THE GEOLOGY OF THE PRISM HILL AREA, NORTHERN FLINDERS RANGES, SOUTH AUSTRALIA

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ABSTRACT

The oldest rocks in the Prism Hill area are Cambrian sediments assigned to the Billy Creek Formation, Wirrealpa Limestone and Lake Frome Group. The upper 45 metres of the Billy Creek Formation consist of plane-laminated and ripple cross-laminated red silts and very fine sandstones that were deposited in an intertidal environment. The overlying Wirrealpa Limestone records a transgressive period with deposition in the lower intertidal to subtidal zone. This passes transitionally into the Moodlatana Formation which consists of red siltstones and sandstones with some cryptalgal carbonate beds, mainly at the base. Deposition of the finer grained clastics and carbonates occurred in the intertidal zone while the sandstones were deposited in a higher energy subtidal environment. The base of the overlying Balcoracana Formation is taken as the first cherty stromatolitic carbonate bed. This formation which is characterized by an alternating sequence of red and green siltstones and stromatolitic and unlaminated carbonates was deposited in the intertidal to supratidal zone and records numerous oscillations in sea level. The boundary with the overlying Pantapinna Sandstone is marked by the influx of coarser clastics. These are plane-laminated, cross-bedded and ripple cross-laminated sandstones and rare siltstones. Deposition occurred in intertidal to shallow subtidal environments. Sedimentation was continuous into the Grindstone Range Sandstone which is more quartzose but was also deposited in a tidally dominated shoreline environment. The upper part consists of coarse grained, pebbly and conglomeratic arenites which show large scale cross-bedding. They are associated with ripple bedded units that indicate wave activity and emergence. The top of the Grindstone Range Sandstone is nowhere exposed.

The Grindstone Range Sandstone is overlain by a sequence of Tertiary and Quaternary sediments. Silcrete has developed on and in the pre-silcrete unit which may correlate with the Eyre Formation. This unit is overlain unconformably by the Nambo Formation which consists of sandstones, sandy clays, clays and carbonates deposited in a fluvial and lacustrine environment. It is overlain by coarser

alluvial fan sediments of the Willawortina Formation which form a capping to the tablelands in the north. This Tertiary sequence dips at up to 45^o and is cross-cut by a younger limestone conglomerate. This latter unit is generally thin but forms a capping to the tablelands in the south.

The dipping Tertiary sequence indicates quite recent tectonic activity, the folding probably induced by basement faulting. A major fault associated with folding occurs in the east of the area mapped. Folding is not of the typical fault drape style but was generated in the Tertiary.

It is not possible to determine the source area for the Lake Frome Group clastics or the palaeogeography of the basin from the available data but further studies should be more revealing.

ACKNOWLEDGEMENTS

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INTRODUCTION

The geology of the Prism Hill area, located on the eastern flank of the northern Flinders Ranges approximately 250 km north of Yunta, was studied by the writer between May and November 1980 (Location Map Figure 1).

The field area, a square approximately 15 km x 15 km (225 km^2), is flanked by the Flinders Ranges to the west and forms a gently sloping surface which flattens off towards the Frome plains in the east. Tablelands capped by Tertiary and Quaternary gravels form remnants of piedmonts that once covered the area. These alluvial surfaces are dissected by deep creeks which have exposed the underlying Tertiary sequence and bedrock of Cambrian age (see Geological Sketch Map Figure 1).

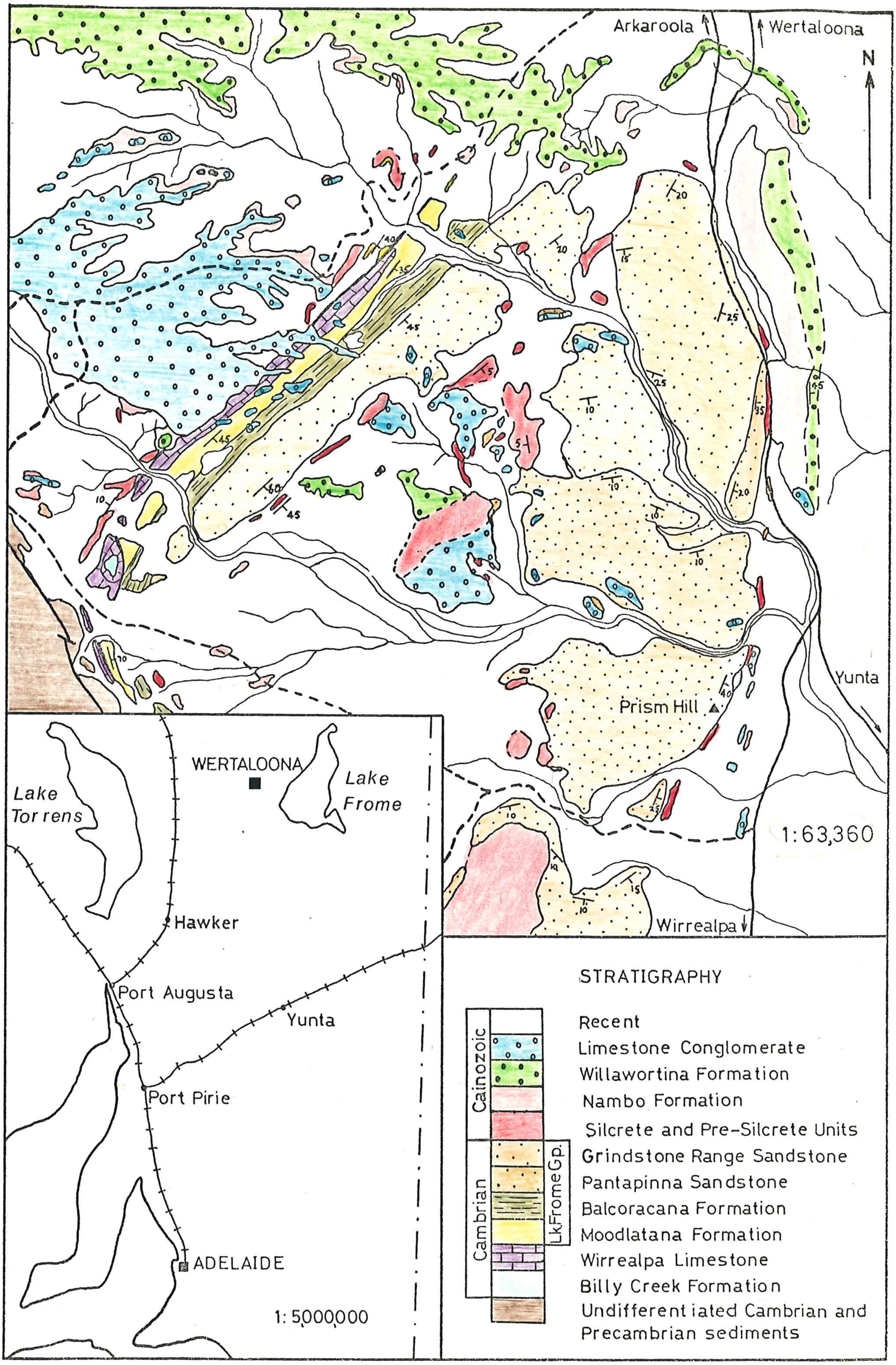
The main road north from Yunta passes through the field area in the east and is joined by the road running north from Hawker, through Wirrealpa Station, in the south-east of the area mapped. Access within the area is generally good with tracks in the northern and southern parts.

A mid-latitude continental (semi arid) type climate prevails with low rainfall, usually in the summer months and high temperatures all year round. The water courses are ephemeral but generally lined with red gums or tea-trees. Elsewhere vegetation is sparse consisting of shrubland and grassland associations.

Previous investigations include the geological mapping of the Wertaloona area as part of the Balcanoona 1:63,360 sheet (Leeson 1967) and the Copley 1:250,000 sheet (Coats 1973). These maps, published by the Geological Survey of South Australia, are accompanied by explanatory notes. This area was also included in Stock (1974) study of the clay mineralogy, petrology and environments of deposition of the Lake Frome Group and Youngs (1973) report on the Wirrealpa and Aroona Creek Limestones. Callen (1976) describes the Tertiary units outcropping in the dipping sequence east of the main road south of Wertaloona homestead.

Fieldwork was undertaken for six weeks in June and July and for a further two weeks during late August. This included geological mapping of the area and the measuring and sampling of detailed stratigraphic sections. Geological information was plotted directly onto an aerial photo (survey 2484 number 083) enlarged to 1:12,500. Numerous palaeocurrent measurements were also made. Laboratory work included a petrological study, preparation of geological maps and cross-sections and stratigraphic sections, collation of structural and palaeocurrent data and examination of subsurface cores and cuttings.

Figure 1. Location Map and Geological Sketch Map (modified from Leeson, 1967).



The aims of this study are outlined below.

- map and document the general geological history of the Prism Hill area
- determine the palaeoenvironments of the Cambrian units
- make correlations with outcrops in the Flinders Ranges and subsurface in the Frome Embayment to determine the palaeogeography of the basin.

REGIONAL GEOLOGY

Palaeozoic sediments in the Prism Hill area range in age from late Lower Cambrian to Upper Cambrian possibly into the Ordovician (Wopfner 1966). These sediments were deposited within a large depression known as the Arrowie Basin. The Arrowie Basin is an intracratonic Cambro-Ordovician basin located in central northern South Australia lying in a downwarp between crystalline basement of the Willyama and Gawler blocks (Figure 2). The Adelaide "Geosyncline" forms a prominent trough in the central part with the stable Stuart Shelf to the west and the substable Curnamona Shelf to the east. Stratigraphic similarities with the Warburton Basin suggest a connection to the north, and a connection south with the Stansbury Basin (Daily 1956).

The Adelaide "Geosyncline", particularly the central trough was actively subsiding in the late Precambrian with the deposition of the Adelaidean sediments. Precambrian sedimentation closed with the deposition of a massive clastic/red bed sequence deposited under regressive conditions. The unconformable or in some cases disconformable contact between the Precambrian and Cambrian proves emergence before the seas again transgressed the basin in the Early Cambrian. This Early Cambrian transgression is recorded by a thick limestone sequence, the Hawker Group. Wopfner (1966) recognised that the thickest sequence occurs in the Arrowie region in the north-eastern part of the Flinders Ranges. This Early Cambrian basin was defined as the Arrowie Basin and sedimentation at this time is described in Parkin (1969). Pronounced subsidence of the central trough at this time is interpreted from the rapid facies changes and thickness variation within this unit. A dark basinal limestone, the Parara Limestone thins laterally on to the margins and passes into paler coloured biohermal limestones of the Wilkalwillina Limestone. Stromatolitic limestones and cherty dolomites of the Andamooka Limestone occur to the west with a more clastic-rich sequence to the east. Stabilization of the craton

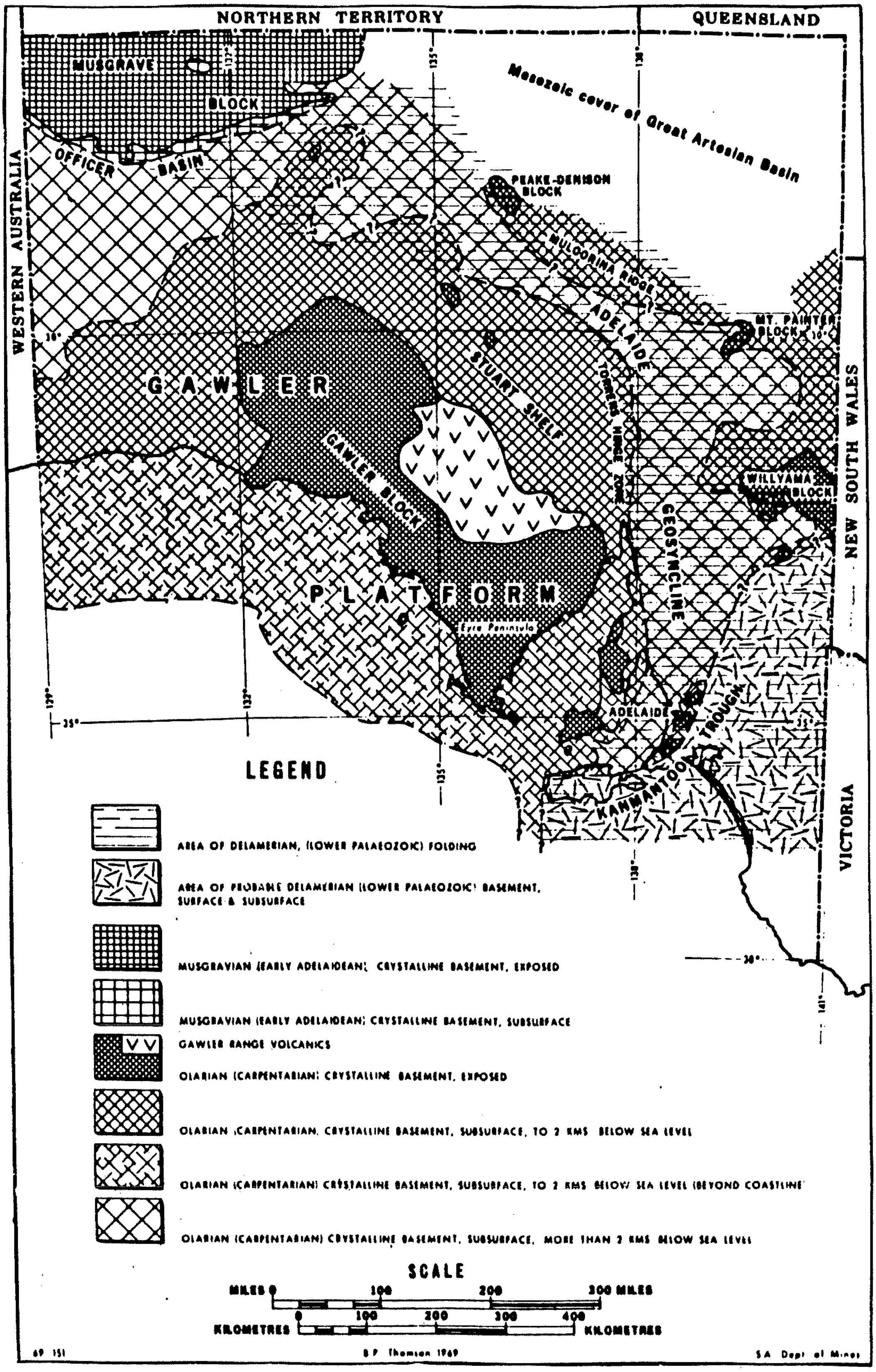


Figure 2. Major structural units of South Australia

in late Early Cambrian led to regressive conditions with the deposition of mildly evaporitic red beds of the Billy Creek Formation. Red bed sedimentation was interrupted by a brief but widespread marine transgression recorded in the deposition of the Wirrealpa-Aroona Creek Limestones. There was a return to generally regressive conditions in the Middle Cambrian with deposition of the Lake Frome Group red beds. This is a thick sequence (2,600 metres in the type area) that was deposited at a time when the basin was subsiding rapidly with clastics being derived from erosion of the adjacent highlands.

Sedimentation ceased in the Late Cambrian to Early Ordovician with the commencement of the Delamerian Orogeny. Tectonic activity at this time resulted in major uplift with the development of broad folds and major faults. Cambrian sediments are preserved in the cores of broad synclines and on the margins of the Flinders Ranges.

The present topography of the Flinders Ranges is a result of uplift along ancient lineaments during Tertiary times. Alluvial fan deposition has occurred in response to this rejuvenation. Tectonic activity in the Tertiary also produced basement faulting in the adjacent shelves. This resulted in broad monoclines which penetrate to the surface at the margins and control the present topography.

STRATIGRAPHY

A detailed geological map (1:12,500) of the Prism Hill area is present in Enclosure 1 and the stratigraphy is summarized in Table 1. The oldest rocks are Cambrian sediments of the Billy Creek Formation, Wirrealpa Limestone and Lake Frome Group which may extend in age into the Ordovician. Stratigraphic sections of the Billy Creek Formation, Wirrealpa Limestone and the Moodlatana and Balcoracana Formation are shown in Enclosure 3 with locations given in Enclosure 2. Sediments of Tertiary and Quaternary age comprise the cover sequence. The petrology is discussed in Appendix 1.

CAMBRIAN

BILLY CREEK FORMATION

The Billy Creek Formation (Daily 1956) is the oldest unit outcropping in the area and consists of a red bed sequence that was deposited under generally regressive conditions. Fossil evidence (Pocock 1970) indicates a late Early Cambrian age. It is overlain transitionally by the Middle Cambrian Wirrealpa Limestone. Moore (1979) subdivided the Billy Creek Formation

TABLE 1
STRATIGRAPHY

	UNITS		THICKNESS (metres)	LITHOLOGY
Quaternary	Recent			- Stream alluvium, slope deposits and thin aeolian sands.
	Limestone conglomerate		10	- Gravel, mainly composed of rounded limestone clasts. Forms a capping to the tablelands to the south.
Tertiary	Willawortina Formation		140	- Conglomerates mainly composed of quartzite clasts with interbedded quartz arenites in the lower part.
	Nambo Formation		280*	- Variable unit, calcareous sandstone and pebble sandstones, grey and green clays and sandy clays and limestones.
	Silcrete		2	- Columnar silcrete.
	Pre-silcrete (Eyre Formation?)		15	- Botryoidal silcrete patchily developed in calcareous sandstones and conglomerates.
Cambrian	Grindstone Range Sandstone	Lake Frome Group	>350*	- red and white feldspathic sandstones and quartzites with large scale cross-bedding. Conglomeratic towards the top.
	Pantapinna Sandstone		1300*	- red and white feldspathic sandstones with large scale cross-bedding.
	Balcoracana Formation		185	- red and green silts and cherty stromatolitic limestones and dolomites.
	Moodlatana Formation		200	- red micaceous silts and shales and feldspathic sandstones with minor green silts and foetid limestones.
	Wirrealpa Limestone		110	- oolitic limestones and calcareous grey-green silts.
	Billy Creek Formation		45	- red micaceous silts and very fine sandstones

*approximate thickness

into five members. It appears that in the Prism Hill area only the Eregunda Sandstone Member is present.

