GEOLOGY

OF THE

TORROWANGEE AND FOWLERS GAP

1:100,000 SHEETS 7135, 7235

DEPARTMENT OF MINES NEW SOUTH WALES

1978

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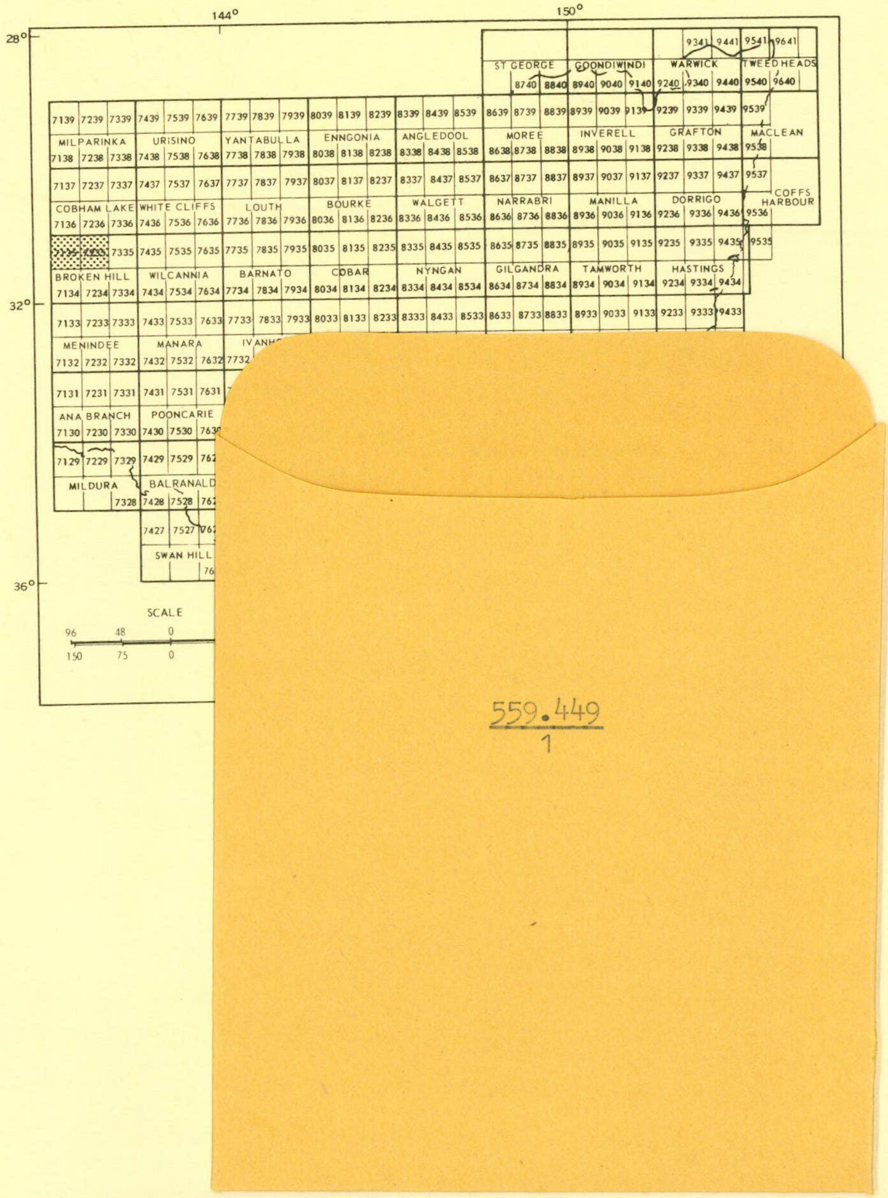

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GEOLOGICAL SURVEY OF NEW SOUTH WALES
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N. L. MARKHAM, DIRECTOR

GEOLOGY OF THE TORROWANGEE AND FOWLERS GAP 1:100,000 SHEETS 7135,7235

BY

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INTRODUCTION

The Fowlers Gap and Torrowangee 1:100 000 sheets lie to the north of Broken Hill, between latitudes 31°00' S. and 31°30' S. and longitudes 141°00' E. and 142°00' E. The two sheets cover an area of approximately 5200 km^2 (figure 1).

The aim of this work was primarily the elucidation of the Adelaidean stratigraphy and correlation with similar sequences in South Australia. Information on the Willyama Complex and Late Devonian sediments is mostly from existing thesis work. No field work was carried out on the surficial sediments beyond a geomorphic subdivision from airphoto interpretation to enable completion of the map sheet. Mapping was carried out in the period 1969-1972, initially at 1:50 000 scale on to aerial photographs. No adequate base map was available, and Royal Australian Survey Corps 1:125 000 field sheets were used to compile the final base map. These notes were compiled in 1972-1973.

Omissions and corrections to the published map sheets are as follows:

1. Homestead locations — "Bijerkerno" GR 585245; "Wilangee" GR 305192; "Corona" GR 420379; "Acacia Downs" GR 855231.
2. The correct position of Bobs Well should be GR 387243 not GR 387256.
3. The correct course of Caloola Creek is the more easterly fork upstream from GR 618297, not as shown.

PHYSIOGRAPHY

The area is dominated topographically by the Euriowie Block, a large, northwesterly trending block of Willyama Complex which forms part of the Barrier Range and lies at 320-400 m asl. The Poolamacca Inlier, another block of Willyama Complex, forms a small elevated area (about 300 m asl) to the north of "Poolamacca" homestead.

The Adelaidean usually has little topographic expression, and forms a broad undulating area lying at about 240 m asl, east of the Euriowie Inlier. However, the Yancowinna Sub-Group sediments are a notable exception and form prominent ridges over 320 m asl to the west of the Torrowangee quarries. The upper part of the Farnell Group also forms quite elevated areas, reaching 400 m asl to the southwest of "Floods Creek" homestead. Resistant quartzites (the Faraway Hills Quartzite) form northwesterly trending ridges in the eastern part of the Floods Creek area. Where quartzites are poorly developed, the general elevation of the land surface is much higher; for example, the Floods Creek Syncline is mostly above 240 m asl.

CLIMATE AND VEGETATION

The Fowlers Gap - Torrowangee area is semi-arid, the annual rainfall being approximately 230 mm. The wettest months of the year are February, October, and November. Winds generally blow from the south and southwest.

Vegetation on the alluvial flats is usually Bladder Saltbush *(Atriplex vesicaria)* and Bluebush *(Maireana sedifolia)*. In the watercourses, Tree Tobacco *(Nicotiana glauca)* is common, and in the larger watercourses large River Red Gums *(Eucalyptus camaldulensis)* are present.

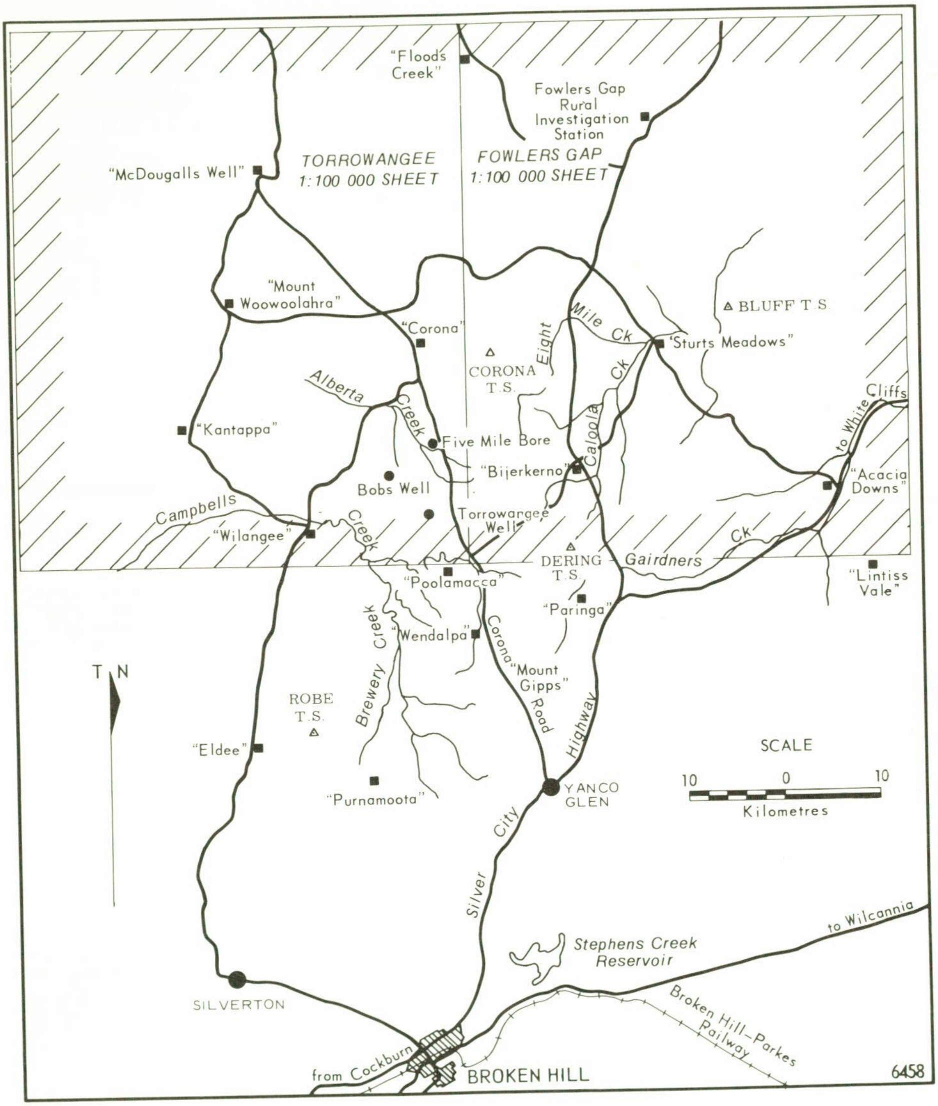

Figure 1. Locality map

The Mulga *(Acacia aneura)* grows almost exclusively on the Willyama Complex. The Adelaidean sediments, with the exception of the Yancowinna Sub-Group, are usually devoid of trees. One notable exception is the Corona Dolomite where the Curly Mallee *(Eucalyptus gillii)* is common. In the Broken Hill area this eucalypt grows only on dolomite-derived soil (photo 1).

LAND USE

The main land use is the grazing of sheep, although a small number of cattle are run on the areas where lush grass is abundant in the wetter seasons.

ACCESS

Access is provided by the Silver City Highway, the Corona road, and numerous graded and ungraded station tracks. Because of the lack of vegetation and general flatness of the area, the authors were able

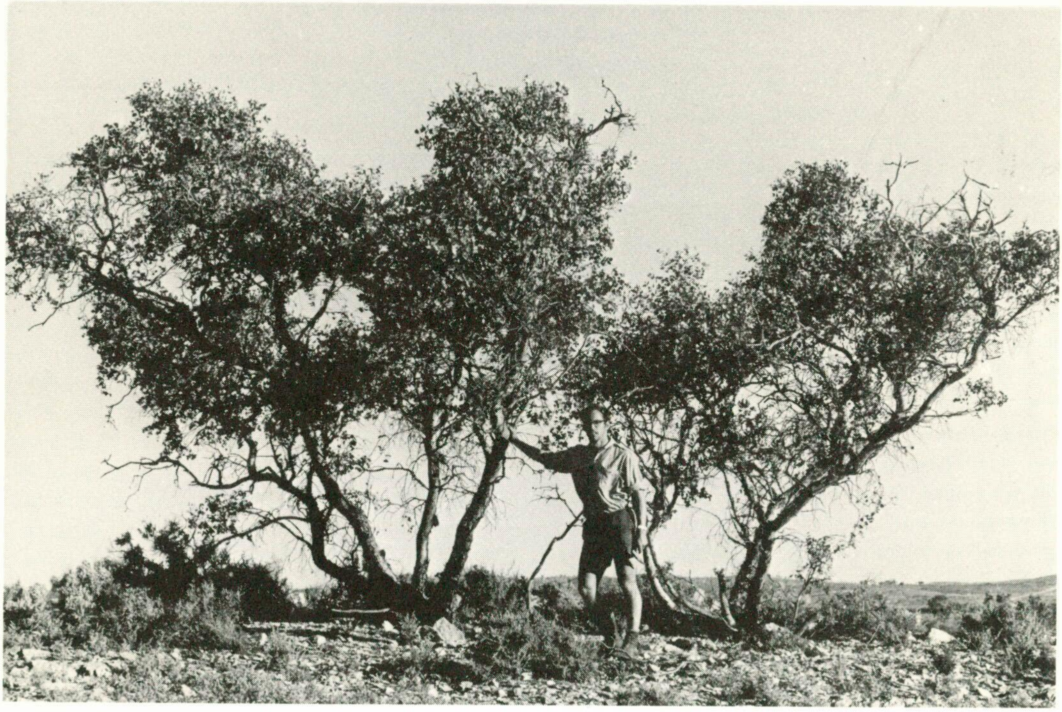

Photo 1. *Eucalyptus gillii* which is restricted to dolomite - rich soil and is commonly found on the Corona Dolomite

to go virtually everywhere in a four-wheel drive vehicle.

General Geological Setting

The area covered by this study is mainly part of the Adelaide Fold Belt; a minor area in the northeast belongs to the Kanmantoo Fold Belt (Scheibner 1974) (figure 2). The Adelaide Fold Belt consists of several, old, uplifted, fault-bounded anticlinorial blocks which are separated by synclinorial zones of relatively unmetamorphosed sediments.

In the Broken Hill - Olary area, high and low-grade metamorphics and minor igneous rocks of probably mid Precambrian age constitute what is known as the Willyama Complex (Mawson 1912). This complex crops out in the form of a structural block which was named the Willyama Block by Thomson (1969, 1970). Thomson (1969, 1970) suggested that these metamorphics are similar to those forming the Gawler Block in South Australia. Hence, it can be accepted that the metamorphics constituting the Willyama Complex and those in the Gawler Block formed an orogenic belt which can be referred to as the Gawler - Willyama Fold Belt. Later, during Late Precambrian Adelaidean time this fold belt was covered by cratonic cover (except for a few inliers), in which an elongated intracratonic mobile zone developed, the Adelaide Aulacogene or Geosyncline of some authors. After the deformation of this intracratonic mobile zone during the Delamerian Orogeny (Thomson 1969, 1970), the Adelaide Fold Belt was formed. The basement complexes were uplifted and they form anticlinorial blocks or inliers. It is very probable that only minor separation of basement blocks occurred during the existence of the intracratonic mobile zone, hence, the basement is physically continuous throughout the Adelaide Fold Belt, or more precisely under the synclinorial zones of it (figure 3).

In New South Wales the Willyama Block (Thomson 1969) can be further subdivided into the Broken Hill Block, Euriowie Block, small inliers of Willyama Complex, and synclinorial zones where the Willyama Complex is covered by younger Adelaidean strata (figure 4). The Adelaidean cratonic cover occurs in three synclinorial zones, the Kantappa, Torrowangee, and Caloola Synclinorial Zones.

The sediments of the Adelaide Fold Belt are subdivided into four major units: the Lower Callanna Beds and its New South Wales equivalent the Poolamacca Group; the Upper Callanna Beds and Burra Group which have no New South Wales equivalent*; the Umberatana Group and its New South Wales equivalent the Torrowangee Group; the Wilpena Group and its New South Wales equivalent the Farnell Group (figures 5 -8).

Rocks of the Lower Callanna Beds and the Poolamacca Group indicate a period of tectonic stability, with shallow marine conditions and restricted outpouring of basalt. The known area of sedimentation is shown in figure 5.

* Recently (Tuckwell pers. comm.) has discovered sediments beneath the Torrowangee Group west of Poolamacca (GR 376154) which are probably equivalent to part of the Upper Callanna Beds. They are highly contorted, poorly lithified friable sandstones and grits with halite(?) clasts and sulphide nodules.

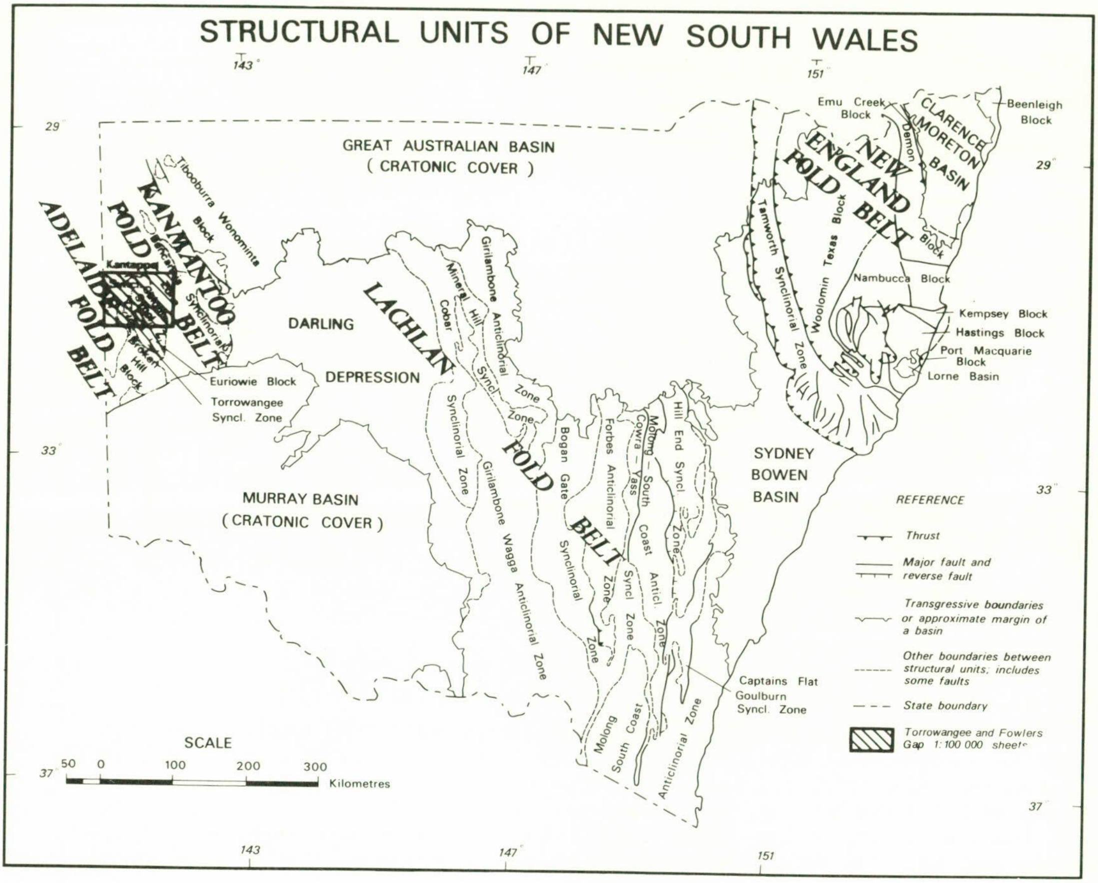

Figure 2. Structural map of western New South Wales showing the location of the Torrowangee and Fowlers Gap 1:100 000 sheets

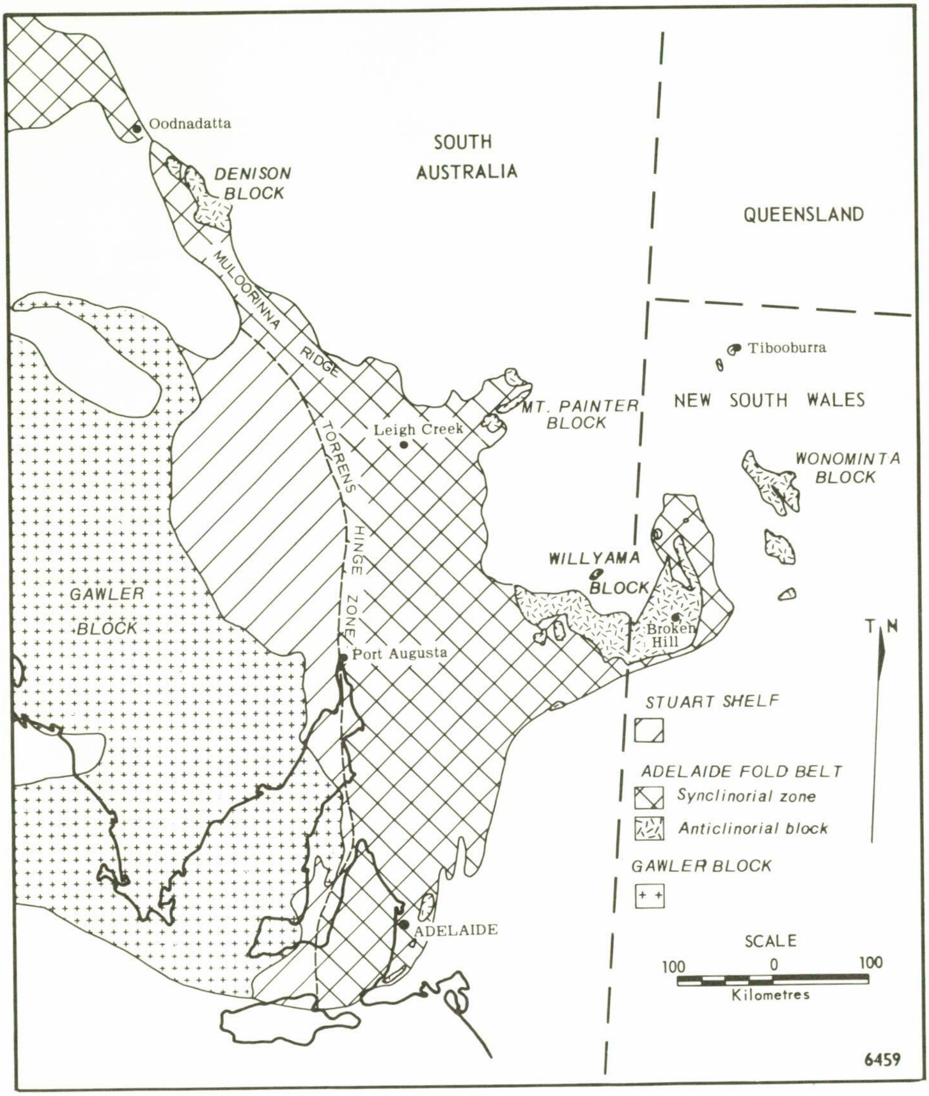

Figure 3. Structural map showing the disposition of the Adelaide Fold Belt and the various basement blocks

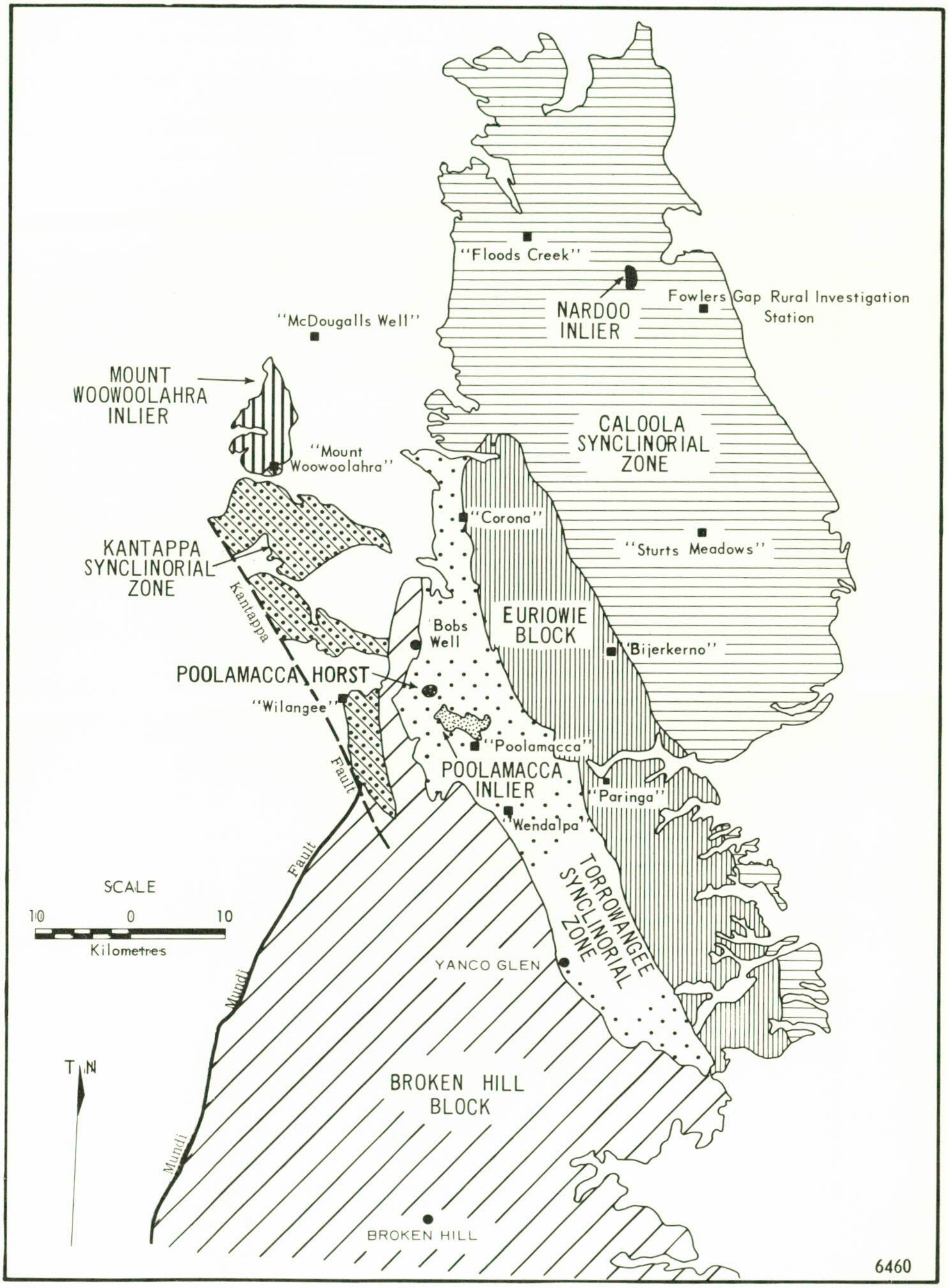

Figure 4. Structural terminology, Broken Hill area

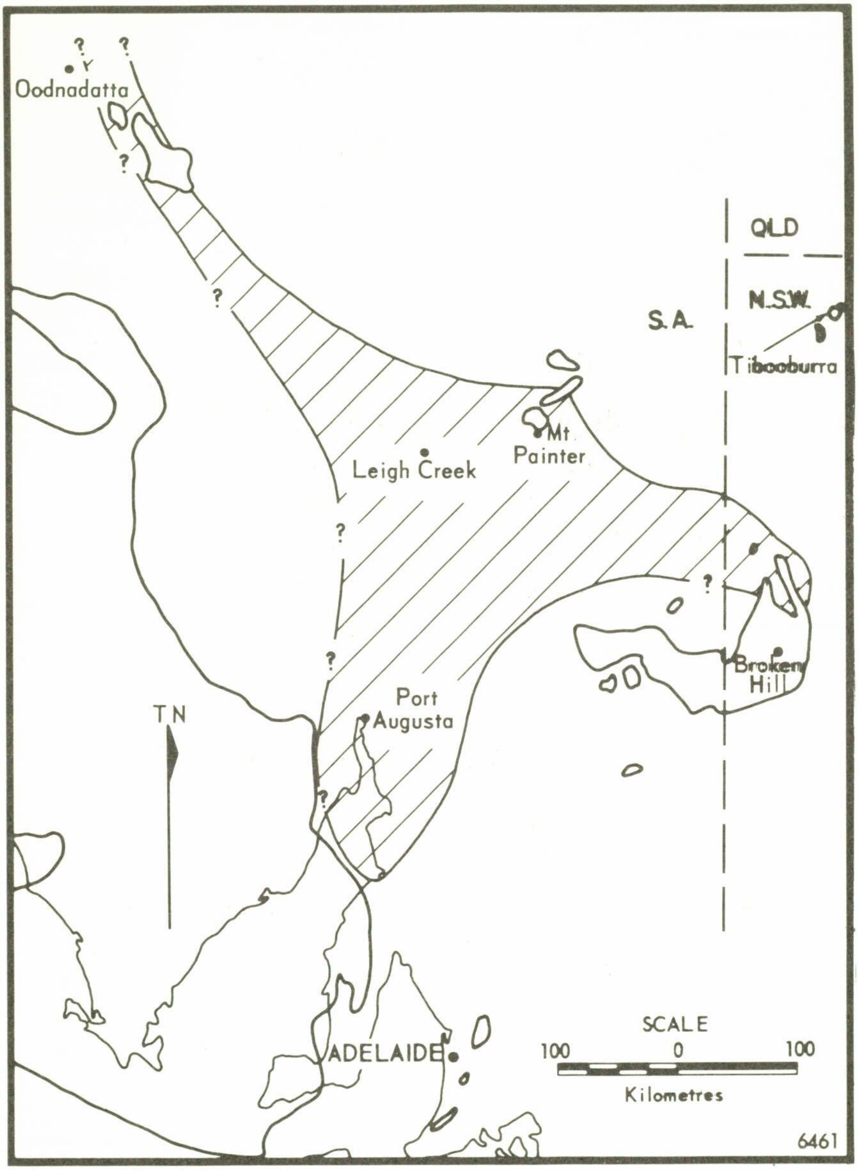

Figure 5. Known area of sedimentation for the Lower Callanna Beds and Poolamacca Group (modified after Thomson 1969)

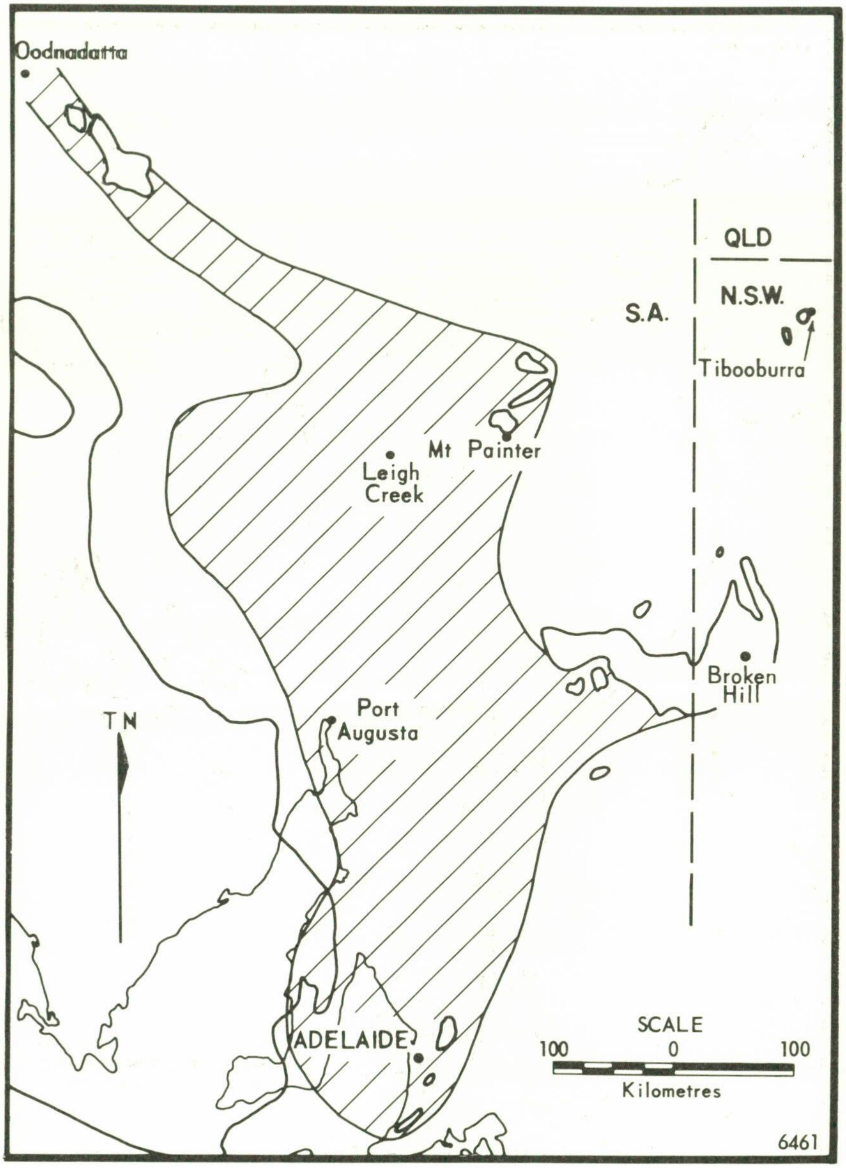

Figure 6. Known area of sedimentation for Burra Group, River Wakefield Group, and Upper Callanna Beds (modified after Thomson 1969)

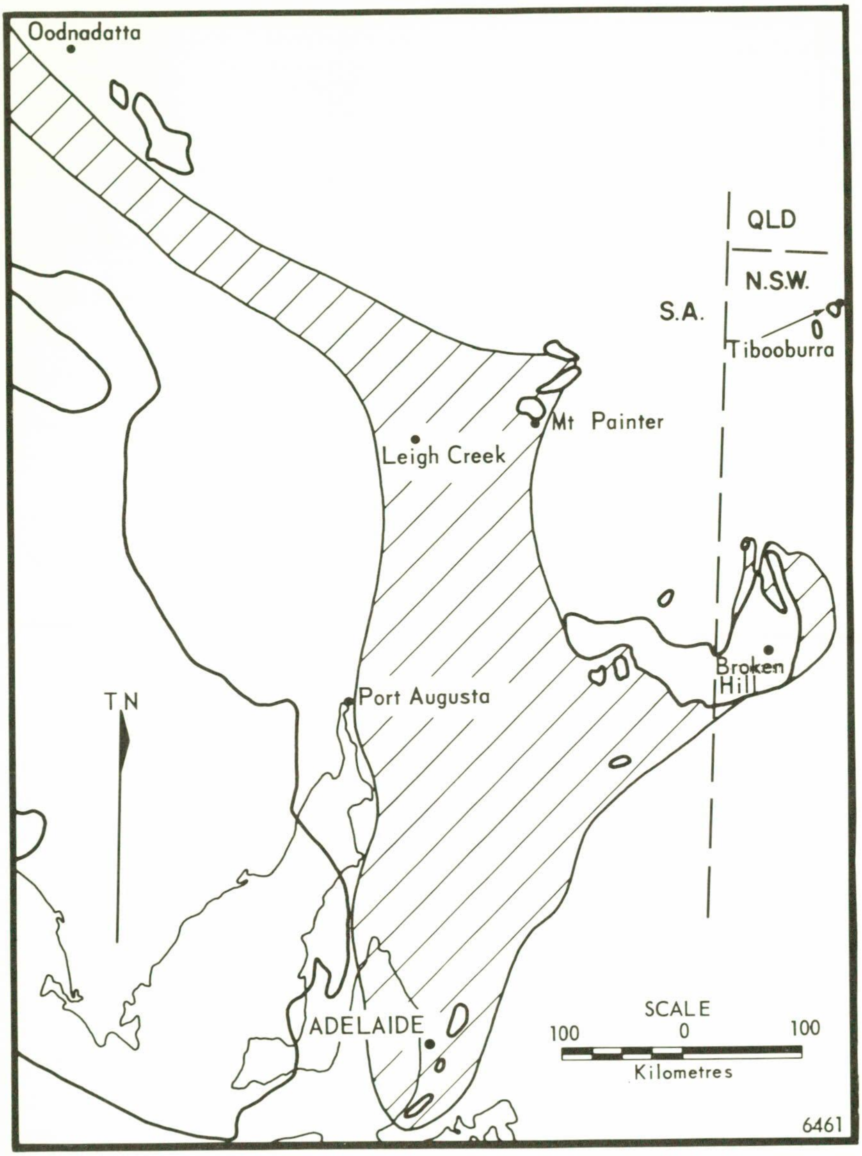

Figure 7. Known area of sedimentation for the Umberatana and Torrowangee Groups (modified after Thomson 1969)

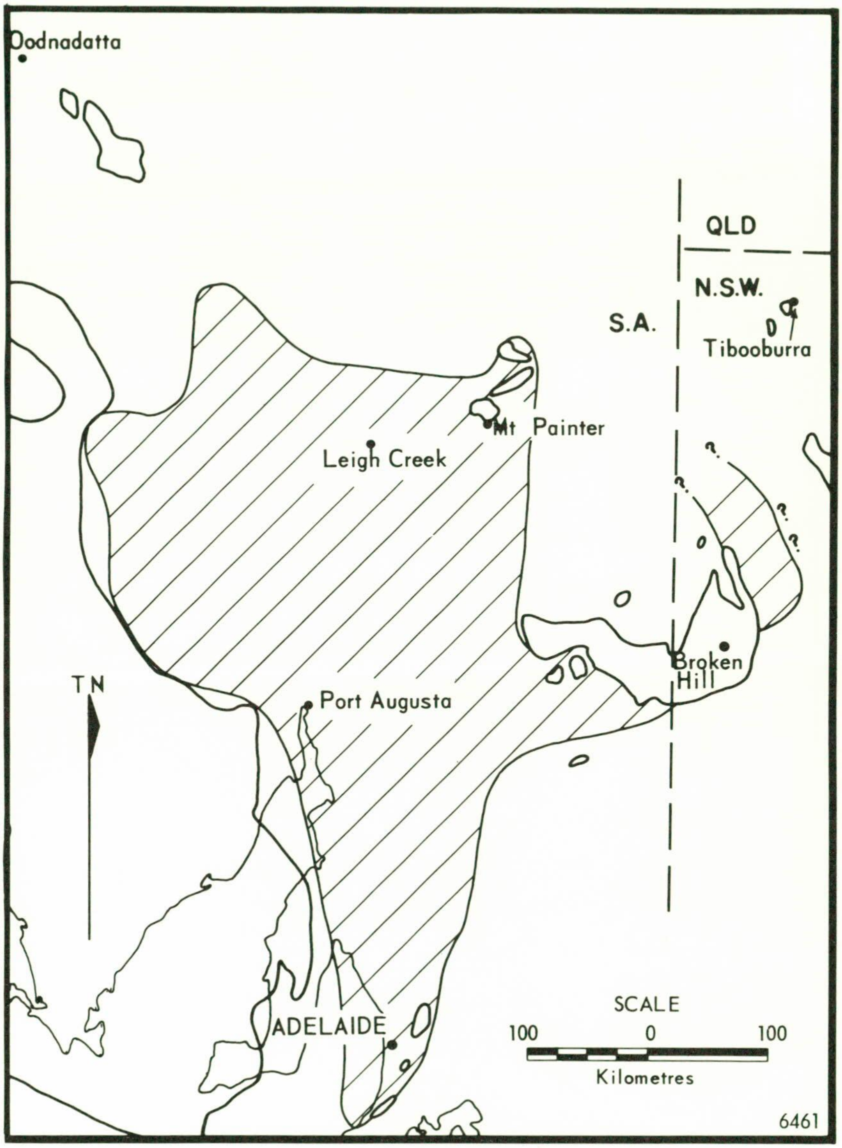

Figure 8. Known area of sedimentation for the Wilpena and Farnell Groups (modified after Thomson 1969)

The Burra Group and Upper Callana Beds are generally a carbonate sequence but have no equivalent in New South Wales (figure 6). It seems probable that there was no sedimentation of this type in New South Wales, as substantial erosion of the Poolamacca Group has occurred.

