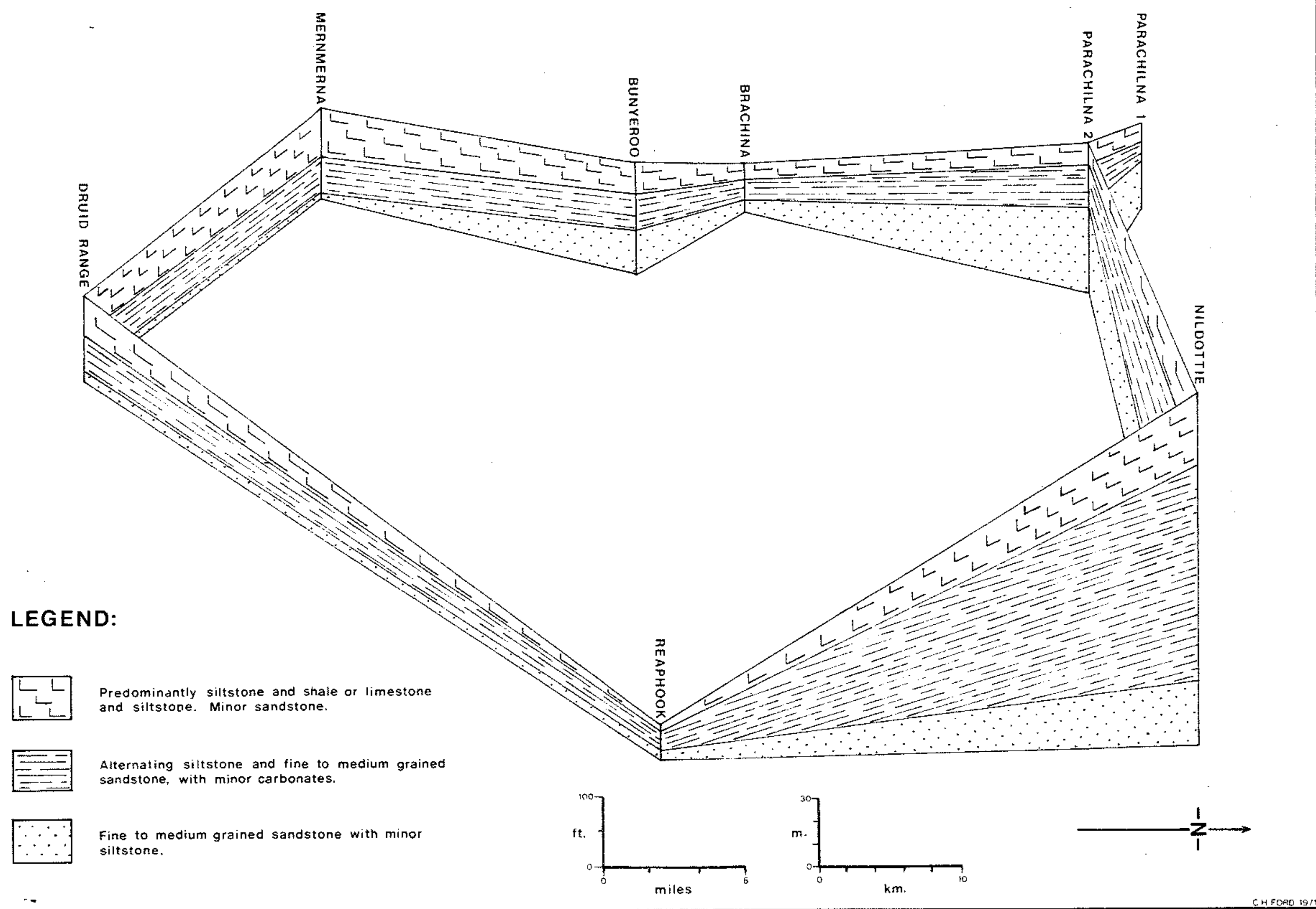

Fig. 5

detected in these siltstone sequences were a few poorly preserved Diplocraterion burrows in a sandier lens adjacent to the Mernmerna section, and an oblique U-burrow found isolated in a fine-grained sandstone some distance north of the Bunyeroo section. Other sedimentary structures were absent.

The four northerly sections (Brachina, Parachilna Nos. 1 and 2 and Nildottie) show an increasing carbonate content (see fig. 4D). Associated with the bedded limestones and calcareous siltstones are both fine and coarse-grained clastics. The Mn-Fe capping characteristic of the southern sections is developed only very patchily, although manganese staining and dendritic growths are common, particularly on the limestones. Sedimentary structures, both biogenic and inorganic, are profuse in the sandstones and arkoses of Parachilna No. 1, although not seen elsewhere.

The thickness relationships of the three members are summarized in the panel diagram, [fig. 5] which illustrates the thickening of Member 1 to the north-west, the overall constancy of thickness in the west and south, and the rapid thickening to the north-east, where the greatest thickness of Parachilna Formation is recorded.

Long-range facies and lithological correlations are necessitated by the infrequency of complete sections and the generally poor outcrop of the readily weathered units of the formation. Individual beds can be seen to be markedly lenticular, being traceable for only short distances laterally, and hence reflect local depositional environments. However, as fig. 4 illustrates, a demonstrable lithostratigraphic variation justifies the subdivision of the Parachilna Formation proposed herein.

3. SEDIMENTARY STRUCTURES.

A. INORGANIC.

(i) Ripple marks. Ripple marks were present in three sections studied. Near the base of two of these sections (Mernmerna and Parachilna No. 2) the ripple marks were preserved on the upper surface of more indurated sandstone beds as symmetrical ripples with rounded crests and low amplitudes. Wavelengths varied from 2 to 5 inches (5 to 13cm.). Crestal orientations were varied, with trends of 170° to 190° recorded at Mernmerna (Goldring and Curnow, 1967, record trends of 020° at Mernmerna), and three trend directions - 050°, 105° and 150° to 160° - noted at Parachilna No. 2 (c.f. Goldring and Curnow, op. cit., 090° and 155°). These large, gentle ripple marks are inconclusive as palaeocurrent indicators; they probably reflect local current action. Near the top of Parachilna No. 1 section small symmetrical ripple marks are exposed on the top surface of the uppermost sandstone unit. Wavelength is 1.5 to 2 inches (4 to 5cm.) and amplitude less than 0.5 inch (about 1cm.).

(ii) Mudcracks. Mudcracks were observed in Member 1 of the Mernmerna and Brachina sections, testifying to exposure and desiccation of the depositional surface early during Parachilna sedimentation. It is significant that mudcracks are recorded only from western sections, as it is proposed hereunder that the shoreline of the basin of deposition was, in fact, located in this western region. Daily, Twidale and Alley (1969) also record mudcracks from the nearby Wilpena Pound section. Further mudcracks are preserved in Member 3 of the Parachilna No. 1 section, where overlying sand has infilled irregular desiccation cracks in a micaceous silt layer; similar structures were observed in Pound Quartzite float near Reaphook Hill.

(iii) Cross-bedding. Relict cross-bedding can be detected in many sandstone beds despite bioturbation, although in highly bioturbated beds all inorganic sedimentary structures have been destroyed. Sediment of Member 1 of Parachilna No. 1 section has suffered little reworking and tabular planar cross-bedding has been highlighted by differential weathering. Cosets, with cross-stratification angles of 15° to 20°, measured 2 to 3 feet (0.6 to 0.9m.) thick, with three superimposed cosets exposed. Crossbedding of this type is indicative of a sudden decrease in the velocity of the sediment-bearing currents, such as would occur on encountering deeper water (McKee, 1964, p.268).

(iv) Scour-and-fill structures. These structures are plentiful, being particularly evident as small scale features in indurated sandstones.

Erosional scours were seen locally gouging the surface of the Pound Quartzite, so that the contact with the Parachilna Formation was undulose, with coarse-grained sediment filling these scours.

(v) Ooliths and pisolites. Spherical bodies up to 1cm. in diameter were found in an impure silty limestone near the base of Member 2 within the Parachilna No. 2 section. Such structures may be taken as indicative of a shallow water bank environment.

B. BIOGENIC SEDIMENTARY STRUCTURES.

These structures will be described in detail in Section V. It will suffice to point out here that intensive burrowing, as occurred in the sands of the Parachilna Formation, has led to a redistribution of the sediment and destruction of many primary sedimentary structures. The burrow structures, particularly *Diplocraterion*, are composed of clean quartz grains of fairly uniform size, whereas the groundmass of the rock contains a variety of quartz grains from very fine sand to granule size, set randomly in a matrix of clay minerals.

4. THE POUND QUARTZITE-PARACHILNA FORMATION BOUNDARY.

The nature of the contact between the Pound Quartzite and the Parachilna Formation has long been debated. Segnit (1939), in mapping the Mt. Scott area, recognized a disconformable contact between these two units, as the junction is very irregular, with arenaceous material filling scours in the Pound Quartzite surface. Elsewhere, the contact, although generally structurally conformable, has features indicative of a disconformity, as postulated on a regional scale by Dalgarno (1964). A stratigraphical break is primarily suggested by the fact that the Parachilna Formation is a transgressive unit overlying the regressive Pound Quartzite. However, the Pound Quartzite shows signs of rejuvenation of its palaeodrainage pattern, as channel-sand bodies have been described by Goldring and Curnow (1967) at the top of this unit. Lenticular coarse-grained sand-bodies up to 8 feet (2.5m.) thick and of very limited lateral extent were observed locally below the Pound-Parachilna boundary. These sands were typically pure, cross-stratified and pale yellow or pink in colour, possibly channel-sands equivalent to the Unit A of Goldring and Curnow (op. cit.) at Ediacara.

The uppermost Pound surface tends to be undulose, or even knobbly in appearance, suggestive of scouring of an unlithified sand prior to deposition of the transgressive Parachilna sands. The postulation that the Pound sand was unlithified is supported by the fact that the upper 1 to 2 cm. of the Pound has been penetrated by burrows of Diplocraterion descending from overlying Parachilna sediment. This feature is characteristic of the contact, and was noted at five of the eight sections studied, as well as at intermediate stations.

At the base of the type section in Parachilna Gorge, sandstone pebbles are found in hollows on the contact; similar structures exist near Reaphook Hill (J.C. Gehling, pers. comm.). The sections at Reaphook have abundant pebbles of crystalline quartz weathered out of the soft Parachilna sediments. The source of these pebbles is uncertain, although they could be reworked elements of an older orthoquartzite.

Wopfner (1970) reports a low-angle unconformity between the Pound Quartzite and Parachilna Formation in Brachina Gorge; this was not observed by the author, although a small dip fault cutting across the contact close to the best exposed section found here leads to an angular juxta-position of the two units, and interpretation is rendered difficult by poor exposure of Pound Quartzite on the upthrust block [see fig. 6].

Thus the evidence indicates a disconformity between the Pound Quartzite and Parachilna Formation. The temporal significance of the break between the two units has not been resolved, although the time span involved is curtailed by the necessity for the underlying Pound sand to remain unlithified, enabling it to be burrowed by Diplocraterion.