Approximately 45 metres of Billy Creek Formation is exposed below the Wirrealpa Limestone in a doubly plunging anticlinal structure. This unit consists dominantly of cleaved red micaceous silts and very fine sandstones. These sediments are laminated or show asymmetrical ripple cross-laminations with occasional irregularly (compactional) bedded layers. Some intervals contain sub-rounded to sub-angular generally medium sized quartz grains and rock fragments which generally constitute less than 15% of the bed. A waterlaid rather than aeolian origin is indicated from the associated rounded silty intraclasts and erosional basal contacts. No halite casts or desiccation features were found but this could be due partly to the poor state of outcrop. The silts become more calcareous towards the top and pass into red calcareous silts with flat to wavy bedding of probable algal origin. These cryptalgal laminated silts form the passage into the Wirrealpa Limestone.

Deposition occurred in a low energy tidal flat environment with an argillaceous transition into the overlying marine carbonates of the Wirrealpa Limestone.

WIRREALPA LIMESTONE

The Wirrealpa Limestone (Daily 1956) records a brief but widespread transgressive period in the early Middle Cambrian and is transitionally overlain by red beds of the Moodlatana Formation.

This unit has a total thickness of 105 metres in the Prism Hill area and outcrops as resistant strike ridges. Fine grained blue-grey limestones transitionally overlie the calcareous cryptalgal silts of the Billy Creek Formation. Although recrystallized, some fenestral porosity infilled with calcite is present. These pass upwards into grey-green calcareous silts and oolitic limestones which constitute the bulk of this formation. The silts are laminated or show asymmetrical ripple cross-lamination and occasionally contain minor ooids. The ooids are the most important allochems and were precipitated within the basin of deposition. Ooid grainstones are moderately sorted to well sorted and have a fine to medium grainsize. In the study area they are the most prominent lithofacies in the Wirrealpa Limestone and show medium to small scale cross-bedding with occasional silty drapes and have a mottled appearance in places (Plate 1a). Fossil fragments, rounded intraclasts and oncolites are also important allochems but rarely form more than 30%-40% of the bed (Plate 1b). These are generally associated with coarser ooids. Fossil fragments were difficult to classify because of the recrystallized nature of the rock but brachiopods (<u>Obolella wirrialpensis</u>) and trilobite fossils were identified.

Youngs (1973) proposed a depositional model for the Wirrealpa Limestone. Oolites are precipitated in warm shallow seas where turbulence from wave and current action is high. They are transported and accumulate in the lower intertidal to subtidal environment as shoals. In the epieric sea setting that existed at this time such an environment would be many kilometres wide and correspond to Shaw (1964) high energy Y zone. Oncolites were deposited on the margins of the shoals and in tidal channels which dissected the ooid bank. Intraclasts are rounded indicating transport and may have originated as platy clasts derived from desiccation or sub-aqueous erosion of fine-grained micrites. Fossils occur as fragments and are associated with oncolites (sometimes as nuclei), intraclasts and coarse ooids. Deposition of these units probably occurred on the margins of shoals where wave and current action was concentrated or in turbulent tidal channels as lag.

The plane-laminated and ripple cross-laminated silts were deposited under less turbulent conditions but still under the influence of tidal currents. The environment was less suitable for the precipitation of carbonate and facies associations suggest deposition occurred landward of the ooid shoals. Carbonate precipitation in the passage into the Wirrealpa Limestone is associated with cryptalgal laminates and deposition probably occurred on the intertidal flats or in large ponds in the upper intertidal to supratidal zone. Channels carrying clastic material seaward may have dissected these areas. The passage beds at the top of the Wirrealpa Limestone were deposited in a similar environment but it is not as recrystallized and depositional features are more readily observed.

LAKE FROME GROUP

MOODLATANA FORMATION

The Moodlatana Formation (Daily 1956) is the lower-most unit of the Lake Frome Group and transitionally overlies the Wirrealpa Limestone. The base is marked by the influx of red silts and as this is transitional a passage out of the Wirrealpa Limestone rather than a precise contact is described. The passage beds consist of red silty limestones and calcareous silts with cryptalgal laminae. Sedimentary features such as desiccation cracks,

Palaeocurrent Rose Diagrams

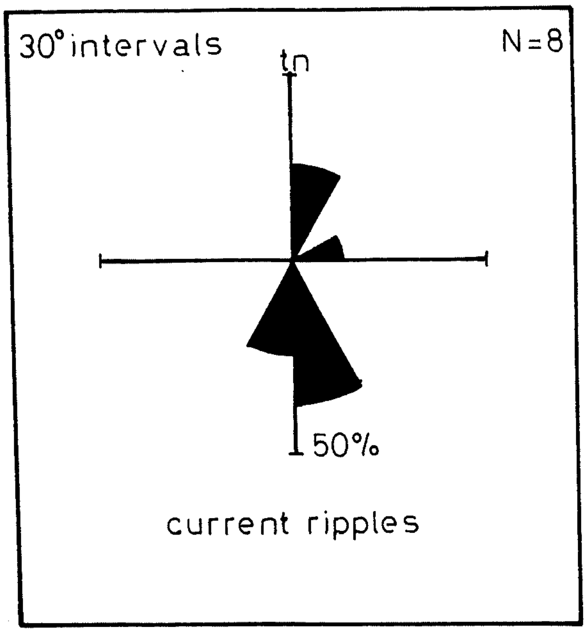


Figure 3.1.
Passage into the
Moodlatana Formation.

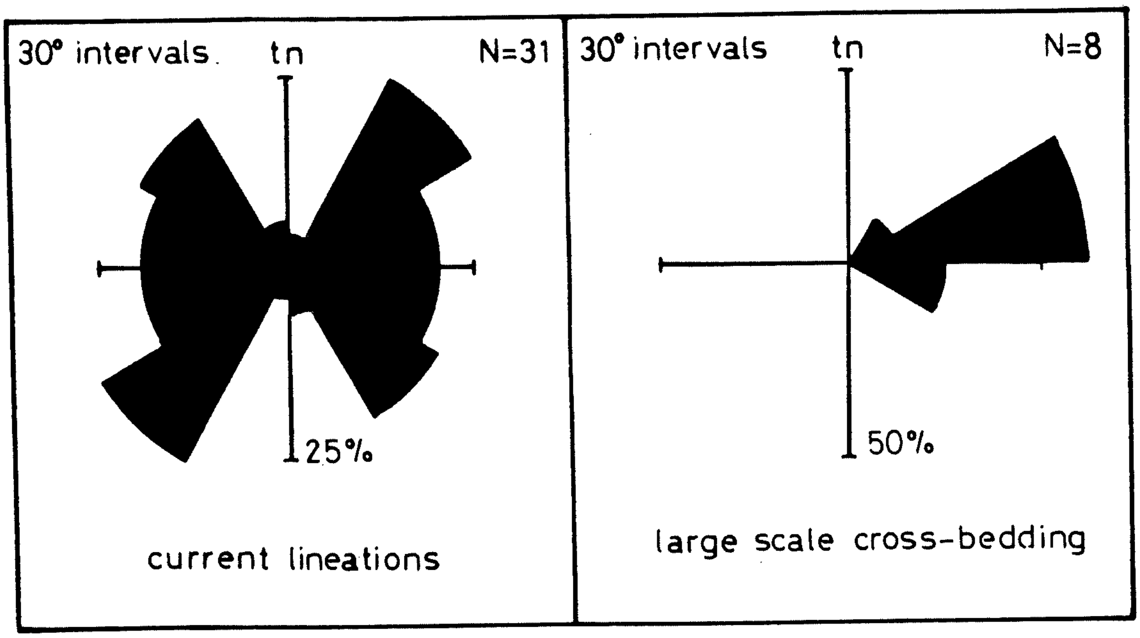


Figure 3.2. Moodlatana Formation.

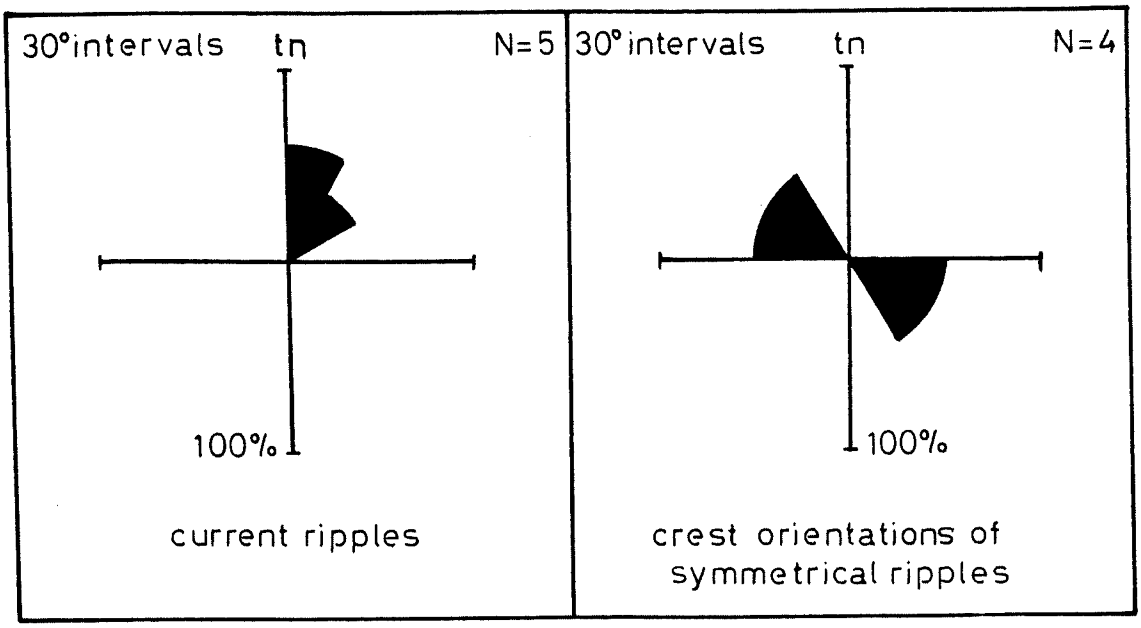


Figure 4. Balcoracana Formation.

intraclasts, fenestral porosity and calcite pseudomorphous after anhydrite suggest deposition took place in the intertidal zone (Plate 1c). Asymmetric and near symmetric ripple surfaces sometimes distorted by algal growth are present and palaeocurrent modes are shown in Figure 3.1 (Plate 1d). The dominant flow directions were to the north and south suggesting an east-west orientation of the shoreline during deposition of these beds. Some transportation of sediment to the east, possibly along shore, is also indicated. The direction of the source area cannot be determined from this data.

The 200 metre thick Moodlatana Formation is composed of red micaceous siltstones and sandstones and some red-brown shales. A sandstone unit approximately 70 metres thick occurs in the lower part but unlike the type section in the Wirrealpa area, no major sandstone sequence is found in the upper part. Instead several thin (< 3 metres) sandstone units are present and interbedded with thicker siltstone and shale units. These solitary sandstone units are usually low-angle to plane laminated but some trough cross-bedding, generally of a broad shallow nature, occurs. This facies is also prominent in the lower sandstone sequence and shows good current lineations. Horizontally laminated and asymmetrical ripple cross-laminated very fine sandstone and siltstone units are often associated with these two facies and are prominent throughout the formation (Plate 2a). Trilobite trace fossils were found in the lower sandstone unit.

Siltstones and shales in the Moodlatana Formation are generally poorly bedded. Coarser more micaceous siltstone units are current ripple cross-laminated and often contain trilobite trace fossils and desiccation cracks. Calcite, psuedomorphous after anhydrite, is occasionally found in poorly bedded siltstones towards the top. Some siltstone intervals particularly at the base contain medium to coarse quartz grains and rock fragments. Such units may be patchily calcified where these grains are concentrated, preserving granule trains down the cross-bedding. Cross-bedding indicates currents flowing southwards.

Recrystallized cryptalgal limestones and associated green siltstones are interbedded with red siltstones at the base. The only other carbonates found occur in the middle part of this formation. These are dark foetid limestones with a lamination that may be of cryptalgal origin and contain desiccation cracks. The limestones which are interbedded with green silts are similar to those containing metadoxidid trilobites in the Moodlatana Formation in the Wirrealpa area (Daily and Forbes, 1969).

The presence of trilobite trace fossils throughout this formation indicates deposition in a marine environment. Desiccation cracks indicate periods of emergence while calcite pseudomorphous after anhydrite suggests evaporitic conditions. Cryptalgal limestones may also indicate deposition in a hypersaline environment where browsing invertebrates were unable to survive. Much of the Moodlatana Formation was therefore deposited in the intertidal zone of a clastic dominated shoreline. The sandstones contain trace fossils and were therefore deposited in a marine environment. Palaeocurrent modes for large scale cross-bedding are shown in Figure 3.2 and indicate a dominant flow direction to the east. Palaeocurrent data for current lineations also indicates an east-west orientation although more variable. Sediment transport appears to be along shore with redistribution of the sands occurring in a high energy marine environment. Although large-scale cross-bedding indicates a unimodal current direction this may be the dominant current (ebb or flood) in a tidally influenced environment. Klein (1970) discusses examples of unimodal dispersal patterns of sands in modern tidal environments. These sandstone facies are similar to those found in the Pantapinna Sandstone and will be discussed in more detail in the section on that formation. Deposition probably occurred in a tidally dominated shallow subtidal to lower intertidal environment.

BALCORACANA FORMATION

The Balcoracana Formation (Daily 1956) conformably overlies the Moodlatana Formation and the base is taken as the first laminated and cherty dolostone. A late Middle Cambrian Age is suggested from the presence of an agnostid trilobite Lejopyge (Hawle and Corda) in the subsurface in the Lake Frome area. The Balcoracana Formation is 180 metres thick and is conformably overlain by the Pantapinna Sandstone.

This formation consists of alternating red and green silts, dolomites and limestone some of which are algal (Plate 2b). Several facies can be recognized. Red laminated micaceous siltstones and indistinctly bedded, less micaceous red siltstones and shales dominate the sequence. The silts are horizontally laminated to asymmetrical ripple cross-laminated, sometimes climbing. Palaeocurrent data for asymmetrical and symmetrical ripples indicates a north-south flow direction and also suggests an east-west orientation of the shoreline (Figure 4). Trilobite tracks and burrows and desiccation cracks are common in some intervals (Plates 2c and 2d). Calcite pseudomorphous after anhydrite or gypsum were found in the lower part but may occur throughout the sequence. Anhydrite nodules and lenses are found in the subsurface core. Grey-green reduction spots within the red silts may be related to localized concentrations of organic material (Stock 1974). Green silts are less common and are generally associated with carbonate units.

Limestones and dolostones are generally blue-grey but with increasing silt content become pink to pale red. Some carbonates have a typical wavy cryptalgal lamination while others are horizontally laminated and may have an algal origin. Desiccation features which include cracks, intraclasts and intraformational breccias are associated with these carbonates (Plate 3a). Bioturbation is present in some layers. Chert bands and nodules occur in some of the stromatolitic layers and are of secondary origin with laminae continuous into the cherts. Some carbonates usually dolomites are poorly laminated to unlaminated with occasional halite casts (Plate 3b). The detrital content of the carbonates is variable and pink silty limestones or more commonly dolomites occur throughout the sequence.

Sedimentary features and facies associations in the Balcoracana Formation suggest deposition in a mixed carbonate clastic marginal marine environment. The cyclic alternation of facies records the oscillations of the shoreline and corresponding shift of lateral facies equivalents. Stock (1974) has suggested a depositional model for the Balcoracana Formation based on West et al, 1968. This model suggests that carbonates are deposited under more marine conditions and pass landwards into green silts and with increased emergence and oxidation, red silts. Evidence suggests that this model is not entirely accurate.

Dolomite is an evaporitic mineral that is precipitated directly from hypersaline brines or more commonly develops penecontemporaneously in the subsurface as a result of grounwater circulation. The dolostones are very fine grained and not recrystallized and occasionally contain halite casts. Dolomite precipitation occurs mainly in the evaporatic upper intertidal to supratidal zone. In modern day environments algae are most prominent in the upper intertidal areas and supratidal ponds where hypersaline conditions prevent browsing by invertebrates. The cryptalgal laminated carbonates of the Balcoracana Formation are poorly bioturbated and desiccation features are common. Green silts are associated with these foetid limestone and dolomites suggesting a reducing environment. The red colouration in some of these carbonates suggests that this is the primary colour. The red pigment is derived from erosion and deposition of red soil rather than oxidation in the environment of deposition. Red micaceous silts are cross-ripple laminated and contain trilobite trace fossils with desiccation features. These units are deposited within the lower to middle intertidal zone but marine influence is greater than for deposition of the carbonates. The presence of evaporitic nodules indicates the red siltstones were also deposited in the upper intertidal to supratidal zone. Deposition probably occurred on a tidal flat which was blanketed by red silts. Where carbonate precipitation was rapid, and clastic input lower, dolostones and limestones were deposited. This probably occurred in the upper intertidal zone or in large ponds developed in the supratidal zone. Shallow channels may have dissected these zones carrying clastic material into the lower intertidal and subtidal zone. Landward of this tidal flat environment an alluvial plain composed of fine red clastics probably occurred. The fine grained nature of clastics in the Balcoracana Formation suggests a very mature hinterland.

PANTAPINNA SANDSTONE

The name Pantapinna Sandstone has not been formally appointed but was applied to the unnamed sandstone unit of Daily (1956) on the Blinman 1:63 360 map sheet and has been used in subsequent literature. This is a marine unit that conformably overlies the Balcoracana Formation. No shelly fossils have been recorded but a late Cambrian age is suggested. This formation has a thickness of approximately 1300 metres. Its base is marked by the influx of sands.

In the Wertaloona area red silts with trilobite tracks and desiccation cracks within the Balcoracana Formation give way to a sequence of interbedded green silts and feldspathic sandstones. The sandstones are generally ripple cross-laminated with the silts occurring as drapes. Flaser, wavy and lenticular bedding are present in interbedded siltstone and sandstone layers (Plate 3c). Load casts are prominent and this unit is strongly bioturbated (Plate 3d and Plate 4a). Desiccation cracks are also present. Large tidal channels are developed in this unit and have a general north-south orientation (Plate 4b). Although distorted by compaction, ripple surfaces also indicate a shoreline with an east-west orientation. Interbedded siltstones and sandstones are characteristically deposited in environments with fluctuating current strengths. Bioturbation, desiccation and the type of channelling are also indicative of tidal deposition. This intertidal sequence is about 10 metres thick and becomes sandier towards the top, passing into flat to horizontally laminated current lineated feldspathic sandstones (Plate 4c). An impersistent oolitic limestone is interbedded with these sandstones approximately 7 metres above the base of the Pantapinna Sandstone. Although dolomitized, oolites and silty drapes are preserved. Its facies is comparable with ooid grainstones found in the Wirrealpa Limestone. The transition from the Balcoracana Formation to the Pantapinna Sandstone therefore records a transgressive period from upper intertidal through the lower intertidal zone into a subtidal environment.