The sediments of the Umberatana - Torrowangee Groups (figure 7) indicate the occurrence of two periods of glaciation with an intervening interglacial stage. In New South Wales this interglacial stage is represented by essentially carbonate sedimentation.

Sediments of the Wilpena and Farnell Groups indicate widespread stable, probably marine, conditions (figure 8). These groups consist predominantly of quartzite and siltstone.

PREVIOUS WORK

The name "Willyama" was assigned by Mawson (1912) to rocks which have wide distribution in South Australia but which are exposed only in restricted areas at Broken Hill. Prior to 1968 the only significant work done on the Willyama Complex in the Torrowangee and Fowlers Gap 1:100 000 sheet areas was that of Andrews (1922), who considered it to be of Archaean age.

During 1968-1969, mapping of the Willyama Complex was carried out by Tuckwell (1968), Cowan (1969), Gilligan (1969), Meares (1969), Roberts (1969), Woodhouse (1969), and Cooper (1969) (see figure 9). The notes on the Willyama Complex contained herein are essentially a compilation of information from this thesis work.

For a general review of the Willyama Complex and the Broken Hill orebody the reader is directed to Vernon (*in* Packham 1969, pp. 20-55) and Hobbs et al. (1968).

The Mundi Mundi Granite has been described by Mawson (1912), Andrews (1922) and Browne (*in* Andrews 1922, pp. 346-348). Kenny (1934) was the first to use the term formally. Later workers include Richards and Pidgeon (1963) and Pidgeon (1967).

Probably the first recorded statement regarding the nature of the Late Precambrian sediments was that of Sturt in 1844, who noted the peculiarity of ancient deposits of "glacial waste" on the hills around Poolamacca. It seems that since Sturt's time these great thicknessess of coarse, poorly sorted material have been assigned a glacial origin - or, more specifically, they have been termed tillites!

Mawson (1912) studied the Late Precambrian rocks in the vicinity of Broken Hill. He considered them to be of Cambrian age because of similarities with the unfossiliferous sequence which apparently conformably underlies the early Cambrian of South Australia. He used the term "Torrowangee Series" to apply to the Cambrian (now Late Precambrian) rocks "typically developed north-west of Boolcoomata

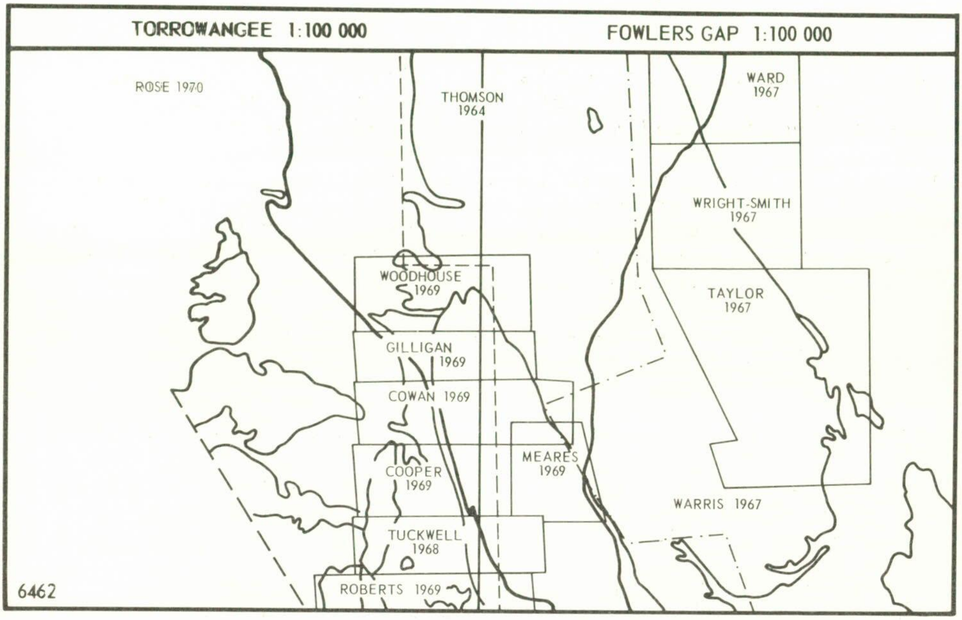

Figure 9. Previous geological mapping

station in South Australia, and at Torrowangee, north of Broken Hill" (p. 235). Thus, Mawson used the term "Torrowangee Series" for the now late Precambrian rocks of both Olary and Broken Hill.

He said (p. 244) of alternating bands of "tillite" and more sandy, well-sorted material near "Poolamacca" homestead:

"The two horizons referred to are uniform in texture, and pass on either side into grits to some extent of the greywacke variety, and into slates usually laminated. The junctions are sharply demarked below, but more often indefinite above the tillite.

"Examined in the field, these products, the grits and laminated slates, are obviously derived by the agency of water from tillite. Microscopic investigation is confirmatory, showing that the ground-mass of the tillite contains angular particles identical with those forming the grit, whilst the rock-flour of the tillite is not to be differentiated from the body of the slate".

Recent investigations have shown these features to be almost universal and that almost all coarse-grained material is, in its present configuration, the product of aqueous deposition. The origin of this detritus, prior to reworking, is discussed later (see section on "Palaeoenvironment - Torrowangee Group"). Mawson (1912) called some of the rocks in the area "tillite", but pointed out (p. 244) that the large bulk of associated rocks was not tillite, but had other characteristics, being "formed in water from materials transported by ice"; these he included under the general heading of boulder beds.

It is obvious from the works that were published after Mawson (1912) on the rocks of the Broken Hill area, that a gross misuse of the term "tillite" has occurred. Although Mawson restricted his use of the term, later workers have used it uncritically such that it has come to include any boulder/pebble-bearing sediment in the area.

Andrews (1922) further examined the "Torrowangee Series" and was of the opinion that these rocks were of Precambrian age rather than Cambrian.

However, several points Andrews made are worth commenting upon.

> "1. The tillite and the quartzite, which are so widely spread through the Torrowangee appear to have been derived from the waste of the older series". (p. 63).

This statement is only partially true. Almost all the typically grey quartzite pebbles, cobbles, and boulders in the Late Precambrian have been derived, not from the Willyama Complex, but from the basal formations of the Late Precambrian.

> "2. No igneous intrusions were noted in the Torrowangee". (p. 63)

In the Sturts Meadows - Acacia Downs area, dykes of intermediate to basic material have been intruded along the major joint direction (north-northeasterly).

Andrews also mentioned the widespread occurrence of tillite in the "Torrowangee Series", and he, too, said "that water re-arranged the tillite [at The Sisters] ... during certain milder seasons" (p. 65).

King and Thomson (1953) carried out further work on the "Torrowangee Series", but were hampered in their interpretations as they considered the Mundi Mundi Granite to be intruded after deposition of the "Torrowangee Series". They also discovered the "volcanics" towards the base of the sequence.

Leslie and White (1955) studied the "Torrowangee Series" and the unconformity around the Brewery Well granite pluton in detail. However, they considered that the basal sediments in their study (a "granite tillite") were below the "Basal Quartzite" of Mawson and Andrews. Later work by Tuckwell (1968) has shown that the basal quartzite is not developed in the area they mapped, and in fact they probably observed the Kantappa Quartzite Member (Cooper and Tuckwell 1971). They also provided excellent evidence for a pre-Torrowangee age for the Mundi Mundi Granite.

Bowes (1956) further described the development of granite "tillites" and granite gneiss "tillites" on the Poolamacca Inlier. These unusual rocks directly overlie their respective source rocks - granite and granite gneiss. To explain this phenomenon, Bowes evoked land ice erosion, with deposition occurring immediately above the source rocks, a situation which requires a glacier that erodes but does not transport!

Thomson (1964) published by far the most comprehensive study of the Late Precambrian sequence in the Broken Hill district, and made some very astute observations. He was the first to suggest that the "Torrowangee glacial units are underlain by an earlier Proterozoic sequence equivalent to the Willouran Rocks of the Flinders Ranges". He mentioned that vertical movements along basement faults and shears occurred during sedimentation of the Late Precambrian and that "topographic relief was probably very pronounced during Sturtian Glaciation". Thomson also attempted the first definite correlations with the Adelaidean in South Australia. He suggested that the uppermost exposed part of the sequence, in the Caloola Syncline, is Cambrian; however, the authors disagree with this interpretation.*

Warris (1967 unpubl.) dealt with the Torrowangee Group east of the Euriowie Block, and proposed the redefinition of the "Torrowangee Series" as the Torrowangee Group. This change was published by Rose (1970). Warris' description of the section is generally good, except that he also used the term "tillite" loosely. He recorded stromatolites from the limestone sequence but gave inadequate particulars as to their location and to the locations of his measured sections.

During 1967, students from the Australian National University mapped the geology of the Fowlers Gap Rural Investigation Station as a requirement for their degree studies. Their work (unpublished) consists of detailed mapping of the Teamsters Creek Sub-Group and Farnell Group sediments (our terminology), Late Devonian sandstone, and Tertiary silcrete. It was they who discovered some stromatolite(?) colonies in the Teamsters Creek Sub-Group and the Farnell Group.

Rose (1970) was the first to publish a detailed stratigraphic subdivision of the Late Precambrian; the term "Torrowangee Series" was changed to Torrowangee Group, and this group was further subdivided into several units (table 1). These units, the "Wilangee Volanics", "Pintapah Quartzite", "Yancowinna Beds", "Euriowie Beds", "Teamsters Creek Beds", "Far-Away-Hills Quartzite", "Fowlers Gap Beds", "Camels Hump Quartzite", and "Lintiss Vale Beds", were not all defined because of the reconnaissance nature of the mapping. The work of Rose (1970) was generally correct, although Tuckwell (1968) has shown that the "Pintapah Quartzite" is overlain by the "Wilangee Volcanics" rather than the reverse as indicated by Rose (1970).

Ward et al. (1969) discussed the structure and stratigraphy of the Sturts Meadow - Fowlers Gap area. The authors disagree with

* More recent work by Daily (1973) supports Thomson's suggested Cambrian age for the uppermost exposed part of the sequence.

their subdivision of the sequence and do not consider it a viable proposition on the regional scale.

The Devonian sediments on the Torrowangee - Fowlers Gap sheet have been studied by Ward et al. (1969).

EVOLUTION OF LATE PRECAMBRIAN ADELAIDEAN NOMENCLATURE

The nomenclature used by past workers for the Late Precambrian Adelaide System of the Broken Hill area is compared on table 1.

Mawson (1912) was the first to formally name the Late Precambrian of New South Wales and South Australia. Mawson (1912, p. 235) stated:

> "The Cambrian rocks, typically developed north-west of Boolcoomata station in South Australia, and at Torrowangee, north of Broken Hill, will be hereafter styled the Torrowangee* Series."

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* Torrowangee is the native name for the district.

Thus, Mawson (1912) intended the use of the term "Torrowangee Series" for the rocks of both Olary and Broken Hill. Mawson's work in New South Wales was concerned mostly with the diamictites and associated sediments of the Campbells Creek area.

Andrews (1922) continued the use of the term "Torrowangee Series" but suggested that the sediments were Precambrian rather than Early Cambrian.

Thomson (1964) did not introduce new nomenclature to describe the Late Precambrian, but made a substantial contribution by recognizing the main lithological types in the Broken Hill district and correlating them with similar types in South Australia.

The nomenclature of the rock units did not change until 1967 when Rose and Warris separately proposed redefinition of the "Torrowangee Series" as Torrowangee Group. Warris (1967) did not publish his proposed subdivisions. Those of Rose, who, in, addition to his own work, used data from the investigations of C.R. Ward, C.N. Wright-Smith, and N.F. Taylor, were shown on the Broken Hill 1:250 000 Geological Sheet (preliminary edition 1968, first edition 1970). Unfortunately no formal definition of the newly proposed units was given at that time. This led to confusion, and in the subsequent publication by Ward et al. (1969) a "tillite" horizon was incorrectly attributed to the "Euriowie Beds" of Rose (1968), and consequently their definition of the overlying "Teamsters Creek Beds" is incorrect as well. {This error was also followed by Webby (1970a).} The definition of the "Euriowie Beds" and the "Teamsters Creek Beds" by Ward et al. (1969) should be ignored, as the break-up shown by Rose

TABLE 1

PREVIOUS NOMENCLATURE, LATE PRECAMBRIAN ADELAIDEAN OF THE BROKEN HILL AREA

MAWSON (1912)	THOMSON (1964)		ROSE (1968, 1970)		WARD, TAYLOR, WRIGHT-SMITH (1969)			WEBBY (1970a)		COOPER AND TUCKWELL (1971)		
TORROWANGEE SERIES	TORROWANGEE SERIES	Siltstones and quartzite	TORROWANGEE GROUP	Lintiss Vale Beds	TORROWANGEE GROUP	Farnell Sub-Group	Lintiss Vale Beds	TORROWANGEE GROUP	Lintiss Vale Beds	FARNELL GROUP		Lintiss Vale Formation
				Camels Hump Quartzite			Camels Humps Quartzite		Camels Humps Quartzite			Camels Humps Quartzite
				Fowlers Gap Beds			Fowlers Gap Beds		Fowlers Gap Beds			Fowlers Gap Formation
				Far-Away-Hills Quartzite			Faraway Hills Quartzite		Far-Away-Hills Quartzite			Faraway Hills Quartzite
		Upper tillite lenses		Teamsters Creek Beds			Teamsters Creek Beds		Teamsters Creek Beds			Sturts Meadows Siltstone
												Mantappa Dolomite
										TORROWANGEE GROUP	Teamsters Ck Sub-Group	Nunduro Conglomerate
												Dering Siltstone
												Gairdners Creek Quartzite
												Alberta Conglomerate
		Siltstone, quartzite, dolomite, limestone, arkose		Euriowie Beds			Euriowie Beds		Euriowie Beds		Euriowie Sub-Group	Floods Creek Formation; Yowahro Formation
												Mitchie Well Formation; Corona Dolomite; Tanyarto Formation; Wammerra Formation
		Lower tillitic sediments		Yancowinna Beds					Yancowinna Beds		Yancowinna Sub-Group	Yangalla Formation; Mulcatcha Formation; McDougalls Well Congl.; Waukeroo Formation —?—?—?—
				hiatus								hiatus
		Quartzite conglomerate		Pintapah Quartzite					Pintapah Quartzite	POOLAMACCA GROUP	Wendalpa Sub-Group	Wilangee Volcanics*
												Boco Formation
		Basic volcanics		Wilangee Volcanics					Wilangee Volcanics		Pintapah Sub-Group	Christine Judith Conglomerate
												Lady Don Quartzite
WILLYAMA COMPLEX	WILLYAMA COMPLEX		WILLYAMA COMPLEX							WILLYAMA COMPLEX		

* Cooper and Tuckwell (1971) called this unit the Wilangee Volcanics but the name has since been changed to Wilangee Basalt

(1968, 1970) is the more reasonable.

Ward et al. (1969) defined the "Farnell Sub-Group" which is described in the text of their paper as overlying the "Teamsters Creek Beds" (the break-up on their table 2 showing their "Farnell Sub-Group" extending well down into the "Teamsters Creek Beds" is probably a printer's error).

To add to the confusion, two of the names for the units comprising the "Farnell Sub-Group" of Ward et al. (1969) are misspelt on the Broken Hill 1:250 000 Geological Sheet (1970).

Webby (1970a) largely followed the nomenclature of Rose (1970) but defined the "Euriowie Beds" and the "Teamsters Creek Beds" as per Ward et al. (1969).

As a result of detailed work on the Adelaidean rocks of Broken Hill, Cooper and Tuckwell (1971) clarified the situation. The subdivisions of Rose (1968, 1970) were expanded and altered in part in the light of the new information and brought into uniformity with the subdivision of the Adelaidean succession in South Australia. Furthermore, the term *Torrowangee Group* was restricted to include only the coarse, glacially(?)-derived material — the Yancowinna and Teamsters Creek Sub-Groups — together with the interglacial(?) sequence — the Euriowie Sub-Group. This subdivision is believed to be valid in the light of Mawson's original work, in which the "Torrowangee Series" was restricted to the glacial(?) sequence.

The distribution of the Poolamacca Group, Torrowangee Group, and Farnell Group, which comprise the entire Late Precambrian sequence (Adelaide System) at Broken Hill, is shown on figure 10.

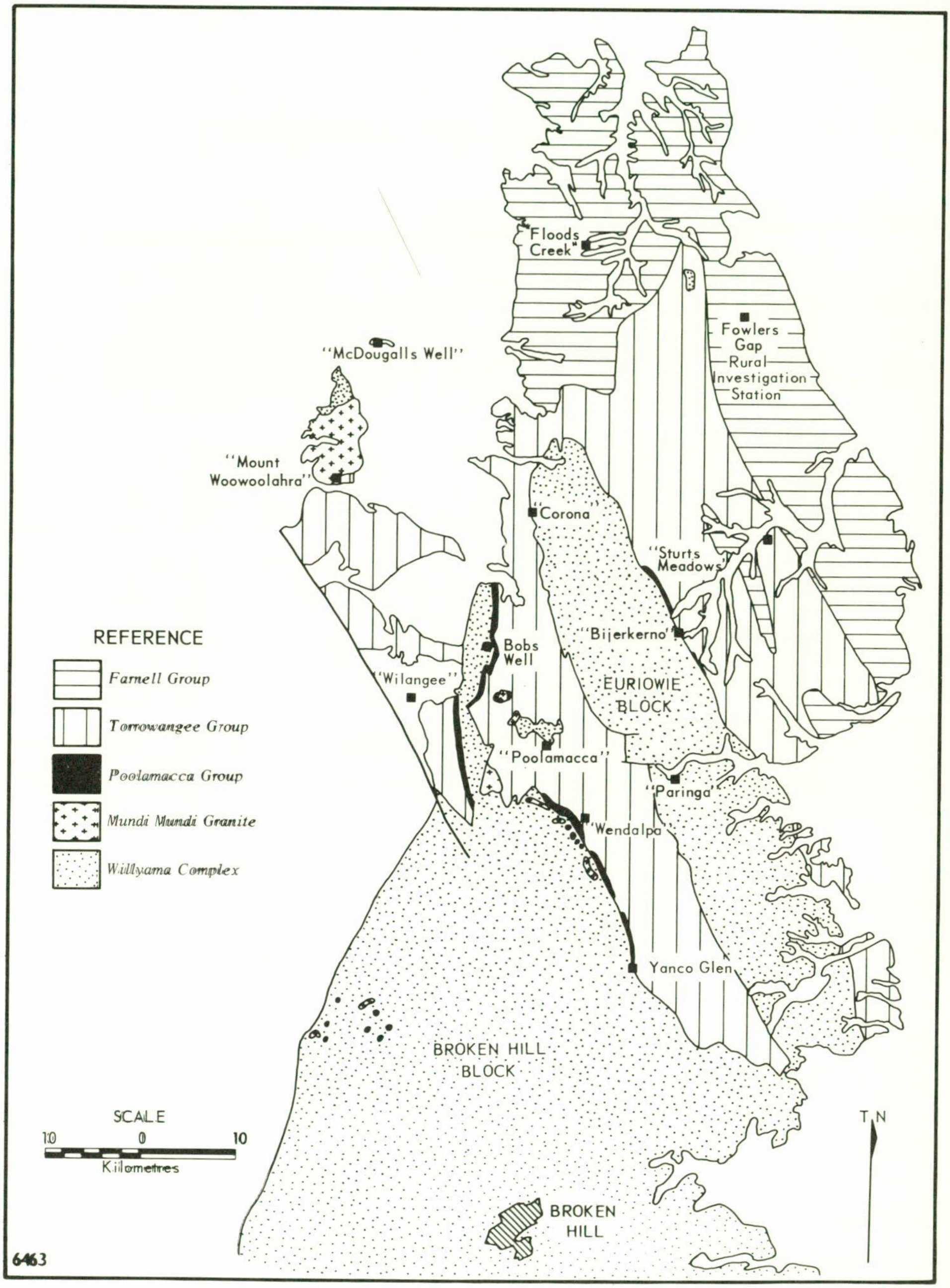


Figure 10. Distribution of the Poolamacca, Torrowangee, and Farnell Groups

WILLYAMA COMPLEX (pεw)

By P.F. Cooper, R.M.D. Meares, and L.B. Gilligan

Metamorphic Zones

Six metamorphic zones have been mapped in the Willyama Complex in the northern section of the Euriowie Block (see Torrowangee - Fowlers Gap 1:100 000 Geological Sheet), each consisting of a distinct group of mineral assemblages. Zones A to E are "conformable" to bedding and wrap around the nose of the Bijerkerno Syncline (Meares 1969).

The rock types contained in zones A to G are listed below:

Zone A: Quartz - mica phyllite, with interbedded spotted phyllite, laminated phyllite, siltstone, quartzite, black shale, and chert.

Zone B: Andalusite, chiastolite, and chloritoid-bearing quartz - mica schists, phyllite, calc-silicate, 'hornfels', and quartzite.

Zone C: Sillimanite schist and quartzite.

Zone D: Quartz - sericite and quartz - sericite - muscovite schist.

Zone E: Predominantly retrogressed sericite schist, with subordinate gneiss and amphibolite increasing in abundance to the east and north.

Zone F: Sillimanite - garnet gneiss, abundant amphibolite, minor schist.

Zone G: Predominantly retrogressed sericite schist, phyllite, and spotted phyllite, with minor quartzite.

A summary of the general characteristics of these zones is presented in table 2.

ZONE A (pεwA)

Zone A represents the lowest grade of metamorphism in the area, and has a maximum thickness of 1500 m. It consists of laminated siltstone, quartzite, phyllite, spotted phyllite, chert, and black shale. The sediments are well sorted and extremely fine grained.

TABLE 2

METAMORPHIC ZONES OF THE WILLYAMA COMPLEX IN THE NORTHERN SECTION OF THE EURIOWIE BLOCK

Zone	Characteristic features	Major rock type (excluding pegmatite)	Minor rock type	Metamorphic grade	Other
A	Bedding and sedimentary structures preserved	Phyllite and siltstone	Spotted phyllite, chert, black shale, quartzite	Greenschist facies, quartz-albite-muscovite-chlorite subfacies	Similar to zone H
B	Presence of andalusite and/or chloritoid and/or chiastolite	Andalusite schist, chloritoid schist	Calc-silicate rock, quartzite	Greenschist facies, quartz-andalusite-plagioclase-chlorite subfacies	Bedding still present
C	Presence of sillimanite	Sillimanite schist, quartz-mica schist	Quartzite, sericite schist	Cordierite-amphibolite facies, sillimanite-cordierite-muscovite-almandine subfacies	Sillimanite often retrogressed to sericite. Overlap of sillimanite and andalusite assemblages at zone B/zone C boundary
D	Narrow zone of sericite schist	Quartz-sericite schist		Retrogressed	Muscovite plates oblique to foliation common (retrogressed)
E (east)	Quartz-rich-amphibolite	Quartzo-feldspathic gneiss (east) Sericite and chlorite schists (west)	Amphibolite, quartzite	Retrogressed	Rocks become retrogressed to the west of area where chlorite schist is common
E (west)	Presence of retrogressed schist	Retrogressed quartz-sericite	Amphibolite, metatexite, gneiss	Retrogressed	Amphibolite common in the northeastern side of Zone E, adjacent to "Corona" homestead
F	Presence of sillimanite	Amphibolite, sillimanite gneiss	Sericite schist, quartzite	Cordierite-amphibolite facies, sillimanite-cordierite-muscovite-almandine subfacies	Amphibolite common in western part of area, metatexite common in northern part of zone
G	Bedding and sedimentary structures preserved	Phyllite and siltstone	Quartzite	Greenschist facies quartz-albite-muscovite-biotite chlorite subfacies	Spotted phyllite present similar to zone A

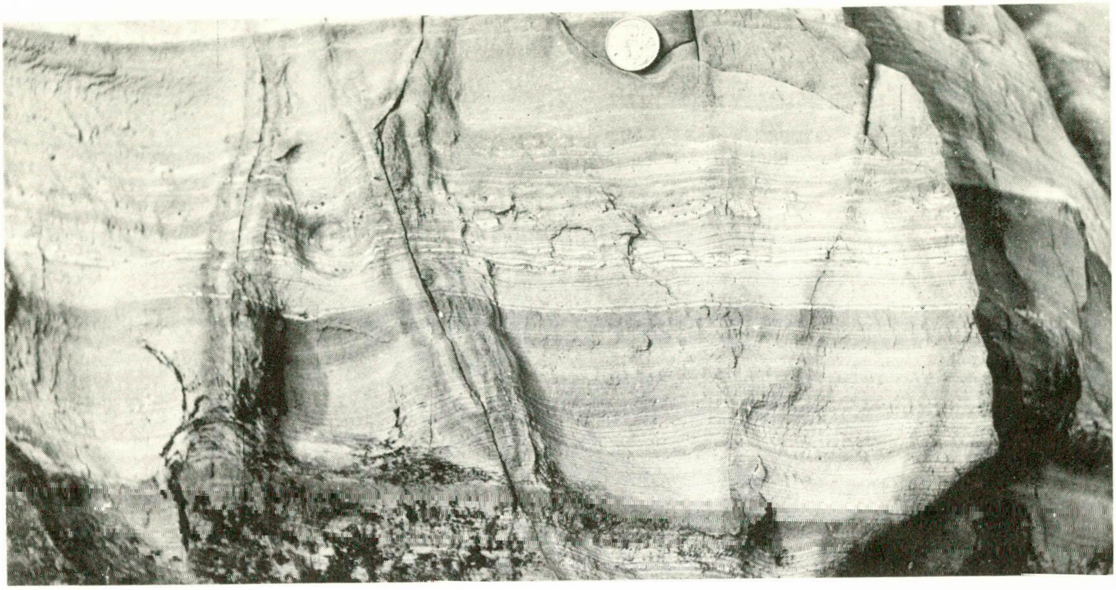


Photo 2. Laminated siltstone from Zone A of the Willyama Complex, 1.6 km northeast of Euro Gorge (GR 552296)

Sedimentary structures are confined to the laminated siltstone (photo 2), and consist of small-scale slumping, load casts, and flame structures, as well as minor occurrences of asymmetric, internally crossbedded ripple marks (photo 3), graded bedding, and crossbedding.

Facing is preserved, and it can be shown that the structure called the "Bijerkerno Synform" (Rose and Brunker 1969) is in fact a syncline (Meares 1969). Units are persistent and can be mapped with ease throughout the syncline.

Phyllite is the most commonly developed rock type in this zone. Some phyllites contain elliptical spots whch range from 2 mm up to 6 mm in diameter and grow across bedding planes. Meares (1969) suggested that these spots are retrogressed andalusite as he was able to trace their development with increasing grade. S_1, the axial plane cleavage, wraps around these spots.

A stratigraphic column of Zone A is shown in figure 11.

Petrography

The phyllites and siltstones of this zone are extremely fine grained and contain abundant fine-grained carbonaceous matter. The texture is generally foliated, with subparallel alignment of laths and fine-grained aggregates of muscovite, chlorite, and some biotite. Rutile and iron oxides are common accessories. Spots are present in several bands of phyllite, and are usually circular in cross section and composed of intergrowths of muscovite, chlorite, sericite, and

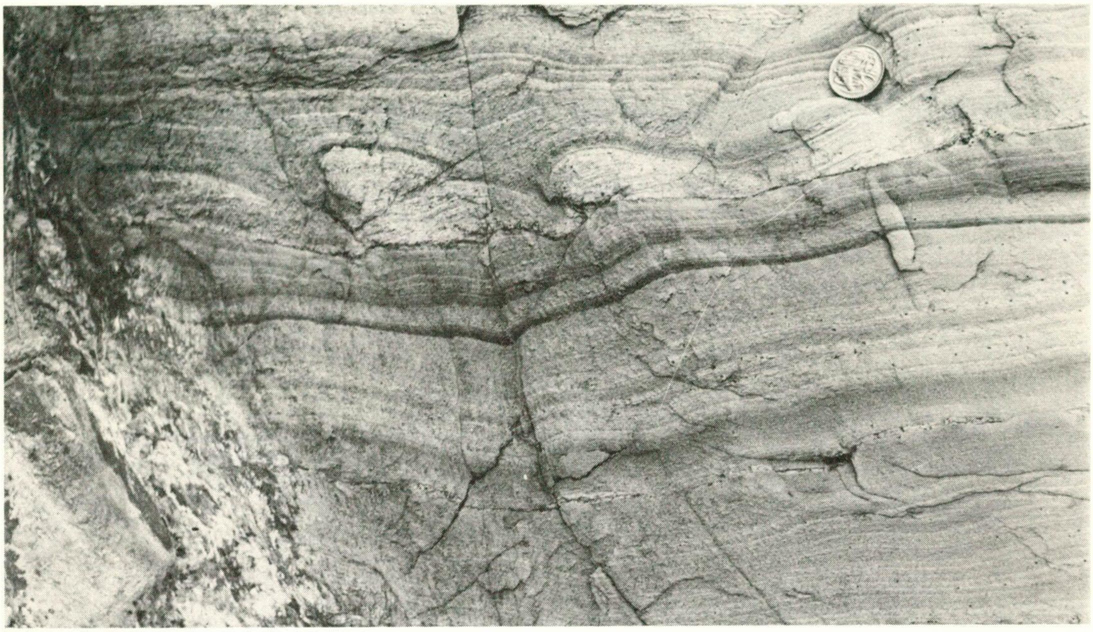


Photo 3. Asymmetric, internally crossbedded ripple marks in laminated siltstone of Zone A, 1.6 km northeast of Euro Gorge (GR 552296)

biotite. The foliation in the matrix wraps around these porphyroblasts, and quartz-filled pressure shadows are commonly developed. Some of the spots show the typical diamond-shaped outline of andalusite, and are composed of fine-grained mica. Relict porphyroblasts of andalusite were observed in a single thin section, and also relict rectangular porphyroblasts which resemble chloritoid and are very rich in iron oxides. Pressure shadows were observed adjacent to these porphyroblasts. Chloritoid porphyroblasts are developed in the phyllites adjacent to the pegmatites at the Huel Bijerkerno mine, just north of the Bijerkerno Gorge. These are apparently due to contact metamorhphism of the country rocks by the intrusive pegmatite.

ZONE B (pεwB)

Zone B is characterized by the development of prograde andalusite and chiastolite schists and retrograde chloritoid schist. It is of higher metamorphic grade than Zone A. Rose (1968, 1970) considered that the boundary between his "Bijerkerno Beds" (Zone A) and the Willyama Complex (Zones B to G) was an unconformity. However, Meares (1969) found no evidence to support this contention and considered that there was no break in the sequence. Other rock types present in this zone are quartz - mica schist, a horizon of calc-silicate rock, phyllite containing large amounts of carbonaceous material, and quartzite. The quartz - mica schist often contains small micaceous spots similar to the spots developed in the phyllites of Zone A.

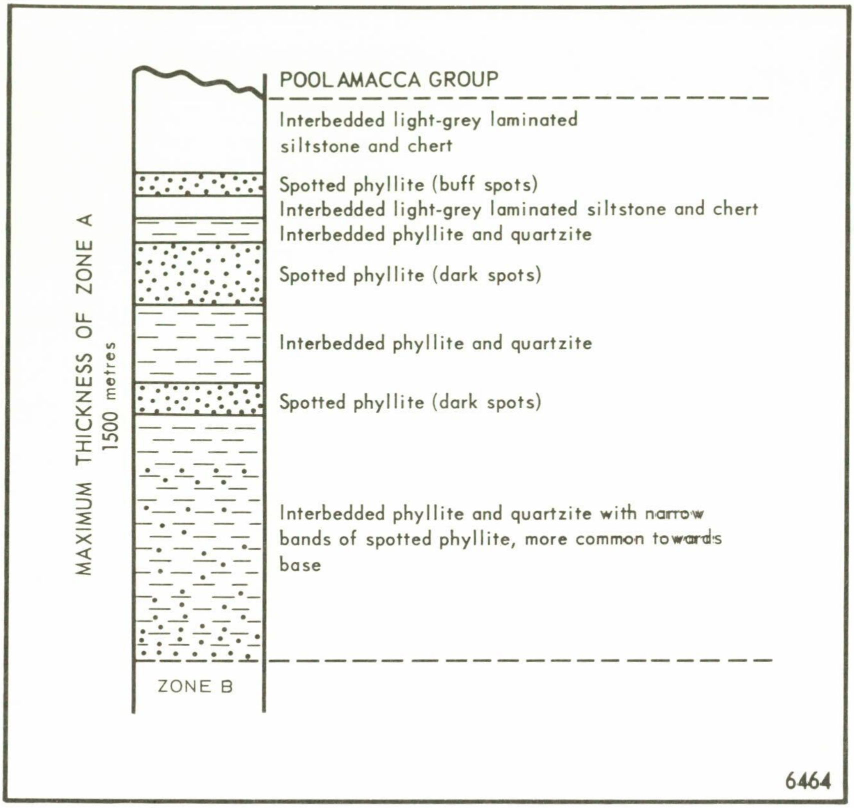


Figure 11. Stratigraphic column of Zone A (modified from Meares 1969)

In the andalusite schist, andalusite breaks down to sericite but still maintains its typical shape and is enclosed by the S_1 schistosity.

The chloritoid in the chloritoid schist is usually obliquely oriented to a pink, foliated, sericite matrix. The chloritoid also occurs within, but does not pseudomorph, retrogressed andalusite.

A 1 to 6 m thick calc-silicate rock band is also present and can be traced around the Bijerkerno Syncline. This rock consists of tremolite with minor clinozoisite, quartz, calcite, and sericite, and is folded into near isoclinal F_1 folds in the nose of the major syncline.

Zone B is the best in which to establish the relationship between stratigraphy and imposed metamorphism because of the well-preserved bedding (photo 4) and easily distinguishable rock types.

Several rock units can be traced around the major fold (the Bijerkerno Syncline) for a total distance of 14 km. The zone has a maximum thickness of 900 m.

A stratigraphic column of Zone B is shown in figure 12.

