THE UNIVERSITY OF ADELAIDE

FACIES AND PALEOGEOGRAPHY
OF LATE PRECAMBRIAN STURTIAN GLACIAL SEDIMENTS,
COPLEY AREA, NORTHERN FLINDERS RANGES
AND IN THE STURT GORGE NEAR ADELAIDE,
SOUTH AUSTRALIA

by

Paul Karl Link
(B.S. Yale University)

April, 1977

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To Brian Daily
with my sincere thanks
and best regards.
Paul

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This thesis is submitted as partial fulfilment
of the requirements for the Honours Degree of
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ABSTRACT

West of Copley and Leigh Creek, northern Flinders Ranges, South Australia, late Precambrian diamictite of the Merinjina Formation unconformably overlies dolomite and fine sandstone of an unnamed member of the Burra Group. The Merinjina Formation, 130-310 m thick, consists of diamictite (boulder to pebble bearing sandy mudstone), bedded fine sandstone, laminated siltstone, and conglomerate. Maximum clast length is 1.5 m. Clast types include 95% quartzites, siltstones, and dolomites probably derived from the underlying Burra Group, with a minor fraction of volcanic, plutonic and metamorphic rocks. Dropstones, till pellets and till clasts occur and are considered diagnostic criteria for a glacigene origin. No glaciated floor was recognized. Paleocurrents and paleogeographic reconstructions indicate that sediment probably came from a northeasterly source.

In the Sturt Gorge near Adelaide, the Sturt Formation, about 220 m thick, is lithologically similar and probably stratigraphically equivalent to the Merinjina Formation. It overlies thin-bedded fine sandstone and siltstone of the Belair Subgroup disconformably. Clasts are up to 1.5 m in length and consist of 75% granite and gneiss and 25% sedimentary rocks, mostly carbonates. Basement clast types were probably derived from a westerly source.

In each area the glacigene formations are conformably overlain by thin dolomites and laminated siltstones of the Tapley Hill Formation.

Massive clast-poor diamictites are interpreted as waterlaid tillites deposited from a grounded or floating ice shelf. Bedded siltstones, sandstones, and clast-rich diamictites are interpreted to represent reworked till deposited in a glaciomarine environment with weak bottom currents and periodic incursions of floating ice. Cross bedded granule conglomerates represent deposits from high energy traction

currents in glacial meltwater. Local subaqueous mass movement deposits occur.

Addendum

This thesis was completed on April 27, 1977. On April 28, Victor Gostin, Burton Murrell and the author travelled to Apex Hill, east of the Copley study area of this report and the only area where the unconformable relation between the "Merinjina Formation" and Yudnamutana Subgroup had been mapped by Coats (1973).

We established that this unconformable relation does not exist, and that the "Merinjina Formation" is, in that locality, a conformable pebbly sandstone and sandy diamictite member of what is mapped as Bolla Bollana Formation. Thus the name "Merinjina Formation" is not necessary, and the rocks from the Copley study area described in this report belong to the Bolla Bollana Formation, of the Yudnamutana Subgroup as defined by Coats (1964).

All references in this report to Merinjina Formation should read Bolla Bollana Formation. The stratigraphic chart (Table 1) should be modified to include only one Sturtian glaciation (the Yudnamutana Subgroup), with all glacigene units approximately contemporaneous over the geosyncline. Established stratigraphic relations in local areas (i.e. Mt. Painter, Olary, Oraparinna) are valid, but the regional correlations of Forbes & Coats in Thomson et al. (1976) are incorrect.

The comments (p.14,24) on a different tectonic framework for the thick accumulations of Yudnamutana Subgroup than for the thin glacigene sequences of the Copley study area and Sturt Gorge are still valid, though the references to two glaciations "of very different character" (p.24) are not.

The author apologizes for the fact that his imminent departure from Australia does not allow correction of the references to Merinjina Formation in this thesis.

Adelaide

May 4, 1977.

ACKNOWLEDGEMENTS

The writer is deeply grateful to Professor Brian Skinner and the Howland Fellowship Committee of Yale University, New Haven, Connecticut, U.S.A., for the opportunity to come to Adelaide.

In Adelaide I received willing help and encouragement from my supervisors Brian Daily and Victor Gostin, and from a long list of colleagues and friends in the Department of Geology and Mineralogy. I especially wish to thank Peter Moore, Robin Uppill and Dave Gravestock for help in the field, and Phil Plummer, Mike Fitzgerald, Millie Swan, Burton Murrell and Bill Laing for aid and discussion in Adelaide. Ron Coats of The South Australian Department of Mines made his time and resources readily available. Rick Barrett provided masterful help in the dark room. Sepp Trzicky and Geoff Trevelyon produced the thin sections. Mrs. Joan Brumby did the typing.

DEDICATION

TO LUIGI

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CHAPTER 1: INTRODUCTION

A persistent stratigraphic horizon of diamictite of the Sturtian Series, Adelaide System in South Australia, known as the Sturt 'Tillite'[1] and its equivalents, has been attributed to late Precambrian glaciation. The origin and classification of similar diamictites elsewhere has been the subject of much controversy (Schermerhorn, 1974, Crowell, 1957, Crowell and Frakes, 1967). However, since its discovery by Walter Howchin in the early 1900's a glacigene origin for the Sturt Formation has been accepted by most observers. The purpose of this study was to describe the Sturt Formation in its type area: the Sturt Gorge, and its temporal equivalent, the Merinjina 'Tillite'[2] in the Copley area, western Flinders Ranges, South Australia, and to reconstruct sedimentary conditions and paleogeography during deposition. (Figure 1 is a map showing the areas studied).

Field work was conducted in the Copley area in September, 1976, and in the Sturt Gorge in October and November, 1976.

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[1] In this paper the Merinjina and Sturt 'Tillites' will be referred to as the Merinjina and Sturt 'Formations' since they are not entirely direct glacial deposits. Referring to formations as 'tillites' leads to confusing stratigraphic descriptions, for example: "Unit 4 of the Pualco Tillite is composed of beds of sandstone and tillite." (Forbes and Cooper, 1976, p. 2).

[2] In International Geologic Congress Guidebook 33A (Thomson et al. 1976) this unit is labelled the "Tillite of Mt. Jacob". On the COPLEY 1:250,000 map area it is labelled Py_1 and unnamed. Ron Coats (personal communication 1977) has proposed that diamictites within this unit be called "Merinjina Tillite" and essentially nonglacial marine sequences be called "Wilyerpa Formation". The writer feels that since the type area for the "Merinjina Tillite" near Wooltana H.S. contains stratified interbeds it should not be called a "tillite", nor can the waterlaid tillite end member of a glaciomarine sequence be isolated from the purely marine end member. Thus a single formation name is suitable, and "Merinjina Formation" will be used.

1.1 Regional Stratigraphy

The rocks examined in this study belong to the "Sturtian Glacial Sequence" (Dunn, Rankama and Thomson, 1971) or the "Lower Glacial Sequence of Sturtian Age" (Parkin 1969, p.65), which comprises the basal part of the Umberatana Group, late Precambrian Adelaide System. The term "Sturtian Glacial Sequence" will be used in this paper.

Table 1 shows regional stratigraphic correlations over the Adelaide "Geosyncline".

At present the Sturtian Glacial Sequence is tentatively subdivided into three units (Forbes and Coats _in_ Thomson _et al_. 1976, p.13). The upper unit, the subject of this paper, is widespread over South Australia and is interpreted to lie unconformably on older glacial and pre-glacial rocks. Forbes and Coats (op.cit.) define a middle unit consisting of the Braemar and Holowilena Iron Formations. The lowest unit includes the Yudnamutana Subgroup, originally defined by Coats (1964) to represent the entire Sturtian Glacial Sequence in the Mt. Painter area, but redefined by Coats (1973) and Coats _et al_. (1973) to encompass only the lowermost portion of this sequence. According to this interpretation there are at least two glaciations, separated by unconformity, within the Sturtian Glacial Sequence.

The writer has observed the Holowilena Iron Formation developed as a local facies variant in the base of the Wilyerpa Formation (upper phase of Sturtian glaciation) south of Mt. Plantagenet on the east flank of the Worumba Diapir (PARACHILNA map area, Dalgarno and Johnson, 1966) and therefore does not accept it as a marker unit at the top of the Yudnamutana Subgroup, unconformably below the upper phase of Sturtian glaciation (see Table 1).

Glacigene rocks possibly correlative with the Sturtian Glacial Sequence elsewhere in Australia are reviewed by Dunn, Thomson and Rankama (1971), although their postulation of a great continent-wide

FIGURE 1

LOCALITY MAP WITH DIRECTIONS OF STURTIAN GLACIAL TRANSPORT.

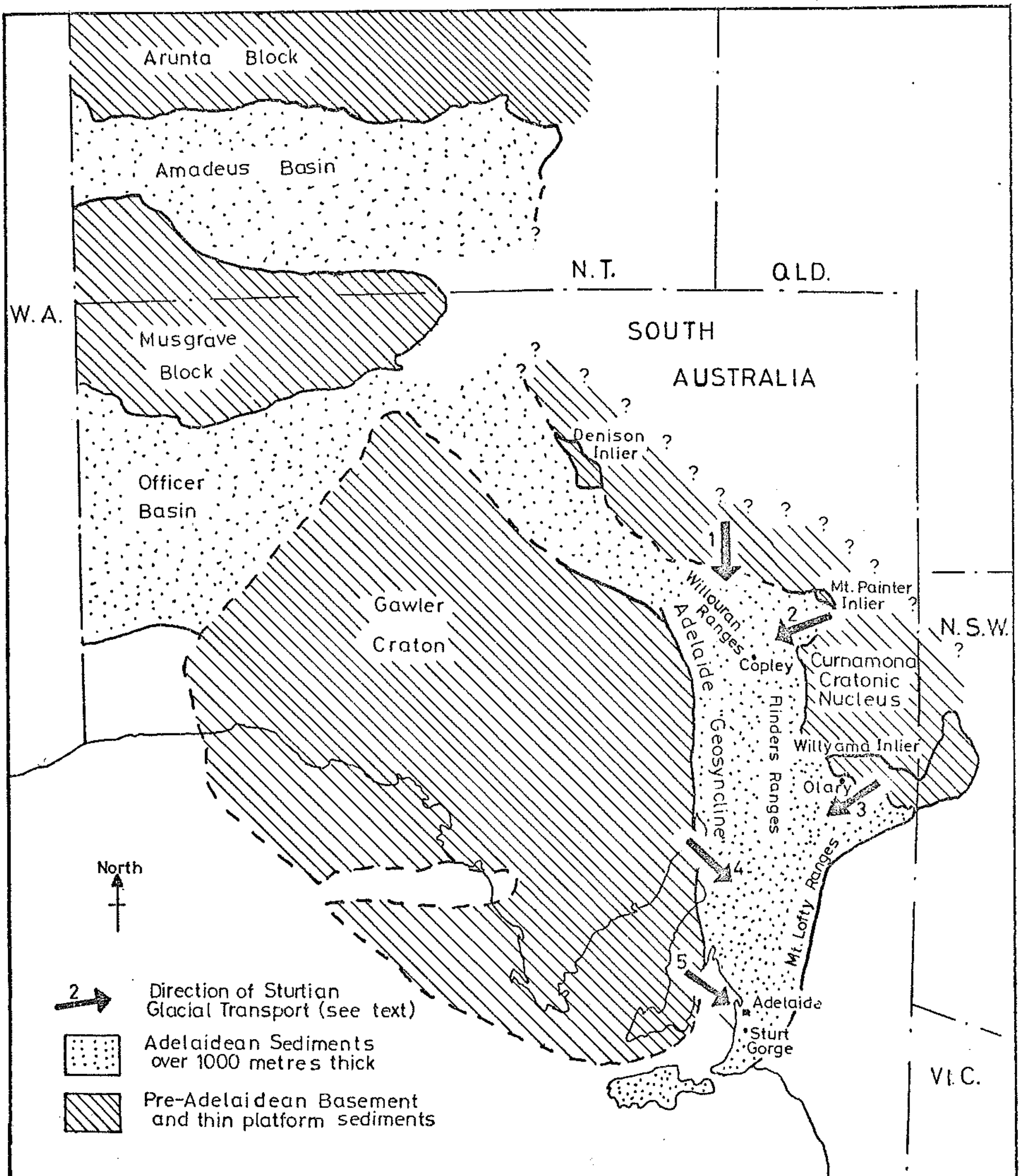
(1) Willouran Ranges. Source area is hypothetical basement high to the north, Murrell (1977).

(2) Copley area (this study) and Mt. Painter region (Belperio, 1973). Source area is Curnamona Cratonic Nucleus to the east.

(3) Olary Region and Bibliando Dome. Source area is Willyama Inlier to the east (Forbes and Cooper 1976, Mawson, 1949b).

(4) ORROROO map area, (Binks 1971). Source area is Gawler craton to west.

(5) Sturt Gorge (this study). Source area is Gawler craton to the northwest.



LOCALITY MAP WITH
DIRECTIONS OF STURTIAN GLACIAL TRANSPORT
Figure 1

TIME UNITS	CORRELATION OF GLACIGENE UNITS ADELAIDE "GEOSYNCLINE"		ROCK UNITS
MARINOAN			WILPENA GROUP
	NUCCALEENA FORMATION ELATINA FORMATION	YERILINA SUBGROUP	Marinoan Glaciation (Upper Glacial Sequence)
STURTIAN	BRIGHTON LIMESTONE TAPLEY HILL FORMATION Tindelpina Shale Mem.	FARINA SUBGROUP	UMBERATANA GROUP
	STURT and MERINJINA FMS., APPILATILLITE, WILYERPA FM. HOLOWILENA IRONSTONE	UPPER PHASE of STURTIAN GLACIATION	
	BENDA SILTSTONE + BRAEMAR IRON FM. ... LYNDHURST FM. PUALCO TILLITE BOLLA BOLLANA FM. FITTON FM.	YUDNAMUTANA SUBGROUP	Sturtian Glaciations (Lower Glacial Sequence)
~740 m.y.		? ? ? BELAIR SUBGROUP ? ? ?	
TORRENSIAN			BURRA GROUP

Interpretation modified from Thomson et al, 1976

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TABLE 1

ice age lasting 100 m.y. is speculative at best (Crawford and Daily, 1971). These correlative rocks include the Yancowinna Subgroup of the Broken Hill area (Cooper and Tuckwell, 1971) and possibly the Areyonga Formation of the Amadeus Basin (Wells et al. 1970), the Moonlight Valley Tillite of the Kimberley Ranges (Dow and Gemuts, 1969) and "tillites" (Cotton's Breccia) on King Island, Tasmania (Carey, 1947 and Jago, 1974b). Dates on shales in the Moonlight Valley Tillites of 739±30 m.y. (Bofinger, cited in Dow and Gemuts, 1969) are the only age estimates for the Sturtian Glaciations, and more dating is badly needed.

1.2 Definitions

Considerable controversy has been generated over the terminology of glacial and non-glacial sediments containing dispersed mega-clasts (Schermerhorn and Stanton, 1963, Harland, Herod and Krinsley, 1966, Flint, 1971, Schermerhorn, 1966, 1974, Jago, 1974a, 1976). Caution must be observed in not using words with genetic connotation (like tillite) unless the mode of deposition is proven. Diamictite (Flint et al. 1960) has been proposed as a non-genetic term for a clastic sediment with a wide variation in particle size, and is the only term suitable for hand specimen or general field description. Although initially defined to exclude calcareous sediments, it has been used to describe calcareous matrix till-like rocks by many authors. Mixtite (Schermerhorn, 1974) is essentially synonomous.

The writer agrees with Nystuen (1976) that terminology of ancient glacial sediments should parallel that of the Pleistocene and Recent. The terminology of Dreimanis (1976) will be followed here. Till is a clastic deposit directly from glacial ice; its lithified equivalent is tillite. Waterlaid Tillite is lithified till deposited beneath a floating ice shelf, aquatillite of Schermerhorn is equivalent. It may grade to basal tillite (deposited directly beneath the glacier) or to glaciomarinite (Schermerhorn, 1974) also called glacial laminite

(Nystuen 1976) which is subaqueous sediment with contribution of ice-rafted debris. All sediments deposited in an environment with some glacial imprint are glacigene. A proven non-glacial diamictite is a tilloid (Schermerhorn, 1974).

Sandstone terminology used in this paper is after Folk, (1974).

The northern study area in this paper is referred to as the Copley area, but it is only a small part of the COPLEY 1:250,000 map sheet of Coats, *et al*. (1973).

1.3 Previous Investigations

Excellent summaries of the geology of South Australia are found in Howchin (1929), Glaessner and Parkin (1959), and Parkin, (1969). However these reports recognize the existence of only one glaciation in the "Lower Glacial Sequence".

The Sturt Gorge is the type area for glaciation in the Adelaide System, and has been described by Howchin (1901, 1904, 1908, 1912, 1929), Sprigg (1942, 1946), Johnson (1956, 1962), Webb (1962) Coats, (1967), Oliver and Daily,(1969), and Love (1972). Howchin and Sprigg measured sections in the Sturt Gorge, and several maps of the area have been published, the most recent by Oliver and Daily (1969). Regional geological maps including the Sturt Gorge are the Echunga 1:63,500 sheet (Sprigg and Wilson, 1954), and the BARKER 1:250,000 sheet (Thomson and Horwitz, 1962) of the Geological Survey of South Australia.

The first published survey of the Copley Region was by Mawson (1941), and his stratigraphic section is shown in Figure 4. Geologic maps of the area include the 1:63,500 Copley (Parkin and King, 1952a) Angepena (Sprigg and Wilson, 1953), Serle (Parkin, *et al*. 1953) and Myrtle (Parkin and King, 1952b) sheets, and the 1:250,000 COPLEY sheet (Coats, *et al*. 1973), published by the Geological Survey of South Australia.

CHAPTER 2: STRATIGRAPHY

2.1 Copley Area

In the Copley area the Merinjina Formation is a sequence of massive diamictite (cobble-bearing sandy mudstone), bedded siltstone, fine sandstone, and granule conglomerate 130 to 310 m thick. A representative section is shown in Fig. 3. The formation may be readily divided into three units:

Unit 3 : bedded siltstone, sandstone, and diamictite;

Unit 2 : massive diamictite;

Unit 1 : (base), bedded siltstone, sandstone and diamictite.

Comparative stratigraphic sections in the Copley area are shown in Fig. 4. They demonstrate that though the three units can be correlated with few changes in thickness or character over the study area, the minor sub-units are highly variable and lateral continuity of thin beds is usually less than one kilometer.

The sharp basal contact is a low angle (less than 5 degrees) regional unconformity on fine sandstone, laminated silty dolomite, and quartzites of an unnamed member of the Burra Group. Its angular nature can be seen on air photos or by walking out Burra Group beds which are truncated at the unconformity. Although this surface has been described as a peneplain (Coats, 1973), considerable local relief on the surface was observed southwest of Copley Railway Station where the Merinjina Formation thickens rapidly from 190 to 310 m within 2 km along strike (Sections 23 to 26, Fig. 4). In Fig. 4 this unconformity is interpreted as a flat surface but a very different picture would result from using another datum, for example the base of Unit 2.

A striated pavement was not observed at the base of the Merinjina Formation.

The basal bed of Unit 1 of the Merinjina Formation is either diamictite or non-pebbly sandstone. This diamictite is of two types:

FIGURE 2

LOCATION OF MEASURED SECTIONS AND PALEOCURRENT DIRECTIONS, COPLEY AREA.

Paleocurrent readings are averaged for each locality. Most readings are from trough axes in small-scale trough cross beds. Other data is from planar cross beds and axes of channels. Paleocurrents showed no significant variation with either type of indicator or position in stratigraphic column at any one locality.

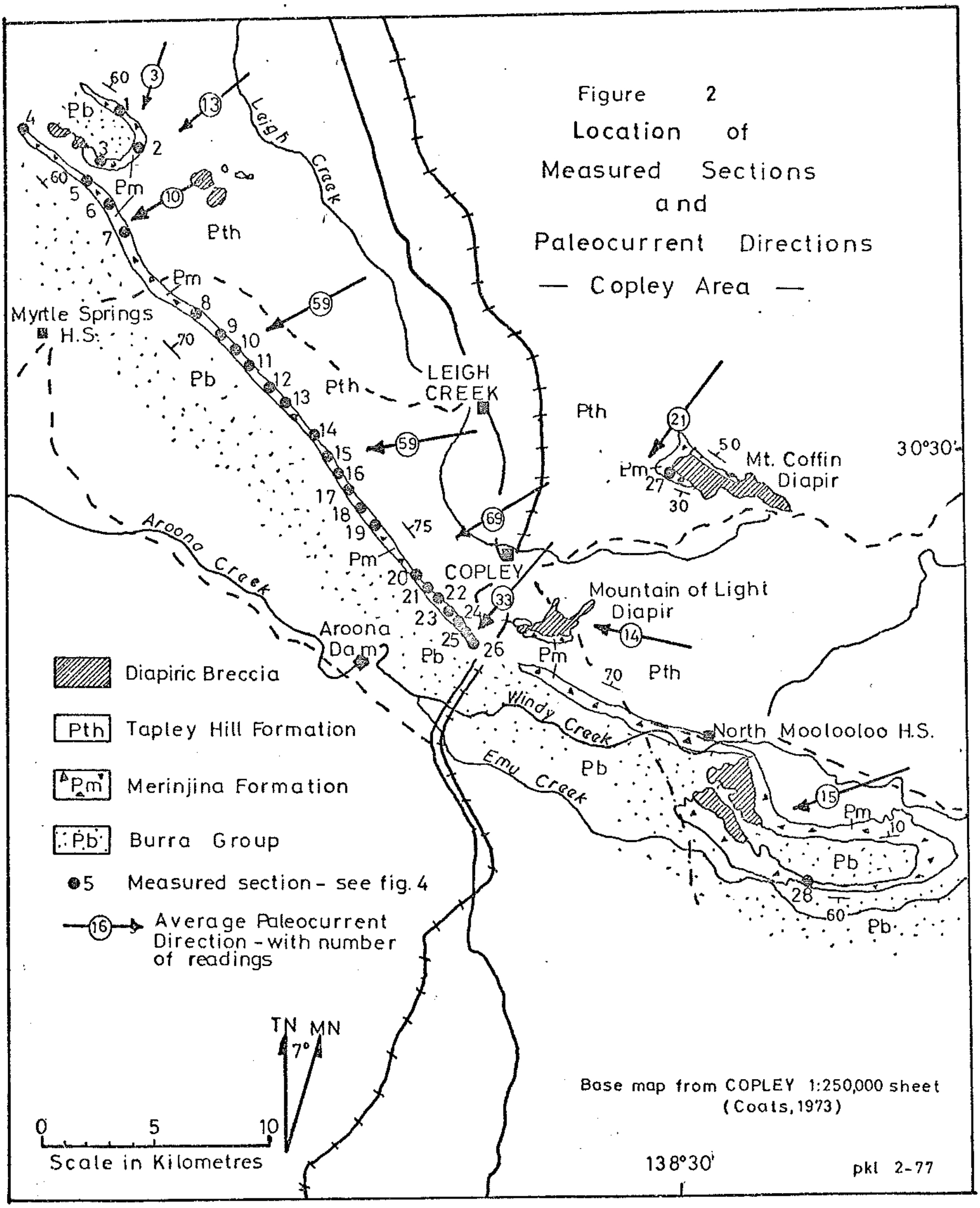
Figure 2
Location of Measured Sections and Paleocurrent Directions
— Copley Area —
Myrtle Springs H.S.
LEIGH CREEK
Leigh Creek
COPLEY
Aroona Creek
Aroona Dam
Mt. Coffin Diapir
Mountain of Light Diapir
Windy Creek
Emu Creek
North Moolooloo H.S.
Pb
Pm
Pth
30°30'
Diapiric Breccia
Pth Tapley Hill Formation
Pm Merinjina Formation
Pb Burra Group
●5 Measured section - see fig. 4
(16) Average Paleocurrent Direction - with number of readings
TN MN 7°
0 5 10
Scale in Kilometres
Base map from COPLEY 1:250,000 sheet (Coats, 1973)
138°30'
pkl 2-77