The Pantapinna Sandstone consists of red to pink micaceous feldspathic sandstones and arkoses with some red-brown silts. Several facies can be recognized within the unit. In the lower part of this formation flat laminated fine sandstones with concentrations of micas and heavy minerals are most prominent. These are associated with broad shallow trough shaped structures which show a general north-south orientation. Palaeocurrent measurements on current lineations and current crescents are presented in Figure 5. These also show a north-south trend with the two crescent measurements indicating a current flowing towards the north.

Large scale cross-bedding mainly of the planar type is common throughout the rest of the formation. Sets are generally about .5 metres thick and have foreset dips of $20^{\circ} - 25^{\circ}$. These are stacked into thick cosets with horizontal erosional surfaces and probably correspond to Allen (1963) Omikron cross-stratification (Plate 4d). Syn-depositional slumping down the cross-beds is common and as these structures are related to current drag they are useful palaeocurrent indicators. Palaeocurrent modes for large scale cross-bedding and slumping are shown in Figure 5. Trough cross-bedded sets and cosets sometimes occur with the planar cross-bedded cosets but more commonly with low angle and flat bedded units. Herring-bone cross-bedding is present but not common. Silty intraclasts are occasionally associated with the large scale cross-bedded sandstones.

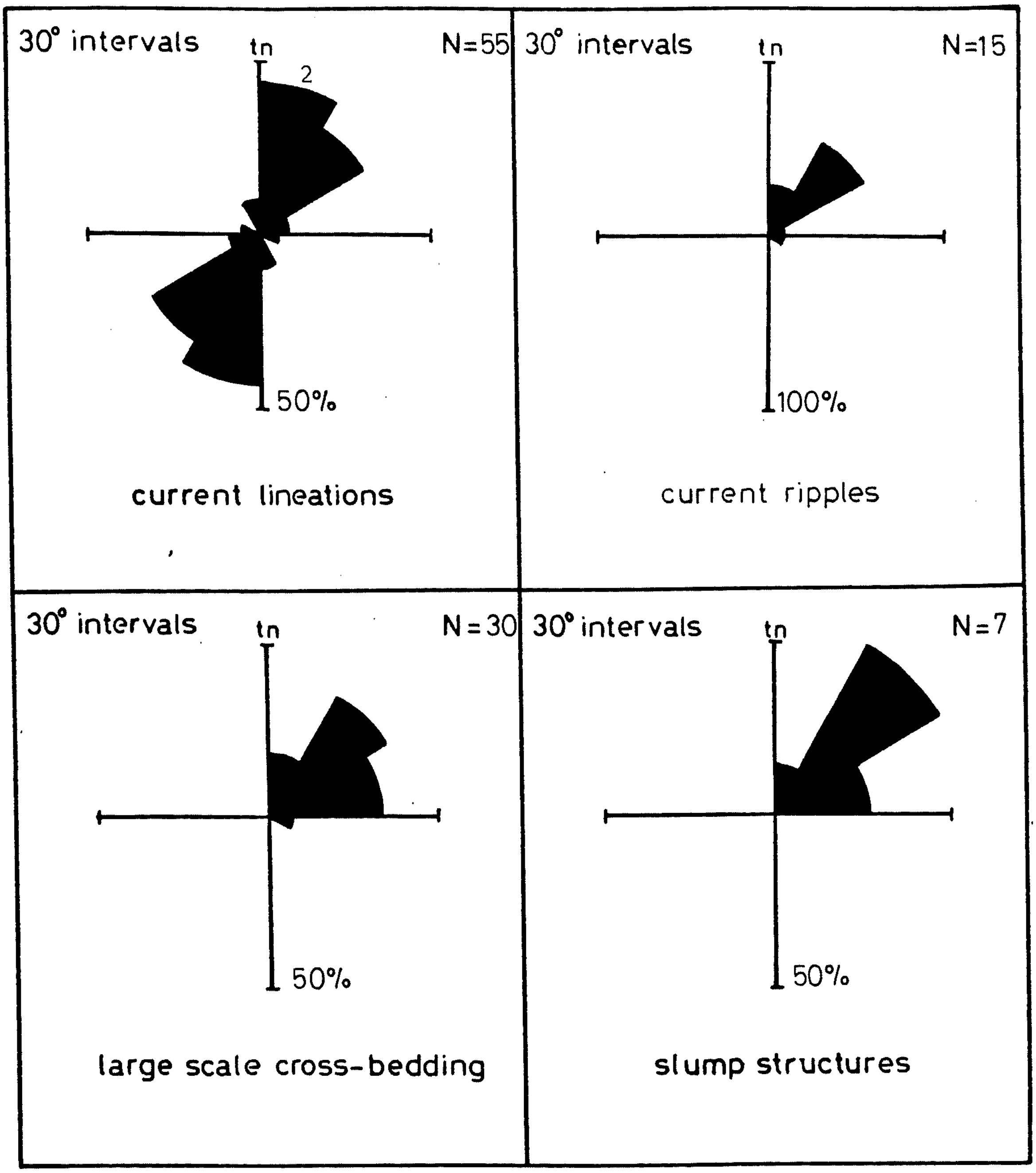


Figure 5. Palaeocurrent rose diagrams, Pantapinna Sandstone. Numbers on rose diagrams for current lineations indicate the number of lineations in each sector which have known direction (current crescents).

Interbedded siltstone and sandstone units similar to those found at the base occur at several intervals. The sandstones are flat bedded to ripple cross-laminated with bioturbation, desiccation cracks and possible raindrop prints. Where silty layers are thick, load casts develop. With decreasing silt content, ripples are better preserved and show less indication of soft sediment deformation (Plates 5a and 5b). Asymmetrical current ripples are the major type and are sometimes flat topped or double crested. These ripples were therefore deposited in the intertidal to shallow subtidal environment. Palaeocurrent measurements taken on these structures are presented in Figure 5 and indicate a current flow towards the north-east. The facies is more prominent in the Prism Hill area than the Wirrealpa area.

The horizontally laminated sandstones at the base of the Pantapinna Sandstone are interbedded with an oolitic limestone. Oolitic limestones are deposited in the subtidal to lower intertidal zones where turbulence due to wave and current action is high. A similar environment is envisaged for the deposition of the sandstones but carbonate precipitation was hindered by rapid influx of clastics. The lack of sandstones in the Balcoracana Formation suggests that this facies is not a lateral seaward equivalent of that tidal sequence. The combination of a rapid influx of sands and transgressive conditions suggests a relative rise in sea level with clastics being derived from either reworking of alluvial sands or more likely increased supply of clastics from the source area. During sedimentation of the Pantapinna Sandstone and Grindstone Range Sandstone the position of the shoreline was relatively stable with sediments in the Wertaloona area being deposited in the lower intertidal to subtidal environment. The rate of clastic supply during this time must have been similar to the rate of subsidence of the basin.

The horizontally laminated current-lineated sandstones were deposited under high energy conditions. This facies has been reported from numerous tidal deposits, both modern and ancient. The origin of plane-laminated sandstones is discussed by Daily et al (1980). Barnes and Klein (1975) interpreted plane-laminated sandstones as tidal current bed load deposits. Kumar and Sander (1974) reported plane-laminated sands formed by upper regime flow in shallow tidal channels and may be analogous to those associated with the plane-laminated sandstones. The origin of mica-rich and heavy-mineral-rich bands may be particularly significant.

Palaeocurrent evidence indicates a dominant north-easterly flow direction. Herring-bone cross-bedding is typical of tidal environments. Palaeocurrent data from large scale cross-bedding is unimodal and possibly corresponds to the dominant tidal current direction (ebb or flood). Stock (1973) observed a similar pattern for the Pantapinna Sandstone in the Wertaloona area but recorded a bimodal situation in the Balcoracana area. Slump structures also indicate a unimodal current direction towards the north-east. Silty intraclasts, associated with cross-bedding deposited under high energy, reflect fluctuating current strengths. Silts were deposited during periods of low turbulence and later ripped up and redeposited, indicating reactivation. Allen (1963) suggests omikron cross-stratification is formed by the migration of trains of large scale straight crested ripples. Such conditions are found in channels or the open sea in depths many times the ripple height. The extent of this facies suggests an open sea situation. A partially exhumed very large scale (10-15 metres high) sedimentary structure is shown in Plate 5c. The bedding is dipping south but current ripple cross-lamination indicates a current flowing to the north.

Deposition of the Pantapinna Sandstone occurred in a rapidly subsiding basin. The lower part of the sequence was deposited in the intertidal to shallow subtidal zone while in the middle and upper parts deposition generally occurred in deeper waters. This unit was therefore deposited under essentially stable to transgressive conditions. The shoreline is not prograding seawards as would be expected in a normal deltaic situation. Clastics entering the basin were redistributed by tidal currents and deposition occurred in a tidally dominated lower intertidal to shallow subtidal environment.

Palaeocurrent modes indicate that the dominant current flow was to the north with a shoreline possibly orientated east-west. Two alternatives seem possible. Either the currents were directed essentially onshore with a landmass to the north, possibly in the vicinity of the Mount Painter Block, or directed offshore with a landmass to the south. There is not enough information available at present to determine the configuration of the basin of deposition but this is discussed in more detail in the section on palaeogeography.

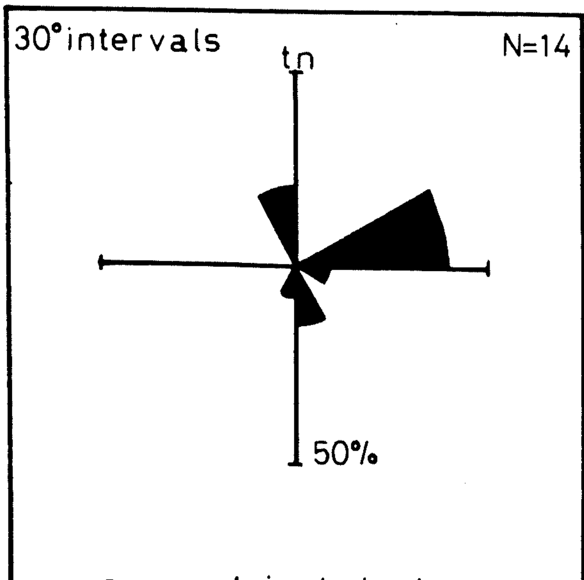
GRINDSTONE RANGE SANDSTONE

Resistant quartz sandstones of the Grindstone Range Sandstone (Mawson 1939) conformably overlie softer feldspathic sandstones of the Pantapinna Sandstone (Plate 5d). Erosion has removed the top of the sequence but approximately 350 metres of this formation is preserved in the Wertaloona area. No shelly fossils have been recorded from the Grindstone Range Sandstone but stratigraphic relationships suggest Late Cambrian to Early Ordovician age.

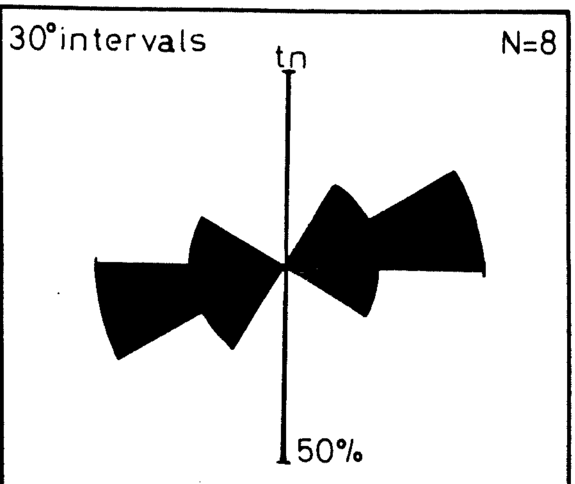
Resistant pale-coloured quartz sandstones at the base give way to red and pink sandstones which are more feldspathic and poorly outcropping. Sedimentary structures in the lower and middle part of this formation are similar to those found in the Pantapinna Sandstone. Planar cross-stratification and slumping are prominent but trough cross-bedding, low angle and herringbone cross-bedded and plane laminated units are present (Plate 6a). Palaeocurrent measurements on large scale cross-bedding, slumping and current lineations are shown in Figure 6. Sediment transport was essentially easterly, possibly parallel to the shoreline. Trilobite trace fossils are found in the basal sandstones commonly on mudcracked surfaces (Plates 6b and 6c). Like the Pantapinna Sandstone trace fossils in the plane-laminated and cross-bedded units are rare. These facies were deposited in high energy environments which would have been unsuitable for both habitation by marine organisms and preservation of traces.

The environment of deposition for the lower and middle part of this formation was similar to that of the Pantapinna Sandstone and therefore lithological differences must be related to external factors. The Grindstone Range Sandstone is less feldspathic and coarser grained than the underlying unit and deposition may correspond to a period of increased chemical weathering in the source area or reworking in the marine environment. Unlike the underlying Pantapinna Sandstone, the Grindstone Range Sandstone contains no red-beds (Stock 1974). Although the significance of redbeds is conjectural this may provide a clue to the lithological differences between these two formations.

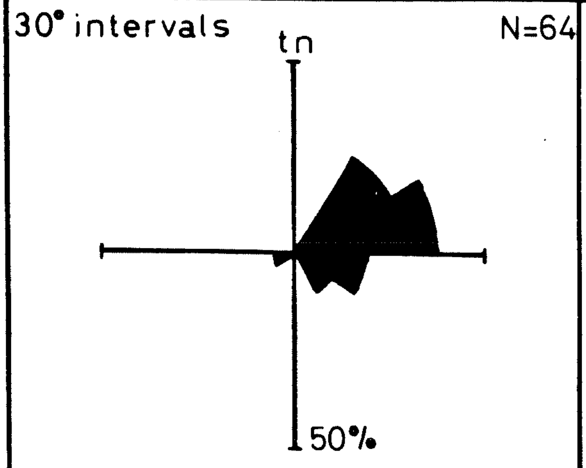
Pebbly and conglomeratic quartz arenites and quartzites occur in the upper part of the Grindstone Range Sandstone. These are lithologically super mature and contain well rounded quartz and quartzite clasts. Clasts are concentrated down the planar cross-beds and at the base of channels. Low angle and herringbone cross-bedding are also present. Ripple cross-laminated intervals are associated with these cross-bedded units and ripple



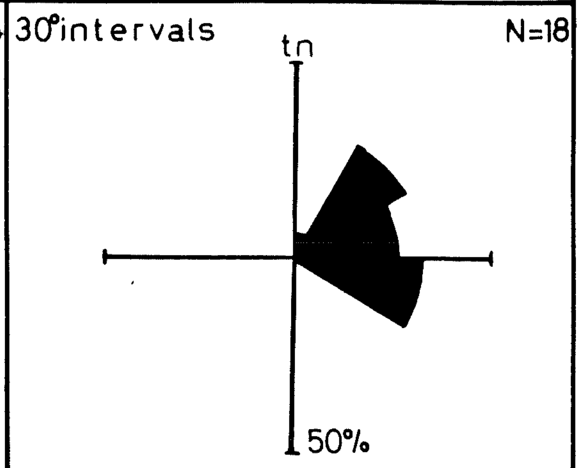
asymmetrical ripples



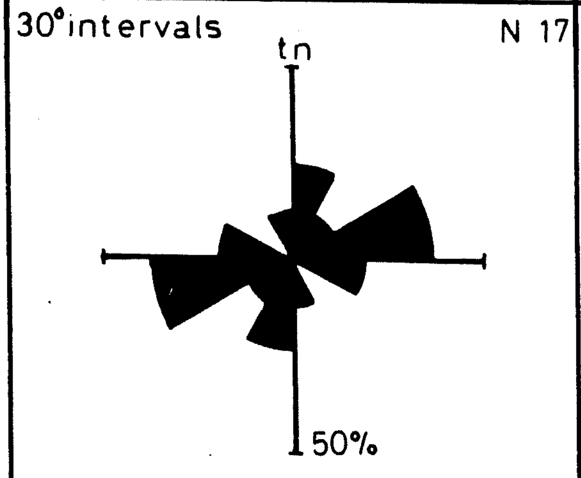
crest orientations of symmetrical ripples



large scale cross-bedding



slump structures



current lineations

Figure 6.
Palaeocurrent rose diagrams, Grindstone Range Sandstone.

surfaces are often well exposed (Plates 6d, 7a and 7b).

Current ripples are asymmetric to slightly asymmetric, straight crested or slightly sinuous and non-bifurcating. Linguoid ripples also occur but less commonly. Wave influence is indicated by the presence of interference, ladder and double-crested and rounded off ripples. Some of the more symmetrical ripples may also be wave generated. Desiccation cracks and possible raindrop prints indicate periods of exposure.

The upper part of the Grindstone Range Formation is similar to the Graafwater Formation, described by Tankard and Hobday (1977). The super mature lithogies of the pebbly and conglomeratic quartz arenites suggest much reworking in a high energy environment with sediment transport mainly to the east. Periods of lower energy, with shallowing and subaerial exposure are recorded by these ripple-bedded units. Palaeocurrent measurements from these units suggest a shoreline orientated east-west with some sediment transport along the shore to the east. No interbedded silts are found in these lower energy units. Deposition of the upper part of the Grindstone Range Sandstone occurred on a low tidal sand flat and in a shallow subtidal environment.

TERTIARY

Four units of Tertiary age outcrop in the Prism Hill area. The pre-silcrete unit is generally thin and lithological similarities and stratigraphic relationships suggest a possible correlation with the Eyre Formation. Silcrete is developed on or within this unit. The formation is overlain unconformably by the Nambo Formation. This in turn is conformably overlain by sediments of the Willawortina Formation. These two units were recognised in the Prism Hill area by Callen (1976). This sequence is dipping at $30^\circ - 40^\circ$ east of the main road, which indicates quite recent tectonic activity (see section on structure).