5. THE PARACHILNA FORMATION - WILKAWILLINA LIMESTONE BOUNDARY.

The contact between these two units is usually well-exposed and conformable. The change in lithology is abrupt, with, at best, only a few minor beds of limestone within the Parachilna Formation prior to the deposition of the massive sandy and oolitic Wilkawillina limestones. The rocks on either

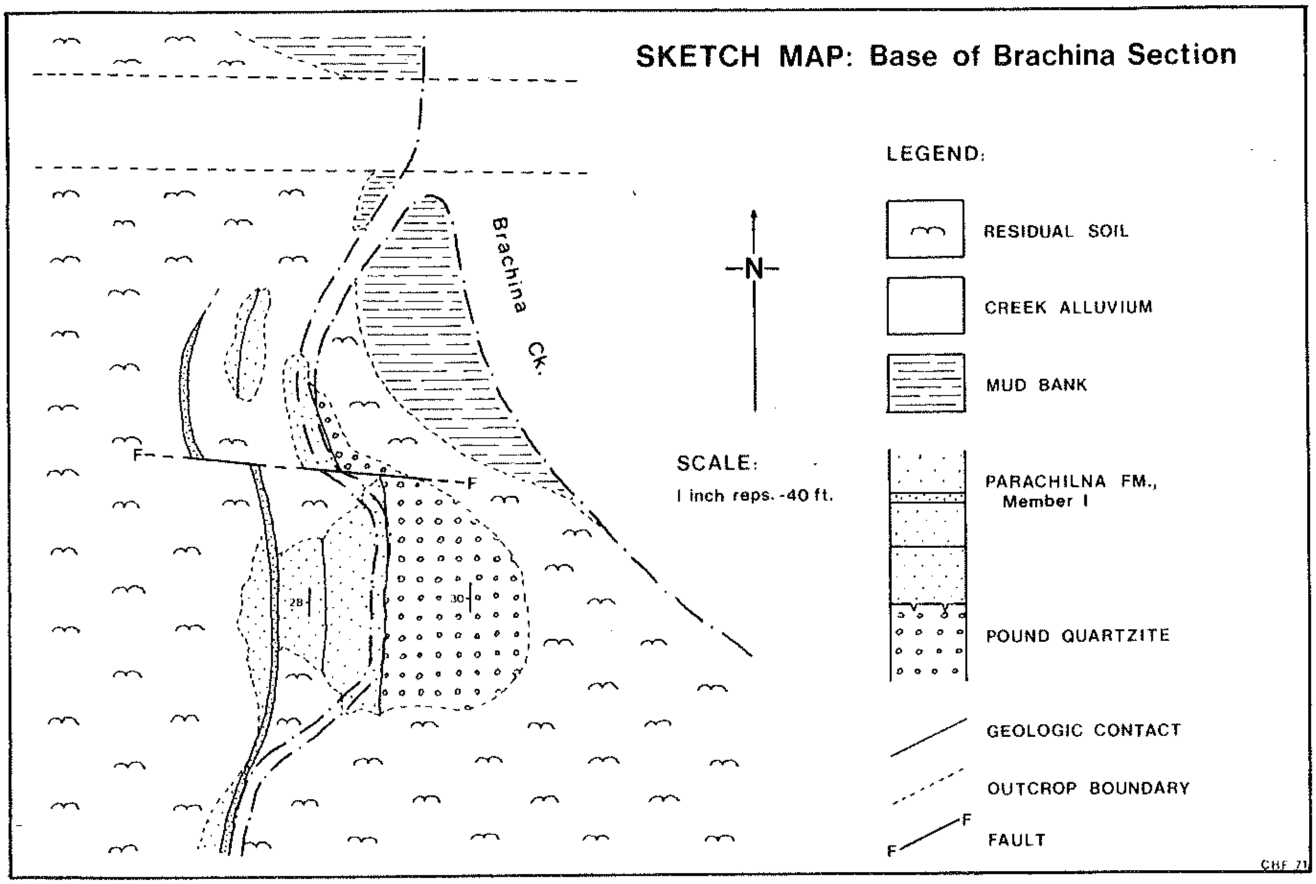
SKETCH MAP: Base of Brachina Section
LEGEND:
RESIDUAL SOIL
CREEK ALLUVIUM
MUD BANK
PARACHILNA FM., Member I
POUND QUARTZITE
GEOLOGIC CONTACT
OUTCROP BOUNDARY
FAULT
SCALE:
I inch reps. -40 ft.
N
Brachina Ck.
F
F
28
30

Fig. 6

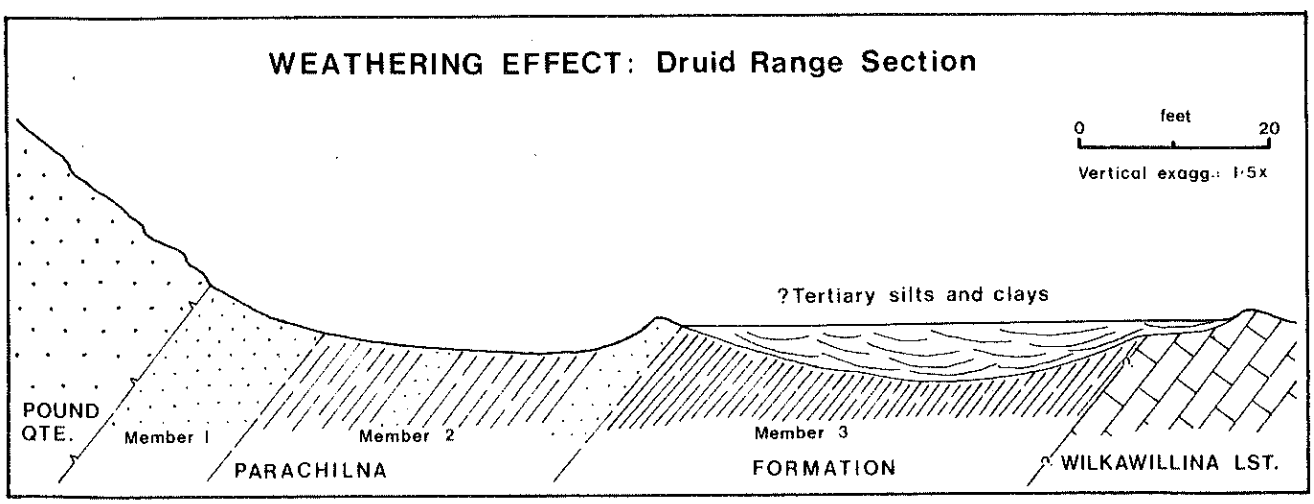
WEATHERING EFFECT: Druid Range Section
0 feet 20
Vertical exagg.: 1·5x
?Tertiary silts and clays
POUND QTE.
Member I
Member 2
Member 3
PARACHILNA
FORMATION
WILKAWILLINA LST.

Fig. 7

side of the contact often show a characteristic but variable mangano-ferruginous capping, or, in more moderate cases, staining and dendritic growths.

6. WEATHERING EFFECTS.

In several localities, Parachilna sediments show evidence of stripping and redeposition closeby. This is particularly true of the overturned Druid Range outcrops, where Member 2 is frequently deflated, while Member 3 is partially covered by an apron of flat-lying white silty clay [see fig. 7].

Gypsiferous weathering products are characteristic of the Parachilna Formation; Parachilna sediments in suboutcrop can frequently be detected by the crackling noises produced by treading on the overlying gypsiferous soil. On recently exposed Parachilna sediment, large crystals of gypsum often form; specimen A365/1 was collected from a railway cutting within the Parachilna Formation near Mernmerna.

IV. MINERALIZATION.

There is no certain record of the Parachilna Formation having been mined, but there appears to be some relationship between the widespread mangano-ferruginous capping of uppermost Parachilna and lowermost Wilkawillina sediments, and the Mississippi Valley-type lead deposits once mined at Ediacara. The lead mineralization occurs as galena and cerussite in brecciated dolomitic lenses at the base of the Ajax Limestone (Wilkawillina Limestone equivalent) and is commonly associated with manganiferous oxides (Nixon, 1963). The southern workings at Ediacara are located in "weathered calcareous silts and shales and sandy horizons" (Nixon, op. cit.) which are conceivably of the upper Parachilna Formation, although not stratigraphically categorized by Nixon. Mineralization aspects which lead Nixon to classify the deposits as Mississippi Valley type were confinement of the ore to carbonate rocks, absence of igneous source rocks, lack of wallrock alteration, the stratiform nature of the deposits and their relationships to depositional features (Nixon, op. cit., p.107).

Copper mineralization is found in the same stratigraphic horizon as the lead at Ediacara, and manganese is particularly evident at the copper producing locality. The mineralization occurs as malachite and is again confined to intraformational breccia in lowermost Ajax dolomites.

Sporadic workings were located elsewhere in the areas studied; near Reaphook Hill, fairly intense manganiferous mineralization is possibly associated with the occurrence of scholzite, a calcium zinc phosphate, within the Parachilna Formation (F. M. Gaunt, pers. comm.). Approximately midway between Brachina and Bunyeroo Gorges abandoned diggings were found in a brecciated zone of the basal Wilkawillina Limestone. All material in the dumps was heavily encrusted with manganese oxides, and the ore minerals sought were not determined.

Thomson (1962) notes widespread lead, and lesser copper mineralization in lowermost Cambrian sediments of the Adelaide 'Geosyncline', and postulates a volcanic exhalative origin for the metals. Another postulated metal source is eroded diapiric breccia (Coats, 1964). However, until detailed geochemical studies are carried out, it can only be stated that mangano-ferruginous developments are characteristic of the interface between the impervious Wilkawillina Limestone and the underlying porous Parachilna clastics, and that post-depositional recrystallization has possibly led to a concentration of lead and copper minerals in intraformational breccias within the Wilkawillina Limestone.

V. DESCRIPTIVE PALAEONTOLOGY.

1. INTRODUCTION.

Trace fossils are the only indications of the existence of life that have been recorded from the Parachilna Formation. This does not exclude the possibility of finding body fossils; however the predominance of clastic sediments in the formation lends a greater overall fossilization potential to biogenic sedimentary structures (Goldring, 1965). A trace fossil has been defined as "a sedimentary structure resulting from the activity of an animal moving on or in the sediment at the time of its accumulation" (Simpson, 1957). The inadequacies of this definition have been pointed out by several authors (e.g. Martinsson, 1970; Webby, 1970), but since trace fossils (sensu lato) may be actively or passively formed, and structural or textural in relation to the sediment, an adequate definition is difficult to phrase, without tending to gross oversimplification. Rather than striving for a precise definition, it should suffice to point out here that the trace fossils preserved in the Parachilna Formation are the result of firstly, animal activity within the sediment or at a sediment interface, and, secondly, differential weathering processes to enable the structures to be discerned.