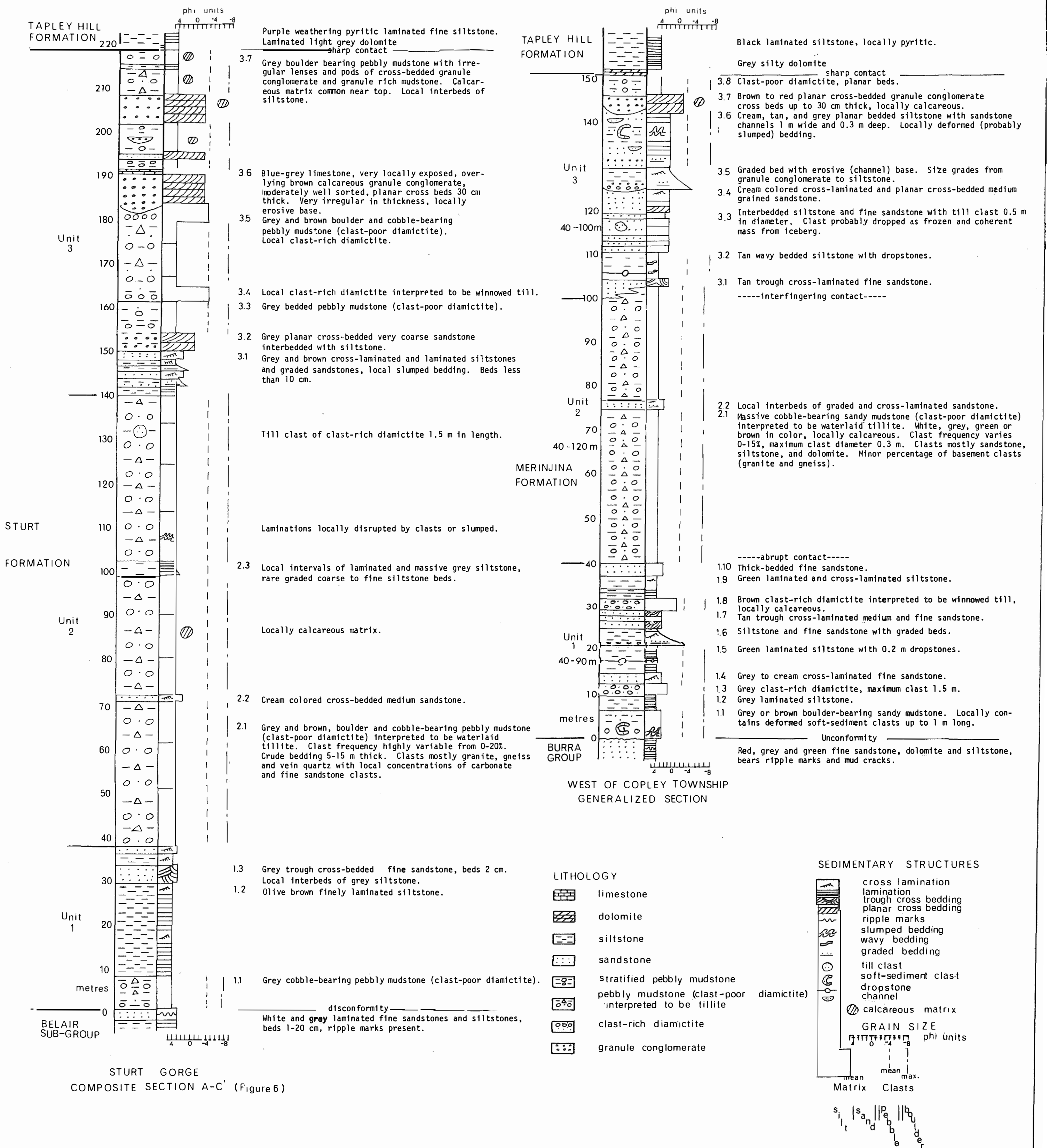

Figure 3

STURT GORGE AND COPLEY AREA STRATIGRAPHIC SECTIONS

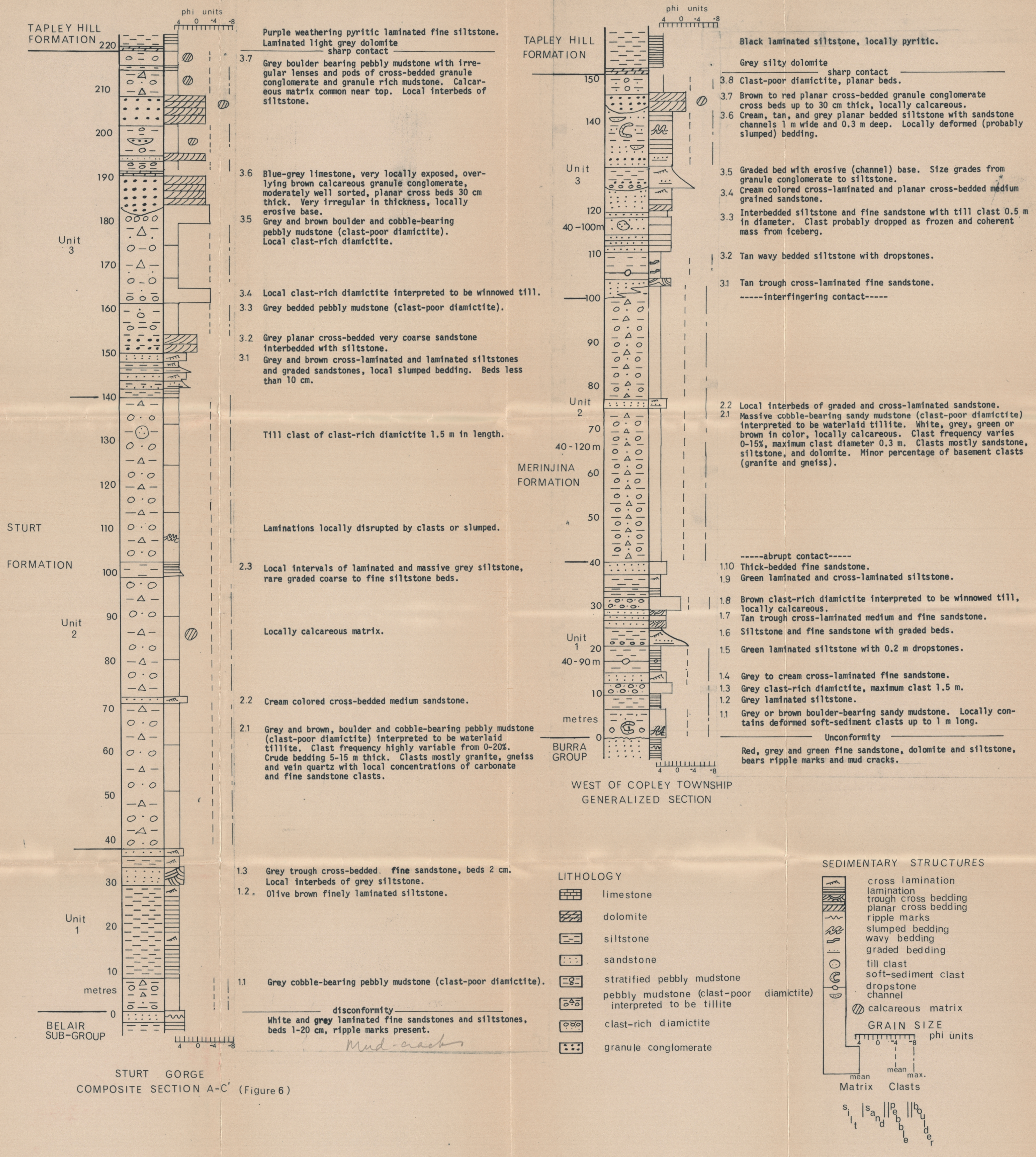

Figure 3

STURT GORGE AND COPLEY AREA
STRATIGRAPHIC SECTIONS

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FIGURE 4

COMPARATIVE STRATIGRAPHIC SECTIONS, COPLEY AREA.

The unconformity at the base of the Merinjina Formation is taken as datum. Diagram demonstrates the continuity of three major units throughout the study area, and also the heterogeneity within these units.

clast poor (less than 10% clasts that are greater than coarse sand size) boulder to pebble-bearing sandy mudstone, 5 to 60 m thick, seen at 13 localities, and clast rich (over 10% clasts) boulder, cobble, and pebble-bearing muddy medium to coarse-sandstone, one to five meters thick, occurring at 9 localities. At one locality, (Section 20) the clast-rich diamictite contains deformed soft sediment clasts of siltstone and sandstone (Plates 3B and 3C). A small clastic dyke of the coarse sandstone matrix from a clast-rich diamictite injects one of these clasts (Plate 2C). Clasts in these basal diamictites are very angular to sub-rounded and up to 1.5 m in diameter. They consist of 95% sedimentary rock fragments: quartzite, siltstone, sandstone, dolomite, and chert, with a small but uniform percentage of basement granites and gneisses. Striated and faceted clasts were not observed, though they were reported by Mawson (1942). Extreme local variation in percentage of clast types occurs,(see Fig. 5).

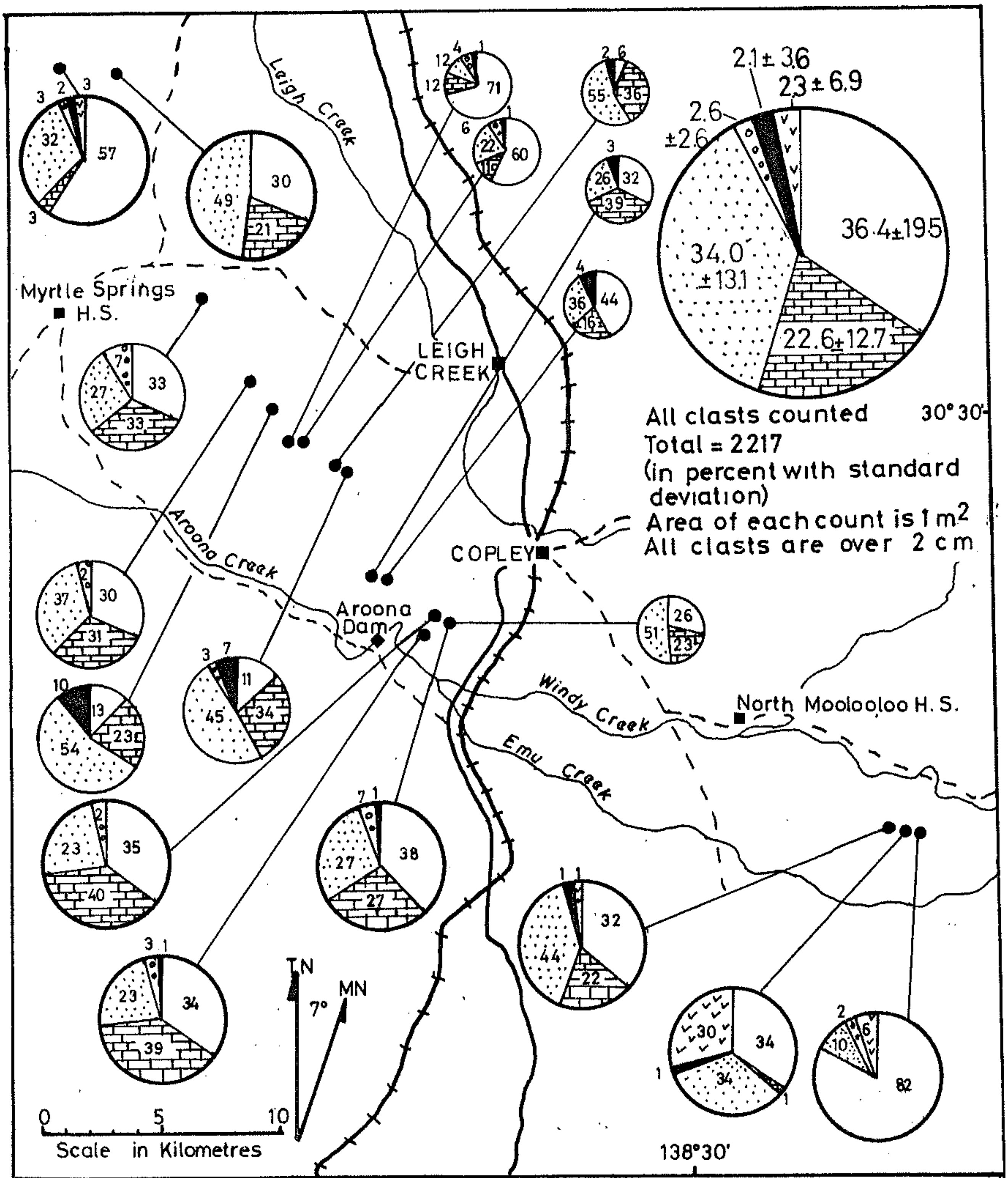
At five localities non-pebbly medium-grained sandstone forms the base of Unit 1, although at three of these a clast-poor diamictite bed occurs within 10 m of the base of the section. The main part of Unit 1 consists of laminated or cross-laminated siltstone in 2-5 cm beds, fissile shale that breaks into 0.5 cm plates, very fine sandstone with small scale trough cross-bedding (wavelength of 5-10 cm), interbedded fine to medium grained sandstone, siltstone and coarse sandstone (with beds 5-10 cm thick), clast-rich diamictite, and rare clast-poor diamictite (see Plates 2A and 2B). Five-cm thick beds grading from coarse sandstone to siltstone occur locally, as do diamictites bearing deformed soft-sediment clasts up to 2 m long (Plate 2C).

Beds of clast-rich diamictite are sometimes graded but are more often ungraded with sharp boundaries to laminated siltstone above and below. Where siltstone beds are covered by sandstone, load casts

FIGURE 5

CLAST PERCENTAGES, MERINJINA FORMATION - COPLEY AREA.

This figure demonstrates the predominantly sedimentary (Burra Group) provenance of clasts in the Copley area, but also the extreme local variation in clast percentages. Percentage of carbonates and clastics vary independently. High proportion of volcanics in middle locality southeast of North Moolooloo H.S. is probably related to diapir 2 km east.



CLAST PERCENTAGES - MERINJINA FORMATION - COPLEY AREA

FIGURE 5

- Quartzite - grey, purple, white, pink
- Grey silty dolomite and limestone
- Fine sandstone, minor coarse sandstone
- Black chert
- Granite, gneiss, pegmatite
- Grey porphyry, localized near diapirs

Unit 1 Unit 2 Unit 3

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and flame structures occur.

Till pellets (Ovenshine, 1970) (Plate 1C) and dropstones (Plates 1A and 1B), disrupting bedding in fine siltstones are found locally. These criteria are considered diagnostic of glacigene sediments by Schermerhorn (1974). Several lumps of clast rich diamictite (Plate 5B and 5C) interpreted to be till clasts occur. These have been reported from Recent (Gustavson, 1975) and Pleistocene (Harrison, 1975) glacial sediments, but not from Precambrian diamictites.

Composition of the sandstones is immature feldspathic sublitharenite to litharenite, with rare sub-mature quartz arenites. Quartz grains have mostly straight extinction, indicating a sedimentary source area (probably the underlying Burra Group). Undulose extinction and polycrystalline quartz is often abundant (up to 40%). Rock fragments are mainly chert, shale, siltstone, and quartzite. Feldspars are usually fresh and consist of grid-twinned microcline and albite-twinned plagioclase. Rare green and blue tourmalines and zircons occur as fine and medium-sized sand grains. No garnets were observed. Pyrite cubes, replaced by a brown hydrous iron oxide (probably goethite or limonite) are present locally in laminated siltstone (Plate 5A).

Grain shape varies from very angular to sub-rounded. Coarse sand grains tend to be more angular than medium and fine sand grains. Silt grains are usually angular to subangular, possibly due to grinding during glacial transport. Rock fragments and feldspars tend to be more angular than quartz grains of the same size.

Textural immaturity due to very poor sorting and presence of over 5% clay in most sandstones distinguishes the Merinjina Formation from the Burra Group below.

The contact between the bedded rocks of Unit 1 and massive clast-poor diamictite of Unit 2 is sharp and defined by the disappearance of bedding. There is no uniformity in the upper member of Unit 1.

Unit 2 consists of structureless cream, yellow, red, and tan colored diamictite, bearing subangular to rounded cobble and pebble-size clasts in a very poorly sorted matrix of angular fine silt and clay containing coarse to fine sand grains. Local development of iron concretions occurs in highly weathered diamictite and is accompanied by a bleached white color. This unit is called the "main tillite" by Mawson, (1941) and is similar to units labelled "typical tillite" and "true tillite" in various papers by Howchin, Mawson, and Sprigg. Clasts are rarely in contact with each other, and are randomly distributed within the groundmass. There is extreme local variation in clast frequency from 0 to 10%. In thin section the only sedimentary structures observed are wispy segregations of clay-rich matrix deformed by sand-sized clasts Outcrop is massive, and no partings occur to reveal bedding planes. Maximum clast size is 0.5 m, with 5 cm average. This is smaller than the mean size in Unit 1. As with the basal diamictites, sedimentary rock fragments compose the vast majority of the clasts. Rare two-meter thick interbeds of non-pebbly graded or laminated fine sandstone occur in this unit (Sections 13 and 20).

Bedded sediments of Unit 3 overlie the massive clast-poor diamictite of Unit 2 with what is interpreted to be an interfingering gradational contact over a thickness of 10 m. Unit 3 is similar to Unit 1, consisting of bedded siltstone, fine sandstone, bedded clast-rich diamictite, and rare clast-poor diamictite. In addition, near the top of the unit north of Myrtle Springs H.S., (Sections 5-7) it bears 0.5 to 1 m thick beds of planar cross bedded granule conglomerate and very coarse sandstone. Clast-rich diamictite beds (often approaching conglomerates in being clast supported) sometimes bear erosional channelled bases, though most often rest on a smooth contact. Maximum clast size is 1.5 m, and clast percentages are similar to the other units. Occasional till clasts less than 2 m in diameter are found in this unit, as are boulder and cobble dropstones.

In Section 25 a bedded sequence of climbing ripple cross-laminated siltstone, graded beds of coarse sandstone fining upwards to siltstone, and clast-rich diamictite occurs 10 m from the top of Unit 3. The diamictite is deformed, and appears slumped (Plate 2A).

The upper contact with the Tapley Hill Formation is sharp and defined by the disappearance of grains over medium silt size and, in some localities, the appearance of thin dolomite beds. The basal Tapley Hill Formation consists of black (purple weathering) pyritic shale (Tindelpina Shale Member) and occasional grey dolomites. A monotonous sequence of up to 1525 m (Coats, 1973) of fine laminated siltstone overlies these basal beds.

2.2 Sturt Gorge

The Gorge of the River Sturt, 10 km south of Adelaide, is the type area for the Sturt 'Tillite' (Howchin, 1908). There, a well developed subvertical cleavage, formed during the early Paleozoic Delamerian Orogeny, has obscured bedding. Clasts have been elongated parallel to cleavage and often bear tension fractures perpendicular to least compressive stress (Plate 5D). This deformation has obscured original surface textures of most clasts, and prevents interpretation of original clast shape and orientation. One striated pebble has been collected from the Sturt Gorge (see Appendix 3). A series of gentle folds and minor reverse faults postdates the cleavage. Vein quartz occurs along fault planes. Local deposits of sphalerite and pyrite occur near the top of the formation (Johnson, 1956). Figure 6 is a geological map embracing the Sturt Gorge.

The Sturt Formation (previously called Sturt Tillite) consists of diamictite, laminated siltstone, fine sandstone, and granule conglomerate (see detailed section, Figure 3 and comparative sections, Figure 7). This sequence can be divided into 3 units.

Unit 3 : laminated siltstone, graded sandstone, clast-poor diamictite, granule conglomerate and grey limestone, 80 m thick;

Unit 2 : massive diamictite with minor sandstone and siltstone interbeds, 105 m thick;

Unit 1 : (base), clast-poor diamictite overlain by laminated siltstone and crossbedded sandstone, 35 m thick.

The Sturt Formation overlies a thinly bedded sequence of siltstones and feldspathic fine sandstones of the Belair Subgroup with a sharp contact (Plate 4C). On the south side of Sturt River the contact is irregular and appears erosional with massive diamictite truncating thin beds of sandstone in the Belair Subgroup. Coats (1967) has interpreted the contact as a regional disconformity.

On the BURRA and ORROROO 1:250,000 map areas an unconformity exists between the Appila Tillite and underlying feldspathic sandstones and siltstones (Forbes 1967). These feldspathic sandstones have been equated with the Belair Subgroup by Segnit (1939) and Forbes (1971).

The stratigraphic position of the Belair Subgroup has been disputed over the last 30 years. Mawson and Sprigg (1950) included it with their Sturtian Series based on the presence of unweathered feldspar indicating a cold climate. The ADELAIDE 1:250,000 map sheet (Thomson, 1969) includes it with the Burra Group (elsewhere correlated with preglacial conditions of the Torrensian Series) based on the presence of ripple marks and mudcracks indicating shallow water conditions (Coats, 1967). However, ripple marks and mudcracks can easily occur in a glacigene environment as they record water depth rather than temperature.

In thin section sandstones from the uppermost Belair Subgroup are very similar to sandstone interbeds in the lower part of the

FIGURE 7

COMPARATIVE STRATIGRAPHIC SECTIONS, STURT GORGE.

The section of Howchin and the present section are quite similar, the major difference between the present section and that of Sprigg is estimation of the thickness of the massive diamictite of Unit 2. Sprigg interpreted the structure to be more complex than the present author, and placed a fault at the base. The sharp basal contact is shown in Plate 4C.

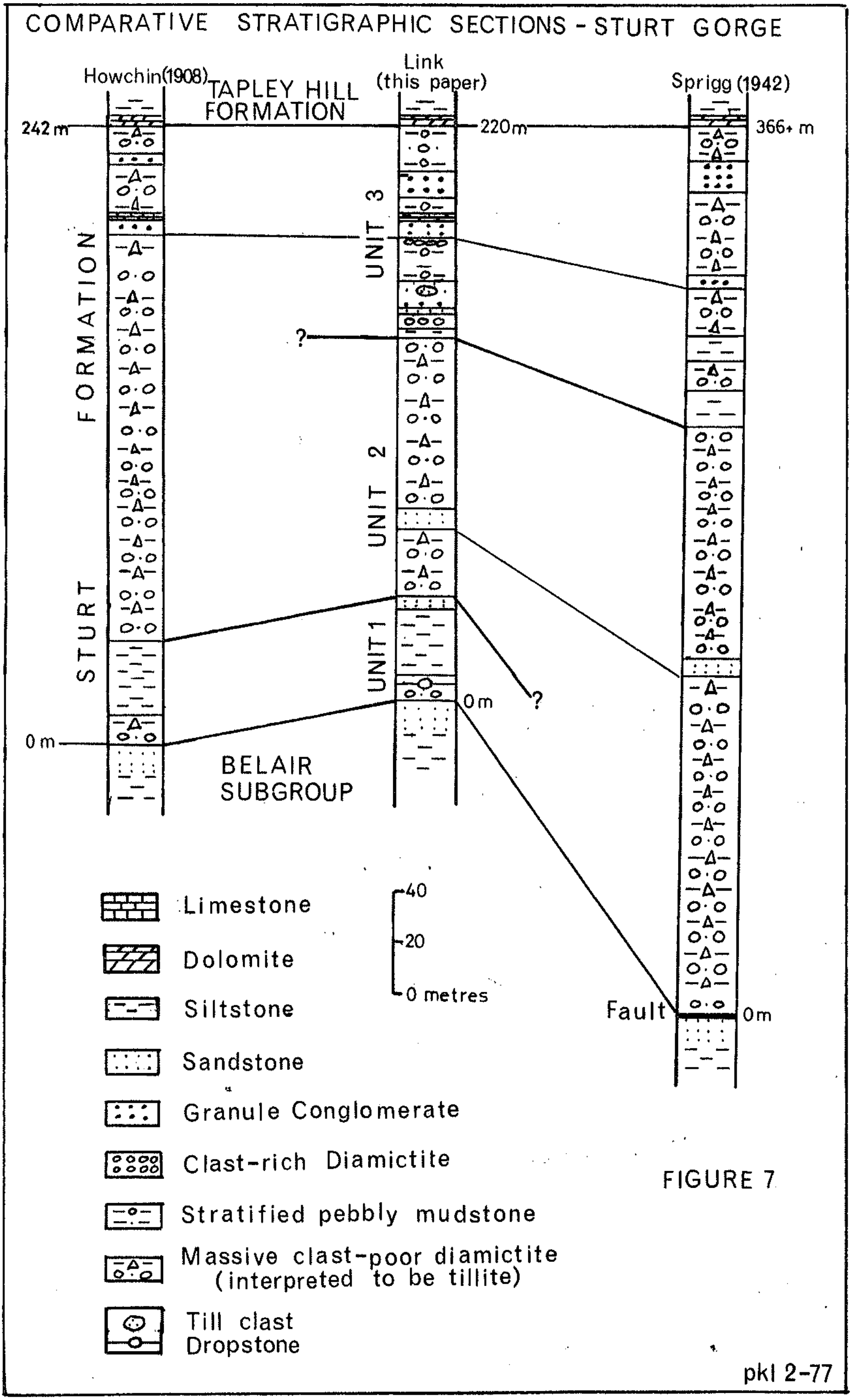
COMPARATIVE STRATIGRAPHIC SECTIONS - STURT GORGE
Howchin(1908)
Link (this paper)
Sprigg (1942)
TAPLEY HILL FORMATION
242 m
220m
366+ m
STURT FORMATION
UNIT 3
UNIT 2
UNIT 1
?
0 m
0m
BELAIR SUBGROUP
Fault
40
20
0 metres
Limestone
Dolomite
Siltstone
Sandstone
Granule Conglomerate
Clast-rich Diamictite
Stratified pebbly mudstone
Massive clast-poor diamictite (interpreted to be tillite)
Till clast
Dropstone
pkl 2-77

FIGURE 7

Sturt Formation (see Appendix 1, samples 522/212-6A, 522/213-5A) in texture and quartz grain composition. The main difference is the textural immaturity of the Sturt Formation due to the presence of clay matrix. Though far from conclusive, this line of evidence suggests more similarity than difference between the two rock units.