PRE-SILCRETE UNIT (EYRE FORMATION)

All post-Cambrian cover below or in which the silcrete is developed is described as pre-silcrete. This "unit" shows different characteristics east and west of the main northeast-southwest trending fault and the two areas will be discussed separately.

To the east of the fault the pre-silcrete sequence is generally thin (2 metres) and is composed of pebbly and conglomeratic calcareous quartz arenites. The conglomeratic clasts consist of well-rounded quartz and quartzites and minor more angular cherts. Silcrete pebbles are also present in some outcrops and the significance of this is discussed later. These sediments are generally silicified with silicification occasionally extending down to or more rarely into the Cambrian sandstones. Ferruginization of the pre-silcrete unit is observed in some outcrops. A regolithic profile may develop with large fractured quartzite fragments (Cambrian?) dispersed amongst silicified sands. Lithological similarities suggest a possible correlation with the Eyre Formation of early Tertiary age (Callen 1976).

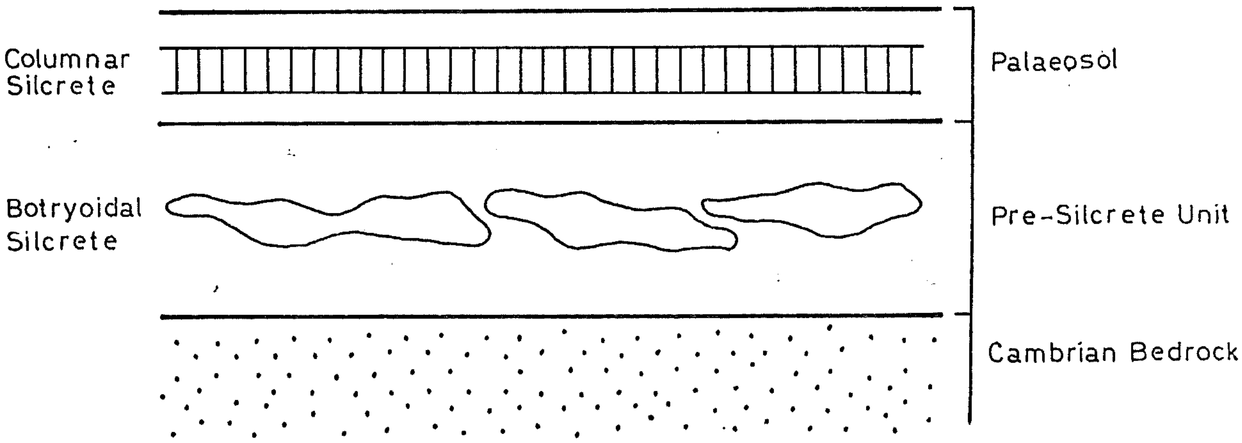
A thicker (up to 15 metres) conglomeratic and sandy unit occurs west of the fault. This conglomerate contains large quartzite clasts (maximum diameter about .4 metres) which occasionally show cross-bedding and may have been derived locally from Lake Frome Group sandstones. The imbrication on the clasts indicates deposition from a current flowing to the southeast. This unit thins to the north where silcrete is almost directly overlying the Moodlatana Formation. To the south where the conglomerate unit thickens a typical siliceous weathering profile develops. The absence of any limestone clasts in this conglomerate unit adjacent to outcropping Wirrealpa Limestone suggests a fault contact. Although some large quartzite clasts are present in the pre-silcrete east of the fault the relationship between the two units is not known.

SILCRETE

Silcrete is composed of very fine grained crystalline silica and has a concretionary appearance. Two main types termed columnar and botryoidal occur in the Wertaloona area (Plates 7c and 7d). These are generally massive to poorly bedded but unlike silicified sediments, sedimentary features such as bedding are not preserved. Precipitation of silica is related to chemical weathering in arid and semi-arid climates. Silica is soluble in an alkaline environment and forms a gel which moves through the substrate by capillary action. Silcrete usually develops in calcium-rich units and Krauskopf (1967) suggests that the replacement of calcium with silica can occur from slightly acidic solutions that are supersaturated with silica, however the exact mechanism is not known.

The columnar or in some cases pisolitic silcrete develops within the ancient soil profile (palaeosol) and forms a resistant crust termed duricrust. Silica is precipitated from solutions moving vertically up through the soil. Columns analogous to those of stromatolites develop with the successive deposition of layers. The columns, up to two metres high, are always aligned vertically as a result of the mechanism of precipitation and can be used to determine any subsequent tilting of the sequence. The silcrete surface may itself not be deposited horizontally but follow the topography, therefore reflecting the palaeotopography. Pebbles and coarse grains of quartz and quartzite contained within the soil are preserved in the silcrete.

Where the pre-silcrete is thick a typical siliceous weathering profile develops and is shown below.



Botryoidal silcrete was developed within the pre-silcrete sediments and always occurs below the columnar type, which was precipitated in the palaeosol. Botryoidal silcrete has an irregular concretionary appearance and tends to show a patchy distribution, with adjacent zones being unsilicified. Like columnar silcrete it tends to follow the palaeotopography and so these surfaces cannot be used as indicators of folding or faulting. Casts of fossil plant material, deposited with the sediment and root casts of plants, growing at or near the time of silicification are preserved in botryoidal silcrete but are not found in the columnar silcrete. Sandstones and conglomerates of the pre-silcrete unit and Cambrian formations are pallid. Silica was probably leached from this zone and precipitated as silcrete. Where the pre-silcrete unit is thin the two types are superimposed and the profile described above does not develop. Silcrete pebbles occur in conglomerates below and in these silcretes, indicating the existence of an older silcrete. No earlier silcrete surfaces are found in the Prism Hill area and were probably removed by erosion.

NAMBO FORMATION

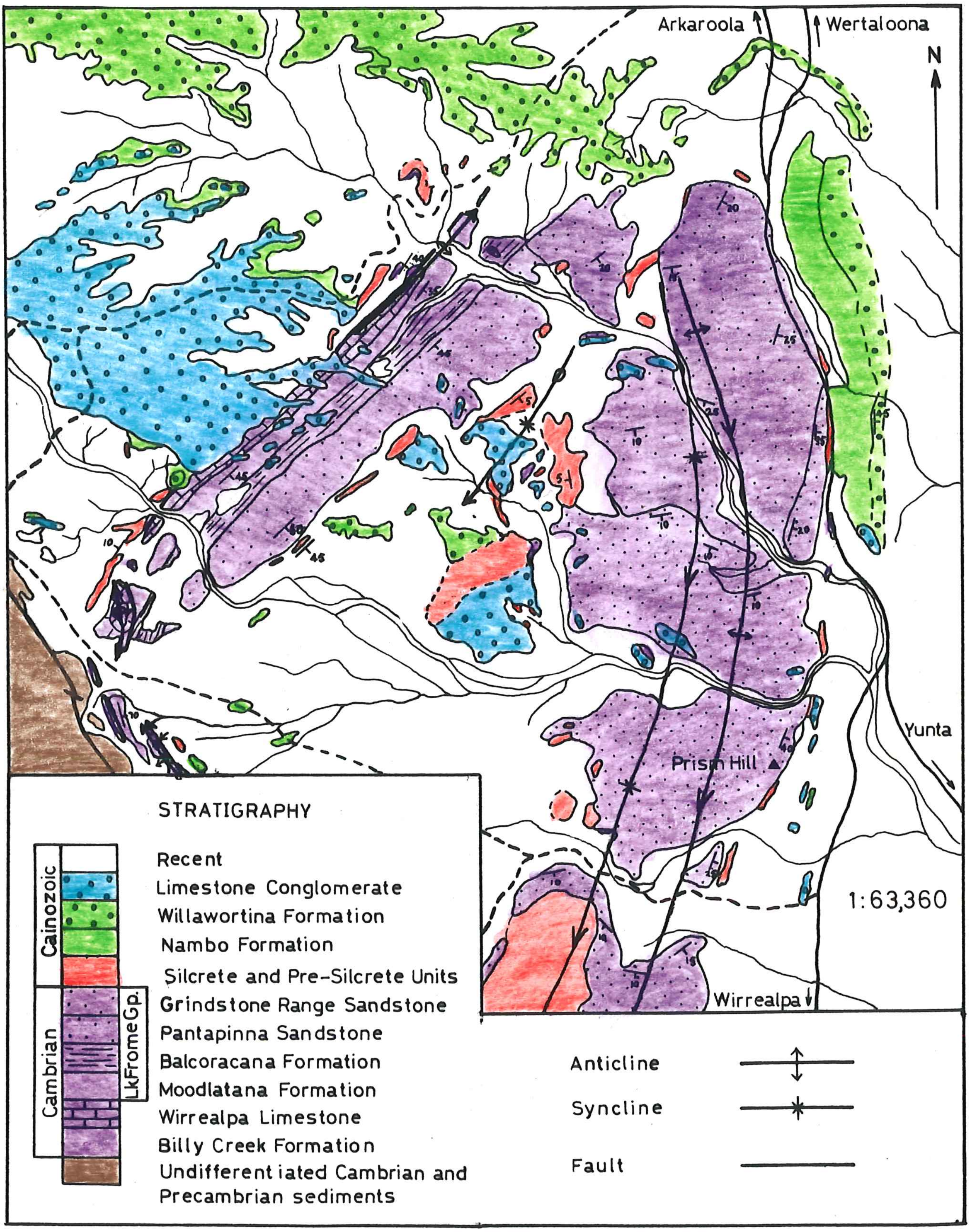
Columnar silcrete develops in the palaeosol and therefore indicates an unconformable contact between the pre-silcrete unit and overlying Nambo Formation (Callen 1974). The Nambo Formation is approximately 280 metres thick and is conformably overlain by the Willawortina Formation. Leeson (1967) correlated this unit with the Avondale Clay while Coats (1973) mapped it as part of an undifferentiated Tertiary-Quaternary sequence. Flora in the lower part of this formation indicates an early to middle Miocene age.

The Nambo Formation is generally poorly outcropping and consists of fine grained immature muddy sediments. Green and grey clays and sandy clays are prominent and occasionally contain dark grey clay interbeds. The clays sometimes have a mottled appearance and often contain gypsum nodules at the surface. These features are typical of the weathering profile developed in semi-arid and arid environments. Cross-bedding is sometimes observable in calcareous quartzose sandstones, pebbly sandstones and silty sandstones but bedding is usually indistinct. The sandstone units may be patchily ferruginized with adjacent zones being pallid due to leaching. Dolomitic limestones and sandy limestone also occur in this sequence and sometimes have a black manganese oxide staining. The Nambo Formation was deposited in a low energy fluvial and lacustrine environment, possibly partly estuarine or lagoonal.

WILLAWORTINA FORMATION

The Willawortina Formation (Callen 1974) conformably overlies the Nambo Formation and is 140 metres thick. Leeson (1967) mapped this unit as Telford Gravel while on the Copley 1:250 000 geological map sheet (Coats 1973) the sequence was assigned to an undifferentiated Tertiary-Quaternary unit. The base of the Willawortina Formation is taken as the lowest conglomerate unit. Conglomerates are prominent in this sequence particularly in the upper part where they occur as thick unconsolidated gravel bands. Clasts are mainly rounded quartzites averaging about 10 cm in diameter but silcrete and limestone clasts also occur. Poorly sorted and indistinctly bedded sands and sandy clays are interbedded with conglomerates in the lower part. The poorly sorted nature of this sequence and the presence of numerous channels and cross-bedding suggests deposition probably occurred in an alluvial fan environment. Clasts of

Figure 7. Structural Elements of the Prism Hill Area



Cambrian and Precambrian rock were derived from erosion due to uplift in the Flinders Ranges. The Willawortina Formation caps the tablelands to the north and dips with the Tertiary sequence east of the main road (Plate 8a). The conformable relationship with Nambo Formation suggests a middle Miocene age or younger. The Willawortina Formation may be overlain by the Millyera Formation (Callen 1976).

QUATERNARY

LIMESTONE CONGLOMERATE

A much younger conglomerate composed dominantly of limestone clasts caps the tablelands to the south (Plate 8b). This conglomerate unconformably overlies the Tertiary and Cambrian units and occurs lower in the topography than the tablelands capped by the Willawortina Formation to the north. This conglomerate forms a gently dipping surface that cross-cuts the steeply dipping Tertiary sequence east of the main road and is considered to be of Quaternary age.

Recent sediments consist of fine-grained alluvium with some coarser gravels derived from erosion of the unconsolidated conglomerates. Aeolian sandstones have accumulated against the side of Prism Hill but are not prominent elsewhere.

STRUCTURE

The interpretation of the structure in the Prism Hill area is based on the cross-sections presented in Enclosure 4. It was necessary to exaggerate the topography in order to display clearly the thin Tertiary sequences. The dips have not been exaggerated as should have been done normally but this is considered to be the best way of representing the data. The location of these sections is shown in Enclosure 2.

Salient structural elements of the Prism Hill area are shown in Figure 7. The regional dip is to the east with a dominant strike trend to the northeast. This pattern is complicated in the west by folding which parallels a major fault and in the east by the development of a large monocline. The fold-fault structure has a general northeast trend but swings around towards the ranges to parallel the north-northwest trend of the Arrowie Fault. The Arrowie Fault separates Middle and Late Cambrian sediments in the Prism Hill area from Early Cambrian and Late Precambrian units in the Flinders Ranges indicating major vertical displacement. This fault is composed of slices of Early Cambrian and Late Precambrian sediments that are separated by thrusts that dip at 50° to 75°

to the west (Coats 1973). These are probably Delamerian lineaments but the presence of alluvial fan conglomerates (composed mainly of limestone clasts) marginal to the ranges suggests rejuvenation in the Cainozoic. Thick conglomerates occur in the Willawortina Formation but imbrication of clasts at several outcrops indicates that the current of deposition flowed from the north.

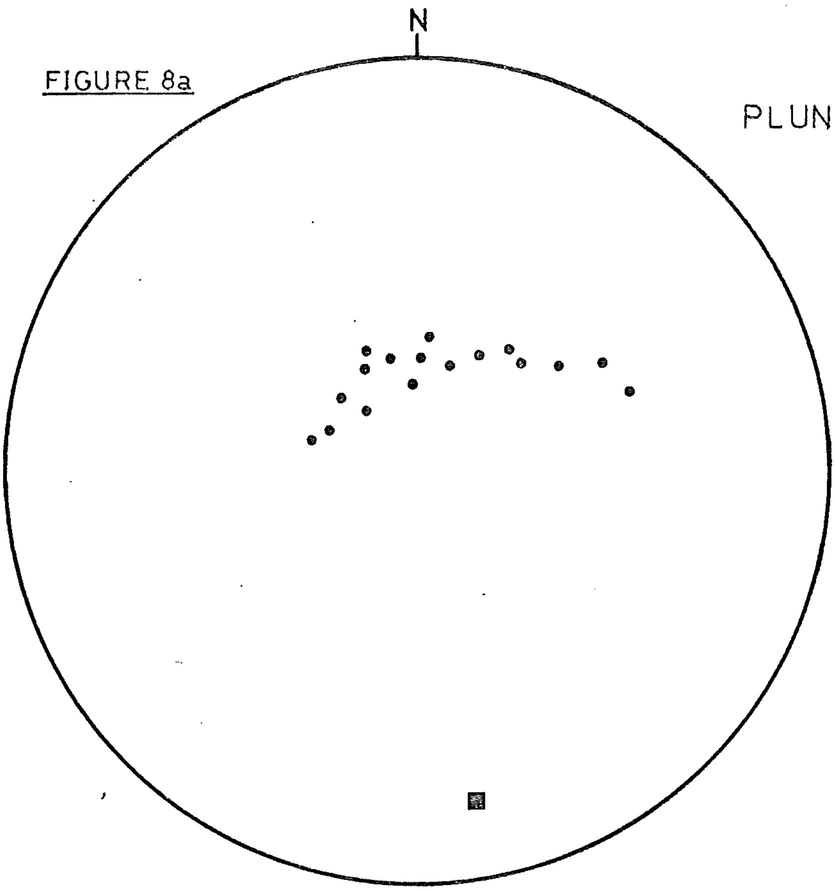
Folding in the east of the area has affected units as young as the Willawortina Formation, indicating a post-Miocene age of development (Plate 8c). The form of the folding at location A (Enclosure 2) can be seen from a stereonet plot of poles to bedding. This is shown in Figure 8a and indicates a southward plunging monocline. A reconstruction of the fold is presented in Figure 8b. This structure broadens and becomes more open towards the south which is higher in the stratigraphy (see Enclosure 4). Folding is probably related to tensional basement faulting with the eastern block up and possibly tilted. The fold axis is itself warped from 170° in the north to 190° in the south. This warping may be related to movement on the Arrowie Fault.

The Tertiary on the eastern side of this structure has a similar dip to the Cambrian but to the west there is a difference in dip of about 20°. To the west the fold axis of folds developed in the Tertiary units will therefore be west of their counterparts developed in the Cambrian units. This can be seen from the cross-section C to C" in Enclosure 4. Folding is indicated in the Tertiary north of the field area (Coats 1973) and is possibly a continuation of this structure.

The close association of folding and faulting in the west of the area suggests that development was probably related. Faulting has occurred along the anticlinal hinge and is warped with it close to the ranges. This change in trend direction towards the ranges is probably related to movement on the Arrowie fault.

Dark foetid limestones typical of those in the Moodlatana Formation occur to the west of the fault and indicate that this side is downthrown by approximately 150 metres. The fault is normal and dips at about 80° - 85° towards the west. A conglomerate with no limestone clasts outcrops adjacent to the Wirrealpa Limestone along the faults and suggests movement since the deposition of this pre-silcrete (Plate 8d). Sediments of the Nambo Formation appear to have been slightly affected by the faulting. Displacement at this time may have been due to rejuvenation of an older lineament.

