THE UNIVERSITY OF ADELAIDE

ENVIRONMENTAL ANALYSIS OF THE LATE PRECAMBRIAN APPILA TILLITE EQUIVALENT AT DEPOT FLAT, SOUTHERN FLINDERS RANGES, SOUTH AUSTRALIA.

BY

David L. Hopton, B.Sc.

November, 1983

3.

ENVIRONMENTAL ANALYSIS OF THE LATE PRECAMBRIAN APPILA TILLITE EQUIVALENT AT DEPOT FLAT, SOUTHERN FLINDERS RANGES, SOUTH AUSTRALIA

National Grid Reference 1:100,000
S1 53/6433

by

David L. Hopton, B.Sc.

This thesis is submitted as partial fulfilment of the requirement for the Honours Degree of Bachelor of Science in Geology at the University of Adelaide.

Submitted November, 1983.

ABSTRACT

The Appila Tillite Equivalent at Depot Flat near Quorn in the southern Flinders Ranges belongs to the younger phase of Sturtian glaciation recorded in the sediments of the Adelaide Geosyncline. This glacial sequence rests unconformably on a regolith formed on Burra Group sediments and consists of 112 to 146 metres of bedded and massive diamictites interbedded with sandstones and lesser amounts of conglomerates, breccias and laminated shales containing dropstones. Lenticular units of pebbly and non-pebbly ankeritic dolomites are concentrated near the top of the sequence and probably represent deposition in small saline lakes formed during deglaciation.

A prominent varve unit containing till pellets and dropstones can be traced laterally across the map area for approximately one kilometre. It occurs near the base of the glacial sequence and records a period of glaciolacustrine sedimentation probably resulting from temporary damming of the area by glacial ice.

The marked dissimilarity between closely spaced stratigraphic sections testifies to rapid lateral and vertical facies changes. Evidence from these rapid transitions and the association of diamictites with dropstone laminates, varves, ankerites and coarse clastics suggests that the environment of deposition was proglacial to ice-contact superimposed on shallow marginal marine conditions. The tectonic setting was probably that of a labile shelf thus representing a continuation of this type of setting from preglacial times.

Approximately 75% of the clasts were derived from the sediment of the underlying Burra Group and extrabasinal lithologies such as granites, metamorphics and volcanics were probably derived from the basement rocks of the Gawler Craton to the west.

The presence of a disconformity separating the glacial sequence from the post-glacial Tapley Hill Formation is suggested by the removal of some of the upper beds in the glacial sequence.

The newly discovered volcanic tuff unit which occurs very near to or at the top of the glacial sequence is a useful marker horizon, however, it's presence may be of far greater importance. The similarities in stratigraphic position and lithology with the Beda Volcanics, dated at 1076± 34Ma, suggest a possible correlation. If this correlation proves correct, the age of the Sturtian Tillites would be set back approximately 350 million years.

ACKNOWLEDGEMENTS

I especially wish to thank my supervisor Dr. Brian Daily for initiating this project and also for his assistance and encouragement throughout. The helpful contributions from Dr. Victor Gostin are also gratefully acknowledged. The writer is also indebted to the technical staff for their efficiency and professional attitude.

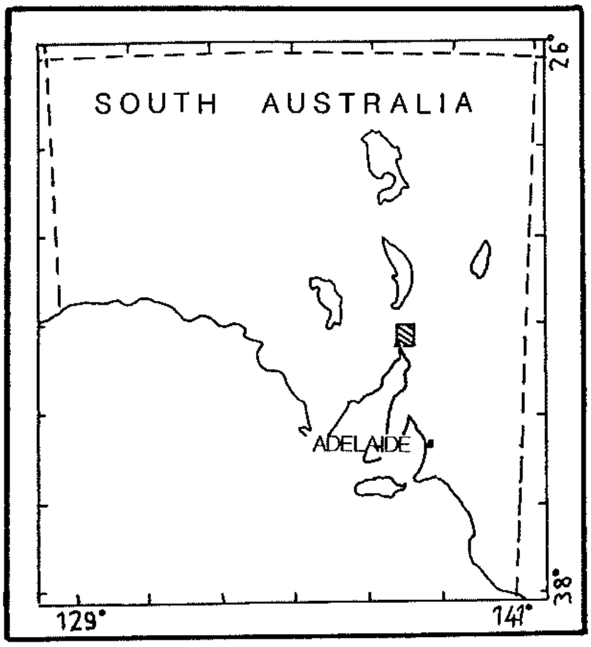
Sincere thanks are also due to my family, in particular my mother who did all the typing and Kevin Fitzgerald of Arden Vale Station for his hospitality. Aerial photographs were supplied by the Geology Department.

TABLE OF CONTENTS

FIGURES and TABLES

PLATES

LOCALITY MAPS DEPOT FLAT AREA



ENLARGEMENT

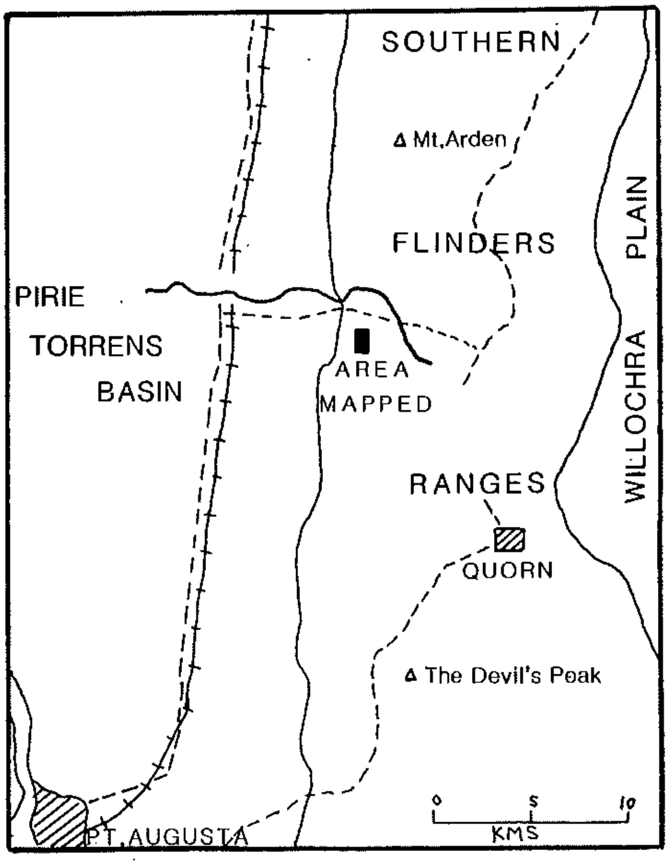


Figure 1.

CHAPTER 1 : INTRODUCTION

The Appila Tillite Equivalent (Thomson et al., 1964) forms part of a relatively thin but laterally continuous stratigraphic horizon of glacigenic sediments deposited as a second, younger phase of glaciation during Sturtian time over much of the area of the Adelaide Geosyncline and locally on the Stuart Shelf.

West of Quorn in the southern Flinders Ranges, the Appila Tillite Equivalent, hereafter referred to as the glacial sequence, occurs as a thin unit (up to 146 metres thick in the map area) trending roughly north - south near the margin of the western scarp of the Flinders Ranges, which owes its high relief to late Cenozoic block faulting.

The rugged, youthful topography and plentiful vegetation has contributed to generally poor exposure of the glacial sequence making detailed mapping very difficult. Much of the work carried out between May and August 1983 was concentrated on measuring and describing stratigraphic sections through the glacial sequence in areas of best exposure (usually creeks). A 2 metre staff was used for measuring the sections.

The area mapped (see Figure 2) follows the glacial sequence approximately two kilometres along strike and is fault bounded in the south near Thompson Gap. North of Section 5 another major fault is inferred to cut the sequence. Apart from minor faulting, the rocks within the map area are not complicated by structure; all the sediments dip moderately eastwards. Although the sediments are unmetamorphosed, the development of a persistent cleavage tends to obscure primary features of the sediments.

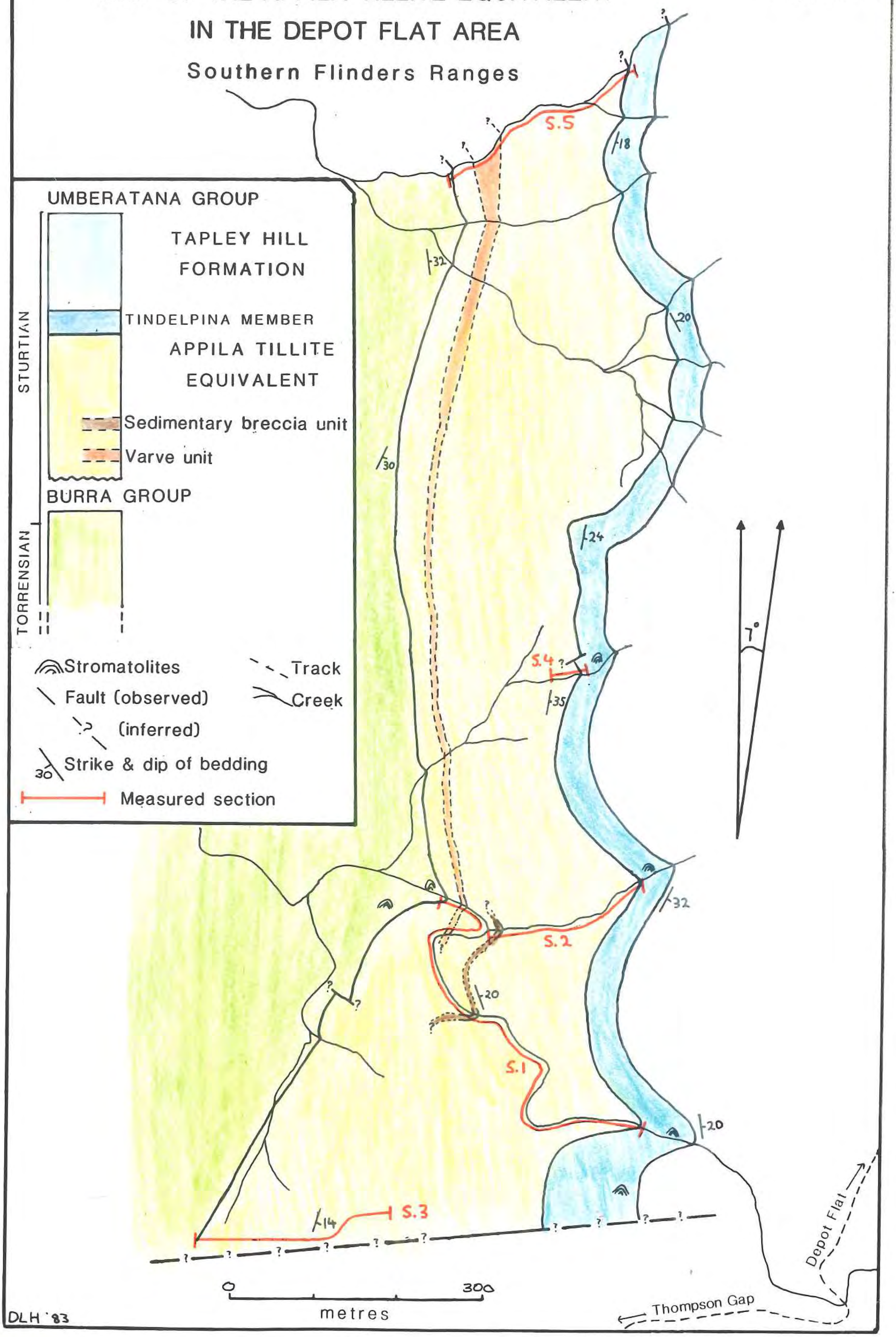
The purpose of this study was to describe in as much detail as possible, the various sediments in the glacial sequence and to reconstruct sedimentary conditions at the time of deposition using the latest available models and other information on the interpretation of ancient sediments of this type.

A comparison between the Appila Tillite Equivalent at Depot Flat and its temporal equivalents, the Merinjina Tillite (Copley area) and the Sturt Tillite (Sturt Gorge), both recently described by Link (1977) is also attempted.

Figure 2.

MAP OF THE APPILA TILLITE EQUIVALENT IN THE DEPOT FLAT AREA

Southern Flinders Ranges



Stratigraphy : Younger Sturtian glacigenic successions

The late Proterozoic (late Precambrian) sediments of the Adelaide Geosyncline record the occurrence of two major glaciations. In a time-stratigraphic subdivision of the Adelaide Geosyncline, the younger glaciation is assigned to Marinoan time (c. 690-680 Ma) and is separated from the older Sturtian glaciation (c. 800-790 Ma) by a thick interglacial sequence of around 3,000 metres (Coats, 1981). The lithostratigraphic subdivision of the Adelaidean strata, first proposed by Thomson et al., (1964), places all the glacigene and interglacial sediments of the Adelaide Geosyncline in the Umberatana Group of Sturtian to early Marinoan age.

The older Sturtian glacials are currently thought to register two distinct phases of glaciation (Coats and Forbes, 1977) although this is disputed by Murrell et al., (1977). The evidence for this according to Coats and Forbes (1977) is the diagnostic occurrence of red-purple quartzites and to a lesser degree red porphyries in the younger Sturtian glacigenic successions indicative of different provenances for the two phases. There is also evidence to suggest a probable regional unconformity separating these phases.

The older of the two Sturtian glacigenic successions, which include the thick Bolla Bollana and Pualco Tillites has been formally defined as the Yudnamutana Subgroup (Thomson et al., 1964).

The younger Sturtian glacigenic successions (Coats, 1981) have a wide geographical distribution in the Adelaide Geosyncline and include such units as the Sturt Tillite in the Adelaide region, the Appila Tillite in the Southern Flinders Ranges, the Merinjina Tillite in the northern Flinders Ranges and the Calthorinna Tillite in the Peake and Denison Ranges. The sequences have lower contacts with either older tillites, Burra Group or Callanna Beds sediments that are on a regional scale, a slight angular unconformity or disconformity. The upper boundary is marked by the sharply disconformable or conformable contact with the sediments of the post glacial Tapley Hill Formation. The base of this thick sequence of finely laminated silts and shales is characterised by the presence of the thin but persistent Tindelpina Shale Member comprised of interbedded laminated carbonates and black, pyritic and carbonaceous shales.

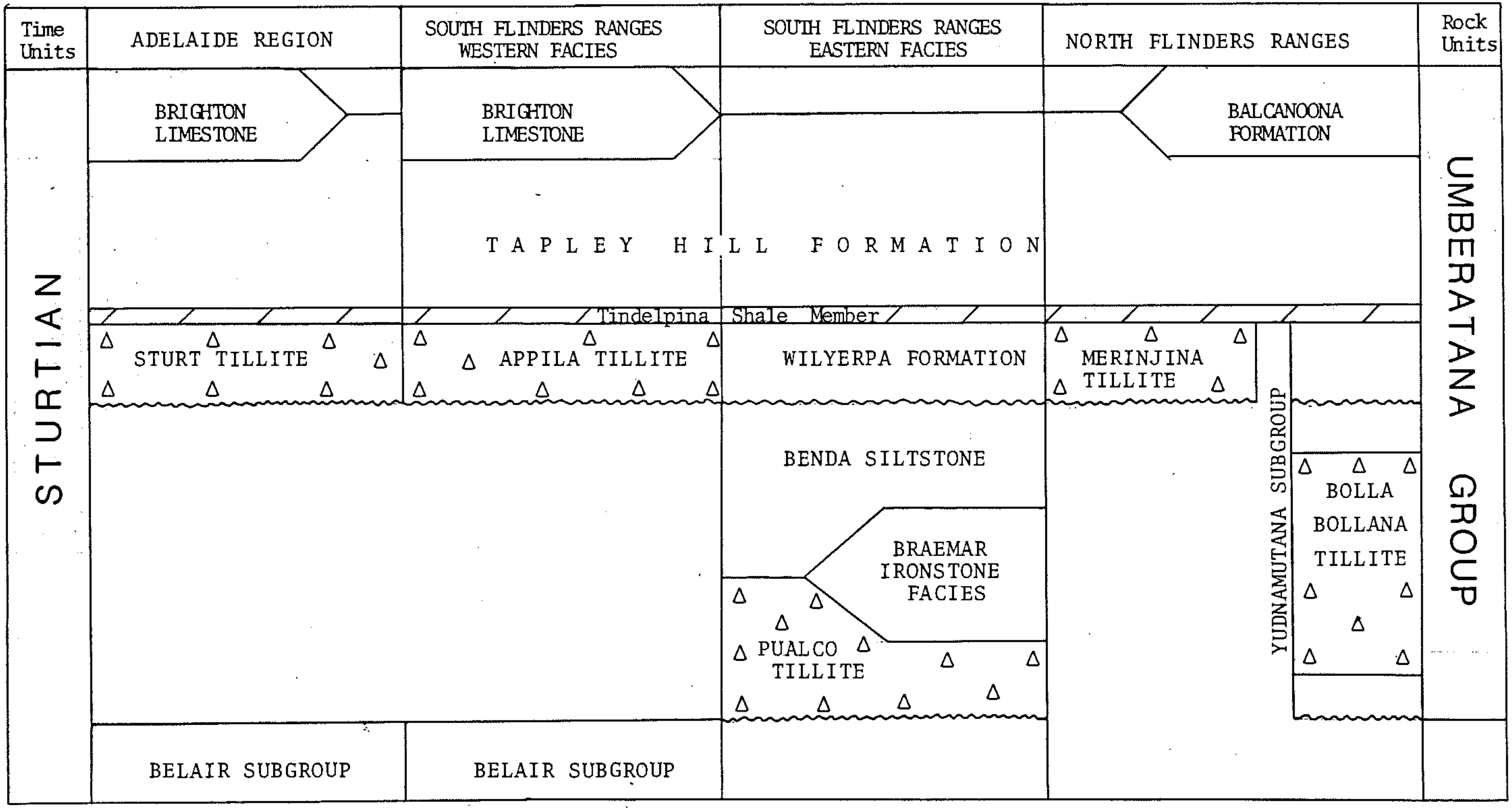


Figure 3. Simplified time-rock diagram showing the stratigraphic setting of both younger and older Sturtian glacigenic successions in the Adelaide Geosyncline. Modified from Rutland *et. al.* (1981).

Regional Geology

General

The region around Depot Flat near Quorn in the southern Flinders Ranges is well known for exposure of the basal units of the Late Precambrian sediments deposited in the Adelaide Geosyncline.

The view westwards from the western scarp of the Flinders Ranges in this area clearly demonstrates the tectonic controls of sedimentation from the Late Precambrian to the present day. The prominent flat topped mesas seen in the western distance consist of thin Adelaidean sediments capped by Tertiary silcrete and record stable platformal sedimentation marginal to the geosyncline on the Stuart Shelf.

The Stuart Shelf and the Adelaide Geosyncline are separated by the Torrens Hinge Zone, a narrow tectonic zone trending north - south here, bounded on the west by the Torrens Lineament and by a fault system on the east. The Adelaidean strata in the Torrens Hinge Zone were slightly deformed by the Cambro-Ordovician Delamerian Orogeny and record the transition between the rocks of the Stuart Shelf, relatively undeformed by this orogeny and the rocks of the Adelaide Geosyncline which were relatively strongly deformed.

The present geomorphology of the area is mainly due to Cenozoic tectonics. The Torrens Hinge Zone was the sight of Cenozoic graben structures complementary to the uplift of the ranges to the east (Rutland *et al.*, 1981). Lake Torrens now occupies a large part of these lowlands west of Depot Flat and extensive alluvial fans extend westwards from the uplifted western scarp of the ranges.

Geology of the Preglacial Sequence*

Callanna Beds

The oldest known Adelaidean sediments in the Depot Creek area, the Callanna Beds, form a sequence of red and purple dolomitic siltstones and sandstones about 90 metres thick. The sediments are laminated, flaggy to medium bedded and sedimentary structures include lenticular bedding, edgewise breccia, ripple marks, mudcracks, load casts and rare halite casts. These features and the lithology of the sediments are suggestive of a shallow water, evaporitic environment which was subjected to periods of subaerial exposure.

This sequence is overlain by reddish - grey amygdaloidal volcanics, known as the *Depot Creek Volcanics*, which range in thickness between 90 and 230 metres in the area. The lower contact is sharply conformable on a thin tuffaceous bed. The greater part of the volcanic sequence is composed of very vesicular and amygdaloidal rocks interpreted as a sequence

---

* Unless otherwise referenced, most of the information contained in this section is after Forbes *et al.*, (1982 pp. 37-40 and 51-53.)

of subaerial lava flows. The volcanics are best described as altered trachytic basalts and are correlated with petrologically similar volcanics of Willouran age elsewhere in the Adelaide Geosyncline (e.g. the Wooltana Volcanics). These volcanics, some of which occur in disrupted and diapiric sequences, are known to occur over an area of about 250,000 square kilometres. According to Rutland et al., (1981) these volcanics represent the widespread extrusion of flood basalts during a phase of tensional rifting early in the history of the Adelaide Geosyncline. The Depot Creek Volcanics are also currently correlated with the Beda Volcanics on the eastern Stuart Shelf.

Burra Group

There is as yet inconclusive evidence that the contact between the Callanna Beds and the Burra Group may be a regional unconformity throughout the Adelaide Geosyncline. The nature of the contact at Depot Creek provides some evidence of an unconformity as the basal Emeroo Quartzite overlies an erosional surface on the volcanics. The volcanics immediately below the contact are bleached and volcanic fragments are reworked into a coarse basal conglomerate at the base of the Emeroo Quartzite.

The Emeroo Quartzite here is largely composed of medium to thick-bedded medium-grained feldspathic quartzite which varies in colour from purple near the base to pale red and grey higher in the sequence. Tabular and trough crossbedding and ripple marks are developed locally. Preiss and Sweet (1966) mapped thicknesses of between 360 and 700 metres for this unit in the Depot Creek area.

The deposition of the Emeroo Quartzite is part of a postulated widespread trangressive clastic sedimentation event with sediment derived from the adjacent Gawler Craton entering the geosyncline probably as a series of easterly prograding deltaic complexes (Rutland et al., 1981).

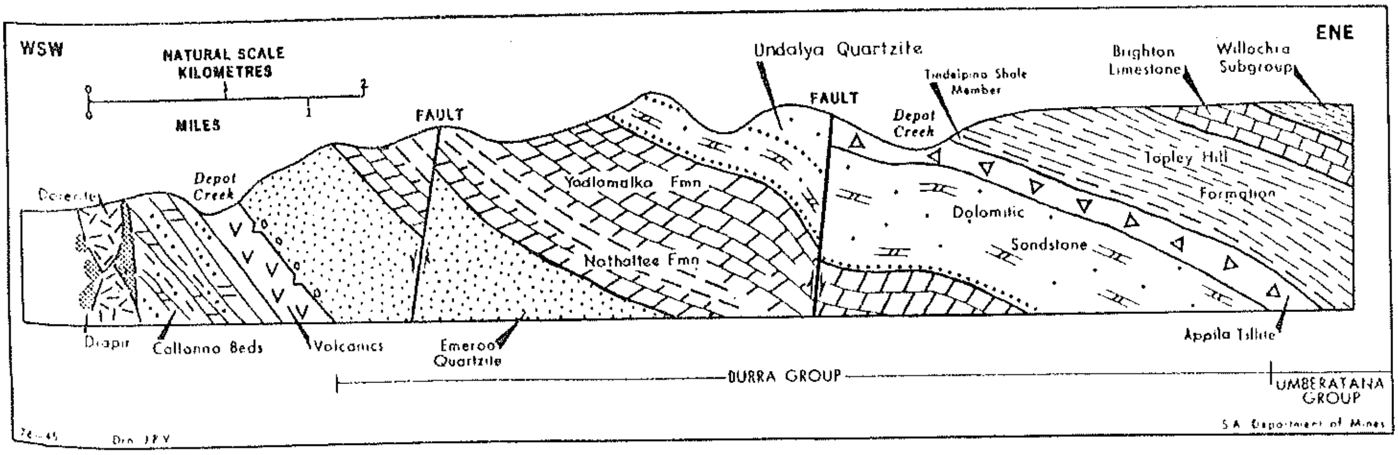
The overlying Mundallio Subgroup (Uppill, 1979) records a period of widespread carbonate shelf sedimentation characterized by the deposition of primary dolomite without limestone, sedimentary magnesite and diagenetic black chert (Rutland et al., 1981).

In the Depot Creek area, the Mundallio Subgroup is approximately 380 metres thick and it is divided into two formations. The lower Nathaltee Formation contains a higher proportion of clastic sediments than the overlying Yadlamalka Formation which is also notable for abundant sedimentary magnesite. Both formations consist predominantly of laminated dolomite displaying many features of shallow water sedimentation such as desiccation cracks, teepee structures, intraformational conglomerate and stromatolites.

All the available evidence suggests that deposition took place under very shallow basinal conditions that were either restricted marine (lagoonal) or alternatively lacustrine. The sediments were also subjected to periodical subaerial exposure.

A gradual increase in the influx of clastics marks the upward transition into the Undalya Quartzite. In the Depot Creek area, this unit varies in thickness between approximately 100 and 250 metres and consists largely of pale to medium grey dolomitic sandstones (Preiss and Sweet, 1966).

In Depot Creek this unit is faulted against the overlying Appila Tillite Equivalent, however, in the present map area this unit appears to be absent with the glacial sequence unconformably overlying beds of Mundallio Subgroup lithologies.



Geological section along Depot Creek (near Depot Flat); after Forbes et. al., 1982.

Previous Investigation of the glacial sequence, Depot Flat area.

The first published report on the geology in the vicinity of Depot Flat was by Howchin (1928) titled "The Sturtian Tillite and Associated Beds on the Western Scarp of the Southern Flinders Ranges." He examined sections at Pichi Richi Pass, Devils Peak, Dutchmans Stern, Mundallio Creek and in the upper part of Depot Creek (several kilometres north of Depot Flat).

Howchin observed approximately 600 feet (180 m) of Sturtian Tillite in Depot Creek striking north - north westerly and dipping moderately eastwards. He described the tillite as predominantly composed of gritty mudstones, coarse grits, siliceous slate, quartzites and breccias with prominent clast lithologies being quartzites, quartz, slates, chert and muscovite granite. These were mostly angular and reached up to 2 feet in diameter.

In 1947, Mawson published a discussion on the Adelaide Series rocks of the Western Margin of the Flinders Ranges. He measured a section at Mundallio Creek (23 kilometres south - southwest of Depot Flat). Mawson's glacigene sequence (Units 17, 18) can be related to Howchin's Sturtian Tillite seen at this locality in 1928.

Bottom: Units		Thickness (ft.)
17 (a)	True tillite, quite unsorted containing erractics, also fragments of chert and dolomite of the underlying series. With some intercalated bands of morainic mud	62
(b)	Finer grained, fluvioglacial beds more firmly cemented and resistant in the upper section.	200
(c)	Irregular sand intercalations (each a few yards across) ramifying through the more regularly distributed fluvioglacial sediments	13
(d)	Sandy tillite passing upwards into typical tillite for a few yards in thickness then reverting to fluvioglacial sediments	25
18 (a)	Fluvioglacial, well laminated slates	539
(b)	Slate (rock flour type) poorly laminated	167
Series of Glacial and Glacigene sediments		1006 (307m)

In a general review of these sediments, Mawson (1947, p.272) commented on the variable thickness of the glacigene beds and concluded that the irregularity was due mainly to glacial erosion of the underlying beds. He summarized the main depositions (facies) as true tillite, bedded fluvioglacial mudstones with or without embedded erractics and some interglacial bedded erractics and some interglacial bedded arenaceous and argillaceous sediments, which are on occasions typically varved.