Petrography

The assemblages of Zone B are characterized by andalusite,

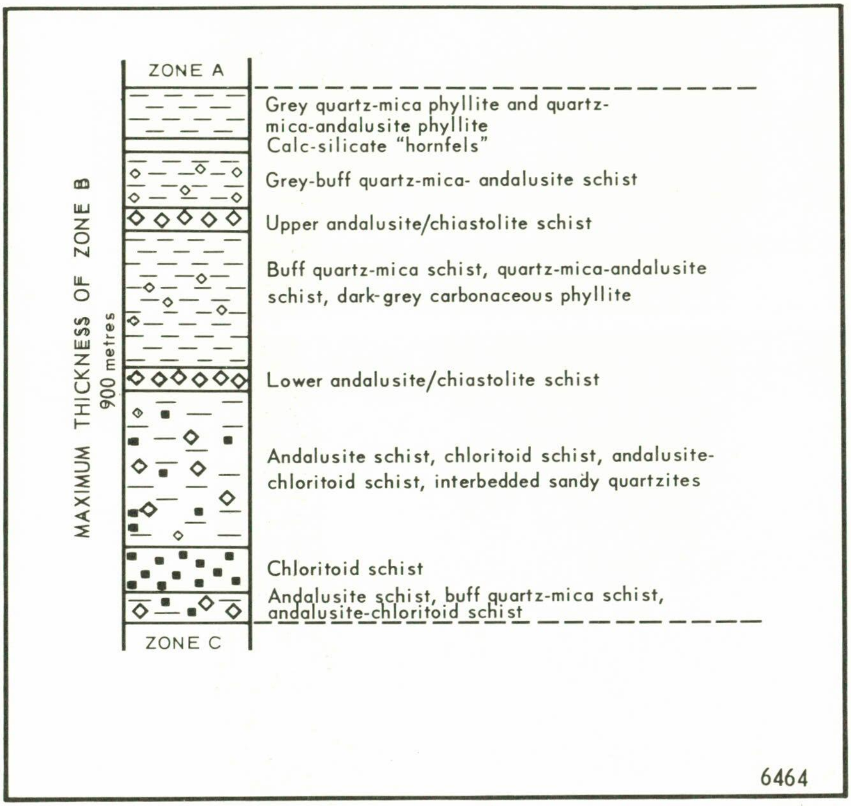


Figure 12. Stratigraphic column of Zone B (modified from Meares 1969)

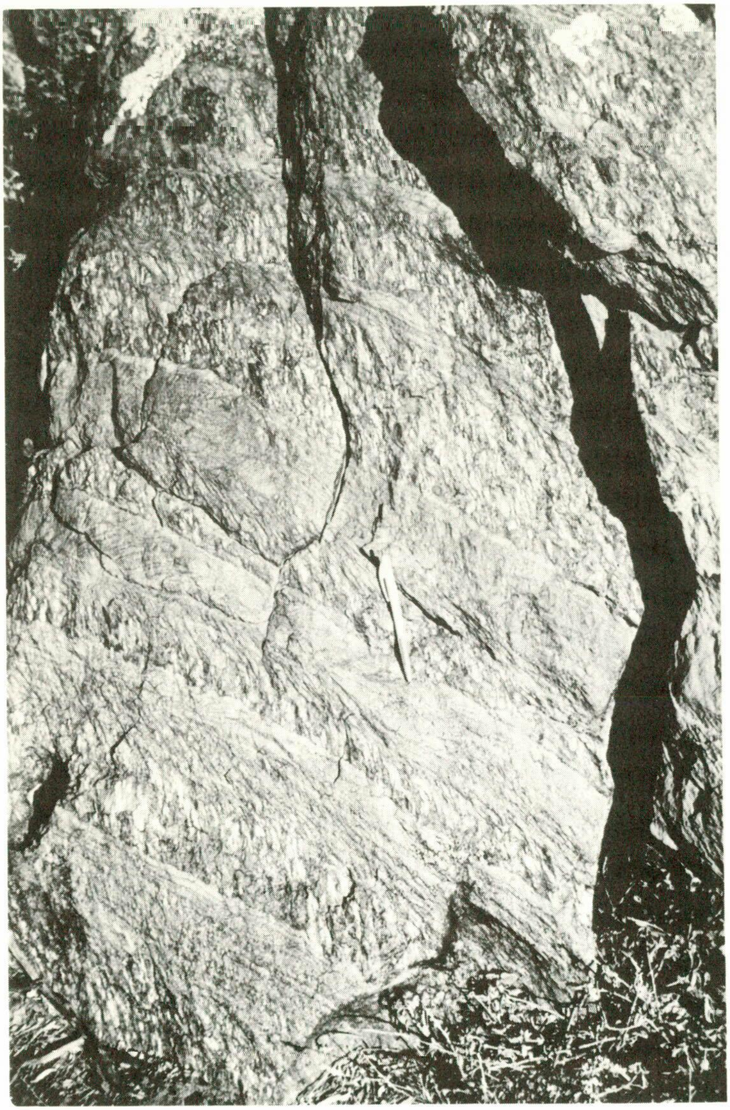


Photo 4. Metamorphically reserved graded bedding in andalusite schist of Zone B. The specimen is overturned. (GR 573225)

chiastolite, or chloritoid. Typical assemblages include

(a) andalusite - quartz - muscovite - biotite - sericite,

(b) andalusite - quartz - muscovite - chlorite - sericite,

(c) chiastolite - quartz - muscovite - biotite - sericite,

(d) chloritoid - quartz - sericite - muscovite - biotite - chlorite,

(e) tremolite - clinozoisite - quartz - calcite - sericite, and

(f) quartz - muscovite - chlorite - biotite - sericite.

Andalusite porphyroblasts are partly or completely retrogressed to fine-grained mica, but often retain the diamond shape typical of andalusite. Chiastolite is oval in cross section. The characteristic cross formed by the arrangement of carbonaceous material is quite distinct in chiastolite, while andalusite has expelled the carbonaceous material and it often forms a rim around each porphyroblast. Where complete alteration to mica (sericite(?)) has occurred, the shape of the original andalusite or chiastolite porphyroblast is roughly preserved. The matrix consists of recrystallized quartz, muscovite, and biotite, the last being filled with small inclusions of quartz and chlorite. These minerals are intergrown to give the schist a subparallel foliation which encloses the andalusite and chiastolite porphyroblasts. Pressure shadows filled with polygonal quartz and chlorite often occur adjacent to the porphyroblasts.

Chloritoid is present only within large masses of sericite, many of which were originally andalusite. The foliated matrix in the chloritoid schist is similar to the matrix in the andalusite schist, consisting of muscovite, biotite, chlorite, and sericite. The foliation wraps around the chloritoid porphyroblasts. The chloritoid is often full of small inclusions of quartz, and commonly shows lamellar twinning. The foliation developed in the matrix of the chloritoid schist is a later phenomenon, as it encloses relicts of biotite and quartz containing a pre-existing foliation oblique to the main foliation seen in thin section. This was also found to be the case in several other thin sections of quartz - mica schists, in which the main foliation measured in the field was interpreted to be the first foliation developed, but later microscopic observation indicated that a foliation (preserved in relicts) pre-dated this foliation. This problem is discussed in detail in the section on "Structural Interpretation".

The calc-silicate rock mentioned above (page 24) contains mostly tremolite (present as unorientated prismatic crystals), together with minor clinozoisite, quartz, calcite, and sericite. No foliation is present and the texture is granoblastic.

ZONE C (p∈wC)

Sillimanite schist characterizes Zone C. The sillimanite occurs in radiating clusters averaging 10 mm in diameter. The rocks are further characterized by small plates of biotite which give the schist a speckled appearance. Much of the sillimanite has been retrogressed to sericite, and in places delineation of Zone D is difficult. Bedding is preserved and averages 70 mm but reaches 0.3 m in thickness. The best examples of sillimanite schist interbedded with quartzite occur on the road to "Poolamacca" from "Bijerkerno", west of Caloola Creek (GR 557217).

The Zone C/Zone B boundary is a gradational one. K.D. Tuckwell (pers. comm.) has found a small overlap between andalusite and sillimanite assemblages. In this area of overlap, andalusite and sillimanite co-exist.

Petrography

Sillimanite characterizes the assemblages of this zone, and occurs in both quartzite and sericite schist. The sillimanite-bearing assemblages include

(a) sillimanite - microcline - quartz - muscovite - sericite - biotite

(b) sillimanite - quartz - chlorite - muscovite - biotite, and

(c) sillimanite - quartz - sericite - biotite - chlorite.

Sillimanite, much of which has been retrogressed to sericite, occurs as large, unoriented masses of fibrous needles. Sillimanite is also intergrown with polygonal quartz. In these intergrowths the needles show a radiating arrangement and have not been altered to sericite.

Large muscovite plates have broken down in part to sericite, and are bent. Fresh muscovite has developed obliquely to the foliation which is defined within the muscovite by small, parallel, sillimanite needles. Biotite, which is altered to chlorite in places, often occurs in aggregates with recrystallized quartz grains.

The quartzite within this zone exhibits the effects of directed stress, as quartz grains are elongate and show undulose extinction, while sericite and chlorite laths emphasize the foliation defined by the quartz grains. A little albite is present in some of the quartzites.

The retrograde sericite schist of this zone is similar to that of Zone D. In most of the assemblages, small sillimanite needles, mostly retrogressed to sericite, are present within recrystallized quartz mosaics. Biotite, altered to chlorite plus quartz in part, is enclosed by the sericitic foliation, and narrow laths of muscovite have developed along the cleavage planes of the biotite. Thus, biotite and the large muscovite plates which are enclosed by the regional foliation are often bent. Where the muscovite plates occur at a high angle to foliation, pressure shadows have developed adjacent to the plates and these pressure shadows are filled with mosaics of recrystallized quartz and chlorite. Crosscutting muscovite plates enclosing the foliation are also developed.

ZONE D (pεwD)

Zone D is narrow. It contains quartz - sericite and quartz - muscovite - sericite schists, and generally lacks any interbedded quartzite.

Petrography

The sericite and muscovite schists present in this zone contain the following assemblages:

(a) quartz - sericite - muscovite, and

(b) quartz - sericite - chlorite - muscovite.

The schists have a cataclastic texture and the effects of retrogression are pronounced. Quartz has sutured boundaries, shows undulose extinction, and is often recrystallized into unstretched aggregates of small polygonal grains. Fine-grained sericitic aggregates form the major part of the assemblages, and in those assemblages richest in sericite the foliation is obscured by the aggregates.

Two generations of muscovite are present. The first generation forms large plates which are enclosed by the sericite foliation and are often partially sericitized. The second generation is quite fresh and developed obliquely to the foliation, which does not wrap around the muscovite plates. These crosscutting muscovite plates are observable in hand specimen and characterize many of the schists of this zone.

ZONE E — EASTERN PORTION (pεwE)

The major rock types present in the eastern portion of Zone E are quartzo-feldspathic gneiss and amphibolite. However, to the west there is an increasing amount of sericite and chlorite schist.

The quartz - feldspar gneiss contains quartz, pink K-feldspar, and biotite. The average grainsize is about 1 - 2 mm. Discontinuous mineralogical layering up to 3 mm in width is also present. Some of the larger bodies have been shown on the map as pεwr - granite gneiss.

The amphibolites consist predominantly of hornblende and quartz. The coarse-grained amphibolites contain 40-60 per cent dark-green hornblende; the fine-grained amphibolites contain 60-80 per cent hornblende; the remainder is mostly quartz but some feldspar is also present. Although the amphibolites are generally garnet free, some garnet-rich amphibolite occurs at approx. GR 503243 , 6 km northwest of Tex's bore (bore is at approx. GR 5341191).

The retrogressed schists become more prominent westwards, and are generally a greenish colour in hand specimen. They consist of abundant highly strained quartz, shredded muscovite mica, sericite, and chlorite.

Petrography

The characteristic metamorphic assemblages in this zone of quartzo-feldspathic gneiss and amphibolite, are listed below.

The amphibolites contain

(a) quartz - hornblende - plagioclase - ilmenite,

(b) quartz - hornblende - plagioclase - clinozoisite - ilmenite, and

(c) quartz - hornblende - chlorite plagioclase - garnet - ilmenite.

The quartzo-feldspathic gneisses contain

(a) quartz - microcline - plagioclase - biotite - sericite, and

(b) quartz - microcline - muscovite - sericite.

The retrogressed schists contain

(a) quartz - muscovite - sericite - chlorite.

The amphibolites commonly contain 25-40 per cent quartz but are usually free of plagioclase. In the amphibolites that do contain plagioclase (not more than 5 per cent), it is labradorite with albite and combined Carlsbad - albite twins. When chlorite is present, it is altered to fine-grained sericite. Where the hornblende has been altered to chlorite, quartz occurs as polygonal mosaics but appears stretched and exhibits undulose extinction. Garnet constitutes up to 10 per cent of some amphibolites, is traversed by chlorite-filled fractures, and contains inclusions of quartz. Hornblende occurs as large, roughly oriented plates, between which are granular aggregates of quartz, clinozoisite, and a little plagioclase, giving the amphibolite a granular texture. The pleochroic scheme is X = yellow, Y = dark brown-green, and Z = deep blue-green. In several sections parallel to (010), narrow twin lamellae with (100) as the twin plane are present.

Retrogression has affected most of the amphibolites. Much of the hornblende has been altered to chlorite, the plagioclase has altered to clinozoisite, and, in some cases, hornblende grains are bent.

Recrystallized polygonal quartz, and large unoriented porphyroblasts of microcline showing a granoblastic texture, characterize the quartzo-feldspathic gneisses of Zone E. Oligoclase, where present, has been partly altered to sericite, while microcline has undergone little retrogression. Biotite has retrogressed to chlorite. Muscovite laths are present within the plane of foliation, which is defined by the thin, subparallel sericite. The effect of stress on the assemblage is expressed by bent twin lamellae in oligoclase, bent muscovite laths, and undulose extinction in some quartz grains. The retrogressed schists show a pronounced schistosity, quartz is severely strained, and sericite is a common constituent. The mosaic texture is no longer present, and muscovite, chlorite, and biotite are often aligned parallel to the schistosity, although some muscovite is often enclosed by the foliation.

Although quartz is usually strained, producing undulose extinction, it is not uncommon to see small aggregates of post-kinematic, recrystallized quartz alongside large strained grains.

Chlorite is a very common constituent and seems to be a product of the breakdown of biotite. Biotite flakes are altered to chlorite around the edges and along the cleavages. The intergrowth of chlorite and muscovite between quartz grains could also be due to the breakdown of biotite.

The plagioclase present shows the development of fine mica along cracks and cleavages, while breakdown to chlorite and mica (paragonite (?)) has been noted.

Almost all these rocks are characterized by large amounts of fine mica, often forming the matrix and showing a schistosity. The source of this "sheaf" mica was probably feldspar or perhaps sillimanite, these being the only minerals available capable of producing such large amounts of mica. In the rocks that have not undergone retrogression, the feldspars tend to show some alteration to sericite(?) and therefore would seem to have been a likely source for the mica.

Garnet, when present, does not show a strong tendency to break down, but chlorite is present along fractures and within the garnet.

ZONE E — WESTERN PORTION (pεwE)

Zone E (western portion) consists predominantly of retrogressed quartz - sericite schist with some minor occurrences of amphibolite.

The quartz is severely strained and chlorite is often shredded, indicating a good deal of cataclastic deformation and associated retrogression. Metatexite (Mehnert 1971) and gneiss are present throughout this combined zone, and amphibolite is common on the western side (Gilligan 1969). Metatexite is very common in the combined zone adjacent to the northernmost portion of Zone F (Gilligan 1969). Chloritoid is developed as a post-kinematic mineral as it grows across Σ_1. (see table 6).

ZONE F (pεwF)

The boundary of Zone F is defined by the first appearance of sillimanite; it is not an isograd as the absence of sillimanite is purely a function of retrogression. Within this zone the rocks are predominantly gneiss, amphibolite, and metatexite with some retrograde schist.

A large belt of amphibolites (pεwa) strikes in a northerly direction along the western margin of Zone F. These amphibolites are extremely quartz rich, but in outcrop have a very dark colour.

In the southwestern portion of this zone several intrusions(?) of quartz norite (εn) have been observed; their relationship to the basement rocks is unknown.

Petrography

The common assemblages are listed below:

The amphibolites contain

(a) hornblende - almandine - plagioclase (oligoclase - andesine) - quartz, and

(b) hornblende - plagioclase (oligoclase - andesine) - quartz.

The gneisses contain

(a) sillimanite - muscovite - microcline - biotite - quartz,

(b) sillimanite - muscovite - biotite - quartz, and

(c) sillimanite - almandine - oligoclase - biotite - muscovite - quartz.

The gneisses commonly have a granoblastic texture. The mineral assemblage is consistent with that of the sillimanite - almandine - muscovite subfacies of the almandine - amphibolite facies (Turner and Verhoogen 1960).

The hornblendes within the amphibolites commonly exhibit triple point textures, while individual grains are free from inclusions and display curved boundaries. The pleochroic scheme of hornblende is X = yellow, Y = dark brown-green, and Z = dark green. The hornblende often displays an edge retrogression effect, a rim of bluish green amphibole (actinolite(?)) having developed at the edge of the hornblende grains.

The feldspar (calcic plagioclase) is most readily retrogressed and alters to clinozoisite.

Quartz is present in most amphibolites and generally constitutes about 25 - 30 per cent of the rock.

Mexatexites are also present and become more common in the northern portion of this zone (Cowan 1969). They are usually restricted to small zones, and a gradation exists between oridinary gneiss and metatexite. Metatexites form from the selective melting and/or mobilization of the low-melting components of the rock; the mafic layers which do not melt become drawn out and, in more advanced stages, become discontinuous wisps. In the present examples the quartzo-feldspathic components seem to have melted, possibly because of a local increase in water pressure and/or temperature. "Fluid" folds are characteristic of these rocks. Throughout the process of metatexis, the more mafic residue (mostly biotite) seems to have remained unmelted. The leucocratic components are quartz, albite, muscovite, and microcline (often altered to sericite).

ZONE G (pεwG)

Zone G consists of a montonous sequence of fine-grained, light-grey to dark-grey, finely laminated siltstones and phyllites, together with some quartzite and chert. The maximum thickness of this zone is estimated to be about 1800 m.

The name WILLYWANGEE (a contraction of WILLYama and TorroWANGEE) was often applied to these rocks because of the uncertainty regarding their age relation to the Willyama Complex and "Torrowangee Series" (Mawson 1912). Tuckwell (1968), Roberts (1969), and Cooper (1969) all considered them to be low-grade Willyama Complex, and the authors agree with this conclusion.

The sediments are all extremely fine grained and well sorted. No graded bedding was observed, although crossbedding and slumping are very common (Tuckwell 1968).

The sediments are finely laminated, the laminations being extremely persistent and traceable as far as outcrop will allow. Dark laminations due to the presence of carbonaceous material constitute as much as 15 per cent of some rocks (Tuckwell 1968).

Another common rock type in this zone is spotted phyllite. The size of the spots varies from about half a millimetre to as large as 20 mm. They are post-depositional; bedding can often be seen passing through them and is sometimes distorted by them. Cleavage wraps around them, indicating that their growth was pre-kinematic. The spots consist of muscovite, sericite, quartz, and some biotite. Tuckwell (1968) considered the spots to be controlled by the original chemical composition of the sediments as they are confined to certain stratigraphic horizons. He considered that they are incipient andalusite; however, they could be retrogressed andalusite.

Quartzite is also present and forms very persistent units. These are usually only 0.5 to 1.5 m thick and are blocky in outcrop and buff coloured in hand specimen. Tuckwell (1968) recorded crossbedding as a common feature of this quartzite.

Pegmatites

Of the three types of pegmatites discussed in this section, only the garnet-bearing ones have been shown on the map. The characteristics of the three types are summarized in table 3.

TABLE 3

CHARACTERISTICS OF THE PEGMATITES OF THE WILLYAMA COMPLEX

Pegmatite type	Occurrence (zone)	Constituent minerals					Structural control	Age
		Quartz	Alkali feldspar	Plagioclase	Muscovite	Other		
Cassiterite bearing	A, B, G	40	Minor	40	15	Tourmaline, cassiterite	Parallel S_1 or S_0	Some pre-F_1 most post-F_1 but pre-F_2
Garnet bearing	B, C, D, E, F	60	1	35	1	Garnet	Parallel to S_1 or Σ_1 or S_o or discordant to S_o, or S_1 or Σ_1	pre-F_1 F_1, ϕ_1 F_2, ϕ_2
Quartzo-feldspathic	All zones except A	40	45	3	22		Parallel to S_1 or S_o	Post-F_1-pre-F_2

CASSITERITE-BEARING PEGMATITES

Cassiterite-bearing pegmatites occur only in Zones A, B and G. On a regional scale, and at individual mines, the cassiterite pegmatites are arranged in a left-handed, en echelon pattern in a north - south trend. This trend reflects the regional influence of F_1 axial plane cleavage. The pegmatites are located in three main groups: south of the Euriowie Tank, centred on GR 582223; west of Mount Pintapah, centred on GR 560280; and from Bijerkerno Gorge to Euro Gorge, centred on GR 553303.

Most pegmatites are parallel to the S_1 direction, except on the western limb of the Bijerkerno Syncline where contrasts in lithology have a greater influence than structural control and many pegmatites are parallel to bedding. At the Lady Don mine (GR 580219), a pegmatite parallel to bedding has been isoclinally folded during F_1.

Although some pegmatites are pre-F_1, most are post F_1 but pre F_2. Generally these pegmatites contain approximately equal proportions of quartz and albite, with some muscovite, much of which has been replaced by sericite, as well as rarer alkali minerals (Meares 1969), tourmaline, and cassiterite.

GARNET-BEARING PEGMATITES (pɛwg)

Garnet-bearing pegmatites occur in Zones B, C, D, E, and F.

Some of these pegmatites are concordant to S_1, or Σ_1 , some are concordant to bedding, and some are discordant to both.

The average composition is: quartz 60 per cent, oligoclase 35 per cent, almandine 3 per cent, orthoclase 1 per cent, and muscovite 1 per cent.

In the lower grade zones the intrusive nature of these pegmatites is shown by metasomatic development of tourmaline and garnet in enclosing schist for 0.15 to 0.3 m out from the contact. In most cases the metasomatism occurs only on the eastern side of the pegmatite. The eastern side of the pegmatite is the stratigraphically higher side, and the concentration of minerals on this side suggests the pegmatite was intruded while the bedding was near horizontal.

QUARTZO-FELDSPATHIC PEGMATITES

The controls on orientation of the quartzo-feldspathic pegmatites are similar to those acting on the cassiterite-bearing pegmatites. They are parallel to S_1 in the nose of the Bijerkerno Syncline and parallel to bedding on the limbs of the syncline.

This type of pegmatite occurs in all zones except Zone A and is characterized by the preponderance of microcline over sodic plagioclase. A typical assemblage is: microcline 45 per cent, quartz 40 per cent, muscovite 2 per cent, sericite 20 per cent, and albite 1 per cent.

Original Rock Types

The mineral assemblages of the metamorphic rocks indicate that the original sequence consisted of interbedded argillaceous and arenaceous sediments, some basic rocks, and minor dolomite towards the top.

Amphibolites can be formed by the metamorphism of calcareous sediments, basaltic dykes/lavas, or basic tuffs. Binns (1963) considered the amphibolites of the Broken Hill area to be of basaltic origin in spite of their high iron and low alkali content (relative to basalts). The amphibolites of the Willyama Complex in the Torrowangee - Fowlers Gap area have high quartz and iron-oxide content, which would seem to preclude either a basaltic or calcareous sediment origin. They are probably metamorphosed basic tuffs.

Structural Geology

The structure of the area is dealt with in two sections, viz: Zones A, B, and G (the low-grade rocks), and Zones C, D, E, and F (the higher grade rocks). This division is necessary because the exact structural relationships between the boundaries of the low-grade rocks and the high-grade rocks is unknown.

The fabric elements associated with Zones A, B and G (the low-grade rocks) are shown in table 4.

STRUCTURE WITHIN ZONES A, B, AND G (the low-grade rocks)

Mesoscopic F_1 folding has formed the major structural feature in the Bijerkerno area, the *Bijerkerno Syncline* (nov.) which plunges towards 345°M at 30° - 70°, increasing to the south. Bedding is the form surface of this fold and is easily recognizable in places on the western limb and in the nose area. The eastern limb is mostly concealed by sediments of the Adelaide System.

The orientation of mesoscopic F_1 folds varies but there is an overall plunge varying from 30° to 60° to the north. The mesoscopic folds are confined to the eastern, lower grade part of the area. They are well developed in a thin "calc-silicate" horizon, which has been intensely folded during F_1 folding into a series of near-isoclinal folds. These folds have an amplitude of 20-30 m and a wave length of 2 - 12 m. They have vertical to subvertical axial planes and shallow northerly plunges, although plunge reversals do occur such as at the Lady Don mine near "Bijerkerno" homestead. At this locality, near-isoclinal folds in

TABLE 4

FABRIC ELEMENTS OF ZONES A, B, AND G

Episode	Element	Symbol	Components/Results	Remarks
	Bedding	So	Grading, ripples	Minor slumping
F_1	Slaty cleavage Fold axis Lineation Spot lineation	S_1 B_1 L_1 L_s	 $B_1 = B^{S_1}_{S_o}$ $L_1 = S_o \wedge S_1$ In S_1, perpendicular to B_1	
F_2	Cleavage Fold axis Lineation	S_2 B_2 L_2	Crenulates S_1 $B_2 = B^{S_2}_{S_1}$ $L_2 = S_1 \wedge S_2$	

$\wedge$ = intersection

S_o with vertical axial planes plunge shallowly to the south.

The buckling of the calc-silicate horizon reflects the high contrast in viscosity between these rocks and the enclosing phyllites. The degree of buckling is also partly a function of the thickness of the horizon. The low-viscosity phyllite has shortened by homogeneous strain, whereas the thin, highly viscous, calc-silicate horizon has shortened by buckling. The features that are consistent in both macroscopic and mesoscopic folds are nose thickening, planar limbs, and planar axial surfaces.

S_o — Bedding

Bedding is well preserved throughout the area and defines a large north-plunging syncline, the Bijerkerno Syncline. Rose and Brunker (1969) referred to this structure as a synform, but facing structures within these rocks indicate that the synform is in fact a syncline. Bedding is recognized by gross lithological changes. Sedimentary structures such as crossbedding, ripple marks, slumping, and ball and pillow structures are often well developed in these lower grade metamorphic rocks. The major rock types developed are light-grey laminated siltstone, chert, and spotted phyllite.

F_1 Folding

S_1 — Slaty cleavage

The slaty cleavage S_1 formed parallel to the axial plane of the F_1 folds and is developed throughout the area except where it has been obliterated by a later foliation (S_2) in the western part of Zone B. S_1 developed as a slaty cleavage in the low-grade rocks, and encloses porphyroblasts of andalusite, chiastolite, and chloritoid as well as spots in the spotted phyllite. In the finer grained schist and phyllite, movement along the plane of S_1 has in some cases resulted in the transposition of thin bedding laminae into the plane of S_1.

In the low-grade rocks in the nose of the Bijerkerno Syncline, S_1 is at a high angle to S_o. On the limbs it was found that S_1 in the pelitic rocks was parallel to S_o, while in the adjacent psammites S_1 is inclined at a high angle to S_o. The difference in orientation of S_1 is due to the lithological variation, a refraction of S_1 occurring at the interface of psammitic and pelitic rocks.

L_1 — Lineation parallel to the group 1 fold axis

L_1 is the intersection of bedding (S_o) and the slaty cleavage (S_1).

L_s — Spot lineation

A second lineation (L_s) was recognized within the plane of S_1, and is defined by the parallel alignment of elongate, dark, micaceous spots. This lineation generally plunges steeply to the south and is inclined at approximately 90° to L_1. These spots probably represent retrogressed, small andalusite porphyroblasts which have been rotated into the kinematic "a" direction during deformation. A similar lineation is developed in the low-grade Willyama Complex rocks west of "Poolamacca" station. The significance of this lineation has been discussed in greater detail by Tuckwell (1968).

The F_1 episode is characterized by considerable shortening — illustrated by the folding of the calc-silicate rock in the nose of the Bijerkerno Syncline. The chief mechanism involved in the folding is considered to be flexing, where the more viscous units buckled and the less viscous units underwent homogeneous strain with cross-laminar flow and the generation of an axial plane cleavage.

F_2 Folding

On a macroscopic scale, F_2 folding has formed a large warp in the western limb of the Bijerkerno Syncline. F_2 folds are observed on mesoscopic and mesoscopic scales, and have been recognized on the basis of their style and overprinting relationships.

F_2 is not penetrative throughout the "Bijerkerno" area, and on a mesoscopic scale is best developed in the fine-grained, less competent, lower grade schists and phyllites. Mesoscopic F_2 folds are characterized by planar, inequant limbs and angular hinges. In many F_2 folds no foliation is developed parallel to the axial plane, while in others, intense crenulation cleavage (S_2) plicates the folded S_1 surface. F_2 folds plunge from north to slightly west of north at varying angles; the usual angle is about 40°. The axial plane (S_2) dips steeply east or west and its strike is variable, ranging from 325° M to 045° M.

L_2 — Crenulation lineation

The lineation L_2, formed by the intersection of S_1 and S_2, plunges shallowly to the north and is subparallel to the fold axis of the F_2 folds.

STRUCTURE WITHIN ZONES C, D, E, AND F (the high-grade rocks)

West and north of "Bijerkerno", in the higher grade metamorphic rocks, amphibolites are commonly developed, along with ubiquitous pegmatite and gneiss. These rocks have been subjected to two major periods of folding, as is the case for the low-grade Willyama Complex in the Bijerkerno area. It is suggested that the two folding periods in the higher grade rocks are equivalent to the two periods in the low-grade rocks.

The earliest recognizable surface is lithological layering Σ_0; defined by the alternation of pelitic and psammitic horizons. A schistosity ($\Sigma_{0,1}$) is strongly developed in the pelites in the immediate vicinity of the more resistant sandy units. This schistosity is crenulated by Σ_1 adjacent to the more resistant psammites. However, within the pelites occurring away from the psammite contact, $\Sigma_{0,1}$ is the not recognizable in hand specimen and is only occasionally identified in thin section as a relict schistosity which has been partly transported into Σ_1.

The fabric elements associated with Zones C, D, E, and F are shown in table 5.

ϕ_1 Folding

ϕ_1 folding is characterized by a well-developed schistosity (Σ_1) parallel to the axial plane of the folds in the lithological layering (Σ_0). The folds are easily recognized on both mesoscopic and microscopic scales, but no individual macroscopic folds were observed. The folds developed within the psammitic horizons generally have considerable nose thickening which indicates a degree of flattening. The folding within the migmatites is attributed to this phase of deformation. These folds are polyclinal or chaotic in style. The geometry of the folding in the

TABLE 5

FABRIC ELEMENTS OF ZONES C, D, E, AND F

Episode	Element	Symbol	Components/Results	Remarks
	Lithological layering	Σ_o		Probably bedding
ϕ_1	Gneissosity	Σ_g	Parallels Σ_o	*Mineralogical layering
	Schistosity	$\Sigma_{o,1}$	Parallels Σ_o	* Poorly developed
	Schistosity	Σ_1		Strongly developed transposition of Σ_o
	Fold axis	Δ_1	$\Delta_1 = \Delta^{\Sigma_1}_{\Sigma_o}$	Crenulation lineation
	Lineation	λ_1	In Σ_1, parallel to Δ_1	Mineral streaking
ϕ_2	Schistosity	Σ_2	Crenulates Σ_1	Crenulation schistosity
	Fold axis	Δ_2	$\Delta_2 = \Delta^{\Sigma_2}_{\Sigma_1}$	
	Lineation	λ_2	$\lambda_2 = \Sigma_1 \wedge \Sigma_2$ parallel Δ_2	
RETRO-GRADE	Schistosity	Σ_R	Parallel to Σ_1	
ϕ_3	Schistosity	Σ_3	Axial plane to folds in Σ_R	Zones E, D
			Chevron folds in Σ_1	Relationship to ϕ_2 not known
	Fold axis	Δ_3	$\Delta_3 = \Delta^{\Sigma_3}_{\Sigma_R}$	

* The relationship of these two surfaces to ϕ_1 is problematical - see "Structural Interpretation"

$\wedge$ = intersection

non-migmatitic rocks is planar, non-cylindrical.

Σ_1 — *Axial plane schistosity*

Σ_1 is a schistosity developed parallel to the axial planes of the folds of this phase. Within the schists this surface is extremely well developed, and within the psammites is represented by a fracture cleavage. The pegmatites occasionally have this cleavage present with muscovite developed along the cleavage planes. In thin section this schistosity is often represented by entrained sheaves of fine mica (sericite), and fracturing of quartz is ubiquitous. It would appear that the tectonism that led to the formation of Σ_1 has been responsible for a considerable amount of cataclastic deforamtion. It is thought that this folding is associated with a phase of intense retrogression. This deformation probably greatly facilitated mineral breakdown during the waning phases of the first major metamorphism.

Originally Σ_1 was apparently a crenulation schistosity. Relict hooks, the presence of a discordant schistosity cut by Σ_1, and the presence of matrix lenticles of an earlier fabric all suggest that a pre- Σ_1 foliation (schistosity) exists. This has been termed Σ_o^1, and will be discussed later in the "Structural Interpretation" section.

As well as $\Sigma_{o,2}$ another pre- Σ_1 surface is recognized and is a gneissosity (Σ_g). This surface is developed in the gneisses, granitic gneisses, and some amphibolites. It maintains a strict parallelism to bedding and may be equivalent to the $\Sigma_{o,1}$ surface.

λ_1 — *Lineation parallel to* $\Delta^{\Sigma_1}_{\Sigma_o}$

A lineation λ_1 is developed parallel to the fold axis of ϕ_1 folds. The intersection of schistosity (Σ_1) and gneissosity (Σ_g) produces a striping on the surface of Σ_1. This lineation is parallel to the ϕ_1 fold axis. In the hinge areas of ϕ_1 folds a crenulation lineation is developed due to the intersection of $\Sigma_{o,1}$ and Σ_1. This lineation does not occur everywhere and is best developed in the nose area of ϕ_1 folds adjacent to folded psammite horizons.

ϕ_2 *Folding*

The schistosity Σ_1 is deformed by a second phase of folding with a well-developed crenulation schistosity (Σ_2) which is parallel to the axial plane of the folds. Macroscopic ϕ_2 folds are developed and plunge plunge 30° to 032° M. Large folds of this phase are developed northeast of "Corona" homestead and also northwest of Torrowangee quarries.

A thin pegmatite horizon provides a good "marker bed" for the definition of the structure northeast of "Corona" homestead. In the nose area of this fold there are well-developed crenulations of Σ_1, some crenulations being up to 30 mm in wavelength.

The structural features developed northeast of Torrowangee quarries occur in an amphibolite horizon. Σ_1 is nearly parallel to the amphibolite and is deformed by a later cleavage (Σ_2) which has strain slip characteristics. The mesoscopic folds are characteristically asymmetric, with a strongly developed crenulation schistosity and associated crenulation lineation developed parallel to the fold axis. Mesoscopic ϕ_2 folds are not strongly developed, and where they do occur are often on the limbs of ϕ_1 folds. The fold axis to the ϕ_2 folds plunges to the south at 60° and is subparallel to $\Delta_1 = \Delta^{\Sigma_1}_{\Sigma_0}$.

ϕ_3 Folding

ϕ_3 folding is developed in Zones E and D west of "Bijerkerno". The form surface of the folding is a well-developed schistosity (Σ_R) which is thought to be a retrograde surface associated with the breakdown of higher grade metamorphic mineral assemblages. Σ_R is parallel to Σ_1, and strikes 150° M - 170° M and dips to the east at 40° - 50°. The folding of Σ_R has produced northeasterly plunging folds with an axial plane schistosity (Σ_3). Gilligan (1969) recorded the presence of shallowly plunging (to 022° M) chevron folds in Σ_1 in the area east of "Corona". These may be related to the chevron folds in Zones E and D.

Kink banding has been recorded by Gilligan (1969), Cooper (1969), and Cowan (1969), but its relationship to ϕ_2 has not been observed and it is tentatively considered to be a ϕ_3 phenomenon.

STRUCTURAL INTERPRETATION

The rocks under consideration have been divided into high-grade and low-grade rocks and the structural observations have been presented separately. However, the authors consider that correlation of the various periods of folding is possible. It is felt that F_1 and ϕ_1 correspond, and that S_1 and Σ_1 are the same surfaces but generated in rocks of differing grade. It is also possible that F_2 and ϕ_2 correspond; however, no relationships between the surfaces generated by these periods were observed.

Two periods of folding (F_1, F_2 in low-grade rocks, and ϕ_1, ϕ_2 in high-grade rocks) can be established. Within the areas mapped the relationships of F_1 to F_2 and of ϕ_1 to ϕ_2 have been determined by overprinting relations observed in the field and through the microscope.