FIGURE 8a



FOLD AXIS
PLUNGING 17° → 170°

FIGURE 8b

RECONSTRUCTED
FOLD STYLE

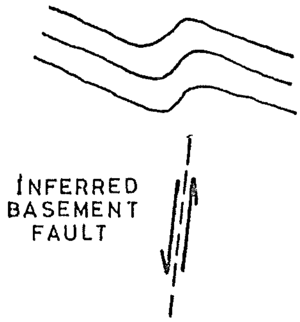
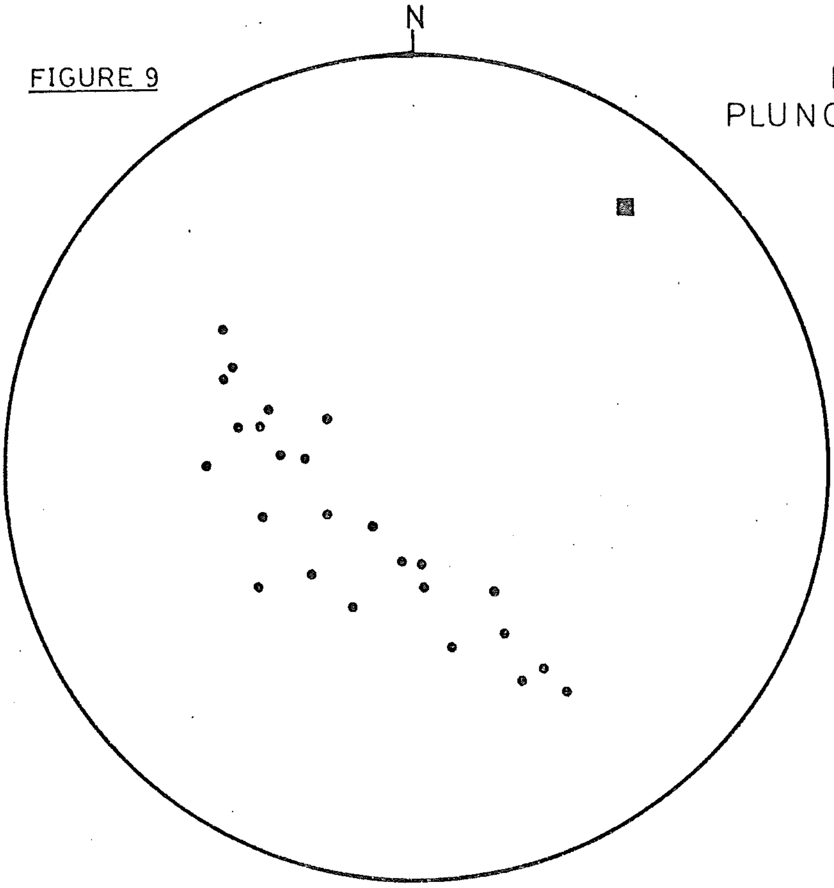


FIGURE 9



FOLD AXES
PLUNGING 20° → 45°

Folding, associated with this faulting at location B, is represented on a stereonet plot of poles to bedding in Figure 9. Folds are plunging at 20° towards the northeast and there is some interference associated with the monoclinal strucutre in the north. Approximately 1300 metres east of the fault silcrete is dipping at 45° east while west of the fault it is dipping at about 15° to the west. This indicates that major folding has occurred post the development of the silcrete unit. Folding of the Cambrian units has therefore also occurred and is probably related to movement on the fault. However some mesoscopic folding along the fault is quite tight and not typical of that developed through fault drape.

On the eastern side of this fold the difference in dip between the Cambrian and Tertiary units is 20° - 25° while further east, adjacent to the main road they show an almost disconformable contact. The difference in dip to the west of the fault is 55° - 60°. Rotation of the silcrete surfaces back to the horizontal indicates an initial variation in the dip of the Cambrian units. Therefore, although much of the deformation can be attributed to tectonic activity in the Tertiary a major easterly dipping structure was present before development of the silcrete.

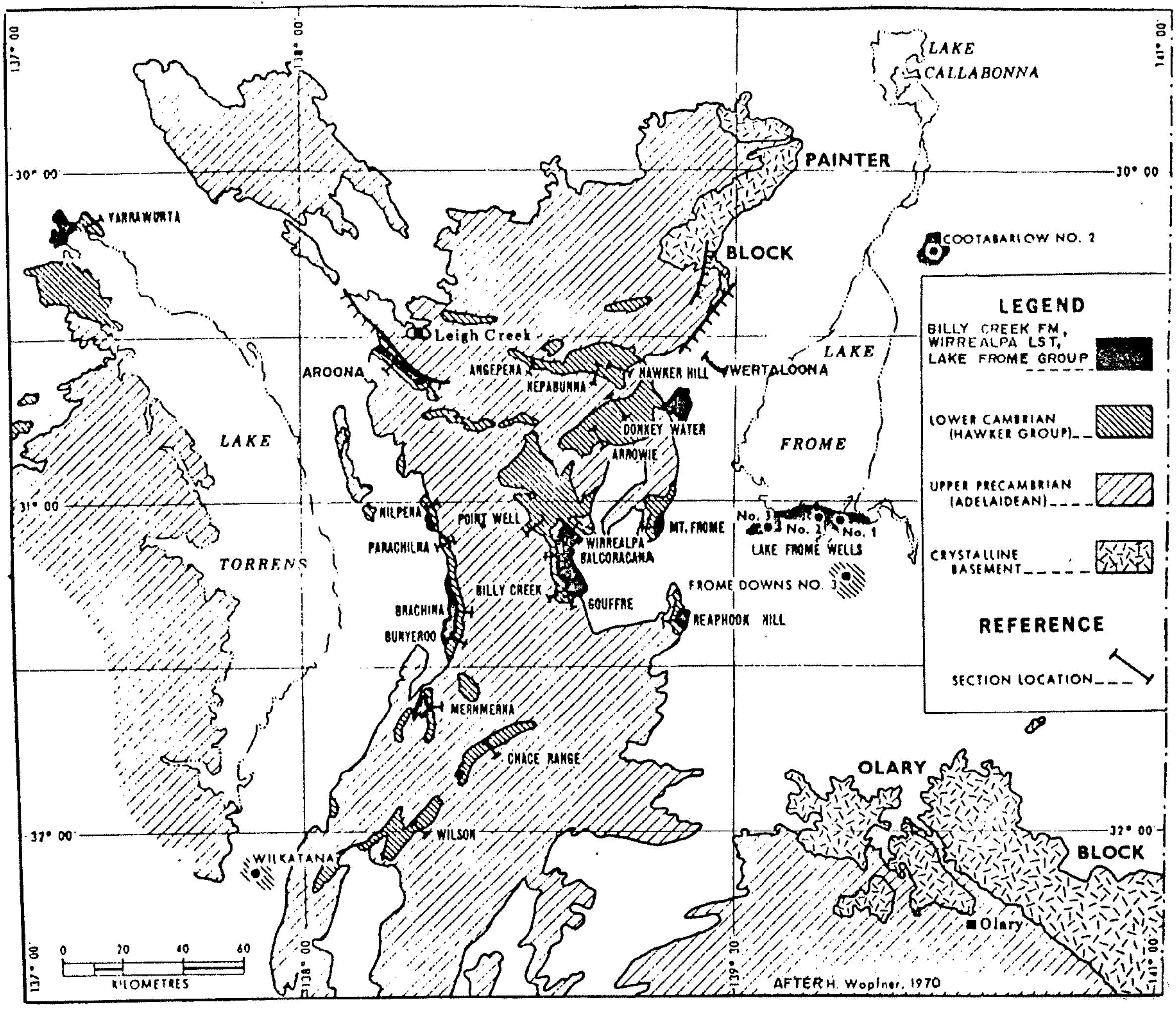
PALAEOGEOGRAPHY

The distribution of Precambrian and Cambrian rocks in the Lake Frome - Lake Torrens region is shown in Figure 10. Middle and Upper Cambrian sediments outcrop on the margins of the Flinders Ranges at Wertaloona, Mount Frome, Reaphook Hill, Wirrealpa, Mernmera, Brachina and Aroona and have been identified in the sub-surface to the east of the Frome Embayment.

The palaeogeography of the Lower Cambrian Hawker Group has been interpreted by Wopfner (1970) from the isopach map shown in Figure 11. He concluded that rapid subsidence occurred in a northeast-southwest trending trough in the Arrowie area and named this Early Cambrian basin the Arrowie Basin. The Arrowie Basin is flanked to the west by the stable Stuart Shelf while on the Curnamona Shelf to the east less stable conditions existed with the deposition of a clastic-carbonate sequence. Wopfner considers the main source of clastic sediment was the Olary Block with minor input from the Mount Painter Block.

Figure 12 shows the isopach map for the Billy Creek Formation (Moore 1979). Major changes in the type of sedimentation and nature of the basin are associated with the development of this

Figure 10. Cambrian Sediments Lake Torrens-Lake Frome area.



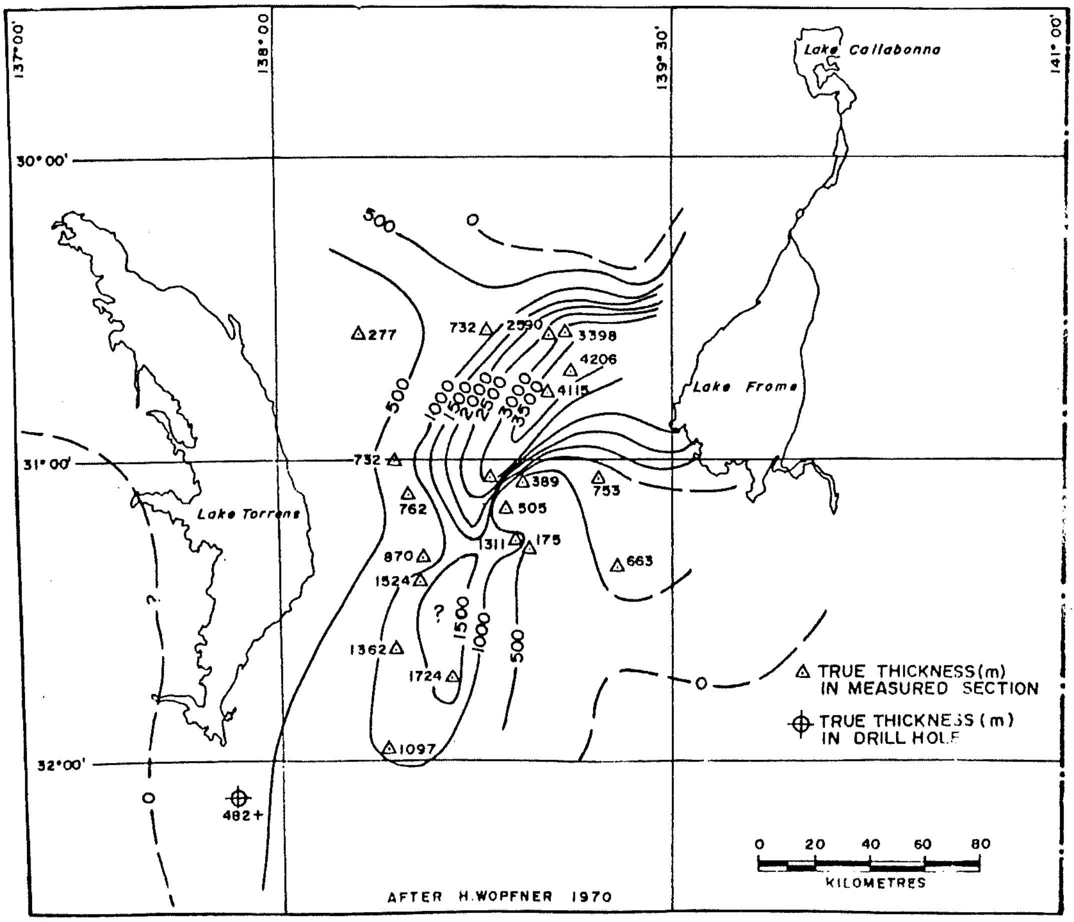
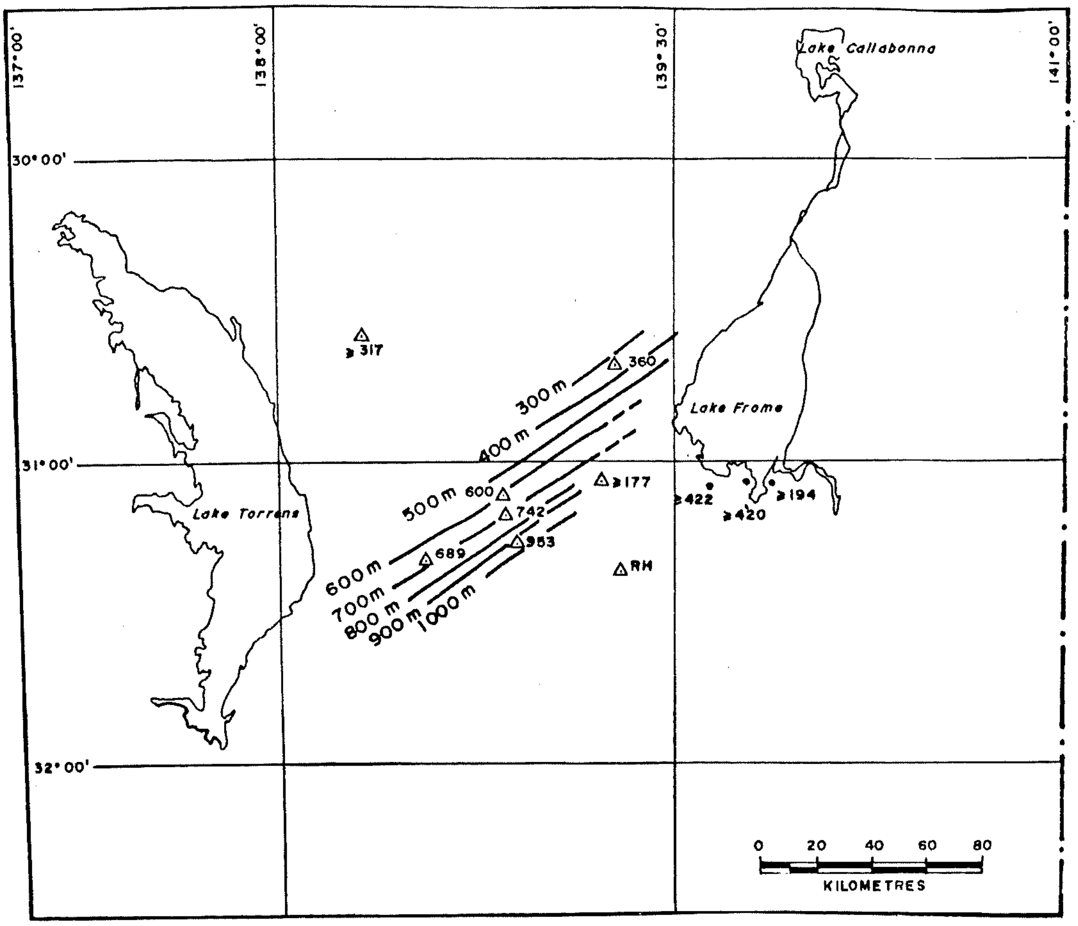


Figure 11. Isopach Map for the Hawker Group.

Figure 13. Isopach Map for Balcoracana and Moodlatana Formations. (After Stock 1974).



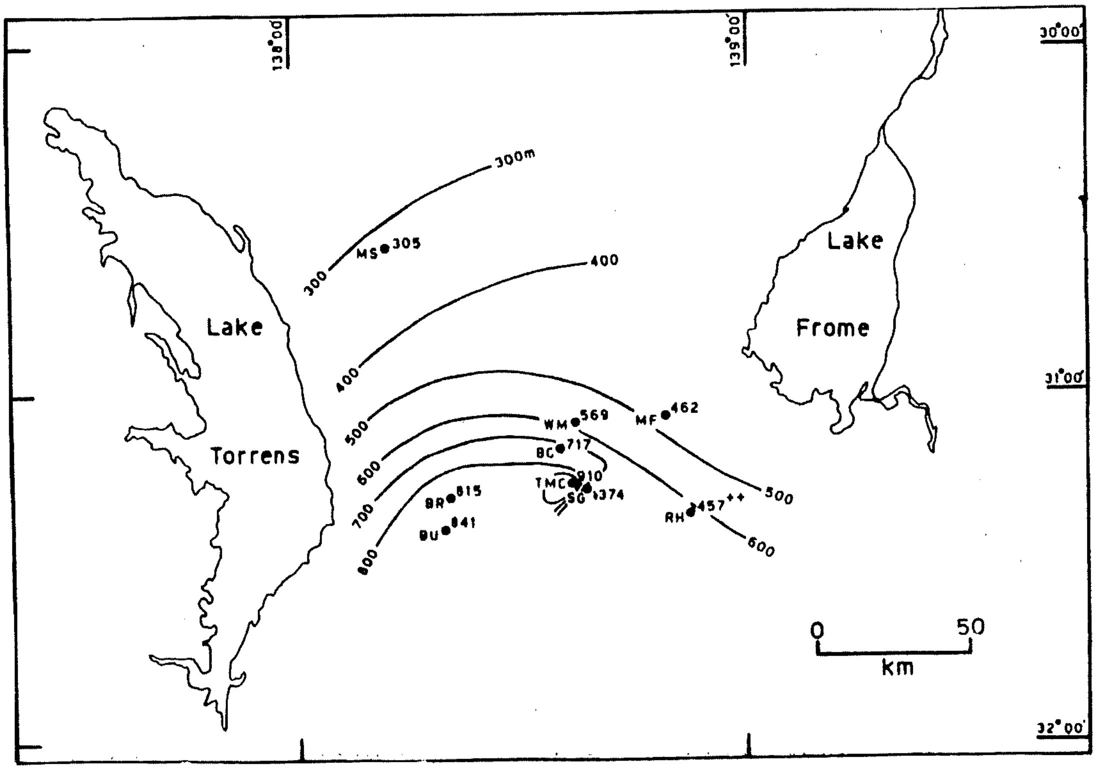


Figure 12. Isopach Map for the Billy Creek Formation. (After Moore 1979).

redbed sequence. Moore suggests a source to the south-east (Olary Block) with a sudden supply of clastic material causing a shift in the depocentre to the south. Therefore despite this thickening to the south, facies in the Arrowie area indicate that this was the deepest part of the basin.