A subsequent regional study relevant to the Depot Flat area was carried out by Preiss and Sweet (1966) who mapped the geology of the Depot Creek area including the tillite sequence at Depot Flat.

The authors defined the "Tillite Sequence" as the basal unit of the Sturt Group overlain conformably by the Tapley Hill Formation. No evidence for an unconformable contact with the underlying Burra Group sediments was found although beds below the contact varied in lithology.

Their sequence consisted of a basal massive tillite 50 - 100 feet thick overlain by sandstones, laminated varve-like siltstones, dolomites, gritty sandstones and sedimentary breccias. The existence of stromatolites in the dolomite interbeds, indicative of shallow water conditions and the lenticular breccias and grits were thought to be of fluvioglacial origin by the authors. The largest boulder recorded in the sequence was a coarse grained granite, 10 feet in diameter, set in a clay matrix.

The sediments of the glacial sequence at Depot Creek were described as predominantly clastic by Forbes et al., (1982) with the exception of interbeds of dolomites (some clast rich) which occur near the top of the sequence. An increase in the frequency of sandstone and conglomerate towards the top of the formation was thought to represent the deposition of clastics winnowed and reworked from earlier deposited glacigenes.

The glacial sequence at Depot Flat is included in the AUGUSTA 1 : 250,000 sheet (Dalgarno et al., 1968) which is mapped as the Appila Tillite Equivalent.

Discussion

The contributions of Howchin and Mawson to the present knowledge of the glacial sequence in the Depot Flat area are probably viewed best from a historical perspective.

Nevertheless, Howchin recognized the presence of dolomites both intercalated and capping the glacial sequence (he called them limestones) and also suggested that an unconformity existed between the tillite and the underlying beds based on the presence of erratics of black chert in the glacigene sediments.

Mawson's sequence at Mundallio Creek is unusual due to it's great thickness, and a comparison with Howchin (1928) reveals that Mawson seems to have included part of the overlying Tapley Hill Formation in his calculations. Howchin's 300 ft. is considered by the present author as the more correct thickness.

This study substantiates many of the general features of the glacial sequence observed by Preiss and Sweet (1966).
These features include:

a) absence of striated clasts
b) lenticular nature of beds
c) variations in thickness of the glacial sequence
d) presence of rounded cobbles and boulders of white granite
e) presence of varves
f) presence of pebbly and clast-free dolomites especially near the top of the sequence (ankerites in this study)
g) presence of lenticular sedimentary breccias
h) varied lithologies at the base of the sequence including siltstones and sandstones

However, there are some features that have not been observed from the glacial sequence by the present author. For example the actual tillite is described by Preiss and Sweet as a thick basal unit up to 100 feet thick. In the present map area the author has noted that diamictites occur at various levels in the sequence and that a thick section of diamictite is only seen at the base in one section. Preiss and Sweet also stated that bedding was rarely observed in the tillite. My investigations reveal that the opposite is true.

Examination of the ankerite beds in the map area has also revealed the absence of stromatolites within the sequence however this in no way invalidates the presence of stromatolites elsewhere in the area. In fact stromatolites capping the glacial sequence in Section 1 of the map area are not seen elsewhere.

Preiss and Sweet concluded that there was insufficient evidence to determine whether the tillite was deposited from grounded or floating ice. Coarse clastics in the sequence were interpreted as products of reworking of the tillite under mainly fluvial conditions and the presence of stromatolites were thought to indicate shallow, possibly marine conditions. The position of the ice-front was judged to be possibly proximal due to the "extreme homogeneity and angularity of clastic material".

Forbes _et al._, (1982) concluded that this sequence was probably deposited in a glaciomarine environment analogous to that surrounding Antartica today.

CHAPTER 2 : STRATIGRAPHY

Lower Boundary

The nature of the base of the glacial sequence in the vicinity of Depot Flat has long been of interest to previous investigators. Howchin (1928) first suggested the possibility of an unconformity based on the presence of erratics of black chert in the glacigene sediments which are also known to occur in the underlying Mundallio Subgroup.

Segnit (1939) recognized an unconformity at the base of the glacial sequence in the Mundallio Creek area using three main lines of evidence;

a) existence of variable lithologies below the contact in different locations

b) absence of indentation on the upper surface of the underlying beds by boulders in the tillite, hence these beds were consolidated prior to glaciation

c) boulders in the basal beds of the tillite were well rounded by water action.

The contact in Mundallio Creek itself has been described by both Segnit (1939) and Mawson (1949b) as an erosional surface.

Although Preiss and Sweet (1966) found no evidence for an erosional surface or angular unconformity in the Depot Creek area, they noted that the beds below the contact varied in lithology. One of these types, seen in the southern part of their map area, was described as a "lenticular bed of yellow weathering dolomite".

It now appears that this bed may in fact be a regolith representing a period of subaerial weathering prior to the onset of glaciation (Dr. B. Daily, pers.comm.) This regolith is best exposed in Section 1 of the present map area where about one metre of yellow, well indurated pebble to cobble rubble consisting mainly of stromatolitic dolomite rock fragments overlies a lithologically similar horizon of stromatolitic dolomite.(see plate 1.). The angularity of the clasts and the unsorted nature of the regolith suggests that weathering took place mainly in situ. The yellow colour is possibly due to bleaching of the originally dark grey dolomite during weathering.

Recognition of the regolith elsewhere in the map area is made difficult by several factors. Firstly, by its nature, the composition of the regolith largely depends on the lithology of the underlying beds, which are known to vary across the map area. For example, in the northern part of the map area, a high percentage of black chert in the regolith suggests that the underlying beds (not exposed) contain chert horizons. Another factor is that, after formation, the regolith may have been modified or even completely removed by subsequent erosion. Evidence for this is found in some parts of the map area where the regolith is either thin and conglomeratic or apparently absent. Lastly, failure to recognize the presence of the regolith may be attributed to poor exposure of the contact.

Any combination of these factors may explain why a regolith has not been previously reported from the basal contact of the glacial sequence in this area or from any of the other younger Sturtian glacigenic successions.

Another possibility is that other areas may not have been uplifted and subaerially exposed for the length of time needed to form a regolith, however, evidence of a widespread slightly angular unconformity or disconformity between the glacials and either older tillites, the Burra Group or Callanna Beds (Coats, 1981) suggests that such a possibility is fairly remote. There is ample evidence of tectonic activity prior to, and early in the deposition of Sturtian glacigenes in the Adelaidean Geosyncline (e.g. Binks, 1971; Link, 1977; Rutland et al., 1981)

The preservation of a regolith and the absence of a glacial pavement at Depot Flat both testify that grounded ice did not enter this area at the start of glaciation. In fact, the presence of laminated shales containing dropstones overlying the regolith in Section 1 suggests that the area was subjected to flooding immediately prior to glaciation. A possible cause of this postulated event may have been isostatic depression due to ice build up on adjacent exposed areas.

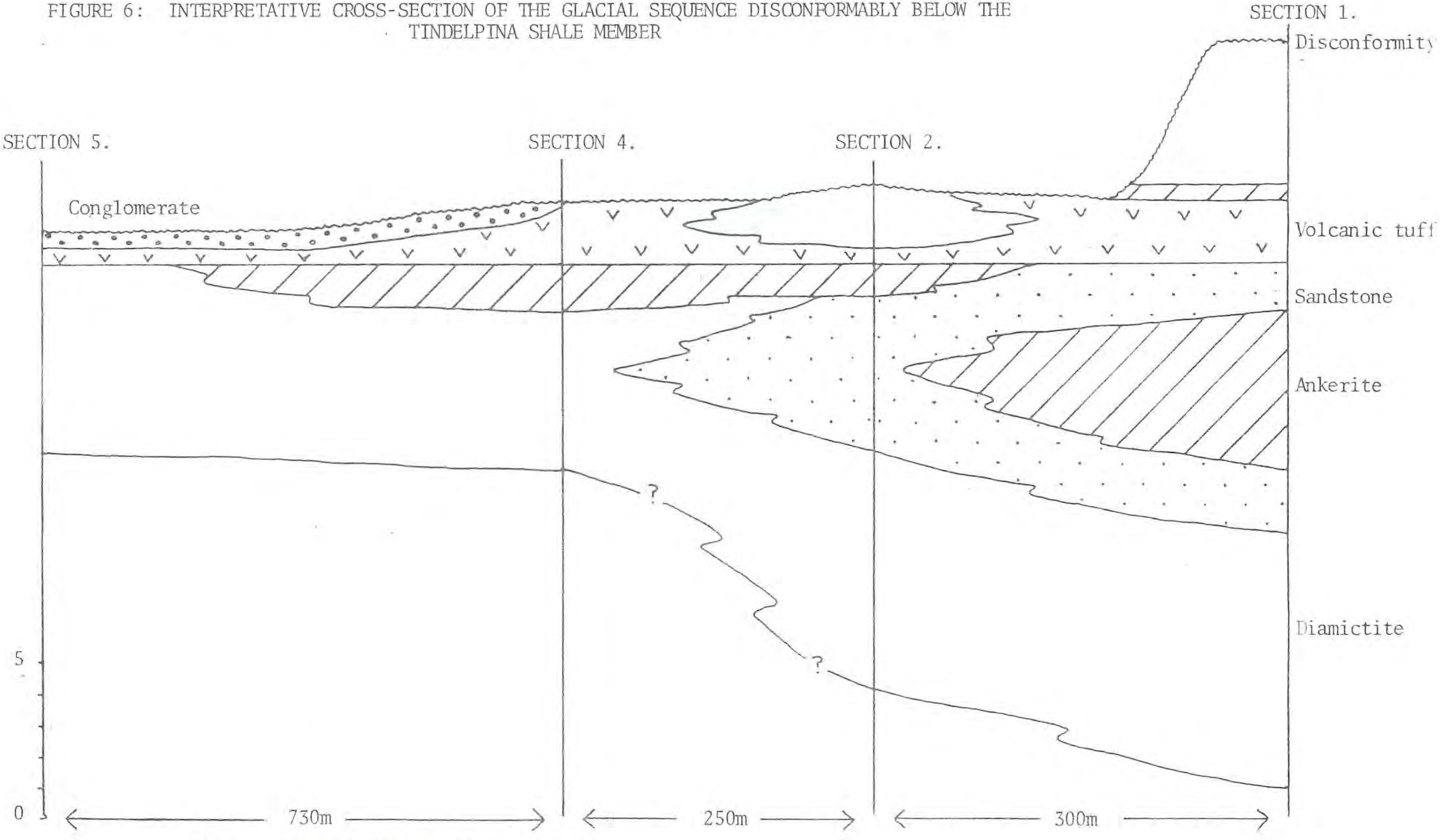
Upper Boundary

To date, Segnit (1939) has been the only author to suggest a hiatus in deposition between the glacial sequence and the overlying Tapley Hill Formation in the Depot Flat area. His evidence for this was that the upper surface of the tillite displayed signs of erosion, namely relief of boulders, which appeared to be water-worn, above the surrounding till matrix.

Detailed mapping of the present map area has uncovered other evidence for a break in deposition, principally the removal of some of the upper beds of the glacial sequence (see Figure 6). Using the base of the volcanic tuff unit as stratigraphic datum, it appears that at least six metres of glacigene sediments have been removed between Section 1 and Section 5, a distance of approximately 1.3 kilometres.

The presence of a thin, well-sorted conglomerate consisting of well rounded pebbles of chert and quartzite (see plate 1.) may be additional evidence of erosion. This unit is first seen scouring into the underlying volcanic tuff at Section 4 and can be traced northwards to Section 5. Although this conglomerate may just be an intraformational cut

FIGURE 6: INTERPRETATIVE CROSS-SECTION OF THE GLACIAL SEQUENCE DISCONFORMABLY BELOW THE TINDELPINA SHALE MEMBER



Datum - Base of the Volcanic Tuff unit

and fill, its presence at the top of the sequence would seem to be more than coincidental.

Uplift and erosion of the glacial sequence may have occurred as a result of post-glacial uplift after the final withdrawal of the ice-sheets. However, the presence of volcanics at the top of the sequence suggests that tectonic uplift is also a possibility.

Nevertheless, the fact that no dropstones have ever been found in the laminated silts and shales of the Tapley Hill Formation suggests that the depositional break persisted for long enough to allow significant warming, with consequent disappearance of ice, to occur.

Investigation of the basal Tindelpina Shale Member in the Depot Flat area by the present author has revealed the presence of lenticular interbeds of stromatolitic dolomite suggestive of a shallow water origin for this unit. This observation supports an earlier proposal for a shallow marine origin for the Tindelpina Shale Member by Sumatojo (1974) based on geochemical evidence.

Previous investigation of the upper boundary of the younger Sturtian glacigenic successions elsewhere in the Adelaide Geosyncline has revealed that there is generally insufficient evidence for a widespread disconformity (see Coats, 1981; pp.541-544).

Volcanic tuff : Possible correlation with Beda Volcanics

The newly discovered lithic tuff unit, which has been interpreted as a slightly reworked pyroclastic deposit (see Chapter 3) is extremely useful as a reliable marker horizon within the glacial sequence at Depot Flat. However, its stratigraphical significance may have much more importance if it can be proved that this unit correlates with the Beda Volcanics on the Stuart Shelf to the west (Dr. B. Daily, *pers. comm.*).

Current knowledge of the stratigraphy of the Stuart Shelf reveals that upper flows of the Beda Volcanics are overlain unconformably by the Tapley Hill Formation. Mason *et al.*, (1978) found from drill holes that the uppermost volcanics are reworked into a thin clastic horizon at the base of the Tapley Hill Formation and also noted that this conglomerate displayed some of the lithological characteristics of a tillite.

This study has shown that the volcanic tuff at Depot Flat occurs at the top or near the top (overlain by diamictite) of the glacial sequence and is separated from the Tapley Hill Formation by an erosional hiatus. Thus there may be a correlation on stratigraphical evidence alone.

A comparison between the composition of the Beda Volcanics (Webb and Horr, 1978) and samples from Depot Flat, has shown that they are quite similar. Nevertheless, any correlation on these grounds, in the absence of detailed geochemical analysis, may be considered equivocal.

There is also the possibility that no equivalent exists on the Stuart Shelf, even if it was the source area of the volcanics. Glacial erosion contemporaneous with volcanism can be invoked to explain both the absence of a temporal equivalent in the stratigraphic record of the Stuart Shelf (major breaks in sedimentation are know from the Stuart Shelf) as well as the presence of slightly reworked volcanics in the glacial sequence at Depot Flat.

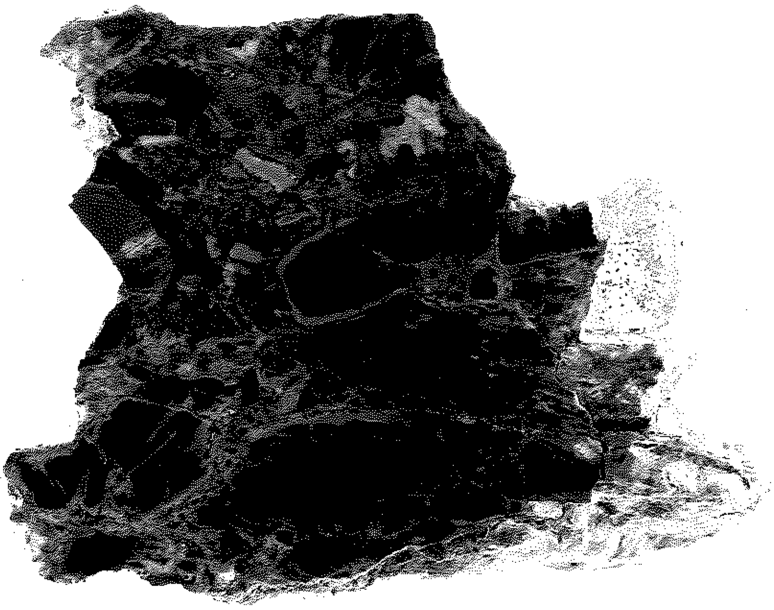
The fact that this unit has not been previously described from lateral equivalents of the glacial sequence at Depot Flat, or even in the vicinity of Depot Flat, could be due to either non-deposition of this unit in other areas, subsequent removal by erosion (partially eroded in the present map area) or non-recognition of this unit by previous investigators.

A more complete investigation including dating of this unit is now clearly warranted. Dating, however, may prove fruitless as previous attempts to date the Depot Creek Volcanics only recorded overprinting by the Cambro-Ordovician Delamerian Orogeny.

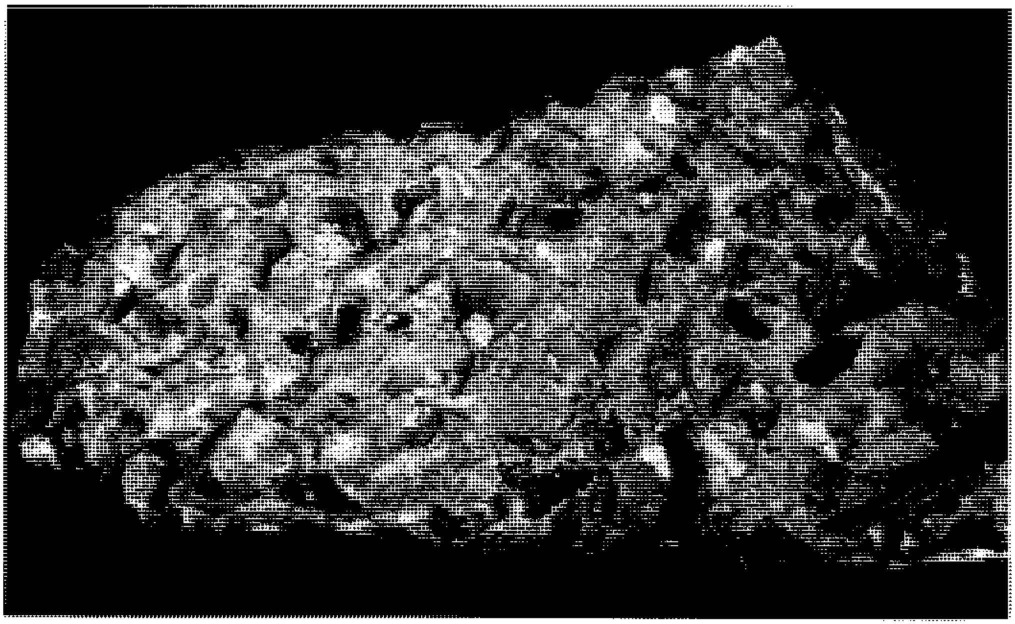
If the volcanic tuff at Depot Flat can be correlated with the Beda Volcanics, the stratigraphic implications may be far-reaching. At present the Beda Volcanics (1076 ± 34 Ma) are correlated with the Depot Creek and Wooltana Volcanics in the geosyncline. This correlation suggests that the base of the oldest Adelaidean sediments (the Callanna Beds) has an approximate age of 1,100 to 1,150 million years.

If the proposed correlation is in fact correct, it would push back the inferred age of the Sturtian glaciation approximately 350 million years and may also vindicate an earlier correlation scheme (Thomson, 1966) in which the Wooltana and Roopena Volcanics were correlated giving an inferred age of 1400 Ma for the commencement of sedimentation within the Adelaide Geosyncline.

PLATE 1



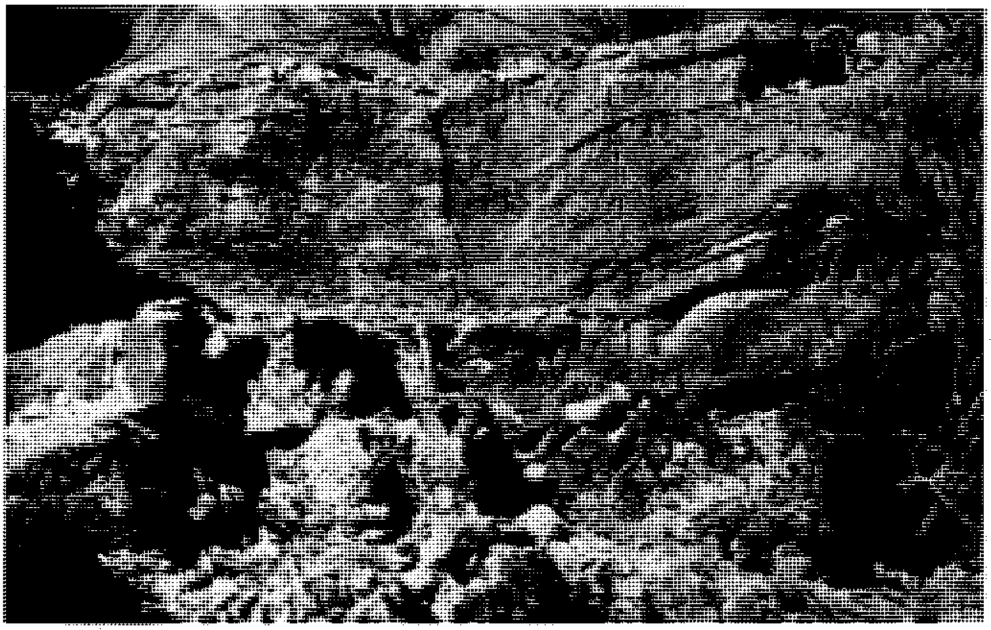
a) Breccia composed almost entirely of dolomite rock fragments interpreted to be a regolith. This 10cm diameter fragment was obtained from the base of the glacial sequence at Section 1.



b) Well sorted pebbly conglomerate composed of well-rounded clasts of quartzite and chert supported by a sandy matrix. This 10cm long fragment was taken from the top of the glacial sequence at Section 4. The presence of this conglomerate is used as additional evidence for an erosional interval prior to the deposition of the Tindelpina Shale Member (see text, page 10).

PLATE 2

a) Finely interbedded black shales and dolomites of the Tindelpina Shale Member overlying the glacial sequence at Section 1.



b) Stromatolitic dolomite directly overlying a diamictite (Unit M) at Section 1. This contact marks the upper boundary of the glacial sequence here as this dolomite is considered to be a part of the Tindelpina Shale Member. Photo a) above directly overlies this dolomite horizon and similar dolomites are found higher up in the Tindelpina Shale Member at this locality.

CHAPTER 3 : SEDIMENTARY FACIES

General Statement

A basic premise in the interpretation of the Appila Tillite Equivalent at Depot Flat in this study, is that the sediments were deposited in a glacigene environment. Ever since the discovery of the Sturtian tillites late last century by Woodward, their glacial origin has never been seriously challenged.

Previous investigation of the younger Sturtian tillites in the Adelaide Geosyncline has documented the presence of faceted and striated clasts, dropstones in fine grained and laminated sediments, till clasts and pellets and massive diamictites which combine to provide excellent evidence of glacial deposition. Many of these features plus a wide geographical distribution the lack of striated pavements, the presence of locally calcareous matrix and rare carbonate interbeds (Gostin, 1982) and also geochemical evidence (Frakes and Crowell, 1973; Sumatojo and Gostin, 1976) have suggested to various workers that the younger Sturtian glacigenic successions are of glaciomarine origin.

According to Link and Gostin (1981) and Gostin (1982), the Sturtian glacigene sediments in the Adelaide Geosyncline are comprised of five main facies:

(1) the Massive Diamictite Facies deposited as subaqueous basal till beneath a dominantly grounded, but locally bouyant ice shelf.

(2) the marine Bedded Diamictite and Siltstone Facies with evidence of abundant ice-rafting and subaqueous mass movement.

(3) the Calcareous Granule Conglomerate Facies of limited extent deposited by englacial or subglacial meltwater during glacial retreat.

(4) the Bedded Sandstone Facies deposited largely as turbidites with a minor ice-rafted component.

(5) the Ironstone Facies of various iron-bearing lithologies deposited mainly in localised aqueous environments, (probably lacustrine).

Coats (1981) cites the generally planar depositional surfaces of the diamictites as further evidence that they were deposited from wet-based floating ice sheets in shallow water, possibly under restricted marine conditions.

N.B. A glossary of selected glacigene terms used in this thesis can be found in Appendix V.

Diamictites

The glacial sequence at Depot Flat contains between 6 and 13 diamictite horizons representing a variation from 25% to 57% of the total thickness of the glacial sequence. The thickness of individual units varies from as little as 1 metre up to 15 metres. Many of the diamictites are separated from each other, usually by sandstones, although, consecutive diamictite beds do occur. In Section 3, the base of the sequence is comprised of 6 diamictite horizons in an unbroken succession 28.5 metres thick.

For the description and interpretation of diamictites from the glacial sequence, Section 1 is considered to be the most representative because of good exposure and also because it can be reasonably correlated with Section 2. The other sections are used to exemplify lateral variations across the sequence.

Section 1

Units 2 and 4 occur just above the base of the sequence and can be considered together as they are almost identical in all respects. Both units are thin (2m) sandy clast-poor diamictites which are interbedded with thin laminated shales. Contacts with the shales are knife sharp with no signs of disturbance in the shale units. Unlike the shales, the diamictites are slightly calcareous. The clasts are predominantly pebble sized, although cobbles up to 15 cm diameter are present. A crude stratification has been produced by the local alignment of clasts.

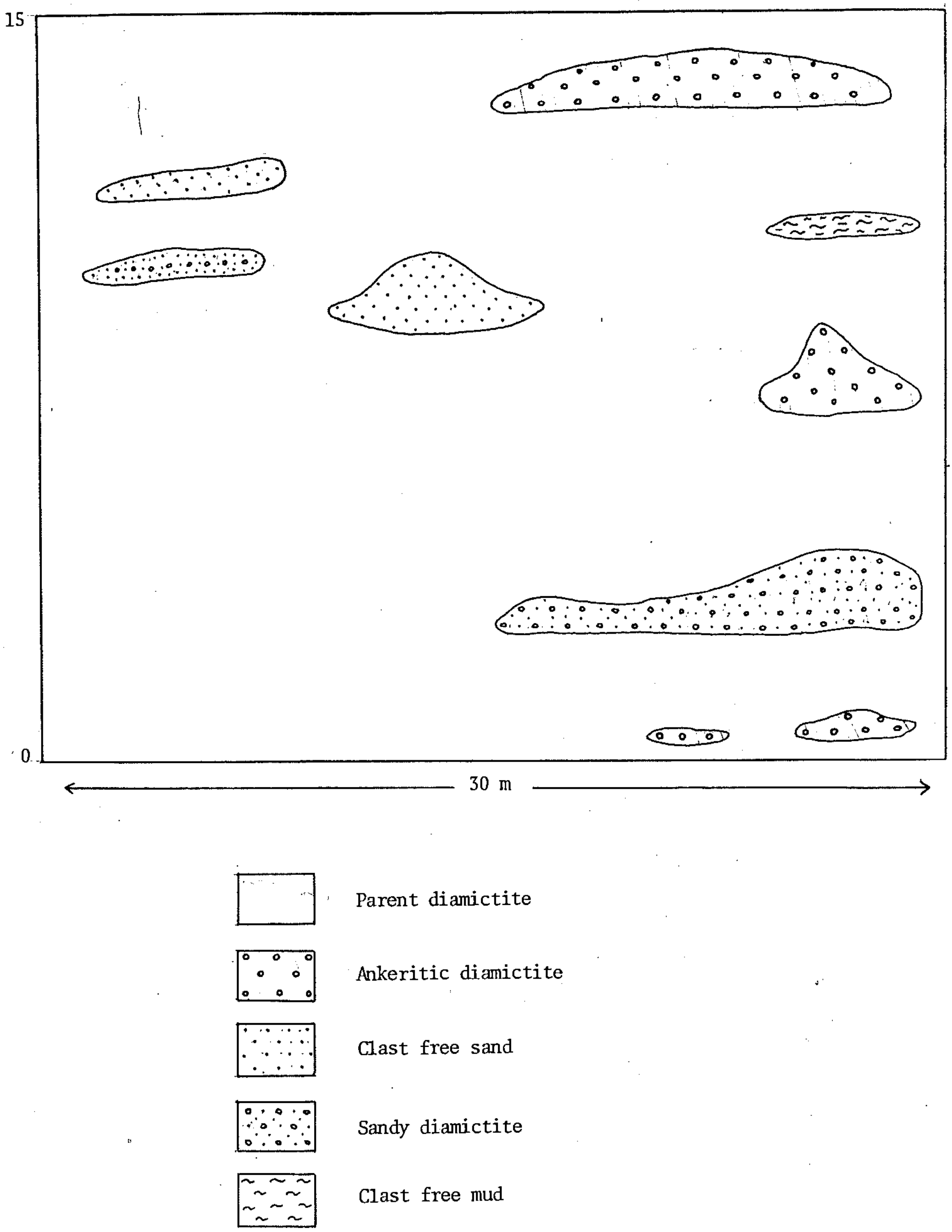
Such diamictites could be interpreted as flow tills or debris flow deposits (Kurtz and Anderson, 1979). The distinction here is rather arbitary as the interbedded shales contain dropstones indicating that these diamictites were deposited in a glacigene environment. Such deposits are also called allochthonous tillites (Harland et al., 1966) where glacially accumulated debris is transported to the site of final deposition by non-glacial processes.