In the following descriptions, Martinsson's (1965, 1970) toponomy has been used in preference to those proposed by Seilacher (1964a) or Häntzschel (1962). Martinsson's classification describes a trace fossil in terms of the main casting medium. Thus, all structures in fig. 8 refer to the sandstone bed S. [Fig. 8 adapted from Martinsson, 1970, p.327].

2. DIPLOCRATERION Torell.

The "vertical worm burrows" of the Parachilna Formation were initially designated Skolithos by Dalgarno (1962) but subsequent examination, prompted by Professor M. F. Glaessner, revealed that the burrows were similar to the U-tube Diplocraterion Torell (Dalgarno, 1964).

Diplocraterion is the most common trace fossil of the Parachilna Formation, being preserved as infilled U-tubes perpendicular to the bedding, with septal laminations indicating earlier positions of the U. The migratory ability of the organism responsible for the burrow is characteristic of the form-genus; the organism burrows to an optimum depth relative to the existing sediment-water interface. If further deposition occurs, the organism will migrate upwards, leaving a series of septa showing earlier, lower locations of the U-tube, unless the rate of sedimentation is greater than the rate of upward migration of which the organism is capable, resulting in the organism's death. Septa produced by upward migration are termed retrusive; protrusive septa are produced by downward migration in response to erosion.

The upper or free ends of the parallel tubes may flare out into funnels at the surface, although this feature is not necessarily diagnostic; Häntzschel (1962) states that the tubes may end in large funnels, in small

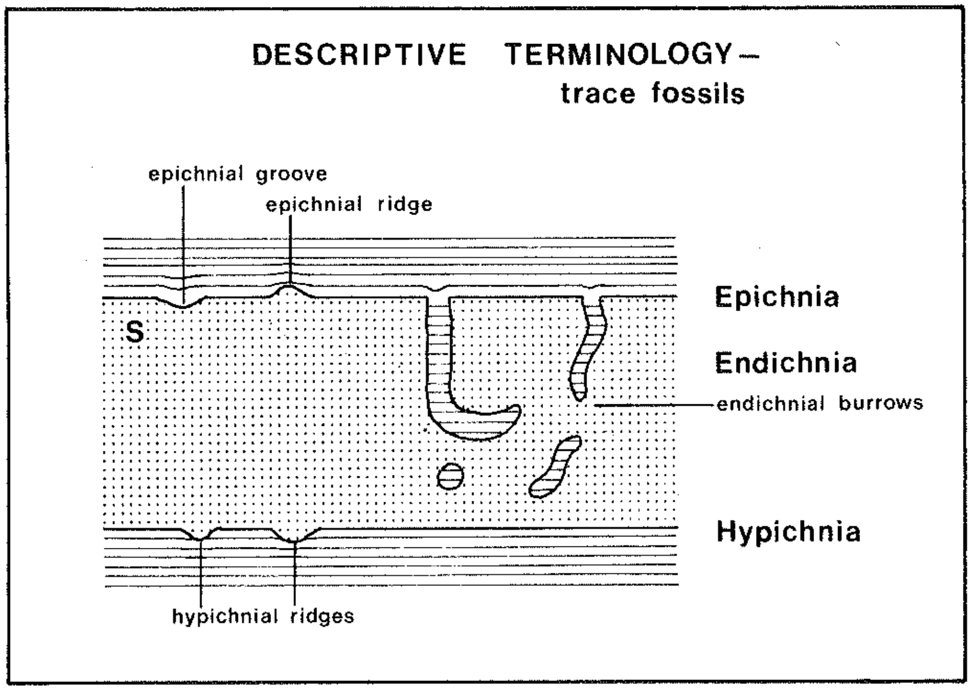

Fig. 8 (Adapted from Martinsson, 1970, fig. 1)

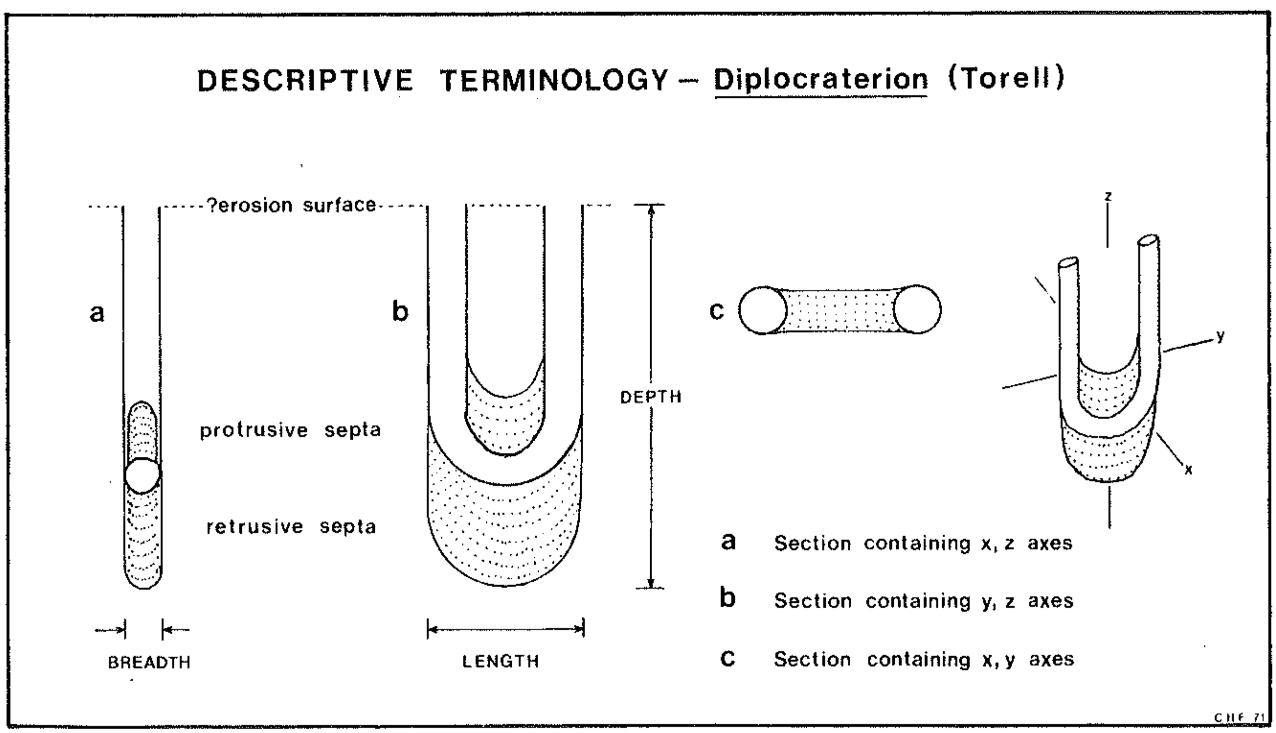

Fig. 9

shallow funnels or remain subcylindrical to the surface. No funnel-shaped terminations have been observed on U-tubes in the Parachilna Formation, but penecontemporaneous erosion could remove such a feature if it were originally present. Goldring (1962) encountered almost invariable truncation of Diplocraterion yoyo in the Upper Devonian Baggy Beds of Devon.

The U-tubes found in the Parachilna Formation can be excluded from the form-genera Arenicolites, which is diagnostically non-septate, and Rhizocorallium which, although septate, is burrowed obliquely to the bedding (Häntzschel, 1962). Distinction from Corophioides, a septate U-tube perpendicular to the bedding, is generally determined by the form of tube aperture. As no terminal apertures have been conclusively recorded from the U-tubes of the Parachilna Formation, this criterion cannot be used to distinguish between the two form-genera, although Westergaard (1931, quoted in Goldring, 1962, p.238) places little emphasis on the apertural form of Diplocraterion. Häntzschel (1962, fig. 117) illustrates Corophioides as having exclusively protrusive septa, and also a smaller depth:length ratio than Diplocraterion, forming, as it were, a wider-based U. Further discussion of generic and specific assignment of U-burrows is given by Goldring (1962, pp.237-239). The morphological characteristics and descriptive terminology pertaining to the form-genus Diplocraterion are shown in fig. 9.

Both retrusive and protrusive specimens of Diplocraterion are found in the Parachilna Formation. The dimensions of specimens show considerable variation from place to place, but in any one outcrop burrow size is fairly constant. Irregular deep weathering badly affects the burrows, but the following range of values was obtained from sections studied: depths range to 14cm.; lengths between 1.5 and 4.0cm.; burrow diameters 0.15 to 0.8cm.; the greatest amount of vertical migration recorded was 5.0cm. of protrusive septa. Transverse sections of burrows do not show the dumb-bell shape of D. yoyo (Goldring, 1962), but septal breadth closely approximates tube diameter.

A burrow is generally considered to have been passively filled after it has been vacated either by the migration or the death of the burrow-dweller. There is considerable variation in the nature of the infilling material. In a majority of burrows studied the burrow fill is sand of the same size range as the hostrock but it is usually deficient in the characteristic clay fraction. Other burrows, however, are filled with well-sorted homogeneous sand, which renders the burrows resistant to weathering (e.g. A365/2). This fact indicates that either the burrow was filled subsequent to the deposition of a clean, well-sorted sand, or the burrower selectively cemented sand grains with mucus to create a tubular burrow wall. Transverse sections of tubes favour the former explanation, as the entire section of the tube is filled with homogeneous cemented sand, but clean sands seldom outcrop in the Parachilna Formation. Distortions of tube shapes are thought to reflect compactional movements, rather than indicating that the burrower evaded impenetrable sediment.

While specimens with retrusive septa are found, burrows with protrusive septa are far more prolific, indicating that minor penecontemporaneous erosion proceeded almost continuously between infrequent influxes of sediment; the burrowers could maintain an optimum living depth for long periods of slow erosion, but were incapable of migrating upwards in response to a sudden flood of sediment.

Colonization of sediments by Diplocraterion was variable. Greatest utilization of the sediment seemed to have been made in an alternating sand and silt sequence, exemplified by Member 2, Mernmerna section, where the beds of sand were densely colonized, and no fossils can be found in the silts. In areas of almost continuous sand deposition (e.g. Member 1, Druid Range), burrow preservation is patchy, although the burrowers were gregarious. It is suggested that initial colonization was sporadic (Goldring and Curnow, 1967); however, the burrows of one 'colony' are of fairly constant size, with no periphery of 'juvenile' burrows as noted by Goldring (1962) in the Baggy Beds. This phenomenon could be due either to the simultaneous colonization of an area by groups of organisms all of the same growth stage, for example, seasonal colonization by groups of newly emergent adult forms, or to the localization of food sources, necessarily delimiting the area available for colonization.

The occurrences of uppermost Pound Quartzite being burrowed by Diplocraterion have been discussed in Section III, part 5; the distribution of Diplocraterion within the Parachilna Formation is considered in Section VI.

3. BEDDING SURFACE ICHNOFOSSILS.

Epichnial trails of six distinguishable forms and two forms of hypichnial trails were found on bedding surfaces within the Parachilna Formation. These are described below.