In Zone D a retrograde schistosity (Σ_R) has formed parallel to Σ_1 and is tentatively placed after ϕ_2. Another period of folding (ϕ_3), post-dating both ϕ_1 and ϕ_2, has been proposed. This period is known to be older than ϕ_1 from overprinting relationships but its age relative to ϕ_2 is unknown.

A pre-existing schistosity ($\Sigma_{0,1}$) parallel to a gneissic layering predates the first period of folding. The origin of this foliation is uncertain.

Numerous mesoscopic folds were observed in which bedding and a parallel schistosity ($\Sigma_{0,1}$) were the form surfaces. This parallelism of schistosity and bedding has made interpretation of the relative ages of the foliations difficult because of the considerable difference of opinion as to the origin of the schistosity ($\Sigma_{0,1}$).

Folds in pelitic rocks which contain beds of competent quartzite often display a foliation parallel to the quartzite/pelite interface in the nose areas. The axial plane structure which is developed in the pelitic horizons in the nose area of the fold has crenulation characteristics; however, further away from the quartzite/pelite interface the crenulation characteristics of the axial plane schistosity are lost as the foliation parallel to the interface is not developed. Sometimes the presence of a relict foliation is pervasive for distances up to several metres from the quartzite/pelite interface. Away from the competent horizons the axial plane foliation grades from a crenulation schistosity to a schistosity with no obvious crenulation characteristics.

Thus, it seems that the foliation parallel to the interface between the competent and non-competent horizons may have been formed during folding by a concentric shear mechanism. This concentric shearing aligned the platy micas at the interface, forming a foliation. However, further away from the interface the influence of the concentric shear was less and a foliation did not develop. Consequently, when the axial plane schistosity formed, the crenulation characteristics were only produced adjacent to the interface.

An alternative explanation for the foliation was suggested by Cowan (1969). He defined the bedding foliation as a pre-kinematic, metamorphically produced compositional layering representing recrystallization of psammitic/pelitic horizons. The micas which grew in the pelitic layers were random in orientation and did not necessarily produce a schistosity ($\Sigma_{0,1}$). Any subsequent deformation of these pre-kinematic micas would produce crenulation characteristics. An example given by Cowan indicates that bedding foliation can form by the mechanism he suggested. In this example a unit from the low-grade Willyama Complex showed crossbedding, and parallel to each crossbed set was a foliation. From this example it would seem that a bedding foliation was present and this could explain the presence of pre-kinematic muscovites contained within the Σ_1 foliation.

Cowan (1969) extended this mesoscopic example to indicate the mechanism for the regional parallelism of bedding and schistosity. The extension of this argument is not convincing, as the very foliation that Cowan explained as a bedding foliation often contains the pre-kinematic muscovite which he regarded as a relict bedding foliation.

Both of the forementioned mechanisms are of local significance, but do not adequately explain the regional parallelism of lithological layering and schistosity in Zones E and F. A period of deformation producing transposition would seem to be the most logical solution to the problem. Cowan (1969) has reported intrafolial folds in Zone E (west), but transposed fold hinges are not observed in other zones. However, there is a general lack of conclusive evidence for transposition. At this stage in our knowledge it would seem inadvisable to propose a period of transposition prior to the major period of deformation ϕ_1. This problem requires further study.

Metamorphism

The distribution of metamorphic grades in the Euriowie Block will be discussed in terms of metamorphic zones. The zone boundaries shown on the accompanying map are not necessarily isograds as defined by Tilley (1924), as each zone represents the maximum areal distribution of a specific index mineral.

The concept of a metamorphic facies series was introduced by Miyashiro (1961), who suggested that each facies series involves a definite regional distribution of temperature and pressure and that each individual metamorphic area is characterized by a particular facies series.

The mineral assemblages present in the "Bijerkerno" area are typical of the andalusite - sillimanite - type facies series. This facies series is formed under low-pressure conditions and is characterized by the stability of andalusite in lower temperature zones and of sillimanite in higher temperature zones. Kyanite, staurolite, and glaucophane (which characterize other facies series) are absent. The andalusite - sillimanite-type facies series has been studied in detail in the Central Abukuma Plateau of Japan by Miyashiro (1961) and his co-workers, and is known as the Abukúma-type facies series. Winkler (1967) has divided the Abukuma-type facies series into the greenschist facies and the cordierite - amphibolite facies.

The quartz - chlorite - biotite - muscovite assemblages of Zone A are typical of the lowest temperature subfacies of the greenschist facies, the quartz - albite - muscovite - biotite - chlorite subfacies. Tremolite - clinozoisite - calcite rocks would also be within this subfacies, as, in the higher temperature subfacies of the Abukuma type, hornblende is characteristic of the basic assemblages.

The andalusite and chloritoid-bearing assemblages of Zone B fall within the higher temperature subfacies of the greenschist facies, the quartz - andalusite - plagioclase - chlorite subfacies.

In Zones C, and F, sillimanite occurs together with muscovite, almandine, and a limited amount of orthoclase. This assemblage is consistent with the sillimanite - cordierite - muscovite - almandine subfacies of the cordierite - amphibolite facies. However, unlike the Abukuma area, cordierite has not been observed.

This is the medium temperature subfacies, in which muscovite is stable in the presence of quartz. The elimination of muscovite in favour of orthoclase indicates the highest subfacies of the cordierite - amphibolite facies. Some orthoclase is present in Zones C, and F, but it is not widely developed. The presence of cordierite is again not recorded.

Thus, the metamorphic assemblages present in the "Bijerkerno" area are typical of the greenschist and cordierite - amphibolite facies of the Abukuma - type regional metamorphism (for further references see Turner 1968).

ORIGIN OF ANDALUSITE

Experimental work (Holdaway 1971) has suggested that andalusite forms by low-pressure/low to medium-temperature metamorphism of hydrated aluminium silicates such as pyrophyllite. Pyrophyllite is present in rocks rich in alumina and low in alkalis, and forms through the metamorphism of kaolinite. With increasing temperature, pyrophyllite changes to andalusite under conditions of low H_2O pressure, and to kyanite under conditions of high H_2O pressure.

The spots developed in some of the phyllites of Zone A are believed to represent both incipient and retrogressed andalusite porphyroblasts. The incipient spots are those preserved in the very early stages of their formation. They formed under conditions of temperature and pressure slightly lower than those necessary for the formation of andalusite. Some spots show the typical diamond shape of andalusite, although they are composed of sericite and micas. These spots are probably small, retrogressed andalusite porphyroblasts.

ORIGIN OF CHLORITOID

Chloritoid is developed only within large aggregates of fine-grained sericite, which in places pseudomorph andalusite. Where a foliation is developed within the aggregates of sericite, it wraps around the chloritoid porphyroblasts, which lack any orientation and often develop as rosettes. It is concluded that chloritoid developed prior to the period of retrograde metamorphism, during a phase of metamorphism lacking directed stress. The apparent intergrowth of chloritoid and andalusite (now sericite) indicates that chloritoid developed during the first phase of regional metamorphism, prior to the first period of deformation.

Chloritoid is an iron-aluminium silicate which occurs in rocks high in alumina and low in potash, lime, and soda. Until recently chloritoid was believed to develop only under conditions of high stress. However, recent investigations have shown that chloritoid can develop in stress-free conditions, and Halferdahl (1961) concluded that stress has little effect on the stability of chloritoid and that the role of shearing stress, if present, is to facilitate the introduction of material not already present but necessary for the development of chloritoid.

Staurolite, the higher grade equivalent of chloritoid, has not developed in the "Bijerkerno" area, possibly due to the fact that where the temperature and pressure conditions necessary for the formation of staurolite were developed, the chemical composition of the present rocks was not suitable, and vice versa. Browne (*in* Andrews 1922) and Anderson (1966) attributed the formation of chloritoid at Mount Robe to late-stage retrograde metamorphism, by which andalusite and biotite break down in the presence of water to form chloritoid and muscovite. The occurrence of apparently fresh chloritoid within retrogressed andalusite porphyroblasts in the "Bijerkerno" area supports a retrogressive origin for the chloritoid, except for the fact that the retrograde schistosity wraps around the chloritoid porphyroblasts and thus post-dates the development of chloritoid.

Origin of Sillimanite

The aggregates of sillimanite needles in rocks of the "Bijerkerno" area exhibit little evidence to indicate the phase of metamorphism during which they develop. The aggregates of sillimanite show little orientation, and any orientation they do show is believed to be due to imprinting of the retrograde schistosity on the rock. Sillimanite occurs within a stratigraphic horizon of higher grade than the andalusite-bearing horizon, and it is suggested that the temperature and pressure conditions were slightly greater in the stratigraphically lower, sillimanite-bearing horizon during the first period of regional metamorphism. This would have allowed the development of sillimanite instead of andalusite. The sillimanite occurs with microcline, an assemblage belonging to the high-temperature grade of Francis (1956):

muscovite + quartz→sillimanite + K-feldspar + water

As noted earlier, the appearance of microcline in the sillimanite schists appears to have been a relatively late development. This suggests that there may have been two generations of sillimanite, with the development of microcline from quartz and muscovite during the second phase.

There appears to be a small overlap between the andalusite and sillimanite-bearing assemblages. The transition from the andalusite stability field to the sillimanite stability field is dependent on both pressure and temperature, and is favoured by increasing temperature and increasing pressure; these are changes that occur with increasing depth.

Retrogression

Zones D and E consist predominantly of retrogressed rocks.

A great deal of mechanical deformation was associated with the retrogression, as the textures of retrogressed rocks approach a cataclastic character. Quartz grains are extremely sheared, muscovites have been shredded, and both chlorite and sericite(?) are extremely common.

The basic rocks have not been as severely deformed; they do not show the cataclastic character of some of the pelitic rocks. The feldspar has retrogressed to clinozoisite. Hornblende was not altered greatly; however, the "Z" direction colour is deep blue-green, whereas in prograde basic rocks the "Z" direction is usually a dark-green colour. The overall texture of the retrograde amphibolite is different from that of the prograde amphibolite in that the equilibrium curved boundary textures are not now present. Retrogression within the quartzo-feldspathic gneiss is not marked except for some sericitization of K-feldspar and some marginal alteration of biotite. The general lack of alteration is possibly due to the gneiss acting as a rigid body during the major period of deformation.

Structural and Metamorphic Synthesis

The relationship between the deformation and metamorphism in the Willyama Complex is somewhat complicated.

A major complication arises if it is proposed that the so-called bedding schistosity and accompanying gneissosity are a result of a flexural process at the onset of the ϕ_1 deformation. This bedding foliation ($\Sigma_{0,1}$) is cut and transposed by the imposed Σ_1 schistosity, which is also a response to ϕ_1 deformation. So it must be proposed that in the early stages of ϕ_1 there was only slight flexing and no intense folding, and that at some time in the late stages of ϕ_1 there was an intensification of this folding, resulting in the overprinting of $\Sigma_{0,1}$ by Σ_1. This suggests that ϕ_1 was a very drawn out episode of folding with an intense terminating phase.

The other alternative is that there was an earlier phase of isoclinal folding responsible for the formation of the bedding schistosity. However, this must be ruled out on the grounds that sufficient evidence has not been found of a period of deformation prior to ϕ_1.

The relationships between the deformation phases and metamorphic episodes are outlined in table 6 and figure 13. M_1 metamorphism is believed to be the first event, possibly being coeval with the initiation of flexing due to ϕ_1 and the equivalent to F_1. The gneissosity, which formed as a product of ϕ_1 by a flexural mechanism, tended to become migmatitic in places where elevated temperature and/or water pressure existed, and pegmatites were injected into the country rock causing a localized contact metamorphism and metasomatism (M_2). Discordant muscovites are believed to have developed at this stage as a result of potash metasomatism associated with the pegmatite emplacement.

Water introduced into the systems with the intrusion of the pegmatites caused retrogression (M_3).

Following the intrusion of the pegmatites and retrogression of the M_1 products, there occurred, possibly contemporaneously with the retrogression, an intensification of the ϕ_1 and F_1 folding, with the development of a strong schistosity parallel to the axial plane.

TABLE 6

STRUCTURAL AND METAMORPHIC SYNTHESIS FOR THE WILLYAMA COMPLEX

Metamorphism	Remarks	Deformation
M_1 — Prograde metamorphism. Formation of sillimanite, andalusite, and muscovite	Formation of bedding schistosity $\Sigma_{o,1}$ by flexural process. Some bedding gneissosity formed. In some areas with elevated temperatures and/or increased water pressure, melting occurred giving rise to metatexites.	Onset of ϕ_1 F_1 deformation
M_2 — Pegmatites injected discordantly into country rock	Local contact metamorphism and metasomatism associated with pegmatites. Garnet, tourmaline, and chloritoid formed. Discordant muscovites.	
M_3 — Retrograde metamorphism	Caused by water from pegmatite intrusion and facilitated by ϕ_1/F_1 deformation.	Maximum ϕ_1 F_1 deformation. Schistosity Σ_1 S_1 forms axial plane to Δ_1 B_1 folds respectively and has crenulation characteristics where bedding foliation is present. Minor boudinage developed. Transposition occurs in some areas.
M_4 — Minor event. Post-kinematic muscovite and chloritoid formed	Slight phase of heating.	ϕ_2 F_2 folding of Σ_1 S_1. Formation of Σ_2 S_2 axial plane to ϕ_2 F_2 folds and essentially coplanar to F_1. Well-developed crenulation cleavage formed. Formation of Σ_R in Zone D.
		ϕ_3 chevron folding of Σ_R and minor kinking in S_1 and S_2 as well as in Σ_1 and Σ_2.

Boudinage of pegmatites and quartzites developed as a result of this folding.

The transgressive muscovites were included as pre-kinematic porphyroblasts within the Σ_1 schistosity.

At some later stage, ϕ_2 and F_2 folding occurred, the axial plane of both ϕ_2 and F_2 folds being approximately coplanar with the Σ_1 and S_1 schistosities respectively.

Following the folding there was a late-stage recrystallization of muscovite, resulting in the post-kinematic development of muscovite porphyroblasts.

In the "Bijerkerno" area, metamorphic grade increases from east to west. It was also observed that metamorphic grade increases down the sequence. Because bedding can be observed in the Bijerkerno Syncline, it is known that the oldest rocks (those to the west of "Bijerkerno") are the rocks of the highest metamorphic grade. The youngest rocks are shales and cherts which, with increasing grade, become phyllites and then eventually schists and

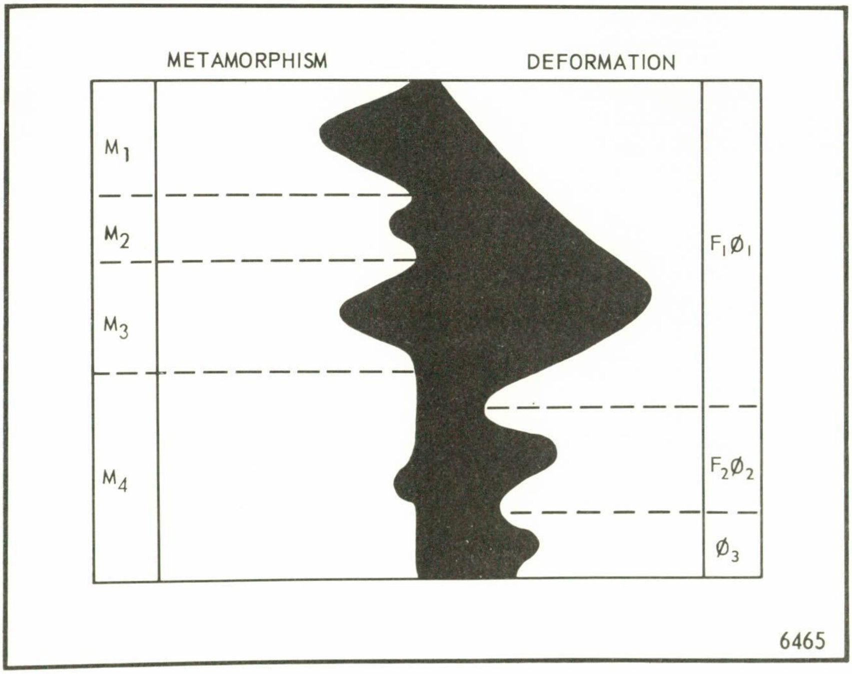


Figure 13. Time relationships of metamorphism and deformation

quartzites. No stratigraphic break was observed between the low-grade rocks of Zones A and B and those of the remaining zones. These facts lead to the conclusion that there must be some correlation between stratigraphic position and grade of metamorphism.

Meares (1969) observed that S_1 (the first formed tectonic surface) wraps around andalusite porphyroblasts formed during the first period of deformation. Tuckwell (1969) noted that undisturbed bedding was included in andalusite porphyroblasts, indicating a pre-kinematic origin for the andalusite.

Meares (1969) considered that the metamorphic zones were conformable to bedding and had been folded during the initial period of deformation. The authors agree that the metamorphic zones are conformable to bedding. However, this does not necessarily indicate anything about the time of metamorphism, but only that the growth of certain minerals was restricted to favourable horizons.

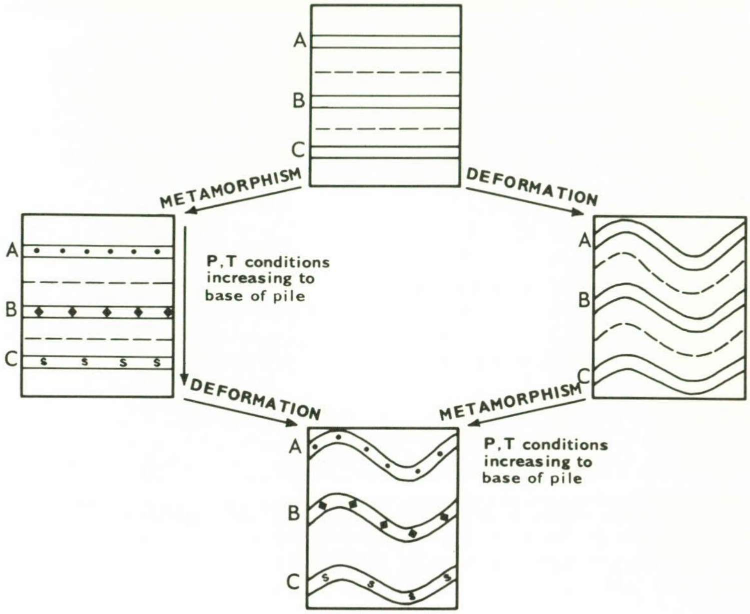
The fact that the zones are folded is indicative, but not conclusive, of metamorphism before deformation. Two alternative schemes could be proposed to explain this feature (see figure 14). However, because of the presence of pre-kinematic andalusite, the idea of the sedimentary "pile" being metamorphosed and then deformed is favoured.

The situation is not a simple case of a period of metamorphism followed by a period of deformation. In the higher grade zones the sillimanite needles are not aligned. This indicates that these minerals were post-kinematic and that in the higher grade rocks (those deepest in the sedimentary pile) deformation preceded metamorphism. However, higher in the sequence (towards the top of the sedimentary pile) the minerals seem to be pre-kinematic.

It is proposed that argillaceous and arenaceous sediments in the "Bijerkerno" area formed a sedimentary pile, in which deformation preceded metamorphism at depth. However, the metamorphic front travelled at a greater rate than the deformation, so that higher up in the sequence metamorphism occurred before deformation.

Age

The Rb-Sr geochronological work of Pidgeon (1967) and Shaw (1968) indicated 1695±21 m.y. as the age of high-grade metamorphism of the Willyama Complex. The U-Th-Pb data measured by Reynolds (1971) also indicated a similar metamorphic age of 1690 ±35 m.y. Although emphasizing the uncertainties involved, Pidgeon and Shaw estimated an age of sedimentation of the Willyama Complex of about 1820 m.y.



Topmost part of figure represents sedimentary pile after deposition with three alumina-rich horizons A,B, and C. From this situation two possible pathways exist.

Left Hand Pathway

The pile is metamorphosed, the metamorphism at the base of the pile, because it is deepest and closer to the source, is more intense. Horizon C develops sillimanite; metamorphic intensity decreases towards top of pile so horizons B and A develop andalusite and spots respectively. The pile is then deformed.

Right Hand Pathway

The pile is deformed, metamorphism occurs. In the vicinity of C, conditions are such that sillimanite develops. Metamorphic intensity drops towards top of sequence and andalusite and spots form in B and A respectively.

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Figure 14. Possible relationships of metamorphism to deformation

MUNDI MUNDI GRANITE (pεmg)

A granite occurs to the north of "Mount Woowoolahra" (GR 225420); however, the outcrop is generally rather poor. Other small bodies have been mapped east and north of Valley Well (GR 397166). Rose (1970) regarded these outcrops as belonging to the Mundi Mundi Granite.

Barron (1971) described the body at "Mount Woowoolahra" as an adamellite with an approximate modal composition of: quartz 45 per cent, orthoclase 25 per cent, plagioclase 20 per cent, muscovite 8 per cent, biotite 3 per cent. The average grainsize is about 3 mm.

Radiometric age dates have been determined for the Mundi Mundi Granite (Brewery Well Stock) by Richards and Pidgeon (1963) and Pidgeon (1967). Pidgeon (1967, p.311), who carried out three total rock, two microcline, and two muscovite Rb-Sr isotopic analyses, stated that the "muscovite age is identical to that of the total-rocks supporting the conclusion that the granite was formed 1520±40 m.y. ago".

The granite stock north of Valley Well (GR 397166) displays excellent intrusive relationships with muscovite schists of the Willyama Complex, and is overlain unconformably by the Christine Judith Conglomerate. Similar relationships are developed at "Mount Woowoolahra".

Contact metamorphic effects are not very pronounced. Laing (1969) recorded minor contact metamorphism around the Brewery Well stock*, within this sheet area; however, Mundi Mundi Granite/Willyama Complex contacts are mostly obscured by Adelaidean cover.

* Thomson (1976) recently recorded minor contact effects around the Gum Creek stock.

ADELAIDE SYSTEM

By P.F. Cooper and K.D. Tuckwell

Poolamacca Group

The Poolamacca Group is the lowest unit of the Adelaidean sequence in the Broken Hill area. However, extensive erosion prior to the deposition of the overlying Torrowangee Group has left only relatively thin remnants preserved along the unconformity. The sequence comprises quartzite, silicified quartzite conglomerate, stromatolite-bearing limestone, altered basalt, and minor sandstone.

The most complete sections are developed along the unconformity with the Willyama Complex of the Broken Hill Block, on "Poolamacca" and "Corona" stations, north from Campbells Creek to Bobs Well (figures 10 and 15). Further north along the same unconformity, only altered basalts are developed, while on the Poolamacca Horst (GR 400190) the group is represented by a well-exposed outcrop of quartzite conglomerate overlying Mundi Mundi Granite.

Good exposures of quartzite and quartzite conglomerate exist to the south of the sheet, along the unconformity north from Yanco Glen to The Paps at "Wendalpa" (GR 451095, Broken Hill 1:250 000).

East of the Euriowie Block, from Blackfellows Creek (GR 608210) to north of Eight Mile Creek (GR 552322), good exposures of quartzite and quartzite conglomerate exist, lying with marked angularity on basement.

The Poolamacca Group is not developed on the western flank or the northern extremity of the Euriowie Block.

A stratigraphic column for the Poolamacca Group is given below:

Torrowangee Group

Poolamacca Group	Wendalpa Sub-Group	Wilangee Basalt
		.... Disconformity
		Boco Formation
	....	.... Disconformity
		Christine Judith Conglomerate
	Pintapah Sub-Group	.... Disconformity
		Lady Don Quartzite

Willyama Complex/Mundi Mundi Granite

The distribution of the Poolamacca Group with respect to the Euriowie Block is as follows:

	WEST	NORTH	EAST
Wendalpa Sub-Group	Wilangee Basalt Boco Formation	Not present	Boco Formation(?)
Pintapah Sub-Group	Christine Judith Conglomerate Lady Don Quartzite	Not present	Christine Judith Conglomerate Lady Don Quartzite

PINTAPAH SUB-GROUP

The major area of outcrop of the Pintapah Sub-Group extends northwards from "Bijerkerno" homestead for several kilometres along the unconformity with the Willyama Complex (figure 15). Discontinuous outcrops occur at Yanco Glen and northwards along the unconformity to The Paps ("Wendalpa" homestead).

Lady Don Quartzite (apl)

The type section of the Lady Don Quartzite is in Bijerkerno Gorge, (GR 552322 - GR 553325), where approximately 150 m of quartzite are present; this is the maximum measured thickness of the unit. It is difficult to determine the exact thickness of the section as bedding is not easily recognized.

The Lady Don Quartzite unconformably overlies the Willyama Complex/ Mundi Mundi Granite basement. At some localities the nature of the quartzite changes at the contact, and in places some small clasts of basement rocks are present: slate, pegmatite, schist, and Mundi Mundi Granite. Generally, however, the surface of the unconformity is remarkably sharp and distinct, and the clasts (where present) are only in the basal 1 to 2 m of the unit.

The Lady Don Quartzite is quite uniform lithologically and is a fine-grained (average grainsize is 0.75 mm), silicified, white quartzite. However, in Bijerkerno Gorge a thin, partially recrystallized, calcareous sandstone 1 m thick is intercalated with the quartzite and occurs towards the middle of the unit.

Some graded bedding and large-scale cross laminations are present towards the base of the unit.

In thin section the boundaries of individual quartz grains (quartz constitutes about 98 per cent of the rock) are sutured, some grains have recrystallized, and most grains display undulose extinction. A period of silification is indicated by the new growth of quartz around primary quartz grains. Minor chlorite and muscovite have crystallized in the quartzite.

Christine Judith Conglomerate (apc)

The Christine Judith Conglomerate apparently lies conformably upon the Lady Don Quartzite in its type section (the Bijerkerno Gorge, GR 553325 - GR 554327), but it can be observed directly overlying basement where the Lady Don Quartzite has been eroded (GR 406190). It is difficult to determine the boundary relationships between this unit and the Lady Don Quartzite because of poor outcrop and lithological similarity.

The Christine Judith Conglomerate has a similar maximum thickness to the Lady Don Quartzite (approximately 150 m) but has a greater lateral extent. It consists almost exclusively of quite rounded and usually well-sorted quartzite pebbles and cobbles in a quartzite matrix. The quartzite clasts in the conglomerate are identical with quartzite of the Lady Don Quartzite. Clast size of the conglomerate varies, but most quartzite clasts are in the cobble size range. The matrix of the rock is a pure quartzite which is well silicified and not unlike the Lady Don Quartzite; however, it is usually a little coarser grained. Bedding is observed, but only on a large scale, individual beds being greater than 5 m thick.

On the Poolamacca Horst the Christine Judith Conglomerate sits directly on the Mundi Mundi Granite (photo 5). Neither granite pebbles nor granite waste material were observed within the quartzite conglomerate. However, small embayments in the granite are filled with arkosic material derived directly from the granite; this material is overlain by the Christine Judith Conglomerate.

In the Poolamacca Horst area, later deformation has given rise to the development of a spectacular stretched pebble conglomerate (photo 6).

WENDALPA SUB-GROUP

The Wendalpa Sub-Group crops out mainly along the unconformity in the "Poolamacca" - Bobs Well area (figure 15). However, small outcrops have been recorded in the "Mount Woowoolahra" area and also possibly occur north of "Bijerkerno" and Yanco Glen.

Boco Formation (apb)

The Boco Formation lies disconformably upon the Christine Judith Conglomerate and, where this unit is absent, unconformably upon basement. It has a quite variable thickness, the maximum observed being 30 m. The type section of the Boco Formation is approximately 1.5 km due east of the place where Campbells Creek leaves the Barrier Ranges (GR 369191).

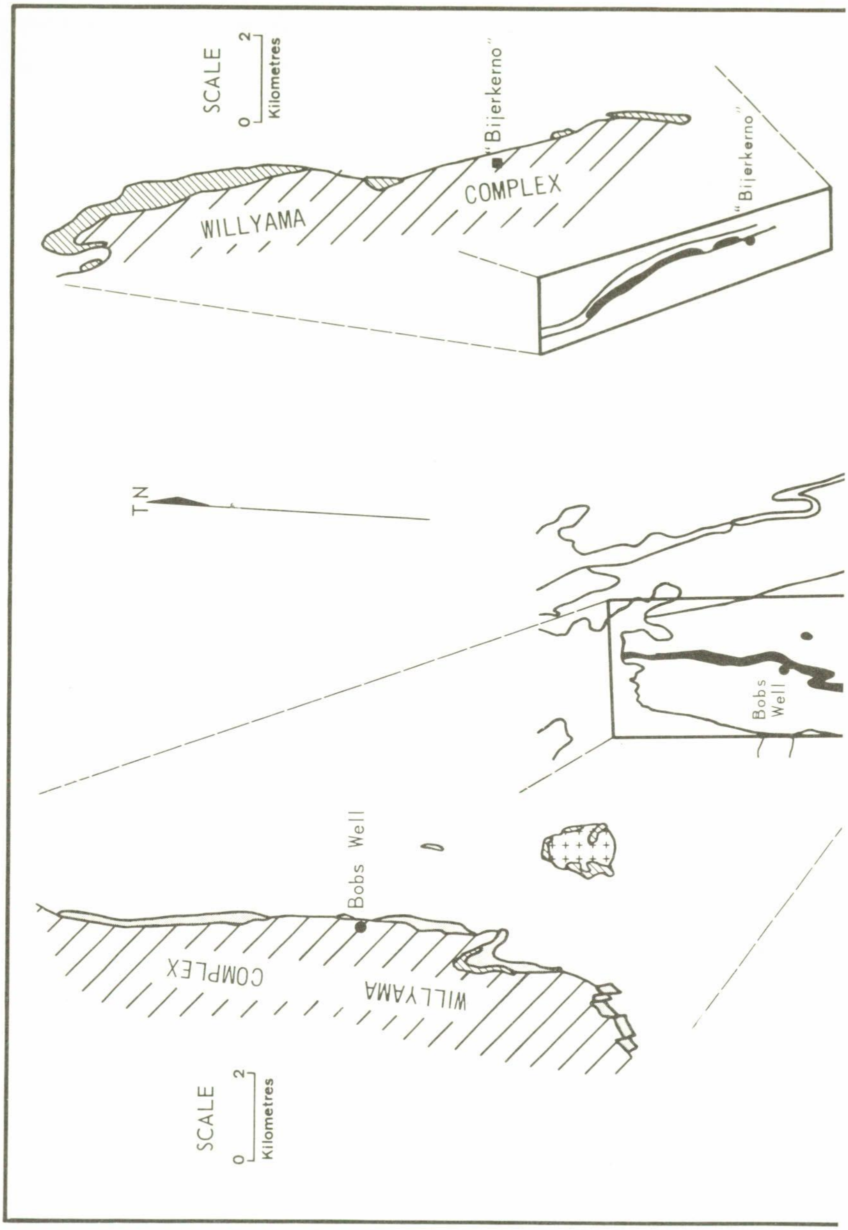
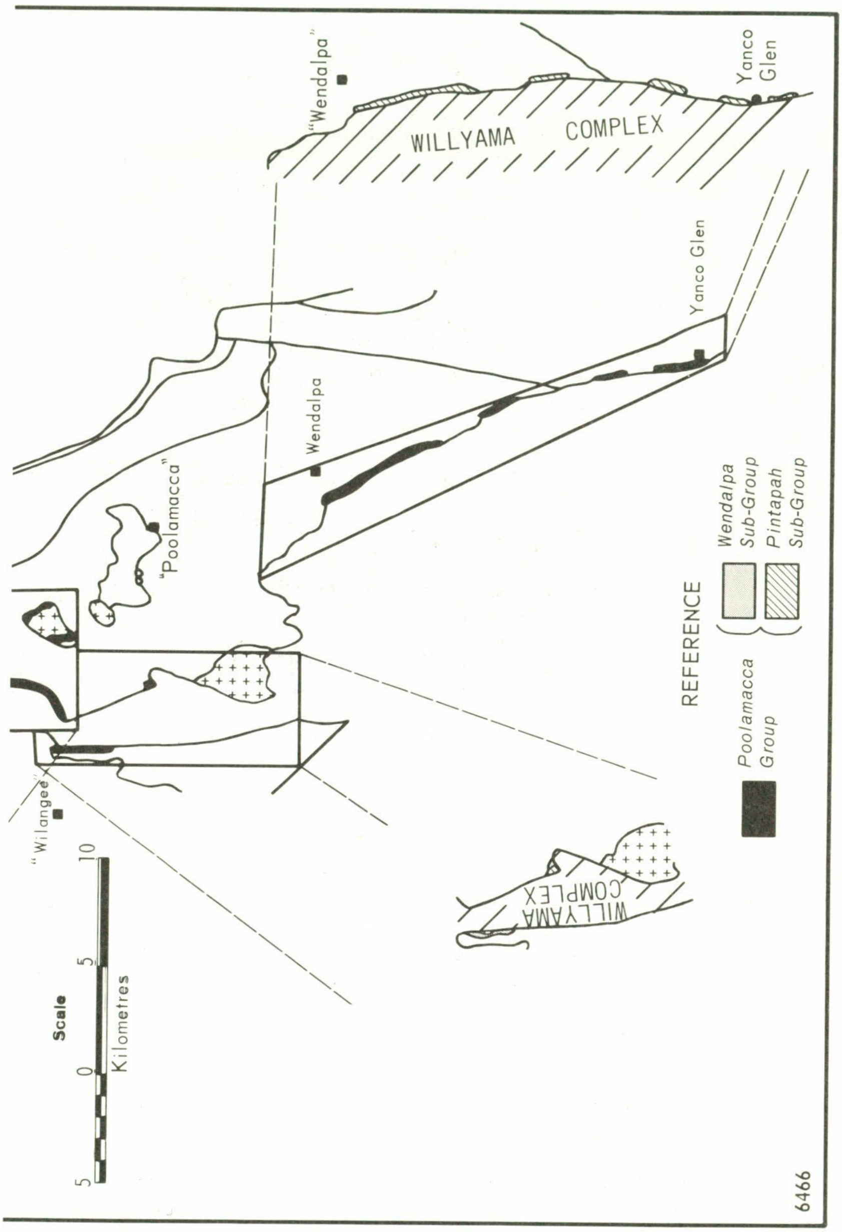


Figure 15. Distribution of main



outcrops of the Poolamacca Group (Pintapah and Wendalpa Sub-Groups)

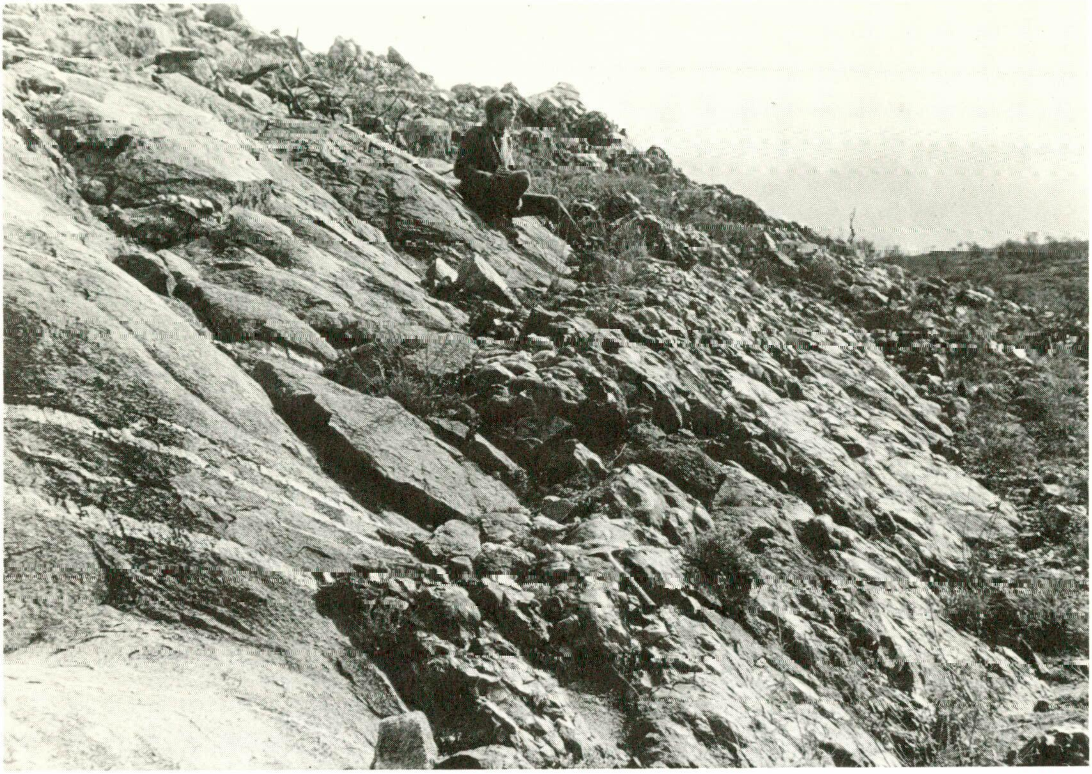


Photo 5. Christine Judith Conglomerate overlying the Mundi Mundi Granite, Poolamacca Horst (GR 408194)

North of Bobs Well the Boco Formation is extremely thin, and in places it is absent and the overlying Wilangee Basalt lies directly upon basement. In this northern area the unit consists predominantly of a medium-grained, well-rounded, yellow quartz sandstone, with minor chert. Just south of Bobs Well, brown quartzite becomes more common, but sandstone is still the dominant lithology. Overall, the sandstone, chert, and quartzite crop out poorly.