All the features described above are compatible with those found in pebbly muds currently forming on the continental shelf of Antartica which have been interpreted as debris flows by Kurtz and Anderson (1979). The diamictites are also similar to flow tills described by Edwards (1978) and postulated to occur under wet based ice-shelves (Carey and Ahmad, 1961).

The present author envisages that these deposits originally accumulated either supraglacially or subglacially and subsequently flowed downslope from the glacier to become interstratified with laminated shales. Water depth may have been either deep or shallow.

Figure 7

Diagrammatic representation of the distribution and types of lenses seen in a diamictite, Unit 3, Section 3.



Unit 6 is a thick (15m) unit which grades from a dark grey, muddy, clast-poor diamictite at the base to a more clast-rich sandy diamictite at the top. Rare granite megaclasts up to one metre diameter occur throughout the unit and they are considered to be dropstones as they deform bedding and because of the fine grainsize of the matrix. Bedding is intermittent and varies from silty laminations near the base to sandy and pebbly bands further up in the unit. The top of the unit is marked by a concentration of granite megaclasts at an intraformational erosion surface, overlain by a four metre thick sedimentary breccia unit.

The presence of bedding, dropstones and a random clast fabric identify this diamictite as a waterlain tillite. The trend towards the coarser, more clast-rich diamictite upwards may reflect shallowing or increasing proximity to the glacier with currents winnowing away the finer fraction of the matrix. The boulder bed and the breccia at the top of the unit testify to strong reworking of the tillite by vigorous meltwater currents under very shallow or subaerial conditions. According to Dreimanis (1979), waterlain tills can be deposited from either floating ice-shelves, icebergs or in proximity to locally grounded ice in glaciomarine, glaciolacustrine or glaciofluvial environments.

Units 10, 12 and 14 above are virtually indentical and therefore have also been interpreted as waterlain tillites. Additional evidence for this origin in these units is the presence of local clast concentrations, some of which may be till clasts (Harrison, 1975) and the obvious fragility of some clasts.

The remaining diamictites in Section 1 (Units B, E, J and M) are generally sandy and clast-rich and appear to be more sorted than the underlying diamictites. Stratification is either absent or present as crude banding due to the segregation of better sorted layers. Association with ankerites and well stratified sandstones and breccias and the absence of striated pavements suggests that these diamictites were deposited in shallow water. The diamictites may have originally been waterlain tills (similar to those occurring below) that were winnowed either during or after deposition causing the removal of most of the finer particles and the development of crude stratification. Alternatively the diamictites may have been modified subaqueous basal tillites deposited from ice grounded in water. Unfortunately, due to a lack of suitable evidence there is no way of delineating between these two types of tillites in the present study.

Section 5

Section 5 contains only six diamictite horizons, two near the base, one in the middle and three near the top. Units 2 and 3 are sandy clast-rich partly stratified diamictites which also appear to be moderately sorted. Unit 2 overlies a basal sandstone unit and is separated from Unit 3 by a thin laminated shale. Sharp lower contacts were noted for both diamictites. In view of the close similarity of these diamictites at the base of Section 5 and those at the base of Section 1 suggests that these diamictites may also be interpreted as flow tills.

Unit 6 occurs above the thick varve unit in the middle part of the sequence. This unit is a sandy clast-poor diamictite with gradational upper and lower contacts and have been interpreted as a reworked waterlain tillite.

Unit 10 is a thick (8 m) dark grey, muddy clast-poor diamictite which is generally well laminated and also contains coarser conglomerate bands. This diamictite has probably been deposited as a result of icerafting in quiet and possibly deep water under glaciomarine or glaciolacustrine conditions. The presence of a large granite megaclast one metre in diameter supports the interpretation of a dropstone facies. Such deposits can come under the heading of waterlain tillites although the terms glacial laminate or laminated tillite (Edwards, 1978) may be more appropriate.

Unit 12 is similar to Unit 10 except that lamination is absent giving the unit a more massive appearance resembling the waterlain tills in Section 1. Unit 13 is a sandy clast-rich diamictite very similar in appearance to other diamictites already described as either reworked waterlain or subaqueous basal tillites.

Section 3

Section 3, although incomplete, contains more diamictites than any of the other sections and is noted for the succession of six diamictite beds above the base. Unfortunately the section is poorly exposed and highly cleaved, making the observation of sedimentary structures very difficult.

Unit 1 is a thin (1m) silty clast-rich diamictite with predominantly pebble-size clasts dispersed evenly through the matrix which is also calcareous. Similarities in stratigraphic position, thickness and matrix composition between this unit and the postulated flow tillites in Section 1 suggests a similar interpretation.

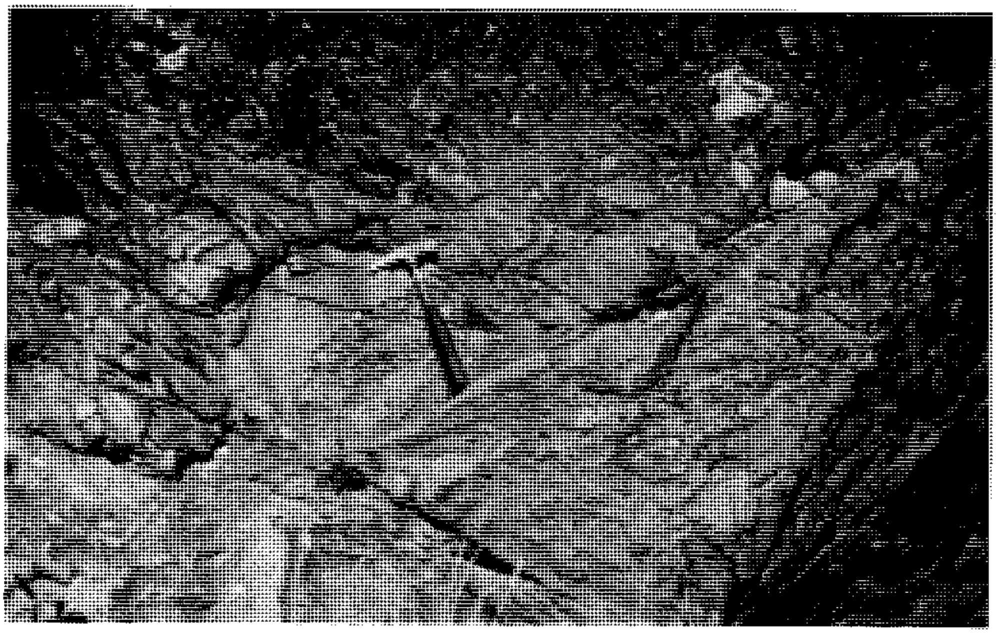
Unit 3 is an unusual diamictite as it appears to contain pod-shaped to elongate lenses of differing lithologies. (see Figure 7.) They apparently lie parallel to the base of the diamictite which is otherwise undisturbed. Four main types of lithology were recognized:

1) lenses of unstratified clast-free medium sand
2) lenses of diamictite more resistant to weathering due to a significant degree of carbonate in the matrix
3) a clast free lens i.e., consisting only of mud and silt
4) a sandy diamictite lens where the matrix is significantly coarser than that of the parent diamictite.

These lenses are similar in appearance and lithology to lenses in diamictites described by Spencer (1971) from the late Precambrian glaciation in Scotland. Spencer interpreted the lenses as having formed at the base or within grounded ice-sheets. Similar lenses have also been reported from Pleistocene tills deposited by grounded ice (Simpson, 1961).

Units 4 to 16 are all generally clast-poor pebbly mudstones usually displaying some degree of stratification indicating that they were probably deposited as waterlain tillites or glacial laminates. The remaining diamictites (Units 18, 21, 22) near the top of the section are associated with ankerites and sandstones. They are generally unstratified, sandy clast-rich diamictites although Unit 18 has lenses of well-bedded sandstone. Under criteria previously outlined for similar diamictites occurring in the upper part of Section 1, these diamictites may be interpreted as either reworked waterlain or subaqueous basal tillites.

PLATE 3



a) Massive clast-rich diamictite (Unit J, Section 1) interpreted to be either a subaqueous basal till or a modified waterlain till. The rounded clast left of the hammer is a reddish-purple quartzite. The presence of such clasts are considered by Coats and Forbes (1977) as diagnostic of all younger Sturtian glacigenic successions.

b) Pod-shaped lens of an apparently massive, clast-free medium sandstone occurring in a muddy, clast-poor diamictite (Unit 3, Section 3).

Varves

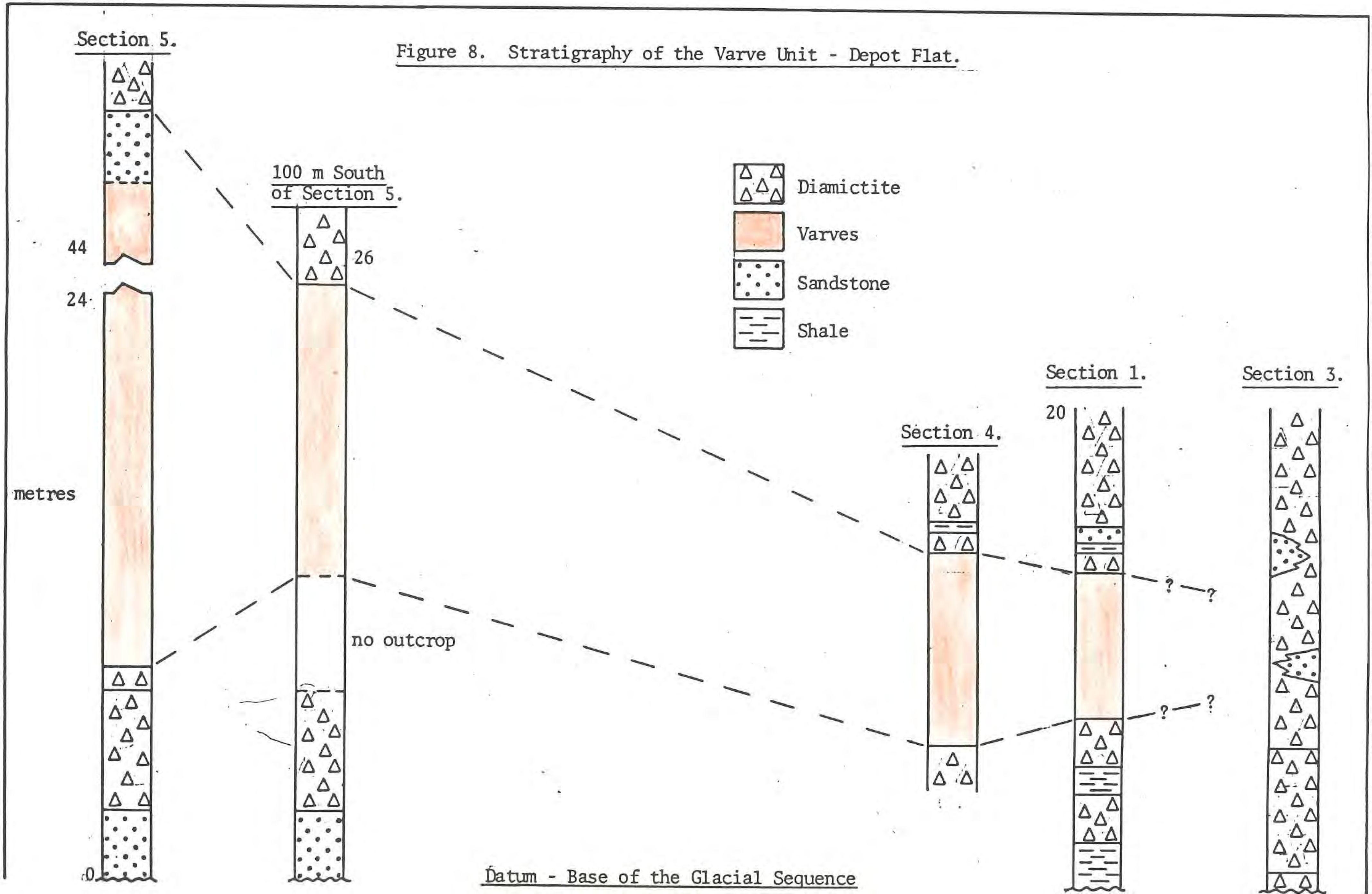
Apart from the reported presence of varves (glacial rhythmites) in the Depot Creek area by Preiss and Sweet (1966), no proven occurrences of varves have been reported from the Sturtian tillites in South Australia until this study. Inadequate documentation of those reported varves makes it impossible for the present author to ascertain whether the varves seen at Depot Flat in this study are the same ones that they observed. The extent of the varve unit north of the present map area is unknown as it was not followed north of Section 5 where it disappears due to the presence of a major fault cutting across the glacial sequence.

South of Section 5 the varve unit can be traced laterally in patchy outcrops for approximately one kilometre to Section 1. The unit is 38 metres thick at Section 5 and initially thin out rapidly (21 metres over 100 metres) and then gradually thins down to a six metre sequence in Section 1. The unit is thought to lens out into diamictites somewhere south of Section 1, but due to lack of outcrop the actual extent of the unit is unknown. Despite thickness variations, the unit maintains a fairly constant stratigraphic position above the base of the glacial sequence, even though it is underlain by different lithologies.

Across the map area the varves vary appreciably in appearance from well weathered red and white coloured outcrops to well indurated, grey and brown outcrops. The varves also display varying degrees of penecontemporaneous deformation varying from slight warping to complex contortions and micro-faulting of the laminae. Such deformation may have been gravity induced or due to other forces such as seismic activity, over-riding ice movement or compaction and dewatering processes.

In all of the sections the varves contain a small but variable amount of subangular to well rounded dropstones ranging from sand grains up to clasts of 5 cm diameter. Till pellets (Ovenshine, 1970) have been identified from Section 5 and also from an outcrop in the same creek as Section 4. (see map). A rhythmic pattern of alternating coarse and fine laminae is seen at all localities despite variations in terms of relative thickness of individual layers, total couplet thickness, grain size and sedimentary structures. Other features that distinguish these rhythmites as glacial varves using the criteria of Ashley (1975) obtained from Pleistocene varves of proven glacial origin, are sharp silt-clay contacts demonstrating that couplets are composed of two distinct layers and are not a single graded bed. In addition, the variation in thickness and grain-size of the coarse layer versus the contant thickness of the clay layer seen in these varves implies

Figure 8. Stratigraphy of the Varve Unit - Depot Flat.



two different mechanisms of deposition for the layers which is a fundamental characteristic of clastic varves.

Overall, the varves conform to the Type III varves of Ashley (1975) in which the coarser layer is thicker than the clay layer although local exceptions occur. The special features of the varves at different localities in the map area are described below.

Section 5

The majority of varves in this section are Type III with the coarse layer being two to four times thicker than the clay layer which has a constant thickness throughout the unit. The average couplet thickness is usually between 1 and 2 millimetres. Varves with such small couplets (less than 0.25 cm) may be referred to as microvarves (Ashley, 1975).

In addition to thickness variations, the grainsize of the coarse layer varies between silt and medium sand-size, however, a direct relationship between these variables is not apparent. Occasional perturbations in the coarser grained layers have been interpreted as starved ripples.

Near the top of the sequence the varves thicken upwards with an increase in thickness of the sand layers and gradual thinning of the clay layer until the unit gradually passes into a massive sandstone. Till pellets and dropstones are generally rare in the sequence and tend to concentrate at certain horizons.

Section 4

The varve unit here is approximately 8 metres thick and is poorly exposed and heavily weathered. The main feature of the varves here is that the coarse layers are quite thick (up to 10cm) and are poorly sorted and contain ripped up varve fragments. Clay layers are often obliterated and replaced by multiple graded coarser layers. There are also locally, abundant dropstones and till pellets.

Section 1

Six metres of varves occur between two thin diamictite units in this locality. The varves are contorted and faulted but do not display any features similar to the varves in Section 4 which is only about 100 metres to the north. The varves are Type III with an average couplet thickness of 5 mm. The clay layer has a constant thickness (1 mm) whereas the silt layer varies between 1 and 6 millimetres. Contacts between layers are sharp and are best viewed on a weathered surface. No till pellets were found and dropstones are rare.

The presence of these finely laminated varves containing dropstones and till pellets is not only excellent evidence for glaciation (Flint, 1975) but also of glaciolacustrine conditions. There is general agreement amongst researchers that clastic varves will not form under marine conditions. Such factors as the lack of seasonal influence, the presence of other sediment sources and various types of currents, flocculation of clay particles and wide sediment dispersal via overflow mechanisms are cited by Edwards (1978) as causes preventing the formation of varves in a marine environment.

Lakes are a common feature of the proglacial landscape (along glacier margins) and their development and destruction is usually glacier-controlled (Goldthwait, 1975). Consequently, glacial lakes are often short-lived. In the Depot Flat area it is possible to envisage the development of a lake during early stages of glaciation with local ice encroachment blocking drainage and damming the area and/or causing a reversal of drainage by isostatic depression. Some basinal movement is indicated by the large variation in thickness of the varve unit across the map area. Perhaps some local tectonic movement unrelated to, or possibly induced by, the presence of glacial ice may also be responsible for the development of the postulated lake.

The sequence at Section 5 is of particular interest as its anatomy can be used to reconstruct the sedimentary conditions that prevailed during the lifetime of the postulated lake.

We can postulate that the lake was fed by one or more streams or rivers, that under glacial conditions, were strongly seasonal. Most of the sediment carried into the lakes would occur in summer when melting of ice would release large volumes of meltwater carrying high loads of suspended sediment. Upon entering the lake the waters would become density currents depositing the coarser fraction. The finer fraction would settle slowly out of suspension and only accumulate in definite layers during winter when rivers became choked with ice.

Upon applying this scenario to the varves at Section 5, some important conclusions can be reached. For example, the constant thickness of the clay layer suggests a very regular rhythm which is best described by the annual rhythm described above thereby confirming that these rhythmites are true varves. The variation in grain-size of the coarser layer is thought to be related to the position of the sediment source, relative to the site of deposition. The relative thickness of the coarse layer was probably controlled by the degree of melting occurring during summer as this ultimately controls how much sediment will become available for deposition.

The starved ripples are evidence that at least some of the coarser layers were finally deposited under traction. The concentration of till pellets and dropstones in certain horizons records the intermittent presence of floating ice capable of picking up debris at the lake margin.

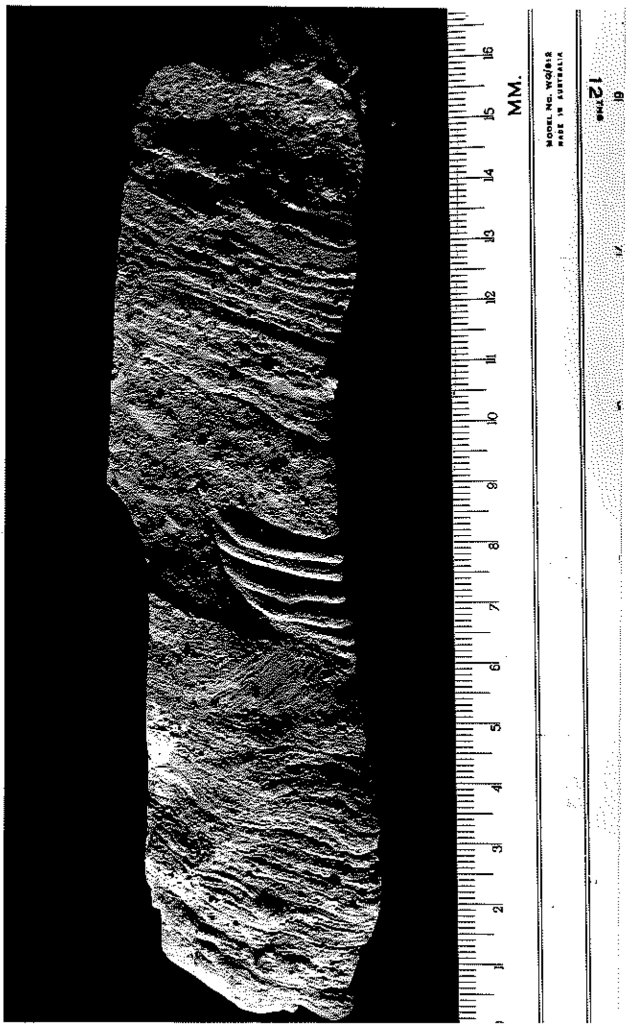
The thickening of varves and gradual transition into a sandstone unit at the top of Section 5 represents a shallowing upwards from lacustrine to deltaic sedimentation. Similar transitions have been reported from Glacial Lake Hitchcock by Ashley (1975).

The varves at Section 4 bear witness to the occurrence of locally strong currents flowing within the lake capable of ripping up semilithified sediments and depositing much coarser debris.

The features of the varve sequence described above and their interpretation has been based on observations noted during general field mapping of the area. The author believes that this sequence deserves a more complete investigation hopefully yielding even more information on the origin of this interesting deposit.

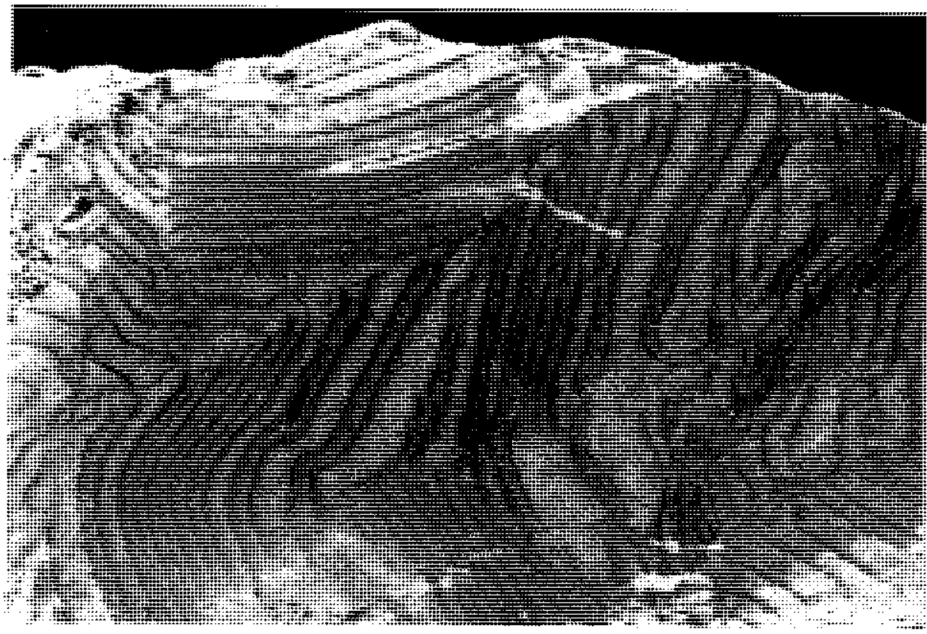
PLATE 4

a) Sample of the varve unit from Section 4. The presence of ripped-up varve fragments and thick coarse-grained layers are indicative of reworking of the varves at this locality. The small lumps of sediment seen at the bottom are thought to be till pellets.



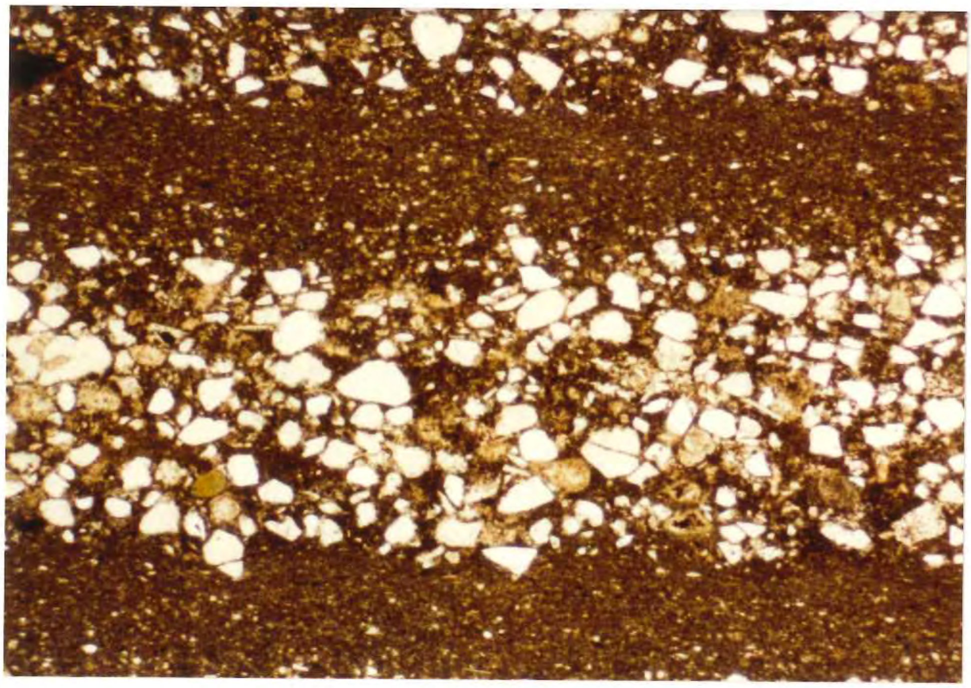
b) Deformed varves from Section 1. This deformation involving the ductile contortion and brittle micro-faulting of the laminae was probably penecontemporaneous. The darker laminae are composed of clay. The rock is 5cm long.