The assertion that the thick glacigene sequences of the Yudnamutana Subgroup in the Mt. Painter region (Coats, 1973) and of the Pualco Tillite of the OLARY map area (Forbes and Cooper, 1976) lie unconformably below the Merinjina Formation and its correlative Sturt Formation bears important implications for this issue. It seems possible to this author that the Belair Subgroup in the ADELAIDE map area is the time equivalent of the Yudnamutana Subgroup in the COPLEY and OLARY map areas. The presence of unweathered feldspar, whether caused by rapid deposition, cold climate, or both, is related to the tectonism which marks the gap between the Burra Group (Torrensian) and Umberatana Group (Sturtian), and suggests affinities between the Belair Subgroup and Sturt Formation.

At the base of Unit 1 of the Sturt Formation is a cobble-bearing sandy mudstone 10 m thick, locally pyritic, with clasts less than 20 cm in length. On the north side of Quarry Creek irregular interbeds of fine sandstone occur in this unit. Conformably above this basal diamictite is a 13 to 26 m thick olive brown laminated siltstone (0.3 cm laminae) bearing no clasts or grains larger than coarse silt. A 1 m thick, cross-bedded, medium-grained grey sandstone bed marks the top of Unit 1.

Unit 2, 105 m thick, is a cleaved grey diamictite of boulder, cobble and pebble bearing sandy mudstone. Percentage of different clast types, their size (up to 1.5 m) and their frequency (0-15%) are locally variable (see Fig. 8). The unit contains irregular local interbeds and lenses of non-pebbly shale and cross-bedded sandstone,

FIGURE 8

CLAST PERCENTAGES, STURT GORGE.

Three mutually independent clast sources are demonstrated: basement rocks, carbonate, and clastics.
An extrabasinal basement source area and two intrabasinal sedimentary source areas may be represented.

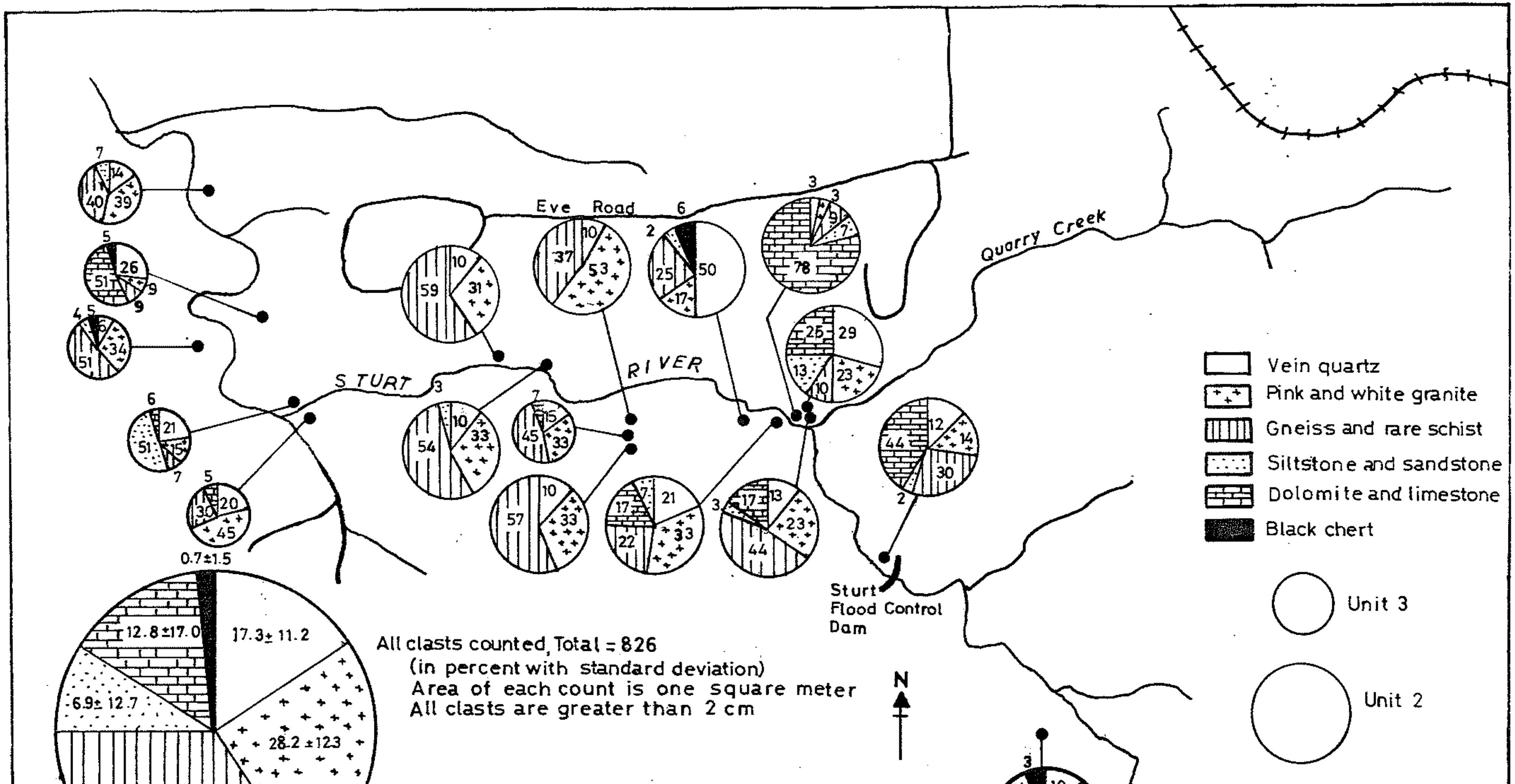

FIGURE 8

CLAST PERCENTAGES - STURT GORGE

(Sturt Formation)

less than 2 m thick. Near the Sturt River Flood Control Dam, interbeds of pyritic siltstone with convolute laminae are common.

Most of this diamictite reveals no structure in hand specimen, but from a distance of several metres bedding surfaces 3 to 10 m apart are apparent (Plate 4A). X-radiographs reveal irregular and disrupted silt and clay layers (see Appendix 2). The matrix is angular quartz silt and clay, and is locally calcareous. Dispersed pyrite crystals replaced by iron oxide occur locally. The rock is usually an immature litharenite, with very poor sorting and a dominance of granitic and metamorphic rock fragments.

Unit 2 grades, over an interval of several meters, into bedded and varied Unit 3 (80 m thick). Rock types in Unit 3 include laminated and cross-laminated siltstone, clast-rich diamictite, fine sandstone, graded beds of granule conglomerate to siltstone, and massive beds of clast-poor diamictite, similar to Unit 2. A distinctive horizon of granule conglomerate in beds and lenses sometimes mixed with diamictite and often with a calcareous matrix occurs near the top of Unit 3, (Plate 4B). It is cross bedded with cross sets up to 30 cm thick, varies from 1 to 10 m in thickness, and is local in occurrence. It bears a high percentage of sedimentary rock fragments, suggesting a distinct provenance from that of the massive diamictite. An irregular bed of blue-grey limestone (slightly silty micrite) occurs locally on top of the granule conglomerate. The bedded parts of Unit 3 (Plate 4D)are similar to Units 1 and 3 in the Copley area. Calcareous matrix (up to 40%) in diamictite becomes more common near the top of the unit, though it is very irregular in distribution.

Dropstones up to 3 cm in diameter occur in laminated siltstones, as do slumped and graded beds.

Unit 3 is overlain by grey dolomite and laminated siltstone of the Tapley Hill Formation with a sharp contact which can be best observed at the Geological Society of Australia Monument on the grounds of Flinders University, just northwest of the Sturt Gorge.

2.3 Comparison with previous Stratigraphic Sections in Sturt Gorge

Figure 7 shows sections measured by Howchin (1908), Sprigg (1942) and the present author. Howchin's measured thickness of 240 m is close to that of the present study, and correlation between the two sections is quite good. The major differences are Howchin's inclusion of the laminated siltstone beds in his "main tillite". Sprigg's section in the Sturt Gorge differs from the present section in including two rather than one laminated siltstones in Unit 3, and in greatly increasing the thickness of Unit 2. In the present study, a measured section (A-A' on Fig. 6) from the inlier of Belair Subgroup in Quarry Creek to the laminated siltstone at the base of Unit 3 near the junction with the Sturt River, was calculated assuming a constant dip of 20 degrees to the southwest. Outcrop does not permit view of the folding of beds in this area, but several isolated dip measurements seem to justify this assumption.

Sprigg found a fault at the base of the Sturt Formation in the Sturt Gorge, but the sharp contact at the base is shown in Plate 4C. It is suggested that Sprigg interpreted the fault just above the basal contact in the Sturt River to be the contact itself.

CHAPTER 3: SEDIMENTARY FACIES

3.1 General Statement

A glacial origin for the Sturt Formation was proposed early in this century (Howchin, 1901). The vast areal extent (740 by 400 km) of outcrops of the Sturt Formation and its equivalents, the ubiquitous presence of faceted and striated clasts (Howchin, 1908; Sprigg, 1942; Mawson, 1949; Glaessner and Parkin, 1958; Parkin, 1969, Appendix 3 this study) the occurrence of dropstones in laminated fine siltstones (Daily and Forbes, 1969, Belperio, 1973, this paper), till clasts (this paper), till pellets (this paper and Mortimer, 1973) and geochemical studies (Sumartojo and Gostin, 1975) support a glaciomarine origin for the Merinjina and Sturt Formations. As emphasized by Crowell and Frakes (1967), when a coherent regional picture of glacigene facies can be developed, the sediments concerned are most probably glacigene. Such a picture is outlined on pp. 15-18 below.

3.2 Regional Sturtian Tectonics

In Torrensian time (Burra Group and equivalents) the style of sedimentation in the Adelaide Geosyncline was one of shallow water marine, tidal flat, and beach deposits forming fine clastic and carbonate sediments (Thomson *et al.* 1976). The sudden appearance of coarse clastics at the base of the Sturtian Series can be explained by either erosion following major tectonism, or by glaciation of a physiographically positive area, not necessarily of high relief.

In the northern Flinders Ranges pre-Sturtian and early Sturtian tectonism is recorded in elevation of diapirs (Coats, 1973) and major faulting in the Mt. Painter area (Coats, 1973, Coats and Blisset, 1971) and Willouran Ranges (Murrell, 1977).

In the Adelaide region early Sturtian tectonism elevated basement source areas for coarse arkosic debris of the Belair Subgroup and may have caused injection of sandstone dikes of Sturtian Mitcham Arkose into Torrensian Glen Osmond slates along the Sturtian-Torrensian contact (Sprigg, 1946).

3.3 Yudnamutana Subgroup

The lowest unit within the Sturtian Glacial Sequence is represented by the Yudnamutana Subgroup which consists of thick (up to 4400 m) and local accumulations of diamictite and glaciomarine sediments in fault-bounded troughs north of Mt. Painter (Coats, 1973, Belperio, 1973, Mortimer, 1973, Ashton, 1973) and near Olary (Forbes and Cooper, 1976). These sediments show extremely rapid lateral variation in lithology and thickness directly related to nearby tectonism. Similar very thick accumulations of sediment occur in the Bibliando Dome (PARACHILNA map area, Mawson, 1949b) and east of Burra in the BURRA map area but the exact correlation in these areas has not been recently studied. Mawson (1949b) proposed the name Bibliando Stage for the lowest glacial units of the Bibliando Dome. Tectonically active environments are subject to subaqueous mudflow (Crowell, 1957) and such processes have been proposed, within a glacigene environment, by Schermerhorn (1974) for the Yudnamutana Subgroup. However, the presence of floating ice has also been verified by the discovery of dropstones (Belperio, 1973) and till pellets (Mortimer, 1973).

3.4 Sturt and Merinjina Formations

The Sturt and Merinjina Formations represent glaciation of much greater areal extent (covering all of South Australia) and smaller thickness (less than 1000 m), representing a very different tectonic environment, that of shallow marine glacigene sedimentation. A considerable variety of sedimentary environments exists within this glacigene framework. Three main sedimentary facies are interpreted to make up the rocks observed: the Massive Diamictite Facies, the Bedded Silty Facies, and the Granule Conglomerate Facies.

3.5 Massive Diamictite Facies

The seemingly structureless clast-poor diamictite at both Copley and Sturt Gorge belongs to the Massive Diamictite Facies. It is characterized by an almost complete lack of sorting of clasts and matrix, with structure limited to thick bedded intervals seen in the Sturt Gorge (Plate 4A), and the crude segregation of clay-rich bands seen in thin section and X-radiographs. Rare stratified interbeds of graded sandstone, laminated and convolute laminated siltstone occur. The range in clast size in the Sturt Gorge is up to 1.5 m in length, while in the Copley area the maximum clast size is 0.3 m. There is no preferred orientation of clasts as has been reported from Pleistocene continental tills.

Massive diamictites of this nature can be formed by glaciers as subaerial or subaqueous tills, by subaqueous, subaerial or volcanic mudflow, and postdepositional tectonic activity (wild-flysch). Volcanic and tectonic origins may be rejected due to the lack of volcanic debris or nearby large scale faulting, and subaerial mudflows are rejected because of the lack of "well developed but discontinuous planar bedding" (Crowell and Frakes, 1967, p.47). Of the remaining possibilities, both till deposition and subaqueous mudflow can occur in a glacigene environment.

The limited amount of knowledge of the nature of recent mudflow and subaqueous tills provides few solid criteria for distinguishing them, although mudflows have been reported to locally contain deformed soft sediment clasts and highly irregular slumped bedding (Crowell, 1957, Dott, 1961, Crowell and Frakes, 1967). The regional glacial conditions, the uniform thickness (for 20 km along strike in the Copley area) and the lack of deformed soft sediment clasts and convolute bedding in the Massive Diamictite Facies supports a glacial origin.

Lack of clast fabric and of striated pavements below these massive diamictites, the presence of locally calcareous matrix and stratified interbeds, and the low Fe and Mg, and high B contents (Sumartojo and Gostin, 1975, Angino, 1966, Frakes and Crowell, 1973) suggest that they are not subaerial, but <u>waterlaid tillites</u> deposited beneath an ice shelf by a floating ice sheet. Almost no currents acted to sort these sediments and the only structures formed are partings along bedding surfaces seen in the Sturt Gorge and rare silt bands disrupted by clasts. Rare interbeds of fine to coarse sandstone are deposited along with the surrounding till. Such stratified interbeds are to be expected in waterlaid tillites below a wet base glacier (Carey and Ahmad, 1961).

The irregular distribution of calcareous matrix in diamictite suggests that conditions of $CaCO_3$ precipitation existed locally. The calcareous matrix is probably derived from ground-up limestone and dolomite clasts, with precipitation initiated by slight increase in water temperature. Such models have been proposed by Carey and Ahmad (op.cit.) and Dow and Gemuts, (1969).

3.6 Bedded Silty Facies

Most of stratigraphic Units 1 and 3 from the Copley area and the laminated siltstone and graded beds of Units 1 and 3 in the Sturt Gorge are interpreted as belonging to the Bedded Silty Facies, which accumulated as glaciomarinite in a shallow water environment free from permanent shelf ice, but subject to sediment input from proglacial streams, seasonal shore ice, and free-floating icebergs (wet base glacier of Carey and Ahmad, 1961). Water depth was probably more than 40 m as major ice gouging of sediment above that depth has been reported from the north coast of Alaska (Barnes and Reimnitz, 1974). These and similar sediments elsewhere in South Australia were labelled 'fluvio-glacial' by Mawson (1941, 1949a)and Sprigg, (1942, 1946).

The overturning of a sediment-laden iceberg will introduce vast amounts of coarse and unsorted debris to be reworked by currents on the sea floor (Ovenshine, 1970). On the other extreme, long periods of little sedimentation result in laminated siltstones with rare dropped clasts. The segregation of moderately to poorly sorted fine sandstone and siltstone from clast-rich diamictite is caused by winnowing of unsorted (clast-poor) diamictites by weak bottom currents able to move particles no larger than medium sand. Very few high energy traction currents occur. Thin beds, mean grain size of silt to fine sand, wide shallow channels and lack of fining upwards sequences or associated subaerial (mudcracked) flood plain sediments fit a shallow subaqueous environment better than a fluviatile one.

Clast-rich diamictites in 10 to 20 cm beds (Plate 2A and 2B) represent the unwinnowed fraction of till. Pods and lenses of clast-poor diamictite represent ice rafted deposits. Till clasts represent masses of frozen material dropped from overturned icebergs (Plate 5B). Till pellets are analogous structures less than 1 cm in diameter (Plate 1C).

Thin graded beds associated with slumped diamictites and ripple cross laminated siltstones are turbidity current deposits. They are common in the Bedded Silty Facies where the basin deepens southwest of Copley Railway Station (Sections 24-27) and near the Flood Control Dam in the Sturt Gorge.

Bedded clast-rich diamictites bearing deformed soft-sediment clasts (Plate 3B and 3C) represent subaqueous mudflow of remobilized till (flowtill). These occur twice at the base and at several localities near the top of the Merinjina Formation.

It should be noted that massive diamictites and bedded siltstones represent two ends of a continuum with total ice cover and no reworking of sediment at one end, and normal marine conditions at the other.

3.7 Granule Conglomerate Facies

In isolated localities mainly near the top of the glacigene sequence, arkosic granule conglomerate with calcareous matrix occurs in 1 to 10 m beds (Plate 4B) with cross stratification up to 30 cm thick. These granule conglomerates are irregular in thickness and distribution and usually cannot be traced more than several tens of metres along strike. They were formed by traction currents much stronger than those in the Bedded Silty Facies. The lenticular nature of these conglomerates and association with unsorted diamictite suggests that they were deposited by high energy meltwater streams flowing in proximity to the glacial ice. In the Sturt Gorge, the uppermost part of Unit 3 consists of an irregular mixture of granule conglomerate and diamictite. Only englacial meltwater streams could bring this juxtaposition of unsorted diamictite with coarse but moderately well sorted sediment.

The occurrence of conglomerates near the top of a glacial sequence is reported from the Permian sediments near Bacchus Marsh, Victoria (Bowen et al. 1976), Pleistocene glaciation in Denmark (Marcussen, 1973) and is part of the receding phase of the wet base glacial model of Carey and Ahmad (1961).

In the Sturt Gorge, thin limestones occur locally on top of granule conglomerate beds, and laminated dolomites cap the Sturt and Merinjina Formations and many other late Precambrian glacigene units. The soluability of calcium carbonate (and magnesium carbonate) decreases with increasing water temperature above 0^0 centigrade and Anderson (1972) has reported direct correlation of carbonate precipitation and warm water plankton with melting glaciers in the Weddell Sea off Antarctica. It is hypothesized that the addition of slightly warmer meltwater in the Sturt Gorge area triggered carbonate precipitation during and after the rapid deposition of the granule conglomerate facies, and that general warming after the glacial sediment supply had ceased and before the influx of fine silt of the Tapley Hill Formation, caused precipitation of dolomite from super-saturated waters.

The explanation of this ubiquitous dolomite cap over late Precambrian glacials is a major paleogeochemical problem that may have far-reaching implications.

CHAPTER 4: PALEOGEOGRAPHY

4.1 Copley Area

It is suggested that the Merinjina Formation of the Copley area represents a distal glacio-marine deposit of glaciers and shelf ice flowing southward and westward from possibly separate source areas in the Willouran Ranges and east of Mt. Painter, (see Fig. 1).

The coarse and irregular Serle Conglomerate lying on a locally scoured and channeled erosion surface in the Tindelpina Hut Region northwest of Mt. Painter (Belperio, 1973) is correlated with the Merinjina Formation by Coats, (1973). This conglomerate here is proposed to represent a proximal late-glacial deposit, formed by high-energy currents of meltwater from a glacier retreating to the northeast.

Paleocurrent indicators: trough axes in cross-laminated silt-stones and planar cross sets in medium to coarse sandstone indicate that weak bottom currents came from the east north-east in the Copley area (Fig. 2). In addition, rare large-scale channels and elongate sole marks (50 cm long, 4 cm wide, 1/2 cm deep) suggest that higher energy movement was also from this direction.

In the COPLEY map area the Merinjina Formation "becomes more arkosic to the north and west" (Coats, 1973), and in the Willouran Ranges it is mostly a coarse arkose with lenses of what is interpreted to be subaerial glacial deposits (Murrell, 1977). In the present study, the waterlaid tillite of Unit 2 thins to the north and east of Myrtle Springs H.S. (Sections 1-3, 5-10) and granule conglomerates start to appear at the top of the sequence, suggesting an approach to a land area with fluvio-glacial conditions and representing a northerly source area. Paleocurrents in this area are dominated by a northerly component (see Fig. 2).

To the south of Copley R.S. a thick basal diamictite and a generally thicker sequence is evidence for local deepening of the basin in that direction.

The source area for the Merinjina Formation and indeed all Sturtian glaciation has been proposed as having been 550 km to the southwest in the Gawler Platform based on the occurrence of two diagnostic clast types: rhyolites of the Carpentarian Gawler Range Volcanics and pink quartzites bearing fossil liesegang bands of the Willouran-Torrension Pandurra Formation (Coats, 1973, Thomson et al. 1976). These diagnostic clasts are very abundant in the Merinjina Formation near Wooltana H.S., east of Mt. Painter, and are present, though rare in the present study area. Rhyolites have been recently discovered during drilling in the Curnamona Cratonic Nucleus east of Mt. Painter (Thomson, 1976), and the possibility exists of finding pink quartzites from this area also (Coats, 1977, pers. comm.). Belperio (1973) suggested that during deposition of the Serle Conglomerate a shoreline existed east of Mt. Painter, behind which lies the Curnamona Cratonic Nucleus.

As outlined in Figure 5, the clast percentages in the Copley area indicate that the source area was one of predominantly sedimentary rock types of the Burra Group. However, the great local variation in clast percentages reveals that glacial transport and deposition did not allow mixing of sediments from discrete source areas.