A. EPICHNIAL TRAILS.

Form E1 [fig. 10] occurs as straight or very gently sinuous white-coloured trails preserved as low epichnial ridges parallel to the bedding planes of fine to medium-grained pale grey sandstones. Trail length: 1 to 15cm.; width: 0.4 to 1.0cm.; with variation along the length of individual trails. Simple branching at about 60° to 70° is occasionally developed, with a weak polygonal pattern resulting. Trail terminations, where observable, are generally full and rounded. Form E1 was found in the basal 8 feet (2.5m.) of Member 1, Mernmerna, and within Member 2, 85 feet (26m.) above the Pound Quartzite, at Bunyeroo.

Form E2 [fig. 11] is a group of discrete epichnial ridges with low, rounded relief, forming straight or arcuate trails 1.5 to 3.5cm. in length and 0.3 to 0.4cm. wide. Form E2 trails are preserved in a fine-grained, slightly indurated sandstone, with relief providing the only differentiation from the host rock. This form was found within Member 2, Parachilna No. 2, 138 feet (42m.) above the Pound Quartzite.

Form E3 [fig. 12;] appears as strong epichnial ridges, the trails being straight, arcuate or sinuous and exhibiting simple branching. Length 1.0 to 6.5cm.; width fairly constant between 0.3 and 0.4cm. This form is apparently phobotactic, as trails do not interpenetrate. Some trails show weak annulation, while others pertain to a "string-of-beads" structure. One trail tends to the "feather-stitch" trail from the Proterozoic-Cambrian succession of Norway (Banks, 1970), but this is probably a fortuitous similarity. Form E3 is preserved in a fine to medium-grained feldspathic sandstone, 118 feet (36m.) above the Pound Quartzite, in Member 3, Parachilna No. 1. The bedding surface of the casting medium is undulose, indicating current action at the time of deposition, although bioturbation probably occurred following subsequent burial.

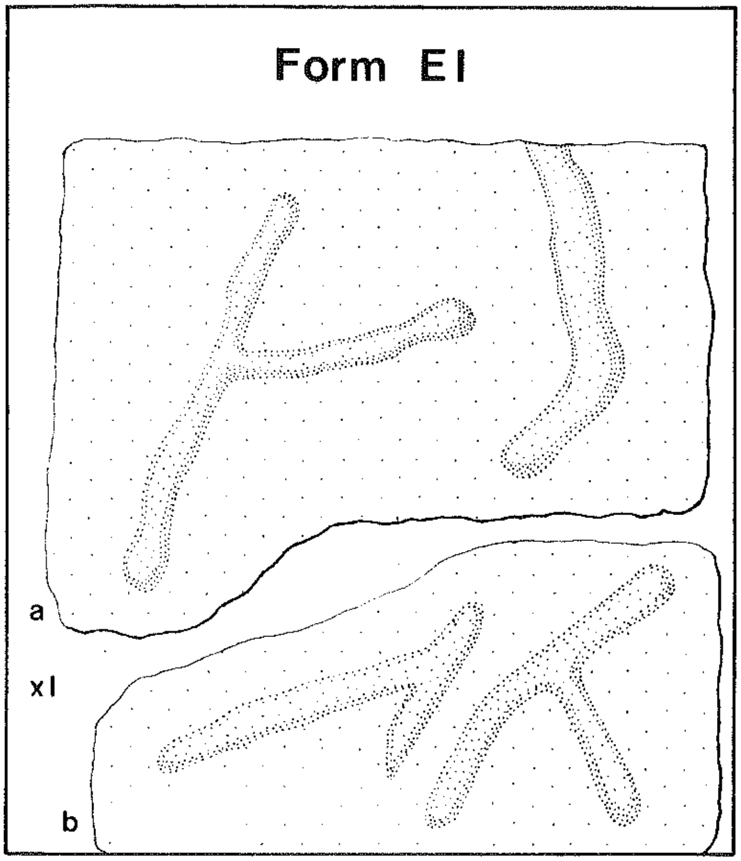

Fig. 10 Specimens from a, Mernmerna, b, Bunyeroo

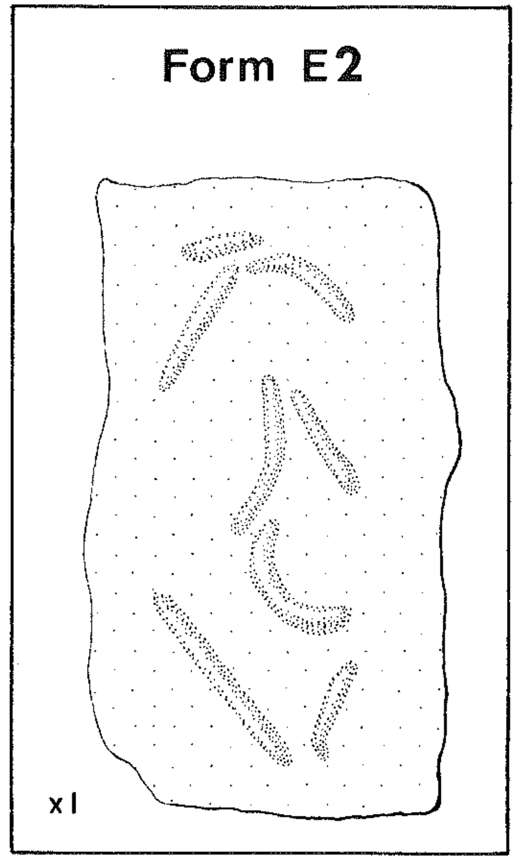

Fig. 11

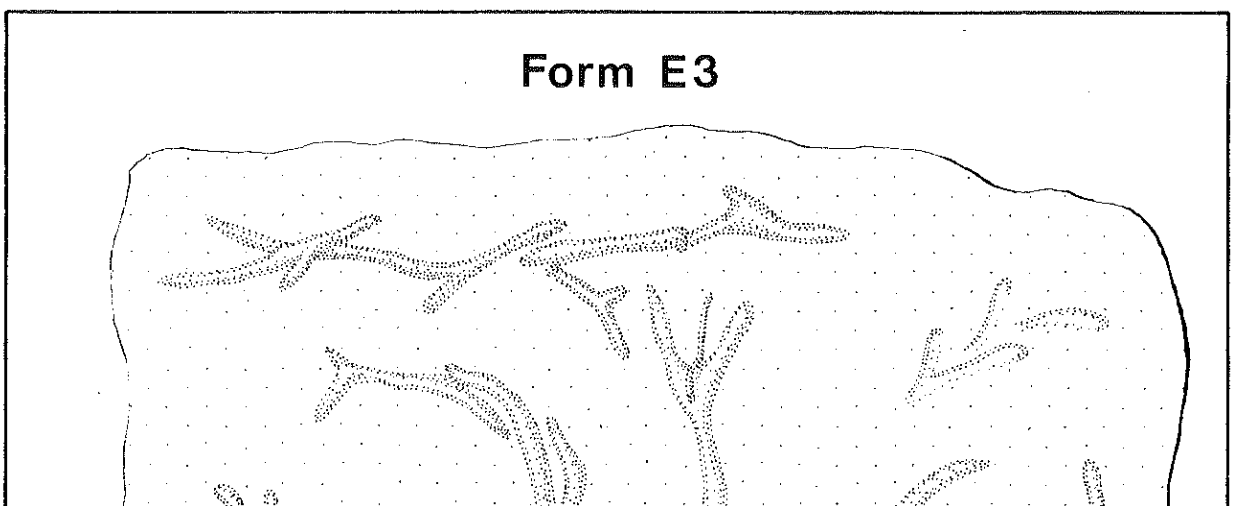

Fig. 12

Form E4 [fig. 13] is associated with form E3, being found on the same slab of rock (A365/3). The trails appear as fine epichnial ridges, straight or curved, unbranched, and exhibiting phobotaxis. Length: 0.3 to 1.2cm.; width: 0.1cm. or less, with a consequent loss of detail, as the trail width is of the same order of magnitude as the grain size of the sediment. Trails of similar morphology are found 44 feet (13m.) above the Pound Quartzite in Member 2, Parachilna No. 2.

Form E5 [fig. 14] occurs as straight or very slightly curved trails, 1.0 to 3.0cm. long and 0.3 to 0.4cm. wide, preserved as epichnial ridges on a glauconitic sandstone. These trails appear to terminate with knob-like structures of slightly greater diameter than trail width. Simple branching, generally at 90°, is exhibited. The sand infilling the trail is coarser and purer than the host-rock. Associated with Form E5 are a few narrow trails of Form E4, and several 'knobs', 0.3 to 0.4cm. in diameter, similar to the terminations of Form E5 trails, and possibly representing vertical burrows. This form is located in Member 1, Parachilna No. 2, 44 feet (13m.) above the Pound Quartzite.

Form E6 [fig. 15] occurs as small 'twig-like' epichnial trails associated with Form E1 at Mernmerna. The trails are 1.0 to 2.0cm. long and 0.2 to 0.3cm. wide, and generally straight or slightly zig-zag, with pointed terminations, giving a blade-like appearance. Branching is common, with off-shoots set at between 30° and 90° to the main trail. Form E6 is found in the basal 8 feet (2.5m.) of the Mernmerna section.

B. HYPICHNIAL TRAILS.

Form H1 [fig. 16] is found as short, branching bodies preserved as high hypichnial ridges on a medium-grained grey sandstone. The trails are 1.5 to 3.0cm. in length, and 0.7 to 1.2cm. wide, with one narrower side-branch being 0.4cm. wide. The trail terminations are indistinct, as weathering has reduced clarity of form. Form H1 was found 53 feet (16m.) above the Pound Quartzite, near the top of Member 2, Druid Range.