PLATE 5

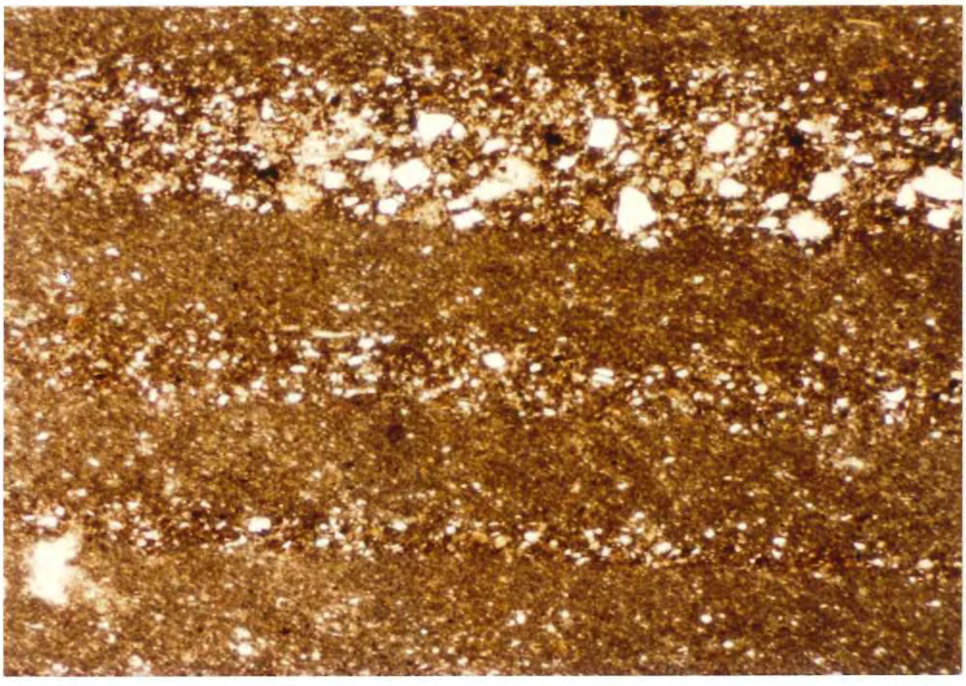


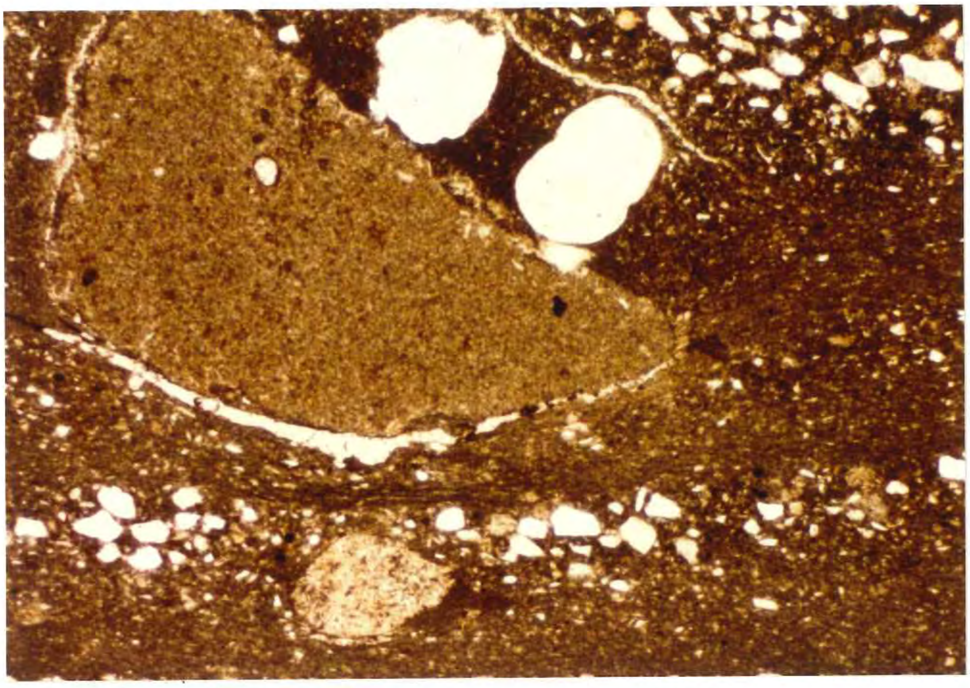
a) Severly contorted and faulted varves from a locality just south of Section 5. This fragment is 3cm long.

b) Excellent example of finely laminated microvarves in a 5cm fragment from Section 5. Features to note are the sharp sand-clay contacts, the constant thickness of the clay laminae versus the irregularity of the sand laminae and the small dropstone (possibly a till pellet).
The arrow on the side indicates the direction of younging.

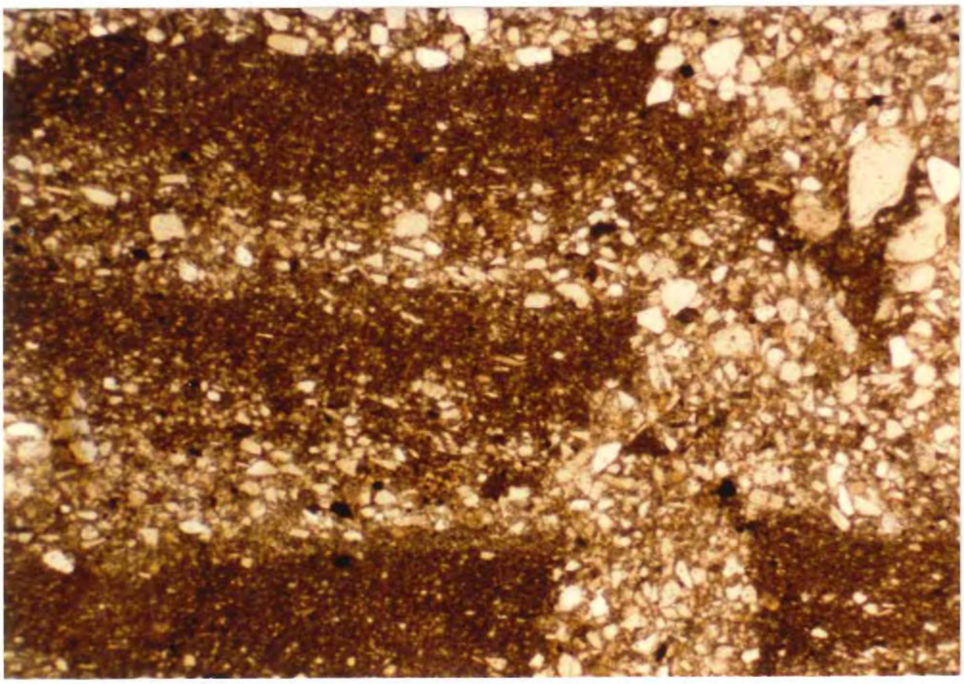


a), b) Photomicrographs of varves from Section 5 (under plane light). In each case the vertical thickness is approximately 4mm., and the younging direction is towards the top of the page.





a) Till pellet 2mm in diameter from the varve unit at Section 5. The pellet is composed of two quartz clasts and a dolomite clast originally cemented together by an ice matrix.



b) Photomicrograph of deformed varves from Section 1. The thickness of the dark coloured clay layer is approximately 1mm. Photo taken under plane light.

Sandstones

Sandstone units are known from all sections in the map area and vary in abundance from 15% in Section 3 up to 50% in Section 2 (% of total sediment thickness). Individual units range between one and fifteen metres in thickness.

Compositionally, the majority of sandstones are immature sublitharenites containing mainly subrounded grains of quartzite with variable amounts of sedimentary rock fragments, fresh feldspars and micas. This kind of composition is to be expected in glacial sequences, reflecting the effects of erosion, transport and deposition under glacial or at least climatically cold conditions. The sandstones are often poorly sorted with scattered pebbles and cobbles a common occurrence. Boulders up to 30 cm diameter have also been found embedded in thick sandstones and may represent a contribution from ice-rafting.

A common feature of the sandstone units is the lack of a comprehensive sedimentary structure suite; the majority are massive or horizontally stratified. Apart from this, the thicker sandstones display poorly defined coarsening upwards.

A general upward increase in grain-size is usually accompanied by an increase in abundance and thickness of breccia bands which may be very poorly sorted and diamictite in aspect. The amount of scattered coarse grain-sized clasts also increase upwards. Sandstone units are generally concentrated in the upper two thirds of the sections; the only exception being the basal unit of Section 3. The majority of sandstones form divisions between diamictite horizons in the glacial sequence. The differences in thicknesses and members of sandstone between the various closely spaced sections implies that many of the units are lenticular in nature although this has not been substantiated in the field. Sugden and John (1976) have noted that "coarsening upwards" is a characteristic of kames and kame terraces in modern glacigene proglacial environments. Such grading is thought to occur by the buildup and progression of a fluvioglacial sequence across an ice marginal or proglacial area from distal to proximal to the icefront. This may be partly deltaic or may be due to a gradual increase in stream discharge.

The general lack of sedimentary structures apart from horizontal stratification and alignment of gravel-size clasts parallel to bedding suggest that the sandstones were deposited rapidly under an upper flow regime (Church and Gilbert, 1975).

Medium to coarse grained poorly sorted sands that are either massive, graded or show irregular to parallel bedding are described by Saunderson (1975) as a major facies of eskerine sedimentation interpreted as having been deposited either subaerially or subaqueously as delta-front deposits. Similar sandy facies have been described from subaqueous outwash fans by Rust and Romanelli (1975) and Gostin and Rust (1981).

Many of the features of the sandstones mentioned above including close association with diamictites and limited lateral extent suggest that these units were deposited at times of local ice retreat i.e., times of high discharge. Sedimentation may have taken place either subaqueously or subaerially and may have been quite rapid.

Sedimentation of sands from density (turbidity) currents under subaqueous conditions may have also been a contributing factor in the deposition of these units, although many of the features commonly associated with turbidites are apparently absent.

Conglomerates and Breccias

Apart from occurrence as interbeds in sandstone units the relative abundance of conglomerate and breccia in the glacials is fairly minor. In many cases the lithological composition of these coarse clastics is broadly similar to those of the diamictites although there are certain exceptions.

The remainder of these units can be grouped into three main types:

1) thin discontinuous lenses and interbeds in laminated shales
2) usually thicker discontinuous beds overlying diamictites
3) thin discontinuous beds and lenses within diamictites.

Type 1

Conglomerates and breccias of this type are a common occurrence in laminated shale which also invariably contain some percentage of dropstones. Most of these are quite poorly sorted with the majority of clasts in the angular to subrounded range. These deposits are interpreted as lag deposits formed by winnowing of the shales by strong bottom currents which in some cases must have been quite strong as clasts up to 10 cm diameter are commonly found in these bands.

At the other end of the spectrum some of these bands are composed of well sorted and rounded granule and pebble conglomerates. Such deposits probably represent periodic incursion of density currents carrying debris that was extensively reworked upslope.

Type 2

The best example of this type of deposit occurs in Section 1 where a four metre thick sedimentary breccia unit (Unit 8) overlies a thick diamictite containing granite megaclasts up to one metre in diameter.

The breccia is moderately well sorted with generally angular to subrounded pebble-sized clasts partly supported by a sandy matrix. In outcrop the breccia is generally massive although there seems to be a weak presence of two or three coarsening upward cycles within the unit. The relative proportions of the different clast lithologies is similar to that in the underlying diamictite.

The unit can be traced laterally northwards to Section 2 however, to the south the unit lenses out into sandstones and diamictite over a distance of approximately 200 metres.

Another interesting feature is the occurrence of about six large granite megaclasts scattered along the basal contact with the breccia being draped over them (see plate 9.).

All the evidence suggests that this breccia was ~~found~~ formed as the result of extensive reworking of the underlying diamictite. Such reworking is most likely to occur above wave base in a subaqueous environment or subaerially under fluvial conditions. In either case the currents needed to concentrate such large boulders would suggest that the icefront was quite proximal at this time.

Further up in Section 1 there is a two metre thick conglomerate unit (Unit A) which is unusual as it is a matrix supported conglomerate with a clast assemblage composed almost entirely of pebbles and cobbles of dolomite. Most of the clasts are well rounded and a large percentage are stromatolitic. Such a deposit probably originally accumulated as a result of a glacier eroding a dolomite horizon of the underlying Burra Group. Subsequent release of this debris and reworking by currents resulted in the deposition of this conglomerate. Dolomite conglomerates have been reported from the Port Askaig Tillite (Spencer, 1971) and the Fargoo Tillite in Western Australia (Dow, 1965) both of the late Precambrian age.

Another coarse oligomictic clastic unit occurs in Section 3. This is a two metre thick breccia unit composed of tightly packed and quite angular laminated silt and shale fragments and the unit is underlain and overlain by diamictites (see plate 9.).

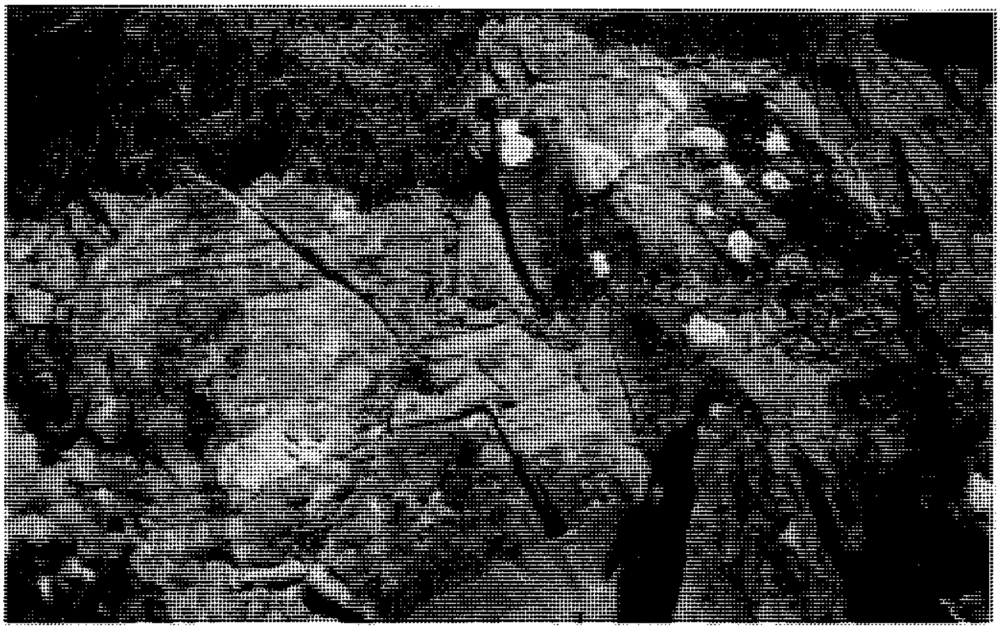
The most likely origin for this deposit is the virtual in situ erosion of a siltstone-shale unit by an overriding icesheet or perhaps erosion from strong currents ripping up the sediment whilst semi-lithified.

Unit D in Section 1, is a thin sandstone-conglomerate unit (2 m) which is underlain and overlain by clast-rich diamictites. The sequence consists of three discrete units coarsening upwards from a medium sand to a coarse sand to a granule conglomerate which forms the bulk of the unit. The conglomerate is clast supported and consists of well rounded clasts of quartz, quartzite and chert and it is well sorted. The unit is horizontally stratified and elongated clasts are aligned parallel to bedding. All the features indicate that the deposit was laid down under upper flow regime currents. Horizontally stratified clast supported conglomerates are a dominant facies in proximal braided river systems (Rust 1979). Therefore, it could appear that this unit represents a shift from a distal to a proximal position during deposition. Similar conglomerates associated with diamictites have been interpreted by Link (1977), as having been deposited by englacial meltwater streams.

Type 3

These conglomerates and breccias which may be beds up to 0.5 metres thick can grade from well sorted and rounded conglomerates to poorly sorted breccias within diamictite horizons. This gradation represents the relative degree of reworking of the diamictite by intermittent currents. Spencer (1971) described similar bedding from the Port Askaig Tillite in Scotland and attributed them to meltwater currents acting on till formed either at the base or within a grounded ice sheet. Reading and Walker (1966) preferred an origin via winnowing of waterlain tillites. Whether these waters were acting on diamictite beneath a grounded ice sheet or as local currents sweeping under a floating ice shelf may be impossible to prove conclusively. There are of course other criteria that can be used to determine the origin of diamictites in the glacial sequence.

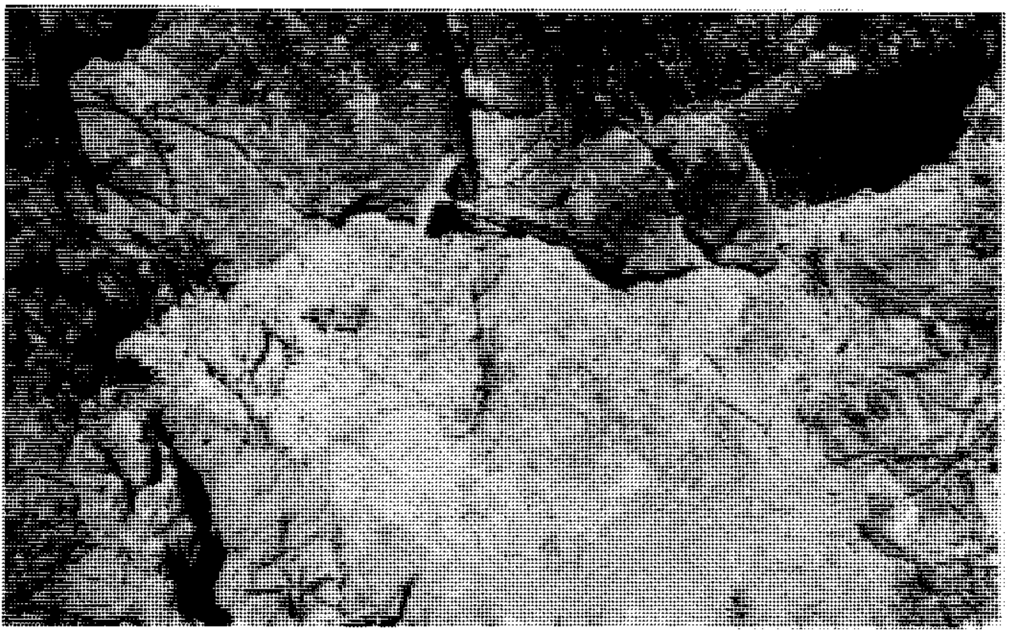
PLATE 8



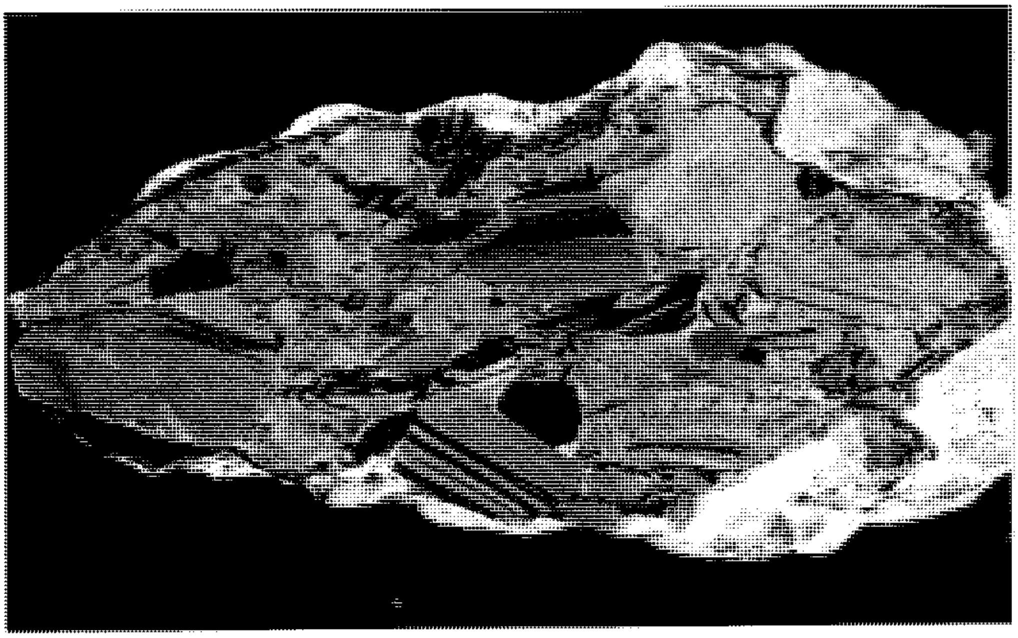
a) Horizontally stratified medium to coarse sandstone (Unit 11, Section 3). Bedding is well defined by the segregation of both muddy layers and bands of conglomerate. There is a sharp contact with the overlying diamictite unit. Scattered clasts occur throughout.

b) Interbedded medium-coarse sandstones and pebble to cobble breccias from Unit 1, Section 1. Sandstone units of this type in the glacial sequence are interpreted as either subaqueous or subaerial outwash deposited under upper-flow regime conditions in an ice-proximal environment.

PLATE 9



a) Photo showing the base of a 4 metre thick breccia unit (Unit 8, Section 1) draped over a large granite megaclast (beneath hammer). The presence of similar clasts scattered along this contact in the vicinity are thought to indicate the position of a intraformational erosion surface of limited extent.



b) Breccia from Unit 17, Section 3. This 2 metre thick unit was probably produced by intraformational erosion of a laminated shale.

Ankerite (Fe-rich dolomite)

Ankerite units are known from all sections in the map area except Section 5 to the north. In the other sections the units vary in thickness and relative abundance. A general feature of these units, however, is that they tend to concentrate near the top of the glacial sequence with one exception (base of Unit 9, Section 1).

In outcrop the ankerites are weathered to a buff colour whilst on fresh surfaces the ankerite is dark grey. The majority of ankerites are usually silty and contain small but variable amounts of sand and small clasts, some are clast free and at least one unit grades from clast free at the base to clast-bearing upwards.

In thin section the ankerites appear as massive micrites, sometimes locally recrystallized. No evidence of biogenic activity associated with the deposition of these carbonates has been found. On textural grounds, these ankerites are considered to be primary precipitates or possibly early diagenetic.

Ankerites are generally associated with thin laminated shales or sandstone units. A comparison of the upper parts of the closely spaced Sections 1, 2 and 4 (Figure 11) reveals that the lateral extent of these ankerites must be very limited as well as being quite variable in vertical distribution.

The occurence of dolomites within supposedly glacial sequences has been the subject of much controversy amongst geologists in the past, as the formation of dolomite was generally considered to require warm water conditions. Nevertheless, the existence of dolomite interbeds within sequences of accepted, proven glacial origin (e.g., Port Askaig Tillite, Scotland) and even containing dropstones such as the Berridale Limestone of Permian age in Tasmania (Rao, 1981), testify to the formation of dolomites in cold water.

Carey and Ahmad (1961) postulated that freezing of seawater under thermally cold glaciers would create a brine solution saturated with respect to $CaCo_3$ that upon mixing with slightly warmer waters away from the glacier could directly precipitate $CaCo_3$.

This does not explain the formation of dolomite however. Tucker (1982) believes that precipitation of dolomite in the Precambrian is analogous to the precipitation of limestone in the Phanerozoic on which the model of Carey and Ahmad is based.

Another model for precipitation of dolomites in association with a glacigene environment, that better fits the observed features of the glacial sequence at Depot Flat and Depot Creek, is based on processes currently occurring in Antartica. Bauld and Walter (1981) have found that deposition of carbonate sediments, sulphate evaporites and stromatolites is common in lakes of high salinity in Antartica. If we accept Tucker's view that dolomite was preferentially deposited in the Precambrian, a plausible model for the ankerites of Depot Flat can be constructed.

The limited lateral extent and presence of stromatolites in the ankerites (Preiss and Sweet, 1966) are certainly indicative of shallow water and possibly lacustrine conditions. The intermittent presence of dropstones may be due to water often too shallow to support floating ice. Alternatively, these lakes may be predominantly periglacial, formed at times of maximum ice withdrawal with floating ice depositing debris picked up at lake margins. Such ice formation would be sporadic and icedropped debris would be small in grain-size and sparse in distribution. Much of the foreign material in the Depot Flat ankerites rarely exceeds pebble size.

Where the ankerites are intimately associated with laminated shales (Section 4), the intermittent barring of a lacustrine basin permitting hypersaline conditions to develop with consequent dolomite precipitation, can be envisaged. Similarly, thick deposits of coarse sandstones and breccias overlying ankerite units may indicate a more proximal position of the icefront with higher discharges of sediment-laden waters.

The abundance of ankerites near the top of the sequence may indicate a general retreating phase of glaciation (discussed later). The occurrence of dolomite in the form of ankerite (determined by staining) is intriguing. Uphill (1979) concluded that high Fe content of dolomites from the Mundallio Subgroup probably reflected the influence of waters of continental origin that have higher Fe concentrations than waters of normal marine chemistry. A similar origin for ankerites in the glacial sequence could also be invoked. Perhaps the high Fe content of the dolomites in the glacial sequence is a geochemical feature inherited from the dolomites of the Mundallio Subgroup especially if these dolomites are the source of the carbonates in the younger Sturtian glacials as suggested by Link and Gostin (1981).

Laminated shales

Laminated shales are a relatively minor facies in the glacial sequence and they generally form thin deposits less that four metres thick.

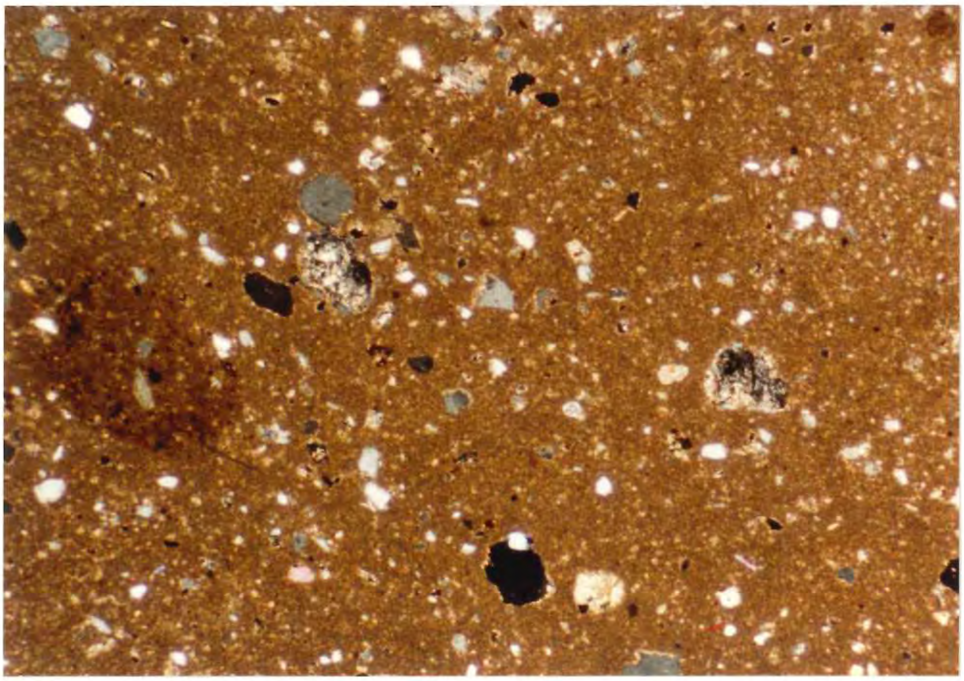
The majority of laminated shales are randomly laminated, show evidence of winnowing by strong currents and invariably contain some percentage of small dropstones. They are all dark grey-green in colour and Units 1 and 3 from Section 1, have been found to be pyritic. Examination of these units has shown that bedding varies between 5 cm and >>1mm., and have sharp contacts and are commonly graded. other features include soft sediment faulting, flame structures and load casts. These units are commonly associated with ankerites and sandstones in the glacial sequence and appear to be of limited lateral extent.

Laminated shales with very similar features have been described from the late Precambrian Moelv Tillite in Norway by Nystuen (1976). He attributed their origin to deposition from turbidity currents in a glaciolacustrine environment.

Laminates are described by Edwards (1978) as a major facies of both glaciomarine and glaciolacustrine sedimentation. Although the development of random lamination is generally attributed to the glaciomarine environment they can also form under glaciolacustrine conditions, although varved sediments are the dominant facies.