The transgression recorded by the Wirrealpa Limestone in the Wirrealpa area was from the north with lagoonal facies becoming more prominent to the south (Youngs 1977). Oolitic limestones and calcareous siltstones are the dominant lithofacies in the Wertaloona area and indicate deposition in a more marine environment. Youngs (1977) proposes a connection with the Warburton Basin to the north. The Wirrealpa Limestone was intersected by Lake Frome Wells 1 and 2. Two cores were cut in Lake Frome 1 and one in Lake Frome 2 giving a total thickness of 50 feet and representing about 15% of the Wirrealpa Limestone. The cores consist of mottled green and grey calcareous silts and shales with anhydrite nodules, indicating deposition in an evaporitic, probably upper intertidal environment. Although the interval sampled was only small the cores are widely spaces and indicate that marine influence is not as prominent as in the Wertaloona area with shallowing occuring towards the east.

An isopach map for the Moodlatana and Balcoracana Formations is presented in Figure 13 from Stock (1974). Data is sparse but indicates a thickening towards the south. Stock proposes that the source for these clastics was the Mount Painter Block to the north and Gawler Craton to the west.

Stock's data for thicknesses of these two units in the Delhi-Santos Pty. Ltd. Lake Frome Group Wells 1, 2 and 3 is based on an interpretation by Daily (1969). An examination of the cores and composite logs leads the present writer to believe that an alternative interpretation is possible. In the type section the Moodlatana Formation is about 400 metres thick and consists of a lower and upper sand unit separated by finer silts and shales and minor carbonates. The Cambrian sequence above the Wirrealpa Limestone in the Lake Frome 2 is 420 metres thick and consists of a lower sandy unit overlain by finer clastics and carbonates and a thick upper sandstone unit. These similarities led Daily to classify the sequence as Moodlatana Formation.

In the Wertaloona area the Moodlatana Formation is 200 metres thick and consists of a lower sandy unit about 70 metres thick which is overlain by silts and shales with some interbedded sandstones and minor carbonates. No major upper sandstone unit is present. The lower sandstone unit in Lake Frome 2 is approximately 75 metres thick while the upper sandstone unit is greater than 120 metres thick. This upper sandstone unit could be interpreted as Pantapinna Sandstone giving a combined thickness of the Moodlatana Formation and Balcoracana Formation of 300 metres, compared with 370 metres in the Wertaloona area. Laminated sandstones in core 4 of Lake Frome 3 which were interpreted as part of the Balcoracana Formation appear similar to sandstones of the Moodlatana Formation and may belong to that unit. If these units are thinner to the east it would suggest more rapid subsidence in the Wirrealpa area, similar to the situation observed by Moore (1979) for the Billy Creek Formation. Core material is sparse but a detailed study of cuttings and logs (with which the writer is presently unfamiliar) may be more revealing. It is not possible to be certain which interpretation is correct at present and the answer may not be known until further exploration is carried out in the basin.

In the Pantapinna Sandstone the interbedded sandstone siltstone facies, which indicates deposition in a lower intertidal environment, is more prominent in the Wertaloona area than in the Wirrealpa area. Deposition in the Wirrealpa area occurred in a higher energy more marine environment.

At present it is not possible to make conclusions about the nature of the basin during deposition of the Cambrian units. Information is lacking and there is some conflict of ideas. Wopfner (1970) and Stock (1974) propose that the Mount Painter Block was a source area during the Cambrian while Youngs (1977) and Moore (1979) suggest that no exposed basement existed to the north. The Olary Block to the south, Willyama Block to the east and Gawler Craton to the west have also been suggested as possible source areas (Wopfner 1970, Stock 1974, Youngs 1977 and Moore 1979). Connections with Warburton Basin to the north (Youngs 1977), the Mount Arrowsmith area to the east (Wopfner 1970) and the Stansbury Basin to the south (Daily 1956) have been proposed. Rapid subsidence occurred in the Wirrealpa area but Moore (1979) indicates that this is not the deepest part of the basin. The palaeogeography of the basin is therefore unresolved but further exploration particularly in the subsurface should be more revealing.

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PHOTOGRAPHIC PLATES

PLATE 1

a. Cross-bedded oolitic limestone, Wirrealpa Limestone.

b. Thin section of fossiliferous, oncolitic and oolitic limestone, Wirrealpa Limestone.

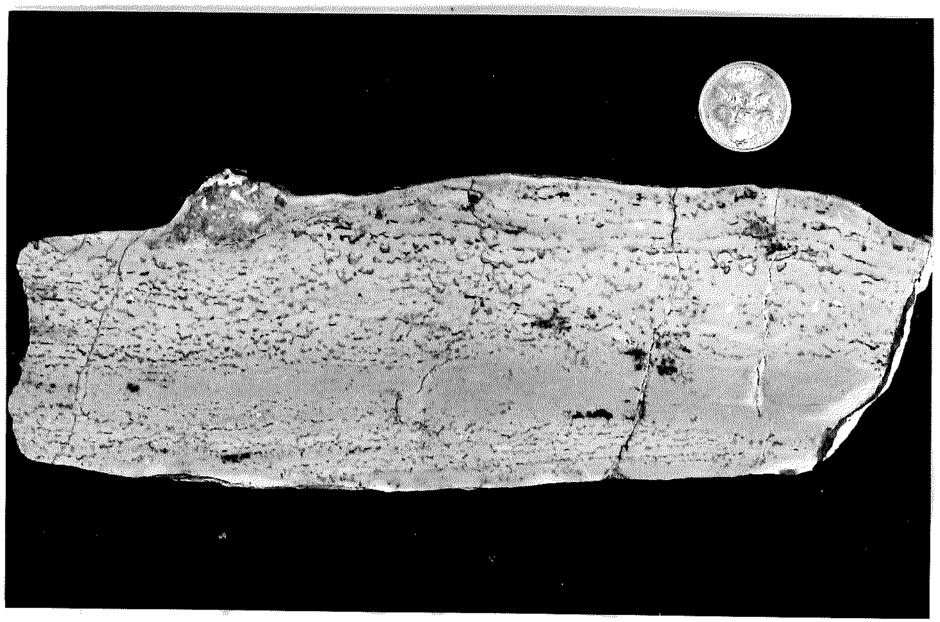
c. Fenestral porosity with possible calcite nodules, pseudomorphous after anhydrite. Passage into the Moodlatana Formation.

d. Current ripples in calcareous siltstone, passage into the Moodlatana Formation.

a

b

c



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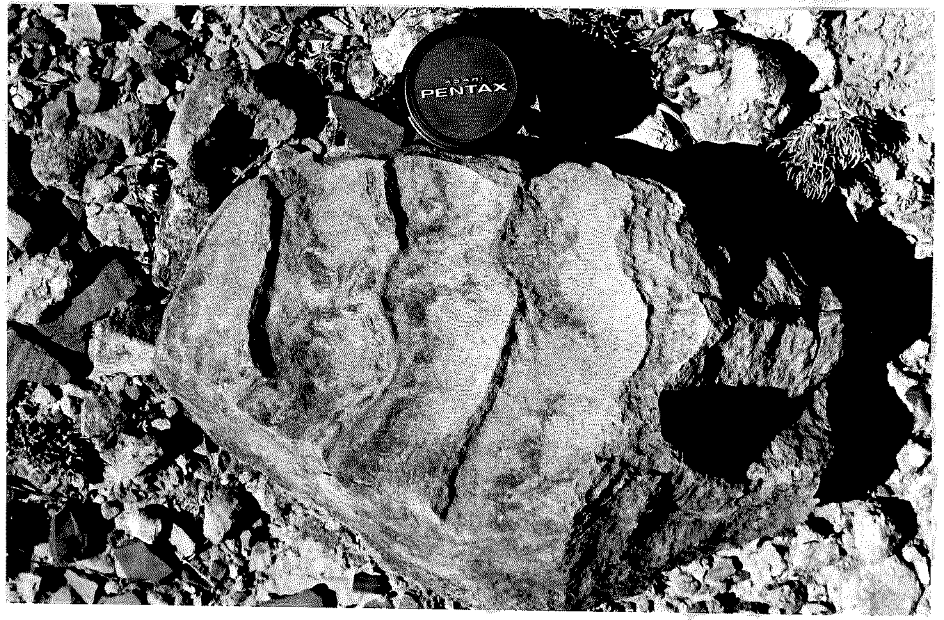


PLATE 2

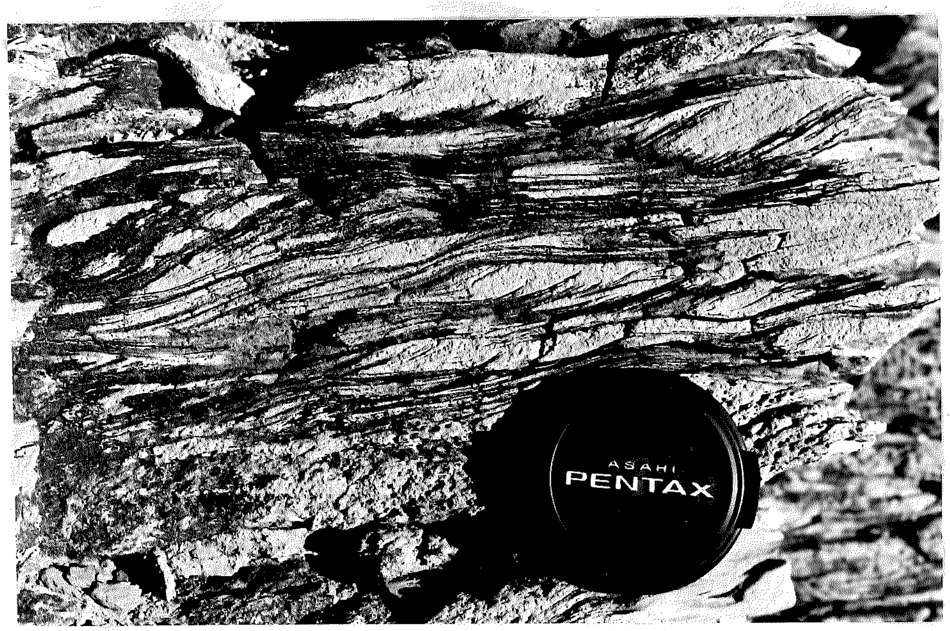
a. Ripple cross-laminated red siltstone, Moodlatana Formation.

b. Limestone with wavy stromatolitic layering, Balcoracana Formation.

c. Trilobite tracks in red siltstones, Balcoracana Formation.

d. Desiccation cracks in silty limestone, Balcoracana Formation.

a



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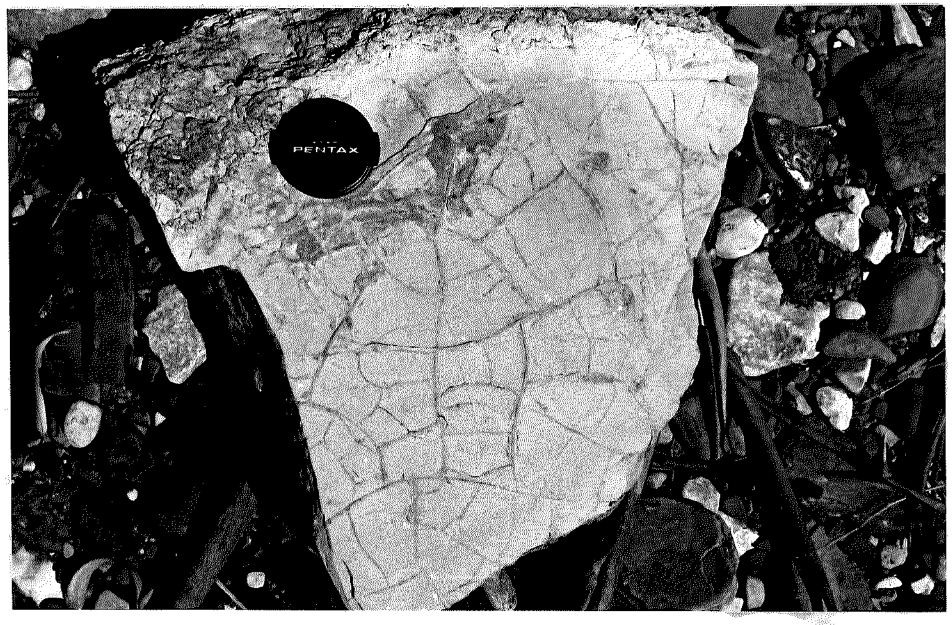

PLATE 3

a. Infraformational limestone conglomerate, Balcoracana Formation.

b. Dolostone with halite cast, Balcoracana Formation.

c. Interbedded sandstones and siltstones showing flaser and wavy bedding, Pantapinna Sandstone.

d. Planolites burrows in interbedded siltstone sandstone facies, Pantapinna Sandstone.

a

b

c

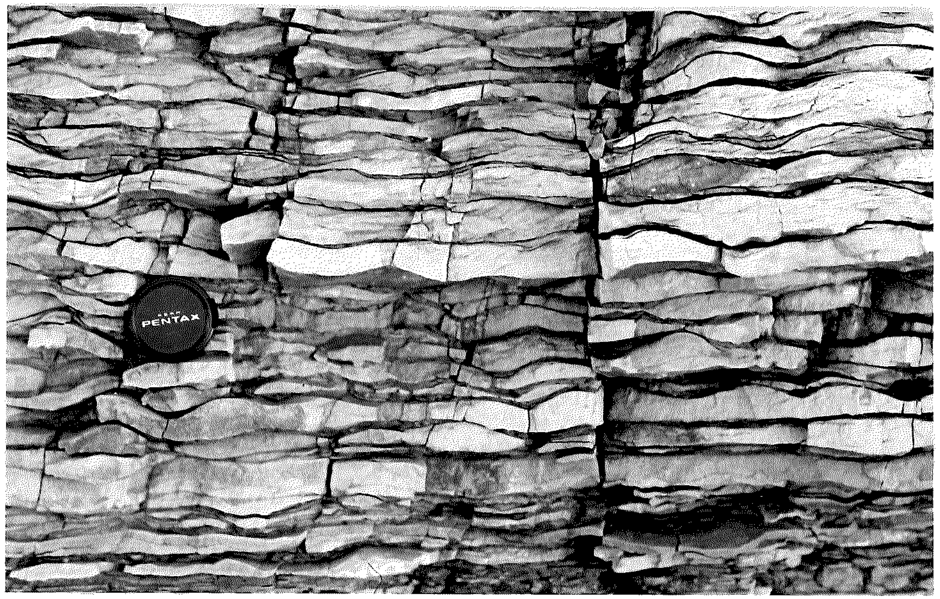

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PLATE 4

a. Bioturbation, mainly trilobite burrows and tracks and load casts. Sandstone and siltstone facies, Pantapinna Sandstone.

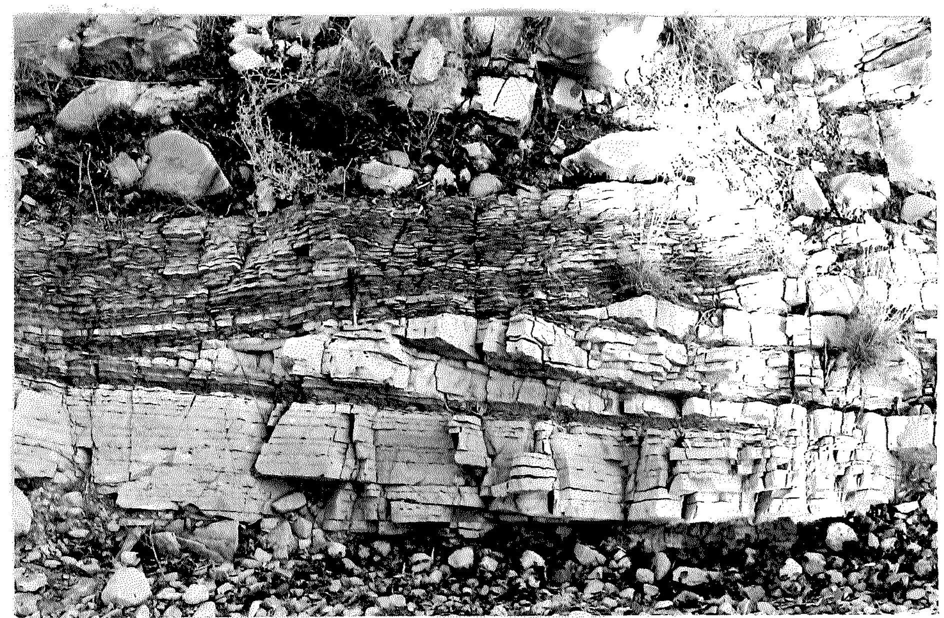
c. Current lineated plane-laminated sandstone, Pantapinna Sandstone.

b. Tidal channels developed in the sandstone siltstone facies of the basal Pantapinna Sandstone.

d. Planar cross-bedding with parallel erosional contacts, Pantapinna Sandstone.

a

b



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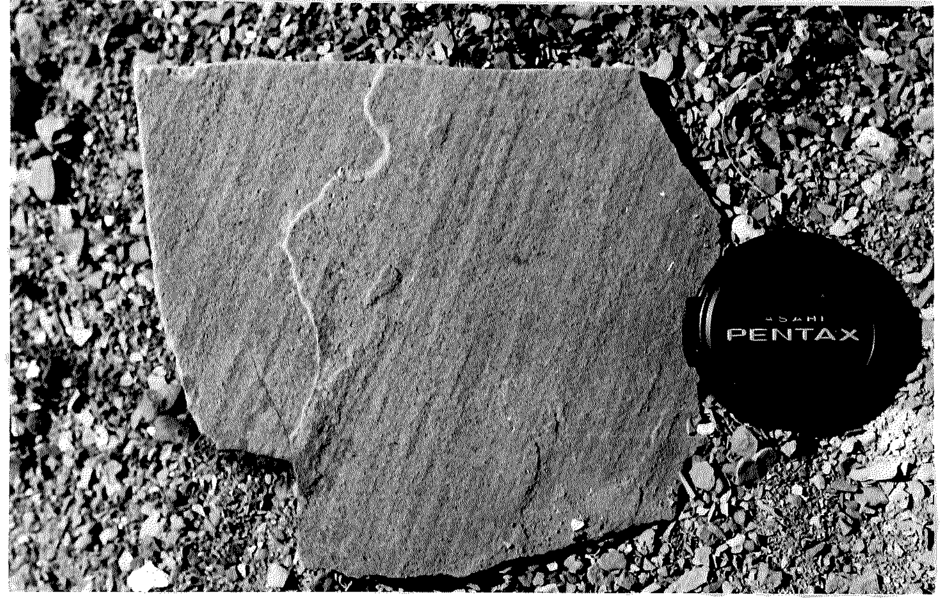