A very sandy limestone occurs 0.8 km south of Bobs Well (GR 387243) along the unconformity. Further south bold outcrops some 3 m high show good examples of stromatolites (photo 9). The stromatolites are restricted to one bed about 1 m thick with a lateral continuity of about 100 m (photos 7-8).

Interbedded with the limestone and dolomite is ironstone, which consists of quartz, magnetite, and haematite. The beds of ironstone vary in thickness from 60 mm to 1.5 m, and the larger beds are often sheared. Partial post-depositional silification of the limestone has resulted in the replacement of some thin horizons (up to 7.5 mm thick) and some stromatolite colonies by pink and white chert.

Thin gritty red beds are also present at a few scattered localities south of Bobs Well in the same stratigraphic position. R.P. Coats (pers. comm.) has recorded red beds from the correlative position in the Mount Painter area.

Several small outcrops of highly silicified limestone(?) containing stromatolites occur about 5 km north of "Mount Woowoolahra", on the eastern side of the "Mount Woowoolahra" - "McDougalls Well" road (GR 234459) (photo 10). Outcrop in this area is discontinuous, being partly covered by scree. However, some quartzites which probably underlie the silicified limestone were observed. It seem probable that both the limestone and the quartzite belong to the Poolamacca Group. They have been further silicified during the Tertiary and are preserved as remnants of the Tertiary land surface.

Eleven kilometres northwest of Bijerkerno Gorge some dolomite (not shown on the map) lies directly on basement and is not underlain by a conglomerate (GR 492415). The dolomite contains several quartzite and chert horizons, and this fact, together with the absence of a basal conglomerate, suggests that the dolomite may belong to the Boco Formation. However, it could alternatively be part of the Corona Dolomite.

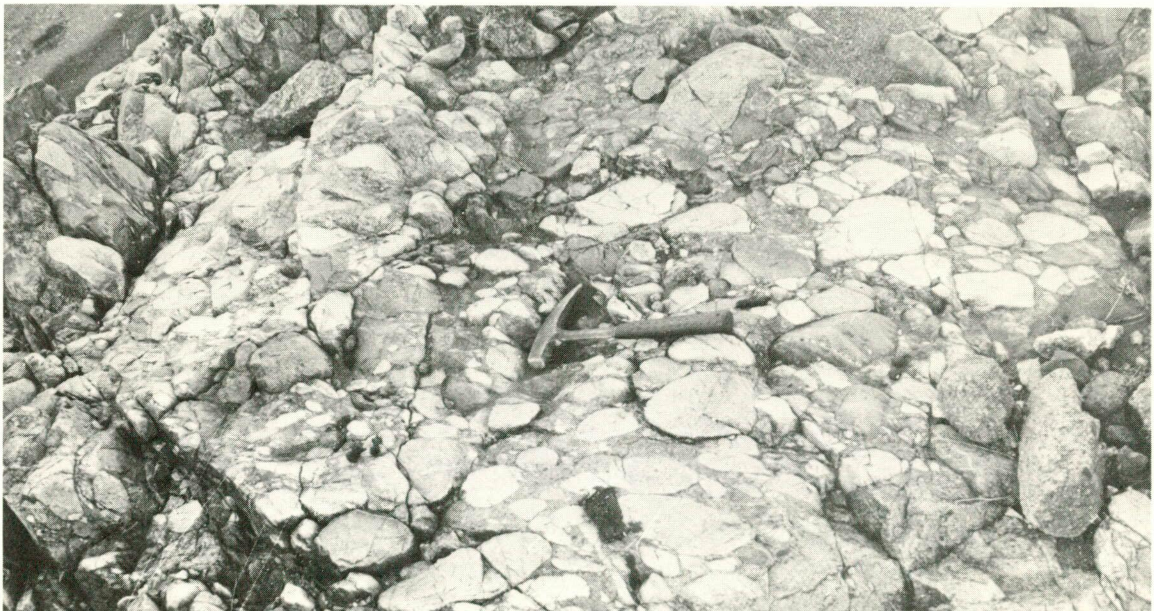


Photo 6. Christine Judith Conglomerate, Poolamacca Horst (GR 408194)

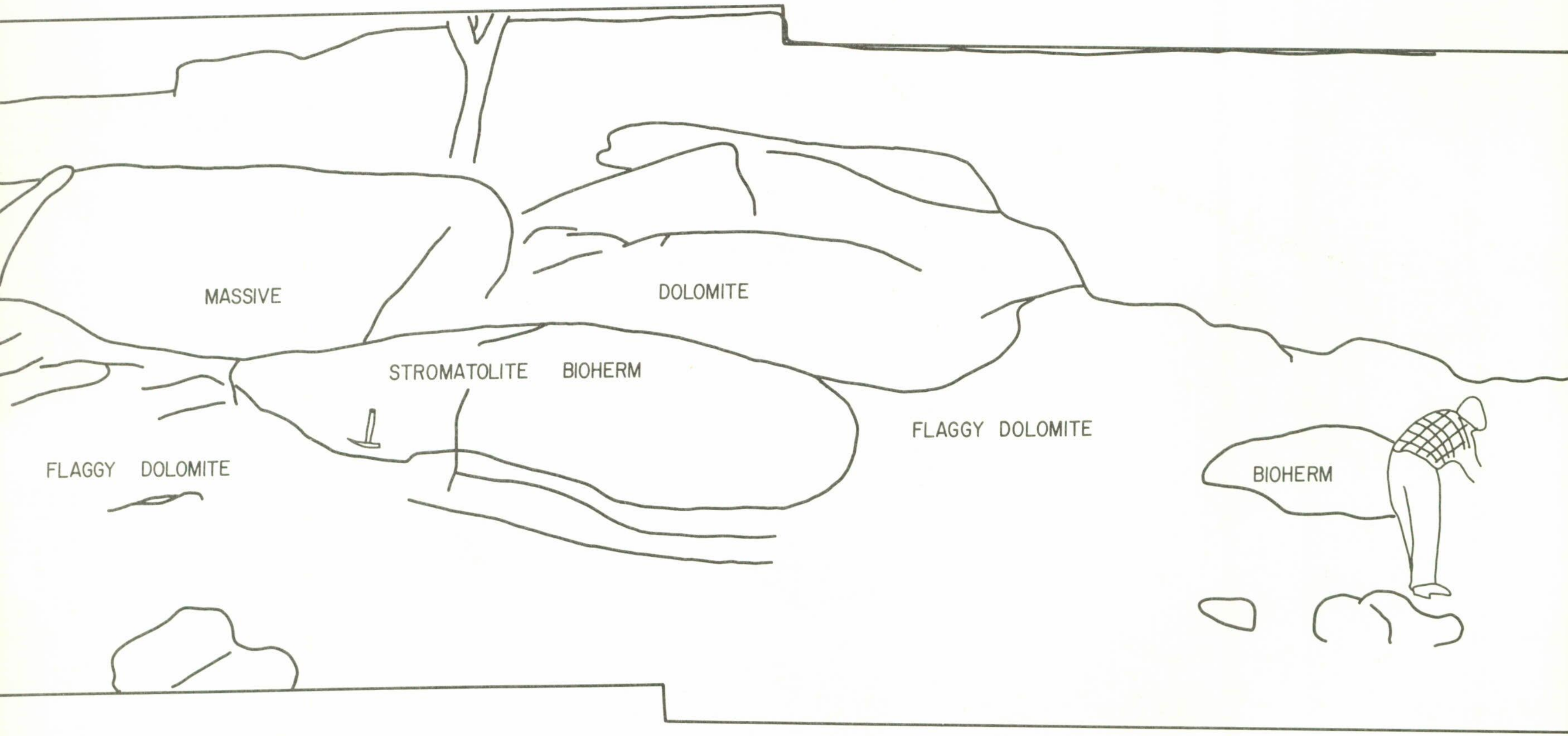


Photo 7. Stromatolite bioherm in the Boco Formation (GR 368190)

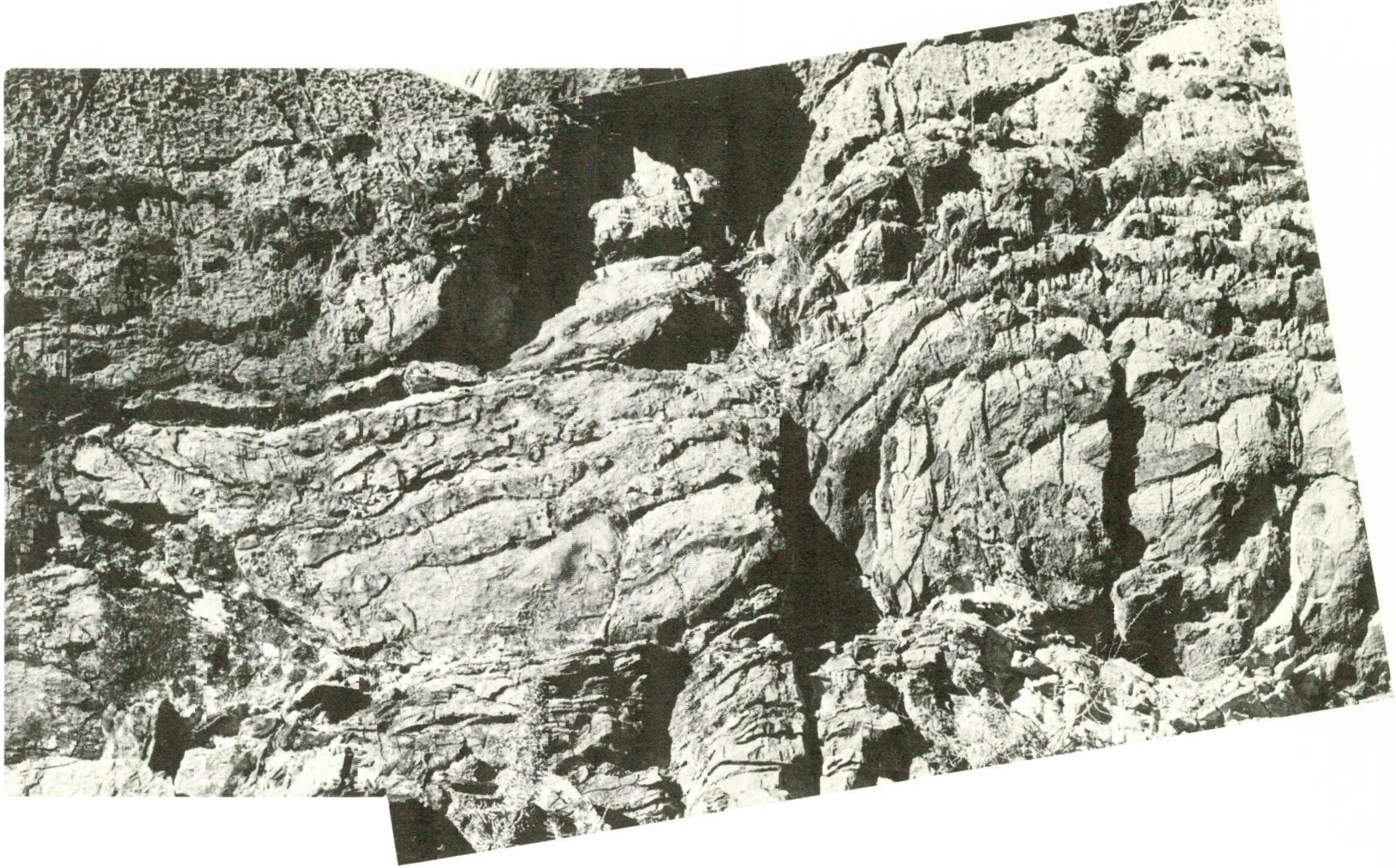


Photo 8. Close-up of stromatolite bioherm shown in photo 7

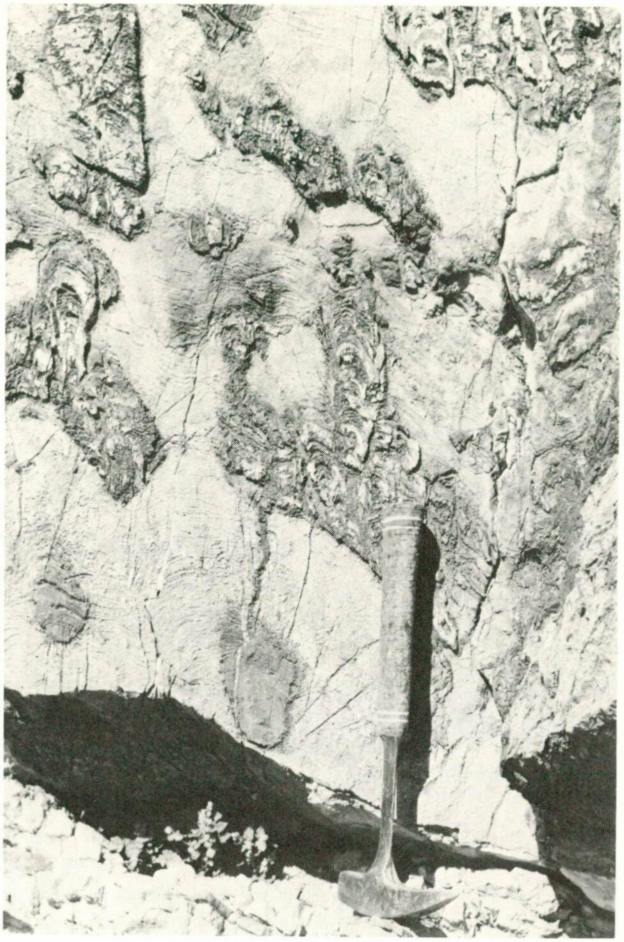


Photo 9. Stromatolites in the Boco Formation

Wilangee Basalt (formerly Volcanics)* (apw)

The Wilangee Basalt lies disconformably upon the Boco Formation or unconformably upon basement where the Boco Formation and Pintapah Sub-Group are absent.

Outcrop of the Wilangee Basalt is confined to the easterly dipping unconformity surface west of "Poolamacca" station. The unit is not present everywhere on the western unconformity as it suffered erosion prior to deposition of the Torrowangee Group. The type section (GR 388275 - GR 389273) can be seen in a creek 1.5 km north of

* The whole of the outcrop of this unit on the Torrowangee sheet consists predominantly of basalt. On this basis it seemed appropriate to replace the word "Volcanics" (published by Cooper and Tuckwell 1971) by "Basalt".

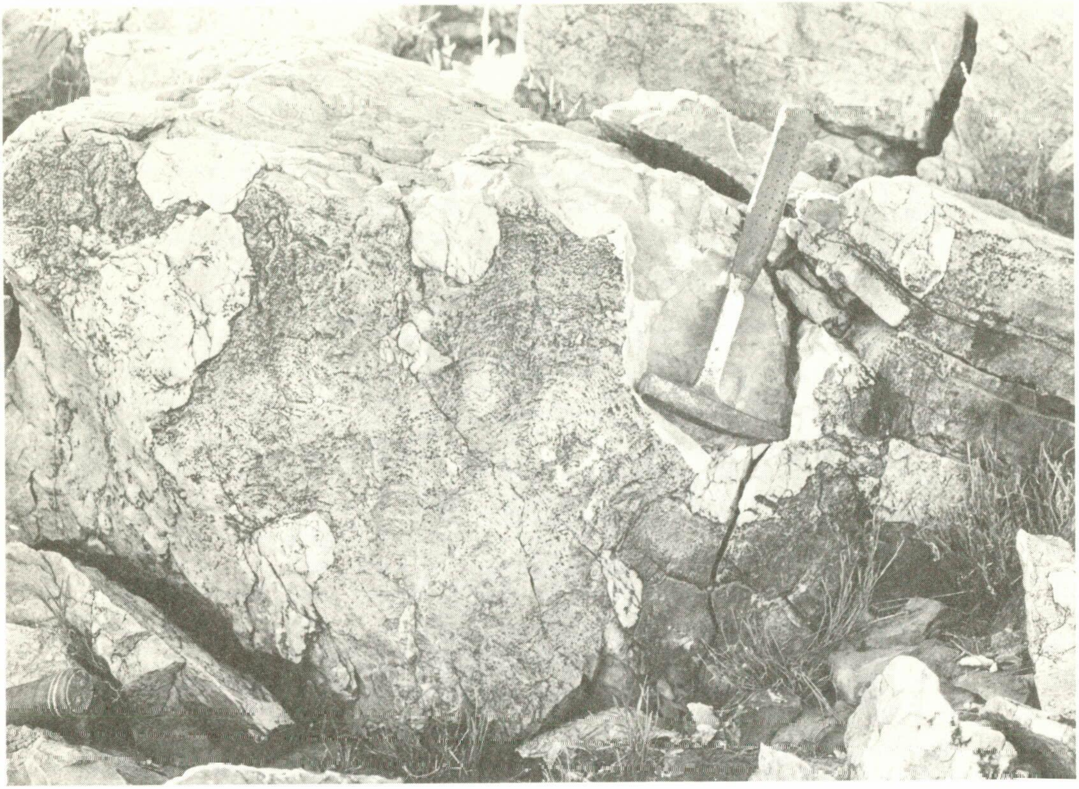


Photo 10. Silicified stromatolite-bearing limestone(?) north of "Mount Woowoolahra" (GR 234459)

the old Bobs Well road which runs from Torrowangee Well to Bobs Well through "Corona" station. A measured section from this location is shown in figure 16.

The basalt is generally very rubbly in outcrop. North of Bobs Well it is approximately 160 m thick. Numerous "flows" of basalt can be recognized in different places, but none can be traced for any distance as most are only a few metres thick. Gas streaming is

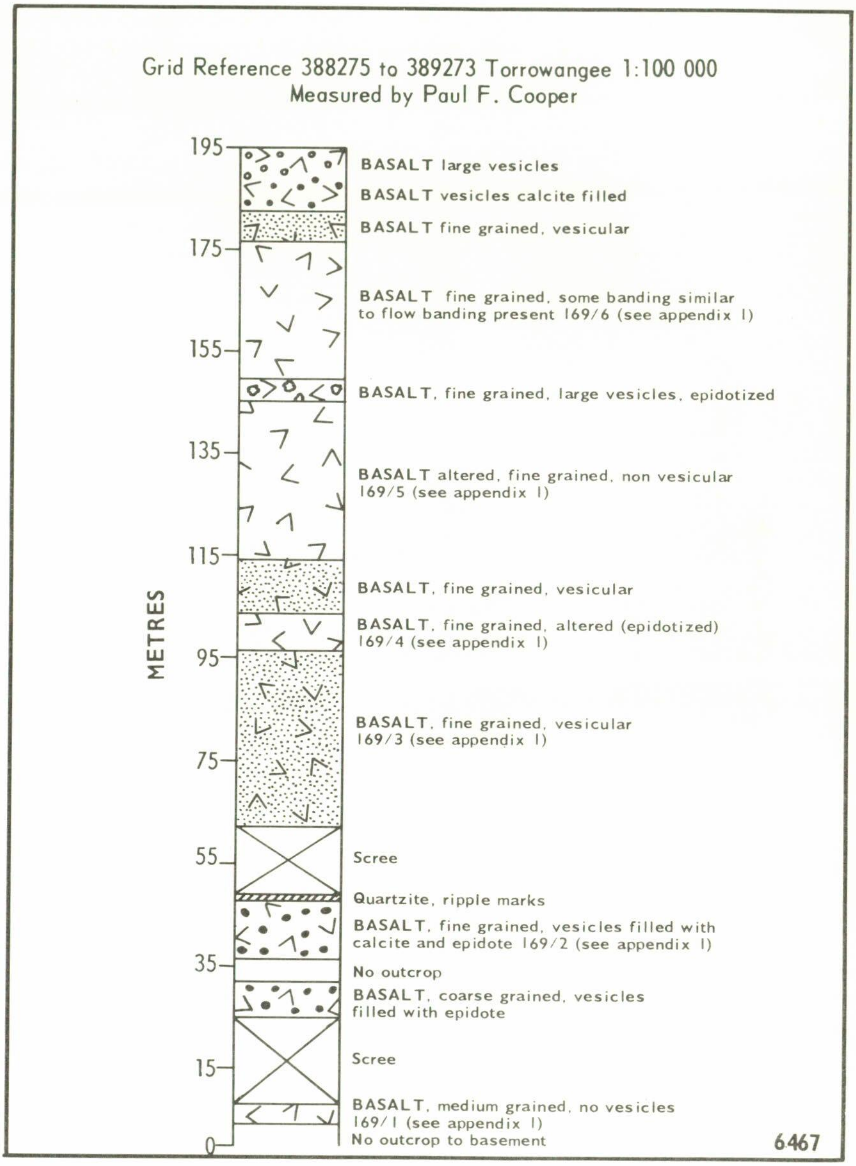


Figure 16. Type section, Wilangee Basalt

common in some localities, and the gas trails are often filled with calcite, epidote, and quartz. Later hydrothermal and deuteric activity has, in places, completely altered the basalt to a quartz - epidote - magnetite - calcite rock. In other localities the basalt is reasonably fresh and in thin section consists of very fine laths of Ca-rich plagioclase (labradorite), fine needles of actinolite, and a very high percentage of dusty magnetite.

Some thin horizons of quartzite have been observed in the Wilangee Basalt. Towards the base of the unit they contain truncated crossbedding and oscillation ripple marks. A single horizon of limestone also occurs near the base, interbedded with the basalt.

Torrowangee Group

Sediments of the Torrowangee Group make up the greatest thickness of Late Precambrian rocks in the Broken Hill area. The restricted stratigraphic extent of the Torrowangee Group, as defined in this paper, brings it into direct correlation with the Umberatana Group in South Australia. Similarly, the subdivision of the Torrowangee Group into the Yancowinna, Euriowie, and Teamsters Creek Sub-Groups is valid in the light of the rock types and established stratigraphy in South Australia. A stratigraphic column for the Torrowangee Group is given below.

Torrowangee Group	Teamsters Creek Sub-Group	Nunduro Conglomerate		
		Dering Siltstone		
		Gairdners Creek Quartzite		
		Alberta Conglomerate		
	Euriowie Sub-Group	Floods Creek Formation		Yowahro Formation
		Mitchie Well Formation	Corona Dolomite	Tanyarto Formation
				Wammerra Formation
	Yancowinna Sub-Group	Yangalla Formation	McDougalls Well Conglomerate	†Waukeroo Formation
		*Mulcatcha Formation		—? —? —?

† Mount Wallop Quartzite Member
* Kantappa Quartzite Member

The broad distribution of the Torrowangee Group with respect to the Euriowie Block is as follows:

	WEST	NORTH	EAST
Teamsters Creek Sub-Group		Nunduro Conglomerate	Nunduro Conglomerate
	Dering Siltstone		Dering Siltstone
	Gairdners Creek Quartzite	Gairdners Creek Quartzite	Gairdners Creek Quartzite
	Alberta Conglomerate	Alberta Conglomerate	Alberta Conglomerate
Euriowie Sub-Group	Yowahro Formation	Floods Creek Formation	Floods Creek Formation
	Tanyarto Formation		
	Wammerra Formation	Corona Dolomite	Mitchie Well Formation
Yancowinna Sub-Group	Waukeroo Formation	?	?
	Yangalla Formation	?	?
	Mulcatcha Formation		
	McDougalls Well Conglomerate	McDougalls Well Conglomerate	McDougalls Well Conglomerate

YANCOWINNA SUB-GROUP

The Yancowinna Sub-Group comprises a sequence of coarse ill-sorted clastic material: grit, argillaceous sandstone, siltstone, "subgreywacke", and diamictite. Its thickness ranges from a minimum of 30 m to greater than 2000 m, and this variation takes place over a very short distance. Similarly, stratigraphy and rock types within the sub-group vary considerably and tend to confuse the overall relationships.

Outcrop distribution of the Yancowinna Sub-Group is shown in figure 17.

A distinctive feature of the Yancowinna Sub-Group is the dependence of rock type, and thickness of that rock type, on the nature and stability of basement in the immediate vicinity. In areas where the unconformity is now easterly dipping, stratigraphy is well preserved, rock types are continuous, and a fairly planar depositional surface during the Late Precambrian is indicated. In those areas where the Yancowinna Sub-Group is represented by a

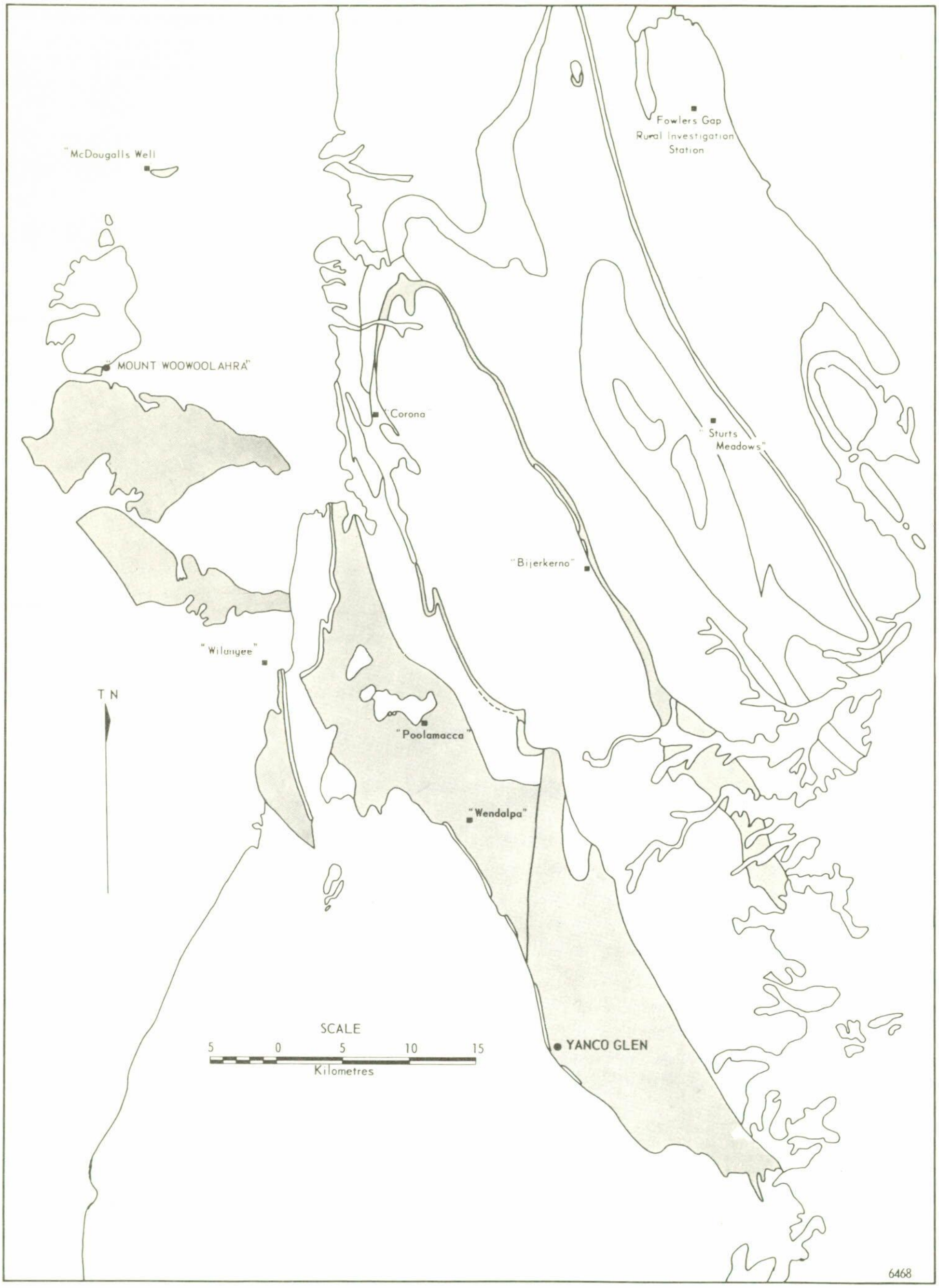


Figure 17. Outcrop distribution of the Yancowinna Sub-Group

jumbled mass of diamictites*, within which interval subdivision is nearly impossible, it can be shown that basement was of a very irregular nature, and was characterized by a mountainous topography. Here the Yancowinna Sub-Group sediments constituted a "submarine valley fill" prior to deposition of the Euriowie Sub-Group.

The random and discontinuous nature of much of the coarse detritus is attributable firstly to this high basement topography and secondly to the instability of the basement during deposition of the Adelaidean (especially Torrowangee Group) sediments. Evidence of the activity of major basement faults is undeniable, and the Euriowie Block and the Poolamacca Horst first appeared during deposition of the Yancowinna Sub-Group.

Mulcatcha Formation (atu)

The greatest development of Mulcatcha Formation sediments occurs at the type locality to the west of the Poolamacca Horst, on the stable, easterly dipping basement. However, a section about 150 m thick is present against the eastern edge of the horst.

The type section of this unit occurs due west of the Mundi Mundi Granite on the Poolamacca Horst (GR 380214 - GR 385195). Here the unit consists of 850 m of flaggy quartzose sandstone, arkose, siltstone, and some massive lenticular diamictite horizons. The diamictites show no bedding and are not unlike the boulder beds in the overlying Yangalla Formation, except that they are not as well developed.

The clasts within the diamictites are principally Pintapah Sub-Group rock types, with subordinate amounts of pegmatite, granite, and metamorphics. At times the flaggy siltstones and quartzose sandstones also contain clasts, most of which appear to be eroded Poolamacca Group sediments, together with some granitic waste. Where exposure permits, it may be seen that the lenticular diamictites are in fact grossly discordant and erosional with respect to the flaggy sandstones.

Towards the middle of the sequence, several thin, massive, orthoquartzite horizons are developed. These horizons have a "bulbuous" or rounded appearance and are lithologically very similar to the Lady Don Quartzite. This sequence of closely spaced, orthoquartzite horizons is approximately 30 m thick and is termed the *Kantappa Quartzite Member* (atq).

* *Diamictite* is a comprehensive, non-genetic term for a non-sorted or poorly sorted, non-calcareous terrigenous sedimentary rock that contains a wide range of particle sizes.

Yangalla Formation (atl)

The Yangalla Formation conformably overlies the Mulcatcha Formation. The type section is also due west of the Mundi Mundi Granite on the Poolamacca Horst (GR 382195 - GR 395187). The base of this unit is defined by a sudden increase in the number of lenticular diamictite bodies, and an accompanying decrease in the amount of interbedded siltstone and sandstone. Both vertical and lateral changes in lithology are common.

The unit is composed chiefly of lenticular diamictites which show erosional contacts with the underlying beds. Many clasts, some well rounded, occur within the well-bedded sandstones and siltstones. Towards the "top" of the sequence the unit becomes more massive and silty, clasts of pegmatitic and granitic material and quartzite predominate, and the matrix rock is a greeny-grey siltstone.

The maximum thickness of the formation is unknown, as the top of the sequence is bounded by faults. However, the maximum exposed thickness is approximately 800 m.

Waukeroo Formation (atk)

The Waukeroo Formation is developed to the east of the Poolamacca Horst, in the vicinity of "Poolamacca" station, and probably further south as well. The unit reaches a maximum thickness of 1500 m, and consists of lenticular paraconglomerate and diamictite interbedded with quartzite, siltstone, and arkose. Clasts of both "extrabasinal" and "intrabasinal" material occur, forming part or all of the coarse detritus of many of the horizons. A sequence of thin beds of pebble and cobble-bearing orthoquartzite, often exhibiting ripple marks and occurring towards the middle of this unit, is termed the *Mount Wallop Quartzite Member* (atp).

The stratigraphic relationship of the Waukeroo Formation to the other formations within the Yancowinna Sub-Group is not clear, but two possibilities exist as shown in figure 18. The Waukeroo Formation could be time-stratigraphically equivalent to the Yangalla Formation or equivalent to the Yangalla Formation as well as part of the Mulcatcha Formation. The latter possibility seems more likely, and could have resulted from the commencement of uplift of the Poolamacca Horst while sedimentation of the Waukeroo Formation was still continuing in the east.

The type section is due east of the Poolamacca Horst (GR 414193 - GR 436205, see figure 19).

Figure 20 is a detailed map of the geology of the Poolamacca Horst, showing the relationships between the various formations.