It would appear that these laminated shales were deposited by turbidity currents in a shallow glaciomarine environment and could also be termed glaciomarinites (Schermerhorn, 1974). Edwards (1978) states that this facies can be found in both marine and terrestrial facies associations as well as ice-marginal facies. Dropstone laminites are a frequent occurrence in late Precambrian glacial sequences (Edwards 1978).

PLATE 10



a) Photomicrograph (20 x magnification under polarised light) of an ankerite (Unit G, Section 1). Showing scattered silt in a micrite matrix.

b) Laminated shale (Unit 3, Section 1) showing disruption of laminae by small dropstones. Rock fragment is 10cm long and the direction of younging is towards the top of the page.

Volcanic tuff

Careful examination of the sediments in the map area has revealed the existence of a thin volcaniclastic unit near to or in some cases at the top of the glacial sequence. It has been traced laterally from Section 1 in the south where it reaches a maximum of two metres in thickness through to Section 5 in the north. In Section 2 it is only o.5 metres thick and in some places it is not present where it has most probably been removed by erosion prior to deposition of the Tapley Hill Formation.

In outcrop the unit is dark to light green in colour with small angular volcanic rock fragments (also green) and minor chert and dolomite clasts dispersed through a silty matrix, which is locally pyritic. The unit is moderately sorted but appears to lack stratification or other sedimentary structures. Its unspectacular appearance resembles in some ways an ordinary lithic greywacke and if this unit occurs elsewhere in the Appila Tillite or its equivalents, it may have easily gone unrecognized.

Microscopic examination of the volcaniclastic unit has revealed it is composed of up to 70% volcanic rock fragments, up to 5% volcanic glass with excellent vitriclastic textures and around 25% of the rock consists of a silty clay matrix and sand-sized or larger clasts of chert, dolomite, quartzite, quartz and feldspar. The degree of sorting and the significant amount of dilution in this volcaniclastic sediment suggests that some minor reworking of this pyroclastic sediment has occurred. The presence of glassy shards and pumice fragments is diagnostic of reworking contemporaneous with volcanic activity. (see plate 12, 13).

Under existing classification schemes for volcaniclastic sediments (see Pettijohn, 1975; Chap. 9) this unit may be termed as a secondary lithic lapilli tuff.

Composition

A) Volcanic rock fragments

In thin section (see plate 11) the volcanic rock fragments occur as angular to subrounded clasts up to 1 cm diameter. An overwhelming majority of fragments have a felted intersertal texture with feldspars ranging from barely visible microlites up to laths 0.5 mm long, randomly dispersed through the amorphous matrix. The matrix is composed of dark brown to grey volcanic glass which is often partly replaced by chlorite and calcite.

These fragments sometimes contain phenocrysts of either single plagioclase feldspar crystals or feldspar aggregates. Also present are rare spherical amygdules filled with either chlorite clay or what appears to be fibrous zeolites. Small scattered specks of an opaque mineral in the interstitial glass may be magnetite or hematite.

The mineralogy of these volcanics suggests that the original lava was basaltic in composition and the textures are indicative of rapid quenching.

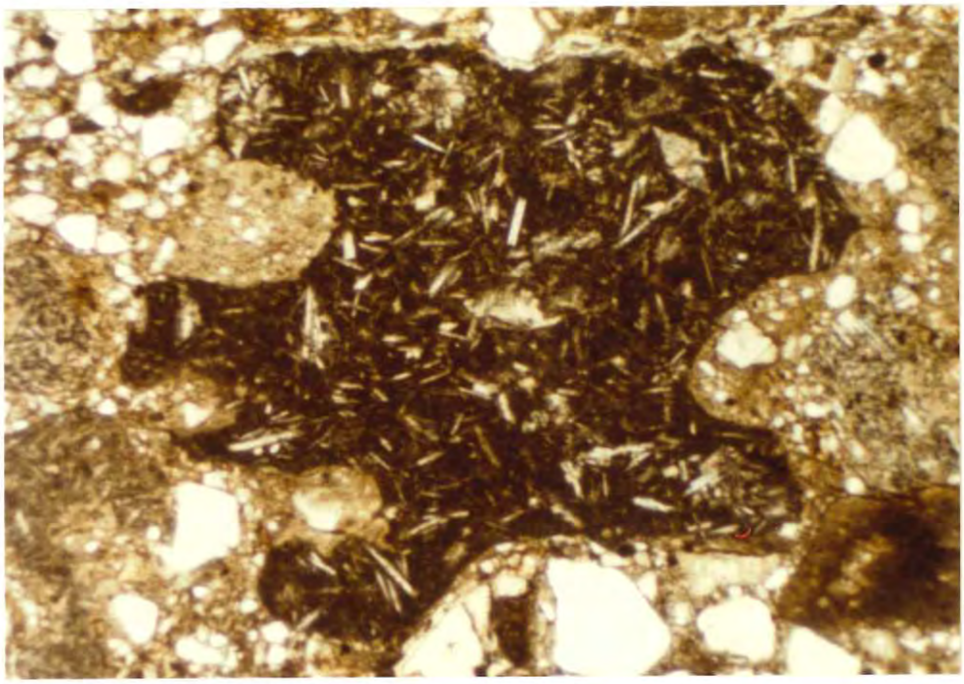
B) Shards

These fragments are generally quite small (up to 0.5 mm diameter) and are generally composed of glass or chlorite. There are some excellent examples of delicate shapes of former vesicle margins and some fragments still retain complete vesicles. A brownish tinge in the volcanic glass is thought to indicate the presence of iron (and possibly Ti) oxides.

C) Matrix

Much of the matrix material consists of clay which may have originally been volcanic ash. Dispersed through the clay are silt to pebble-size clasts of quartz, feldspar and various sedimentary rock fragments which are generally subrounded to well rounded. Undulose extinction of many of the quartz grains plus the fact that many are well rounded would argue against a volcanic provenance. In addition, quartz is highly unlikely to be a product of basaltic volcanism.

PLATE 11



a),b) Photomicrographs of volcanic rock fragments from the volcanic tuff unit at Section 1. Features to note are the felted intersertal texture of both fragments and the embayed outline of the fragment in the photo above. Both photos were taken using plane light and the field of view is approximately 4 x 6 mm.

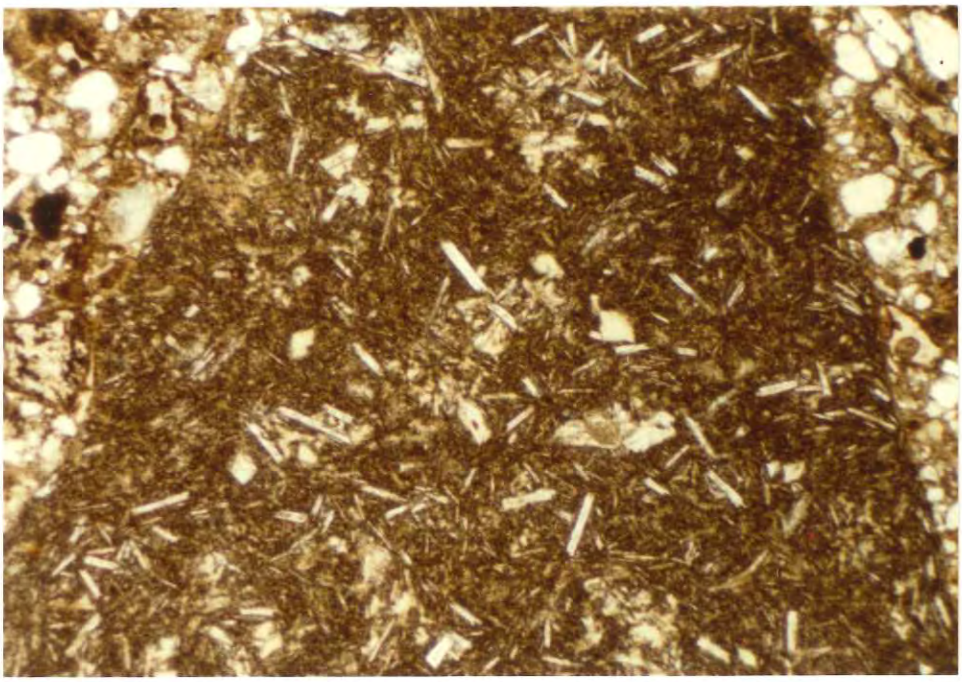
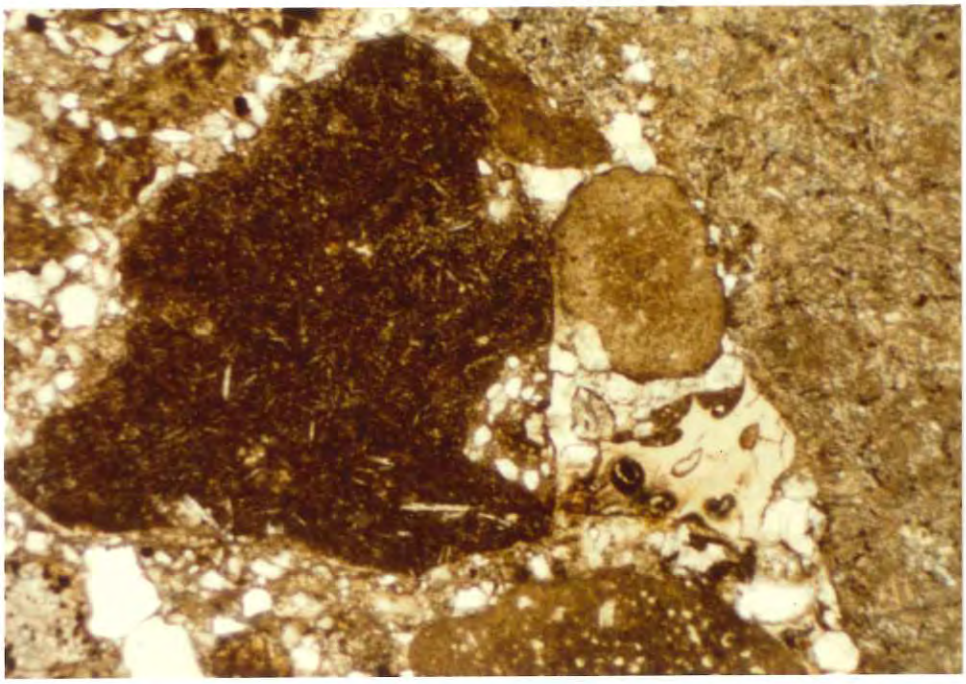
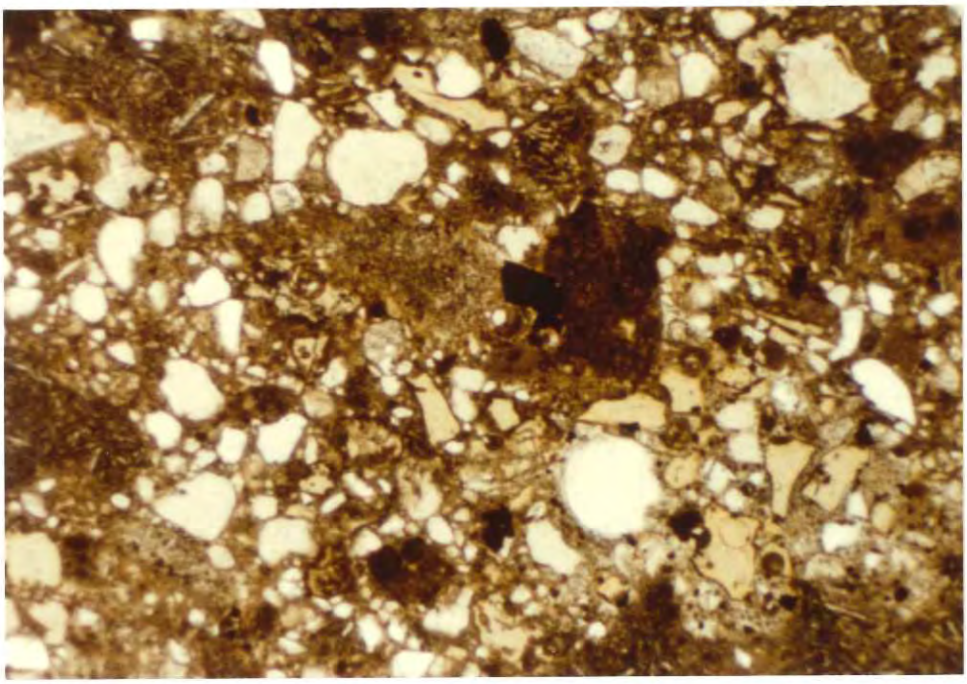


PLATE 12

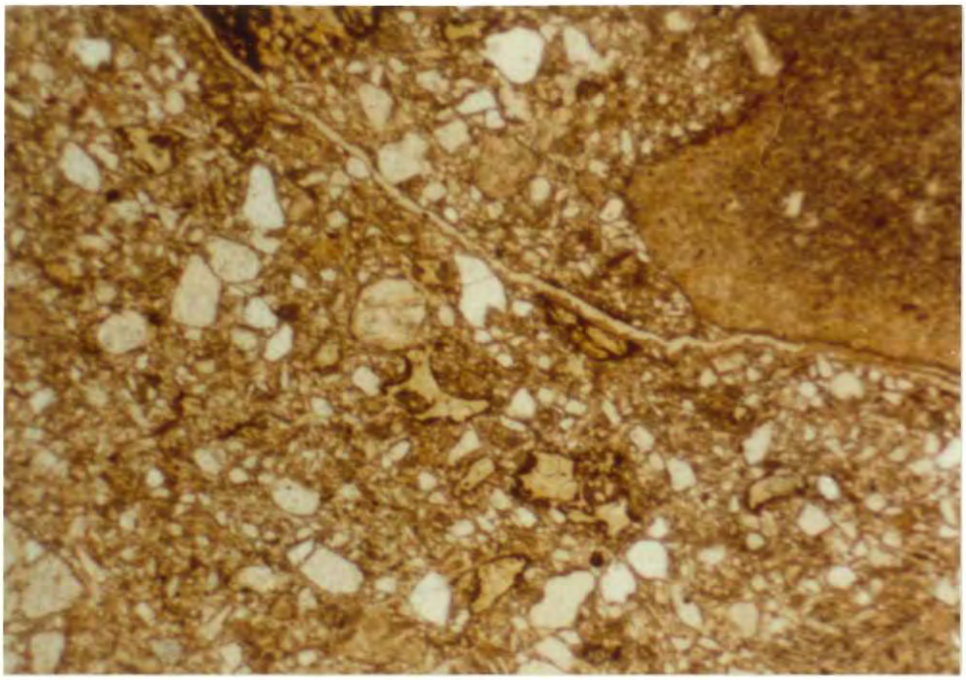


a) Photomicrograph of a pumice fragment (to the right below centre) displaying delicate curved outlines (originally vesicle margins). Some filled vesicles can also be seen within the glassy matrix. Field of view is approximately 4 x 6 mm.

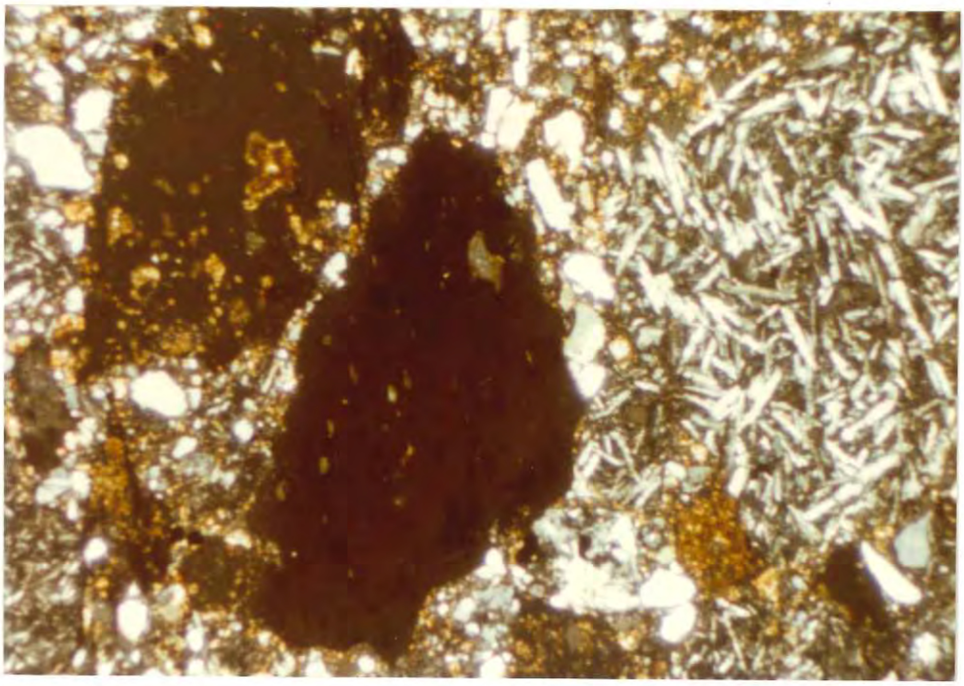


b) Scattered volcanic shards in the matrix of the volcanic tuff (Section 1). Other features include the presence of pyrite (near centre) and the high proportion of subangular to well-rounded quartz grains (colourless). Field of view is approximately 4 x 6 mm.

PLATE 13



a) Scattered shards from the matrix of the volcanic tuff (Section 1). The relict outlines of vesicles are clearly shown and the dark rims of the shards may be due to exsolution of iron oxide.
Field of view is approximately 4 x 6 mm.



b) Two large fragments of dark brown coloured volcanic glass. This colouration is probably due to the presence of iron oxide and the clast to the upper left displays partial replacement by carbonate.
Field of view is approximately 4 x 6 mm.

CHAPTER 4 : GLACIAL STRATIGRAPHY

During mapping of the glacial sequence at Depot Flat, it soon became apparent that the vertical and lateral facies relationships of the glacigene sediments were very complex. Construction of measured sections revealed that only two units could be traced laterally for any appreciable distance across the map area, the varve unit and the newly discovered volcanic tuff unit which has been used as a marker horizon.

In addition, the thicknesses of the glacigene sediments vary between 112 and 146 metres. A part of this is probably due to erosion of the glacial sequence prior to deposition of the Tapley Hill Formation. There may have also been some relief on the underlying unconformity surface and errors in measurement of sections may have also been a contributing factor. Differential basin subsidence across the map area may also be a possibility as it could also account for the thinning and thickening of some facies laterally, most notably the varve unit.

The obvious disparity in the numbers of diamictites and their relative abundances between the closely spaced sections has important implications for the interpretation of these sediments. Under lithological criteria, it appears that the majority of diamictites were deposited subaqueously and subjected to various degrees of reworking under higher energy regimes.

Complex facies relationships, including flow tills, varves, waterlain tills, random laminates and coarse subaqueous or subaerial outwash deposits are strongly suggestive of a proglacial ice-contact to subaqueous marginal marine environment (Edwards, 1978). Relatively shallow water depths are also implied.

The gross stratigraphy of the glacial sequence (particularly Section 1) suggests a tripartite division. The basal section (approximately 40 metres thick) appears to represent a period of glacial advance. Evidence from Section 1 suggests that there was a initial marine transgression flooding the area depositing laminated muds with dropstones, sandstones and also flow tills emplaced by mass-flow processes. Advancing ice is proposed as a contributing factor in the development of lacustrine conditions with the deposition of varves. The overlying waterlain tillite may have been deposited under either glaciolacustrine or glaciomarine conditions and shows evidence of shallowing upwards and/or increasing proximity of the ice-front. Following a major intraformational erosion surface, the presence of a thick breccia unit is suggestive of a minimally reworked and rapidly deposited subaerial or subaqueous outwash deposit, commonly associated with the ice-contact zone (Edwards, 1978).

The presence of a thin ankerite unit overlying the breccia suggests a rapid transition to deposition in a low energy environment.

The middle section of the glacial sequence is generally characterized by the intercalation of reasonably thick sandstones and waterlain tillites The predominantly fine grain-size of the matrix and the presence of lamination and dropstones in the waterlain tills suggests deposition from floating ice in quiet water which may have been in either a marginal glaciomarine or glaciolacustrine environment. The sandstone facies may have been deposited as either subaqueous or subaerial outwash close to the ic contact zone. A number of small advances and retreats of the ice-front across the are may well explain the alternation between these facies which is best seen in Section 1.

The upper part of the glacial sequence (approximately 60 metres in Section 1) is differentiated from the rest of the glacial sequence by the presence of ankerites, coarse clastics and clast-rich diamictites interpreted as either reworked waterlain tillites or subaqueous basal tills which may or may not be reworked. Reworking of diamictites and the presence of interbedded sandstones and breccia suggest shallow water conditions coupled with an abundance of glacial meltwater possibly indicating a general phase of glacial retreat. Ankerites may have been deposited in small lakes around the retreating glacier margin. Lakes are a common feature of deglaciation (Edwards, 1978) as are rapid lateral and vertical facies transitions, which are evident near the top of the sequence, especially involving ankerite units. Dolomites sometimes containing stromatolites have been reported from the upper part of the glacial sequence in Depot Creek by Preiss and Sweet (1966).

Table 1. Variation in some major sedimentary facies within the glacial sequence across the map area.

	SECTION 3 (south)	SECTION 1	SECTION 2	SECTION 5 (north)
NUMBER OF DIAMICTITES	13	11	12	6
% of total thickness	57%	40%	36.5%	25%
SANDSTONES, BRECCIAS, CONGLOMERATES % of total thickness	15%	38%	50%	30.5%
ANKERITES % of total thickness	17%	8.5%	6%	0%

N.B. SECTION 3 incomplete but considered to be representative.

CHAPTER 5 : PETROGRAPHY and PROVENANCE

Analysis of clast types and their relative abundances in diamictites and dropstone facies of the glacial sequence has revealed that around 75% of the clasts are of sedimentary origin. Similarities with underlying Adelaidean, in particular Burra Group, sediments strongly suggest an intrabasinal source for these clasts. As shown in Figure 9, the three main lithologies are dolomite (20%), chert (25%) and white quartzite (30%).

Dolomite clasts are usually subangular to rounded and rarely exceed cobble size. Two main varieties of dolomite have been recognized in the clast assemblage; one type is pale cream to brown in colour and the other is a darker, grey dolomite which is occasionally stromatolitic and oolitic. The majority of chert clasts are black in colour although some mottled and white varieties have been indentified. Due to the brittle nature of chert, the clasts commonly occur as angular and subangular pebble-sized fragments.

Both clast types are easily recognizable as fragments of Mundallio Subgroup lithologies. More specifically, the pale cream and brown dolomites are characteristic of the lower part of Mundallio Subgroup (locally the Nathaltee Formation) and the darker, grey coloured dolomites are characteristic of the upper part of the Mundallio Subgroup (locally the Yadlamalka Formation). Nodules of black chert are sporadically developed throughout the Mundallio Subgroup in association with carbonate facies. As the glacial sequence at Depot Flat overlies an erosional surface on the Mundallio Subgroup an intrabasinal source for the chert and dolomite clasts can be envisaged.

Evidence from other areas, however, suggests than an origin for these clast types via erosion of underlying beds is highly unlikely. For example, clasts of black chert and dolomite form on average 20% of the clast assemblage in the Sturt Tillite at Sturt Gorge (Link 1977). However, in the Adelaide region the dolomite-chert horizons of the underlying Mundallio Subgroup (the Castambul and Montacute Dolomites) are separated from the base of the glacial sequence by a thick, predominantly clastic sequence generally measuring in excess of 1,800 metres (Mawson and Sprigg, 1950).

In view of this fact, other sources for these clasts must be postulated. One possibility is that glacial debris was supplied to the Adelaide region from elsewhere within the Adelaide Geosyncline, notwithstanding a contribution from basement areas. Alternatively, it has been suggested that the Stuart Shelf may have been a source area for these clasts (Dr. B. Daily pers. comm.). Although there is no record of sedimentation of the Burra Group on the Stuart Shelf, it is conceivable that lateral equivalents of the Mundallio Subgroup occurring in the Adelaide Geosyncline were originally deposited there and were subsequently removed by glacial erosion prior to the deposition of the Tapley Hill Formation.

White quartzite is a common clast type in the glacial sequence and sizes range from anywhere between pebbles and megaclasts up to two metres in length. Although there is a tendency for larger clasts to display a greater degree of rounding, a considerable variation in rounding has been observed. Several quartzite boulders now exhumed as glacial erratics were found to be bullet shaped and according to Boulton and Deynoux (1981) such shapes are a characteristic product of glacial abrasion during englacial transport. Similar quartzite clasts have been reported from the Appila Tillite in the Orroroo map area by Binks (1971), who likened them to quartzites occurring in the upper part of the Burra Group.*

The majority of the remaining clasts (15%) are coarse-grained, muscovite-bearing white granites which usually occur as rounded cobbles and boulders up to 1.5 metres in diameter. Their presence in the glacial sequence in the Depot Flat area has been noted by all previous investigators (Howchin, 1928; Mawson 1947; Preiss and Sweet, 1966).

A minor amount of volcanic clasts have been identified in the glacial sequence from thin sections. Small but highly variable percentages of volcanic fragments appear to be generally confined to sediments in the upper half of the glacial sequence. The nearest known source areas for these fragments are the Stuart Shelf and Gawler Craton to the west.

Only single clasts of reddish-purple quartzite and porphyry, considered by Coats and Forbes (1977) as diagnostic of the younger Sturtian glacigenic successions, were identified at Depot Flat.

A rough analysis of clast percentages was performed on Section 1 (best exposure) in order to investigate any possible vertical trends. One of the most apparent trends is the constant proportion of granite clasts vertically. Dolomite and chert both vary appreciably in abundance but tend to decrease upwards whereas quartzite displays a general increasing upwards trend. Trends within the intrabasinal clasts could perhaps represent progressive stripping of the Burra Group during glaciation, especially if the quartzites are postulated to occur below the dolomites and cherts (Emeroo Quartzite?).

* presumably the Undalya or Stonyfell Quartzites.

The extreme variability in the relative abundance of certain clast types, most notably dolomite and to a lesser degree black chert, in some of the diamictites of the glacial sequence may be due to one or more of the following possibilities:

a) intermittent tapping of local sources by ice sheets of local origin
b) the relative ability of far-travelled ice sheets to erode local strata
c) heterogeneity of sedimentary source rocks either locally or in more distant areas (elsewhere in the geosyncline or on the Stuart Shelf)
d) mixing of glacial debris from ice sheets crossing different terrain.