Form H2 [fig. 17] is preserved as arcuate and branching hypichnial ridges

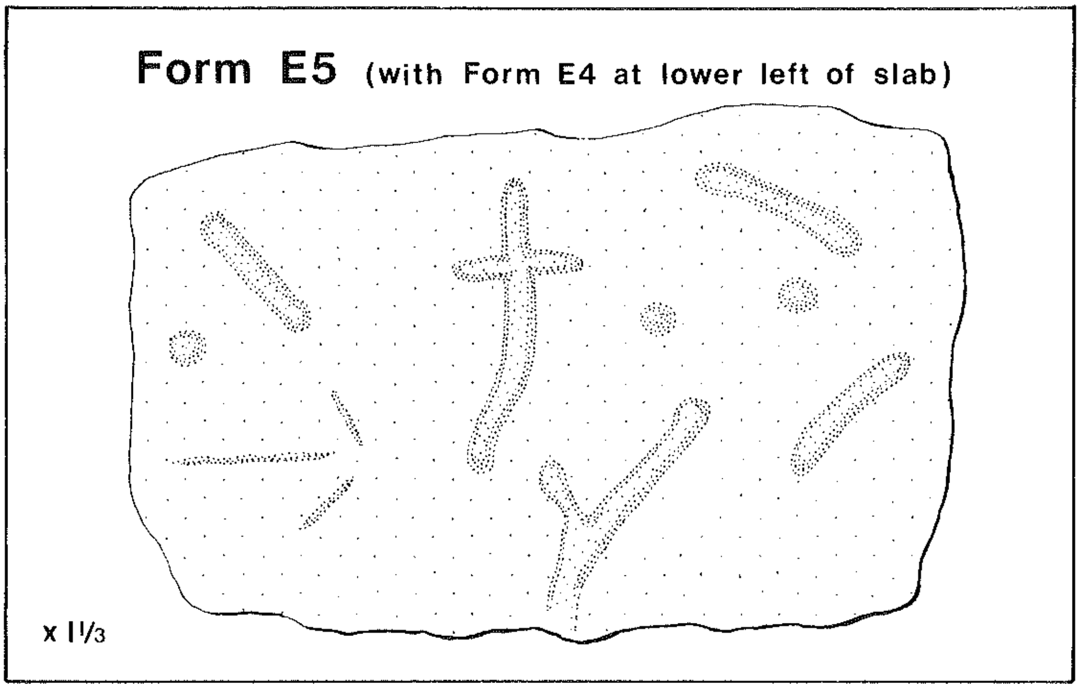

Fig. 14

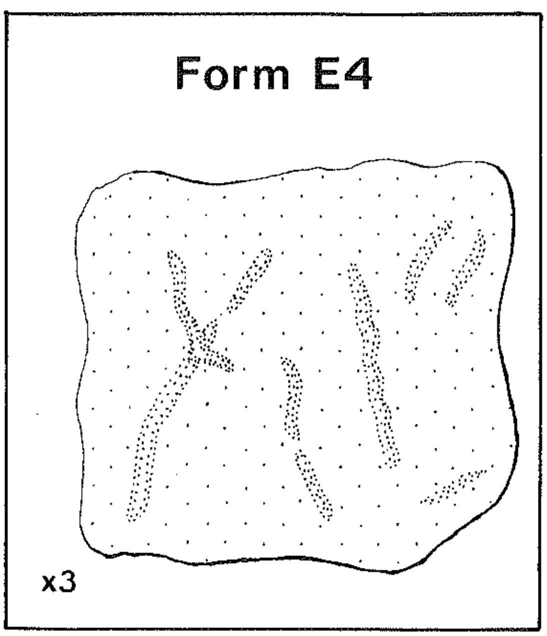

Fig. 13

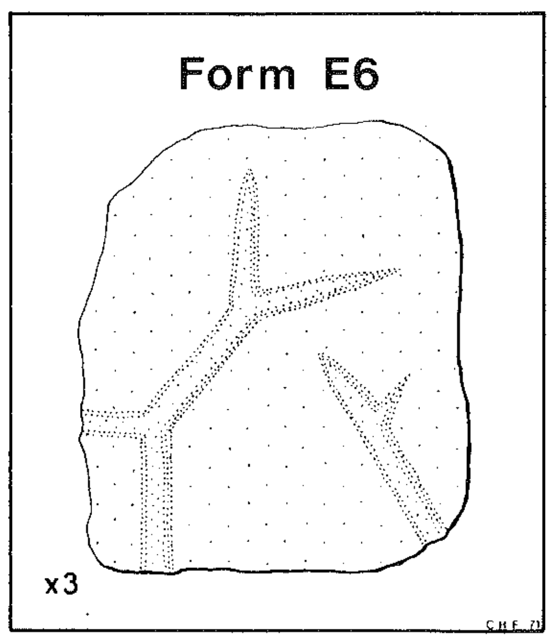

Fig. 15

up to 5cm. long and 0.4 to 0.5cm. wide. The trails are composed of pure medium-grained quartz grains with secondary overgrowths, set in a glauconitic sandstone. Structures of similar form but greater relief are present on the bottom surface of the slab bearing Form E5, but weathering and a pervasive lichen growth render interpretation difficult. 'Knobs' like those associated with Form E5 are also present. Form H2 was found within Member 1, Parachilna No. 2, some 40 to 45 feet (12 to 14m.) above the Pound Quartzite.

All these trails, both epichnia and hypichnia, are considered to be formed by sediment-ingesting organisms extracting nutrient-rich material accumulated at a sediment interface. Evidence for this is given by the adherence of the trails to bedding planes, despite the irregularities of these planes (e.g. Forms E3 and E4 on specimen A365/3). The phobotaxis exhibited by Forms E3 and E4, and the rarity of intersections between other trails is indicative of the efficient utilization of nutrient-bearing sediment by sediment-ingestors (Osgood, 1970). Branching of trails is common amongst worm-like organisms seeking, by a process of trial-and-error, the most nutrient-rich patches on the bedding interface.

4. 'OBLIQUE' U-TUBE.

This single specimen (A365/4; fig. 18) is of a 'bent' cylindrical tube, with another less well-preserved tube parallel to it, suggesting a form of U-tube, although no closure of the U is preserved. The upper ends of the tubes are set at 45° to the bedding, while the lower ends are almost perpendicular to bedding. The tubes bear distinct annulations, 1mm. thick, possibly pertaining to active infilling of the burrow; no septa are visible. Differentiation of the tubes from the host-rock is obvious. The better-preserved arm is 6.5cm. in length; the tubes are perfectly circular in cross-section and 0.4cm. in diameter. This structure was found preserved in a very fine-grained white sandstone, some 26 feet (8m.) below the Wilkawillina Limestone, about 2,000 feet (600m.) north of the Bunyeroo section. The lower Parachilna and upper Pound sequence was

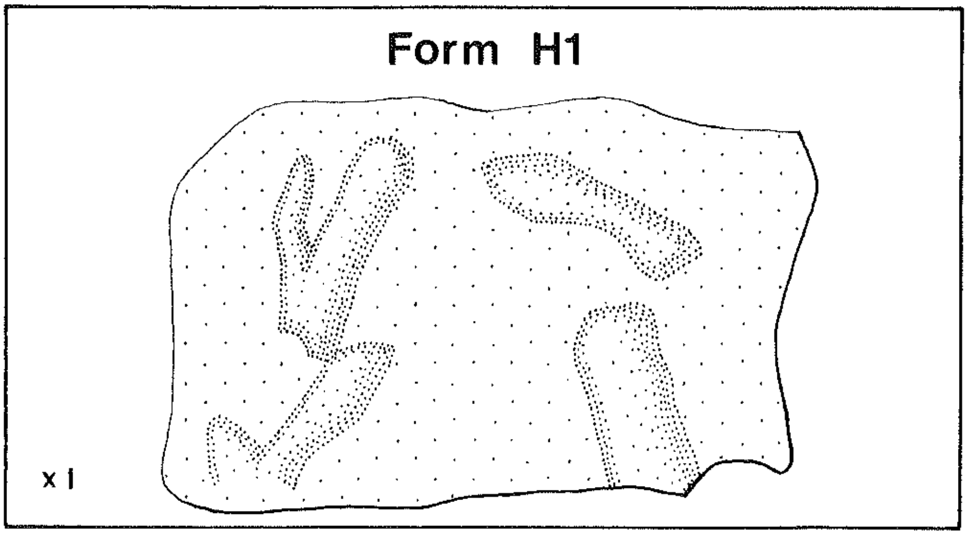

Fig. 16

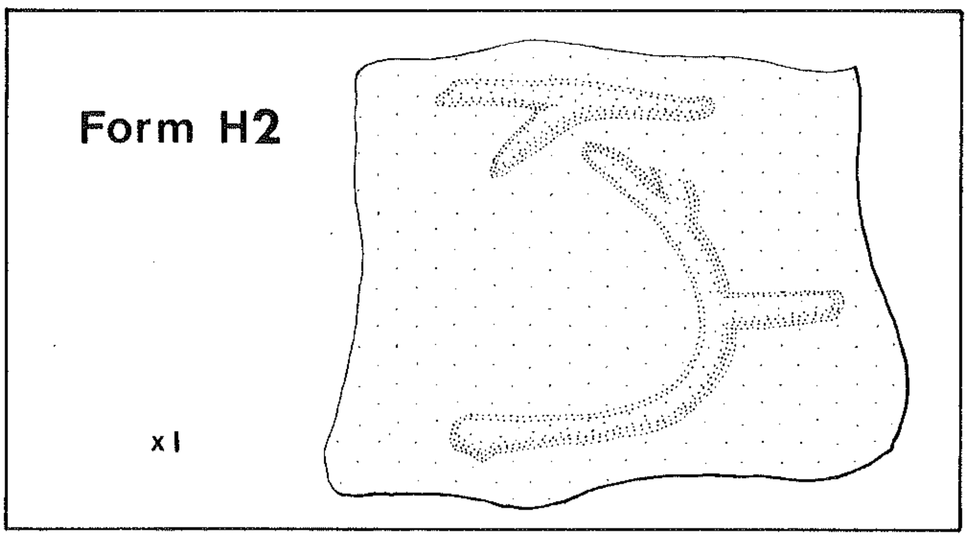

Fig. 17

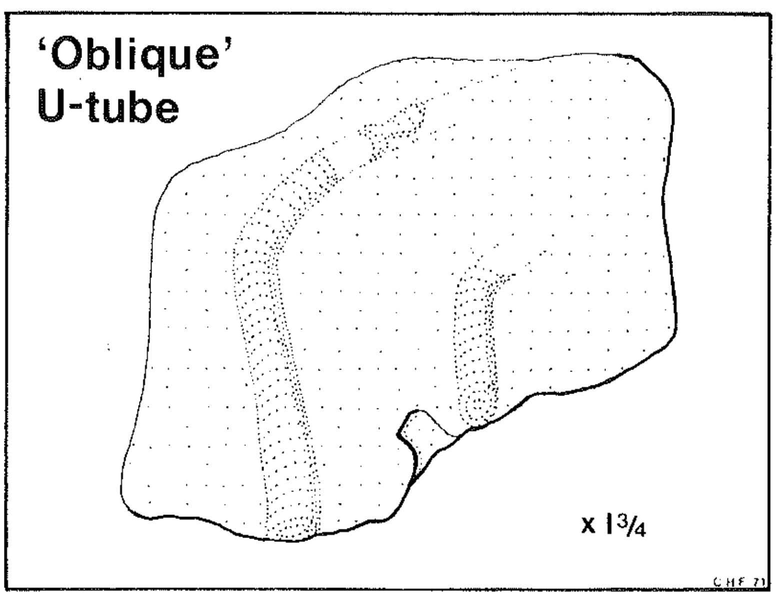

Fig. 18

poorly exposed at this locality.

5. OTHER TRACE FOSSILS FROM THE PARACHILNA FORMATION.

Plagiogmus Roedel has been recorded from the Parachilna Formation (Glaessner, 1969; Daily, Twidale and Alley, 1969), while Wade (1970) mentions Rusophycus Seilacher from the Mundy Waters section. No specimens of these form-genera were found in the outcrops studied for this project.