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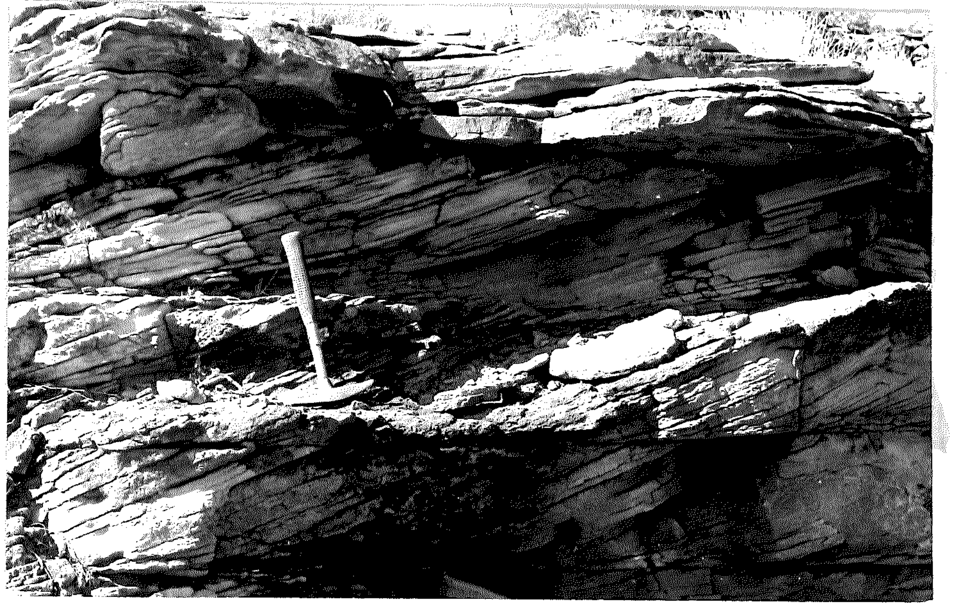


PLATE 5

a. Asymmetrical sinuous current ripples in fine sandstone of the Pantapinna Sandstone.

b. Straight crested asymmetrical current ripples, Pantapinna Sandstone.

c. Large scale sedimentary structure (>12 metres high) developed in the Pantapinna Sandstone.

d. Contact between the soft feldspathic sandstones of the Pantapinna Sandstone and more resistant quartzose sandstones of the Grindstone Range Sandstone.

a

b

c

d

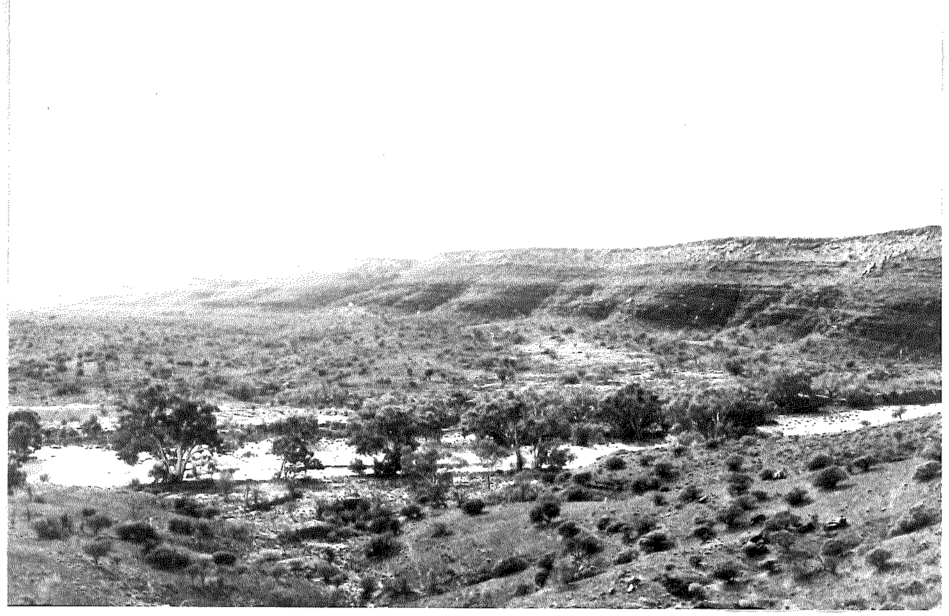


PLATE 6

a. Syn-depositional slumping down planar cross-beds, basal Grindstone Range Sandstone.

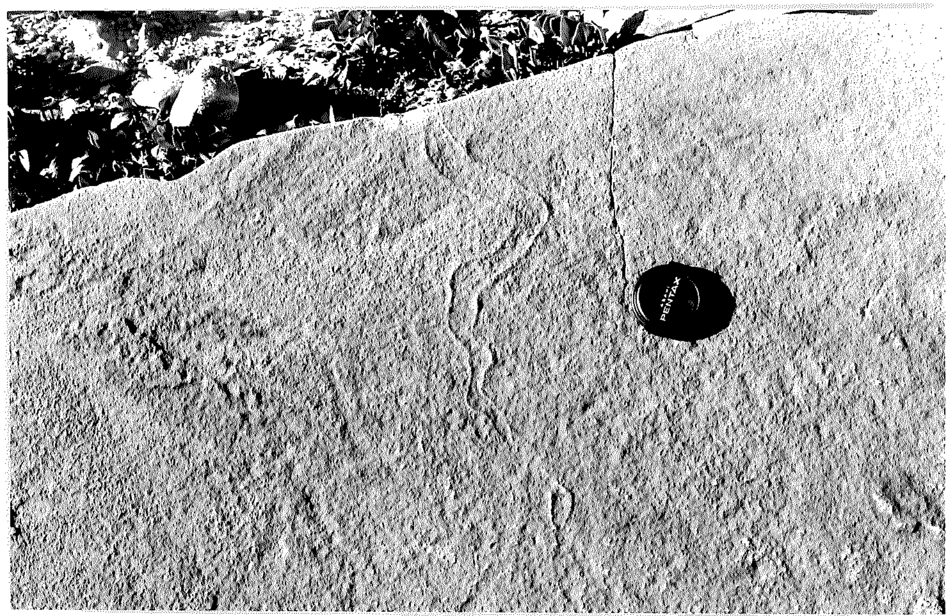
b. Burrow from cross-bedded sandstones in the basal Grindstone Range Sandstone.

c. Desiccation cracks on sandstone surface with trilobite trace fossils, basal Grindstone Range Sandstone.

d. Interference ripples formed through the combined action of currents and waves, upper Grindstone Range Sandstone.

a

b



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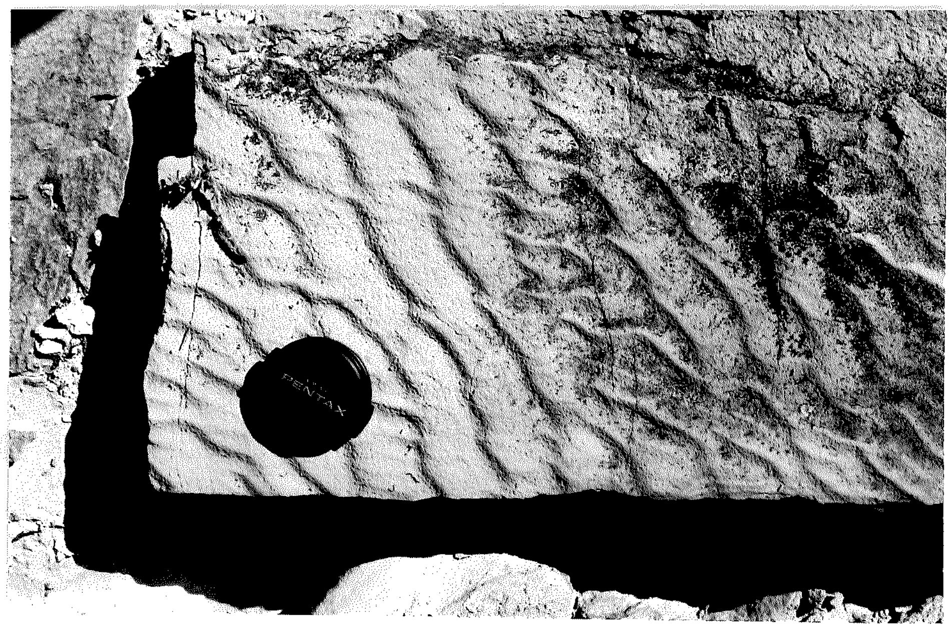


PLATE 7

a. Ladder ripples developed by the combined effects of current and waves, upper Grindstone Range Sandstone.

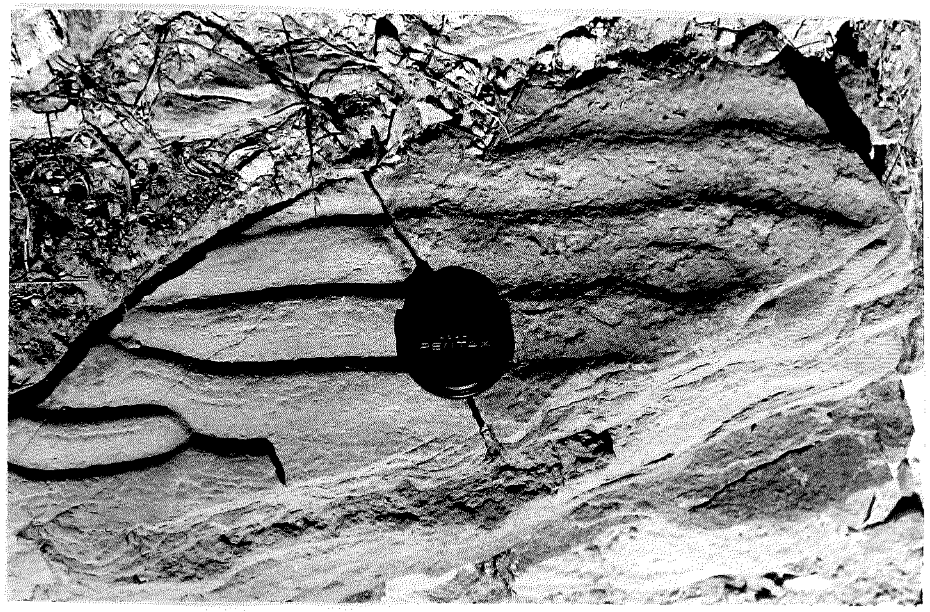
b. Current ripples modified by wave effects to give rounded crests, upper Grindstone Range Sandstone.

c. Columnar silcrete.

d. Botryoidal silcrete.

a

b



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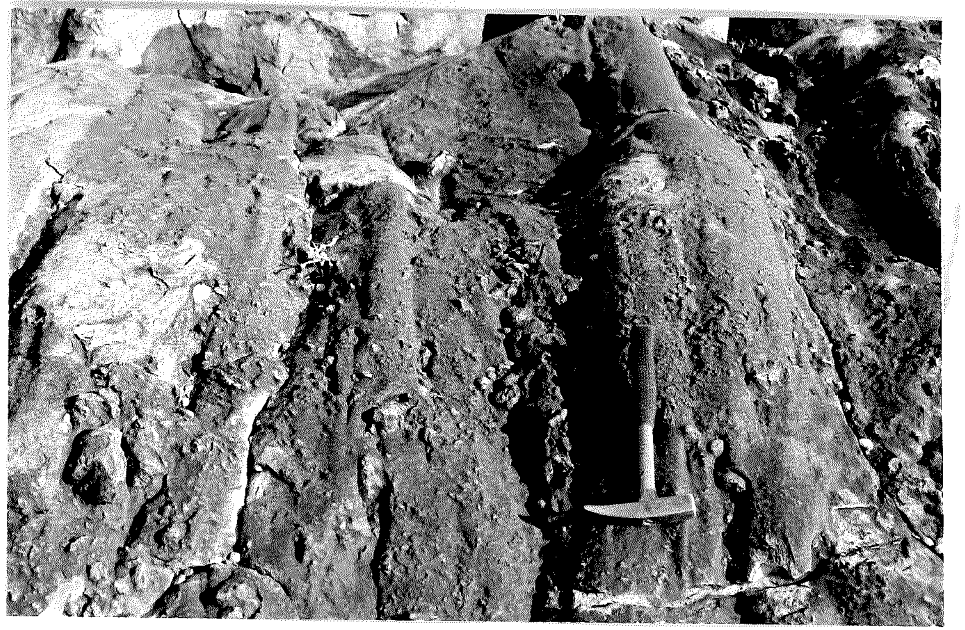


PLATE 8

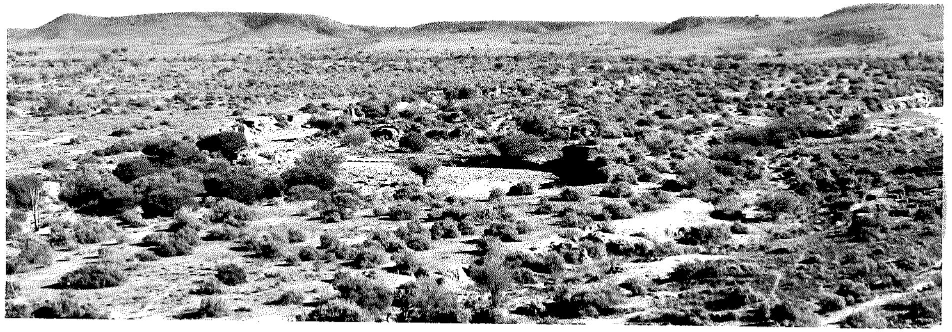
a. Tablelands capped by conglomerates of the Williwortina Formation.

b. Nambo Formation unconformably overlain by thin limestone conglomerates that cap the tablelands.

c. Steeply dipping gravels of the Willawortina Formation.

d. Fault contact between Wirrealpa Limestone and pre-silcrete unit (right).

a



b

c

d

APPENDIX I

Explanation

Hand specimens and thin sections are presented in trays accompanying this thesis and are described in this section. Samples submitted bear the accession number 770 and are stored in the Geology Department of the University of Adelaide. Samples are grouped into stratigraphic units as discussed in the text. Carbonate thin sections were stained to differentiate calcite, ferroan calcite, dolomite and ferroan dolomite. The method of staining is based on Dickson (1965,1966) and outlined in Table A. These are generally strongly recrystallized and depositional textures are often poorly preserved. Where these textures can be observed the classification of Dunham (1964) is used. Mineral compositions of the sandstones in the Moodlatana Formation, Pantapinna Sandstone and Grindstone Range Sandstone are plotted in Figure A and were classified using Folk (1974) (Figure B). Locations of samples are shown in Enclosure 3.

BILLY CREEK FORMATION

(770-5) Hand specimen: Fine red calcareous siltstone with wavy cryptalgal laminae.

Thin section: A layering is present and consists of an alternation of silt sized grains, composed mainly of quartz, with a clay matrix and calcareous limonitic clays. Coarser crystallized calcite infills veining and is stained blue (ferroan calcite

WIRREALPA LIMESTONE

(770-7) Hand specimen: Blue grey mottled limestone with yellow brown ferruginous patches.

Thin section: Blue grey patches consist of finely crystalline sparry calcite (ferroan stained pale purple) with some coarser crystals and minor silt sized quartz grains. Yellow brown patches are composed of limonitic calcareous clays with up to 40% silt sized quartz grains and minor feldspar.

(770-10) Hand specimen: Yellow silty limestone with a fenestral fabric. Pores infilled by calcite.

Thin section: Coarsely crystalline sparry calcite (ferroan, stained blue in the centre of the vugs grading to pale pink at the margins) infilling vugs 15%. Matrix consists of a fine graine limonitic sparite.

(770-15) Hand specimen: Fine-grained yellow brown oolitic limestone.

Thin section: Ooids are recrystallized to sparry calcite and are preserved as a limonitic staining. Ooids are well sorted and have an average size of .15mm. Fossil fragments have also been recrystallized and consist of coarsely crystalline ferroan calcite (stained blue). Clastics (10%) consist of rounded very fine quartz grains that are more concentrated in some layers.

(770-24) Hand specimen: Fossiliferous and intraclastic oolitic limestone.

Thin sections: Ooids are completely recrystallized by coarse ferroan calcite (stained pale purple) but can be recognized from the limonitic staining. Ooids are moderately sorted and have an average grainsize of .2mm. The intraclasts are composed of finely crystalline sparry calcite with silt sized quartz grains (15%). Fossil fragments are also recrystallized and make up about 5% of the rock.

(770-28) Hand specimen: Recrystallized packstone with coarse poorly sorted ooids.

Thin sections: The section has been stained purple and consists of ferroan calcite. Ooids are poorly sorted ranging

TABLE A

CARBONATE STAINING METHOD (After Dickson, 1965)

	Procedure	Time	Carbonate	Result
STAGE I	Etching in 1.5% HCl	10-15 sec	Calcite Ferroan calcite	Considerable etch
			Dolomite Ferroan dolomite	Negligible etch
STAGE II	Staining* 0.2g A.R.S. per 100cc in 1.5% HCl 2.0g P.F. per 100 cc in 1.5% HCl Mixed in ratio A.R.S.:P.F. = 3:2	30-45 sec	Calcite Ferroan calcite	Pink red Pale mauve - blue - purple (with increasing Fe^{2+})
			Dolomite Ferroan dolomite	No colour Pale - deep turquoise
STAGE III	Staining 0.2g A.R.S. per 100 cc in 1.5% HCl	10-15 sec	Calcite Ferroan calcite	Pale pink - red
			Dolomite Ferroan dolomite	No colour

*A.R.S. = Alizarin red S, P.F. = Potassium Ferricyanide from 1mm to .2mm. Although recrystallized they are preserved by limonite staining and are radial with some concentric rings mainly at the margins. Oval shaped oncolites are up to 1.5mm in diameter and often have fossil fragments as nuclei. Some of the larger ooids are composite consisting of several smaller ooids. The rock is ooid supported but the original micritic mud has been recrystallized to sparry calcite.

(770-29) Hand specimen: Oncolitic and fossilferous oolitic limestone.