Palinspastic reconstruction of Burra Group sediments in the Willouran Ranges and determination of depth to magnetic basement in the Lake Torrens Basin by Murrell (1977) indicates that an elongate northwest trending basin occupied the Copley area in Burra Group time, with rapid thinning to the west, where no Burra Group rocks were deposited. An easterly source area for the Merinjina Formation is compatible both with the abundance of pink quartzites and rhyolites in the Wooltana area and the dominance of Burra Group clasts in the Copley area. Postulation of a westerly source area makes explanation of the observed clast distribution very difficult.

Southwest trending striations at the base of the Merinjina Formation at Merinjina Well (Mirams, 1964) have also been used to justify a source far to the southwest, but the reinterpretation of this feature as a tectonic one (Daily et al. 1973) invalidates this assertion.

The minor granite and gneiss fraction seen in the Copley area could have been derived from the Curnamona region, but distinctive trachytes found in two localities, proximal to diapirs (sections 1, 27), probably came from the Willouran Callana Beds which are exposed in these diapirs. In thin section, frequent sand sized nests of bladed plagioclase grains reminiscent of ophitic texture in dolerites (Williams, Turner and Gilbert, 1954, p.19) were observed. Dolerites of the Callana Beds could be the source for these grains.

Unit 1 of the Merinjina Formation at Copley is thus proposed to represent the approach of an ice sheet from the northeast and associated shallow marine deposition of Bedded Silty Facies. This deposition was initiated with sediments from icebergs (basal clast-poor diamictite), winnowed ice-rafted material (basal clast-rich diamictites), and mudflows of such material (basal clast-rich dimictite with deformed sandstone bodies).

Varying amounts of coarse sediment, reworked by turbidity currents and weak bottom currents from the east-northeast, are interbedded with laminated siltstone deposited in quiescent periods. The lack of lateral continuity along the strike ridge west of Copley R.S. demonstrates how varied this sedimentary environment was. The onset of shelf ice was accompanied by the deposition of the massive diamictite of Unit 2.

Retreat of the glaciers to the northeast resulted in a resumption of deposition of the Bedded Silty Facies, Unit 3, with lenses of the granule conglomerate facies deposited irregularly near the top of the sequence by glacial meltwater.

This interpretation differs from that of Coats (1973), who proposed a continental glaciation as part of a vast ice sheet from the west.

4.2 Sturt Gorge

A westerly source area for the basement assemblage in Sturt Gorge has previously been proposed, as the nearest plutonic and metamorphic rocks are on the Gawler Platform in Eyre Peninsula, and in basement inliers to the southwest on Flerieu Peninsula. However, examination of Figure 8 reveals that clast percentages vary greatly within the Sturt Gorge, with at least three clast types as independent variables: basement rocks (vein quartz, granite, and metamorphic rocks), clastic sediments (siltstone and sandstone) and carbonate. Clast percentage variation does not correlate with stratigraphic unit, except that within the Granule Conglomerate Facies, sedimentary rock fragments predominate. Possibly there were two extrabasinal source areas, providing the basement rocks and the clastics, and an intrabasinal carbonate source that became predominant during local erosion associated with rapid meltwater flow near the end of the glaciation. No paleocurrent indicators could be located in Units 1 and 2 in the Sturt Gorge.

In Unit 3, measurement of 19 planar cross-beds in granule conglomerates reveal a bimodal source, from the northwest (332^{o}) and the northeast (51^{o}).

These results are not incompatible with a major source area to the west, as first proposed by Howchin (1908), and adopted by most other observers since. Perhaps a northeastern sedimentary source area existed also.

CHAPTER 5: CONCLUSION

This study has documented the occurrence of dropstones, till clasts, and till pellets in the Sturt and Merinjina Formations, which combined with regional continuity and evidence presented elsewhere of the presence of faceted and stirated clasts and distinctive geochemical characteristics strongly supports the view that a major glaciation covered most of South Australia around 740 million years ago.

Three facies of glacial sedimentation have been recognized: the Massive Diamictite Facies interpreted as being deposited beneath a floating ice sheet, the Bedded Silty Facies interpreted as being deposited as a shallow marine glaciomarinite with simultaneous subaqueous mass movement deposits, and the Granule Conglomerate Facies interpreted as being formed by high energy carbonate saturated meltwater during glacial retreat.

This study provides further evidence for the view that multiple source areas existed during the Sturtian glaciation (as advocated by Schermerhorn, 1974, and Belperio, 1973), and that the concept of a single ice sheet from a westerly source (Coats, 1973) is incorrect. Among these source areas were: an area north of the Willouran Ranges, the Curnamona Cratonic Nucleus east of Mt. Painter, the Willyama Block east of Olary, and an area west of Sturt Gorge (the Gawler Craton).

Within subsiding troughs (such as the area west of Mount Painter) extremely thick and variable glacigene sequences were deposited. This environment was quite different from that in the tectonically stable areas examined in this study, where thin and laterally continuous blanket deposits accumulated. If, as asserted by Coats (1973), the Yudnamutana Subgroup type sequence lies unconformably below the rocks of the upper phase of Sturtian glaciation examined here, then these two glaciations were of very different character. The question of whether glaciers eroded all these source areas simultaneously or whether glaciation progressed in time across the geosyncline remains intriguing and unanswered.

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Note: Format follows that used in the Transactions of the Royal Society of South Australia.

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PLATE 1

EVIDENCE FOR GLACIGENE SEDIMENTATION IN BEDDED SILTY FACIES, MERINJINA FORMATION, COPLEY AREA.

A. Angular boulder dropstone in bedded siltstone and clast-rich diamictite at 280 m, Section 25 (Unit 3). Scale

B. Granite porphyry dropstone piercing bedding in siltstone and clast-rich diamictite sequence at 40 m, Section 20 (Unit 1).

C. Till pellet (emplaced as frozen clast) of coarse sandy mudstone (1.5 mm long) from sample 022-1E 88.4 m, Section 17 (Unit 3). 40 x photomicrograph in plane light.

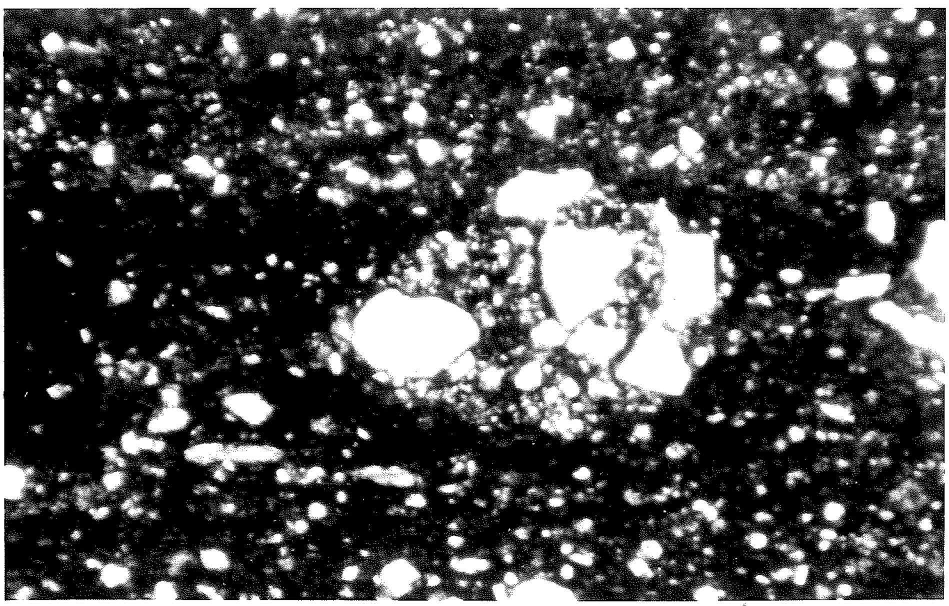


PLATE 2

CLAST-RICH DIAMICTITES IN BEDDED SILTY FACIES, MERINJINA FORMATION, COPLEY AREA.

A. Very angular boulders and pebbles in thin clast-rich diamictite bed interpreted to be dropped by overturning iceberg and then winnowed by weak bottom currents. Particles greater than coarse sand size are left in situ. 285 metres section 25. (Unit 3).

B. Lag pebble conglomerate in Bedded Silty Facies near North Moolooloo H.S., bed of Windy Creek (Unit 3).

C. Soft sediment clast of laminated siltstone in clast-rich diamictite with coarse sandy matrix. Note small vertical faults in siltstone clast and clastic dyke of coarse sandy matrix injecting siltstone clast. Bedding in diamictite youngs upwards. This diamictite was probably emplaced by mudflow, ripping up incompletely lithified siltstone clasts. 15 m, Section 20 (Unit 1).



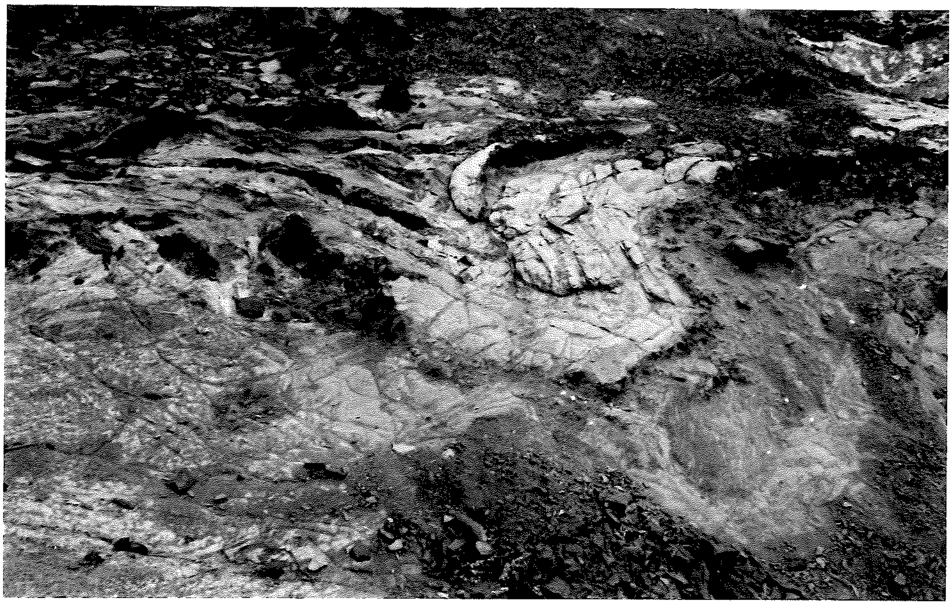
PLATE 3

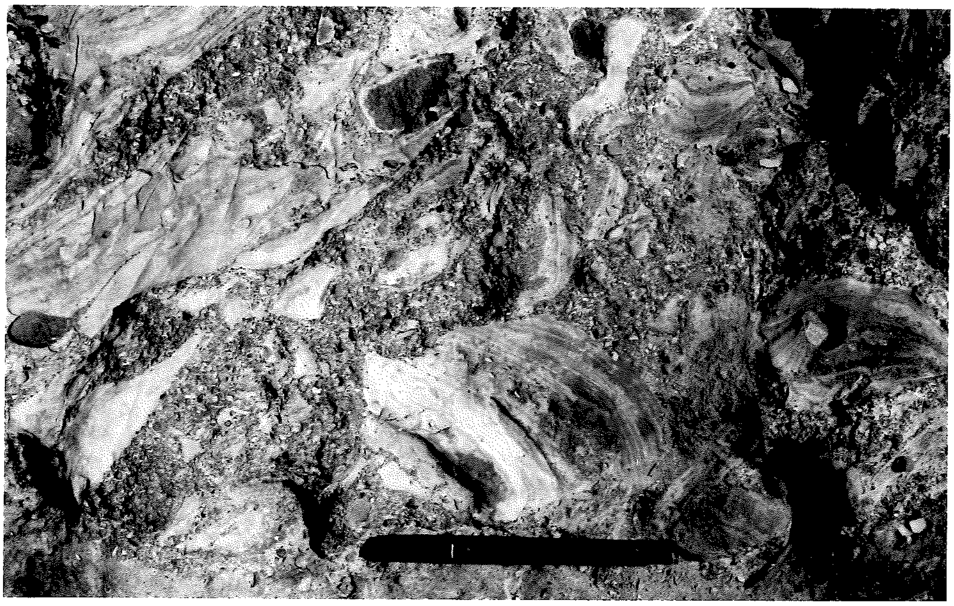
EVIDENCE FOR SUBAQUEOUS MASS MOVEMENT AND SLUMPING WITHIN BEDDED SILTY FACIES, MERINJINA FORMATION, COPLEY AREA.

A. Slump of clast-rich diamictite bed. Photo shows a flat surface, beds dip subvertically and young towards bottom of photo. Note hammer (in middle of slump) for scale. Near Section 25 (Unit 3).

B. Penecontemporaneously deformed siltstone clasts within clast-rich diamictite, probably emplaced by subaqueous mass movement. 10 m Section 20 (Unit 1).

C. Folded soft sediment clast of coarse sandstone within bedded siltstone at 60 m Section 20 (Unit 1).





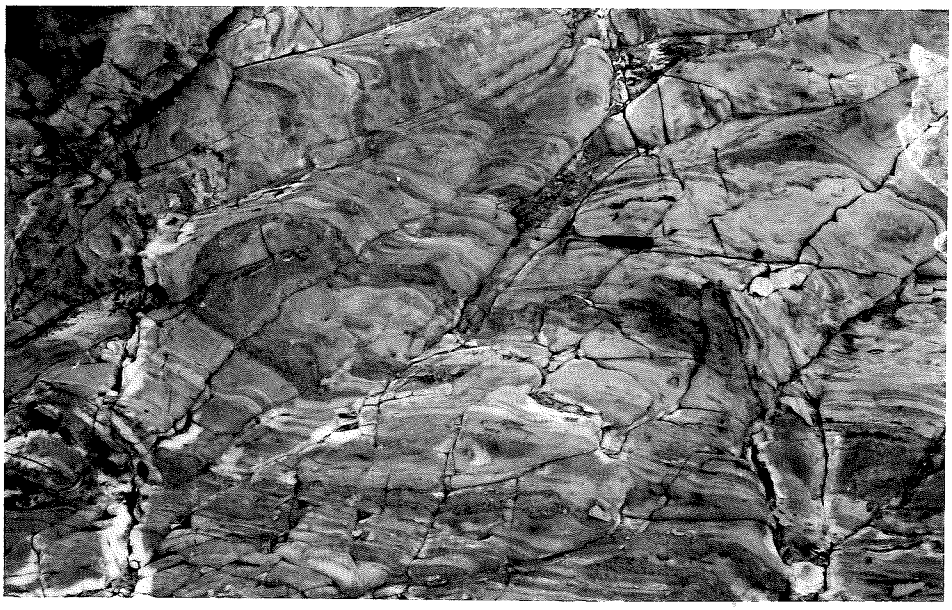


PLATE 4

BEDDING TYPES - STURT FORMATION, STURT GORGE

A. Gently folded thick bedding in Massive Diamictite Facies Unit 2, looking east, middle Sturt Gorge.

B. Channel shaped body of Granule Conglomerate Facies resting on cleaved pebbly mudstone, Unit 3. Lower Sturt Gorge.

C. (left) Overturned contact between thin bedded sandstone and silt-stone of Belair Subgroup (above pen) and bedded diamictite of base of Unit 1 Sturt Formation. Pen lies on sharp contact, north side of Sturt River above Flood Control Dam. Contact is regionally disconformable and locally erosional.

D. (right) Thin bedded medium sandstone Unit 2, south side Sturt River near Eden Avenue Path.



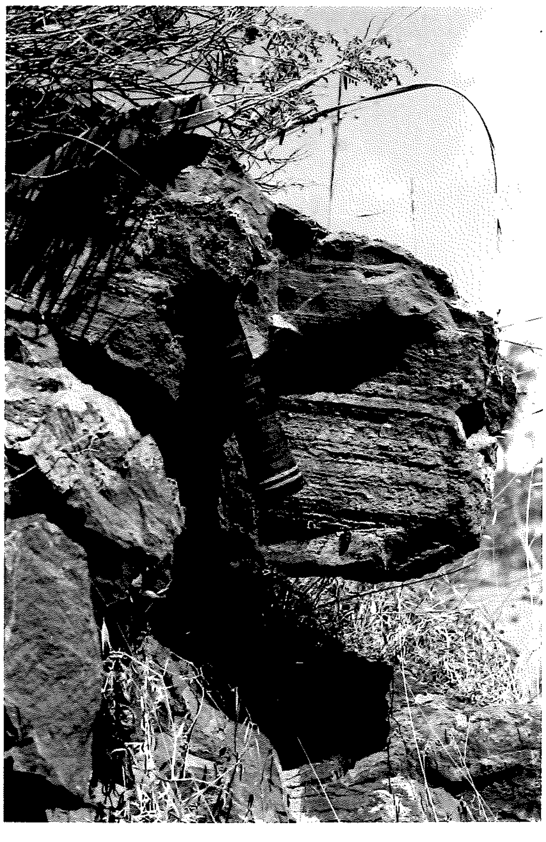



PLATE 5

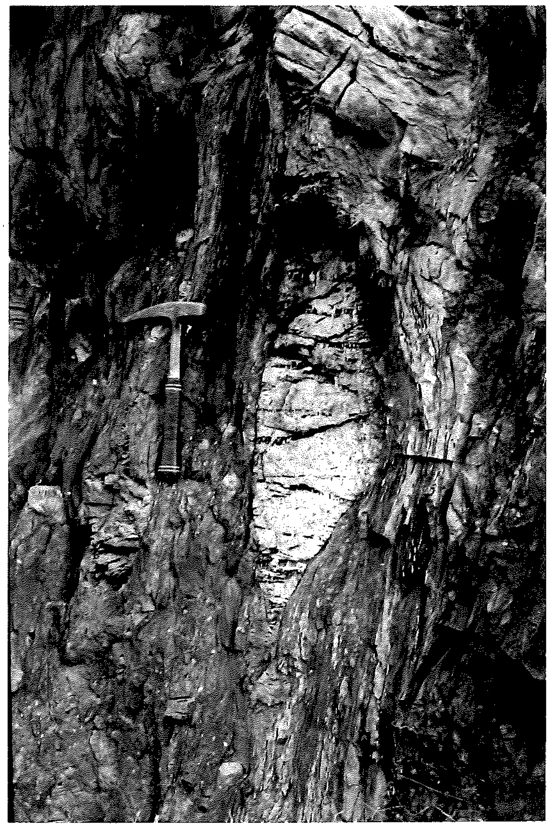
MISCELLANEOUS FEATURES, MERINJINA AND STURT FORMATIONS

A. Pyrite crystals in medium sandstone, thin section 522/022-1E Merinjina Formation from stratigraphic Section 17, 88.4 m, (Unit 1). 40 x magnification. Bedded Silty Facies.

B. Till clast interpreted to be dropped as frozen till lump, Bedded Silty Facies 10 m Section 18, (Unit 1). Merinjina Formation.

C. (left) Till clast in Massive Diamictite Facies, north side Sturt River just west of Eden Avenue path, (Unit 2). Sturt Formation.

D. (right) Tension fractures (perpendicular to cleavage) and elongation of granite clast (parallel to cleavage). South side of Sturt River, Middle Sturt Gorge, Unit 2 Sturt Formation (Massive Diamictite Facies).



APPENDIX 1

THIN SECTION DESCRIPTIONS

Thin sections demonstrating the various rock types examined are described here. Percentage compositions were determined by 10 visual estimates along a micrometer scale for each thin section. Rock names are after Folk (1974).

In specimen numbers, 522 is the accession number for the Adelaide University Geological Museum, the next three digits denote month and day, with month 0 being September 1976, month 1, October 1976, month 4, January 1977, and so on. The final digit refers to locality for each day and the letter refers to specimens from that locality. For example, 522/024-1D was collected September 24, 1976, at the first locality of the day, and is the fourth sample from that locality.

The Copley area samples are 522/016-1C to 522/103-4B inclusive and Sturt Gorge samples are 522/212-4A to 522/501-1B inclusive.

Figure A1 shows localities of samples from the Sturt Gorge. The Copley samples are indexed by stratigraphic section number (see Fig. 1 and Fig. 3).

COPLEY AREA SAMPLES

522/016-1C Merinjina Formation, Bedded Silty Facies
Section 20 9.5 m, Unit 1.

Sandy mudstone: immature clay cemented litharenite

70% clay matrix
30% quartz and rock fragment sand size grains, sub-angular to sub-round

of sand size grains,

90% quartz, mostly straight extinction
10% sedimentary rock fragments

522/016-1I Tapley Hill Formation, Tindelpina Shale Member,
Section 20, 187.9 m

Fine siltstone: submature pyritic calcareous siltstone

95% calcareous silt, mostly micrite ooze
5% rounded quartz silt grains

522/017-1B Merinjina Formation, Bedded Silty Facies.
Section 21, 16.5 m, Unit 1.

Coarse sandstone: submature siliceous sublitharenite

30% quartz cement
70% sand grains

of sand grains,

80% quartz, sub-rounded to rounded, 70% straight extinction 25% undulose extinction, 5% polycrystalline
20% rounded clasts of fine siltstone.

522/017-1C Merinjina Formation, Bedded Silty Facies
Section 21, 182.2 m, Unit 3.

Fine sandy mudstone: immature clay cemented sublitharenite

50% clay matrix
50% silt and sand size grains, stratified, 10 mm layers

of silt and sand

80% quartz silt, subangular
20% fine sandstone sand sized grains.

522/018-6C Merinjina Formation, Massive Diamictite Facies
Section 23, 93 m, Unit 2.

Pebbly mudstone: Ferruginous immature litharenite

Micro: Clay size grains make up 65%, sand grains 30%, clasts 5%. Red-tan color.

63% quartz, rounded, undulose and straight extinction
2% chert rounded
5% feldspar, less round than quartz, plagioclase and microcline
3.5% biotite
24.5% rock fragments, siltstone, carbonate, sandstone
1% green tourmaline, limonite replacing pyrite cubes.

522/019-1A Merinjina Formation, Bedded Silty Facies
Section 24, 16.0 m, Unit 1.

Fine sandstone: hematitic siliceous immature litharenite

Macro: pock marked kaolinized white sandstone.

49% quartz with straight extinction
7% quartz with undulose extinction
6% polycrystalline quartz
15% rock fragments, siltstone and sandstone
23% clay matrix

522/019-1B Merinjina Formation, Bedded Silty Facies
Section 24, 30.0 m, Unit 1.

Very coarse sandstone: siliceous submature sedimentary rock fragment litharenite.

Micro: poorly sorted, sand grains rounded, larger rock fragments subrounded.

40% quartz, mostly straight extinction
52% rock fragments, quartz sandstone, siltstone, carbonate
1% biotite
5% carbonate fragments.

522/019-1C Merinjina Formation Bedded Silty Facies
Section 24, 54.5 m, Unit 1.

Sandy mudstone: siliceous hematitic immature sublitharenite

Macro: pinky greenish grey siltstone with sandstone beds, kaolinized.

Micro: very poorly sorted, parallel laminations, no evidence of traction currents, settled out of quiet water.

80% quartz
10% sedimentary rock fragments
5% mica
5% other - green tourmaline.

522 /019-1D Merinjina Formation, Massive Diamictite Facies
Section 24 96.8 m, Unit 2.

Granule bearing mudstone: limonitic immature chlorite and sedimentary rock fragment bearing litharenite.

Micro: red color, extremely poorly sorted, grains sub-rounded to subangular.

10% quartz, mostly straight extinction
40% rock fragments, mostly siltstone and fine sandstone
5% feldspar, microcline with grid twinning
1% green tourmaline, limonite dispersed through section
44% clay matrix.

522 /020-1A Merinjina Formation, Bedded Silty Facies
Section 26 21 .0m, Unit 1.

Fine sandstone: ferruginous immature sublitharenite

Micro: moderately sorted brown sandstone, rounded and subrounded grains.

75% quartz, mostly straight extinction
10% sedimentary rock fragments
5% mica-biotite and chlorite
2% carbonate grains
7% clay
1% zircons

522 Ø20-3A Merinjina Formation, Bedded Silty Facies
Section 25 246.5 m, Unit 3.