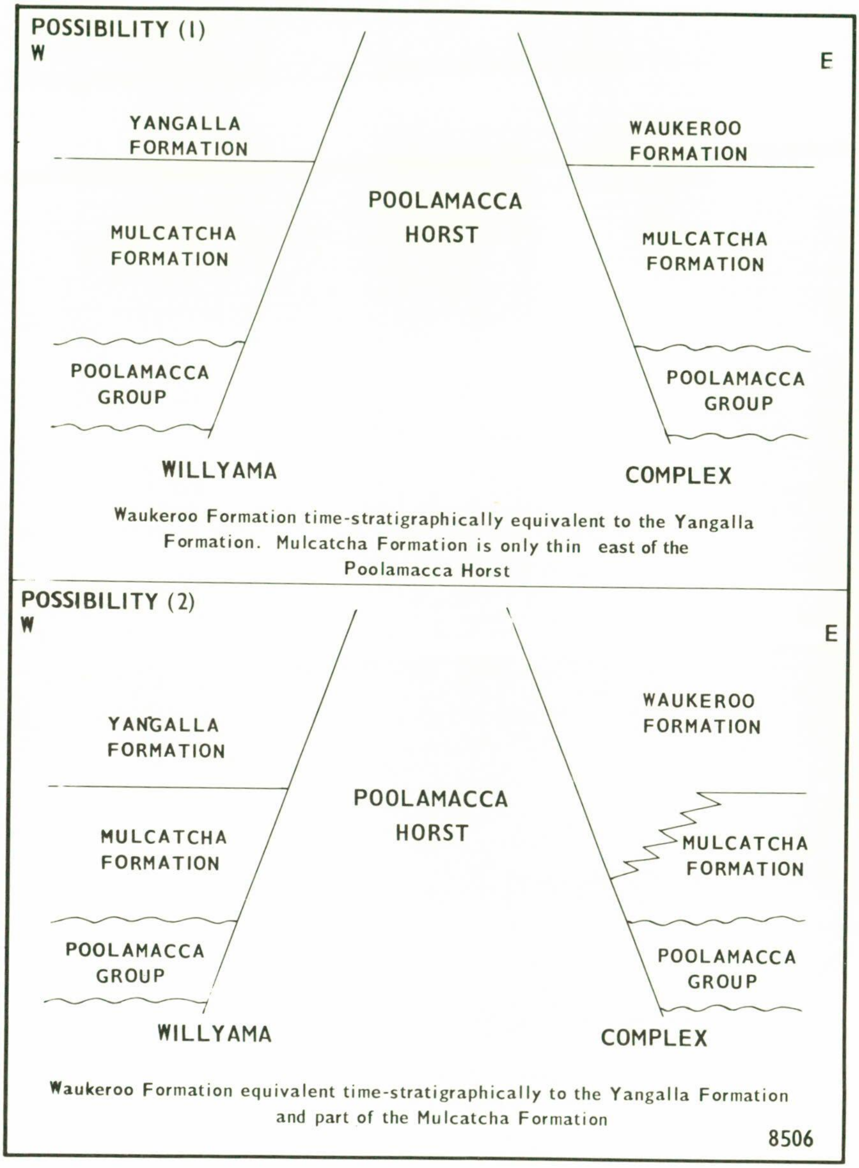


Figure 18. Stratigraphic relationships between the Waukeroo Formation and other formations of the Yancowinna Sub-Group (modified after Tuckwell 1968)

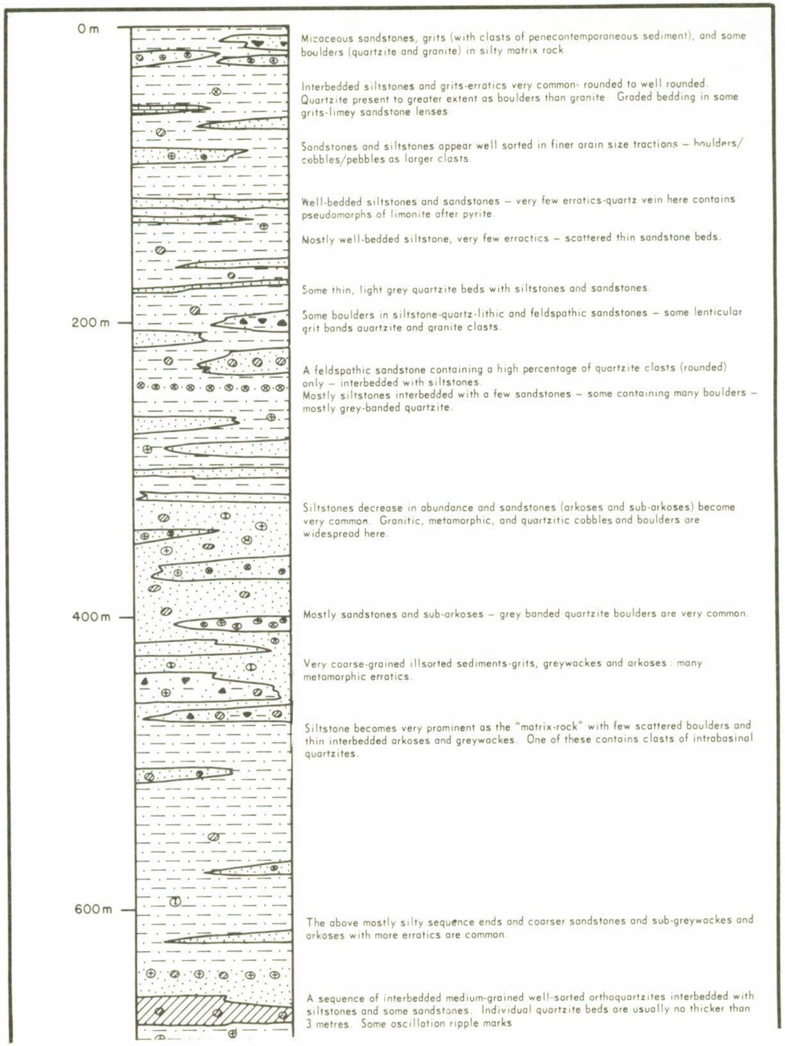
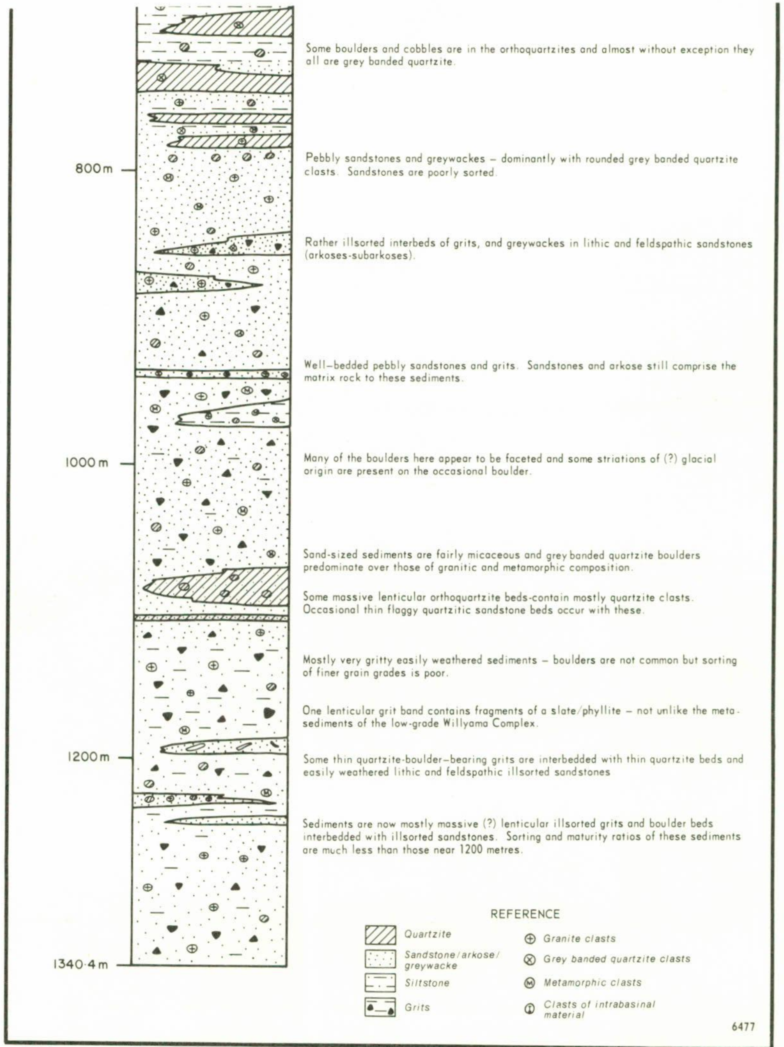


Figure 19. Measured section,



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Waukeroo Formation (modified from Tuckwell 1968)

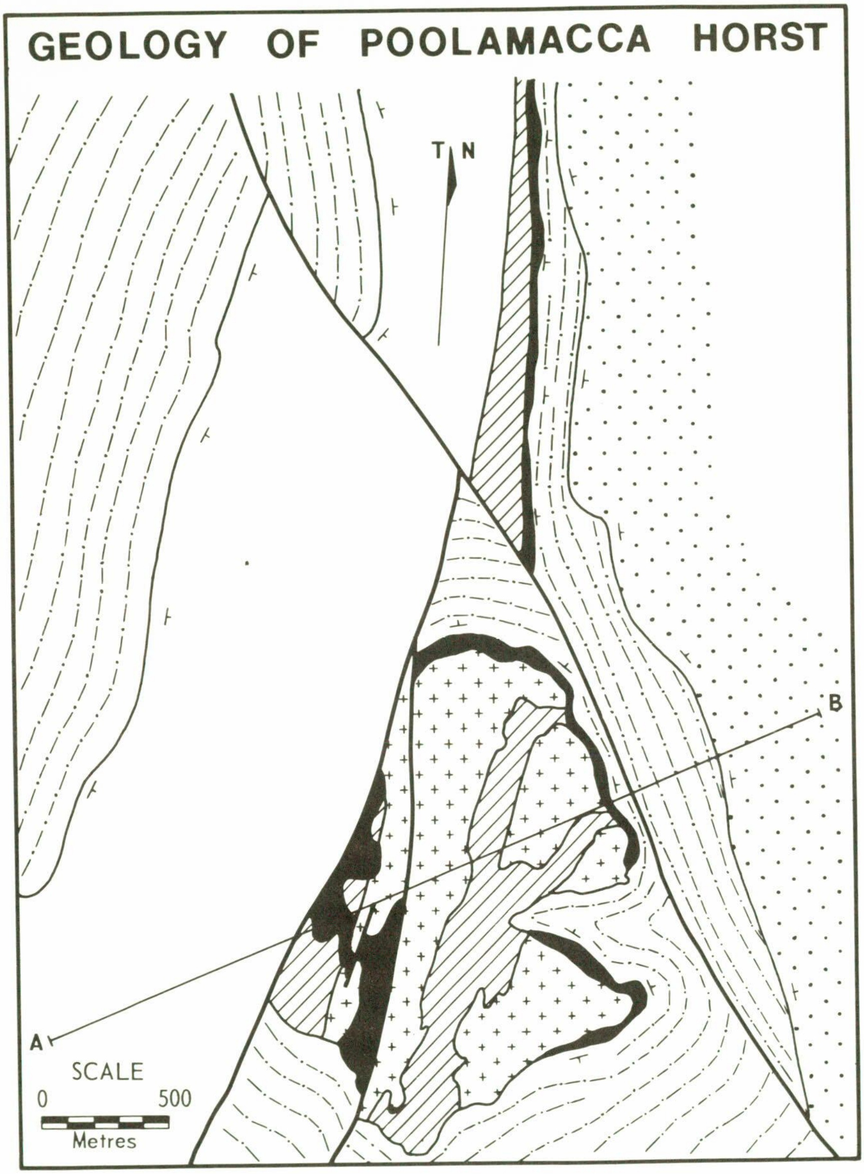
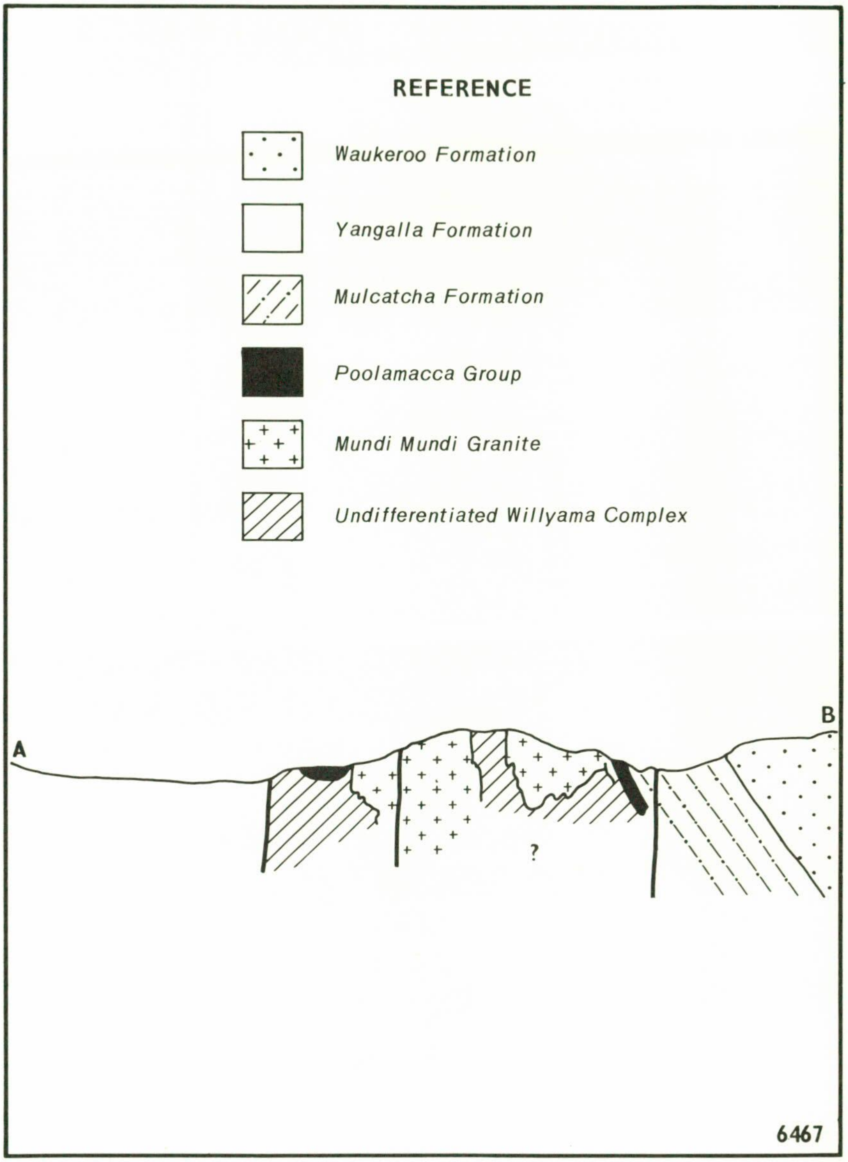


Figure 20. Geology of



the Poolamacca Horst (after Tuckwell 1968)

McDougalls Well Conglomerate (ato)

In places, the McDougalls Well Conglomerate may represent the whole of the Yancowinna Sub-Group. The unit was deposited only in those areas which were highly unstable, and is developed exclusively on the Euriowie Block. It mainly rests unconformably on basement Willyama Complex, but north and south of "Bijerkerno" homestead it lies unconformably upon Poolamacca Group sediments. The type section is located where a tributary of Alberta Creek cuts the "Corona" road near 5 Mile Mill (Bore on map) (GR 443292 - GR 442292). Poor outcrop and variability of the unit make determination of the true thickness at any locality difficult; however, at the type section it could be as much as 30 m.

This unit is a paraconglomerate, the pebbles consisting principally of schist, quartzite, and pegmatite in a poorly sorted matrix of the same material. The composition of the unit is variable and the detritus is always locally derived. The larger clasts, of pebble and cobble size, tend to be subrounded. The MacDougalls Well Conglomerate bears no evidence of a glacial origin. Many of the clasts are large — up to 1 m across — but can be traced to rocks in the immediate area adjacent to the outcrop.

The true character of the McDougalls Well Conglomerate is often obscured, partially through lack of outcrop, but principally by the fact that it is extensively sheared, having been laid down at the edge of the very "mobile" Euriowie Block.

Other Rock Units (atY)

There is a thick sequence of what appears to be Yancowinna Sub-Group developed overlying the Mundi Mundi Granite in the Mount Woowoolahra area. However, because of extremely poor outcrop, little could be interpreted from them, although data from drillers' logs and very scanty outcrop indicate that the Yancowinna Sub-Group extends south to the vicinity of "Wilangee" homestead as well as northwards to "McDougalls Well".

A pebbly, boulder-bearing siltstone overlies the granite west of the "Mount Woowoolahra" homestead (GR 209420). It is extremely ill-sorted and has virtually all the size range of particles from silt to boulders. Pebbles include granite, chert, dolomite with chert bands, volcanics, and numerous small pebbles of low-grade Willyama quartzite. Although few striated pebbles were found in situ, the ground is littered with many excellent examples of striated, polished, and faceted pebbles (photo 11). The very ill-sorted nature of the sediment, together with the abundance of striated pebbles, indicates that this is the first record of a *true* TILLITE in the Broken Hill Adelaidean (Cooper 1973). The pebble content indicates that the Poolamacca Group has been eroded, but no glacial pavements could be observed on the granite. The thickness of the tillite is difficult to estimate, but we consider it to be only 1 m to perhaps 3 m thick, as further up the sequence the striated pebbles quickly disappear and more aqueous characteristics appear.

Photo 11. Striated siltstone pebble from "Mount Woowoolahra". Specimen is about 130 mm in length (GR 210420)

Approximately 10 m above the unconformity a band of purple laminated claystone immediately overlies a horizon of boulder sediment containing mostly granite boulders up to 1 m in diameter. This high degree of sorting immediately above the tillite indicates that the conditions necessary for tillite deposition did not persist for long. The tillite is a very thin deposit, as would be expected for a rock type which conforms to the strict definition of the term (Cooper 1971).

Yancowinna Sub-Group sediments occur elsewhere on the map sheet and in adjacent areas.

To the south of the Poolamacca Horst is a large area of complexly deformed sediments which probably belong to the Yancowinna Sub-Group. The relationship of these rocks to adjacent units is not clear and time did not permit elucidation of the problem.

On the Taltingan 1:100 000 sheet (7234), to the south of the Fowlers Gap sheet, two broad subdivisions can be recognized. These occur east of the Euriowie Block, along the White Cliffs road. The lower unit, which is thought to overlie the Willyama Complex, consists of a coarse diamictite, poorly bedded gritty sandstone with erratic clasts, and minor coarse siltstone. The overlying unit is well bedded, better sorted, and lacks the wide range of particle sizes. It is composed of well-bedded quartzose sandstone, siltstone, minor pebbly siltstone, and some subarkose.

On the Broken Hill 1:100 000 sheet (7134) to the south of the Torrowangee sheet, in the vicinity of Yanco Glen Hotel (figure 21), Geology III students from the W.S. and L.B. Robinson University College, Broken Hill, found very little correction with established rock units of the Yancowinna Sub-Group. However, sediments similar to those of the Mulcatcha and Waukeroo Formations occur as discordant erosional bodies towards the top of a sequence of flaggy quartzose sandstone, siltstone, and conglomerate bands (photo 12).

EURIOWIE SUB-GROUP

The Euriowie Sub-Group contains the following units:

	Floods Creek Formation		Yowahro Formation
Euriowie Sub-Group	Mitchie Well Formation	Corona Dolomite	Tanyarto Formation
			Wammerra Formation

Photo 12. Coarse diamictite underlain and overlain by fine laminated siltstone. This diamictite was probably deposited by a mudflow mechanism. Undifferentiated Yancowinna Sub-Group south of Poolamacca Inlier (GR 463157)

Geology of the Torrowangee – Fowlers Gap 1:100,000 Sheets : Figure 21.

The Mitchie Well and Floods Creek Formations are developed on the eastern side of the Euriowie Block, the Corona Dolomite is developed around the northernmost portion of the Euriowie Block, and the Wammerra, Tanyarto and Yowahro Formations are present west of the Euriowie Block (figure 22). Correlations of these units will be discussed at the end of this section.

The Euriowie Sub-Group consists predominantly of calcareous sediments and interbedded shales and siltstones. The limestones are frequently quite massive and pure at the base of the sequence (well exposed at the Torrowangee quarries), and generally become more sandy towards the top.

The Euriowie Sub-Group has a maximum developed thickness of 3300 m. The base of the sequence is defined by the last occurrence of "conglomeratic" material in the Yancowinna Sub-Group.

Mitchie Well Formation (atm)

The Mitchie Well Formation consists of discontinuous, lenticular, grey, limestone bodies, usually 0.3 m to 1.5 m thick and up to 30 m long, interbedded with green-grey, laminated calcareous siltstone. Towards the base of the unit the limestone lenses tend to be rather pebbly, the fragments being predominantly intrabasinal limestone clasts and subordinate extrabasinal material. The limestones are not developed towards the top of the unit, and here finely laminated shale is the only rock type.

In thin section, the limestone is seen to contain up to 25 per cent angular quartz and feldspar, with calcite making up the remainder. It is also weakly foliated, and the foliation is often cut by narrow veins of calcite and quartz.

The interbedded green-grey siltstones often exhibit good soft-sediment deformation structures.

The type section of the Mitchie Well Formation is from "Bijerkerno" homestead along the road to "Sturts Meadows" homestead (GR 588248 - GR 635281), where the unit shows its maximum development of 2130 m.

Floods Creek Formation (atf)

The Floods Creek Formation conformably overlies the Mitchie Well Formation and its base is defined by the first occurrence of continuous, brown, limy sandstone horizons. The boundary is a gradational one, as in the southwestern portion of the Fowlers Gap 1:100 000 sheet green-grey lenticular limestone can be observed interbedded with the brown, calcareous sandstones.

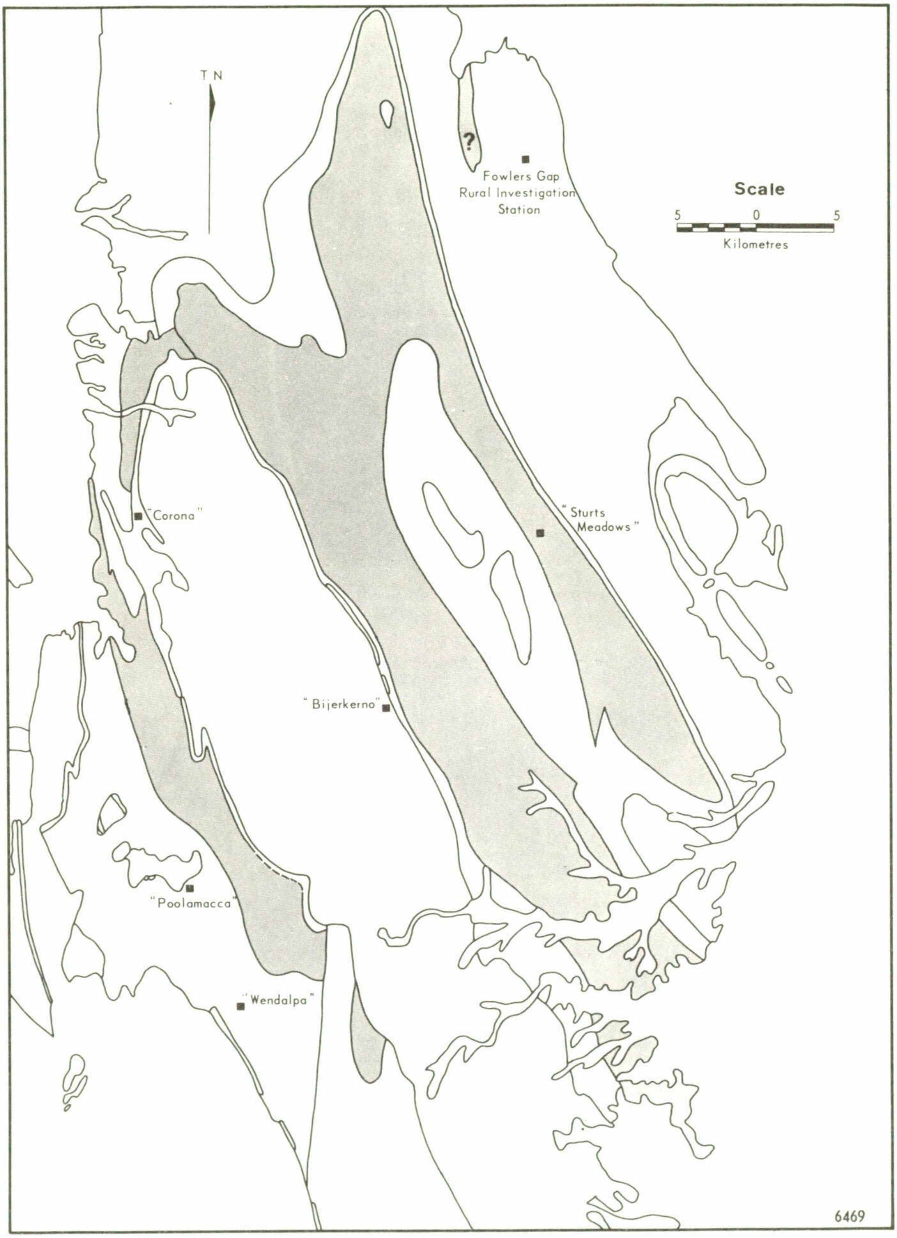


Figure 22. Outcrop distribution of the Euriowie Sub-Group

Each brown calcareous sandstone horizon is usually very continuous and some may be traced for distances up to 1.5 km. These units are approximately 0.3 m thick and contain crossbedding and crossbedded climbing ripples (photo 13). Bedding can be seen on the weathered outcrop surface, where it is defined by a fine, dark lamination. However, it is difficult to detect on fresh surfaces.

The calcareous sandstone is interbedded with laminated grey-green siltstone identical to that of the Mitchie Well Formation.

A massive yellow to brown sandstone unit 3 to 6 m thick marks the top of the formation. It is usually devoid of sedimentary structures and is often silicified.

In thin section the typical calcareous sandstone of the Floods Creek Formation consists of 60 - 80 per cent quartz, the remainder being calcite with minor feldspar and chlorite. The quartz grain shapes have been modified during diagenesis.

The maximum thickness of the unit is 1070 m. The type section is west of the Tibooburra road, midway between the old township of Euriowie and Eight Mile Creek (GR 595354 - GR 601358).

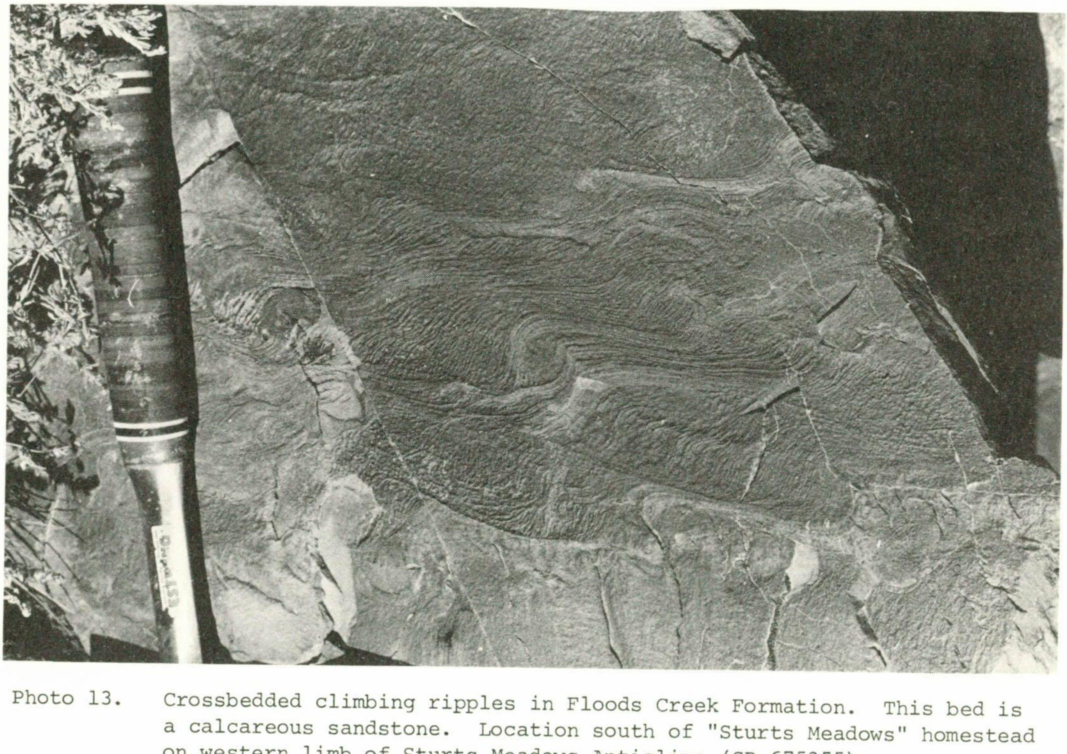


Photo 13. Crossbedded climbing ripples in Floods Creek Formation. This bed is a calcareous sandstone. Location south of "Sturts Meadows" homestead on western limb of Sturts Meadows Anticline (GR 675355)

Corona Dolomite (atc)

The Corona Dolomite crops out over a large area north and west of "Corona" homestead. It conformably overlies the McDougalls Well Conglomerate, but has also been observed sitting directly upon the Willyama Complex basement south of "Corona" homestead (Gilligan 1969).

The type section occurs 5 km east of Old Corona Well on the road which runs around the northern extremity of the Euriowie Block (GR 422418 - GR 417414).

Cowan (1969) estimated that the thickness varies from 900 m in the north to only a few metres to the southwest along the unconformity, where it passes laterally into the Wammerra Formation.

The dolomite is a recrystallized, massive, homogeneous, buff-coloured rock, and is virtually devoid of sedimentary structures except for a few vague remnants of bedding. Gilligan (1969) recorded possible bedding on a large scale; however, it is very difficult to detect, and for this reason any estimate of bedding thickness is only very approximate*.

Within the dolomite the grainsize is variable. However, the rock is normally fine grained and is made up of a mosaic of dolomite grains (0.05 mm) with minor quartz grains (Gilligan 1969).

Wammerra Formation (atw)

The Wammerra Formation lies unconformably on the Waukeroo Formation and is only developed to the west of the Euriowie Block. The base of the sequence is defined by the first appearance of sediment above the conglomeratic horizons of the Yancowinna Sub-Group. Lenticular flaggy limestones with interbedded shales and siltstones are typically developed at its base.

The type section of the formation occurs along a line joining Mount Wallop and a point where the "Corona" road crosses the first major creek north of Torrowangee quarries (GR 444194 - GR 449204). The maximum developed thickness of the unit is 750 m.

Towards the middle of the sequence the limestone becomes exceptionally massive, especially in the core regions of major folds where it is also extensively recrystallized. Almost all primary structures within the limestone have been destroyed, although interbedded pyritic shales, slump breccias, and slide blocks are

* Recently numerous probable algal/stromatolite structures have been observed in the Corona Dolomite at GR's 463227 and 418417 by Tuckwell. These comprise both single elliptical bodies up to 1.5 m across and large colonies 2 m x 2 m.

preserved in part (photos 14 - 15). The massive limestones are dark grey in colour and the interbedded dark-grey shales contain abundant pyrite.

Photo 14. The Wammerra Formation at Torrowangee quarries (GR 457204) — looking south. The base of a slump block is shown by a limestone/shale breccia (as marked). The upper block moved to the east.

Tanyarto Formation (att)

Conformably overlying the Wammerra Formation is a sequence of green-grey siltstones (photo 16) containing scattered pseudomorphs of limonite after pyrite and occasional sandy limestone lenses. The base of the unit is marked by the last sandstone horizon occurring at the top of the Wammerra Formation.

Photo 15. Limestone breccia in the Wammerra Formation to the north of Torrowangee quarries (GR 457204)

The type section occurs from a point 700 m northwest of Torrowangee quarries through Torrowangee Well (GR 451205 - GR 434246). The maximum developed thickness of 950 m occurs at the type section.

The siltstones are similar to those previously described in the Wammerra Formation, but they are less silicified and turn a distinct green on weathering. The limonite pseudomorphs are usually distorted, are hardly ever cubic, and range in size from 5 to 30 mm along "crystal" edges.

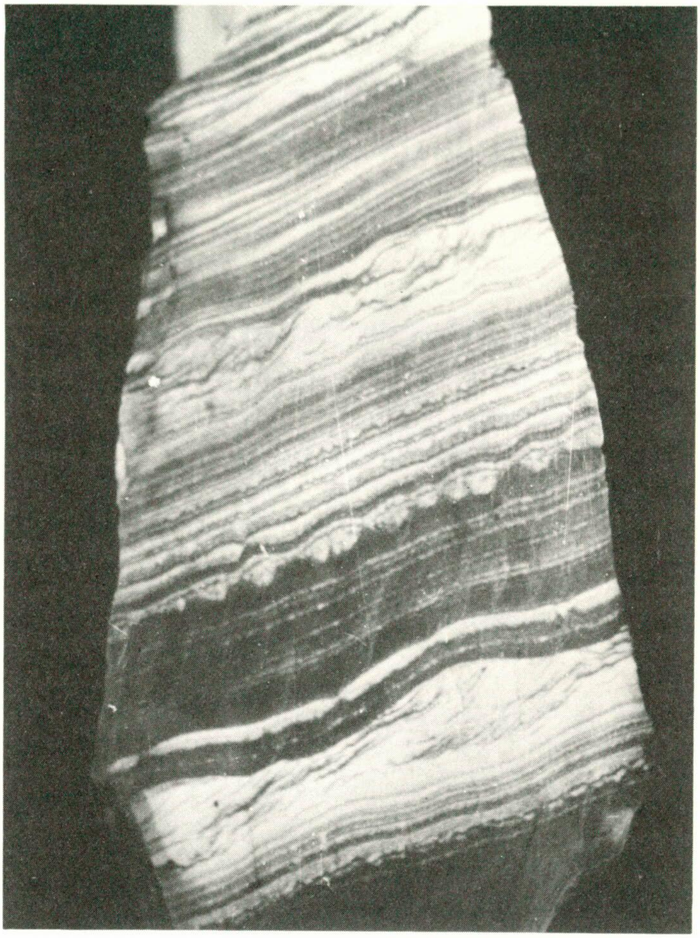


Photo 16. Calcareous siltstone of the Tanyarto Formation at GR 440261 showing crossbedded ripples, small load casting, and bottom structures associated with lighter coloured more sandy material

Yowahro Formation (aty)

The Yowahro Formation conformably overlies the Tanyarto Formation. The base of this unit is marked by a buff, flaggy, sandy limestone which changes laterally from limestone with minor silty horizons to predominantly siltstone with minor carbonate horizons. Above the flaggy limestone, black siltstone crops out. This siltstone gives a sharp ringing sound when struck. When weathered it shows fine bedding laminations, but bedding is difficult to detect in the unweathered specimen. Thin calcareous sandstones, identical with the horizons within the Floods Creek Formation, are interbedded with dark siltstone. These sandstones contain small-scale crossbedding, internally crossbedded ripple marks, and some small-scale slumps. Towards the top of the sequence, quite thick, white quartz sandstones crop out.

The estimated maximum thickness of this unit is 440 m and is developed at the type section which is situated along the "Corona"/"Poolamacca" boundary fence, east of the old road from Torrowangee Well to Bobs Well (GR 439259 - GR 432258).

Correlation within the Euriowie Sub-Group

The main area of outcrop of the Euriowie Sub-Group is divided by the Euriowie Block which had some effect on the environmental conditions at the time of deposition of the sub-group. Both east and west of the Euriowie Block, the sequence shows similar trends, being fine grained and calcareous at the base and less calcareous and more sandy towards the top.

During deposition of the Wammerra and Tanyarto Formations the environment west of the block was a reducing one, with restricted water circulation (pyrite is common), whereas the time-equivalent unit east of the block, the Mitchie Well Formation, was deposited in an open circulation, non-reducing environment.

North of the block, shallow water covered a large area and conditions were suitable for the deposition of dolomite. During deposition of the dolomite, essentially similar sandy deposition occurred both east (the Floods Creek Formation) and west (the Yowahro Formation) of the Euriowie Block.

The Wammerra and Tanyarto Formations are together equivalent to the Mitchie Well Formation and to part of the Corona Dolomite. The Floods Creek and Yowahro Formations are equivalent to each other, and their basal part is equivalent to the top portion of the Corona Dolomite (see figure 23).

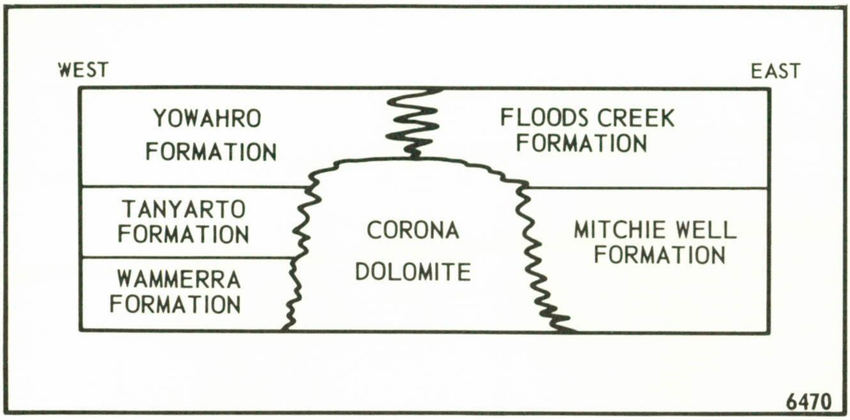


Figure 23. Correlation within the Euriowie Sub-Group

TEAMSTERS CREEK SUB-GROUP

The Teamsters Creek Sub-Group is a variable sequence of shallow-water sediments consisting of diamictite, conglomerate, siltstone, and some quartzite and sandstone.

It is principally developed east and north of the Euriowie Block, but some of the sequence is still preserved west of the Euriowie Block in the Corona area (figure 24).

The thickness of the unit varies considerably. It thins rapidly to the east and northeast of the area studied.

Alberta Conglomerate (ata)

The Alberta Conglomerate, the basal unit of the Teamsters Creek Sub-Group, is a thin, variable sequence of diamictite, pebbly siltstone, siltstone, sandstone, and some conglomerate.

The unit consists principally of well-laminated siltstone containing sporadic pebbles, cobbles, and boulders. Thin pebble bands, boulder horizons, and diamictites also occur within the siltstone (photo 17).

The clasts are predominantly grey quartzite (probably derived from the Lady Don Quartzite), pegmatite, granite, limestone (either Corona Dolomite or Mitchie Well Formation), and conglomerate (probably Yancowinna Sub-Group), as well as small pebbles of low-grade Willyama Complex. The only exotic rock-types occurring as clasts are some pebbles and boulders of quartz - orthoclase porphyry and quartz - plagioclase - orthoclase porphyry. The source of this material is unknown as there are no similar rock types within the

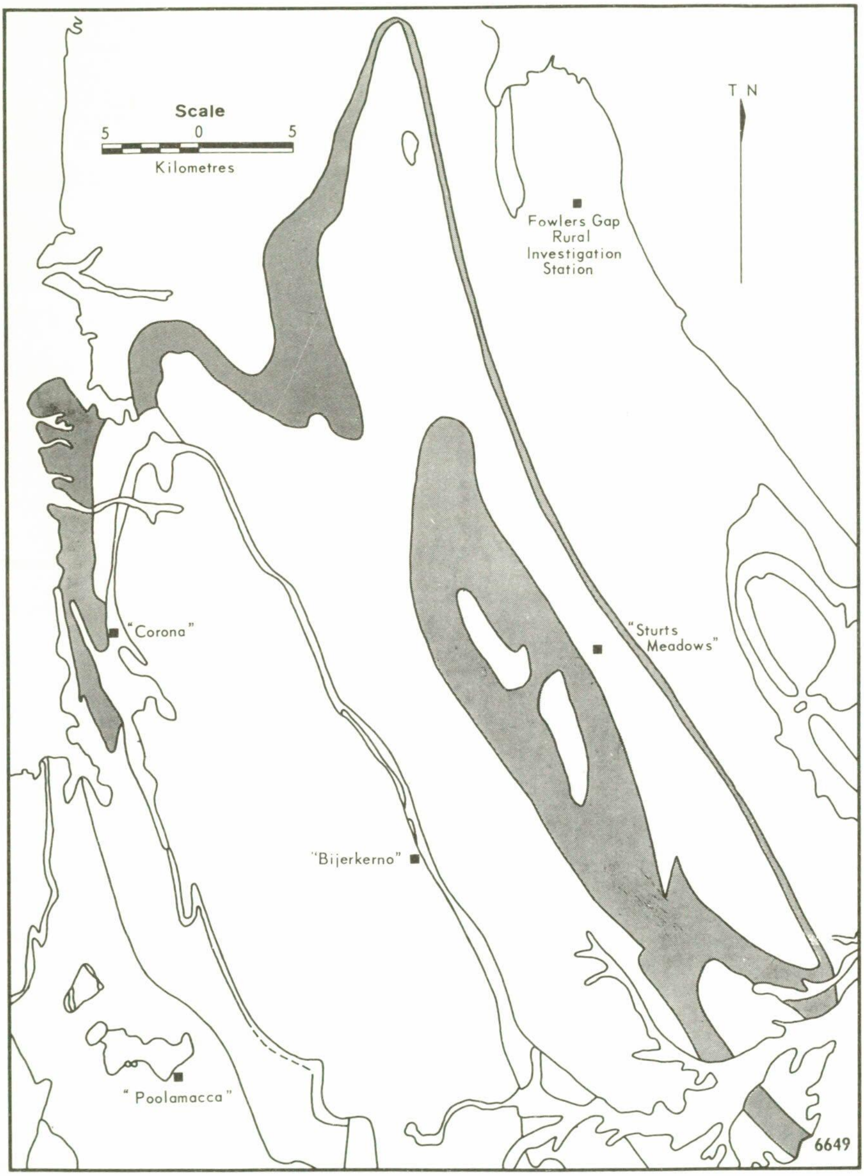


Figure 24. Outcrop distribution of the Teamsters Creek Sub-Group

Photo 17. Alberta Conglomerate near Eight Mile Creek (GR 595375). The white pebbles are Lady Don Quartzite fragments and are a common constituent of the conglomerate

Willyama Complex. However, they may be Gawler Range Volcanics (South Australia).