VI. PALAEOENVIRONMENTAL INTERPRETATION.

Seilacher (1964b, 1967) has examined the use of trace fossils as indicators of palaeoenvironmental parameters. The advantages of trace fossils for this purpose are:

(1) long time range, as trace fossils are reflections of long-existing behavioural patterns,

(2) narrow facies range of many trace fossils as direct responses to specific environmental conditions,

(3) autochthony of trace fossils, as no secondary displacement is likely to retail the original structure,

(4) preservation in clastic sediments, where body fossils are rare, and

(5) enhancement of the fossil structures by subsequent diagenetic and weathering processes.

The above advantages are not applicable under all circumstances; for example, Crimes (1970) has demonstrated the facies-dependency and, in some cases, the facies-independency of trace fossils from the Lower Palaeozoic of Wales. However, it was on the basis of these characteristics of trace fossils that Seilacher (1964) proposed three depth-controlled ichnofacies of universal application. Farrow (1966) demonstrated a bathymetric zonation for Jurassic littoral and shallow neritic deposits exposed in Yorkshire. Subsequently Seilacher (1967) expanded and modified his range of ichnofacies to the following scheme:

(1) Scoyenia facies - terrestrial environment.

(2) Skolithos - Glossifungites facies - intertidal environment characterized by deep, vertical burrows of suspension-feeding organisms.

(3) Cruziana facies - littoral and sublittoral environment with assorted 'cubichnia' or resting-traces.

(4) Zoophycos facies - sublittoral to bathyal environments characterized by 'mining' operations of sediment-feeders.

(5) Nereites facies - bathyal and turbidite environments with many 'pascichnia' or surface grazing traces.

While bathymetry may be a primary parameter in trace fossil ecology, it is not exclusive, and other parameters and environmental conditions may influence trace fossil distributions. For example, Frey (1970) has shown that the formation of deep, vertical burrows, in this case by anemones, is a function of substrate incoherency rather than water depth. Nevertheless, a viable bathymetric zonation exists, and is applicable to the trace fossils of the Parachilna Formation.

Diplocraterion is a deep burrow excavated normal to the bedding planes. As such, it affords a position in which a soft-bodied organism can survive in an environment of high hydrodynamic energy, while the ability of the organism to burrow deeper in response to erosion or elevate its burrow in response to deposition, enables it to occupy an intertidal niche. Thus Diplocraterion falls within the Skolithos-facies, and, in marginal seas, may be considered a shoreline indicator. In epeiric seas, however, tidal patterns are subdued (Shaw, 1964), and a high energy tidal environment is hydrodynamically unfeasible. Furthermore, a prolific endobenthonic fauna is indicated by the degree of bioturbation in the Parachilna sediments, and an environment such as an epeiric sea where hypersalinity is easily induced is scarcely conducive to the organisms of low organizational levels existing at that time.

While admitting that the Parachilna Formation is a transgressive unit and postulating an open-sea beach environment for deposition of the sands, it must be realized that no time significance can be attached to any of these occurrences. The extent to which a transgressive unit is diachronous depends on the rate of shoreline advance; in the case of the Parachilna Formation, the surface over which the transgression was proceeding may have been subject to active subsidence due to basement plate movements. The underlying Ediacara fauna, if taken as an admissable time plane as proposed by Wade (1970), is separated from the Parachilna Formation by an undefined stratigraphic break at the top of the Pound Quartzite. Nearly 200 feet (60m.) of limestones of variable facies overlie the Parachilna Formation before the appearance of the first elements of a reliable biostratigraphic zonation (Daily, 1956; Walter, 1967). Thus the panel diagram [fig. 5], although plotted with an assumed isomorphic datum (the base of the Wilkawillina Limestone), has no proven time correlations, and illustrates suggested rock correlations only.

The preservation of Diplocraterion at a particular level in a section serves only to say that at some undefinable point in time of Parachilna deposition, this particular area was subject to an intertidal environment. However, the degree of persistence of Diplocraterion preservation within a section can be utilized to predict the areal extent of the encroaching sea. Of the sections studied in the Central Flinders Ranges, Diplocraterion is found only at the base of the most easterly sequence of Reaphook Hill (F. M. Gaunt and J. C. Gehling, pers. comm.), and restricted to Member 1 of the northeasterly Nildottie section [fig. 3]. But in the western sections, the burrows are found throughout Members 1 and 2, and even persist into Member 3 (Mernmerna and Parachilna No. 1 sections). Elsewhere in the Flinders Ranges, particularly to the north of the area studied, Diplocraterion burrows are cited as being characteristic of the basal Parachilna sediments (e.g. Nixon, 1964; Dalgarno, 1964; and others). This fact suggests either a relatively slow, diachronous transgression, permitting colonization of each fresh intertidal zone by Diplocraterion, or a relatively rapid invasion of a shallow sea onto a peneplane which had subsided due to basement subsidence, resulting in an early stabilization of the shoreline. Differential subsidence of adjacent tectonic plates could account for the thickness variations illustrated by the isopach map of the Parachilna Formation [fig. 19]; however conclusions concerning the tectonic setting of Parachilna sedimentation are beyond the scope of this study.

From the evidence of the distribution of Diplocraterion shown in

Isopach Map of the Parachilna Formation

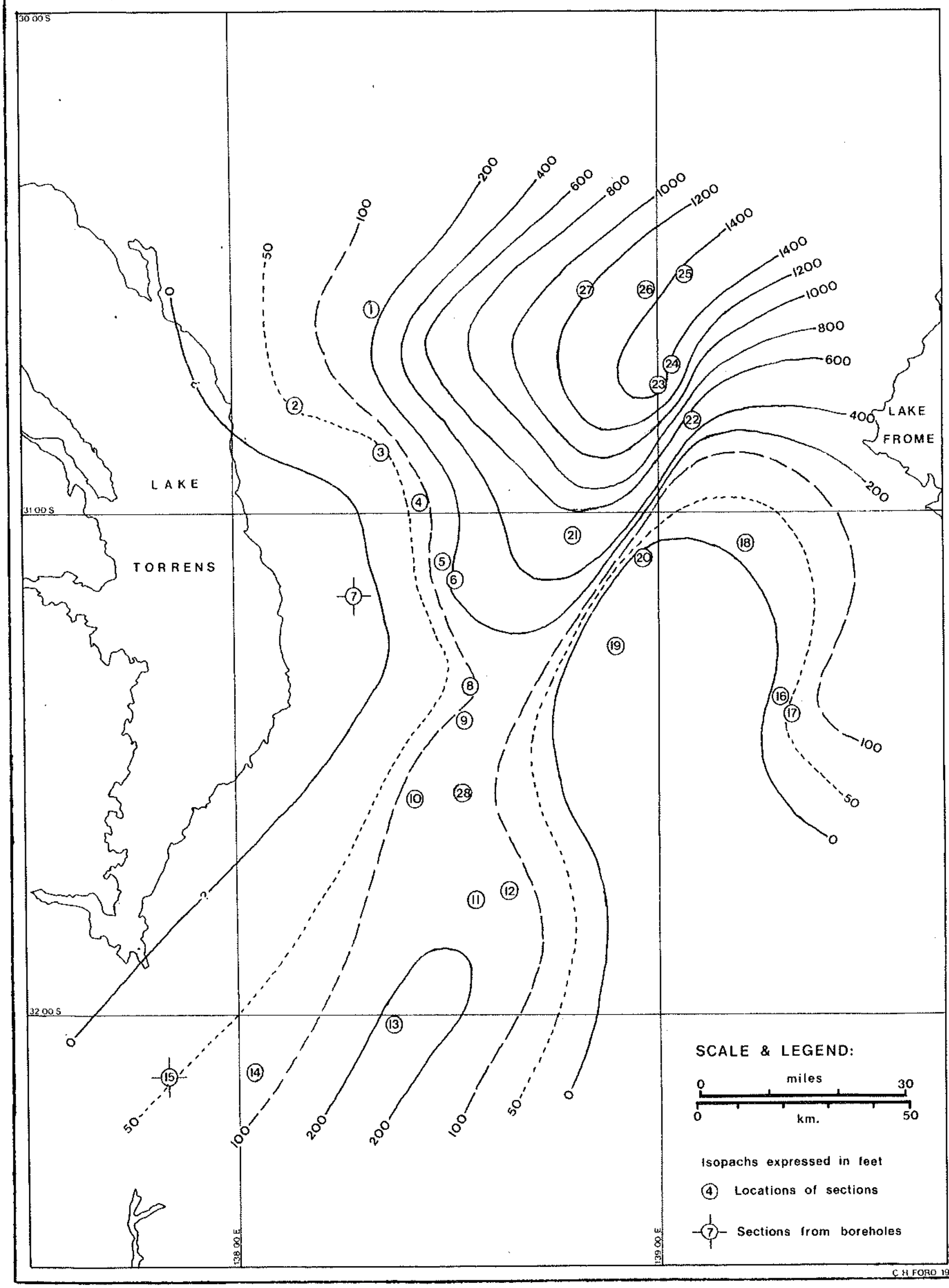

Fig. 19

fig. 3, it is postulated that, following the initial transgression of a shallow sea, a persistent shoreline existed on the western edge of the basin of sedimentation, with a sublittoral environment to the east.

As a complement to the above postulation, it is proposed that the allochthonous element of the Parachilna sediment was derived principally from the erosion and redeposition of the thin veneer of Upper Wilpena Group sediments that had been deposited on the Stuart Stable Shelf. A stylization of the postulated depositional history is given in fig. 20, along with comparative stratigraphic columns for the Stuart Stable Shelf and Adelaide 'Geosyncline'. Evidence for the above postulation is provided by the fact that the remaining shelf sediments which are lateral Wilpena Group equivalents show an eroded upper surface, and the initial overlying deposits are conglomerates and grits containing boulders of feldspathic sandstone, dolomitic siltstones and red and green shales and siltstones (Johns, 1968), these elements corresponding to the "missing" Wilpena Group equivalents.

The volume of sediment required to create the allochthonous portion of the Parachilna Formation is calculated from fig. 19 to be in excess of 400 cubic miles (1,600 cubic km.). This volume of sediment could feasibly be derived from the stripping of an average of 200 feet (65m.) of Wilpena Group equivalents from 10,000 square miles (25,000 sq.km.) of shelf. If this were so, the first sediments to be eroded and redeposited would be the feldspathic sands and silts of the Pound Quartzite equivalent, giving rise to the basal Parachilna sands. The feldspar would have subsequently undergone weathering, forming the abundant clay minerals characteristic of Member 1 of the Parachilna Formation; the preferential weathering of Parachilna feldspar over 'Red' Pound feldspar could be a function of the relative porosities of the two units, as the intimate presence of water is necessary for the conversion of feldspars to clays (Krauskopf, 1967, p.191). Following the removal of the Pound equivalent, dolomitic silts (Wonoka equivalent) would have been stripped and redeposited in the basin to the east, giving rise to the silts of Members 2 and 3.