Fine sandstone: siliceous and hematitic submature sedimentary rock fragment bearing litharenite

Macro: white trough cross bedded sandstone; calcareous matrix

70% quartz
13% sedimentary rock fragments, siltstone, some quartzite
2% feldspar-microcline
2% mica-authigenic and detrital
2% carbonate
1% other green tourmaline, zircon.

522 /021 -4A Merinjina Formation, Bedded Silty Facies
Section 16 5 m, Unit 1.

Very fine sandstone: ferruginous immature sub-arkose

Macro: massive weathering red medium sandstone

Micro: poorly sorted, large grains rounded, smaller ones angular

70% quartz, mostly straight extinction
3% chert
4% feldspar
2% rock fragments
1% green tourmaline
20% iron cement

522/022-1C Merinjina Formation, Bedded Silty Facies
Section 17 1m, Unit 1.

Granule bearing silty fine sandstone: calcareous and pyritic immature litharenite.

Micro: poorly sorted, grains mostly rounded, brown color.

50% quartz, mostly straight extinction
10% chert, larger than quartz
10% feldspar-albite and microcline, smaller than quartz
12% rock fragments, carbonate and siltstone
16% clay
other - pyrite grains.

522/022-1D Merinjina Formation, Massive Diamictite Facies
Section 17 63.6 m, Unit 2.

Sandy mudstone: limonitic immature litharenite

Macro: brown pebbly mudstone, no structure visible

Micro: very poorly sorted, subrounded grains

50% clay matrix
40% quartz, mostly straight extinction
8% rock fragments, mostly siltstone, some quartz sandstone
2% feldspar - microcline

522/022-1E Merinjina Formation, Bedded Silty Facies
Section 17 88.4 m, Unit 3.

Sandy mudstone: pyritic immature chert bearing litharenite with till pellets.

Macro: laminated silty and sandy beds,

Micro: very poorly sorted, quartz grains subangular, rock fragments quite angular, bears till pellets. (see Plate I(C)) of granule size.

80% fine silt and clay matrix
10% quartz - mostly straight extinction
3% chert
1% feldspar
5% rock fragments, shale, medium grained sandstone, quartz siltstone
1% hematite replacing pyrite cubes (see Plate 5(A)).

522/022-3A Merinjina Formation, Massive Diamictite Facies
Section 18 60 m, Unit 2.

Pebbly sandy mudstone: calcareous immature quartz and carbonate bearing arkosic litharenite.

Micro: under low power concentrations of clay and layers of pebbles define a crude layering.
Very poorly sorted, sand size grains rounded, very coarse sand is subangular, silt is very angular.

522/022-3A (cont'd)

40% clay matrix
30% quartz, mostly straight extinction, some polycrystalline and undulose extinction
5% chert - large sand grains
5% feldspar microcline and albite, sandsize grains
10% rock fragments - fine shale, schist, calcareous siltstone
10% calcite cement

522/022-3B Section 18, 113.5 m. Merinjina Formation, Unit 3.

Pebbly sandy siltstone: siliceous immature litharenite

Macro: grey bedded siltstone and coarse sandy siltstone, fine laminations.

Micro: very poorly sorted, quartz grains subangular, rock fragments sub-rounded, coarse half very different than fine half.

Composition of coarse half
40% quartz, mostly straight extinction
5% plagioclase
5% chert
2% biotite
15% rock fragments, quartzite, shale
2% carbonate
40% clay
1% opaques, ilmenite

Discussion: rapidly deposited coarse fraction followed by quiet conditions of laminated fraction.

522/022-4A Merinjina Formation, Bedded Silty Facies, Section 19, 0 m, Unit 1.

Boulder bearing fine siltstone: calcareous immature litharenite.

Macro: massive diamictite, calcareous siltstone clasts, calcareous matrix.

Micro: extremely poorly sorted, quartz in sand size grains is subround, silt grains are angular.
Carbonate cement

52% clay and carbonate cement
30% quartz, mostly straight extinction
2% chert
1% feldspar
1% mica
15% rock fragments, mostly calcareous siltstone
1% hematite replacing pyrite cubes; cubes up to 2 mm in size

522/022-4B Merinjina Formation, Bedded Silty Facies. Section 19, 3.7 m, Unit 1.

Fine sandstone: pyritic hematite submature subarkose.

Macro: tan medium grained non-calcareous sandstone

Micro: moderately sorted, grains rounded to subrounded iron oxide cement and hematite replacing pyrite cubes.

522/022-4B (cont'd)

85% quartz
12% feldspar - bladed plagioclase remeniscent of ophitic plagioclase in dolerites
3% opaques, pyrite cubes replaced by hematite

522/0236A Merinjina Formation, Bedded Silty Facies
Mountain of Light Mine, Unit 3.

Fine sandstone: siliceous mature sub-litharenite

Micro: very well sorted, quartz grains angular, carbonate grains rounded.

80% quartz, about 66% straight extinction
34% undulose extinction
20% chert
8% rock fragments - sedimentary
5% carbonate
5% clay

522/023-7A Merinjina Formation, Bedded Silty Facies
Mountain of Light Mine, Unit 3.

Purple quartzite clast identified by Ron Coats to be "Pandurra type" quartzite that distinguishes his "Merinjina tillite" in the COPLEY map sheet.

522/024-1C Clast from Merinjina Formation,
Hand specimen 13, 47 m, Unit 2.

Medium-grained quartz - microcline - plagioclase - muscovite (sericite) leucogranite.

522/024-1D Merinjina Formation, Massive Diamictite Facies
Section 13, 77 m, Unit 2.

Pebbly very fine sandstone: Ferruginous and clay cement, immature sub-litharenite

Macro: grey fine siltstone with pink granite clast, slightly calcareous matrix.

Micro: layering evident in thin section, clots of very fine silt and of medium quartz silt that are deformed around the granite clast.
Very poorly sorted, sand grains subround, silt angular, cement slightly calcareous, but mostly limonite and clay.

60% clay matrix
35% quartz, straight extinction dominant
5% rock fragments, mostly siltstone, minor limonite after pyrite

Discussion: Wisps of clay-rich material deformed by clast may indicate sedimentation in very quiet water.

522/024-1E Merinjina Formation, Bedded Silty Facies, Section 13, 90 m, Unit 3.

Sandy siltstone: immature quartz-chert-feldspar bearing sublitharenite

Macro: Bedded and laminated siltstone with sandstone channel cutting into it, sandstone bed grades upward to fine silt.

Micro: immature, coarse sand and silt are angular, medium sand is subrounded.

67% clay matrix
20% quartz
5% chert
5% rock fragments - chert, siltstone
2% feldspar - twinned albite, fresh, smaller than quartz
1% carbonate fragments.

522/025-2A Merinjina Formation, Massive Diamictite Facies, Section 14, 76 m, Unit 2.

Pebbly fine sandy mudstone: calcareous immature chert-bearing arkose.

Micro: poorly sorted, grains subangular, no structure observable.

60% clay and calcareous cement
25% quartz
10% feldspar, some sericitized
5% chert
minor mica, carbonate.

522/026-1A Burra Group Section 1 in contact with Merinjina Formation.

Fine siltstone: siliceous mature calcareous quartz arenite. Fine silt with clay beds, soft sediment deformation and carbonate overgrowths, laminated, some beds ripped up.

522/026-1E Merinjina Formation, Bedded Silty Facies Section 1, 37 m, Unit 1.

Clay bearing very coarse sandstone: siliceous immature chert and igneous rock fragment-bearing litharenite.

Macro: No bedding, little silt, unit bears till clast in outcrop.

Micro: Very poorly sorted, grains mostly rounded. Quartz cement.

5% silica cement and clay
54% quartz, half straight extinction, half undulose extinction
29% rock fragments, pebbly sandstone, acidic igneous rock, bladed ophitic dolerite, fine sandstone, shale, mica schist.
2% microcline
minor mica - muscovite.

522/026-1F Merinjina Formation, Bedded Silty Facies
Section 1, 117 m, Unit 3, just below Tapley Hill contact.

Fine sandstone: siliceous submature pyritic chert arenite. Well sorted, grains recemented by quartz cement,

Quartz 82% quartz undulose extinction
11% chert
4% feldspar - bigger than quartz grains
5% opaques, limonite replacing pyrite.

Discussion: This thin section demonstrates a possible transition to the well sorted mature sediments of the Tapley Hill Formation.

522/027-1B Merinjina Formation, Bedded Silty Facies,
Section 10, 18 m, Unit 1.

Granule-bearing fine sandstone: siliceous hematitic immature calcareous litharenite.

Macro: grey dense rock, pebble bed in medium sandstone matrix, calcareous pebbles.

Micro: grain sized angular silt clasts, crude bedding marked by clay accumulation, very poorly sorted.

51% quartz
2% feldspar-bladed ophitic texture
36% rock fragments, mostly siltstone, very angular
8% carbonate
1% opaques - ilmenite.

522/027-2A Merinjina Formation, Bedded Silty Facies,
Section 8, 0 m, Unit 1.

Granule bearing sandy siltstone: siliceous immature litharenite.

Micro: very angular and abundant sedimentary rock fragments, very poorly sorted. Silt layers are well laminated.

50% quartz
7% chert
12% feldspar-microcline + albite
1% mica
30% rock fragments, mostly siltstone.

522/101-1A Merinjina Formation, Bedded Silty Facies,
Section 4, 0 m, Base Unit 1.

Very coarse sand bearing medium sandstone: siliceous immature feldspathic litharenite.

Macro: brown coarse sandstone

Micro: poorly sorted, grains rounded

42% quartz
7% chert
15% feldspar - sericitized microcline
35% rock fragments, abundant shale, quartz sandstones, acidic igneous rocks, dolerite
1% opaques, ilmenite.

522/101-1B Merinjina Formation, Bedded Silty Facies
Section 4, 17.4 m, Unit 1.

Pebbly sandy siltstone: immature micaceous arkose.

Macro: Brownish green bedded pebbly mudstone, laminated silt beds with pebble nests and till clasts.

Micro: poorly sorted, angular grains, shows laminations, clay bands, imbrecation of mica, till pellets are present.

40% clay
39% quartz
2% chert
10% feldspar - some quite weathered
5% mica-muscovite
2% carbonate
2% other - opaques

522/101-1D Merinjina Formation, Bedded Silty Facies,
Section 5, 48 m, Unit 1.

Very fine sandstone: ferruginous and siliceous immature chlorite-bearing sub-chert arenite

Macro: fine cross laminated sandstone

Micro: moderately well sorted, quartz grains angular, feldspar less angular.

77% quartz
7% chert
2% feldspar
7% mica-chlorite
7% cement

522/101-2D Merinjina Formation, Granule Conglomerate Facies
Section 5, 149 m, Unit 3.

Very coarse sandstone: siliceous hematitic and calcareous submature litharenite.

Macro: very coarse sandstone, 4 m thick, cross bedded, calcareous matrix.

Micro: poorly sorted, very angular grains, hematite replaces entire grains, calcareous cement.

20% quartz
15% feldspar - bladed ophitic plagioclase
55% rock fragments, carbonaceous siltstone, quartz sandstone
10% opaque - hematite replacing pyrite(?)

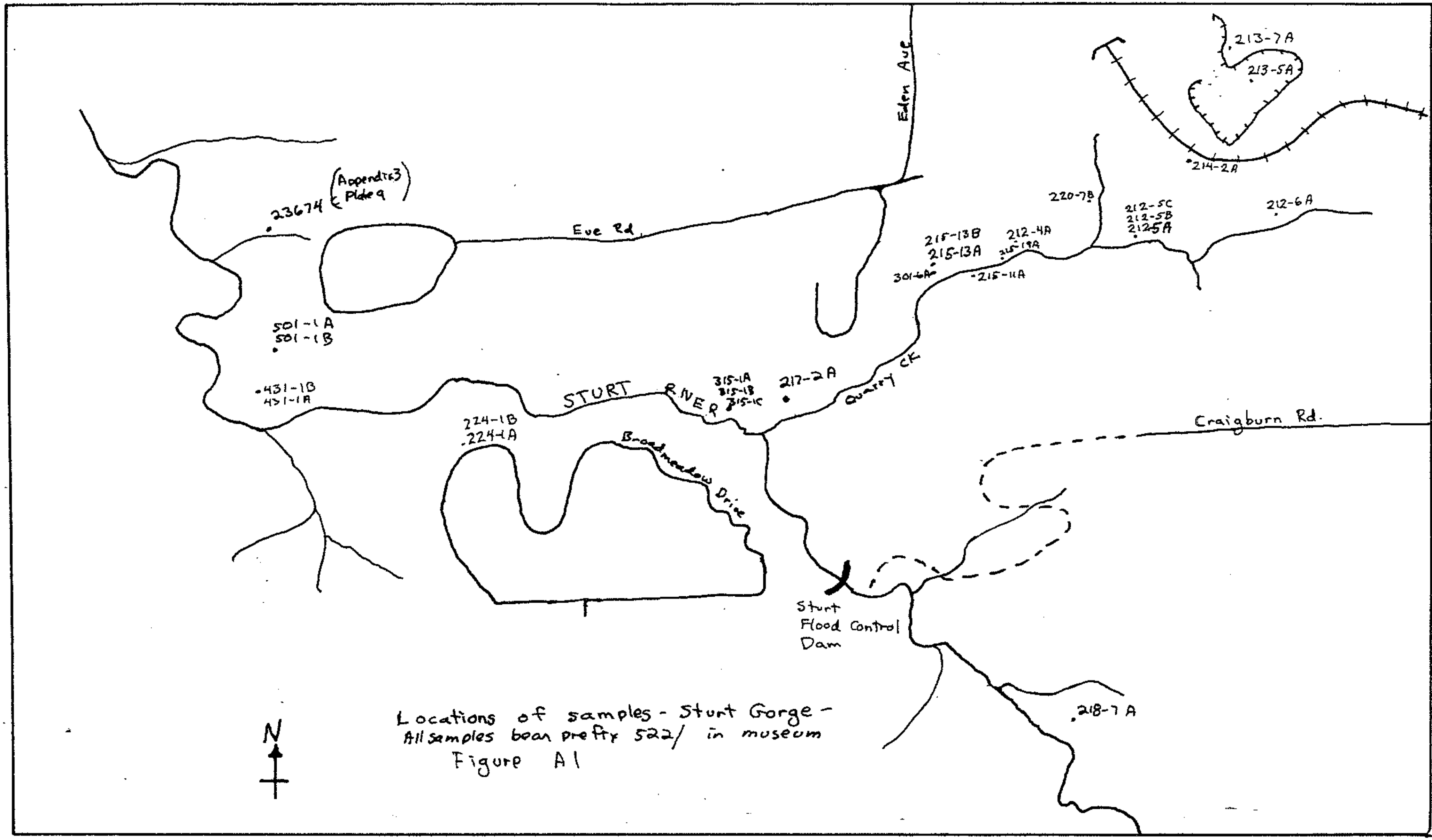
522/103-4B Section 28, North Moolooloo Station,
Merinjina Formation, Unit 3, near top.

Sandy siltstone: hematitic calcareous immature litharenite.

Macro: brown pebbly siltstone
Micro: very poorly sorted, grains round to sub-round, carbonate cement.

522/103-4B (cont'd)

35% quartz
5% chert
15% feldspar, microcline
5% muscovite
35% rock fragments, quartzite, dolomite, siltstone
5% hematite replacing pyrite, brown tourmaline, green tourmaline.



Locations of samples - Sturt Gorge -
All samples bear prefix 522/ in museum
Figure A1

STURT GORGE SAMPLES

522/212-4A Sturt Formation Bedded Silty Facies
Unit 1, Member 1, Quarry Creek, below railroad track.

Pebble bearing slightly sandy mudstone: micaceous quartz and sedimentary rock fragment bearing mudstone.

Micro: clasts subround, elongated parallel to cleavage, micas growing along cleavage.

90% clay matrix
7% undulose quartz
2% sandsize sedimentary rock fragments
1% limonite in .01 mm grains.

522/212-5A Belair Subgroup from just below contact, Quarry Creek

Very fine sandstone: siliceous and micaceous submature feldspathic quartz arenite.

Micro: grains recemented by quartz, moderately well sorted, no clay.

93% quartz
4.5% microcline
2% muscovite
0.5% limonite

Discussion: This sample can be distinguished from the Sturt Formation by the lack of clay, but the sand fraction is similar to basal sandstones of the Sturt Formation.

522/212-5B Sturt Formation, Bedded Silty Facies,
Unit 1, near base, Quarry Creek.

Pebble bearing slightly sandy mudstone: micaceous immature igneous rock fragment bearing litharenite.

Micro: size range pebble to clay, grains angular to subrounded. Very poorly sorted, phyllosilicate cement

72% clay and fine silt matrix
15% quartz -undulose extinction
5% feldspar
8% rock fragments - chert, sediments, igneous rocks
2% limonite.

522/212-5C Belair Subgroup, South Bank Quarry Creek

Fine sandstone: siliceous mature recemented quartz arenite.

Micro: All recemented fine sand grains, no clay

90% quartz, half straight extinction, half undulose extinction.
3% chert
3% feldspar, microcline with grid twinning unaltered
2% muscovite
2% limonite

522/212-6A

Belair Sub-Group from Quarry Creek

Fine siltstone: mature ferruginous quartz arenite

Micro: All coarse to medium silts, well sorted,

90% quartz
5% clay matrix
2% feldspar
3% opaques - ilmenite
- brown tourmaline

Discussion: Not as clean as most Belair Subgroup samples; very similar to 522/213-5A of Sturt Formation.

522/213-5A

Sturt Formation, sandstone band from Metropolitan Brick Quarry, Unit 1.

Fine sandstone: Ferruginous immature subarkose

Macro: olive green fine sandstone, now bleached to white.

Micro: all medium and fine sand grains, well sorted, grains subrounded.

85% quartz
5% feldspar
1.5% chlorite
0.5% hematite
8% clay

Discussion: This sample differs from the Belair Subgroup in having more clay and slightly poorer sorting.

522/213-7A

Belair Subgroup from anticline in Metropolitan Brick Quarry.

Medium sandstone: siliceous recemented submature quartz arenite.

No clay is present.

522/214-2A

Sturt Formation sandstone bed from just below railroad tracks, north of Quarry Creek, Unit 1.

Fine sandstone: Ferruginous clay-rich immature sublitharenite.

Micro: range in grain size from clay to medium sand, poorly sorted, grains subangular to subrounded.

20% clay
60% quartz, mostly undulose extinction, some straight extinction and polycrystalline
5% feldspar
10% rock fragments
5% opaques, ilmenite, limonite

Discussion: There is a large difference between this sample and the Belair Subgroup.

522/215-11A Sturt Formation sandstone pod in Unit 2 north of Quarry Creek.

Muddy medium grained sandstone: inmature ferruginous and clay cemented pyritic sub-arkose.

60% quartz, mostly undulose extinction
10% feldspar - microcline
5% mica, muscovite
5% carbonate fragments
5% limonite replacing pyrite cubes
15% clay matrix

522/215-13A Sturt Formation sandstone bed in diamictite of Unit 2, north of Quarry Creek.

Sandy coarse siltstone: very calcareous immature micaceous micritic arkose.

Size range medium sand to medium silt in micrite matrix.

20% quartz, mostly undulose extinction
10% biotite, small flakes, probably authigenic
20% feldspar, mostly fresh microcline with grid twinning, some albite.
50% micrite matrix.

522/215-13B Sturt Formation Massive Diamictite Facies, Unit 2, south of Quarry Creek.

Pebbly mudstone: micaceous and calcareous immature

Macro: litharenite grey well cleaved diamictite

Micro: extremely poorly sorted, grains subrounded.

20% quartz
5% feldspar-microcline
15% rock fragments, carbonate, quartz sandstone, igneous rocks, mica
55% matrix, clay and mica
5% carbonate cement

522/215-19A Belair Subgroup from inlier in Quarry Creek, 0 m in measured section.

Fine sandstone: siliceous submature recemented quartz arenite.

Macro: cream colored fine sandstone

Micro: well sorted, all fine sand size grains

95% quartz, 50% undulose extinction 50% straight extinction
2% microcline - fresh
2% plagioclase replaced by sericite
1% chlorite

522/220-7B

Sturt Formation, Bedded Silty Facies, Sturt River, south bank, near Eden Avenue, Unit 3.

Medium sandstone: ferruginous immature arkose

Micro: very poorly sorted, grains very angular to sub-rounded, larger grains are rounder, very iron-rich.

40% quartz, 60% undulose extinction
40% straight extinction
5% chert
10% feldspar - microcline with grid twinning
5% rock fragments
20% iron oxide cement

Discussion: This is typical sandstone from bedded facies.

522/224-1A

Sturt Formation Granule Conglomerate Facies Unit 3, just north of Broadmeadow Drive.

Pebble and granule bearing very coarse sandstone: calcareous sub-mature sed-arenite.

Micro: moderately well sorted, grains sub-angular, range pebble to medium sand.

20% quartz
5% feldspar - microcline + sericitized plagioclase
50% rock fragments, granitic rocks, mica schists, but mostly quartz sandstone and calcareous siltstone.
20% calcite cement
5% limonite replacing pyrite.

522/224-1B

Sturt Formation Bedded Silty Facies just north of Broadmeadow Drive, Unit 3.

Pebbly Sandy Siltstone: immature feldspathic litharenite.

Macro: Brown medium bedded clast-rich diamictite

Micro: Very poorly sorted, size range medium silt to pebble, grains subround to subangular, larger grains are more rounded.

45% quartz
5% feldspar - microcline
5% rock fragments - sandstone
5% carbonate fragments
40% carbonate cement

522/431-1B

Sturt Formation, Granule Conglomerate Facies.
Unit 3, near top of hill just south of Eve Road.

Granule conglomerate: calcareous and ferruginous, submature, litharenite.

Macro: Brown granule conglomerate, irregular outcrops.

Micro: Size range coarse sand to granules, medium sorted.

20% quartz, subrounded
65% rock fragments, calcareous siltstone, angular to rounded, some fine sandstone
5% feldspar, microcline, angular
10% calcite overgrowths and limonite cement

Discussion: This sample demonstrates that high energy flow occurred, with some rounding of quartz grains, and medium sorting in water saturated with carbonate.

522/501-1A

Sturt Formation, Granule Conglomerate Facies.
Unit 3, on west facing slope of hill, just south of Eve Road, north of River Sturt.

Muddy granule conglomerate: ferruginous and calcareous immature litharenite.

Micro: range pebbles to clay - extremely poorly sorted, clasts very angular, matrix contains isolated silt grains (5%).

10% quartz, mostly undulose extinction
1% chert
5% bladed feldspar
75% rock fragments, calcareous silt, quartz sandstone, oolitic siltstone
9% matrix - calcite, clay, quartz, silt

Discussion: The occurrence of only sedimentary clasts in this sample means that an intrabasinal source, different to the basement source of the massive diamictite, existed late in the glacial epoch.

522/301-6A

Sturt Formation 68.5 m in measured section.
Sandstone Marker Bed from Unit 2.
Minor interbed in Massive Diamictite Facies.

Medium sandstone: siliceous and micaceous immature feldspathic litharenite.

Macro: tan colored discontinuous marker horizon in Unit 2, reveals some subaqueous sorting within this unit.

Micro: Size range coarse silt to coarse sand, poorly sorted, grains subrounded.

522/301-6A (cont'd)

70% quartz, 60% straight extinction 40% undulose extinction
10% feldspar, grid twinned microcline and plagioclase altered to sericite
10% rock fragments, sedimentary and igneous
10% quartz and phyllosilicate cement

522/931-1A

Sturt Formation Granule Conglomerate Facies
Unit 3, north side Sturt River, below Eve Road.

Granite bearing coarse sandstone: slightly calcareous immature litharenite.

Macro: brown cross bedded conglomerate beds up to 1 m thick.

Micro: quartz subrounded, rock fragments subangular, rock poorly sorted.

50% quartz, 60% undulose, 40% straight extinction
20% sedimentary rock fragments - calcareous siltstone, quartz sandstone, micrite
8% feldspar - microcline + sericitized albite
20% calcareous and clay-rich matrix.