Numerous well-bedded quartz sandstone horizons also occur within the Alberta Conglomerate. These are only 0.3 m thick and often exhibit good crossbedding and small-scale slump structures.

The boundary between the Alberta Conglomerate and the underlying Euriowie Sub-Group is highly irregular, and it may be erosional, although outcrop is never good enough to determine this with confidence.

The type section is on the "Bijerkerno" - "Sturts Meadows" road (GR 642306 - GR 647300), and the maximum thickness is approximately 300 m.

Gairdners Creek Quartzite (atg)

The Gairdners Creek Quartzite is a partially silicified, brown, well-sorted, massive, medium to coarse quartzite, usually about 2 m thick but occasionally thickening to 4 m. This unit conformably overlies the Alberta Conglomerate and is remarkably persistent in outcrop. It often contains numerous quartz veins approximately 5 to 12 mm thick.

In thin section the rock consists of 95 per cent quartz, the remainder being feldspar. The boundaries of all the quartz grains show well-developed suturing.

The type section of the Gairdners Creek Quartzite occurs southeast of the road between "Bijerkerno" and "Sturts Meadows" and approximately 1.8 km southwest of the "Sturts Meadows" homestead (GR 665355). Here the unit is well bedded, quite strongly silicified, and shows occasional crossbedding.

Dering Siltstone (atd)

The Dering Siltstone varies in thickness from 20 to 200 m. It consists of finely laminated and well-bedded siltstone. Individual beds are often graded (photo 18) and usually range in thickness from 12 to 50 mm. Where a graded unit greater than 0.15 m in thickness is present it has usually scoured the top of the underlying unit. Units under 0.15 m in thickness generally have sharp bases and tops. The individual units are quite persistent and can be traced as far as outcrop permits (30 m or so).

The siltstone of this formation characteristically shows many different types of ripple marks. By far the most common are the crossbedded climbing ripples (figure 25 and photo 19) and sharp crest-line ripples (figure 26). The crossbedded climbing ripples tend to occur in horizons as shown, whereas the sharp crest-line ripples, often with wavelengths 1 to 2 m long, are developed through greater thicknesses of sediment. The crest-line of the latter is more or less sinusoidal and the crest itself is quite angular (figure 26). Sediments on the lee side of these ripples tends to be finer grained and also vaguely crossbedded.

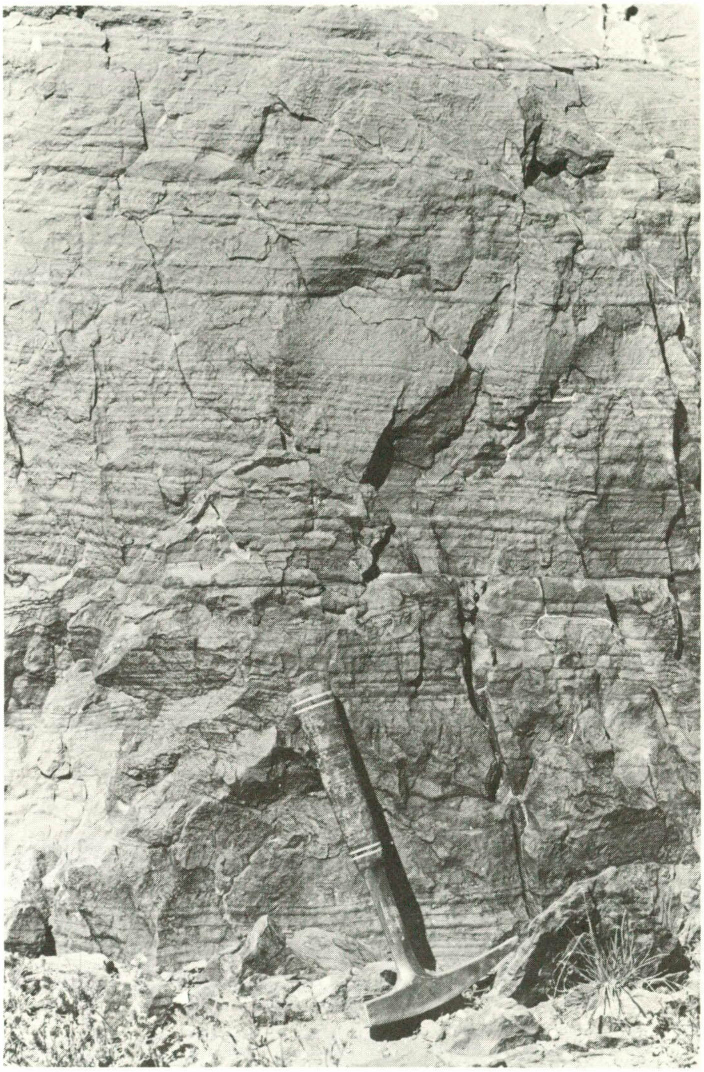


Photo 18. Thin graded bedded units in the Dering Siltstone. Note large bed near handle of hammer (GR 513560)

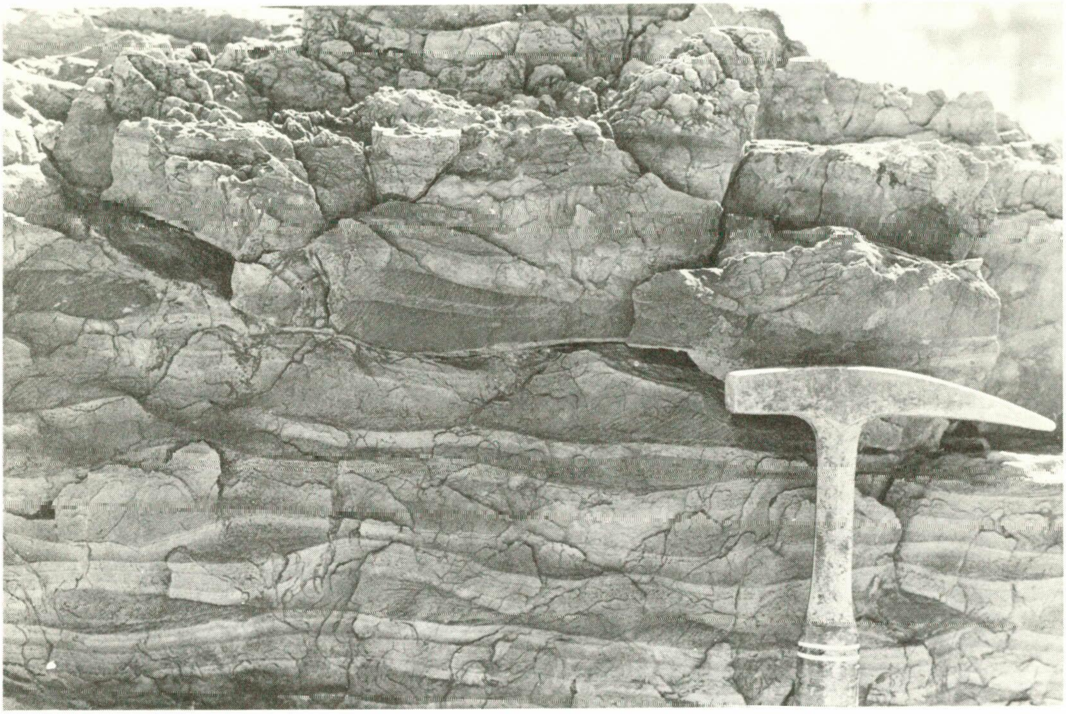


Photo 19. Internally crossbedded ripple marks from the Dering Siltstone. Note the consistent thickness of the layer of sediments draped across the troughs and crests of the ripples (GR 513560)

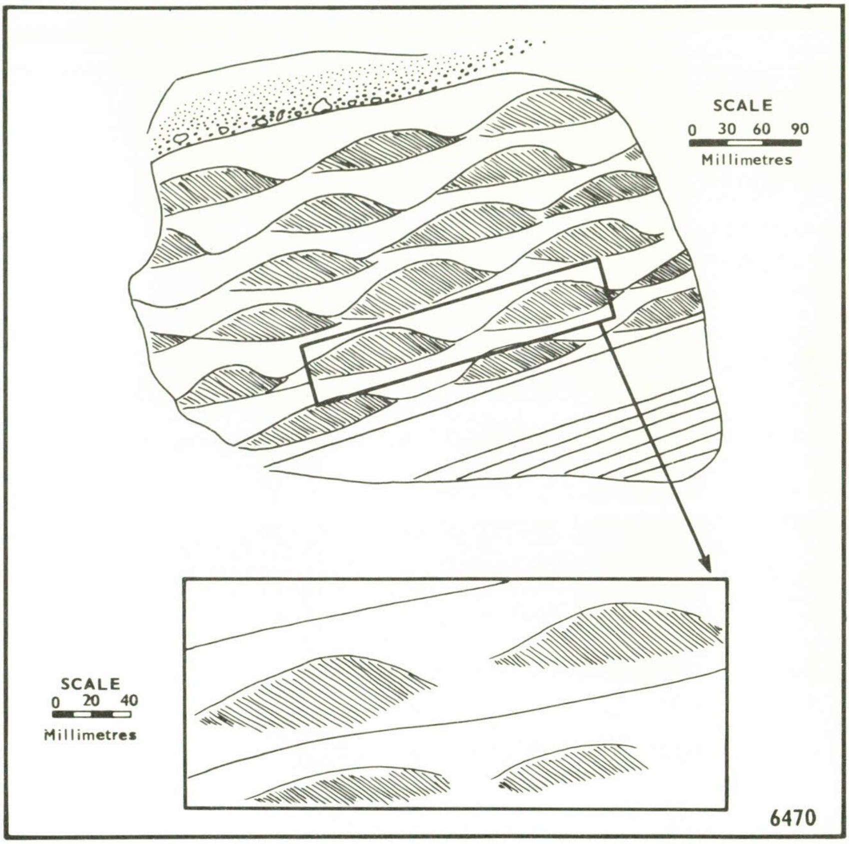


Figure 25. Crossbedded climbing ripples in the Dering Siltstone

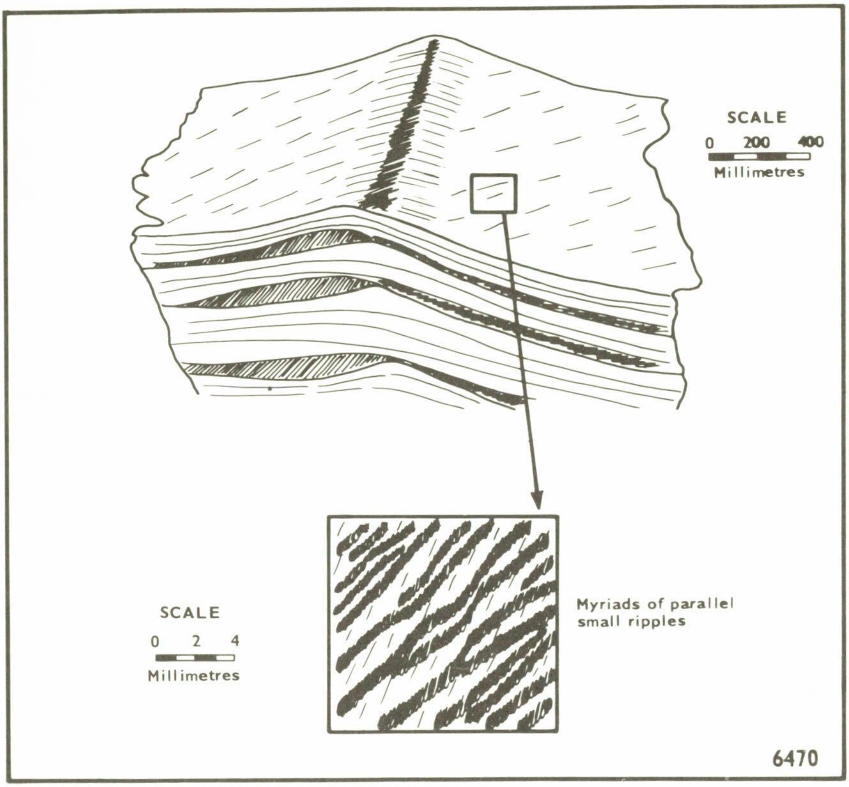


Figure 26. Sharp crest-line ripples in the Dering Siltstone

Ellipsoidal concretionary sandstone nodules measuring up to 0.25 m by 0.1 m are sporadically developed south of the road from "Bijerkerno" to "Sturts Meadows" (GR 670358).

The unit thins to the east and northeast, and is not present east of "Sturts Meadows" homestead, nor southeast of "Floods Creek" homestead. In the Floods Creek (incorrectly shown as Flood Creek on the map) area, the Alberta Conglomerate merges with the Nunduro Conglomerate as the Dering Siltstone lenses out.

Occasional pebble bands occur throughout the unit, and become more common towards the top where the Dering Siltstone grades into the Nunduro Conglomerate.

The type section of the Dering Siltstone occurs due west of the "Floods Creek" road (GR 515570).

Nunduro Conglomerate (atn)

In many places the Nunduro Conglomerate has an erosional contact with the underlying Dering Siltstone. Many large blocks and fragments are incorporated within the conglomerate as extensive slump breccias and pebbly mudstones. The erratic clasts consist almost exclusively of rounded quartzite fragments derived from the Pintapah Sub-Group, with minor amounts of Boco Formation(?) dolomite and Corona Dolomite. The intrabasinal clasts are essentially Dering Siltstone, occurring as large and small masses within a pebbly mudstone matrix. Many of these fragments are up to 20 m in length, are strongly contorted, and lie at random within the mudstone (photo 20 and photo 21).

To the north and northeast of the Euriowie Block, the Alberta Conglomerate and the Nunduro Conglomerate converge. However, they can still be easily distinguished because the Nunduro Conglomerate has a much higher clast to matrix ratio.

On the eastern limb of the Sturts Meadows Anticline the Alberta Conglomerate and Gairdners Creek Quartzite are greatly diminished in thickness and the Dering Siltstone and Nunduro Conglomerate are absent.

The type section for the Nunduro Conglomerate occurs on the "Bijerkerno" - "Sturts Meadows" road (GR 652315). The unit has a maximum thickness of approximately 70 m.

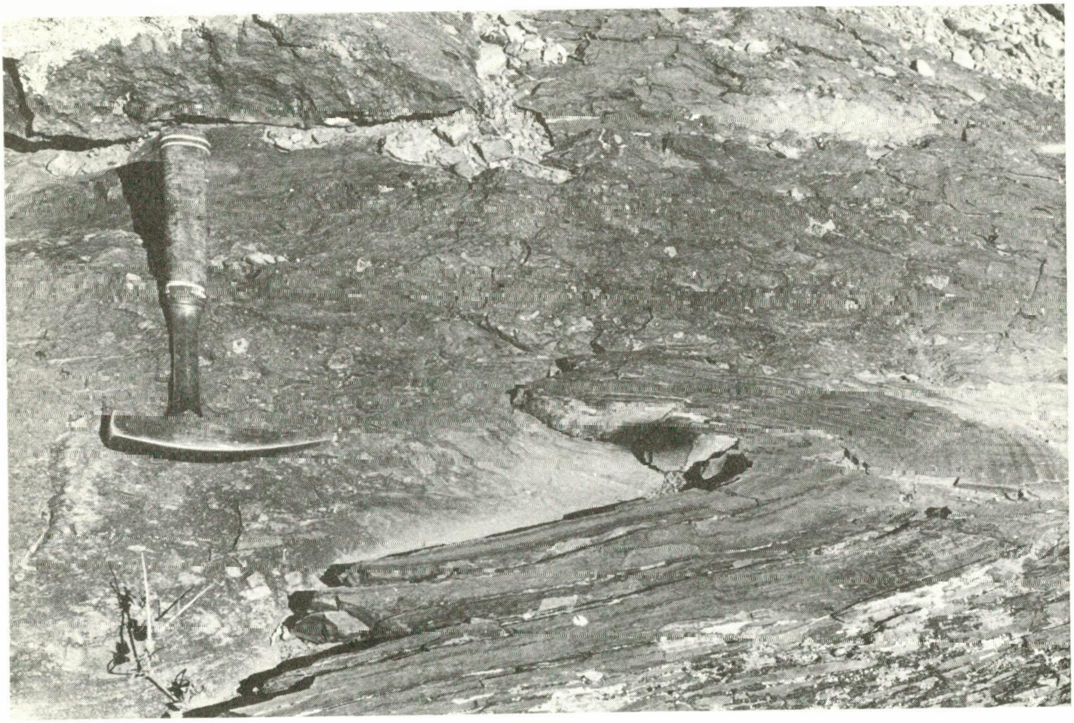
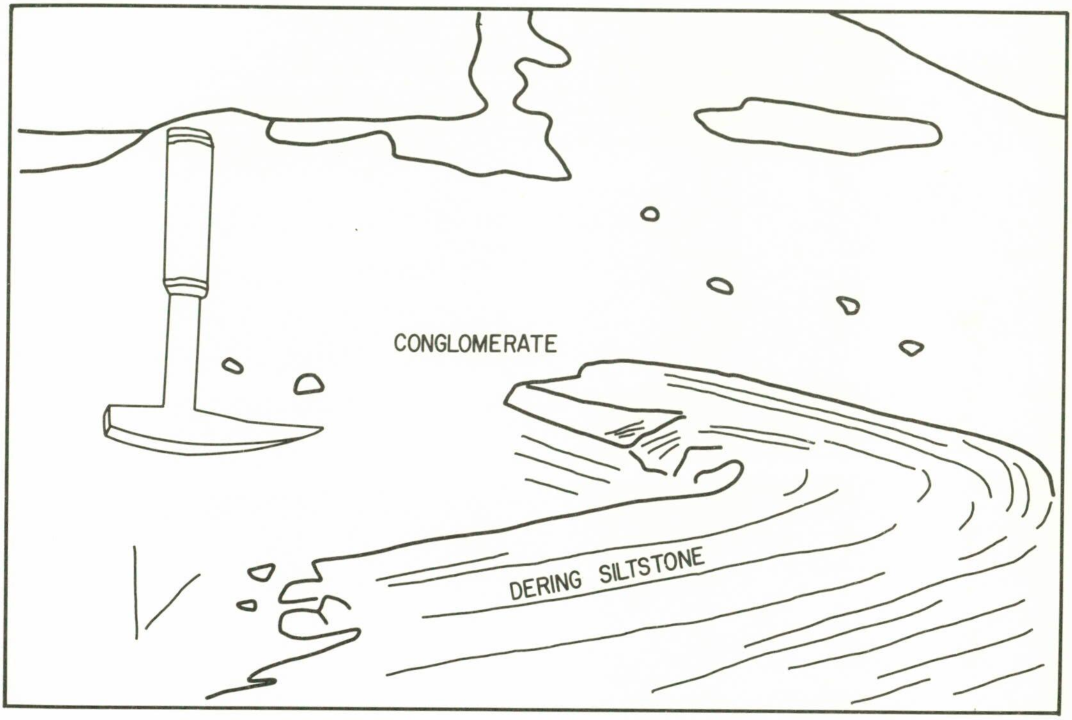
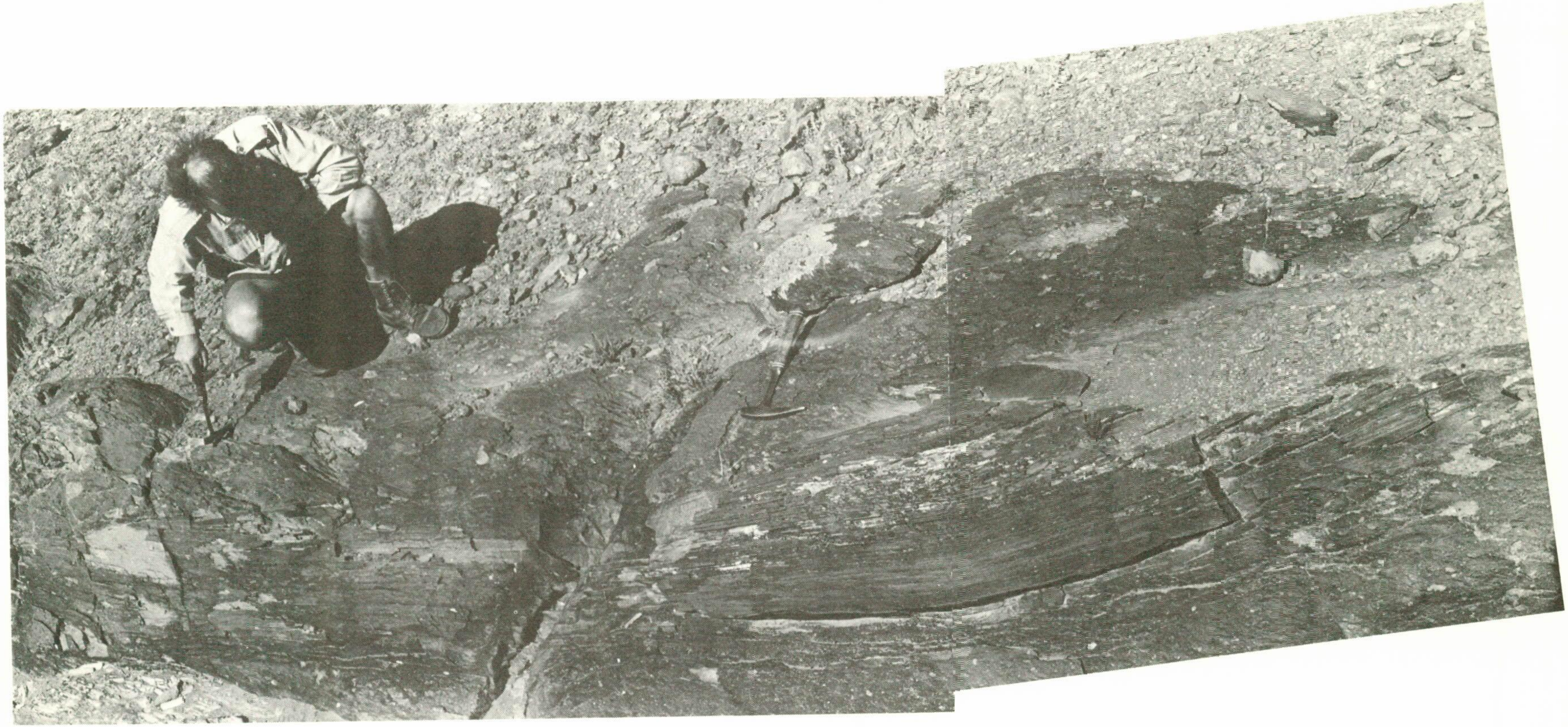


Photo 20. Contorted clast of Dering



Siltstone in the Nunduro Conglomerate (GR 650313)



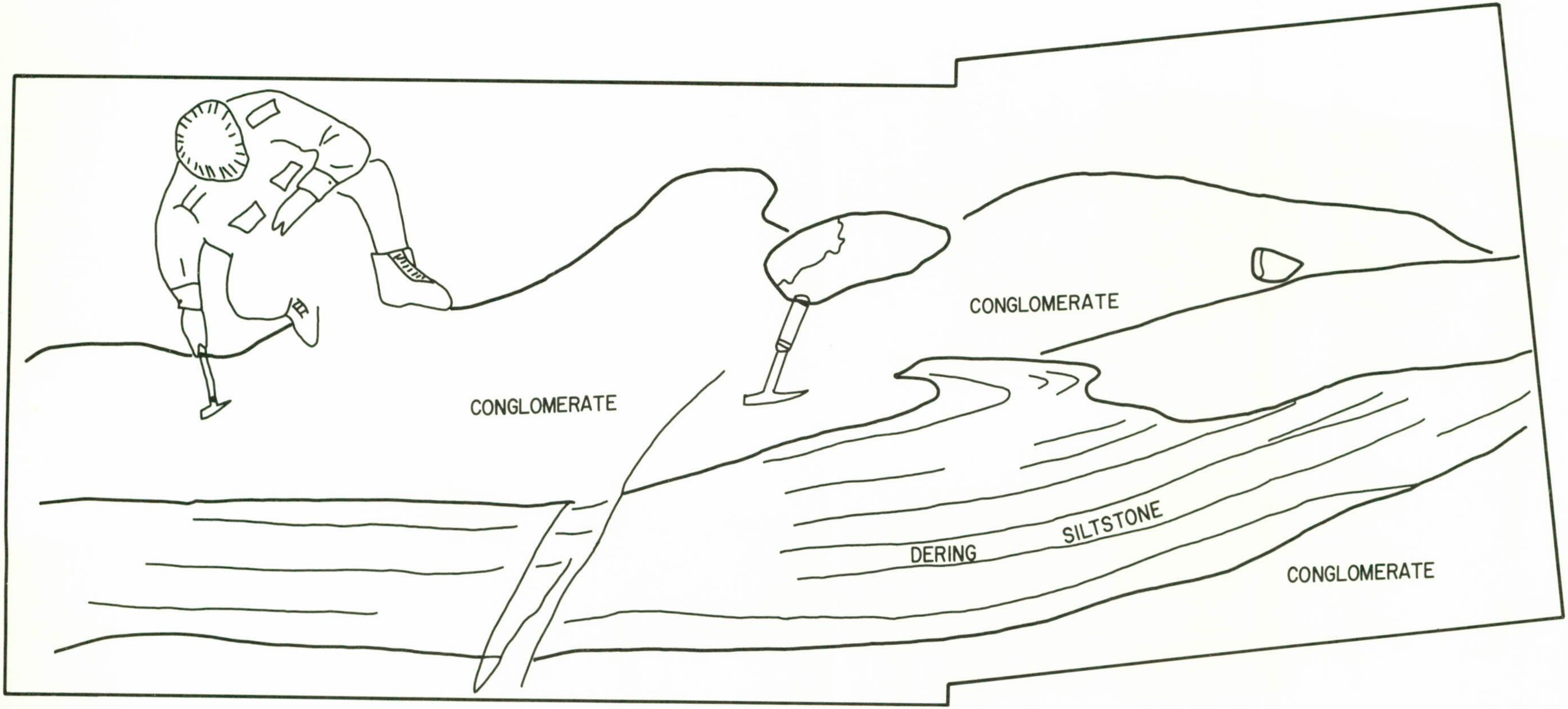


Photo 21. Large contorted clast of Dering Siltstone in the Nunduro Conglomerate indicating the erosive nature of the conglomerate (GR 650313)

Farnell Group

The Farnell Group is subdivided as indicated below.

Farnell Group	Lintiss Vale Formation Camels Humps Quartzite Fowlers Gap Formation Faraway Hills Quartzite Sturts Meadows Siltstone Mantappa Dolomite

The base of the Farnell Group is essentially defined by the base of the Mantappa Dolomite which is an excellent marker horizon throughout the area. The Mantappa Dolomite is present almost everywhere at the base of the Farnell Group, but is mostly absent on the eastern side of the Sturts Meadows Anticline, where the base of the Farnell Group is then defined as the top of the Gairdners Creek Quartzite. Where both of these formations are absent, the lower boundary of the Farnell Group is defined as the top of the last boulder/cobble/pebble horizon in the Teamsters Creek Sub-Group.

Outcrop distribution is shown in figure 27.

Mantappa Dolomite (afm)

The Mantappa Dolomite is buff to yellow coloured in outcrop but can become a dark-brown colour due to limonite(?) staining. When fresh, the dolomite is a pale grey to white.

The type section for the Mantappa Dolomite occurs on top of a prominent hill just north of Eight Mile Creek and 2 km east of the Tibooburra road (GR 603400). The unit has its maximum development (2 m) at this locality.

The dolomite is finely laminated and generally ranges from 0.75 to 2 m in thickness. The unit has remarkable lateral continuity and is nearly always present at the base of the Farnell Group. However, it is absent virtually all the way from the "Floods Creek" road, around the Nardoo Inlier, and along the eastern side of the Sturts Meadows Anticline, although some discontinuous outcrops of dolomite can be observed just to the north and south of Faraway Hills Dam (GR 752296).

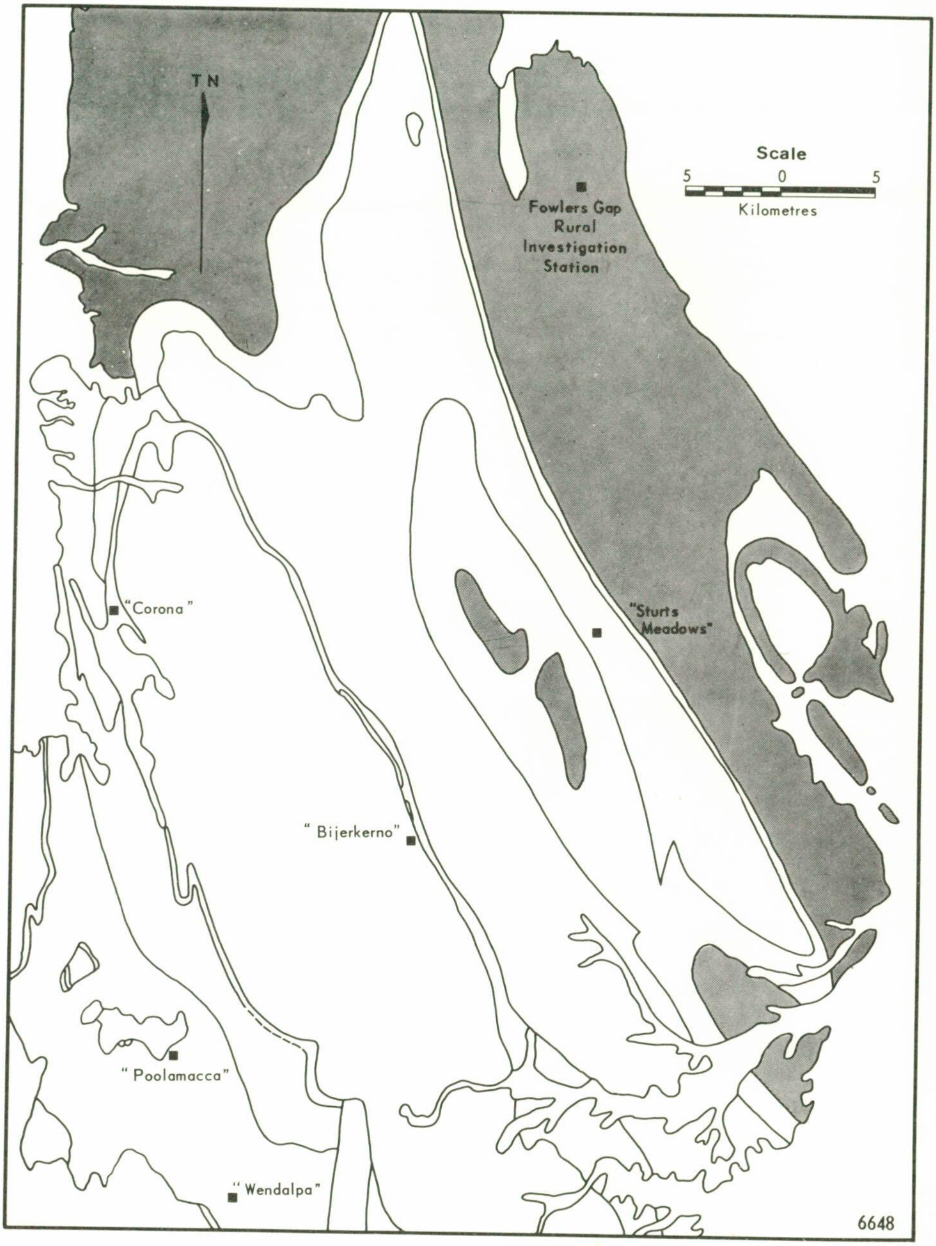


Figure 27. Outcrop distribution of the Farnell Group

Because of the difference in competence between the dolomite and the surrounding siltstones it is strongly folded, but nevertheless it is easily mapped because of its lithological characteristics.

Sturts Meadows Siltstone (afs)

The Sturts Meadows Siltstone is conformable on the Mantappa Dolomite and has an estimated maximum thickness of approximately 200 m. The type section may be seen along the disused road which runs from the windmill (GR 461468) at the northern end of the Euriowie Block northwards to "Floods Creek" station (GR 480677). The road is poorly defined and is best located by commencing at "Floods Creek" station and driving south.

The units comprises a monotonous sequence of finely laminated, medium to dark green-grey siltstone (photo 22) almost devoid of sedimentary structures.

The Sturts Meadows Siltstone is best observed in the Floods Creek Syncline where it crops out very well; elsewhere outcrop is very poor and the ubiquitous cleavage hampers observation of sedimentary characteristics.

A carbonate facies is developed towards the top of the unit in the Floods Creek Syncline. The siltstone in the carbonate facies is not obviously calcareous, but is lighter in colour than the remainder of the unit.

Thin, discontinuous horizons of buff-coloured limestone are developed in the siltstone, and there are horizons of sandy limestone approximately 0.8 m thick containing asymmetric ripple marks and festoon crossbedding. The carbonate facies supports a much lusher grass growth than the dominant siltstone sequence. On the western limb of the Floods Creek Syncline small-scale slumping is abundant and the sediments look superficially like those of the Euriowie Sub-Group.

The transition from the Sturts Meadows Siltstone to the overlying Fowlers Gap Formation or Faraway Hills Quartzite (depending on location) is a gradational one. The siltstone becomes more sandy until the characteristics of the Sturts Meadows Siltstone are gradually lost and the more sandy facies of the Faraway Hills Quartzite or Fowlers Gap Formation is developed.

Faraway Hills Quartzite (afa)

The Faraway Hills Quartzite is best developed in the Caloola Syncline and also in a small syncline to the southeast of "Floods Creek" homestead (GR 530660). Further to the west, in the Floods Creek Syncline and especially on the western limb, the quartzite thins, becomes discontinuous, and can no longer be recognized as a distinct unit.

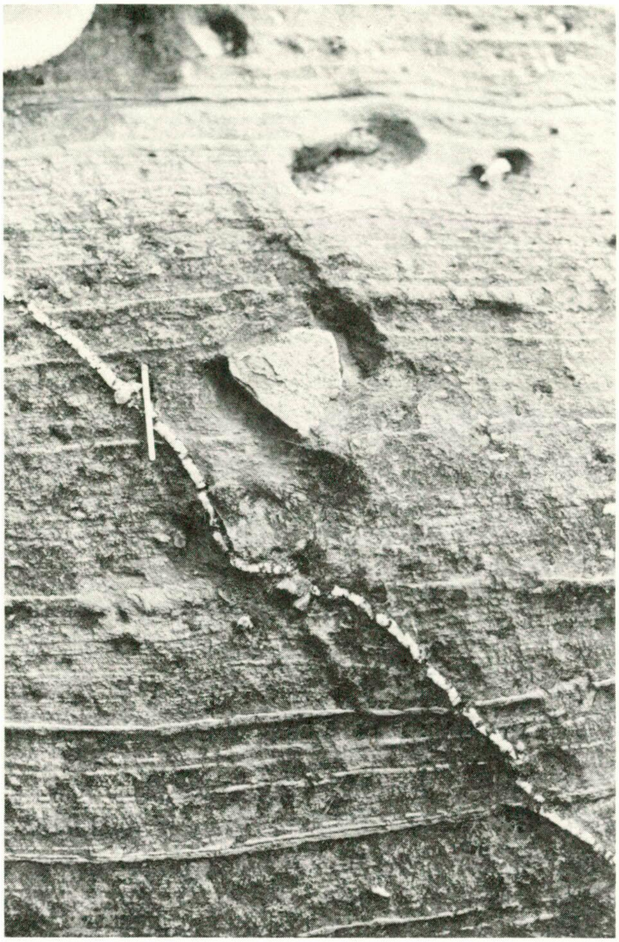


Photo 22. Quartzite pebble in laminated Sturts Meadows Siltstone at GR 513560. The unstable position of the pebble and the laminated nature of the enclosing sediment indicate that this pebble has been dropped. The last suspected glacial activity was just prior to the deposition of the Sturts Meadows Siltstone

The type section for the Faraway Hills Quartzite is approximately 2 km south of the Fowlers Gap Rural Investigation Station, near the main Tibooburra road (GR 664580 - GR 665580). It is difficult to accurately measure the thickness of the unit as it is often partially obscured by scree; however, maximum thickness is probably 40 m.