Thin section: Clastics constitute 10% of this rock sample and consist of silt sized rounded quartz grains with minor mica and feldspar. The carbonate stained blue and is slightly ferroan calcite. The rock is grain supported with ooids up to 2 mm in diameter but average .7mm. They have a radial or concentric pattern defined by a limonitic staining which may also infill veining. Recrystallized fossil fragments are coarsely crystalline and make up 10% of the rock. These often act as nuclei for oncolites. Some of the larger ooids are composite.

(770-WG) Hand specimen: Ooid grainstone with small scale cross-laminations.

Thin section: Poor to moderately sorted ooids with an average size of .08mm. These have been recrystallized but are recognised from the limonitic staining. Calcite is ferroan (stained blue to mauve) and is coarser in vugs. Lamination is defined by the ooid size.

MOODLATANA FORMATION

(770-32) Hand specimen: Pale pink cryptalgal laminated calcareous silt. (Passage into the Moodlatana Formation).

Thin section: Finely crystalline sparry calcite (50%) which is slightly ferroan (stained blue). Some coarser recrystallized calcite infills small vugs. Clastics (40%) consist of silt sized sub-rounded quartz grains with overgrowths, and minor muscovite and feldspar. Clastics are concentrated in thin layers which are separated by micritic clay laminae. Remnant (limonitic) recrystallized ooids (10%) occur in clastic rich layers. Patchy limonitic staining.

(770-50) Hand specimen: Very fine grained pale pink micaceous feldspathic quartz sandstone.

Thin section: Quartz grains (70%) are rounded with an average diameter of .08mm. They show moderate sorting, undulose extinction and have an iron oxide coating. Feldspars have a similar grainsize to the quartz and both microcline (7%) and plagioclase (5%) are present. Fresh and altered grains are found. Rock fragments consist of fine-grained quartz, feldspar and less commonly mica. Micas (13%) mainly muscovite are platy and aligned with the laminae. These are concentrated in some layers. The matrix (5%) consists of limonitic clays. Detrital opaques are less than 1% and accessories include tourmaline and zircon.

(770-37) Hand specimen: Red purple calcareous quartz arenite.

Thin section: Quartz grains (55%) are sub-rounded and moderately sorted with an average size of .15mm. These often have an iron oxide coating on the grain boundaries and overgrowths. Rock fragments (15%) consist of rounded composite quartz and feldspar grains of similar size to the quartz grains. Both plagioclase (multiple twinning) and microcline(cross-hatch twinnin are present and constitute 10% of the sample. Coarse sparry calcite 15%) cements these clastics. Ooids (5%) are recrystallize but are recognisable as remnants defined by limonitic staining.

(770-46) Hand specimen: Pale pink fine grained feldspathic quartz sandstone.

Thin section: Quartz grains are the dominant component (70%) and have an average diameter of .13mm. They are moderately sorted and rounded. Overgrowths are common but the original grain boundary may be defined by a ferruginous coating. Quartz grains show undulose extinction and inclusions are common. Both alkali and plagioclase feldspar are present and form about 12% of the rock. These are rounded and of a similar size to the quartz grains. Fresh and altered grain are found. Rock fragments (10%) consist of aggregates of quartz feldspar and mica and are probably of an igneous origin. Muscovite (3%) occurs as platy grains that are sometimes altered. Biotite is less common and usually limonitic although some pleochroism is evident in some grains. Limonitic clays make up the matrix (5%).

(770-C) Hand specimen: Purple clacareous silt.

Thin section: Fine silt with a limonitic clay matrix. Silt sized grains mainly quartz with some mica and feldspar. Micas are parallel to the layering which is defined by grainsize differences.

BALCORACANA FORMATION

(770-D) Hand specimen: Laminated calcareous pale pink-purple shale to fine siltstones.

Thin section: Calcareous clays make up 60% of the sample. Coarser calcite (stained pale pink) occurs in veins. Silt sized grains (40%) consist mainly of quartz with some muscovite and limonitic biotite parallel to the lamination. Coarser grains are concentrated in some layers.

(770-BDS) Hand specimen: Pale red and yellow brown calcareous siltstone with a layering that may be algal.

Thin section: Mainly medium to fine silt sized quartz grains and some feldspar, with zircon and tourmaline as accessories. Micas (10%) mainly muscovite are concentrated in some layers. Coarse calcite (stained pale purple) occurs in veins and infilling vugs. The calcareous clay matrix (10%) is limonitic.

(770-BL) Hand specimen: Fine grained blue-grey limestone with an algal layering.

Thin section: Slightly ferroan calcite (stained pale purple) which is micritic but coarser calcite occurs in veins and as vug infills.

(770-66) Hand specimen: Calcareous grey-green silt.

Thin section: Poorly sorted mainly sitl sized quartz grains, some very fine and fine grains, with overgrowths. Feldspar and mica are less prominent. The matrix (20%) consists of grey-green clays with the colour probably due to the presence of Fe_3O_2.

PANTAPINNA SANDSTONE

(770-PL) Hand specimen: Strongly recrystallized limestone with coarse rhombohedral dolomite crystals and poorly preserved ooids.

Thin section: No colour to patchy pale pink after staining. Clastics (10%) consist mainly of fine sand sized sub-rounded quartz grains with some ove growth and undulose extinction. Plagioclase and microcline feldspars and minor muscovite are also present. Carbonates (90%) are generally finely crystalline dolomites but some calcite occurs. Some dolomite crystals are found. Interstitial spaces are limonitic sometimes strongly.

(770-72A, 72B, 71, P1 and P) The sandstones in the Pantapinna Sandstone are similar and these sections are described together. There is some variation in mineral composition and this is shown in Figure A.

Hand specimen:
P, 72A and 72B are pink fine grained flat-laminated micaceous feldspathic sandstone.
Sample P1 is similar but contains thin silty whisps and intraclasts. 71 - is also flat-laminated but is finer grained and has a green-grey colour.

Thin sections: Quartz is the most prominent component comprising 60% - 75% of the rock. These have a fine grainsize (average .16mm) and show moderate sorting. Overgrowths are common but where original grain boundaries can be observed the grains are sub-rounded. The original outline is sometimes defined by the presence of an iron oxide coating. Overgrowths show optical continuity with the grains and have slight to strongly undulose extinction. Inclusions are common. Feldspars form 10% - 20% of the sample and may be fresh or have a clouded appearance due to alteration. This suggests derivation from fresh rock (monocyclic) and through recycling (polycyclic). Both plagioclase and alkali feldspar (generally multiple twinned microcline) occur with alkali feldspar generally more common than plagioclase. Twinning may be accentuated by alteration. Fresh grains are rounded and of a similar size to the quartz grains. Altered grains are often limonitic. Rock fragments form up to 15% of the sample and consist of fine grained aggregates of quartz feldspar and less commonly micas. The feldspars and micas may be altered. Some fragments are almost exclusively composed of quartz. The rock fragments are probably derived from an igneous source but some sedimentary lithic clasts (siltstone) are present in 770-P1. Micas mainly muscovite constitute up to 10% of the rock and are concentrated in some layers. These are platy and aligned parallel to the layering. As with feldspars both altered and fresh micas are present. Biotites are commonly limonitic but show pleochroism if not heavily ferruginized (opaque). Chlorite is a minor component. Opaques are sometimes concentrated in bands with the micas but form less than 5% of the total rock. These are rounded sub-spherical grain, usually haematite, and have a smaller grainsize than the quartz grains. The matrix (>10%) is composed of clays which are often limonitic. Where these are not stained they are colourless and show birefringence and are probably haolinite. Accessories include tourmaline, zircon and apatite. Tourmaline grains are pleochroic (light green to dark green) and generally sub-elongate to sub-spherical rounded grains. Zircon grains show high relief and birefringence and are usually sub-spherical and rounded grains. Apatite grains are also sub-spherical and rounded.

GRINDSTONE RANGE SANDSTONE

The mineral compositions of the samples collected from the Grindstone Range Sandstone are presented in Figure A.

(770-S4) Hand specimen: Pale coloured, poorly sorted fine grained quartzite.

Thin section: Quartz is the main constitutent (95%) occurring as rounded grains that show poor sorting (.08 - .2). Overgrowths are common but original grain boundaries are sometimes marked by an iron oxide coating. Extinction is slightly to strongly undulose and overgrowths are in optical continuity. Inclusions are present in most grains. Feldspar (4%) and rock fragments (1%) are minor constituents. Accessories include tourmaline, zircon and detrital opaques. The sample is almost matrix free.
Samples 770-GM1, GM3, GB1 and GB2 are similar and will be discussed together.

Hand specimen: Pink fine to medium grained moderately to well-sorted quartzose sandstone.

Thin sections: These sandstones are more mature than those of the Pantapinna Sandstone with rounded quartz grains comprising 75% - 90% of the sample. The sandstones show moderate sorting

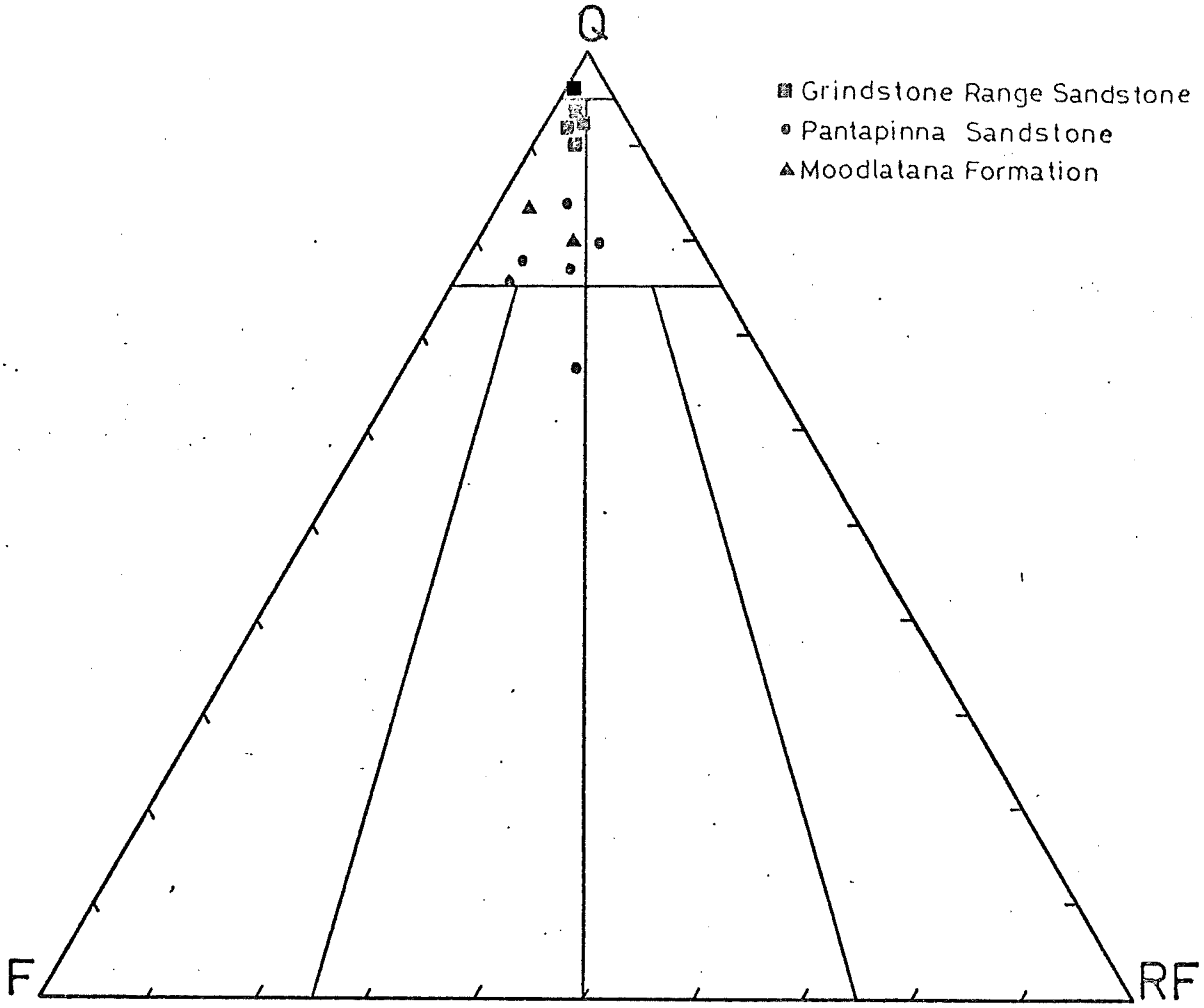


Figure A. Composition of sandstones in the Lake Frome Group.

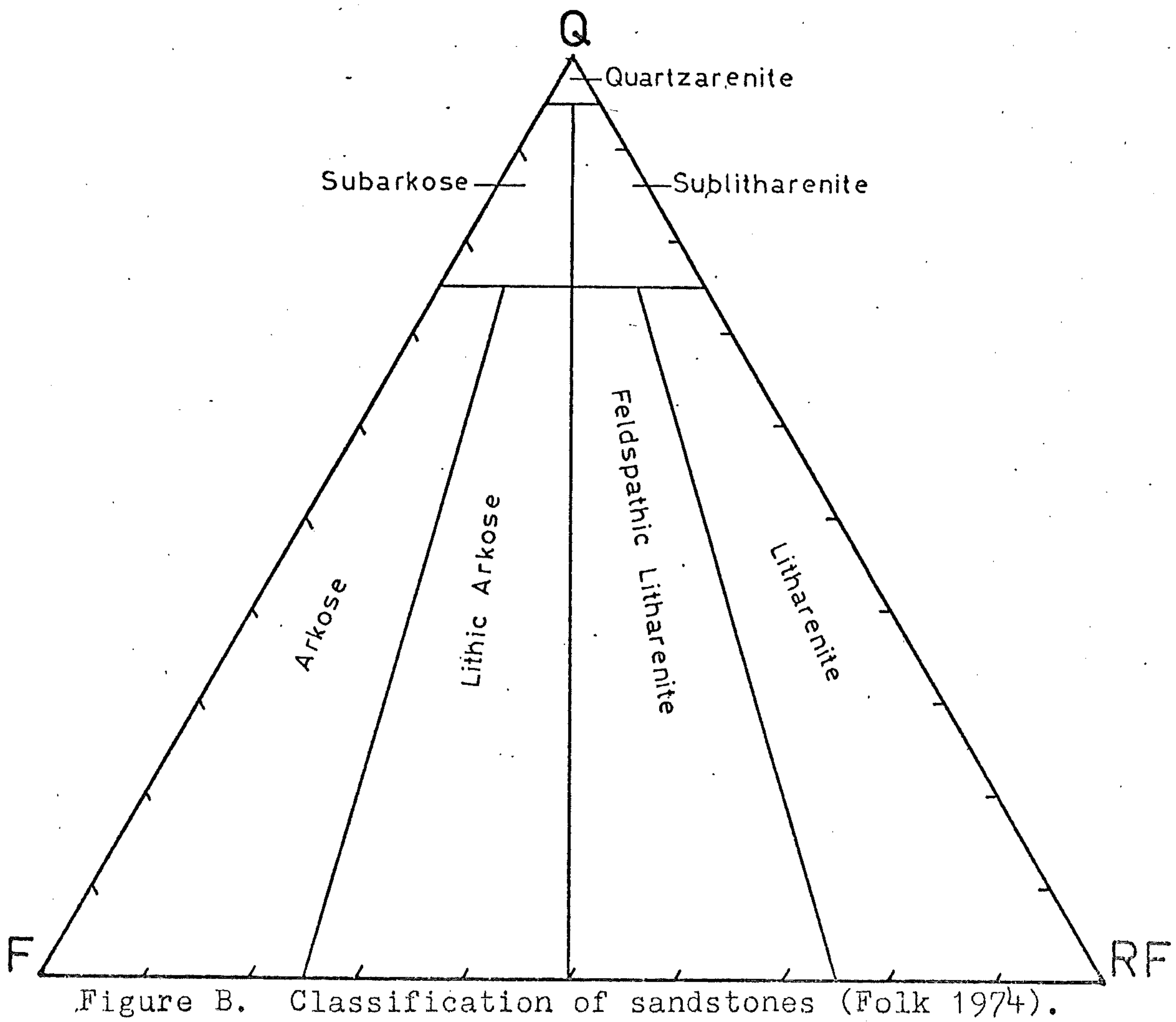


Figure B. Classification of sandstones (Folk 1974).

with quartz having an average grainsize of 1.8mm. Unlike the Pantapinna Sandstone there is no iron oxide coating on the quartz grain. GM1 is higher in the sequence and poorly sorted with grains up to 1 mm in diameter. Overgrowths are common and grains show slight to strongly undulose extinction and inclusions are common. Feldspar is not as prominent as in the Pantapinna Sandstone and forms less than 10% of the rock. Microcline (cross-hatch twinning) is usually more common than plagioclase feldspar. Both fresh and altered grains are present and are the same size as the quartz grains and rounded. Rock fragments (<5%) are fine grained aggregates of quartz, feldspar and minor mica, similar to those in the Pantapinna Sandstone and are often altered. Matric (<5%) is composed of clays (mainly kaolinite) which are often limnotic. Some matrix and altered grains are strongly ferruginized. Detrital opaques (<1%) are sub-rounded and sub-spherical. Micas (up to 4%) are dominantly muscovite which are platy and often altered. Biotite and minor chlorite is also present. Accessories include tourmaline, zircon and apatite.

NAMBO FORMATION

(770-LT) Hand specimen: Pale, very fine grained limestone with thin calcite veining.
Thin section: Fine micritic ferroan calcite (stained section pale blue) with minor rounded quartz grains (4%) of very fine to fine sand size.

(770-T) Hand specimen: Fine grained pale coloured limestone.
Thin section: Stained section is mauve indicating slightly ferroan calcite. Calcite is micritic with coarse crystals infilling veins and small vugs. Minor fine grained rounded quartz grains occur.

(770-T2) Hand specimen: Pale coloured sandy limestone.
Thin section: 80% micritic calcite and limonitic clays which have stained pale purple. Clastics (20%) consist of sub-rounded to sub-angular very fine to fine grained quartz. Some grains have a manganese oxide coating which also occasionally infills vugs.

(770-LA) Hand specimen: Mottled pale coloured limestone with ferruginous yellow brown patches.
Thin section: Fine grained calcite (stained pale purple) with limonitic silty patches that contain fine grained sub-angular to sub-rounded quartz grains (10%) with overgrowth.