Differential rates of erosion on the shelf could explain the sands that appear higher in Parachilna sections; remnants of Pound equivalent could be eroded after the bulk of this unit had been removed from the shelf, or the late Parachilna sands could represent initial erosion of the Arcoona Quartzite. Alternatively, these anomalous sand bodies (e.g. the sands of Member 3 in Parachilna Nos. 1 and 2 sections) could be of local origin, such as deposition adjacent to a rising diapir, although the nearest exposed diapir to these sections is the Blinman Diapir, more than 5 miles (8km.) to the east.

One conceivable difficulty upsetting the above postulations is the disposal of the large quantities of Pound Quartzite, which, according to Wade (1970), were eroded prior to Parachilna deposition, as the variety of Parachilna sediments could not have been created by the reworking and redeposition in situ of Pound sand. Detailed sedimentological studies will have to be made to answer this problem, and to confirm or reject the above hypothesis of the provenance of Parachilna sediments.

VII. CONCLUSIONS.

The subdivision of the Parachilna Formation into three members on the basis of correlatable lithologies is an attempt to elucidate the depositional environment in terms of conditions within the basin of deposition and a postulated sediment source. It must be emphasised that no time significance can be attached to this lithological subdivision. Attempts to delineate time-lines are frustrated by one of the characteristics of trace fossils - their long time ranges. Time correlation by the "first appearance" of the diagnostic Diplocraterion can only be tentative, as the appearance of this form is dependent initially on a suitable substrate (sand) in a restricted environment (intertidal) and subsequently on preservation and textural differentiation. However, the widespread appearance of Diplocraterion at the very base of the Parachilna Formation is considered indicative of the contemporaneity of the initial transgressive sands. Non-appearance of Diplocraterion at the base of some sections (e.g. Angepena and Mundy Waters synclines, Wade, 1970) is probably a function of substrate material and consequent fossilization potentials rather than diachronous deposition, as the initial Parachilna sediments in these sections were shales.

The extensive bioturbation seen within the Parachilna Formation is a result of two diverse factors: firstly, the evolution of suspension feeding organisms by earliest Cambrian time and the maintenance of a sediment-ingesting fauna such as existed at Ediacaran time, and, secondly, the nature of the Parachilna sands, which enables weathering to differentiate biogenic structures. The massive beds of quartzite and indurated sandstone within the Pound Quartzite efficiently mask any bioturbation that may have occurred within the sediment at the time of its accumulation. Daily (1963) notes that extensive bioturbation of the Mt. Terrible Formation (assumed lateral equivalent of the Parachilna Formation in the southern portion of the Adelaide 'Geosyncline') leads to 'kraaksten' bedding, or a spotted appearance of the rock. The widespread bioturbation of basal Cambrian sands led Seilacher (1964b) to suggest that 'explosive' organizational differentiation of benthonic invertebrates occurred at earliest Cambrian time, and the evidence derived from the Parachilna Formation lends support to this hypothesis, with the evolution of sessile suspension-feeders and a continuance of vagile endobenthonic burrowers.

The palaeoenvironment of the Parachilna sands is considered to be the intertidal zone of a transgressive marginal sea, with variations at the sediment source and, possibly, fluctuations of sea level accounting for the deposition of finer clastic sediments. A shore line along the western edge of the basin of deposition is thought to have existed for a greater proportion of Parachilna time, while continued subsidence to the north and east resulted in thicker sequences and deeper water sediments. A westerly sediment provenance is proposed for the Parachilna clastics, in contrast to Wopfner (1970) who postulates the derivation of allochthonous Hawker Group sediment from the Olary Province to the southeast.

The notion of the Parachilna Formation as a "transition unit" between the Pound Quartzite and Wilkawillina Limestone is negated by the well-documented evidence of a disconformity at the top of the Pound, and obviated by the recognition that a transgressive unit does not replace an eroded regressive unit transitionally. However, within the Parachilna Formation itself a transition to the overlying strata is often developed, with oolitic and silty carbonate beds appearing in Members 2 and 3 of several sections prior to deposition of the massive sandy and oolitic Wilkawillina limestones. Carbonate deposition was probably initiated by tectonic stabilization of the basinal area and peneplanation of the Stuart Shelf, terminating the supply of clastic sediments.

The stratigraphy and palichnology of the Parachilna Formation allow some degree of palaeoenvironmental interpretation. Detailed sedimentological studies of this formation would enhance the above interpretation. However, it is hoped that this study has in some way added to the overall portrayal of the history of the Adelaide 'Geosyncline'.

* * *

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* * *

APPENDIX I.

LOCATION OF SECTIONS PLOTTED IN FIG. 19.

(Locations are tabulated as latitudes and longitudes e.g. 3036/13820 represents 30° 36' South, 138° 20' East.)

No.	NAME OF SECTION	LOCATION	THICKNESS (feet)	SOURCE
1	Mt. Scott	3036/13820	180	Segnit (1939)
2	Ediacara	3047/13809	40	Nixon (1964)
3	Red Range	3053/13821	40	Leeson (1970)
4	Nilpena	3059/13826	c. 80	Dalgarno (1964)
5	Parachilna No. 1	3107/13829	124	Ford
6	Parachilna No. 2	3108/13830	209	Ford
7	Motpena	3110/13817	0	Dalgarno & Johnson (1966)
8	Brachina	3121/13833	70	Ford
9	Bunyeroo	3125/13832	157	Ford
10	Mernmerna	3134/13825	130	Ford
11	Chace Range	3146/13834	c. 120	Ford
12	Druid Range	3145/13838	117	Ford
13	Wilson	3201/13822	c. 250	Daily (1956)
14	Arden Vale	3207/13802	80	Ford
15	Wilkatanna	3207/13750	c. 45	Thomson (1962)
16	Reaphook No. 1	3122/13917	3	Ford
17	Reaphook No. 2	3124/13918	80	F.M. Gaunt (pers. comm.)
18	Mt. Frome	3104/13912	25	Hatcher (1970)
19	Billy Creek	3116/13853	0	Dalgarno (1964)
20	Wirrealpa	3106/13858	0	Dalgarno (1964)
21	Nildottie	3103/13848	490	Ford
22	Stirrup Iron Range	3049/13905	500	Horwitz (1962)
23	Mt. Uro	3045/13900	>1400	Dalgarno (1962)
24	Arrowie	3043/13902	1200	Dalgarno (1964)
25	Mt. McKinley	3032/13904	>1400	Dalgarno (1962)
26	Nepabunna	3034/13859	1200	Dalgarno (1964)
27	Angepena	3034/13850	1200	Dalgarno (1964)
28	Wilpena Pound	3133/13833	175	Daily, Twidale & Alley (1969)

APPENDIX II.

DESCRIPTIONS OF HAND SPECIMENS FROM THE DRUID RANGE SECTION.

[Classification of clastic rocks based on that of Williams, Turner and Gilbert 1954: Petrography. Freeman & Co. pp. 289-297 and figs. 96, 97]

POUND QUARTZITE:

A365/5 Collected at the top of the Pound Quartzite.
A white rock with a saccharoidal texture and lacking bedding features. Predominantly subangular to well-rounded clear quartz grains with overgrowths developed. Medium to coarse grain size. Flecks of pink clay minerals in aggregates about the size of the quartz grains. Rare rounded black grains, possibly chert. Rock fractures around grains.
Composition: quartz 95%; clay 5%; rare?chert.
Classification: quartz arenite.

PARACHILNA FORMATION:

Member 1.

A365/6 Collected at the base of Member 1.
A very pale grey rock lacking bedding features. Subangular to rounded quartz grains, generally clear, but often grey or grey-green. Medium to coarse grained with occasional of 1.5 to 2.0mm. diameter. Pervasive matrix of white clay minerals. Very rare black grains of ? chert and red or grey rock fragments.
Composition: quartz 80%; clay minerals 20%.
Classification: quartz wacke.

Member 2.

A365/7 Collected 28 ft. (8.5m.) above Pound Quartzite.
Very pale grey-green fine grained bedded rock. Predominantly very pale grey silt, with thin brown mud layers accentuating bedding. Weathers into white chips. The dominant rock type of Member 2.
Composition: silt-sized quartz 95%; clay minerals 5%.
Classification: fine-grained siltstone.

A365/8 Collected 36 ft. (11m.) above Pound Quartzite.
A white rock with no bedding features. Predominantly rounded to well-rounded medium to coarse grained quartz, clear, yellow or grey. Scattered specks of white clay minerals, coating quartz grains.
Composition: quartz 90%; clay minerals 10%.
Classification: quartz wacke.

A365/9 Collected 38 ft. (12m.) above Pound Quartzite.
An indurated, well-sorted grey rock. Rounded to well-rounded coarse grained quartz, grey in colour, with the occasional grain up to 2mm. in diameter. The quartz grains are coated with white clay minerals.
Composition: quartz 95%; clay minerals 5%.
Classification: quartz arenite.

A365/10 Collected 55 ft. (17m.) above Pound Quartzite.
A compact white rock, lacking bedding. Predominantly fine to medium grained clear quartz, subangular to rounded, with a few coarser grains of rounded quartz. A pervasive matrix of white clay minerals, with occasional small lenses (up to 5mm.) of compacted clay.

Composition: quartz 75%; clay minerals 25%.

Classification: clay-rich quartz wacke.

<u>Member 3.</u>

A365/11 Collected 64 ft. (19.5m.) above Pound Quartzite.
A very pale grey-green fine grained rock with weakly developed bedding and a characteristic conchoidal fracture. Initially a fine grained quartz arenite, grading into a greyish siltstone and then into a grey-green fine grained laminated siltstone.

Composition: Almost totally quartz (fine grained sand to fine grained silt); minor clay.

Classification: siltstone, fining upwards.

A365/12 Collected 70 ft. (21.5m.) above Pound Quartzite.
Pale yellow-grey fine grained rock with no bedding features. Predominantly quartz of very fine grain size, with a clay matrix. Tends to homogeneous silt in parts. A few black grains, possibly chert.

Composition: quartz 90%; clay 10%; rare chert.

Classification: fine grained quartz wacke.

A365/13 Collected 92 ft. (28m.) above Pound Quartzite.
A whitish rock with brown, yellow and purple patches. A fine grained sandstone with a slightly calcareous matrix in addition to the characteristic clay content. Variable staining (brown and purple) due to mangano-ferruginous oxides. No bedding visible.

A365/14 Collected 98 ft. (30m.) above Pound Quartzite.
A compact, indurated pinkish rock with no bedding visible. Almost entirely fine to medium grained clear quartz with overgrowths. Specks of white clay minerals, often weathered out. From a thin bed in Member 3.

Composition: quartz 98%; clay 2%.

Classification: pure quartz arenite.

A365/15 Collected 105 ft. (32m.) above Pound Quartzite.
A dense, vuggy red, purple and black rock, collected in a zone of intense mangano-ferruginous invasion. This fine grained rock is probably composed almost entirely of Mn and Fe oxides, with minor silt patches unaffected by the mineralization.

Classification: mangano-ferruginous siltstone.

A365/16 Collected 115 ft. (35m.) above Pound Quartzite.
A bedded, fine grained yellow rock. Predominantly fine grained quartz silt, with oxide staining giving a colour differentiation. Typical of the upper portion of Member 3.