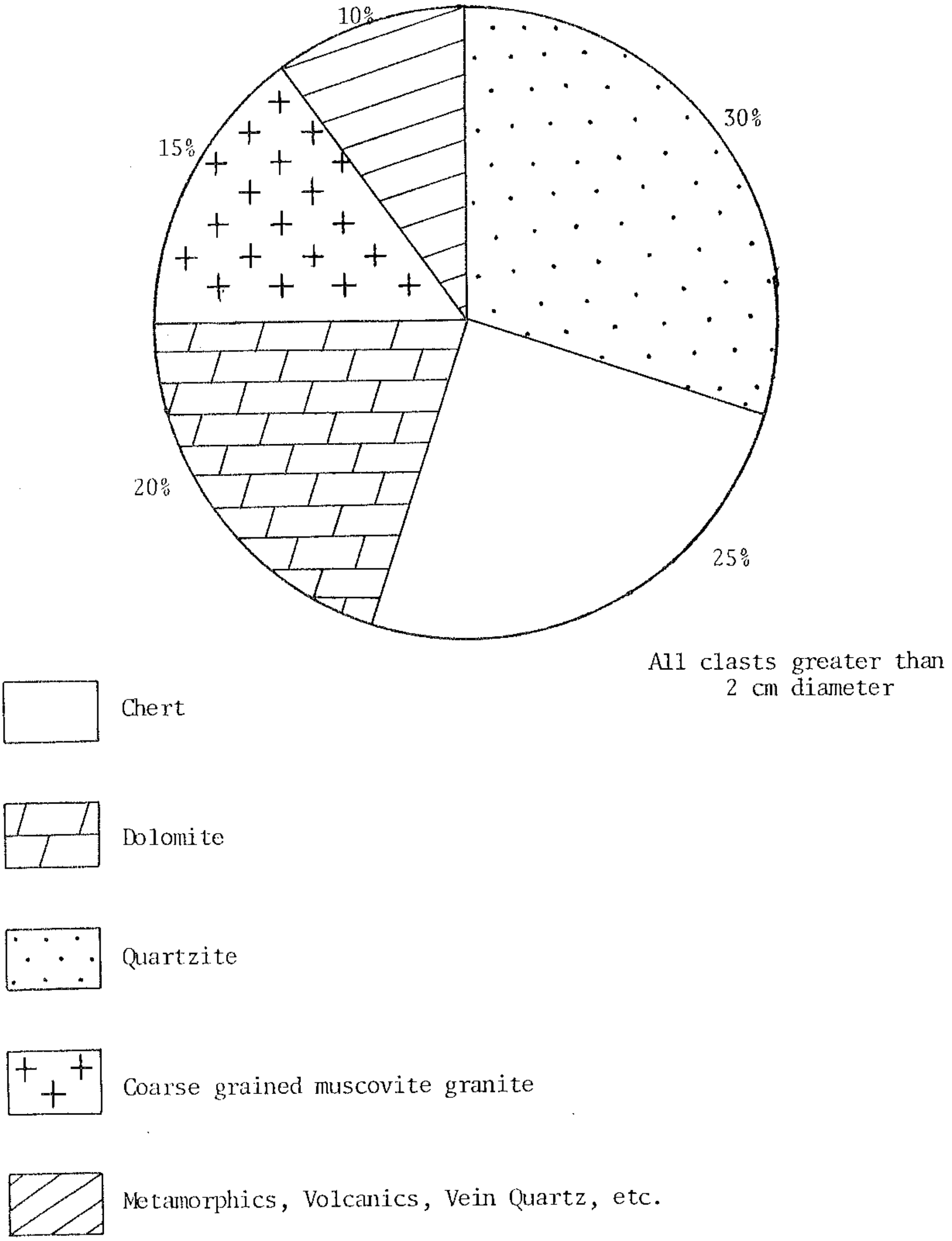
The ubiquitous occurrence of well-worn granites throughout the glacial sequence suggests that these clasts are far-travelled. The similarity of these granites and other intrabasinal clasts with rocks occurring in the Gawler Craton to the west (Binks, 1971) suggests a westerly provenance for the glacial sequence. Other evidence such as thickness variations and distributions of tillites and basinal clastic units has been cited by Rutland et al., (1981) as implying a westerly ice derivation for the younger phase of Sturtian glaciation.

A casual investigation of crossbedding in sandstones within the glacial sequence has revealed that most crossbedding, which is rare, has been caused by currents moving from west to east. Although this observation tends to support sediment movement from the west, it should be remembered that due to the complexity of contemporary glacial geomorphology, features such as crossbedding should not be considered as reliable indicators of glacial transport directions.

In summary, it appears that a major source area to the west is not incompatible with the evidence presented above. Basement clasts were probably derived from the Gawler Craton and sedimentary clasts from the underlying Burra Group or postulated equivalents on the Stuart Shelf. The possibility of some glacial transport from other source areas, including the distinction between local and more distant sources is also envisaged.

AVERAGE CLAST PERCENTAGES

Appila Tillite Equivalent



All clasts greater than 2 cm diameter

Figure 9.

DLH '83

CHAPTER 6 : COMPARISON WITH STURT and MERINJINA TILLITES

The Sturt and Merinjina Tillites are lateral equivalents of the Appila Tillite Equivalent in the Adelaide Geosyncline. The Merinjina Tillite in the Copley area some 125 kilometres north of Depot Flat and the Sturt Tillite in it's type section at Sturt Gorge near Adelaide, approximately 250 kilometres south of Depot Flat, have both been described recently by Link, (1977). Evidence from these widely separated sequences largely formed the basis of an attempted overall interpretation of the facies and paleogeography of the Sturtian glacigenic successions in South Australia by Link and Gostin (1981).

All three glacial sequences are separated from the underlying Burra Group by a regional low-angle unconformity (Coats, 1967) and there is some evidence to suggest that the magnitude of the unconformity increases northwards (Link, 1977; Coats, 1981; this study). Formation thickness is reasonably uniform varying from 220 metres at Sturt Gorge to 146 metres (maximum) at Depot Flat and between 130 and 310 metres in the Copley area. The upper contact with the Tindelpina Shale Member is apparently conformable in the Sturt Gorge and Copley area and disconformable at Depot Flat (this study).

According to Link and Gostin (1981) the younger Sturtian glacial sequences are comprised largely of three sedimentary facies suggestive of glacigene sedimentation in a shallow marine shelf environment. These facies are; the Bedded Diamictite and Siltstone Facies interpreted as shallow marine sediments with major contributions of debris supplied by ice-rafting and subaqueous mass movement, the Massive Diamictite Facies interpreted as subaqueous basal tillite deposited under a dominantly grounded ice shelf and the Calcareous Granule Conglomerate Facies thought to have been deposited by high-flow-regime carbonate-saturated meltwater during glacial retreat.

The distribution of these facies in both Sturt Gorge and the Copley area are quite similar and a tripartite stratigraphy was constructed (Link, 1977) for both sequences. Following this, Link and Gostin (1981) suggested a rather questionable correlation between these sequences based on the lateral continuity of these units. This stratigraphy has also been proposed as a fundamental framework applicable to all equivalents of the Sturt and Merinjina Tillites in the Adelaide Geosyncline.

Unit 1 of this stratigraphy is largely characterized by the Bedded Diamictite and Siltstone Facies and Unit 3 by the presence of the Calcareous Granule Conglomerate Facies. Unit 2 is represented at Sturt Gorge and Copley by a relatively thick and uniform horizon comprised of the Massive Diamictite Facies. This unit varies in thickness between 40 and 120 metres at Copley and in the Sturt Gorge it is 100 metres thick. According to Link and Gostin (1981) this facies was laid down as a thick, laterally continuous blanket of subaqueous basal till under a complete cover of grounded shelf ice (presumably at the height of the second phase of glaciation during the Sturtian).

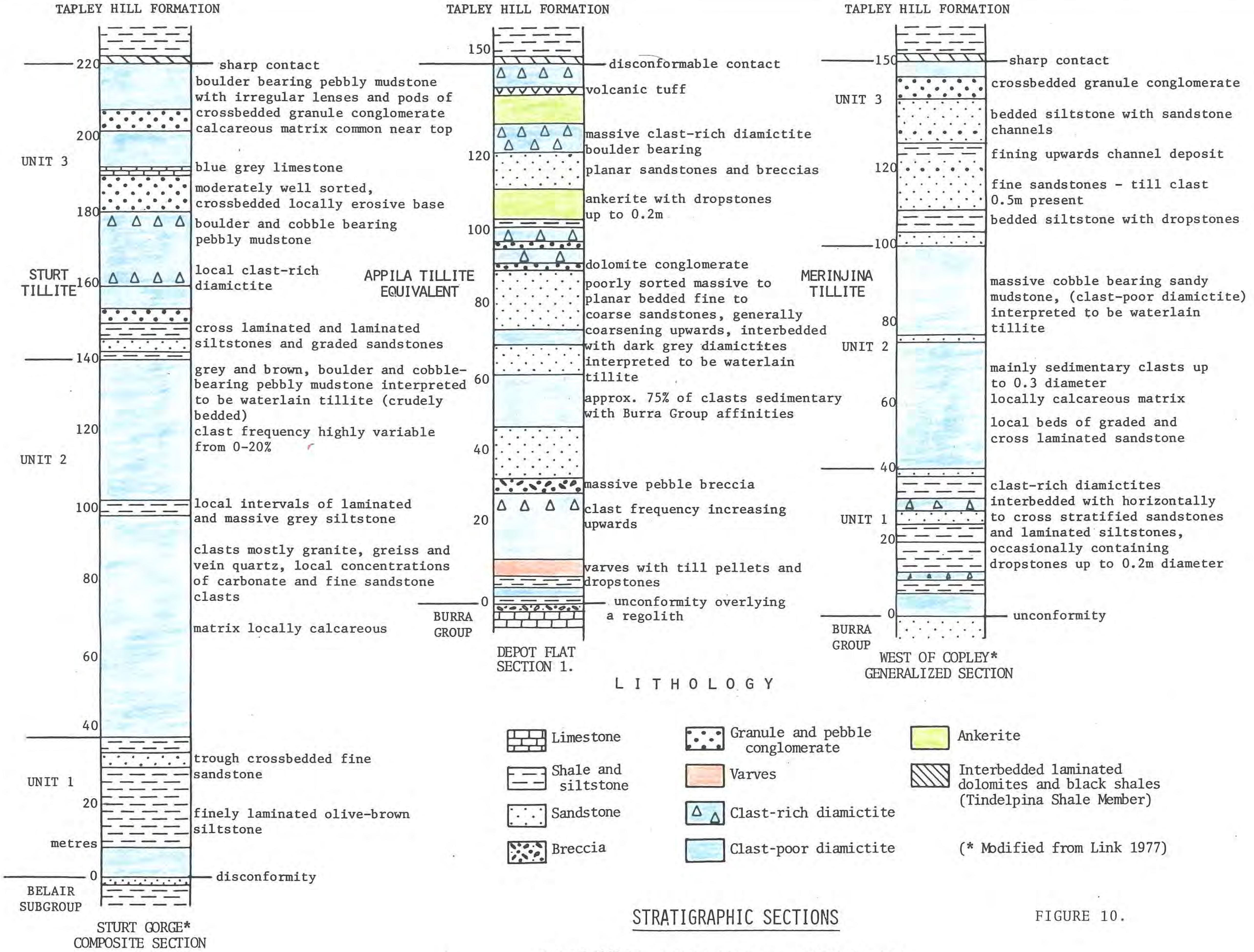
Extrapolation (actually interpolation, see Figure 10) of this framework or model of glaciation to the glacial sequence at Depot Flat reveals some major differences. There are a greater number of facies present at Depot Flat and facies relationships are much more complex than those reported from the Sturt or Merinjina Tillites or predicted from the model.

One of the most striking differences is the absence of a thick blanket of massive diamictite in the middle of the sequence at Depot Flat. Instead this part of the sequence is largely characterised by diamictites similar to those of Link's Bedded Diamictite and Siltstone Facies interbedded with abundant sandstones. This sandstone facies which can comprise of up to 50% of the total sediment thickness in any one section appears to be largely absent at Sturt Gorge and Copley. Nowhere in the sequence are diamictites found exceeding 15 metres in thickness and massive diamictites (generally scarce) are mainly restricted to thinner horizons near the top of the sequence.

Despite these differences the present author believes that the proposed model of glacigene sedimentation in a shallow marine shelf environment, although too simplistic,is basically sound. In any shallow marine environment the variation in such factors as water depth and availability of sediment would strongly affect patterns of sedimentation on a smaller scale.

For example, many of the features from Depot Flat such as the complex facies relationships, presence of varves and abundant sandstones (to name a few) suggests a shallower, more ice-proximal environment than those proposed for the glacial sequences at Sturt Gorge and Copley. This situation was perhaps reversed during deglaciation if the Calcareous Granule Conglomerate Facies is interpreted as the "high energy" equivalent of the ankerite facies seen at Depot Flat.

The similarity in the facies and stratigraphy of the glacial sequences at Sturt Gorge and Copley remains a problem. Whether this similarity is merely coincidental or in fact reflects a uniform, laterally continuous mode of sedimentation over large distances with sequences such as the one at Depot Flat representing localised variations is not clear. Until further investigation of the younger Sturtian glacigenic successions can adequately resolve this problem, the present author is inclined to believe the former suggestion.



STRATIGRAPHIC SECTIONS

STURT GORGE, DEPOT FLAT AND COPLEY AREA

FIGURE 10.

DLH '83

CHAPTER 7 : CONCLUSION

The Depot Flat area lies within the South Flinders zone of the Adelaide Geosyncline which is, according to Rutland et al., (1981), characterised by a labile shelf tectonic setting and the preglacial Adelaidean sediments here provide abundant evidence of shallow water sedimentation in this setting over a long period of time. There is ample evidence from many areas of the geosyncline of a protracted phase of tensional tectonism up to and including early Sturtian times. In the Depot Flat area this tectonism is expressed by such features as the extrusion of the Depot Creek Volcanics, and breaks in sedimentation.

One of these breaks occurs between the Burra Group and the Appila Tillite Equivalent (Umberatana Group) and has been described as a regional unconformity in the Adelaide Geosyncline (Rutland et al., 1981). The important feature of the unconformity in the Depot Flat area (present study) is the presence of a thin rubble layer which has been interpreted as a regolith formed on eroded Burra Group Sediment. This feature has not been previously reported from this contact in the geosyncline. The preservation of this regolith and the absence of a glacial pavement suggests that grounded ice did not enter this area at the beginning of glaciation.

In fact there is evidence (Section 1) that the onset of glacigene sedimentation was initiated by flooding of the area (sudden marine transgression?) which deposited laminated shales with dropstones and thin interbedded diamictites interpreted as flow tills. This postulated flooding may have been caused by isostatic depression in response to glaciation of adjacent land areas or by tectonic subsidence unrelated to glaciation.

Other facies of glacigene sedimentation found in the glacial sequence include;

1) Bedded, clast-poor muddy diamictites interpreted as waterlain tills deposited from floating ice.
2) Massive, clast-rich diamictites interpreted as either reworked waterlain tills or subaqueous basal tills deposited under ice grounded in shallow water.
3) Finely laminated varves containing till pellets and dropstones representing deposition under glaciolacustrine conditions.
4) A prominent sandstone facies deposited largely under upper-flow-regime conditions, probably as subaqueous outwash in an ice-proximal proglacial environment.
5) Conglomerates and breccias, largely representing varying degrees of reworking of previously deposited sediments in an environment similar to above.

6) Pebbly and non-pebbly ankerites interpreted as deposits of saline lakes that probably formed at times of glacial retreat.

Mapping of the glacial sequence has revealed that vertical and lateral facies relationships are very complex and with the exception of the varve unit, none of the above facies formed units that could be traced laterally for any appreciable distance. The association of these types of facies and the complexity of their inter-relationships, suggests that the glacial sequence was deposited largely in a shallow marginal marine environment in the proglacial to ice-contact zone.

The gross stratigraphy of the glacial sequence (in particular Section 1) suggests a possible tripartite division. The basal part appears to represent a period of glacial advance. Following initial flooding, advancing ice is proposed as the contributing factor in the temporary (?) development of lacustrine conditions leading to the deposition of the varve unit. The overlying diamictite unit (in Section 1) displays evidence of deposition under subaqueous conditions that shallowed or became ice-proximal upwards to an erosional surface overlain by a thick breccia unit. The middle section of the glacial sequence is dominated by the intercalation of sandstones and waterlain tills which may represent lateral ice movements across a shallow proglacial marine (?) environment. The upper part is characterised by the presence of ankerites, clast-rich diamictites and coarse clastics. The latter two facies indicate the presence of strong meltwater currents and the ankerites may have been deposited in small saline lakes surrounding the margin of a retreating glacier.

The proposed environment of deposition for the glacial sequence at Depot Flat is a shallower more ice-proximal one than the shallow marine shelf environment proposed for both the Merinjina Tillite in the Copley area and the Sturt Tillite at Sturt Gorge. The absence of a thick massive diamictite unit at Depot Flat casts serious doubts on an earlier proposal of a laterally extensive blanket of this diamictite in the glacial shelf assemblage which was based on similarities between the glacial sequences at Copley and Sturt Gorge.

Analysis of clast types and their relative abundances in diamictites and dropstone facies of the glacial sequence has revealed that around 75% of the clasts are of sedimentary origin. The majority of these were derived from erosion of the underlying Burra Group or possibly from postulated equivalents on the Stuart Shelf. Extrabasinal clasts were probably derived from the Gawler Craton to the west. The possibility of local source areas superimposed on a major westerly source area is also envisaged.

A disconformity separating the Appila Tillite Equivalent and the post-glacial Tapley Hill Formation is indicated by the removal of at least six metres of sediments from the top of the glacial sequence plus the presence of a thin conglomerate at the contact. This erosional hiatus may have been caused by post-glacial uplift or tectonic activity possibly associated with the presence of a slightly reworked volcanic tuff at the top of the glacial sequence.

The presence of lenticular beds of stromatolitic dolomite interbedded with the Tindelpina Shale Member supports proposals of a shallow marine origin for this unit.

REFERENCES

Ashley, G.M., 1975. Rhythmic sedimentation in glacial Lake Hitchcock, Massachussetts, Connecticut. In: A.V. Jopling and B.C. McDonald (Editors), Glaciofluvial and Glaciolacustrine Sedimentation SEPM Spec. Publ. pp. 304-320.

Bauld, J. and Walter, M.R. (1981). Antartic Saline Lakes: Analogue of Proterozoic Evaporite - Stromatolite - Carbonate - Tillite Associations? Geol. Soc. Aust. Abs., No. 3.

Binks, P.J. (1971). The Geology of the ORROROO 1:250,000 map area. Rept. Invest. Geol. Surv. Sth. Aust. No. 36.

Boulton, G.S. (1972). Modern Artic glaciers as depositional models for former ice sheets. J. Geol. Soc. London, 128: 361-393.

Boulton, G.S. and Deynoux, M., 1981. Sedimentation in glacial environments and the identification of tills and tillites in ancient sedimentary sequences. Precambrian Research, v. 15, pp. 397-422.

Carey, S.W. and Ahmad, N., 1961. Glacial marine sedimentation. In: W.O. Raasch (Editor), Geology of the Artic. University of Tasmania Press, pp. 865-894.

Church, M. and Gilbert, R., 1975. Proglacial fluvial and lacustrine environments. In: A.V. Jopling and B.C. McDonald (Editors) Glaciofluvial and Glaciolacustrine Sedimentation. SEPM Spec. Publ., pp. 22-100.

Coats, R.P. (1967). The "lower glacial sequence" in the Sturtian type area. Quart. Geol. Notes, Geol. Surv. S.A. No. 23 pp. 1-3.

Coats, R.P., (1981). Late Proterozoic (Adelaidean) tillites of the Adelaide Geosyncline, in Hambrey and Harland, eds. Earths Pre-Pleistocene Glacial Record. Univ. of Cambridge (IGCP Project 38).

Coats, R.P. and Forbes, B.G., (1977). Evidence for two Sturtian glaciations in South Australia - A reply. Quart. Geol. Notes, Geol. Surv. S.A. No. 64 pp. 19-20.

Dalgarno, C.R., Johnson, J.E., Forbes, B.G. and Thomson, B.P., 1968 Geological Atlas of South Australia, 1:250,000 Series AUGUSTA Sheet, Geol. Surv. Sth. Aust.

Dickson, J.A.D., 1965. A Modified Staining Technique for Carbonate in Thin Section. Nature vol. 205, p. 587.

Dow, D.B., (1965). Evidence of a Late Precambrian Glaciation in the Kimberley Region of Western Australia, Geol. Mag. Vol. 102, No. 5, pp. 407-414.

Dreimanis, A., 1976. Tills: Their origin and properties. In: Legget. R.F., ed., Glacial Till: Royal Soc. Canada Spec. Pub. 12, pp. 11-49.

Dreimanis, A., 1979. The problem of waterlain tills. In: Ch. Schluchter (Editor), Moraines and Varves. Balkema, Rotterdam, pp. 167-177.

Edwards, M.B., 1978. Glacial Environments, in Reading, H.G., ed., Sedimentary Environments and Facies: New York, Elsevier Pub. Co., pp. 416-438.

Flint, R.F., 1975. Features other than Diamicts as evidence of Ancient glaciations. In: Wright, A.E. and Moseley, F. (eds). Ice Ages: Ancient and Modern. Geol. Journ. Spec. IGS. No. 6.

Flint, R.F., Sanders, J.E., and Rogers, J. 1960. Diamictite, a substitute term for symmictite: Geol. Soc. America Bull., v. 71, pp. 1804-1810.

Forbes, B.G., Coats, R.P. and Daily, B., 1982. Precambrian Geology of the Adelaide Geosyncline. In: Archean, Proterozoic and Lower Palæozoic Geology, Eyre Peninsula and Flinders Ranges, South Australia. Guide to Excursion A, 4th Int. Symp. Ant. Earth Sci., Adelaide University, 1982.

Frakes, L.A. and Crowell, J.C., 1973. Characteristics of modern glacial sediments, application to Gondwana Glacials, in Campbell, K.S.W., ed., Gondwana Geology: Gondwana Symposium, 3d, Canberra, Australia, pp. 373-380.

Goldthwait, R.P., 1975. Glacial Deposits. Benchmark papers in Geology, vol. 21. Halsted Press.

Gostin, V.A., 1982. Records of the Late Proterozoic and Late Paleozoic Ice Ages near Adelaide. In: Geology of the Adelaide Region. Guide to Excursion B1, 4th Int. Symp. Ant. Earth Sci., Adelaide University, 1982.

Gostin, V.A. and Rust, B.R. (1981). Late Quaternary ice-margin sedimentary complexes of the Ottawa - St. Lawrence Lowlands. Geol. Soc. Aust. Abs. No. 3.

Hambrey, M.J. and Harland W.B. (Eds.), 1981. Earth's Pre-Pleistocene Glacial Record, Univ. of Cambridge (IGCP Project 38).

Harland, W.B., Herod, K.N. & Krinsley, D.H., 1966. The definition and identification of tills and tillites. Earth Sci. Rev. 2, p. 255-56.

Harrison, S., 1975. Turbidite origin of glaciolacustrine sediments, Woodcock Lake, Pennsylvania: Jour. Sed. Petrology, v. 45, pp. 738-744.

Kurtz, D.D., and Anderson, J.B., 1979. Recognition and sedimentologic description of recent debris flow deposits from the Ross and Weddell Seas, Antartica: Jour. Sed. Petrology v. 49, pp. 1159-1170.

Link, P.K. and Gostin V.A., (1981). Facies and paleogeography of Sturtian glacial strata (Late Precambrian), South Australia. Am. J. Sci., vol. 281, pp. 353-374.

Link, P.K., 1977. Facies and paleogeography of late Precambrian Sturtian glacial sediments, Copley area, northern Flinders Ranges, and in the Sturt Gorge near Adelaide, Sth. Aust. : B.Sc. Honours thesis, University of Adelaide.

Mason, M.G., Thomson, B.P., Tonkin, D.G. (1978). Regional Stratigraphy of the Beda Volcanics, Backy Point Beds and Pandurra Formation on the Southern Stuart Shelf, South Australia. Quart. Geol. Notes, Geol. Surv. S.A. No. 66, pp. 2-9.

Mawson, D., (1947). The Adelaide Series as Developed Along the Western Margin of the Flinders Ranges. Trans. R. Soc. S. Aust., 71(2), pp. 259-280.

Mawson, D., (1949b). The Late Pre-Cambrian ice age and glacial record of the Bibliando Dome. Jour. R. Soc. N.S.W. v. 82, pp. 150-172.

Mawson, D. and Sprigg, R.C., 1950. Subdivision of the Adelaide System. Aust. J. Sci. 13 (3), pp. 69-72.

Murrell, B., Link, P.K., and Gostin, V.A. (1977). Evidence for only one Sturtian Glacial Period in the Copley map area. Quart. Geol. Notes, Geol. Surv. S.A., 64, pp. 16-19.

Nystuen, J.P., 1976. Facies and sedimentation of the Late Precambrian Moelv Tillite in the eastern part of the Sparagmite Region, Southern Norway: Norges Geol. Undersokelse, v. 239, p. 70.

Ovenshine, A.T., 1970. Observations of iceberg rafting in Glacier Bay, Alaska and identification of ancient ice rafted deposits: Geol. Soc. America Bull., v. 81, pp. 891-894.

Parkin, L.W. (ed), 1969. Handbook of South Australian Geology. Geol. Surv. South Aust., 268 pp.

Pettijohn, F.J., 1975. Sedimentary rocks (3rd Edn). Harper. New York.

Preiss, W.V. and Sweet, I.P., (1966). Geology of the Depot Creek Area. University of Adelaide Honours thesis. (unpublished).

Rao, C.P. (1981). Criteria for recognition of cold water carbonate sedimentation: Berridale Limestone (Lower Permian), Tasmania, Australia. J. Sed. Pet., vol. 51 (2), pp. 491-506.

Reading, H.G. and Walker, R.G., 1966. Sedimentation of Eocambrian Tillites and Associated Sediments in Finnmark, Northern Norway. Paleogeog., Paleoclim., and Paleoecol., 2, pp. 177-212.

Rust, B.R. and Romanelli, R. 1975. Late Quaternary subaquatic outwash deposits near Ottawa, Canada. In: A.V. Jopling and B.C. McDonald (Editors), Glaciofluvial and Glaciolacustrine Sedimentation. SEPM Spec. Publ., pp. 177-192.

Rust, B.R., 1979. Coarse Alluvial Deposits. In: R.G. Walker (Editor), Facies Models, Geoscience, Canada, pp. 9-22.

Rutland, R.W.R., Parker, A.J., Pitt, G.M., Preiss, W.V. and Murrell, B. (1981). The PreCambrian of South Australia. In: Hunter, D.R. (ed), Pre-Cambrian of the Southern Hemisphere. Elsevier.

Saunderson, H.C., (1975). Sedimentology of the Brampton Esker and Its Associated Deposits : an Empirical Test of Theory, in Jopling, A.V. and McDonald, B.C., Glaciofluvial and Glaciolacustrine Sedimentation. SEPM Spec. Publ. pp. 155-177.

Schermerhorn, L.J.C., 1974. Late Precambrian mixtites: glacial and/or non-glacial?: Am. Jour. Sci., v. 274, pp. 673-824.

Segnit, R.W., (1939). The Precambrian - Cambrian Succession, the general and economic geology of these systems in portions of South Australia. Bull. Geol. Surv. S. Aust. 18.

Simpson, E.S. (1961). A groundwater mechanism for deposition of glacial till. Int. Geol. Cong. 21 (26) p. 103-7.

Spencer, A.M. (1971). Late Precambrian Glaciation in Scotland. Mem. Geol. Soc. London. No. 6 100 pp.

Sugden, D.G. & John, B.S., 1976. Glaciers and landscape. Edward Arnold, London.

Sumatojo, J., 1974. A study of the mineralogy and geochemistry of the Tindelpina Shale (Upper Proterozoic) Adelaide Geosyncline, South Australia. Univ. Adelaide Ph.D. Thesis (unpubl.).

Sumatojo, J. and Gostin, V.A., 1976. Geochemistry of the Late Precambrian Sturt Tillite, Flinders Ranges, South Australia: Precambrian Research, v. 3, pp. 243-252.

Thomson, B.P., (1966). The lower boundary of the Adelaide system and older relationships in South Australia. J. Geol. Soc. Aust., 13, pp. 203-228.

Tucker, M., (1982). Precambrian dolomites - Petrographic and isotopic evidence that they differ from Phanerozoic dolomites. Geol. vol. 10 (1), pp. 7-12.

Uppill, R.K., (1979). The Late Precambrian Mundallio Subgroup: A Clastic-Carbonate Sequence, South Australia. Univ. of Adel. Ph.D. Thesis. (unpublished).