522/501-1B

Sturt Formation Limestone Bed immediately above 522/501-1A

Blue grey limestone: finely crystalline clay and quartz silt-bearing partially recrystallized micrite.

Micro: fine-grained, medium silt size calcite grains, some recrystallized sparry calcite veins.

85% micrite, stained purple with alizarin red
10% sparry calcite
2% clay, concentrated on cleavage
2% angular quartz silt
1% limonite replacing pyrite

Note: half of section was inadvertently removed during staining.

APPENDIX 2 X-RADIOGRAPHY

Introduction

X-radiographs of samples from the Sturt Gorge were taken to investigate sedimentary structures that might not be visible in hand specimen. This method is particularly useful in observation of apparently structureless diamictites. Among the structures observed were distribution of pebbles and sand grains in diamictites, convolute laminations, slumped and graded bedding in siltstones, concentrations of calcareous matrix, and presence of pyrite grains.

Sample Preparation

Slabs 0.5-1.5 cm thick were cut and ground flat on both sides using 60 mesh grit. Further polishing might be useful for thinner samples or studies requiring great precision. Cleavage flakes from the Sturt Gorge proved unsatisfactory due to irregularity in thickness, and cut slabs gave much better results.

Equipment and Film

After consultation with Dr. Herb Veeh, Bronte Tilbrook, and Kevin Moriarty, of the Department of Earth Sciences, Flinders University, permission was granted to use the Watson Victor Maxigraph Medical X-ray Unit in the basement of that department. This machine has a General Electric HRT tube, a 1.5 mm aluminium filter at the tube, and a 1 mm focal spot with a rotating needle. Kodak RP/S no-screen Medical X-ray film (envelope packed) was used at a focal-film distance of 1 metre. The film was processed in the Auto-Kodak X-omat Rapid Processing Unit at Flinders University Medical Center with the approval of Mr. Graham Tidswell of the Radiography Department (extension 4210). Mr. Tidswell also kindly provided a lead apron for use during exposure to X-rays.

Kodak RP/M Medical X-ray film is finer grained and should be used for work requiring quantitative measurements. It is, however, slower and considerably more expensive.

Kodirex X-ray film is also suitable, but it must be processed by hand using Kodak Type II X-ray developer. Recommended times are 2-3 minutes in developer, 20 minutes in fixer, 30 minutes wash, and 2 minutes in wetting agent before drying. Rapid processing is considerably faster and easier.

Exposure

Exposure guides for X-radiography can be found in Bouma (1969) and Fraser and James, (1969).

In the present study, using 1 cm slabs of diamictite and siltstone from the Sturt Gorge, the exposure times shown in Figure A2 proved suitable. 60 kv provides high enough energy to allow adequate penetration and still provide good contrast. In general, the lowest kv possible should be used, to enhance contrast.

For each exposure a note of the time, kilovolts, milliamps, sample number, orientation, and film should be made.

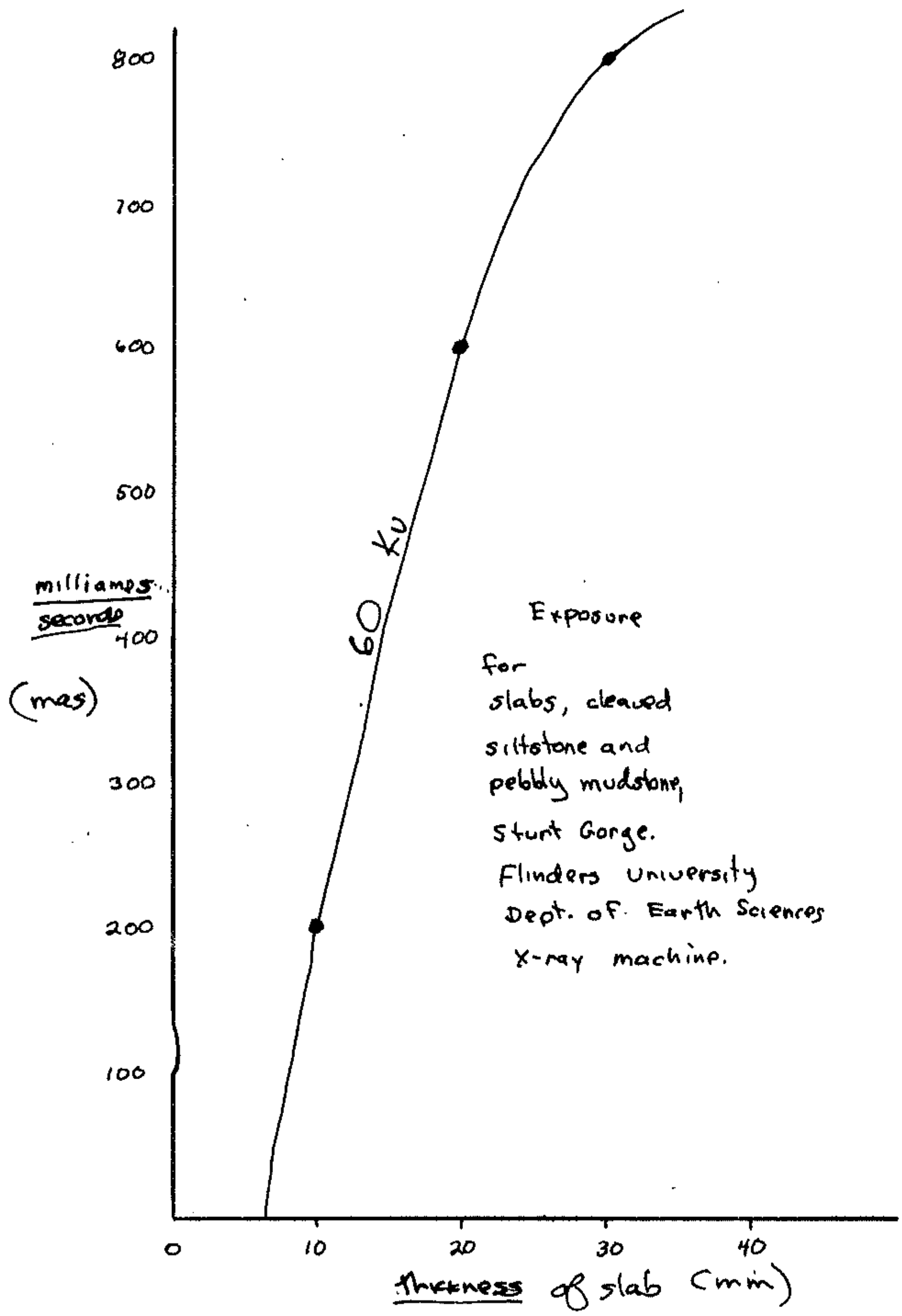
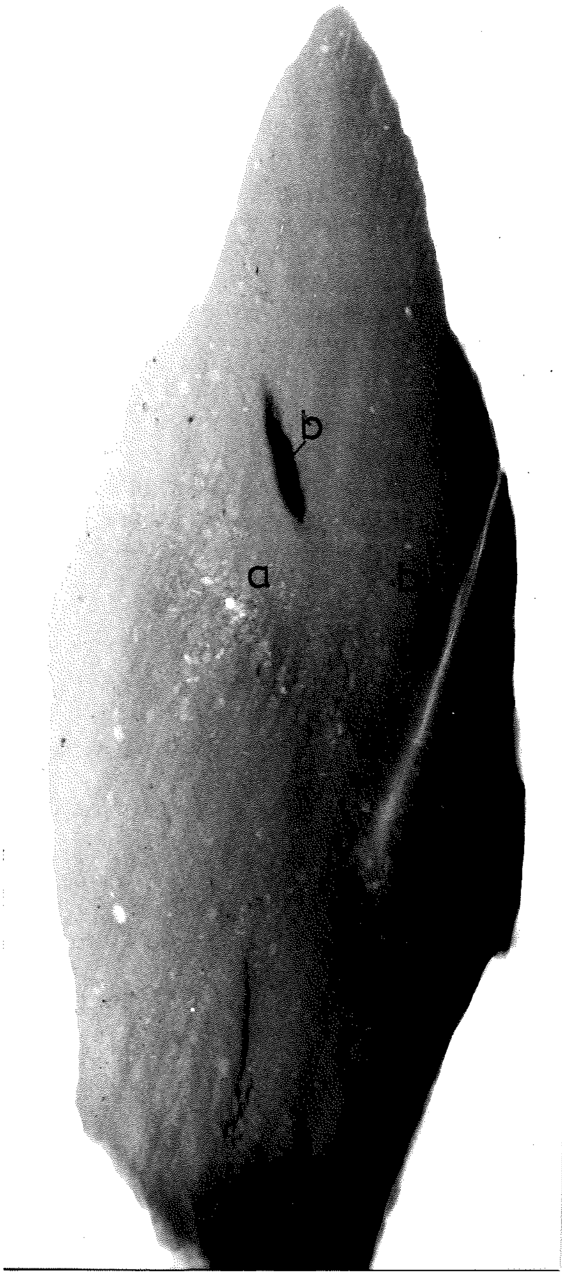

800
700
600
500
milliamps seconds
(mas)
400
300
200
100
0
10
20
30
40
thickness of slab (mm)
60 KV
Exposure
for
slabs, cleaved
siltstone and
pebbly mudstone,
Sturt Gorge.
Flinders University
Dept. of Earth Sciences
X-ray machine.

Figure A2

PLATE 6

A. Brown sandy mudstone 315-1A. Note nest of sand grains (a), black (opaque to X-rays) limonite stained lenses (b), and fracture (c), transparent to X-rays. Cleavage is subvertical, bedding probably subhorizontal.

B. Grey siltstone with graded beds, 218-7A. Bedding in lower half of sample is disturbed. Note graded beds (a) younging to upper right. Black pyrite grains occur along left edge of photo (b). Cleavage is marked by subvertical limonite filled fractures.


b
a
b


a
b

PLATE 7

A. Graded bed in grey siltstone 217-2A. Transparent (white) clasts are carbonate. Note rare opaque pyrite grains above pebble layer and increase in opaque mud grains upwards.

B. Brown pebbly mudstone 315-1C. Sample has slightly calcareous matrix, random distribution of pebbles and concentration of pyrite grains along right edge of photo. Cleavage is subvertical bedding probably subhorizontal.

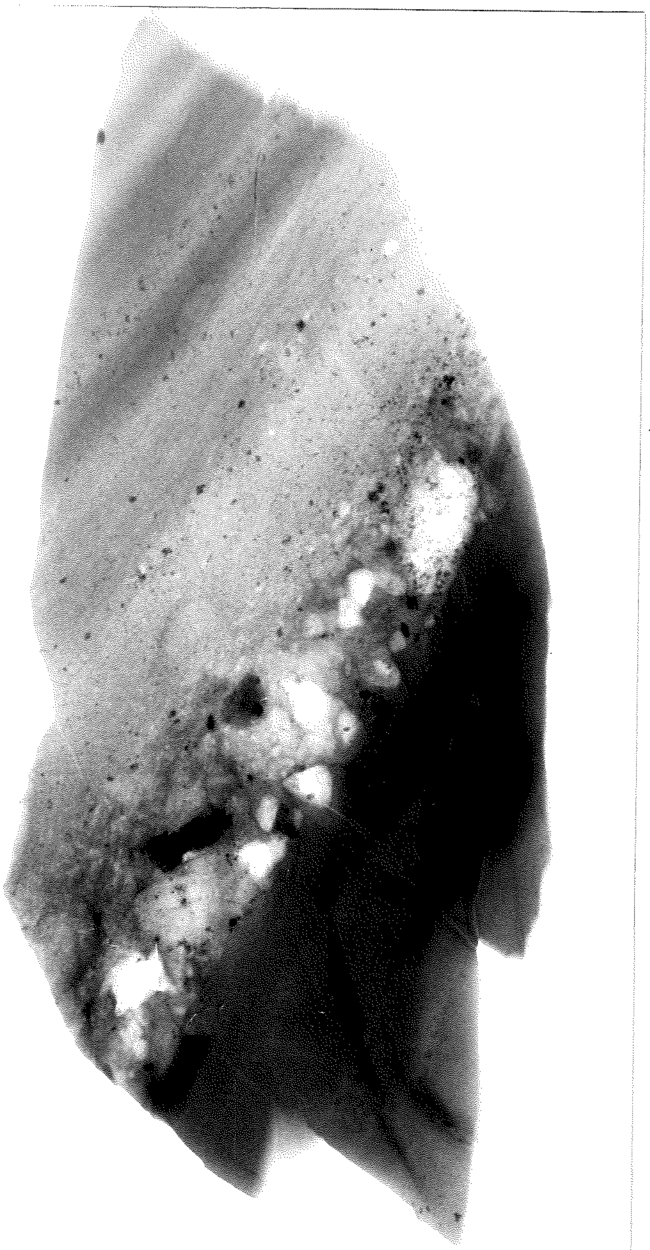


PLATE 8

Grey pebbly mudstone 315-1B. Note wide range of clast sizes and sub-horizontal tension fractures in pebbles (a). Clast (b) is granitic gneiss and (c) probably a carbonate. Cleavage is sub-vertical. Faint sub-horizontal bedding (d) can be detected.


d
a
c
b

APPENDIX 3

Plate 9 is a photograph of Specimen 23674 of the Adelaide University Geological Museum, a 4 cm striated tan sandstone clast collected from the dry waterfall south of Flinders University land on the east side of Sturt Creek by Mary Wade on September 4, 1966. This locality is shown on Figure A1.

This is the only striated clast found in or reported from the Sturt Gorge, and adds to evidence for a glacigene origin of the Sturt Formation. The striations are subparallel. As outlined by Schermerhorn (1974) tectonic processes can produce strictly parallel striations. Subaerial mudflow may produce randomly oriented striations in siltstones and limestones, but not in quartzites (Winterer and Von der Borch, 1968). In this sample the striations are at an oblique angle to cleavage, thus eliminating tectonic rotation as a cause. Subparallel striations occur commonly on glaciated clasts, Flint (1971) and a glacial origin for the striations on this sample is therefore most probable.


1 cm

APPENDIX 4

STURTIAN GLACIATION

IN

SOUTH AUSTRALIA

-- Honours Essay --

INTRODUCTION

Though far from any Pleistocene and Recent ice sheets, South Australia contains sediments from three ancient glaciations, two in the late Precambrian (the Sturtian and Marinoan glaciations) and a third in the Permian. This paper concerns the earliest and most extensively exposed of these ancient glaciations: the Sturtian glaciation, represented by the Yudnamutana Subgroup of the Umberatana Group (Sturtian Series) of the Adelaide Supergroup.[1]

The Sturtian glacial sediments rest either unconformably or disconformably on older rocks. There was pre-Sturtian and Sturtian tectonism (usually warping along basement hinge lines) which elevated source areas and depressed basins of deposition. The Sturtian glacial sediments are here divided into five sedimentary facies which the author has seen in the field, and which record a vast area of glacigene sedimentation (Fig. 1), most of it subaqueous and probably marine, with glacial ice emanating from several centers on the margins of the Adelaide "Geosyncline". These glacigene sediments are overlain, usually conformably but with local unconformity, by fine laminated siltstones, thin carbonates and local conglomerates of the nonglacial Tapley Hill Formation.

LOCALITIES AND THICKNESS

A schematic diagram showing correlation relationships is shown in Fig. 2. The Yudnamutana Subgroup is usually less than 400 m thick, but is unusually thick in four areas:

(a) 6000 m, west of Mt. Painter (Coats and Blissett, 1971)

(b) 1000 to 3300 m, near Olary and Manunda (Forbes and Cooper, 1976)

(c) 3300 m, in the Bibliando Dome (Mawson, 1949b)

(d) 1700 m, east of Burra (Mirams, 1964a).

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[1]The dating, correlation with other areas of Australia, and critical evidence for a glacial origin of these sediments is outlined in the main body of this thesis.

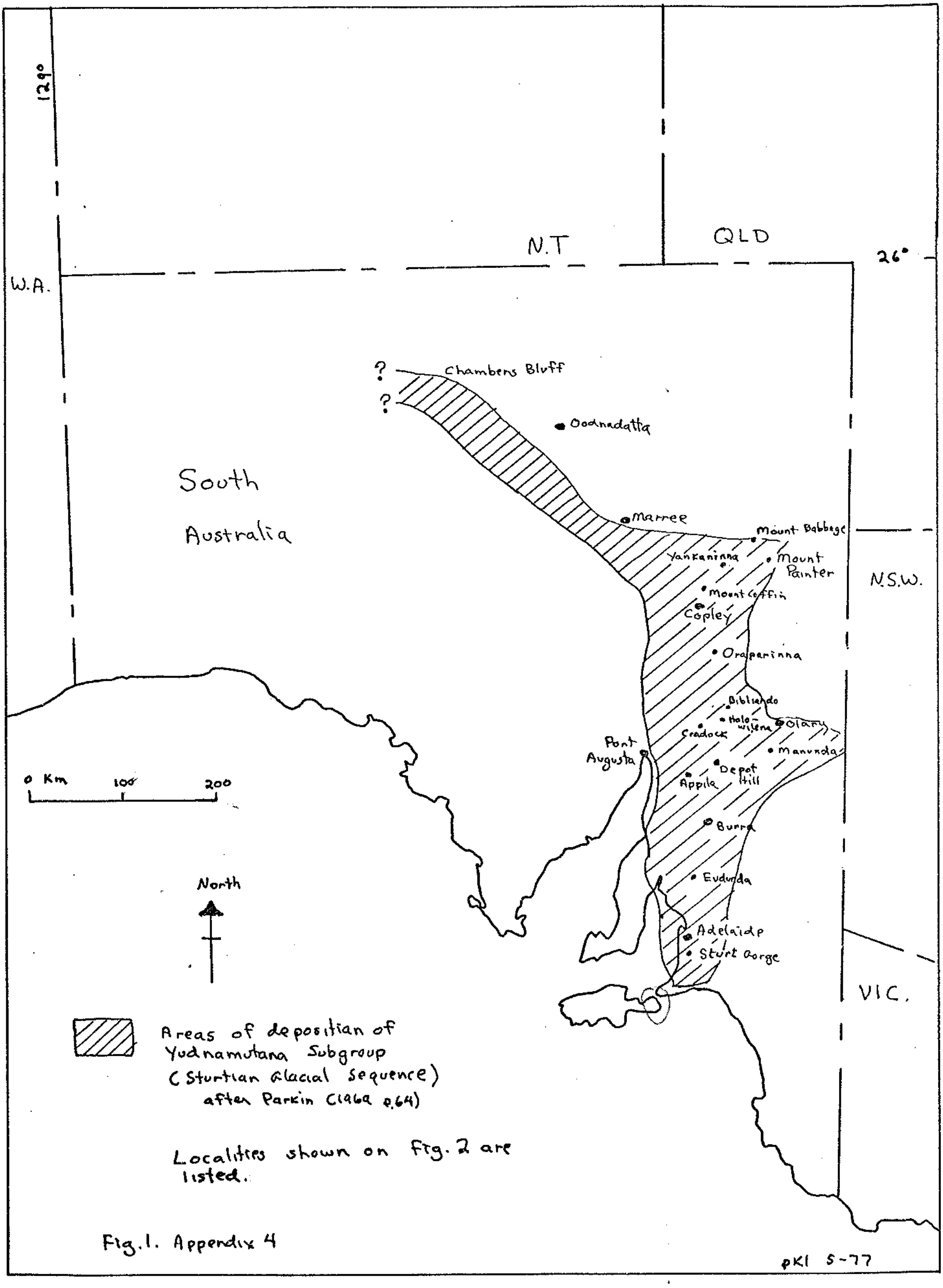


Fig. 1. Appendix 4

All localities are shown on the following 1:250,000 map sheets of the Geological Atlas of South Australia: ADELAIDE (Thomson, 1969) BARKER (Thomson and Horwitz, 1962), BURRA (Mirams, 1964a) COPLEY (Coats et al. 1973), ORROROO (Binks et al. 1968), PARACHILNA (Dalgarno and Johnson, 1966), and the 1:125,000 Mount Painter Province (Coats et al. 1969) and 1:170,000 Olary Province (Campana, 1955) geological maps of the Geological Survey of South Australia.

PRESTURTIAN TECTONISM - FRAMEWORK OF GLACIATION

Sturtian glacial sediments have three relations to older sediments: (a) slightly unconformable or disconformable on Burra Group; (b) highly unconformable on the Burra Group and (c) unconformable on pre-Burra Group sediments and Proterozoic basement.

(a) Over the main part of the Adelaide "Geosyncline" the Yudnamutana Subgroup rests with small angular unconformity on shallow water fine clastics and dolomites of the Burra Group (Forbes, 1971). Locally there was considerable pre-Sturtian erosion and the thickness of Burra Group sediments remaining is highly variable. For example 1500 m of these sediments were removed along a 3^{0} unconformity on a 100 km northwest trending line between Copley (4000 m preserved) and the northern Willouran Ranges (2500 m preserved). In the 30 km from Umberatana H.S. east to Mt. Fitton the Burra Group decreases from 2500 to zero metres.

In the southern part of the "Geosyncline" near Adelaide, a probable disconformity exists between Sturtian glacial sediments and the Belair Subgroup (Coats, 1967, Forbes, 1967). The significance of the Belair Subgroup is discussed in the main text of this thesis (pp. 10-11).

(b) On the margins of some diapirs (Burr diapir for example) an angular unconformity of up to 90^{0} exists between the Yudnamutana Subgroup and the Burra Group attesting to major pre-Sturtian folding.

(c) In several areas the Burra Group has either been removed or was never deposited and the Yudnamutana Subgroup rests on Willouran Callana

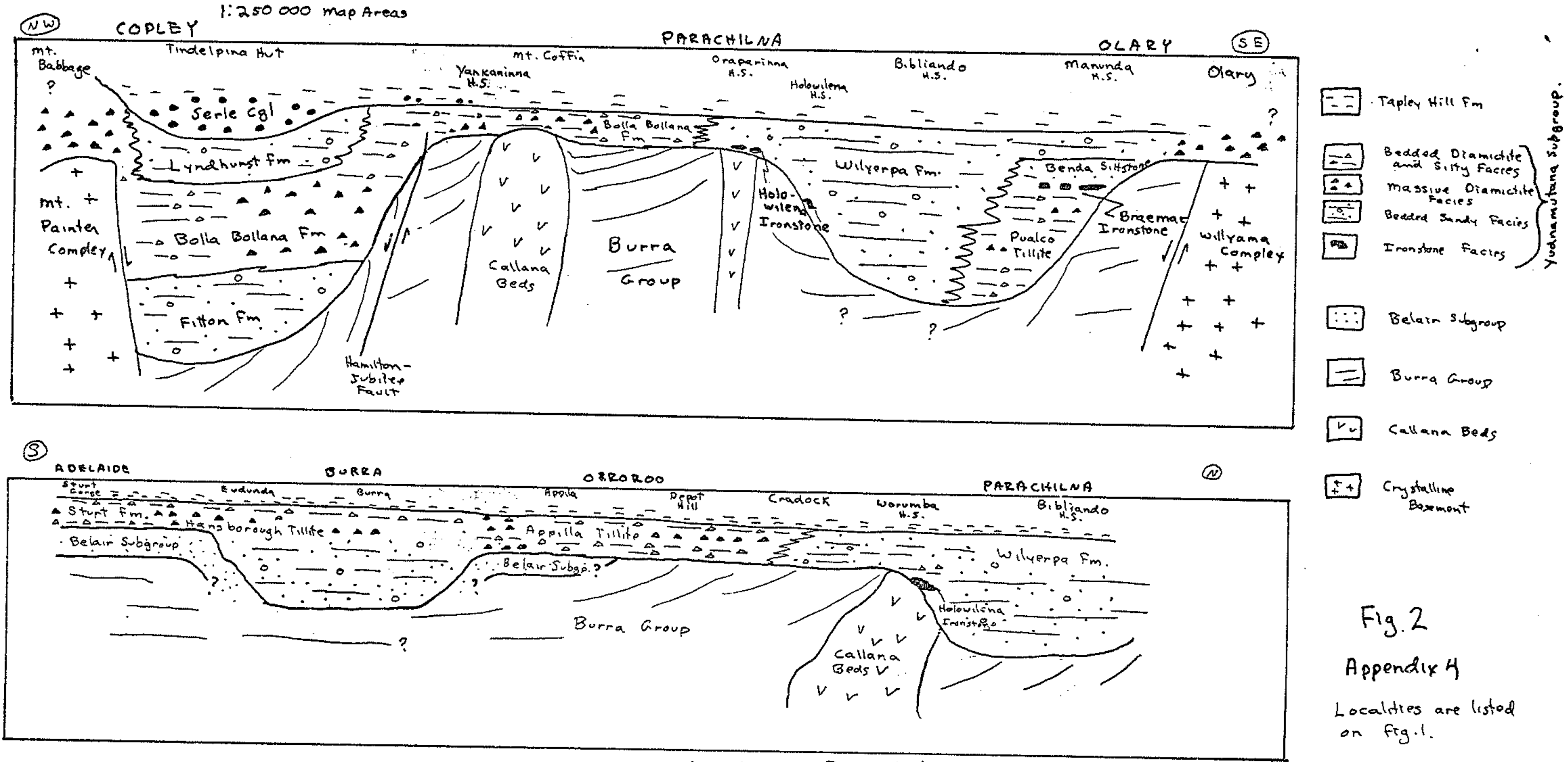


Fig. 2

Appendix 4

Localities are listed on Fig. 1.