Classification: siltstone with oxide staining.

<u>WILKAWILLINA LIMESTONE:</u>

A365/17 Collected at base of Wilkawillina Limestone, 117 ft. (36m.) above Pound Quartzite.
A dense carbonate rock with solution cavities and black oxide staining. Finely crystalline and reddish and grey-green in colour. Slightly silty.

Composition: calcite 95%; quartz 5%.

Classification: limestone.

MEASURED STRATIGRAPHIC SECTIONS – PARACHILNA FORMATION

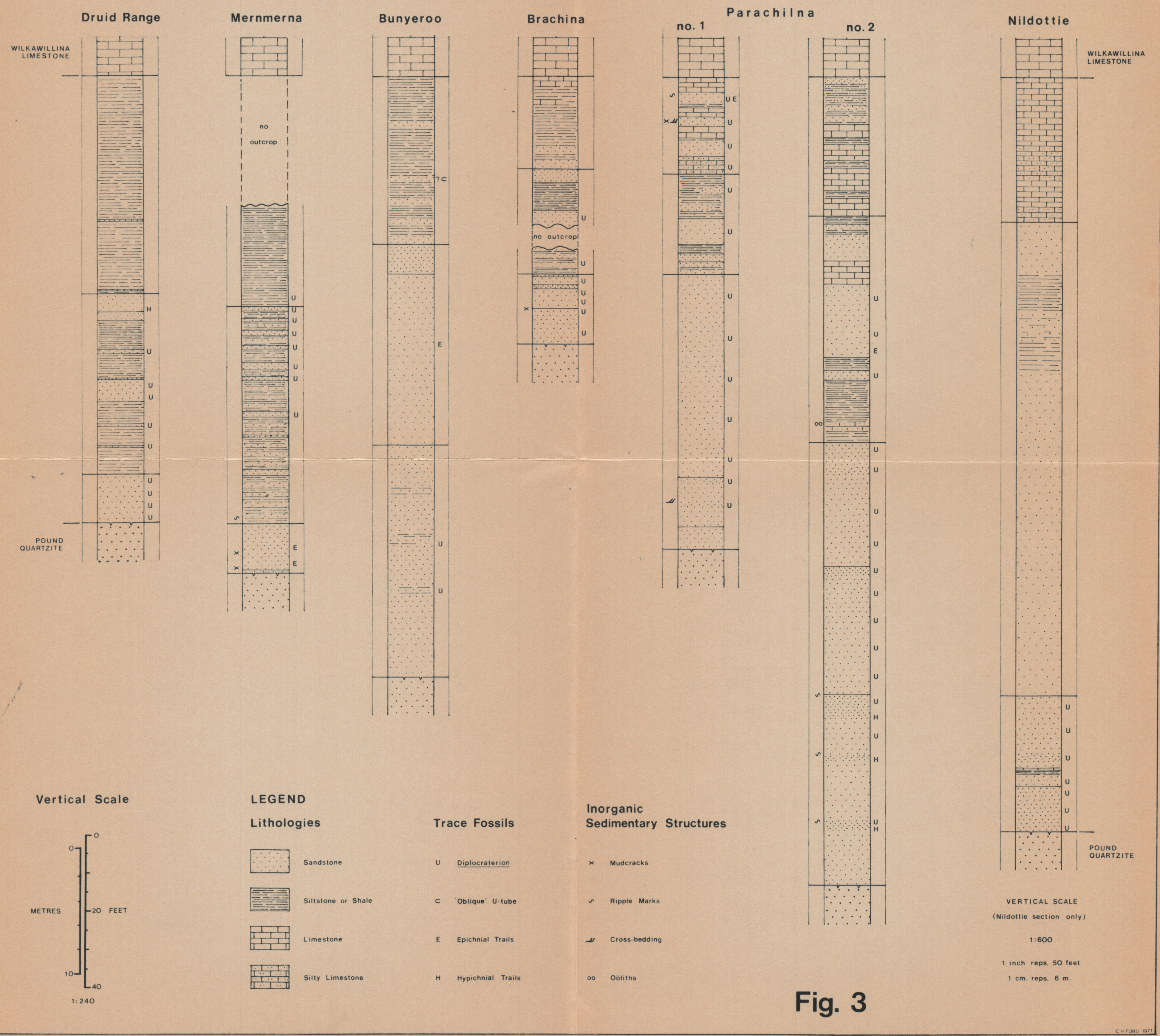

Fig. 3

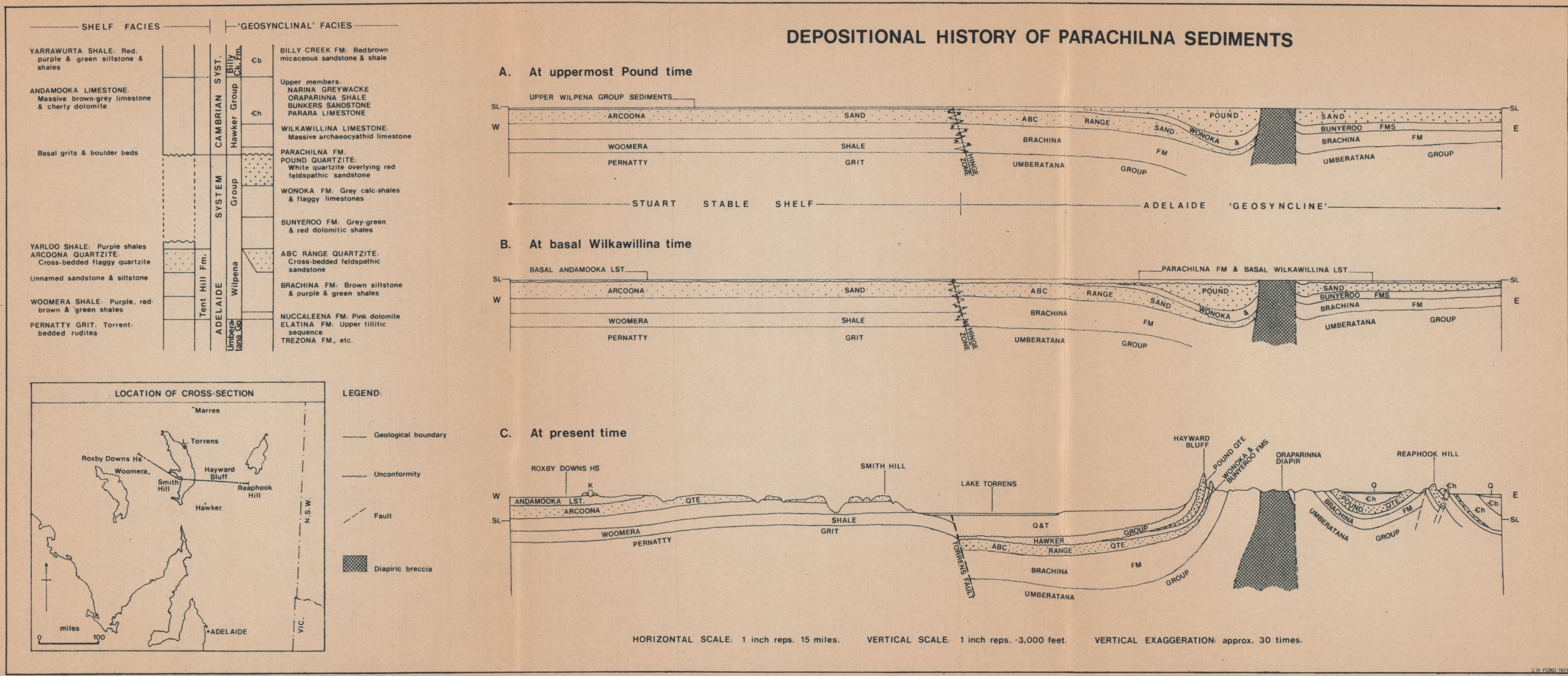
DEPOSITIONAL HISTORY OF PARACHILNA SEDIMENTS
SHELF FACIES
'GEOSYNCLINAL' FACIES
YARRAWURTA SHALE: Red, purple & green siltstone & shales
ANDAMOOKA LIMESTONE: Massive brown-grey limestone & cherty dolomite
Basal grits & boulder beds
YARLOO SHALE: Purple shales
ARCOONA QUARTZITE: Cross-bedded flaggy quartzite
Unnamed sandstone & siltstone
WOOMERA SHALE: Purple, red-brown & green shales
PERNATTY GRIT: Torrent-bedded rudites
CAMBRIAN SYST.
ADELAIDE SYSTEM
Tent Hill Fm.
Billy Ck. Fm.
Hawker Group
Wilpena Group
Umberatana Gp
€b
€h
BILLY CREEK FM: Redbrown micaceous sandstone & shale
Upper members: NARINA GREYWACKE ORAPARINNA SHALE BUNKERS SANDSTONE PARARA LIMESTONE
WILKAWILLINA LIMESTONE: Massive archaeocyathid limestone
PARACHILNA FM.
POUND QUARTZITE: White quartzite overlying red feldspathic sandstone
WONOKA FM: Grey calc-shales & flaggy limestones
BUNYEROO FM: Grey-green & red dolomitic shales
ABC RANGE QUARTZITE: Cross-bedded feldspathic sandstone
BRACHINA FM: Brown siltstone & purple & green shales
NUCCALEENA FM: Pink dolomite
ELATINA FM: Upper tillitic sequence
TREZONA FM., etc.
LOCATION OF CROSS-SECTION
Marree
L. Torrens
Roxby Downs Hs
Woomera
Smith Hill
Hayward Bluff
Reaphook Hill
Hawker
ADELAIDE
N.S.W.
VIC.
miles
0
100
LEGEND:
Geological boundary
Unconformity
Fault
Diapiric breccia
A. At uppermost Pound time
UPPER WILPENA GROUP SEDIMENTS
SL
W
E
ARCOONA
SAND
WOOMERA
SHALE
PERNATTY
GRIT
HINGE ZONE
ABC
RANGE
SAND
POUND
SAND
BUNYEROO
FMS
BRACHINA
FM
WONOKA &
UMBERATANA
GROUP
STUART STABLE SHELF
ADELAIDE 'GEOSYNCLINE'
B. At basal Wilkawillina time
BASAL ANDAMOOKA LST.
PARACHILNA FM & BASAL WILKAWILLINA LST.
C. At present time
ROXBY DOWNS HS
K
SMITH HILL
LAKE TORRENS
HAYWARD BLUFF
POUND QTE
WONOKA & BUNYEROO FMS
ORAPARINNA DIAPIR
REAPHOOK HILL
ANDAMOOKA LST.
QTE
Q&T
HAWKER
GROUP
ABC
RANGE
QTE
TORRENS FAULT
Q
€h
€b
HORIZONTAL SCALE: 1 inch reps. 15 miles.
VERTICAL SCALE: 1 inch reps. -3,000 feet.
VERTICAL EXAGGERATION: approx. 30 times.
C.H. FORD 1971

Fig. 20