Webb, A.W. and Horr, G. (1978). The Rb-Sr age and petrology of a flow from the Beda Volcanics. Quart. Geol. Notes, Geol. Surv. S.A., 66, pp. 10-13

APPENDIX I

Thin Section Descriptions

A selected number of thin sections (T.S.) held under the accession number 814 - by the Geology Department were examined under the petrological microscope and these are described below. The classification scheme and terminology is based on Folk (1974).

814-001-S1, Regolith, Section 1.

Calcirudite

Macro: Pebble to cobble breccia composed almost entirely of angular to subrounded dolomite rock fragments with minor chert set in a fine grained grey carbonate matrix.

Micro: Poorly sorted, granule to cobble size clasts, angular to subrounded in a fine grained matrix partly composed of carbonate cement.

60% dolomite rock fragments
25% shale and siltstone rock fragments
15% angular quartz silt and carbonate cement matrix

814-011-S1, Unit 1, Section 1.

Sandy mudstone: immature clay cemented litharenite

Macro: Laminated shale with sandy to pebbly winnowed bands and small dispersed dropstones.

Micro: Quartz grains and rock fragments predominantly sand size, subangular to well rounded concentrated in bands within a clay rich rock.

30% clay matrix
60% monocrystalline quartz
10% sedimentary rock fragments

814-021-S1, Unit 2, Section 1.

Diamictite

Macro: Poorly bedded and sorted sandy clast-poor diamictite.

Micro: Extremely poorly sorted, pebble to silt-size clasts, angular to well rounded dispersed through a mictite and clay matrix.

50% matrix of micritic carbonate cement and clay
30% monocrystalline quartz
10% dolomite rock fragments
5% chert
4% rock fragments (igneous, metamorphic)
1% composite quartz

814-031-S1, Unit 3, Section 1

Sandy mudstone: immature clay cemented litharenite

Macro: Laminated shale with sandy winnowed bands and small dispersed dropstones.

Micro: Sand size grains subangular to well rounded, concentrated in bands with angular quartz silt dispersed evenly throughout the clay matrix.

80% clay - silt matrix
9% quartz
1% feldspar, opaques, mica

814-091-S1, Unit 9 (base), Section 1.

Sandy micrite

Macro: Dark grey extremely fine grained ankerite, with minor sand size dispersed clasts.
Micro: Angular to subrounded fine silt to sand-size clasts in a micrite matrix. Rare clast 5cm long.

70% matrix
20% quartz
5% dolomite rock fragments
3% chert
2% quartzite

Discussion: Due to the low energy levels needed to deposit microcrystalline dolomite the clasts should be considered as dropstones.

814-092-S1, Unit 9 (above 091), Section 1.
Sandy micrite

Macro: Micritic ankerite.

Micro: Angular to subrounded fine silt to coarse sand-size grains, poorly sorted.

80% matrix
15% quartz
4% dolomite rock fragments
1% chert

814-093-S1, Unit 9 (above 092), Section 1.
Fine sandstone: immature carbonate cemented feldspathic litharenite.

Macro: Dark grey fine grained sandstone.

Micro: Fine to very fine sand-sized, well sorted, angular to subrounded and carbonate cemented.

10% carbonate micrite matrix
40% quartz, straight extinction
40% quartz, undulose extinction
5% feldspar
4% chert
1% sedimentary rock fragments

814-094-S1, Unit 9 (above 093), Section 1
Coarse sandstone: immature carbonate cemented sublitharenite.

Macro: Dark grey massive coarse grained sandstone.

Micro: Poorly sorted, angular to well rounded, silt to pebble-size grains. Larger grains more rounded than smaller ones. Micritic matrix.

20% micrite matrix
60% monocrystalline quartz
9% carbonate rock fragments
1% feldspar
5% chert
5% sedmentary rock fragments

814-095-S1, Unit 9 (above 094), Section 1.
Fine sandstone: submature quartz arenite

Macro: Fine grained massive grey sandstone.

Micro: Homogenous, angular to subrounded coarse silt, very well sorted with minor clay matrix.

95% quarts
5% clay matrix

814-096-S1, Unit 9 (above 095), Section 1

Medium sandstone: immature carbonate cemented feldspathic litharenite.

Macro: Grey bedded medium sandstone.

Micro: Moderately well sorted, subangular to subrounded fine to medium sand-size grains in a micrite matrix.

10% micrite matrix
65% quartz
7% quartzite
3% dolomite rock fragments
5% feldspar
10% chert

814-097-S1, Unit 9 (above 096), Section 1.
Coarse sandstone: immature carbonate cemented cemented feldspathic sublitharenite.

Macro: Massive grey coarse grained sandstone.

Micro: Well sorted, subangular to subrounded clasts dispersed evenly through a micrite matrix.

10% micrite matrix
75% quartz
5% dolomite
4% fedspar
3% quartzite
3% chert

814-131-S1-3, Unit 13, Section 1

Medium sandstone: immature carbonate cemented feldspathic sublitharenite.

Macro: Medium grey coloured homogenous sandstone.

Micro: Moderately sorted, angular to subrounded medium sand grains in a sparite matrix.

75%	quartz
7%	matrix
5%	feldspar
10%	chert
1%	detrital mica
2%	opaques

814-131-S1 (2) Unit 13, Section 1

Fine sandstone: immature carbonate cemented subfeldsarenite.

Macro: Grey fine grained sandstone, homogenous well sorted.

Micro: Moderately sorted clasts angular to well rounded, predominantly fine sand-size, set in a sparite matrix.

10%	matrix
78%	quartz
5%	feldspar
5%	chert
2%	quartzite

814-131-S1 (1)

Similar to the above except for a granite clast, 1 cm. diamater in the sandstone and may be a dropstone.

814-131-S1 (4), Unit 13, Section 1

Conglomerate

Macro: Poorly sorted conglomerate band near the top of the sandstone unit. Angular to well rounded granite to cobble-size clasts in a sandy matrix.

Micro: Coarse sand to granite-size clasts floating in a poorly sorted matrix of silt to sand-size grains and minor carbonate cement. Matrix grains are angular to subrounded and the clasts are angular to well rounded.

Composition (overall)

75% quartz
5% feldspar
10% chert
8% dolomite rock fragments
1% metamorphic rock fragments
1% quartzite

814-141-S1(2), Unit 14, Section 1.

Diamictite

Macro: Grey muddy-silty sparse diamictite

Micro: Very poorly sorted with sand to pebble-size clasts floating in a matrix of clay and silt-sized particles. Clasts angular to well rounded.

50% matrix
23% quartz
1% quartzite
10% metamorphic rock fragments
5% volcanic rock fragments
10% sedimentary rock fragments
1% feldspar

814-151-S1, Unit 15, Section 1

Fine sandstone: immature carbonate cemented sublitharenite.

Macro: Dark grey massive homogenous sandstone with thin wispy silt bands.

Micro: Well sorted, angular to subrounded coarse silt to fine sand-size grains dispersed through a micritic matrix.

10% matrix
80% quartz
5% dolomite rock fragments
2% feldspar

814-A-S1, Unit A, Section 1

Dolomite bearing conglomerate

Macro: Granule to cobble clasts predominantly composed of dolomite rock fragments dispersed through a silty matrix.

814-A-S1, Unit A, Section 1 (cont'd)

Micro: Very poorly sorted, angular to well rounded clasts, coarse silt to pebble-size (mode: medium sand) in a microsparite matrix.

10% microsparite matrix
30% dolomite rock fragments
20% chert
40% quartz

814-B-S1, Unit B, Section 1.

Diamictite

Macro: Dark grey clast, rich sandy diamictite.

Micro: Very poorly sorted, silt to pebble-size clasts, angular to subrounded set in a clay matrix.

7% clay
20% quartz silt
30% quartz sand
3% volcanic rock fragments -
40% sedimentary rock fragments

814-D-S1, Unit D, Section 1

Granule conglomerate

Macro: Clast supported

Micro: Angular to well rounded clasts mainly granule-size in a sparite matrix.

\- monocrystalline quartz
25% straight extinction
40% undulose extinction
10% feldspar
5% volcanic rock fragments
3% dolomite rock fragments
2% chert
5% quartzite
10% sparite matrix

814-G-S1, Unit G, Section 1.

Ferroan dolomite

Macro: Buff weathering, dark grey fine grained carbonate.

Micro: Almost entirely micrite with minor scattered angular quartz silt clasts and minor areas of recrystallization.

99% micrite
1% quartz silt.

814-G-S1 (2), Unit G, Section 1

Granule conglomerate

Macro: Conglomeratic band in the middle of the ankerite unit.

Micro: Fine sand to granule-size clasts, angular to subrounded, poorly sorted, dispersed through a partly recrystallized micrite matrix.

30% micrite matrix
20% monocrystalline quartz
30% quartzite
20% chert

814-G-S1 (3), Unit G, Section 1.

Muddy siltstone: immature carbonate cemented siltstone

Macro: Fine grained laminated siltstone.
Micro: Moderately well suited, fine to coarse angular silt, set in a micrite matrix.

40% micrite matrix
60% monocrystalline quartz
    straight extiction (40 %)
    undulose extinction (60%)

814-H-S1 (1), Unit H, Section 1.

Siltstone

Macro: Grey finely laminated siltstone.
Micro: Very well sorted, homogenous, angular to subrounded silt-sized grains in a clay carbonate matrix.

5% clay-carbonate matrix
1% mica
94% quartz silt

814-H-S1 (2), Unit H, Section 1.

Fine sandstone: submature carbonate cemented quartzarenite.

Macro: Finely bedded massive fine grained sandstone.

Micro: Very well sorted, angular to subrounded fine sand-size grains in a microsparite matrix.

90% quartz
7% matrix
3% feldspar

814-H-S1 (3), Unit H, Section 1.

Medium sandstone: mature feldspathic litharenite.

Macro: Well sorted medium sandstone.

Micro: Well sorted, angular to well rounded, medium sand-size grains in a minor clay matrix (5%)

60% quartz
20% Carbonate rock fragments
10% Feldspar
5% volcanic rock fragments
5% chert

814-J-S1, Unit J, Section 1.

Diamictite

Macro: Clast-rich grey silty diamictite. Mainly pebble to cobble-size clasts with some granite megaclasts up to 0.75 metres diameter.

Micro: Very poorly sorted, angular to well rounded sand to pebble-size clasts in a matrix of clay and fine to coarse angular quartz silt.

20% matrix
50% quartz
5% chert
24% sedimentary rock fragments (siltstone, sandstone, dolomite, quartzite)
1% Volcanic rock fragments

814-K-S1, Unit K, Section 1.

Diamictite

Macro: Dark grey ankeritic clast, poor diamictite with predominantly sand to pebble-size clasts.

Micro: Poorly sorted with silt to granule-size clasts, angular to subrounded dispersed randomly through a micrite matrix which is locally recrystallized.

60% micrite matrix
30% quartz
3% chert
6% sedimentary rock fragments, (siltstone, quartzite carbonate)
1% feldspar

814-M-S1, Unit M, Section 1.

Diamictite

Macro: Sandy clast, rich diamictite containing granite megaclasts up to 1 metre diameter.

Micro: Poorly sorted, angular to well rounded sand to pebble-size clasts in a recrystallized carbonate matrix.

20% matrix
50% quartz
20% sedimentary rock fragments, (dolomite, quartzite)
5% chert
2% volcanic rock fragments
3% feldspar

814-UB-S1, Upper breccia, Section 1.

Macro: Green grey fine grained rock containing granule to pebble clasts of a flaky light green rock and minor dolomite and chert.

Micro: Poorly sorted, angular to well rounded clasts sand to pebble-size in a silty clay matrix.

10% matrix
60% volcanic rock fragments
26% quartz
3% chert
1% dolomite

814-021-S3, Unit 2, Section 3.

Diamictite

Macro: Brown muddy moderately clast-rich diamictite with rare megaclasts up to 0.5 metre diameter - bullet shaped.

Micro: Angular to well rounded sand to pebble-size clasts set in a clay matrix. Poorly sorted and apparently unstratified.

60% matrix
30% quartz
15% sedimentary rock fragments, (dolomite, mudstone)
1% volcanic rock fragments
2% feldspar
3% chert

814-031-S3, Unit 3, Section 3.

Diamictite

Macro: Muddy moderately clast-rich diamictite with sand to boulder-size clasts.
Micro: Poorly sorted, angular to well rounded silt to pebble-size clasts in a clay matrix, apparently unstratified.

30% clay matrix
40% quartz
20% sedimentary rock fragments, (chert, dolomite, quartzite, siltstone)
9% metamorphic rock fragments
1% feldspar

814-031-S3, Unit 3, Cemented lens, Section 3.

Diamictite

Macro: Brown muddy moderately clast-rich diamictite.

Micro. Moderately sorted angular to well rounded silt to granule-size clasts dispersed through a partly micritic clay matrix.
60% matrix
20% quartz
5% chert
10% sedimentary rock fragments
5% feldspar

814-033-S3, Unit 3, Silty clast free lens, Section 3.

Silty mudstone

Macro: Red - brown massive siltstone.

Micro: Moderately well sorted with angular quartz silt scattered through a clay matrix.

75% clay matrix
25% quartz silt

814-034-S3, Unit 3, Sandy lens, Section 3.

Medium sandstone: immature clay cemented litharenite.

Macro: Massive medium brown sandstone.

Micro: Moderately sorted, subangular to well rounded fine to medium sand-size grains set in a clay matrix.

7% clay matrix
70% quartz
5% chert
3% feldspar
15% sedimentary rock fragments

814-035-S3, Unit 3, Sandy matrix lens, Section 3.

Diamictite

Macro: Massive brown clast-poor sandy diamictite.

Micro: Poorly sorted angular to well rounded clasts ranging from coarse silt to granule-size in a clay matrix. Poorly stratified.

5% clay matrix
65% quartz
7% chert
5% feldspar
18% sedimentary rock fragments

814-036-S3, Unit 3, Sandy clast-rich lens, Section 3.
Sandy mudstone: immature clay cemented litharenite.

Macro: Brown massive moderately sorted coarse sandstone.
Micro: Poorly sorted subangular to well rounded sand to pebble-size (dominantly granule-size) clasts set in a clay matrix.

814-041-S3, Unit 4, Section 3.

Diamictite

Macro: Brown sparse silty-sandy pebble diamictite crudely stratified by separation of muddy bands.

Micro: Moderately well sorted fine sandstone with a clay matrix - no clasts larger than coarse sand present.

7%	clay matrix
80%	quartz
5%	mica
7%	sedimentary rock fragments
1%	feldspar

814-061-S3, Unit 6, Section 3.

Diamictite

Macro: Similar to Unit 4 above except for a higher proportion of clasts such that it may be termed clast-poor. No apparent bedding.
Micro: Poorly sorted angular to rounded sand to pebble-size clasts in a silt-clay matrix.

60%	matrix
20%	quartz
12%	sedimentary rock fragments
4%	mica
2%	chert
2%	volcanic rock fragments

814-081-S3, Unit 8, Section 3.

Laminated sandy siltstone

Macro: Laminated green grey siltstone containing small scattered clasts and also clast-rich winnow bands.

Micro: Random laminations of clay-rich bands between thick bands of silt to coarse sand-size grains, angular to well rounded floating in a clay matrix.

30%	matrix
60%	quartz
3%	chert
2%	feldspar
5%	sedimentary rock fragments

814-121-S3, Unit 12, Section 3.

Diamictite

Macro: Sandy to silty matrix clast poor diamictite with mainly pebble-size clasts set in a matrix of clay and silt.

45% matrix
35% quartz
13% sedimentary rock fragments
2% volcanic rock fragments
5% feldspar

814-131-S3, Unit 13, Section 3.

Medium sandstone: immature sublitharenite

Macro: Brown medium sandstone moderately well sorted with small scattered granules and wispy laminations of clay define a crude stratification.

Micro: Moderately well sorted, subangular to well rounded clasts in a carbonate matrix. Irregular thin laminae of clay. Grain-size predominately medium sand with minor scattered granules and pebbles.

5% matrix
75% quartz
19% feldspar
10% sedimentary rock fragments

814-171-S3, Unit 17, Section 3.

Breccia

Macro: Moderately sorted elongate to equant angular to subrounded clasts set in a silty matrix.

Micro: Poorly sorted with angular to well rounded clasts closely packed with minor silt-clay matrix.

60% shale clasts
10% dolomite
1% quartzite
10% quartz
1% chert
10% matrix
3% feldspar

N.B. The deformation of the shale clasts indicate that they may have been semilithified when they were eroded and redeposited.

814-181-S3, Unit 18, Section 3.

Diamictite

Macro: Brown, moderately clast-rich silty matrix diamictite partly bedded and containing sandstone interbeds.

Micro: Subangular to well rounded sand to pebble-size clasts floating in a matrix of 60% quartz silt and 40% clay.

70%	matrix
20%	quartz
6%	sedimentary rock fragments
1%	chert
3%	feldspar

814-191-S3, Unit 19, Section 3.

Laminated siltstone

Macro: Randomly laminated siltstone with both finer clay bands and coarser sandy bands with dispersed granules.

Micro: Clay rich laminae having gradational compacts with the silt layers which consist predominately of angular quartz silt and micas. Larger granules are more rounded.

20%	clay
70%	quartz and mica silt
10%	sand size or larger grains of the clast assemblage
80%	quartz
5%	feldspar
10%	sedimentary rock fragments
5%	mica

814-200-S3, Unit 20, Section 3.

Micrite (ankerite)

Macro: Dark grey fine grained ankerite with a small percentage of dispersed pebble to cobble-size clasts.

Micro: Partly recrystallized micrite matrix with scattered angular to subrounded silt to pebble-size clasts.

90%	micrite matrix
7%	quartz
2%	sedimentary rock fragments
1%	chert

814-211-S3, Unit 21, Section 3.

Diamictite

Macro: Sandy clast-rich pebbly diamictite.

Micro: Poorly sorted angular to subrounded coarse sand to pebble-size clasts set in a matrix of clay to sand-size grains of quartz and carbonate.

25%	matrix
30%	volcanic rock fragments
20%	chert
20%	dolomite
5%	quartz

APPENDIX II

Detailed Section Descriptions

During fieldwork five measured sections accross the glacial sequence were made. Owing to unfavourable topography and exposure Sections 3 and 4 are incomplete. A considerable amount of attention was paid to Section 1 where the best outcrops occur. The sections were measured using a 2 metre Jacob's Staff and the thickness shown are true thicknesses, rounded off to the nearest half a metre.

Section 1

Unit	Metres	
1	0-2	A finely laminated dark grey-green shale with occasional coarse bands and small dispersed dropstones up to 3 cm diameter. Soft sediment deformation features include convoluted bedding, load casts, microfaulting and structures. Sharp upper and lower contacts.
2	2-4	Sandy clast-poor pebble to cobble diamictite. Poorly sorted and alignment of clasts defines crude bedding. Maximum clast size 10 x 15 cm.
3	4-5	Laminated shale similar to above.
4	5-7	Sandy clast-poor diamictite similar to above.
5	7-13	Varves with small dropstones up to 5 cm diameter. Upper and lower contact gradational.
5A	13-14.5	Moderately clast-rich sandy matrix diamictite. Poorly stratified, angular to subrounded granule to pebble-size clasts. Maximum clast size 5 cm. diameter.
5B	14.5-15	Finely laminated shale with coarse bands and rare small dropstones. Diffuse lower contact and sharp upper contact.
5C	15-16	Planar bedded medium sandstone, grey in colour and well sorted and clast free.
6	16-31	Diamictite grading from a dark grey muddy matrix and clast-poor at the base through to sandy and moderately clast-rich near the top. Partly well stratified and contains several large dropstones of white granite (up to 1 metre diameter). Very poorly sorted, clasts angular to well rounded.
8	31-35	Sedimentary breccia, moderately well sorted with sharp upper and lower contracts.
9	35-43.5	Interval begins with a very fine grained ankerite unit approximately 1 metre thick. Above this is a coarsening

		upwards sequence of fine to coarse sandstones, dark grey due to ankerite matrix content. Several poorly sorted breccia bands occur containing clasts up to 30 cm. diameter. Large scale tabular crossbedding.
10	43.5 - 44.5	Grey muddy clast-rich diamictite. Contains megaclasts up to 30 cm. diameter and patches of sandstone which may be contorted lenses. Sharp contacts.
11	44.5-48	Thin sequence of thinly interbedded silt, sandstone and conglomerates. Sandstones display excellent tubular to trough crossbedding, siltstones have plane to wavy laminations and conglomerates tend to have errosional contacts. Scattered clasts increase upwards.
12	48-62	Sharp transition to a dark grey muddy matrix massive to partly bedded diamictite. Large megaclasts of granite up to 1 m. diameter, probably dropstones. Becomes sandier and more stratified upwards gradually passing into the overlying unit. Structural complications occur here where faulting along cleavage occurs and also minor folding.
13	62-71	Coarsening upwards sequence of sandstones from laminated clast free silts at the base to poorly bedded medium clast free sandstones forming the bulk of the unit. Upwards diamictitic bands with clasts up to 30 cm. diameter occur as well as a general increase in scattered clasts. Sharp upper contact.
14	71-76	Dark grey silty granule to pebble sparse diamictite. Finely laminated to massive.
15	76-90	Fine medium grained sandstones, planar bedding with interbeds of conglomerate up to 0.5 metre thick and laminated clast free shale (30 cm.).
A	90-92	Conglomerate consisting predominantly of dolomite clasts (90%) in a matrix of grey silt.
B	92-98	Clast-rich silty diamictite. Average clast size 1 cm. and up to 20 cm. in diameter. No apparent bedding.
D	98-100	Granule conglomerate unit: Well bedded and coarsening upwards from a medium sandstone to a granule conglomerate (clast supported) but sharp contacts occur between layers. Texturally mature.
E	100-103	Gradational contact with underlying unit. Sandy diamictite grading from clast-rich and massive at the base to clast-poor and weakly stratified at the top. Clasts rarely exceed 5 cm. diameter.

F	103-107	Unusual sequence of thinly interbedded laminated dark grey clast free shales with sandstones and well sorted granule and pebble conglomerates which are commonly lenticular. Sharp contacts above and below.
G	107-113	Ankerite unit massive to finely laminated clast free at the base with scattered clasts increasing upwards and up to 5 cm. diameter. Sharp contacts.
H, I	113-122	General "coarsening upwards" sequences. The base of the unit begins with a clast free finely laminated siltstone grading into trough crossbedded fine sandstones and coarsening upwards into a sequence of planar interbeds of coarse sandstone breccias, well to poorly sorted with clasts up to 10 cm. diameter, angular to well rounded. Sharp bed contacts. Some units thicken eastwards. Elongate clasts lie parallel to bedding.
J	122-130	Transition to a sandy clast-rich diamictite which is unstratified and contains megaclasts up to 1 metre diameter. Angular to well rounded clasts. Upwards the unit gradually passes into a sequence of bedded clastics.
	130-132	Thin sequence of moderately sorted sandstones and breccia, planar to crossbedded.
K	132-137	Ankerite with variable amount of scattered clasts up to 30 cm. diameter. Minor sandy interbeds. Sharp upper contact, possibly erosional.
L	137-138.5	Moderately sorted coarsening upwards, sandstone and pebble and cobble breccias
UB	138.5-140.5	Volcanic breccia
	140.5-141	Ankerite bed, clast free
M	141-146	Clast-rich sandy diamictite. Partly stratified with segregation of clast-rich and clast-poor bands. Clasts angular to well rounded and megaclasts up to 1 metre diameter present.
	146-146.5	Laminated (stromatolitic) dolomite.
	146-	Tindelpina Shale Member.

Section 2

	0-16	As for Section 1.
6	16-27	Dark grey clast-poor muddy matrix diamictite partly bedded and containing granite megaclasts up to 1 metre diameter. Becoming sandy and moderately clast-rich upwards.
7	27-31	Generally coarsening upwards sequence of medium to coarse sandstones containing scattered clasts and granule conglomerate bands. Planar bedding with some wispy heavy mineral laminations.
8	31-35	Gradational contact with sedimentary breccia unit laterally traceable from Section 1 to the south.
9	35-36	Thin unit of clast free silts coarsening upwards into a medium sandstone.
10	36-37	Thin ankerite unit containing small scattered clasts.
11	37-46.5	Ankerite passes upwards into a coarsening upwards sequence of planar to tabular crossbedded medium to coarse sandstones. Thin conglomeratic bands, poorly sorted, and scattered clasts up to 30 cm. diameter increasing in frequency upwards.
12	46.5-48	Thin unit of dark grey muddy sparse diamictite with clasts up to 10 cm. diameter. Also contains a thin interbedded sandstone. May be a dropstone facies.
13	48-53	Fine to medium sandstone planar bedded and clast free. Thin interbedded dark grey shales. Upper contact gradational.
14	53-59.5	Dark grey muddy clast-poor diamictite. Angular to subrounded clasts up to 50 cm. diameter distributed irregularly throughout. Bedding outlined by bands of fine silt and also well sorted granule conglomerates.
15	59.5-61.5	Grey sandy clast-rich diamictite. Clast contact increasing upwards. No apparent bedding. Gradational contact with overlying unit.
16	61.5-74	Planar to slightly crossbedded sandstones containing dispersed angular to subrounded pebbles. Upwards the unit grades into a sequence of interbedded thin sandstones, silts and conglomerates with abundant scattered clasts up to a granite megaclast 1 metre diameter which may be a dropstone. Upper contact gradational.
17	74-78	Dark grey muddy clast-poor diamictite with granule to cobble-size angular to subrounded clasts.
18	78-85	Sequence of planar interbedded sandstones and siltstones. Possible till clast located here.

19	85-86	Diamictite similar to the one underlying prior unit.
20	86-88	Sequence of interbedded thin clast free silts and sands with lenticular breccia bands and some dispersed megaclasts.
21	88-90	Weakly bedded sandy clast-poor diamictite.
22	90-91	Laminated shales with dropstones.
23	91-95	Ankerite unit containing small scattered clasts increasing upwards.
24	91-103	Planar bedded fine to medium sandstones with dispersed clasts increasing to 5% upwards. Interbedded breccia and conglomerate bands.
25	103-110	Sandy clast-rich diamictite.
26	110-110.5	Clast free laminated shale.
27	110.5-114.5	Interbedded siltstones, sandstones and conglomerates.
28	114.5-115.5	Clast free ankerite unit
UB	115.5-116	Green silty volcanic breccia.
29	116- 118	Clast rich sandy diamictite.
	118 -	Thinly interbedded dark shales and dolomites of the Tindelpina Shale Member.

Section 3

1	0-1	Silty matrix clast-rich diamictite. Predominantly dolomite and shale clasts angular to subrounded. Sharp upper contact as Unit 1 is more resistant to weathering than Unit 2.
2	1-6	Silty moderately clast-rich pebbly diamictite rich in black chert. Also contains 2 megaclasts of white quartzite up to 0.5 metre diameter. Highly weathered unit.
3	6-21	Red brown muddy matrix diamictite moderately clast-rich pebbly diamictite. Appears to include small lenses which can be divided into 4 types; (1) massive clast free sand, (2) ankerite matrix, (3) clast free matrix, (4) sandy matrix. diamictite contains angular to well rounded clasts up to 10 cm. diameter.
4	21-22	Sandy sparse diamictite. Partly bedded with separation of coarse and fine bands. Grey green colour with small scattered clasts up to pebble-size, angular and well rounded.
5	22-26	Muddy clast-poor diamictite with a clast assemblage similar to the above.
6	26-28	Similar to the above except clast-poor to sparse.
	28-35	No outcrop.
7	35-38	Medium to coarse grained massive to well bedded (planar) sandstones with thin interbedded granule to pebble conglomerates.