Diagrammatic Cross Sections Showing Facies Relationships of Sturtian Glacial Sequence and Stratigraphic Correlation structural contact

Beds in diapiric cores (i.e. Oraparinna, Worumba, Lyndhurst, Mt. Coffin, Witchelina, Arkaba and other diapirs). In the Mt. Painter and Olary Provinces and on Yorke Peninsula the Yudnamutana Subgroup rests unconformably on Proterozoic metamorphic basement.

Thus there was considerable pre-Sturtian tectonism (and subsequent erosion) and the Sturtian glacial sediments are locally transgressive onto what had been basement highs. This tectonism is particularly important in providing a source for the sedimentary and basement clasts which occur in the glacigene sediments. As pointed out by Schermerhorn (1974) the thick accumulations of glacigene sediments near Mt. Painter and Olary are most probably genetically related to Sturtian tectonism. As outlined in the main text of this thesis (pp. 14-15) however, this does not preclude the evidence that there was glacial deposition in these areas.

SOURCE AREAS

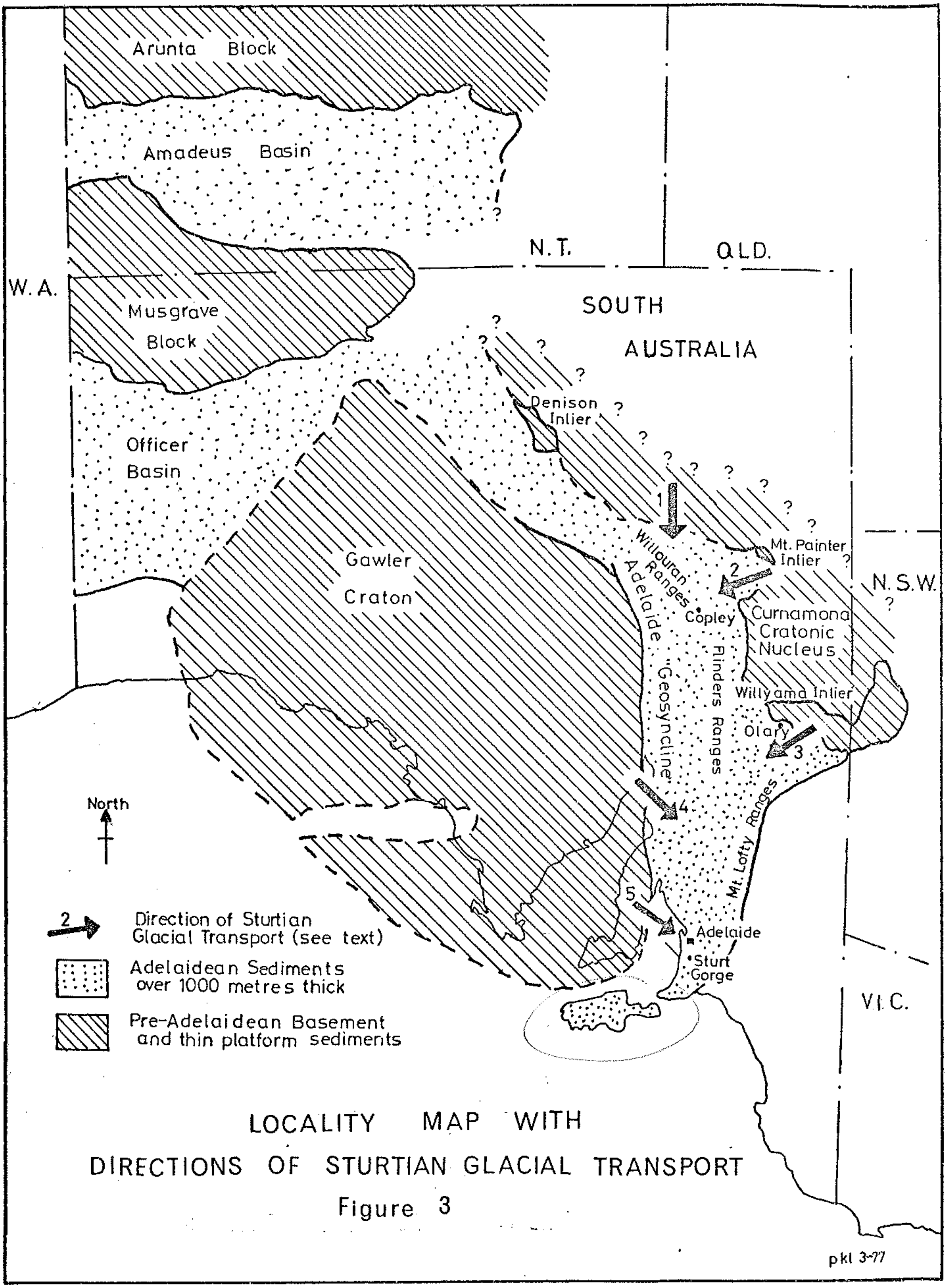
Several source areas from which glaciers eroded sediments existed and are shown in Fig. 3 (reproduced from Fig. 1 of main thesis).

Arrow 1 -- North of the Willouran Ranges, Murrell (pers. comm. 1977), has used two lines of evidence to infer a northerly source:

(a) a general thickening of the Yudnamutana Subgroup to the north approaching Cretaceous cover of the Great Artesian Basin, and

(b) a predominance of clasts similar and sometimes identical to those outcropping in the underlying Burra Group. His palinspastic reconstructions reveal that the Burra Group thins drastically southwest of the Norwest fault and so this area could not have supplied the sedimentary clasts which are dominant in the Yudnamutana Subgroup of the Willouran Ranges.

Arrow 2 -- Curnamona Cratonic Nucleus. In the area west of Copley (this thesis) and in the Mt. Painter area (Belperio, 1973, Ashton, 1973, Ambrose, 1973, Mortimer, 1973) five lines of evidence may be used to infer a northeasterly source:



LOCALITY MAP WITH

DIRECTIONS OF STURTIAN GLACIAL TRANSPORT

Figure 3

(a) paleocurrents in fine to medium sandstones in the Copley area indicate that bottom currents came from a northeasterly direction. Although these are not necessarily indicative of direction of glacial transport, the fact that they are constant over the study area and consistent with other indicators suggests that they do, in this case, point down the Sturtian paleoslope;

(b) the predominance of Burra Group clasts (similar to the Willouran Ranges);

(c) general thickening of the Yudnamutana Subgroup to the north towards the Mt. Painter area which was tectonically active before and during Sturtian glacial deposition. The Burra Group has been locally removed completely from this area, and very thick fault bounded troughs of Yudnamutana Subgroup sediments exist. Probably much eroded Burra Group detritus fills these troughs;

(d) the probability that the rare but supposedly diagnostic "Pandurra type" purplish quartzites (Coats, 1973) come from either underlying Burra Group or Willouran quartzites in the Curnamona Cratonic Nucleus. The author has seen similar quartzites in situ in the Burra Group near Apex Hill (COPLEY map area);

(e) the fact that the small granitic, metamorphic and volcanic fraction of clasts near Copley increases in frequency eastwards towards Mt. Painter (for example near Mulga Well north of Yankaninna H.S.) and the supposedly distinctive Gawler Range porphyry clasts (Coats 1973) are similar to those which have been found in drill holes under the Lake Frome plains (R. Coats pers. comm., 1977).

Arrow 3 -- Willyama Complex. The arguments here are similar to those of the Mt. Painter area including:

(a) a thick basin of glacigene sediments (Pualco Tillite) in the Olary area;

(b) the transgressive nature of Yudnamutana Subgroup sediments which have been called terrestrial moraines in the Olary area (Campana, 1958, p.33) but which in the Bibliando Dome are essentially normal marine sediments with a minor glacigene component;

(c) clast lithology in the Bibliando Dome mentioned by Mawson, (1949b) including distinctive chiastolite schists found in the Willyama Complex.

A change in both clast lithology and sediment type occurs south of a line from Hawker through Cradock to northeast of Peterborough with the thick distal glaciomarine Wilyerpa Formation disappearing and being replaced by proximal glacigene sediments of the Appila Tillite as reported by Howchin (1930), Jack (1913), and Segnit (1939), in the Peterborough, Depot Hill, and Appila areas.

Arrows 4 and 5 -- Gawler Craton. These arrows represent the source area originally proposed by Howchin (1908), and cited by Binks (1971) and others. Binks ascribes the dominantly sedimentary clast assemblage on the ORROROO map area to a westerly source, but a very different clast assemblage dominated by basement rock types and ascribed to a westerly source by Howchin (1908) occurs in the Sturt Gorge. The possibility of a source to the southeast under what is now the Murray Basin also exists, but can probably never be proved.

In addition, local source areas, particularly associated with anticlinal highs within the basin (Burr Diapir, Oraparinna Diapir) probably existed.

NATURE OF CLASTS

The majority of clasts over cobble size at Copley and also at Apex Hill are subrounded and waterworn. Only a small fraction are very angular and appear glacially eroded. Thus there was considerable reworking of earlier sedimentary detritus by glaciers with its incorporation into the glacigene sediments. This poses somewhat of a problem as nowhere in the Adelaide "Geosyncline" has such preglacial coarse detritus been recognized.

The Belair Subgroup, which lies between the Yudnamutana Subgroup and the Burra Group may possibly represent the basinal equivalents of coarser preglacial detritus.

No glaciated floor has been documented from below the Yudnamutana Subgroup, and it can only be assumed that the glaciated highlands have been eroded away since the Sturtian.

FACIES OF GLACIGENE SEDIMENTS

Five distinct sedimentary facies occur within the Sturtian Glacial Sequence:[2]

(1) Massive Diamictite Facies
(2) Bedded Diamictite and Silty Facies
(3) Granule Conglomerate Facies
(4) Glaciomarine Sandy Bedded Facies
(5) Ironstone Facies.

Massive Diamictite Facies

This consists of massive thick bedded to unbedded clast-poor diamictite, and comprises 40-70% of the Sturtian glacial sequence where it is less than 300 m thick over most of the geosyncline. Some crude wispy layering is present locally. Given a glacigene environment such diamictites can occur in four ways: (a) as terrestrial moraines; (b) as subaqueous moraine under a grounded ice shelf; (c) as waterlaid tillite under a floating ice shelf and (d) by submarine mudflow and slumping. All four of these probably occur within the geosyncline. An interpretation of this facies as waterlaid tillite is favored in the two areas studied in this thesis.

Bedded Diamictite and Silty Facies

As outlined in the main thesis this facies is highly variable and records reworking of abundant ice rafted debris by weak bottom currents. It is commonly associated with the Massive Diamictite Facies (i.e. this study, Appila Gorge (Segnit, 1939), Depot Creek (Howchin, 1925), Merinjina Well (Thomson et al. 1976, p.43), Mt. Jacob and Mt. Warren Hastings (Mawson, 1949a)).

[2]The Massive Diamictite Facies, Bedded Diamictite and Silty Facies and Granule Conglomerate Facies are described in more detail in the main body of this thesis (p.13-18).

Calcareous Granule Conglomerate Facies

This facies is well developed near the top of the glacigene sequence in the Sturt Gorge, at Depot Creek (Howchin, 1925) and in the northern portion of the Copley Study area. It probably contains traction current deposits of carbonate-saturated meltwater during waning glaciation.

Glaciomarine Sandy Bedded Facies

This facies comprises the Wilyerpa Formation of the Central Flinders Ranges which reaches 3300 m in thickness in the Bibliando Dome (Mawson, 1949b). It consists of thin to medium-bedded sandstones, siltstones, and locally shales, with a low and variable proportion of lone cobbles, conglomerate beds, and horizons of clasts. It probably represents a basinal (distal) equivalent of the Bedded Diamictite and Silty Facies of the Pualco Tillite of Olary (Forbes and Cooper, 1976).

Sedimentary structures in the Wilyerpa Formation observed by the author along Willow Creek, west of Worumba H.S. and at the Holowilena Ironstone type locality include thin (2-5 cm) graded beds with Bouma a-to-d sequences, slumped siltstone beds, discontinuous and deformed silt clasts, climbing ripples, flute casts and load structures on the base of sandstone beds, and wavy to flat bedding surfaces. These sediments were deposited below wave base with local slope instability and turbidity currents. A small, probably ice-rafted, component of pebbles, cobbles and boulders occurs, as "lonestones" and in nests and beds. No good dropstones piercing bedding were observed.

Ironstone Facies

Hematitic sediments grouped under the name Holowilena Ironstone occur in isolated pods on the PARACHILNA map area, and as rather persistent beds in the Olary Province Map area (Dalgarno and Johnson 1965, Campana, 1958). The magnetitic Braemar Ironstone occurs near Loch Winnoch H.S. on the BURRA map area (Whitten, 1970).

The author has observed three localities of the Holowilena Ironstone

(Oraparinna, Worumba, and the type section near Holowilena) and is of the opinion that the ironstones, at least on the PARACHILNA map area, are a local phenomenon related to local chemical and detrital conditions, and therefore not useful for regional correlation as proposed by Forbes and Coats in Thomson et al. 1976 (p. 13).

At Oraparinna, laminated hematitic siltstones with striated drop-stones (including "pink quartzites") occur, interbedded with non-hematitic lithic sandstones and hematitic diamictites, near the base of the Sturtian glacigene sequence. Deformed (reworked) soft-sediment clasts of hematitic siltstone occur in hematitic diamictite.

West of Mt. Plantagenet, near Worumba H.S., black hematitic diamictite and siltstone occur locally above a regolith on Callana Beds. The diamictite contains rare pink quartzite erratics and may be glacigene. The hematitic pods are overlain by sandstones and siltstones of the Wilyerpa Formation.

In the Holowilena Ironstone type locality (Dalgarno and Johnson, 1965) a probably non-glacial lacustrine sequence of laminated black hematitic silt-stones, thin grey carbonates, red jaspilites, and probable mudflow-origin diamictites bearing only small angular intrabasinal clasts occurs east of the Siccus River. Sedimentary structures include abundant slumped bedding, flute casts and small scale graded bedding. The ironstone is overlain by a thin horizon of erratic boulders often in a yellow dolomite matrix, which passes up into normal Wilyerpa Formation facies.

In thin section of a hematitic siltstone from near Worumba, provided by Wolfgang Preiss of the South Australian Department of Mines, the author has observed sand-sized, apparently detrital, hematite with clay-size dissem-inated hematite interstitial to grains. The abundant evidence of reworked hematite can be explained by an original colloidal iron-oxide precipitate which crystallized to hematite and was later redeposited as detrital grains.

Whitten (1970) interpreted the Braemer Ironstone type locality near Loch Winnoch H.S. (BURRA map area) to contain detrital magnetite.

The occurrence of these ironstones suggests genetic relation to local iron sources, perhaps in Callana Beds exposed in nearby anticlines, and to cold glacigene conditions. Similar ironstones occur within late Precambrian glacigene sequences in Africa, Asia, South America and Canada (Whitten, 1970).

OVERLYING SEDIMENTS

The Tindelpina Shale member of the Tapley Hill Formation, consisting of finely laminated black pyritic siltstones with thin carbonate bands, conformably overlies the Yudnamutana Subgroup over most of the Adelaide Geosyncline (Sumartojo, 1974). The Tapley Hill Formation probably represents post-glacial transgression with deposition of very well sorted siltstones that are geochemically very similar to and probably reworked from underlying glacigene sediments.

In the Mt. Painter district, coarse boulder conglomerates (such as the Serle Conglomerate) within the basal Tapley Hill Formation locally rest with erosional contact on the Yudnamutana Subgroup (Ashton, 1973; Ambrose, 1973; Belperio, 1973). In this area large amounts of glacigene sediments (perhaps continental till deposits) were eroded by late or post-glacial meltwater streams. South of Mt. Saturday, Farina Subgroup sediments (Tapley Hill Formation and above) onlap onto Yudnamutana Subgroup sediments so that only 300 m of Farina Subgroup was deposited before onset of the Marinoan Glaciation.

Other boulder and cobble conglomerates occur locally above the Yudnamutana Subgroup at Mulga Well, north of Yankaninna Station (COPLEY map area) and at isolated localities in the Willouran Ranges (Murrell, pers. comm. 1977).

Impure dolomite beds often occur just above the Sturtian glacigene rocks, and were deposited from slightly warmer Mg-saturated post-glacial water.

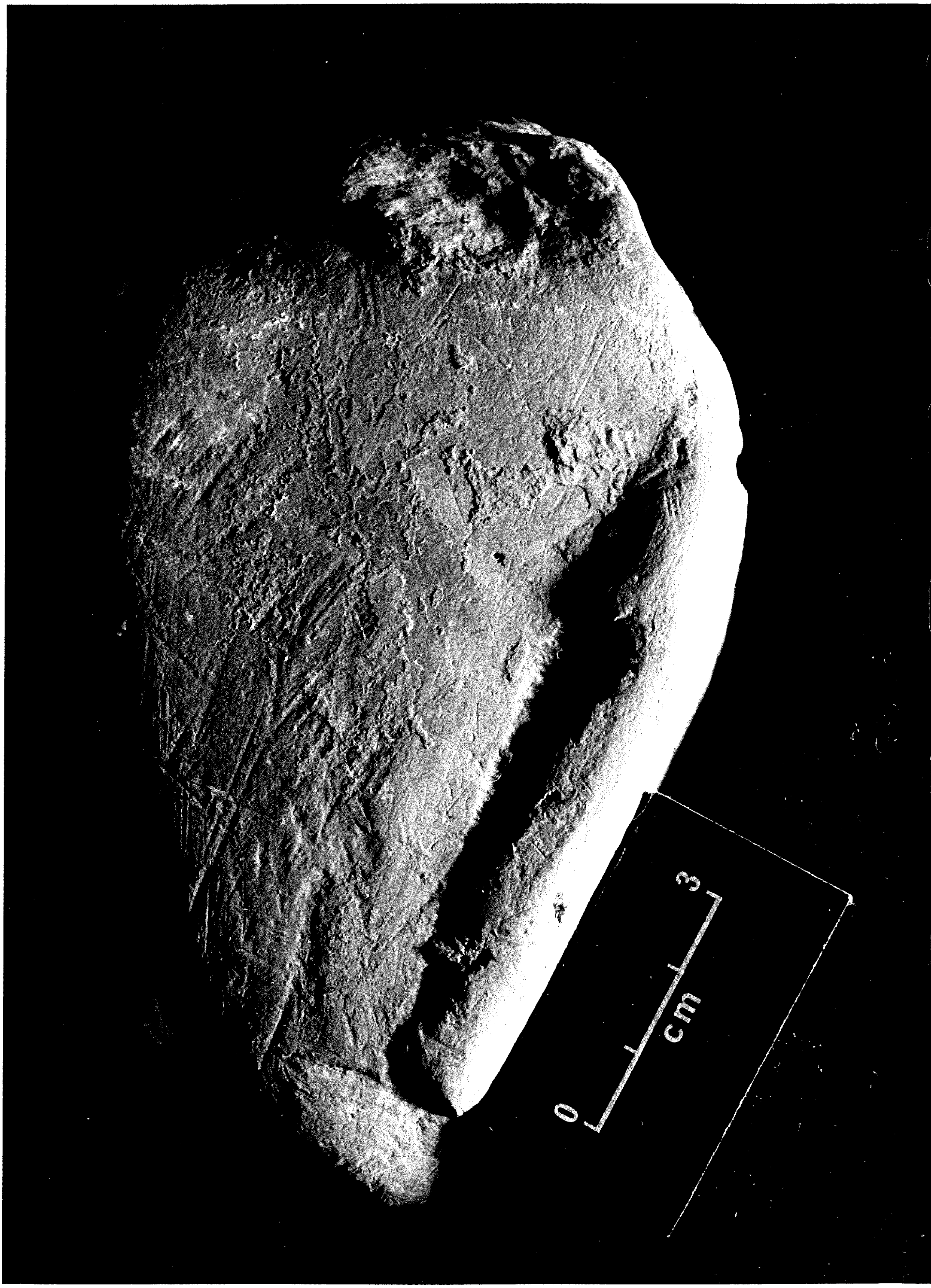
CONCLUSION: MODEL OF STURTIAN GLACIATION

In South Australia the Sturtian glacial sequence consists of a predominantly glaciomarine deposit, comprised mostly of thin shelf sediments with a large contribution from glacial ice, but locally of thick accumulations of coarse glacigene sediments in basins near tectonically active areas (Mt. Painter, Olary), and of thick marine sediments with a minor glacigene imprint as in the Bibliando Dome and east of Burra. Several source areas of glacial ice existed, and glaciomarine sedimentation need not have been contemporaneous over the entire basin. The main source areas were to the north and east in the "Willyama chain" of Campana, (1958, p.12) and probably to the west in the Gawler Craton as advocated by Howchin, (1929). The areas of continental glacial deposits have been eroded away and so only basinal glacigene deposits remain over most of the Adelaide Geosyncline.

N.B. References cited in this Appendix are included in the main reference list of this thesis.

PLATE 10

Striated quartzite cobble from Holowilena Ironstone just east of Oraparinna Asbestos Mine, PARACHILNA Map Area. Collected by Paul Link, April 1977. Adelaide University Geological Museum Specimen 23696.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APPENDIX 5

EVIDENCE FOR ONLY ONE STURTIAN GLACIAL PERIOD IN THE COPLEY MAP AREA

by

Victor A. Gostin

Paul Karl Link

Burton Murrell

Preliminary draft of an article to be submitted to the Quarterly Geological Notes of the Geological Survey of South Australia

May, 1977

EVIDENCE FOR ONLY ONE STURTIAN GLACIAL PERIOD IN THE COPLEY MAP AREA

Examination of the critical area south of Apex Hill on the COPLEY Map area has demonstrated that only one Sturtian glacial period is there represented. There is thus no justification for two distinct Sturtian glacial periods as suggested by Coats (1973) and Coats (et al. 1973). Instead, our findings indicate that the widespread unit labelled Py_1 on COPLEY is a conformable member of the Yudnamutana Subgroup which was defined by Coats (1964) to represent the entire Sturtian Glacial Sequence in the Mt. Painter area. It is continuous with, and equivalent to the Bolla Bollana Formation (Coats, 1964, p.8) and should be therefore called Bolla Bollana Formation.

The authors prefer the name "Bolla Bollana Formation" to "Bolla Bollana Tillite" as renamed by Forbes and Coats (1976, p.13) since, even in its type area the Bolla Bollana Formation does not consist entirely of diamictite, which may or may not be true tillite[1].

Coats (1973 and personal communication, 1977) has used two lines of evidence to establish two Sturtian glacigene units on COPLEY: (a) an apparent unconformity between the two units at the only place in which they are in contact (i.e. south of Apex Hill, Fig. 1), and (b) the occurrence of diagnostic quartzite clasts only in the Py_1 unit. We reject both these lines of evidence.