8	38-41	Laminated grey-green siltstone to fine sandstone unit with thin coarse grained poorly sorted bands. Small amount of small dispersed clasts.
9	41-43	Well bedded (planar) medium sandstone. Clast free.
10	43-53	Sandstone gradually passes upwards into a clast poor muddy diamictite. Segregation of muddy bands defines a crude segregation. Clasts up to 10 cm. diamter and up to 50% shale fragments.
11	53-57	Planar well bedded medium to coarse sandstones with pods,lenses and bands of poorly to well sorted angular to well rounded conglomerates and breccias. Laterally one of the unit appears to lens out against the underlying diamictite. Upper contact gradational.
12	57-59	Clast-poor sandy matrix diamictite;partly bedded and containing granite and quartzite megaclasts up to 0.5 metre diameter. Otherwise similar to previous diamictite. Sharp upper contact.
13	59-61	Medium sandstone with bedding outlined by wispy muddy layers.
14	61-63	Sandy sparse granule to pebble diamictite. Poor outcrop.
15	63-66	Massive to weakly stratified medium sandstone with small percentage of scattered clasts. Upper and lower contacts gradational.
16	66-80	Sandy clast-poor diamictite. Partly stratified with segregation of silty horizons and lenses and clast-rich bands. Average clast diameter 1 cm. Maximum size 20 cm.
17	80-82	Breccia of matrix supported angular pebble to cobble-size clasts of red shales and siltstones (70%) and dolomites.
18	82-87	Moderately clast-rich sandy diamictite with small lenses of well bedded sandstone. Gradational upper contact.
19	87-89	Laminated shale containing small dispersed clasts, angular and oriented parallel to bedding.
20	89-99	Ankerite unit containing a small percentage of pebble to cobble-size clasts.
21	99-101	Sandy clast-rich diamictite containing pebble to cobble clasts. High percentage (60%) of dolomite clasts.
22	101-108	Moderately clast-rich grey sandy diamictite. Angular to well rounded clasts up to 10 cm. diameter.
23	108-109	Massive medium sandstone containing scattered small clasts of chert and quartzite.
24	109-120	Ankerite unit. Clast free.
25	120-122	Medium sandstone with a small percentage of scattered clasts underlain by a thin granule breccia.

End of Section (no reliable outcrop)

Section 4. (measured from the top downwards)

1	0-0.5	Matrix supported pebble conglomerate, well sorted with well rounded pebbles in a silty-sand matrix. Within several metres the unit lenses out against the underlying unit with a sharp contact.
2	0.5- 2	Volcanic breccia. A sedimentary breccia which contains 70% green deeply weathered volcanic rock fragments in a dark green silty matrix. Clasts angular, sand to pebble size. Other clasts mainly chert and dolomite. Laterally becomes the top unit.
3	2-3.5	Ankerite unit containing abundant dropstones. Sharp upper and lower contacts.
4	3.5-8.5	Clast-rich, partly stratified, silty to sandy matrix diamictite. Contains interbeds of shale, sandstone and conglomerate. Sharp contacts.
5	8.5-9	Ankerite mudstone with rare dropstones.
6	9-10	Finely laminated shale with thin conglomeratic bands and sparse small dropstones.
7	10-12	Ankerite mudstone with sparse dropstones.
	12-14	No outcrop.
8	14-17	Laminated siltstone to bedded fine sandstone, clast free. Sharp lower contact.
9	17-17.5	Ankerite with minor dropstones. Sharp contacts.
10	17.5-24	Thin dolomitic breccia granule to pebble-size clasts (10 cm.) overlying a laminated clast free shale (20 cm.) overlying a thick well bedded sandy moderately clast-rich diamictite with pebble to cobble-sized, angular to subrounded clasts.
11	24-32	Breccia/sandstone unit consisting mainly of a well bedded medium sandstones with interbedded conglomerate/breccia bands up to 1 metre thick.
12	32-42	Dark grey muddy clast-poor diamictite, occasional clast-rich bands define a crude stratification. Gradational contact with underlying diamictite.
13	42-48	Silty clast-rich, cobble-rich diamictite containing granite megaclasts up to 50 cm. diameter. Generally well bedded and banded with respect to a layer rich in dolomite rock fragments.
14	48-52	Medium to coarse sandstone unit containing heavy mineral bands.

N.B. An outcrop of varves occurs in the creek where Section 4 was measured in a position approximately 80 metres below the last measured unit above.

Section 5.

1	0-3	Medium to coarse sandstone with scattered clasts up to 30 cm. diameter, also conglomerate and breccia bands, silty laminations, minor crossbedding. Sharp contacts.
2	3-8	Clast-rich sandy diamictite. Moderately sorted, pebble to cobble angular to well rounded clasts. Partly bedded due to clast alignment and segregation of silty bands. Distinctive clast assemblage - 70% dolomite clasts, 10% well rounded quartz granules and pebbles.
3	8-9	Thin clast free shale underlying a bedded sandy clast-poor diamictite.
4	9-45	Varves with till pellets and small dropstones.
5	45-50	Upper part of varve unit where it coarsens upwards into a bedded sandstone with thick beds of sand and thin silt laminations between.
6	50-55	Sandy clast-poor massive diamictite. Angular to subrounded pebble-size clasts.
7	55-70	Coarsening upwards sequence from laminated siltstones to coarse sandstones with dispersed clasts increasing upwards. Planar bedding with occasional granule conglomerate interbeds.
8	70-74	Laminated shale with small dropstones and poorly sorted diamictitic interbeds with clasts up to 30 cm. diameter.
	74-79	No outcrop.
9	79-91	Laminated shale with dropstones and winnow bands coarsening upwards into bedded fine to coarse sandstones containing scattered clasts through to a 1 metre thick pebble breccia layer.
10	91-99	Partly bedded diamictite with thin interbeds of well-sorted conglomerate. Granite dropstone of 1 metre diameter here.
11	99-102	Breccia; clast supported. Angular to subrounded clasts up to 20 cm. diameter.
12	102-105	Dark grey muddy clast-poor diamictite becoming coarser grained upwards. Also conglomerate interbeds present.
13	105-111	Clast-rich sandy diamictite.
14	111-111·5	Volcanic tuff.
15	111·5-112	Well sorted pebble conglomerate consisting of well rounded quartz and chert clasts.
	112 -	Tapley Hill Formation.

APPENDIX III

Carbonate Staining Technique

The indentification of the carbonate mineralogy of massive microcrystalline carbonates from Section One, namely basal Unit 9 (814-091-S1) and Unit G (814-G-S1) was achieved by the application of the combined technique of Dickson (1965) on thin sections using the common stains Alizarin Red S (A.R.S.) and Potassium ferricyanide (P.F.)

The thin sections were firstly etched with 1.5% HCL ($^V/_V$) for 10-15 seconds and thoroughly rinsed with distilled water before the application of the following staining procedure.

Staining test 1.

1) Prepare solutions of
    a. 0.2g A.R.S. in 100 ml. of 1.5% HCL ($^V/_V$)
    b. 2.0g P.F. in 100ml. of 1-5% HCL ($^V/_V$)
2) Mix in the ratio A.R.S.: P.F. = 3:2
3) Immerse thin section in mixture for 30-45 seconds
4) Rinse gently with distilled water

Result

Calcite - Very pale pink-red depending on optical orientation.
Ferroan calcite - Very pale pink-red and pale to dark blue superimposed to give mauve to purple to royal blue
Dolomite - No colour
Ferroan dolomite - Pale to deep turquoise depending on ferrous content.

Staining test 2.

1) Prepare a section of 0.2g A.R.S. in 100ml. of 1.5% HCL ($^V/_V$)
2) Immerse thin section in mixture for 10-15 seconds

Result

Calcite - Ferroan calcite : Very pale pink-red
Dolomite - Ferroan dolomite : No colour

Experimental

Staining test 1.

Result : dark blue-turquoise

Conclusion : either ferroan calcite or ferroan dolomite

Staining test 2.

Result : no colour

Conclusion: Ferroan dolomite (Ankerite)

Although only 2 samples from Section One were stained and found to be ferroan dolomite, other carbonates in other sections with similar lithological characteristics in outcrop, hand specimen and thin section are therefore assumed to be composed also of ferroan dolomite.

N.B. The author has preferred to use the term ankerite in place of ferroan dolomite in the main body of the text.

APPENDIX IV

GLOSSARY OF GLACIGENIC TERMS

This glossary contains selected terms applicable to glacigenic sediments. These terms are widely used and accepted in the more recent literature and in some cases several definitions for the same terms are given. Many of these terms may be found in the main body of the text; and additional terms used in the text will have explanations accompanying them.

basal till:	till deposited on land as a result of deposition from the base of a glacier. Includes "basal meltout till and sublimation till", "lodgement till" and "deformation till". (Dreimanis, 1976).
diamictite:	a term coined by Flint *et al.*,(1960). Current accepted definition is "any non-sorted or poorly sorted terrigeneous sediment that consists of sand and/or larger particles in a muddy matrix". (Hambrey and Harland, 1981). It is preferred to the synonymous term mixtite. (Schermerhorn, 1974).
glaciomarinite:	stratified glaciomarine dropstone deposits (Schermerhorn, 1974). Essentially these deposits are laminated marine mudstones with a subordinate ice-dropped component. Synonymous with glacial laminite. (Nystuen, 1976).
till:	a sediment whose component particles are brought together by the direct agency of glacier ice and which, although it may suffer glacially induced flow, is not subsequently disaggregated. (Boulton, 1972).
tillite:	(1) a lithified till (2) a diamictite of proven glacial origin (Pettijohn, 1975).
tilloid:	a diamictite of proven non-glacial origin (Schermerhorn, 1974). Preferred to pseudotillite. (Harland *et al.*, 1966).
waterlain till:	a diamicton whose glacially derived components are sedimented through a body of water (Dreimanis, 1979). Synonymous with aquatillite (Schermerhorn 1974) and para-till (Harland *et al.*, 1966).

APPENDIX V

List of hand specimens and thin sections (additional to those described in Appendix I) submitted with this thesis. These are held under the accession number 814 - by the Geology Department.

Hand specimens

Section 1.

814 - 001 - S1	Regolith
814 - 011 - S1	Laminated shale, Unit 1
814 - 021 - S1	Diamictite, Unit 2
814 - 031 - S1	Laminated shale, Unit 3
814 - 051 - S1	Varves, Unit 5
814 - 091 - S1	Ankerite, Unit 9
814 - 131 - S1	Sandstone, Unit 13
814 - A - S1	Dolomite conglomerate, Unit A
814 - B - S1	Diamictite, Unit B
814 - D - S1	Conglomerate, Unit D
814 - G - S1	Ankerite, Unit G
814 - H - S1(1)	Siltstone, Unit H
814 - H - S1(2)	Sandstone, Unit H
814 - H - S1(3)	Sandstone, Unit H
814 - I - S1	Breccia, Unit I
814 - J - S1	Diamictite, Unit J
814 - K - S1	Ankerite, Unit K
814 - UB - S1	Volcanic tuff
814 - UB - S1(2)	Volcanic tuff
814 - M - S1	Diamictite, Unit M

Section 3

814 - 021 - S3	Diamictite, Unit 2
814 - 031 - S3	Diamictite (parent), Unit 3
814 - 032 - S3	Ankerite lens, Unit 3
814 - 033 - S3	Muddy lens, Unit 3
814 - 034 - S3	Sand lens, Unit 3
814 - 035 - S3	Sandy matrix lens, Unit 3
814 - 036 - S3	Clast-rich lens, Unit 3
814 - 041 - S3	Diamictite, Unit 4
814 - 061 - S3	Diamictite, Unit 6
814 - 101 - S3	Sandstone, Unit 10

814 - 121 - S3	Diamictite, Unit 12
814 - 131 - S3	Sandstone, Unit 13
814 - 171 - S3	Breccia, Unit 17
814 - 191 - S3	Laminated shale, Unit 19
814 - 200 - S3	Ankerite, Unit 20
814 - 221 - S3	Diamictite, Unit 21
814 - 241 - S3	Ankerite, Unit 24

Other

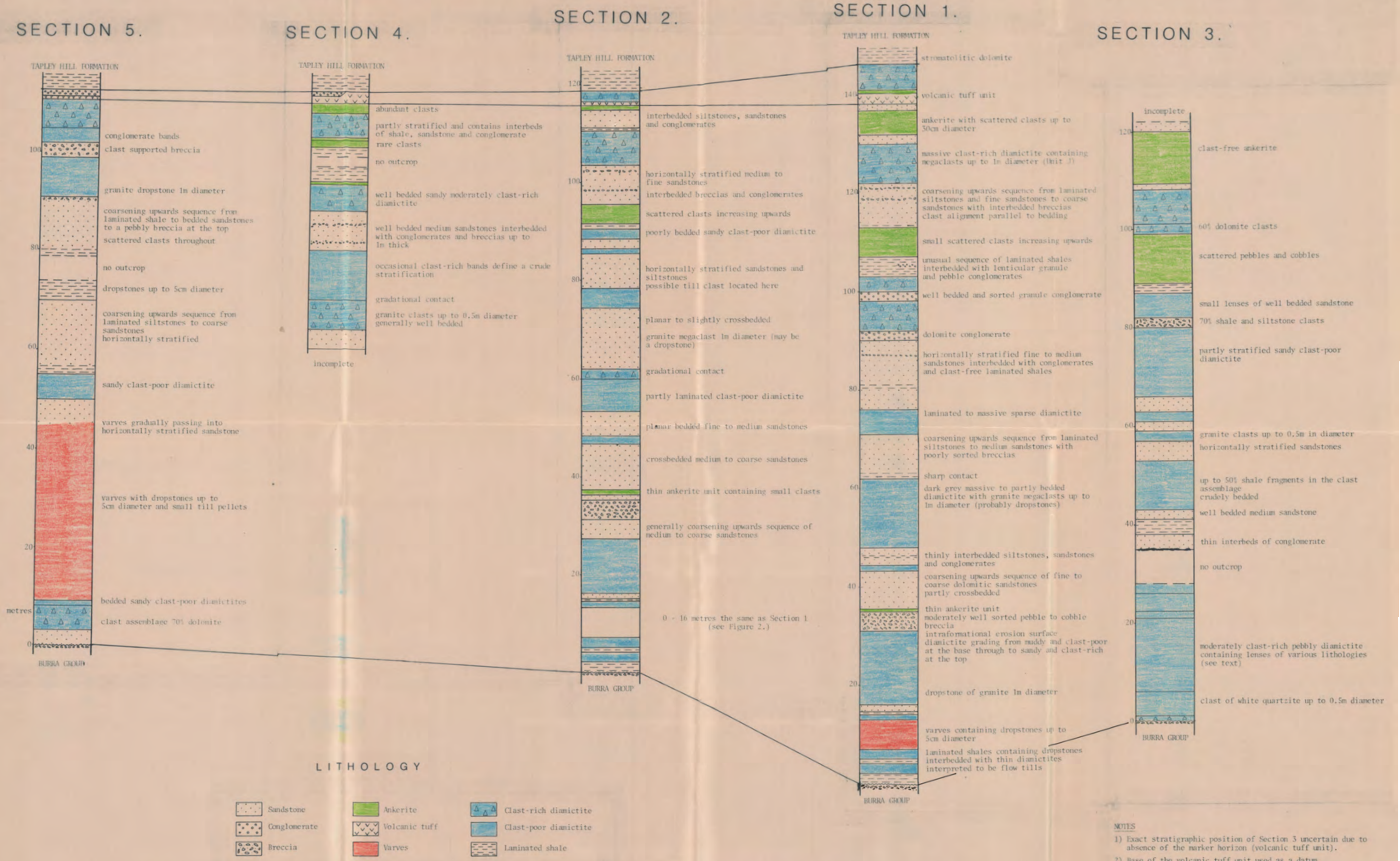
814 - S5 - 4	Varves, Section 5
814 - 2 - S5	Varves, Section 5
814 - S5 - 2	Varves, near Section 5
814 - 1 - S5	Varves, near Section 5
814 - 5 - S4	Varves, Section 4
814 - DC - S4	Conglomerate, Section 4
814 - 140 -S4	Sandstone, Section 4
814 - UB-S1 S2	Volcanic tuff between Sections 1 and 2

Thin Sections

814 - UB - S1)	Volcanic tuff unit, Section 1
814 - UB - S1)	
814 - UB - S1)	
814 - UB - S1)	
814 - S5 - 4	Varves, Section 5
814 - 5 - S4	Varves, Section 4
814 - S4 -	Varves, Section 4
814 -051 - S1	Varves, Section 1

STRATIGRAPHIC SECTIONS - DEPOT FLAT AREA

SOUTHERN FLINDERS RANGES



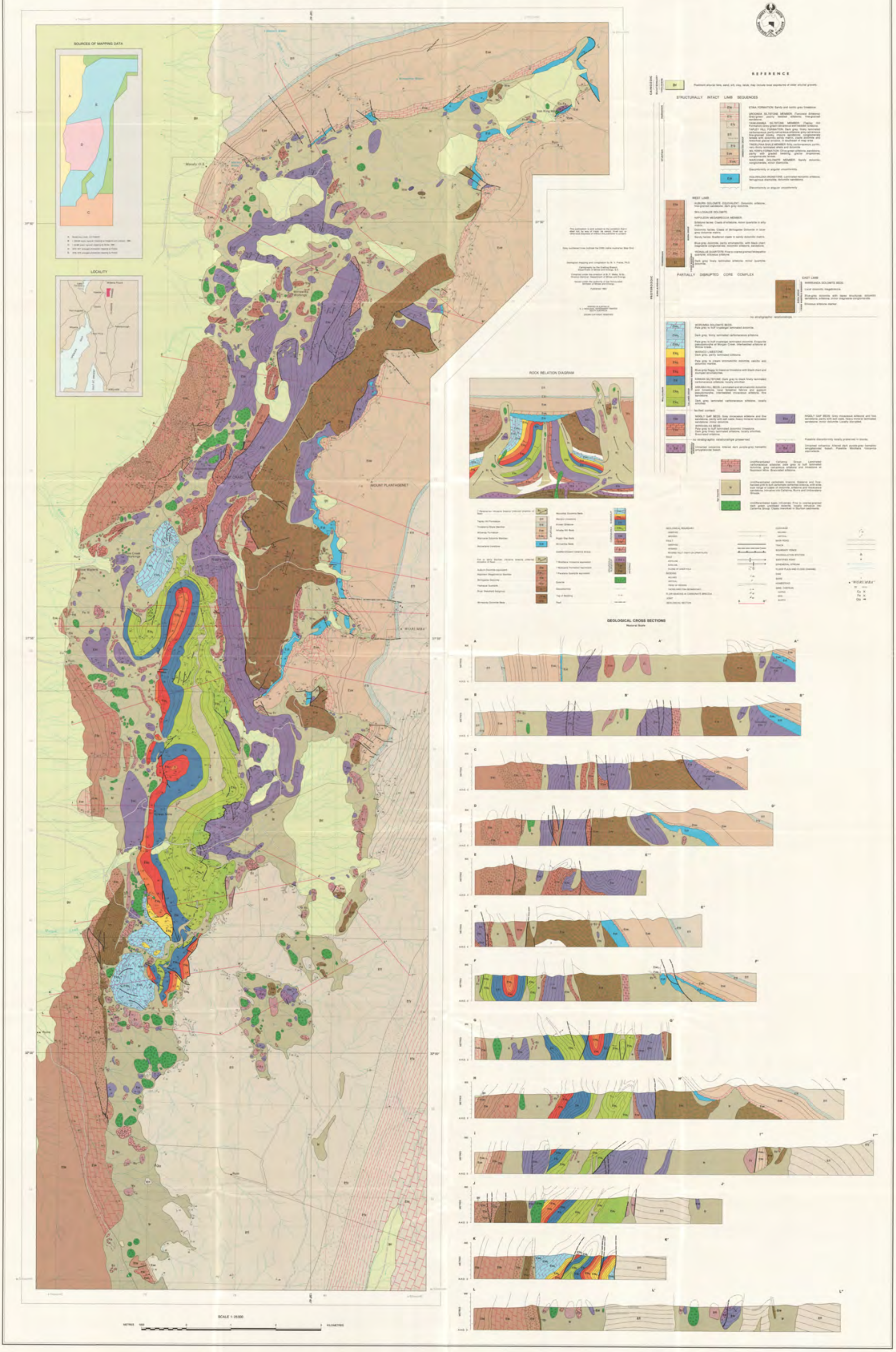
NOTES

1) Exact stratigraphic position of Section 3 uncertain due to absence of the marker horizon (volcanic tuff unit).
2) Base of the volcanic tuff unit used as a datum.
3) All sections overlie a regolith formed on an unconformity surface on Burra Group sediments and are overlain disconformably by the Tindelpina Shale Member.
4) A full description of these sections can be found in Appendix II.
5) Stratigraphic relationships near the top of the glacial sequence are also shown in Figure 6.

D.L.H. 1983

Figure 11.

GEOLOGY OF THE WORUMBA ANTICLINE



REFERENCE

CAINOZOIC QUATERNARY HOLOCENE

Qpt Piedmont alluvial fans, sand, silt, clay, talus; may include local exposures of older alluvial gravels.

STRUCTURALLY INTACT LIMB SEQUENCES

ETINA FORMATION: Sandy and oolitic grey limestone.

UROONDA SILTSTONE MEMBER (Tarcowie Siltstone): Grey-green poorly bedded siltstone, fine-grained sandstone.

YANKANINNA SILTSTONE MEMBER (Tapley Hill Formation): Grey-green calcareous well-bedded siltstone.

TAPLEY HILL FORMATION: Dark grey finely laminated carbonaceous partly calcareous siltstone; grey calcareous fine-grained dolomitic impure sandstone; conglomerate lenses with dolomitic sandy matrix, clasts dolomite and reworked glacial erratics, in southeast of map area.

TINDELPINA SHALE MEMBER: Silty carbonaceous pyritic, very finely laminated shale and dolomite.

WILYERPA FORMATION: Olive-green siltstone, sandstone, partly with graded bedding; glacial dropstones; conglomerate lenses.

WARCOWIE DOLOMITE MEMBER: Sandy dolomite, conglomerate, minor diamictite.

Disconformity or angular unconformity.

HOLOWILENA IRONSTONE: Laminated hematitic siltstone, ferruginous diamictite, dolomitic sandstone.

Disconformity or angular unconformity.

WEST LIMB

AUBURN DOLOMITE EQUIVALENT: Dolomitic siltstone, fine-grained sandstone, dark grey dolomite.

SKILLOGALEE DOLOMITE

NAPOLEON MEGABRECCIA MEMBER

Siltstone facies: Clasts of siltstone, minor quartzite in silty matrix.

Dolomitic facies: Clasts of Skillogalee Dolomite in blue-grey dolomite matrix.

Sandy facies: Scattered clasts in sandy dolomitic matrix.

Blue-grey dolomite, partly stromatolitic, with black chert; magnesite conglomerate, dolomitic siltstone, sandstone.

YEDNALUE QUARTZITE: Fine to coarse-grained feldspathic quartzite, siliceous siltstone.

Dark grey finely laminated siltstone, minor quartzite, dolomite.

PROTEROZOIC ADELAIDEAN

PARTIALLY DISRUPTED CORE COMPLEX

EAST LIMB

WIRRIANDA DOLOMITE BEDS

Local dolomitic megabreccia.

Blue-grey dolomite with tepee structures; dolomitic sandstone, siltstone, minor magnesite conglomerate.

Siliceous siltstone marker.

no stratigraphic relationships

WORUMBA DOLOMITE BEDS: Pale grey to buff cryptalgal laminated dolomite.

Dark grey, thinly laminated carbonaceous siltstone.

Pale grey to buff cryptalgal laminated dolomite. Evaporite pseudomorphs at Morgan Creek. Interbedded siltstone at Willow Creek.

MARACO LIMESTONE: Dark grey, partly laminated siltstone.

Pale grey to cream stromatolitic dolomite, calcitic and dolomitic marble.

Blue-grey flaggy to massive limestone with black chert and slumped stromatolites.

KIRWAN SILTSTONE: Dark grey to black finely laminated carbonaceous siltstone, locally silicified.

ARKABA HILL BEDS: Laminated and stromatolitic dolomite and limestone; local fenestral fabrics and gypsum pseudomorphs. Interbedded micaceous siltstone, fine sandstone.

Dark grey laminated carbonaceous siltstone, locally silicified.

faulted contact

RIGGLY GAP BEDS: Grey micaceous siltstone and fine sandstone, partly with salt casts, heavy mineral laminated sandstone, minor dolomite.

WIRRAWILKA BEDS: Pale grey to buff laminated dolomitic limestone. Dark grey finely laminated siltstone, locally silicified. Brecciated siltstone.

RIGGLY GAP BEDS: Grey micaceous siltstone and fine sandstone, partly with salt casts, heavy mineral laminated sandstone, minor dolomite. Locally disrupted.

no stratigraphic relationships preserved

Possible disconformity locally preserved in blocks.

Unnamed volcanics: Altered dark purple-grey hematitic amygdaloidal basalt.

Unnamed volcanics: Altered dark purple-grey hematitic amygdaloidal basalt. Possible Wooltana Volcanics equivalents.

Undifferentiated Callanna Group: Laminated carbonaceous siltstone; pale grey to buff laminated dolomite; grey calcareous siltstone and limestone at Napoleon Mine. Brecciated siltstone.

Undifferentiated carbonate breccia: Massive and flow-banded pink to buff carbonate cemented breccia, with wide size range of clasts of dolomite, siltstone and micaceous sandstone. Intrusive into Callanna, Burra and Umberatana Groups.

Undifferentiated basic intrusives: Fine to coarse-grained dark green uralitised dolerite, locally intrusive into Callanna Group. Clasts reworked in Sturtian sediments.

This publication is sold subject to the condition that it shall not, by way of trade, be resold, hired out or otherwise disposed of without the publisher's consent.

Grey numbered lines indicate the 1000 metre Australian Map Grid.

Geological mapping and compilation by W. V. Preiss, Ph.D.

Cartography by the Drafting Branch, Department of Mines and Energy, S.A.

Compiled under the direction of B. P. Webb, B.Sc., Director-General, Department of Mines and Energy.

Issued under the authority of the Honourable Minister of Mines and Energy.

Published 1985

Printed by authority of D. J. Woolman, Government Printer, South Australia

ROCK RELATION DIAGRAM

? Delamerian intrusive breccia (inferred direction of flow)

Tapley Hill Formation

Tindelpina Shale Member

Wilyerpa Formation

Warcowie Dolomite Member

Holowilena Ironstone

Pre- to early Sturtian intrusive breccia (inferred direction of flow)

Auburn Dolomite equivalent

Napoleon Megabreccia Member

Skillogalee Dolomite

Yednalue Quartzite

River Wakefield Subgroup

Wirrianda Dolomite Beds

Worumba Dolomite Beds

Maraco Limestone

Kirwan Siltstone

Arkaba Hill Beds

Riggly Gap Beds

Wirrawilka Beds

Undifferentiated Callanna Group

? Wooltana Volcanics equivalent

? Blyth? Formation equivalent

? Paralana Quartzite equivalent

Dolerite

Discontinuity

Top of Bedding

Fault

GEOLOGICAL BOUNDARY

CLEAVAGE

MAIN ROAD

TRACK

BOUNDARY FENCE

TRIANGULATION STATION

IDENTIFIED POINT

EPHEMERAL STREAM

FLOOD PLAIN AND FLOOD CHANNEL

DAM

BORE

HOMESTEAD

MINE, COSTEAN

GEOLOGICAL SECTION

GEOLOGICAL CROSS SECTIONS

Natural Scale