(a) What is mapped as an unconformable contact between Py_1 and Pyb (Bolla Bollana Formation) south of Apex Hill is a conformable and in fact transitional contact between a lower, grey calcareous muddy matrix diamictite and an upper, red weathering sandy, bedded glacigene unit containing both sandstone and sandy matrix diamictite. Red weathering sandstone beds occur below the mapped Py_1 unit and diamictite occurs within it. The contact

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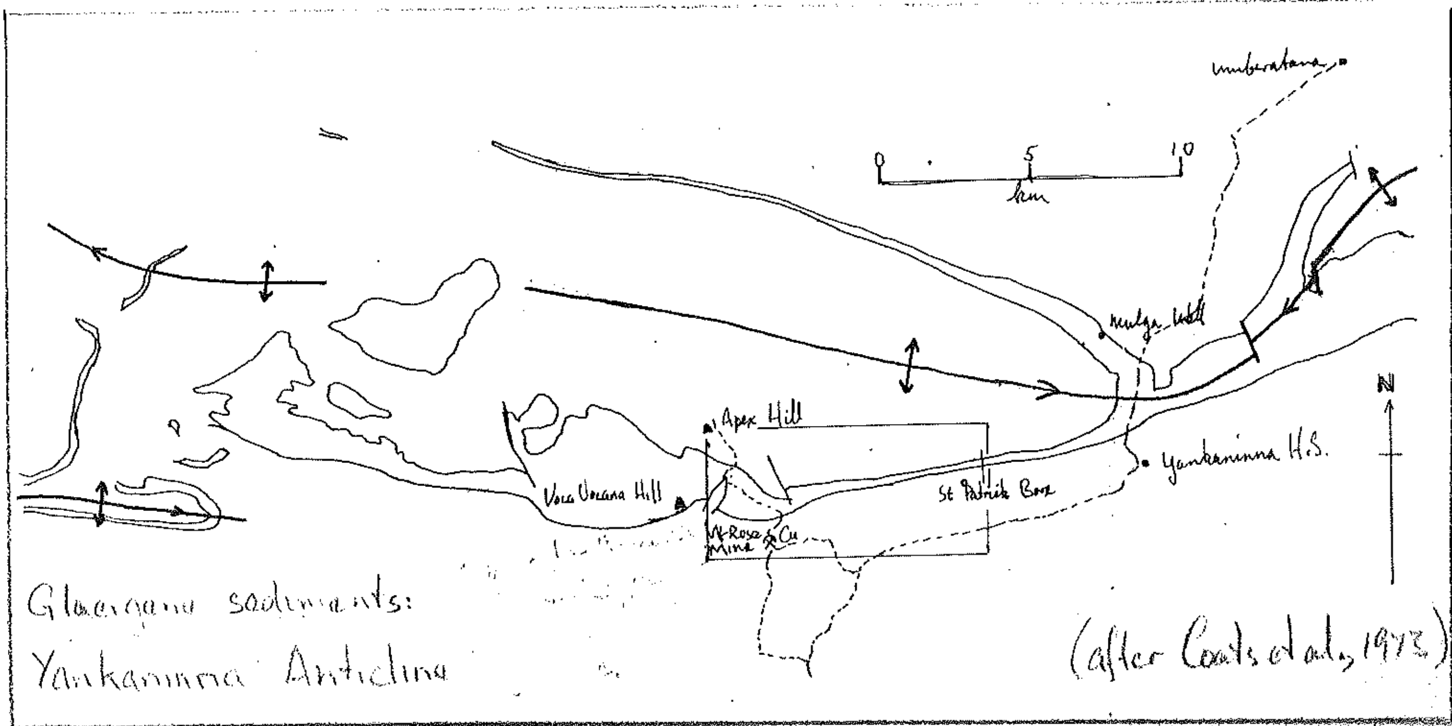
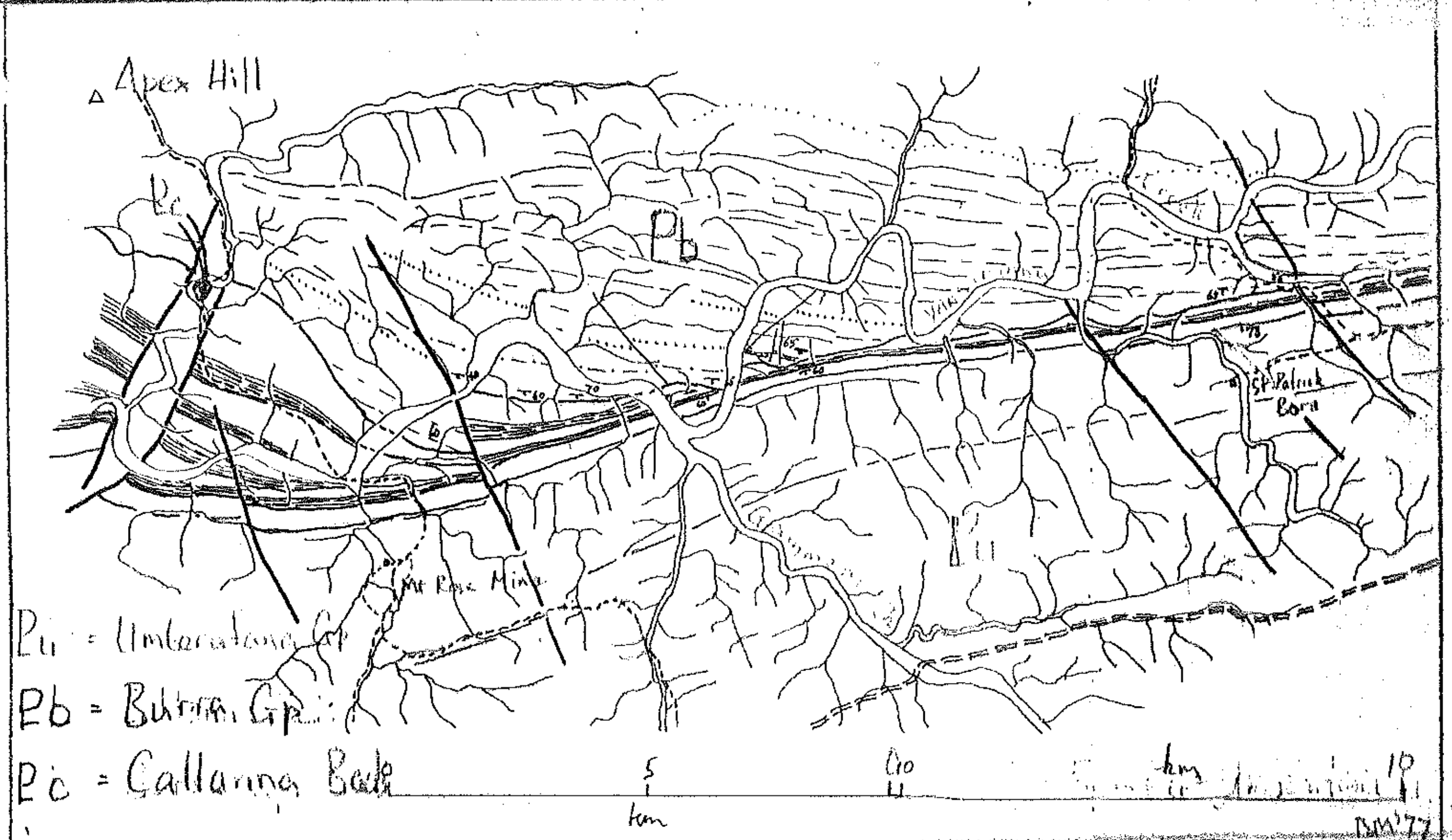
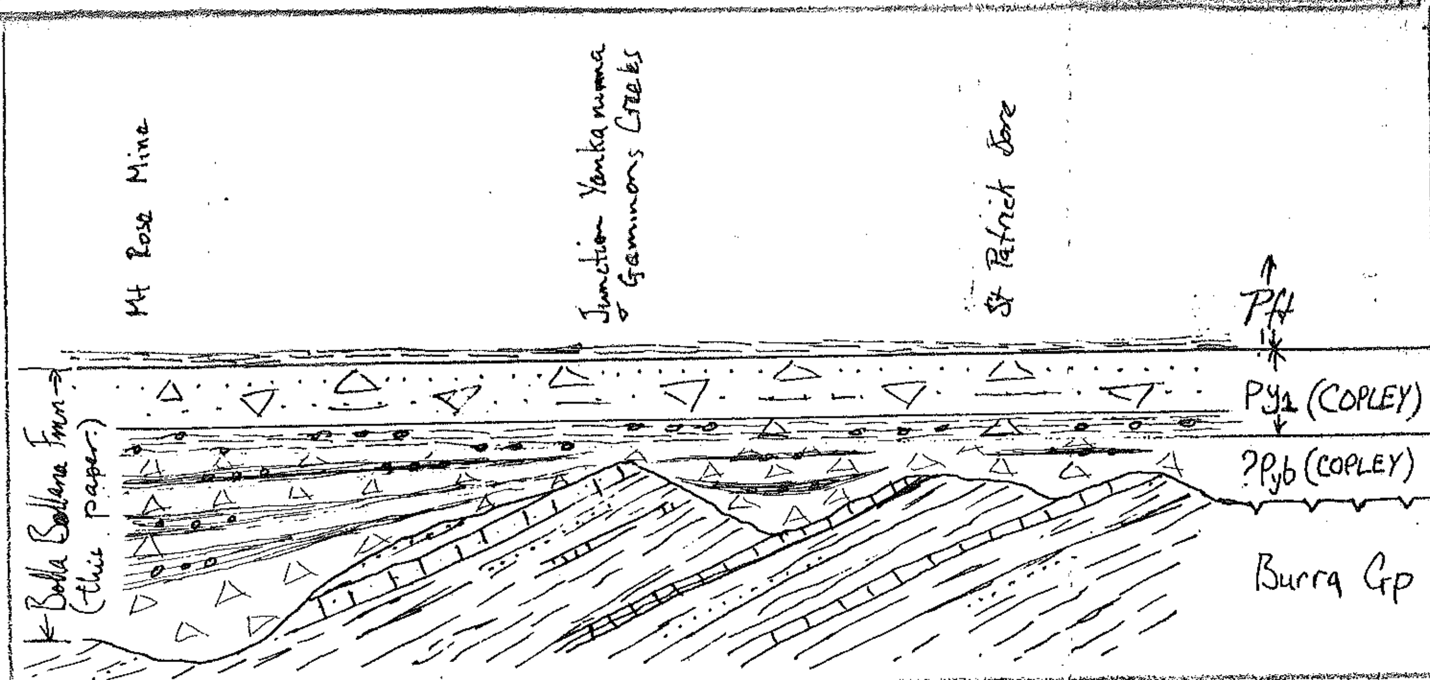
[1]Diamictite, a non-genetic term for a clastic sediment with a wide variation of particle size, is used for rock description. The term "tillite" is avoided both in lithological description and formation name due to its confining genetic meaning. A "tillite" is a lithified sediment entirely deposited directly from glacial ice, its unlithified equivalent is "till".


umberatana
0 5 10
km
mulga Well
N
Apex Hill
Yankaninna H.S.
St Patrick Bore
Mt Rose Cu Mine
Glacigene sediments:
Yankaninna Anticline
(after Coats et al., 1973)


Apex Hill
Pc
Pb
St Patrick Bore
Mt Rose Mine
Pu = Umberatana Gp
Pb = Burra Gp
Pc = Callanna Beds
5
10
km


Mt Rose Mine
Junction Yankaninna & Gammons Creeks
St Patrick Bore
Pf
Py1 (COPLEY)
?Pyb (COPLEY)
Burra Gp
Bolla Bollana Fmn (this paper)

between Py_1 and Pyb appears unconformable on air photos south of Yankaninna Creek because of the angle between cleavage (85^0 magnetic) in the lower diamictite and bedding (striking 70^0 magnetic) in the upper red weathering sandy unit.

An unconformity between Pyb and Py_1 would imply tectonism after deposition of Pyb and truncation of Pyb before deposition of Py_1. In the thick glacial sequence just south of Apex Hill (mapped as Pyb), units deposited in deeper parts of the small basin north of Voca Vocana Hill can be seen both in the field and on air photos to thin eastward due to onlap as they approach shallower parts of the basin just north of Mt. Rose mine. They are not truncated by Py_1.

The faulting south of Apex Hill is post cleavage development[2] and displaces both the glacial units and the overlying Tapley Hill Formation.

(b) The use of distinctive reddish or purplish quartzite clasts to characterize the upper Py_1 unit cannot be successfully applied in the field. We found various such quartzites locally in the lowermost glacial rocks south of Apex Hill, but not in the upper red weathering sandy unit. Coats (pers. comm. 1977) uses these quartzites to distinguish the Py_1 unit from the Pyb unit. In extensive mapping of the Py_1 unit west of the town of Copley, Link (1977) found only one purple quartzite which was identified by Coats to be the distinctive type.

In addition, near Mulga Well in the mapped Py_1 unit a clast probably of Terrapinna Granite was identified. Coats (1971 p.71) discusses how these characteristic granites occur abundantly in the type section of the Fitton Formation of the Yudnamutana Subgroup. This demonstrates further that clast type cannot be used to distinguish the Py_1 unit from the Yudnamutana Subgroup.

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[2] Post-cleavage faults exhibit fault gouge and shattering of adjacent rocks. Quartz filled pre- and syn-tectonic faults at high angles to the cleavage were also observed.

In general, the predominant clasts in the glacigene rocks south of Apex Hill are cream and grey quartzites, quartz pebble conglomerates, and carbonates, all of which occur in the underlying Burra Group. A minor percentage of granitic, metamorphic, and volcanic rocks occurs. There is no variation in clast lithology with position in the stratigraphic sequence.

On the COPLEY sheet, what is mapped as an unconformable contact between Pb_1 (unnamed upper member of the Burra Group) and Py_1, one kilometer east of the junction of Yankaninna and Gammon Creeks is in fact the conformable contact between an upper red weathering sandy glacigene unit and a lower grey diamictite of varying thickness deposited on an irregular erosion surface. We were able to map these glacigene units as continuous from Mulga Well south around the nose of the Yankaninna Anticline, west past St. Patrick Bore, to east of Voca Vocana Hill (Fig. 1). The glacigene rocks (hereafter called Bolla Bollana Formation) consist of a lower boulder to pebble bearing muddy diamictite with local interbeds of laminated siltstone and an upper pebbly sandstone, sandy diamictite and minor siltstone unit mapped as Py_1 on Copley. This entire sequence and the clasts within it are similar to that mapped by Link (1977) west of Copley township and record deposition of waterlaid till (lower muddy diamictite) over an irregular erosion surface followed by reworking of earlier deposits and ice rafting (upper sandy unit). The upper sandy unit was deposited over a surface that had been smoothed by thick till deposition in basins where there was minimal reworking.

Finely laminated black pyritic siltstones and thin carbonate bands of the Tapley Hill Formation overlie the Bolla Bollana Formation over most of COPLEY. In the Yudnamutana Subgroup type area near Mount Painter, regularly laminated dark blue-grey shales with thin sandstones and grits of the Lyndhurst Formation occur between the Bolla Bollana Formation and the Tapley Hill Formation. Local conglomerates of reworked glacial boulders such as the Serle Conglomerate occur at the base of and within the Tapley Hill Formation.

These findings confirm that there is only one major glacial period in the lower Umberatana Group which is represented by the Bolla Bollana Formation on COPLEY and the Sturt Formation (formerly called Sturt Tillite, see footnote 1) in the Sturt Gorge type area south of Adelaide (Howchin, 1908).

As noted by Coats (1971, p. 75) "The greywacke facies of the Bolla Bollana Formation persists throughout the Adelaide Geosyncline, being identical with that of the Sturt Tillite".

The term Yudnamutana Subgroup can thus be used again to include all Sturtian glacigene units.

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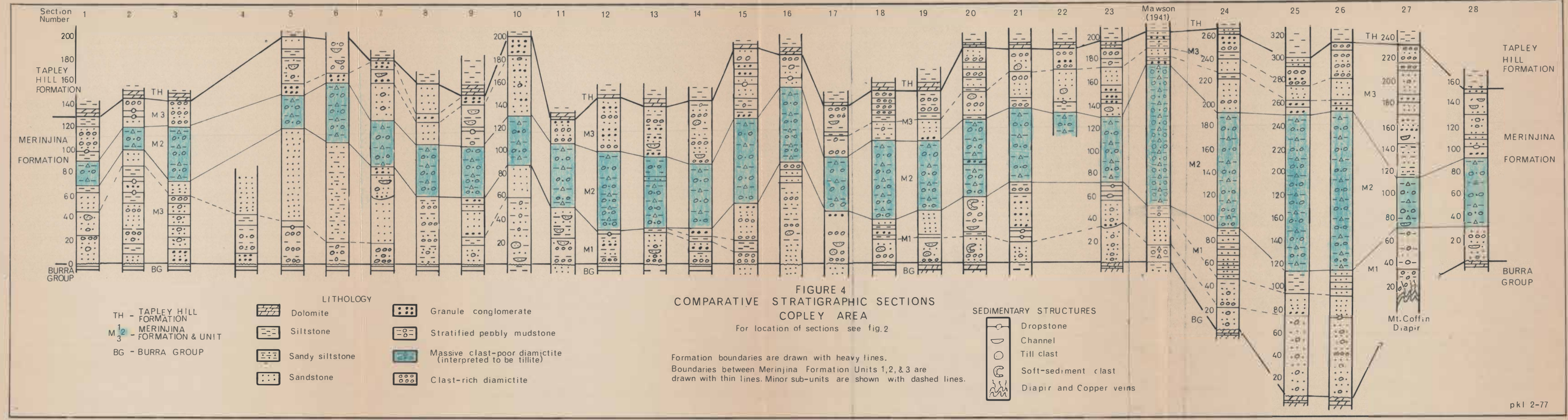
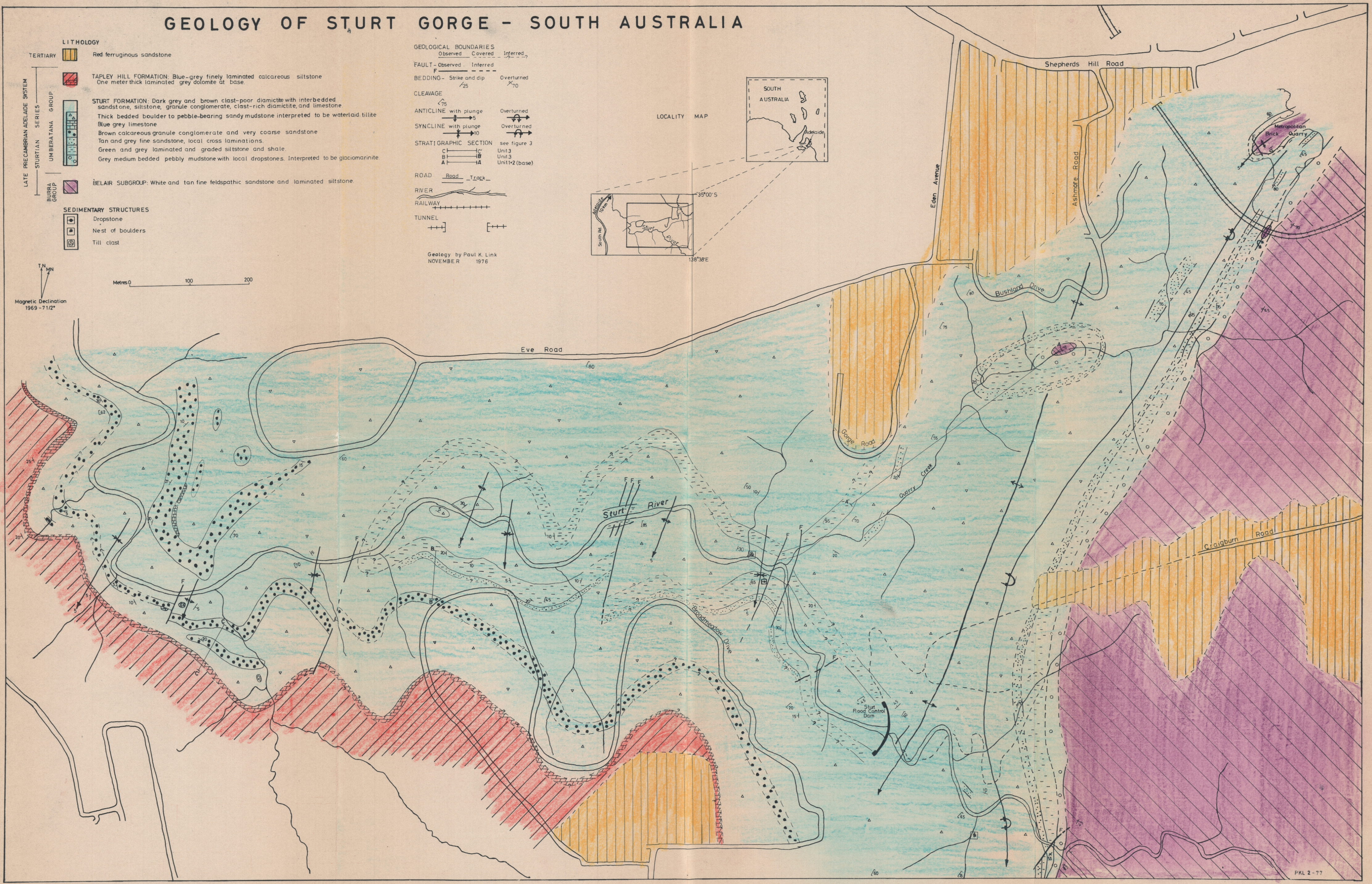


FIGURE 4
COMPARATIVE STRATIGRAPHIC SECTIONS
COPLEY AREA
For location of sections see fig. 2

Figure 6



GEOLOGY OF STURT GORGE - SOUTH AUSTRALIA
LITHOLOGY
TERTIARY
Red ferruginous sandstone
LATE PRECAMBRIAN ADELAIDE SYSTEM
STURTIAN SERIES
UMBERATANA GROUP
TAPLEY HILL FORMATION: Blue-grey finely laminated calcareous siltstone
One meter thick laminated grey dolomite at base.
STURT FORMATION: Dark grey and brown clast-poor diamictite with interbedded sandstone, siltstone, granule conglomerate, clast-rich diamictite, and limestone.
Thick bedded boulder to pebble-bearing sandy mudstone interpreted to be waterlaid tillite
Blue grey limestone
Brown calcareous granule conglomerate and very coarse sandstone
Tan and grey fine sandstone, local cross laminations.
Green and grey laminated and graded siltstone and shale.
Grey medium bedded pebbly mudstone with local dropstones. Interpreted to be glaciomarinite.
BURRA GROUP
BELAIR SUBGROUP: White and tan fine feldspathic sandstone and laminated siltstone.
SEDIMENTARY STRUCTURES
Dropstone
Nest of boulders
Till clast
T.N.
MN
Magnetic Declination
1969 - 7 1/2°
Metres 0
100
200
GEOLOGICAL BOUNDARIES
Observed
Covered
Inferred
FAULT - Observed
Inferred
F
BEDDING - Strike and dip
25
Overturned
70
CLEAVAGE
75
ANTICLINE with plunge
5
Overturned
SYNCLINE with plunge
10
Overturned
STRATIGRAPHIC SECTION
see figure 3
C C' Unit 3
B B' Unit 3
A A' Unit 1+2 (base)
ROAD
Road
Track
RIVER
RAILWAY
TUNNEL
Geology by Paul K. Link
NOVEMBER 1976
LOCALITY MAP
SOUTH AUSTRALIA
Adelaide
Adelaide 10 km
South Rd.
Sturt River
35°00' S
138°38' E
Shepherds Hill Road
Eden Avenue
Ashmore Road
Metropolitan Brick Quarry
Bushland Drive
Eve Road
Gorge Road
Quarry Creek
Sturt River
Craigburn Road
Broadmeadow Drive
Sturt Flood Control Dam
PKL 2-77