The unit is a light-grey, medium to coarse-grained, generally well-silicified quartzite, often showing superficial silicification. Some interstitial white clay (kaolin(?)) is present, as are minor lithic fragments and limonite pseudomorphs after pyrite.

Bedding is difficult to detect and the unit is therefore generally massive in outcrop.

Fowlers Gap Formation (aff)

The two areas of outcrop of the Fowlers Gap Formation are in the Floods Creek Syncline and the Caloola Syncline. In the Caloola Syncline the Fowlers Gap Formation crops out poorly, except for the quartzite units (affq) which are more resistant to weathering than the sandy siltstone interbeds and are now exposed as prominent ridges. Quartzite scree from the more resistent units also covers most of the ground, making mapping difficult. However, the ridges of quartzite can be readily delineated on airphotos. The outcrop of the Fowlers Gap Formation within the Floods Creek Syncline is excellent.

The base of the unit is defined by the last occurrence of continuous quartzite horizons of the Faraway Hills Quartzite.

The type section of the Fowlers Gap Formation is due south of the Fowlers Gap Rural Investigation Station (GR 675595). The maximum developed thickness of the unit is 1500 m.

Lithologically, the Fowlers Gap Formation is a sandy/silty facies. Sedimentary structures are rare, and the quartzite horizons constitute only a minor proportion of the entire unit.

In outcrop the siltstones are usually bleached white, but in fresh samples they can be seen to be composed of alternating dark-grey silty horizons and light-coloured sandy horizons, 2.6 mm thick and 0.8 mm thick respectively.

The quartzites are similar to the Faraway Hills Quartzite, though they are generally finer grained and contain less clayey material. They are usually no greater than 0.3 m thick.

Camels Humps Quartzite (afc)

The thickness of the Camels Humps Quartzite is difficult to determine because of a lack of bedding and the presence of extensive scree. Warris (1967) claimed that the unit varied considerably in thickness and that the sand/shale ratio varied sympathetically. However, Warris measured one section along the nose of the major syncline (Caloola Syncline) and arrived at the thickness of 916 m. Ward et al. (1969) measured a section close by and obtained a thickness of approximately 307 m. The difference in the values is almost certainly due to an error in measurement by Warris who failed to appreciate that the section was measured on a plunging structure.

The type section occurs on the road from the Tarnuna Tank to Carnies Tank (GR 781333 - GR 784336). Here the Camels Hump Quartzite is 332 m thick (Warris 1967). The quartzite horizons are all of similar character, and are fine to medium grained, well-sorted, and, unlike the Faraway Hills Quartzite, contain little or no clay. The quartzites are silicified. Bedding is generally massive but some fine lamination is present.

Warris (1967) observed asymmetric ripple marks. Ward et al. (1969) recorded the presence of clay galls in the upper quartzite horizon of the unit. These galls are about 25 to 50 mm in diameter and number about two or three per square metre of rock surface.

Lintiss Vale Formation (afl)

The "Lintiss Vale Beds" were defined by Rose (1970) as the sequence between the top of the Camels Hump Quartzite and the base of the "Cambrian". Rose (1968, 1970) and Ward et al. (1969) mapped the "Cambrian" rocks over an area of about 2.5 km^2 at the centre of the Caloola Syncline west of Tarnuna Tank, and named them the "Acacia Downs Formation". However, this study has failed to justify the contention that a sequence of Cambrian sediments disconformably overlies the "Lintiss Vale Beds". The Lintiss Vale Formation as used in this study includes all the sediments above the Camels Hump Quartzite, including the so-called Cambrian, which is exposed only in the Caloola Syncline.

The evidence of Rose (1968, 1970) and Ward et al. (1969) for regarding the "Acacia Downs Formation" as Cambrian, is twofold:

1. The presence of a disconformity between the "Acacia Downs Formation" and the underlying "Lintiss Vale Beds".

2. The presence of worm burrows within the "Acacia Downs Formation".

Regarding point (1), the disconformable relationship is only recorded by Ward et al. (1969), whereas Warris (1967) and Packham (1969) did not mention it. Ward et al. (1969) did not give any evidence for the unconformity. The dips (if they are in fact bedding) shown by Taylor (1967) do not support the orientation of the fold indicated by him, nor that indicated by Rose (1968, 1970) and Ward et al. (1969), but indicate a fold axis consistent with the axis of the Caloola Syncline. The evidence for a disconformity rests on the apparent discordance of the fold axis in the "Cambrian" with underlying sediments. However, it is now clear that the axis of the Caloola Syncline is not planar but curviplanar; it swings to the east so that in the "Cambrian" sediments its trace trends to the northwest. There are no outcrops on the ground which show a disconformable relationship, and the orientation of the fold axis in the "Cambrian" rocks is consistent with that of the Caloola Syncline. Therefore, the authors believe that there is no basis for assuming a disconformable relationship.

Regarding point (2), much has been made of the recognition of worm burrows by B. Fitzpatrick and W. Johnson (as quoted by Packham 1969 and Ward et al. 1969). However, Webby (1970a), who did detailed work on the area, has made the following comment (p. 84):

"The basis for dating the Acacia Downs Beds as Lower Cambrian on the presence of worm burrows must be seriously questioned, because the underlying Lintiss Vale Beds contain an abundance of trails and burrows. Despite careful searching, no fauna has been produced from the Acacia Downs quartzites, and it seems likely the worm burrows of Fitzpatrick and Johnson came from the underlying Lintiss Vale Beds ..."

Furthermore, as the lithology of the "Acacia Downs Formation" is identical to that of the underlying units, it is proposed that the term "Acacia Downs Formation" be abandoned and the Lintiss Vale Formation be defined to include all the section from the top of the Camels Humps Quartzite to the limit of outcrop in the Caloola Syncline*.

The type section is found along the track which runs east from the Faraway Hills Dam (GR 752296) to "Acacia Downs" homestead (GR 850330).

The Lintiss Vale Formation crops out rather poorly, and consists predominantly of light-green, brown, and yellow siltstone. Numerous worm trails and burrows have been observed in the lower portion of the formation (Webby 1970b).

Thin, sandy limestone horizons usually 0.15 m thick occur midway through the exposed section. They display abundant festoon crossbedding and slump structures. The upper part of the section becomes more sandy, and several quartzites 0.3 to 1 m thick occur interbedded with the siltstones. The quartzites are medium grey in colour, lack fine lamination, and are almost devoid of sedimentary structures. No fossils were found in these quartzites.

The estimated maximum thickness of this sequence is 1200 m.

Palaeontology

The greater part of the Late Precambrian Adelaidean is devoid of fossiliferous rocks. During this study stromatolites were collected and described from the Boco Formation. Trace fossils were also found in the Dering Siltstone and Lintiss Vale Formation. Warris (1967) and Webby (1970a) are the only workers to have reported on fossils occurring in the area.

* More recent work by Daily (1972, 1973) on Early Cambrian trace fossil assemblages has indicated a clear correlation of the Lintiss Vale Formation with the basal Cambrian Uratanna Formation of South Australia.

Warris (1967) recorded the presence of *Collenia frequens* in the Mitchie Well Formation. Only a scant description of the fossils is presented and inadequate details of the localities are given. Webby (1970a) described the locality where abundant stromatolites may be found and mentioned other localites where stromatolites have been found; however, in discussion in 1971 he stated that these "other localities" had been discredited. A thorough search of the area mentioned by Warris (1967) and Webby (1970a), as well as a thorough search of the section from the base of the Teamsters Creek Sub-Group to the core of the Sturts Meadows Anticline, has failed to reveal any stromatolites. At the locality where abundant stromatolites are supposed to occur, horizons containing ferruginous laminated concretionary structures which could have been mistaken for bulbous and even "columnar" stromatolites were observed. Preiss (1972) observed that

"they cut across the flat bedding lamination and are clearly secondary structures related to liesegang rings, formed by the diffusion of iron oxides. Moreover, the facies of these sediments is totally unlike that of the stromatolite-containing limestones from the Flinders Ranges; in contrast with the latter they are silty lime-mudstones deposited in quiet water, and contain no evidence of shallow water conditions. Therefore the absence of stromatolites was not altogether unexpected".

Gilligan (1969) found a "stromatolite" in the Mitchie Well Formation west of "Corona". W.V. Preiss (pers. comm. 1971) believed the specimens from this locality to be concretions. Specimens from Gilligan's locality are similar to a photograph of the stromatolites found by Warris; however, Preiss has not been able to examine the specimens collected by Warris*.

Webby (1970a) has described in detail trace fossils and problematical structures from the Farnell Group. Some of his conclusions are as follows (pp. 104-105):

"Evidence of animal activity has been found in the sediments of the middle part of the Fowlers Gap Beds, and through most of the Lintiss Vale Beds. In the Fowlers Gap Beds, the activity takes the form of simple, sinuous and branching horizontal to slightly oblique trails interpreted as postdepositional, endogenic burrows, and trails of simple form, rarely with offsets and probably of pre-depositional, exogene or pre-endogene origin. These are considered to have formed by the activity of several, mainly infaunal deposit-feeding worm-like organisms. It is difficult with such a complement of miscellaneous trails to assess the likely diversity and abundance of the metazoan fauna. The possibility

* Recently probable stromatolites and/or algal structures have been observed in the Corona Dolomite by Tuckwell.

of more than one animal forming the same trail and/or the likelihood of similar organisms producing different trails prevents any accurate assessments of numbers. However, some very approximate estimates may be made on the basis of the distinct patterns of activity exhibited. Estimates vary from a minimum of about 3 to a maximum of about 7 distinctive patterns of activity for the Fowlers Gap Beds. The lower value should be adopted if some of the questionable forms are interpreted as inorganic markings.

"The Lintiss Vale Beds exhibit a much greater variety of trails. Seven of the most distinctive patterns of activity have been named: *Planolites ballandus*, *Planolites?* sp., *Cochlichnus serpens*, *Gordia?* sp., *Torrowangea rosei*, *Phycodes? antecedens* and *Curvolithus? davidis*. In addition, there are branching, sinuous, bilobated, transversely-segmented, intertwined and crescent-shaped trails, and other impressions interpreted as rest marks. In terms of approximate estimates of numbers of patterns of activity represented in the Lintiss Vale Beds, something like a minimum of 10 and a maximum of 21 distinct types of trace are recognized. With the exception of *Planolites ballandus*..., they are all confined to the horizontal plane. Three of the species, *Planolites ballandus*, *Cochlichnus serpens*, *Phycodes? antecedens* and one of the bilobated trails... are interpreted with some confidence as endogenic burrows, thought to represent the activity of infaunal, worm-like deposit feeders. The others, with the possible exception of the small transversely-segmented trails..., can only be doubtfully regarded as having an endogene origin. Some may have formed as surface (exogene) trails. The transversely-segmented trail may be either a rest mark or an incomplete feeding burrow. There is no evidence of walk tracks of the kind made by arthropods.

"In summary, the trace-fossil fauna of the Lintiss Vale Beds is considered to represent predominantly feeding burrows (Fodinichnia) of soft-bodied, infaunal worm-like organisms. It may be further suggested that most of the activity was produced by vagile deposit feeders mining the sediment in the horizontal plane. A few forms may be rest marks (Cubichnia), and a few, crawling trails (Repichnia).

"There is a substantial increase in the number of patterns of activity between the Fowlers Gap Beds and the Lintiss Vale Beds, from a maximum of 7 to 21, respectively. Minimum estimates show a comparable increase in activity, from 3 to 10 types, respectively. This suggests a much greater diversity of forms in the Lintiss Vale Beds, and is matched by evidence of greater abundances of some individual forms in this stratigraphically higher formation. Viewing these results in the context of the entire upper part of the Torrowangee Group and as correlative of the Marinoan, it can be seen that, from no visible signs of metazoan activity in the Teamsters Creek Beds (directly overlying the 'upper tillite'), there is a progessive increase (excluding the barren quartzites) in the abundance and diversity of patterns of activity. This strongly supports the view held by Cowie (1967, p. 27) that there was a striking increase in tracks and trails of metazoan benthonic organisms just prior to the Cambrian period.

"There is a little evidence of bioturbation in the upper part of the Torrowangee succession. Apart from *Planolites ballandus*, which exhibits tiny burrows extending vertically through only a few mm of a bed, virtually all the reworking of sediment is confined to the horizontal plane. Deposit-feeding organisms presumably worked on or just below the sedimentary interface in search of food particles, and hence disruption of lamination was minimal, limited to certain nutritious layers. Assuming that the requirements of late Pre-cambrian deposit-feeders were similar to those of the present, it may be suggested that they needed a relatively low-energy environment, allowing finely disseminated organic material and micro-organisms to accumulate from suspension, and lack of substrate mobility for their establishment. According to Seilacher (1964b, [1964] p. 313), deposit feeders become important in slightly deeper and quieter offshore regions.

"In contrast, in the littoral and very shallow water environments where 'physical protection is a major concern' suspension feeders are among the dominant types, producing deep vertical burrows for shelter (Seilacher 1964b, [1964] p. 313). Vertical burrowing forms like *Skolithos* are thought to have been formed by suspension feeders in shallow, agitated waters (Seilacher, 1963: 1967). The Upper Precambrian occurrences of *Skolithos* in central and northern Australia may therefore have occupied a near-shore environment.

"The virtual lack of bioturbation and absence of *Skolithos* in the upper part of the Torrowangee Group may be attributed to the lack of vertical burrowing, suspension-feeding types, and implies a somewhat deeper water environment."

Webby (1970b) has also described problematical disk-like structures from Carnies Tank, but the exact nature of these structures is unknown.

In 1971, at the invitation of the Geological Survey of New South Wales, W.V. Preiss (Geological Survey of South Australia) accompanied by P.F. Cooper examined new stromatolite localities that had been discovered during the mapping programme. Preiss examined the outcrops and took specimens for further detailed examination (see appendix 2).

The stromatolites from the Boco Formation near "Wilangee" (GR 368190) form discrete lenticular bioherms, generally 1 to 6 m wide and up to 1.5 m high. The separate bioherms are in contact both laterally and vertically, often overlapping earlier bioherms. The bioherms all stood in relief above the surrounding sediment floor. The substrate consists of flaggy, poorly laminated, finely crystalline dolomite, containing tabular or lenticular white chert pods. The same sediment continued to accumulate after bioherm growth and is seen lapping on to the bioherm margins. The stromatolites are largely pseudocolumnar, with columnar and columnar-layered intercalations. Chert pods within the bioherms are broadly conformable, but in detail they cut across the lamination. On casual inspection, vertical pillars of chert give the impression of being strict replacements of stromatolite columns, but sectioning reveals that the pillars cut across continuously laminated stromatolites. At "Mount Woowoolahra" (GR 234459) the whole bed is totally silicified, although the earlier chert pods are still visible and are distinct from the later silicification. The stromatolites occur in lenticular bioherms similar to those near "Wilangee".

"The stromatolites of the Boco Formation give little evidence as to its age. They are poorly preserved and can be assigned only tentatively to the group *Omachtenia*, which is in any case long ranging. Its known time range in the U.S.S.R. is Early Riphean to early Middle Riphean, but *O. utschurica* Nuzhnov occurs in the Brighton Limestone, Flinders Ranges (Preiss, 1971a). Thus the total known range of *Omachtenia* is Early to Late Riphean, (1600 ± 50 m.y. to 680 ± 20 m.y.) " (Preiss 1972).

Several boulders of dolomite containing stromatolite were found in the Nunduro Conglomerate. These are thought to have come from the Boco Formation.

Palaeoenvironment

POOLAMACCA GROUP

At the base of the Poolamacca Group a white quartzite (Lady Don Quartzite), which lies directly on the basement, crops out as an erosional remnant. The area which the quartzite now covers is quite small, but during the early Adelaidean the area must have been considerable as a large proportion of the detritus in the overlying units was derived from the Lady Don Quartzite.

In the Bijerkerno Gorge the Lady Don Quartzite is quite uniform in character, and it is thought that it was deposited as a blanket sand in a marine, probably shallow-water, environment. The well-sorted nature of the sediments indicates stable tectonic conditions. However, the presence of the Christine Judith Conglomerate, which disconformably overlies the Lady Don Quartzite, does indicate that there was some tectonic activity during the later part of Pintapah Sub-Group sedimentation.

The occurrence of stromatolites in the Boco Formation indicates that this unit was deposited in shallow marine conditions. Disconformably overlying the Boco Formation is the Wilangee Basalt which contains some thin beds of limestone and several thin crossbedded quartzite horizons. There is very little evidence that the basalts are submarine extrusives as there is no associated sodium enrichment or keratophyre - type alteration. The evidence suggests that there were several minor marine incursions during the time the basalt was extruded and that any alteration was probably due to expelled water from sediments enclosing the basalts. There are no pillows, no glassy rocks, and all flows (where recognisable) are quite planar.

The Poolamacca Group was deposited in a shallow marine environment during a period of widespread stability, characterized by only minor sea-level fluctuations. These general conditions probably existed during deposition of the early Late Precambrian in Australia.

A similar quartzite sequence exists in the Mount Painter area (Paralana Quartzite), and this unit and the Pintapah Sub-Group have been correlated (Cooper and Tuckwell 1971).

The Heavitree Quartzite is similar in character to the Lady Don Quartzite and also is overlain by a carbonate facies (the Bitter Springs Formation). Wells et al. (1970) contended that the Heavitree Quartzite, Bitter Springs Formation, and their equivalents form a continuous sheet in the Amadeus Basin and were deposited over large areas beyond its present margin, some probably as far west as the Gibson Desert and the Ngalia Basin. These workers believed that the rocks were deposited in a relatively stable shallow marine environment. This is precisely the type of environment envisaged by the present writers for the Poolamacca Group and their South Australian equivalent, the Lower Callanna Beds.

Wells et al. (1970) suggested a correlation of the glacial sequences, but did not attempt a correlation of the Heavitree Quartzite and Bitter Springs Formation. B.P. Thomson (in prep.) has suggested that the Burra Group in the Adelaide "Geosyncline" is the Heavitree Quartzite/Bitter Springs Formation equivalent; however, the work by Preiss (1971a) on stromatolites has not substantiated this correlation. Preiss (op. cit.) stated that the early Adelaidean stromatolites have not been studied in great detail and the correlation with the Bitter Springs Formation on fossil evidence is rather uncertain.

The similarities of the Heavitree Quartzite and Bitter Springs Formation of the Amadeus Basin, the Lower Callanna Beds of the Adelaide "Geosyncline", and the Poolamacca Group of Broken Hill are as follows:

1. All occur at the base of their respective Late Precambrian sequence, overlying basement.

2. All represent similar environments and tectonic conditions.

For these reasons it would seem reasonable to suggest the correlation of the abovementioned units and that similar tectonic and environmental conditions existed during the early Late Precambrian over large areas in Australia.

TORROWANGEE GROUP

Yancowinna Sub-Group

Near "Mount Woowoolahra" homestead, sediments bearing a superficial relationship to those of the Yancowinna Sub-Group rest directly upon the Mundi Mundi Granite. However, accurate correlation cannot be made because of the lack of continuity of outcrop. In this region the basal coarse-grained sediments contain definite striated pebbles, and the character of the sediments suggests deposition directly from a glacier.

Above this unit, which is only a few metres thick, are well-bedded coarse sandstones and diamictites whose character and stratigraphic position suggest correlation with the Mulcatcha Formation. The continuity of the sedimentary units south of "Mount Woowoolahra" homestead, indicates shallow-water, fairly stable, glacio-marine conditions of deposition.

Much further south, around "Wilangee" homestead, poor scattered outcrop in some creeks shows that these sediments contain a high percentage of low-grade Willyama rock fragments. The nature of the sediments here is, however, quite different from that of those on the Wilangee Platform (see below).

The following palaeoenvironment is suggested:

1. Glaciation existed in the "Mount Woowoolahra" area and in an area to the east and southeast. These glaciers deposited their load in shallow marine conditions to the south of "Mount Woowoolahra".

2. Still further south, rapid deposition took place in the area around "Wilangee", the sediments being derived principally from a high area to the east. It is believed that the influence of the Mundi Mundi Fault may have contributed to the sediment types as we see them now. It is possible that much of this sediment was initially glacially derived, but uplift accompanying retreat of the glaciers could have caused substantial reworking of this material, possibly by submarine mudflows.

Campbells Creek High and Wilangee Platform

The area of the Precambrian Campbells Creek High was bounded on the west by the Mundi Mundi Fault and on the east by an undisturbed Adelaidean basement unconformity (figure 28).

Southwest of Bobs Well (GR 386254) and on the Mundi Mundi Plain (GR 343234), there are exposures of extremely brecciated, contorted, and quartz-veined Adelaidean rocks. The exposures indicate a zone of deformation at least 100 m wide which is presumed to be an expression of the Mundi Mundi Fault.

Relative uplift along the Mundi Mundi Fault (western block down faulted) probably occurred very early in the history of Adelaidean sedimentation, and uplift of the eastern block formed a stable shelf area, the Wilangee Platform. The Campbells Creek High would have provided detritus, mainly to the east but also very coarse, ill-sorted detritus to the west, against the Mundi Mundi Fault. This sedimentation is in evidence on the western unconformity in Cartwrights Creek (GR 436098, Broken Hill 1:250 000), where there are very coarse, ill-sorted breccias (Tuckwell 1968).

A detailed study of diamictite horizons within the Mulcatcha Formation and the Yangalla Formation has shown that:

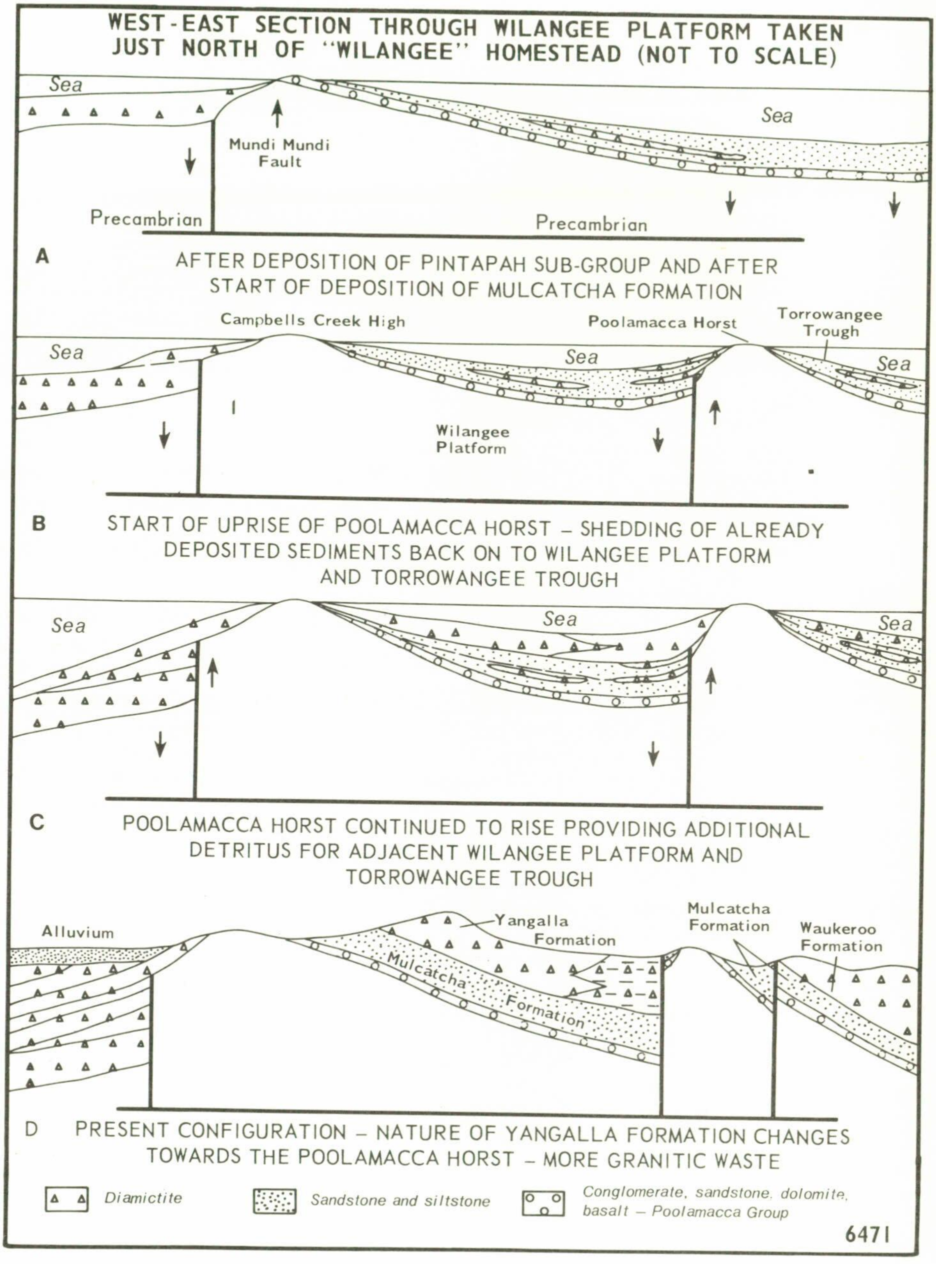


Figure 28. Evolution of Yancowinna Sub-Group sediments in the region of the Wilangee Platform

1. These lenticular, poorly graded, conglomeratic sediments are erosional on the directly underlying finer grained quartzose sandstones and siltstones.

2. They contain clasts of extrabasinal material (basement rocks) as well as clasts of intrabasinal material (Poolamacca Group and Yancowinna Sub-Group).

3. Many of the clasts are subrounded to rounded and some found bear glacial-type markings.

It is suggested then that these diamictites are in fact submarine mudflows and that the finer grained sediments associated with them could, in part, be derived from the mud and silt fraction of the flow. Although probably all of the clasts of extrabasinal material are glacially derived, in their present configuration these sediments are not true glacio-marine deposits.

These mudflows were probably triggered by movements along the faults bounding the Campbells Creek High, while the Wilangee Platform was deepening to the east.

Directional sedimentary structures in the sandstones and the well-laminated siltstones of the Mulcatcha Formation were measured by Tuckwell (1968) and Cooper (1969). The majority of the measurements were taken on groove and flute casts and crossbedded ripples. Most of these structures are not unidirectional indicators; however, Cooper (1969) asserted that the accompanying detritus, because of its unique character, could only have been derived from a source west of the area.

After unfolding the sequence around the fold axis, the direction of sediment transport in the Mulcatcha Formation was found to be from the northwest at the base of the sequence and swinging towards the southwest towards the top (figure 29).

In the east, on the deeper part of the platform, the rock type changes considerably, losing much of its well-sorted and stratified appearance and containing a higher percentage of clasts. The presence of Mulcatcha Formation sediments east of the Poolamacca Horst indicates that uplift of this horst did not start until later in the sedimentary history, probably at the time represented by the start of deposition of the Yangalla Formation. Material shed from the uprising Poolamacca Horst changed the character of these sediments by the addition of great quantities of granitic waste. Figure 28 shows a diagrammatic history of the evolution of Yancowinna Sub-Group sediments in the region of the Wilangee Platform, Poolamacca Horst, and Torrowangee Trough.

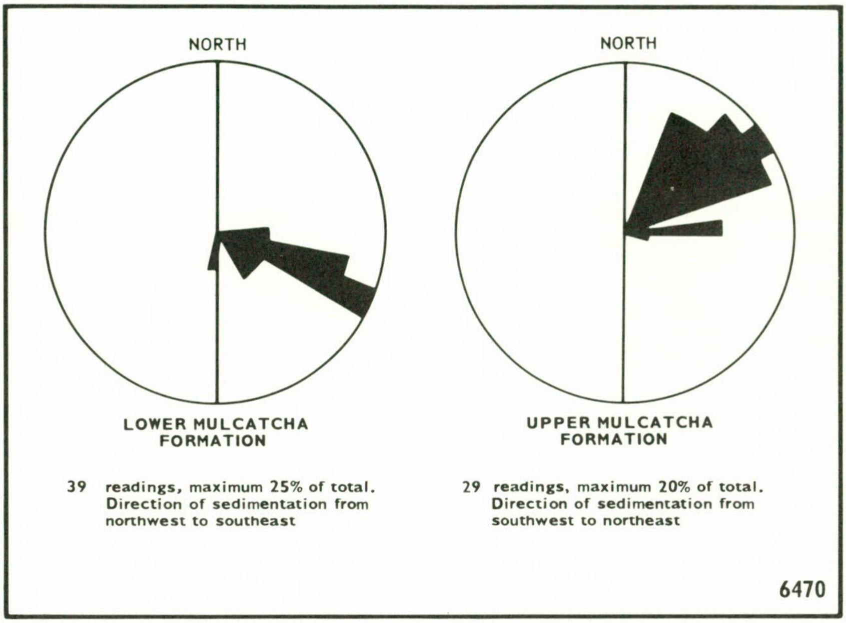


Figure 29. Plots of directional structures in the Mulcatcha Formation

Poolamacca Horst

Sediments of the Mulcatcha Formation are preserved in part on the Poolamacca Horst, indicating that active uplift of this area did not begin until well after deposition of the Mulcatcha Formation commenced.

The faults presently bounding the horst are post-depositional expressions of the basement faults that controlled its movement. To the south lies the Poolamacca Inlier which, although a high area during sedimentation, was not bounded by basement faults. Sedimentation took place on the flanks of the inlier where the Yancowinna Sub-Group appears to onlap, but field evidence indicates that these were fairly unstable areas and much of this material was reworked by mudflows, especially to the north and east of the inlier.

Torrowangee Trough

Sedimentation within the Torrowangee Trough, which runs northwards adjacent to the Poolamacca Horst and the Euriowie Block, was complex. It involved deposition of coarse detritus in the Yancowinna Sub-Group and later fine silts, sands, and limestones in the Euriowie Sub-Group, followed by coarser detritus in the Teamsters Creek Sub-Group.

Sedimentation commenced with the rapid deposition of diamictite, pebbly mudstone, and mudflow conglomerate, constituting some 1500 m of coarse detritus. Much of this material is well bedded and at times partially graded, but individual horizons are not continuous along strike. In fact, around the southern extension of the trough near the Poolamacca Inlier the sediments are extremely irregular and poorly sorted. Towards the north of the trough the following features were observed :

1. Rapid thinning of the sequence.

2. An increase in stratification.

3. A decrease in the content of boulder and cobble-sized material.

As mentioned previously, some Mulcatcha Formation sediments are present in the far west of the trough, against the Poolamacca Horst, but the greatest thickness of sediment in the Yancowinna Sub-Group occurs within the Waukeroo Formation. This formation is equivalent in both time and stratigraphic position to the Yangalla Formation, and is probably also equivalent to part of the Mulcatcha Formation.

Mulcatcha Formation sediments are well developed east of the Poolamacca Horst, but are absent against the very active Euriowie Block. However, a thin horizon of Yancowinna Sub-Group type sediments occurs all round the Euriowie Block. This horizon is termed the McDougalls Well Conglomerate, and, although only a few tens of metres thick at its maximum development, it represents the entire sub-group in this area.

The source of much of the material of the Waukeroo Formation can be traced to several localities.

1. Most of the grey quartzite clasts were derived from the Lady Don Quartzite and the Christine Judith Conglomerate. These formations now crop out only on the Poolamacca Horst and the Wilangee Platform, so presumably some material was derived from these areas.

2. Clasts of basement Willyama Complex could have been derived from any outcrop of basement, but because evidence suggests that transport was from the west and southwest it is presumed that the basement clasts were also derived from an area to the west and southwest. Basement rocks within the Euriowie Block close to its western boundary consist of amphibolite, calcareous gneiss, and a quartz norite intrusion. None of these rock types has been found in the coarse sediments of the Torrowangee Trough, suggesting that little of the material constituting the Waukeroo Formation was derived from the Euriowie Block.

3. The presence of clasts of intrabasinal material within sediments of the trough shows that there was penecontemporaneous erosion of some of the Waukeroo Formation.

Therefore, the sources of sediments of the Waukeroo Formation appear to have been fairly local, viz. the Poolamacca Horst, the Poolamacca Inlier, the Campbells Creek High, and possibly the Euriowie Block.

The locally derived McDougalls Well Conglomerate has a limited development, occurring only on the margins of the Euriowie Block and the Nardoo Inlier. In some areas where the underlying basement is rich in pegmatite the McDougalls Well Conglomerate is similarly rich in pegmatite. Because of the altered nature of the conglomerate it is difficult to determine the environment of deposition. However, the lack of sorting and local nature suggest a deposit formed at the base of cliffs.

Yancowinna Sub-Group sediments have also been deposited on the eastern side of the Euriowie Block. In the Fowlers Gap area only the McDougalls Well Conglomerate is present, but to the south of the area studied the nature of the sediments changes considerably, indicating a different depositional environment.

Euriowie Sub-Group

The sediments of the Euriowie Sub-Group differ greatly in nature from those of the Yancowinna Sub-Group. Both west and east of the Euriowie Block the change from one sub-group to the other is quite sudden. East of the block a few thin beds of limestone with basement clasts are present at the base of the Euriowie Sub-Group, but apart from these the change is marked and sudden.

There are three areas of sedimentation in the Euriowie Sub-Group, and the nature of the sediments in these areas reflects differing depositional conditions. The distribution of sediment was dominated by the Euriowie Block. Similar (but not identical) sediments occur to the east and west of the block; however, at the northern end conditions were apparently quite different.

Both west of the block (the Torrowangee Trough) and east of the block (the Caloola Trough), sedimentation at the base of the sequence was predominantly calcareous but more so in the west than the east. In the Torrowangee Trough, large, massive limestone bodies are present at the Torrowangee quarries, and these bodies were possibly reefs associated with basement highs within the trough. However, on the eastern side of the Euriowie Block, massive bodies are not present and only small limestone lenses interbedded with finely laminated siltstone occur. The sediments indicate tectonically stable, moderately shallow marine conditions.

To the north, conditions were quite different and resulted in deposition of the massive Corona Dolomite. It is significant that on the southern tip of the Nardoo Inlier a similar, but bedded, dolomite mass is present. It is postulated that these areas were quite shallow and conditions were favourable for the primary deposition of dolomite.

In the upper portion of the Euriowie Sub-Group, sandy detritus is much more common, and the sequences both east and west of the Euriowie Block become more sandy until they pass into the overyling Teamsters Creek Sub-Group. The sequences both east and west of the of the Euriowie Block are quite similar and it appears that the effect of local tectonic features in this part of the sequence was minimal. Crossbedded asymmetric ripple marks are quite common in the Floods Creek Formation and indicate a generally consistent current direction from the west towards the east (figure 30).

Teamsters Creek Sub-Group

The basal unit of the Teamsters Creek Sub-Group, the Alberta Conglomerate, marks the commencement of a period of active erosion and deposition. The Alberta Conglomerate contains numerous large clasts of intrabasinal material in a poorly sorted matrix. Bedding is usually absent; however, occasional horizons of coarse, crossbedded sandstone do occur. Some very large slump masses are also present. These features suggest deposition by a mudflow mechanism.

The presence of glacial influences has been shown in South Australia and at "Mount Woowoolahra", and it would seem that, although the Alberta Conglomerate shows no evidence of having been deposited directly from a glacier, the detritus contained within the conglomerate could well have had a glacial origin. In such a scheme, glaciation would have been active, dumping the detritus at some location; reworking would then have occurred through the action of mudflows and fluvial processes. Several, closely packed gravel horizons of limited lateral extent could be small, channelfill fluvial deposits.

The Gairdners Creek Quartzite, which overlies the Alberta Conglomerate, is quite thin but has remarkable lateral continuity. The unit is generally flat bedded, although some crossbedding has been noted. This unit marks the commencement of a quiet period, when fluvial processes removed sand from glacial detritus in the glacial valleys in the highlands of the Willyama Complex and transported it down the valleys and out to sea. It was deposited just off shore as a thin blanket of sand over the Alberta Conglomerate. Further off shore the glacially derived silt fraction (the Dering Siltstone) was contemporaneously deposited by the action of turbidity currents originating from the river deltas. After deposition of the near-shore Gairdners Creek Quartzite, a marine transgression resulted in deposition of Dering Siltstone above the Gairdners Creek Quartzite.

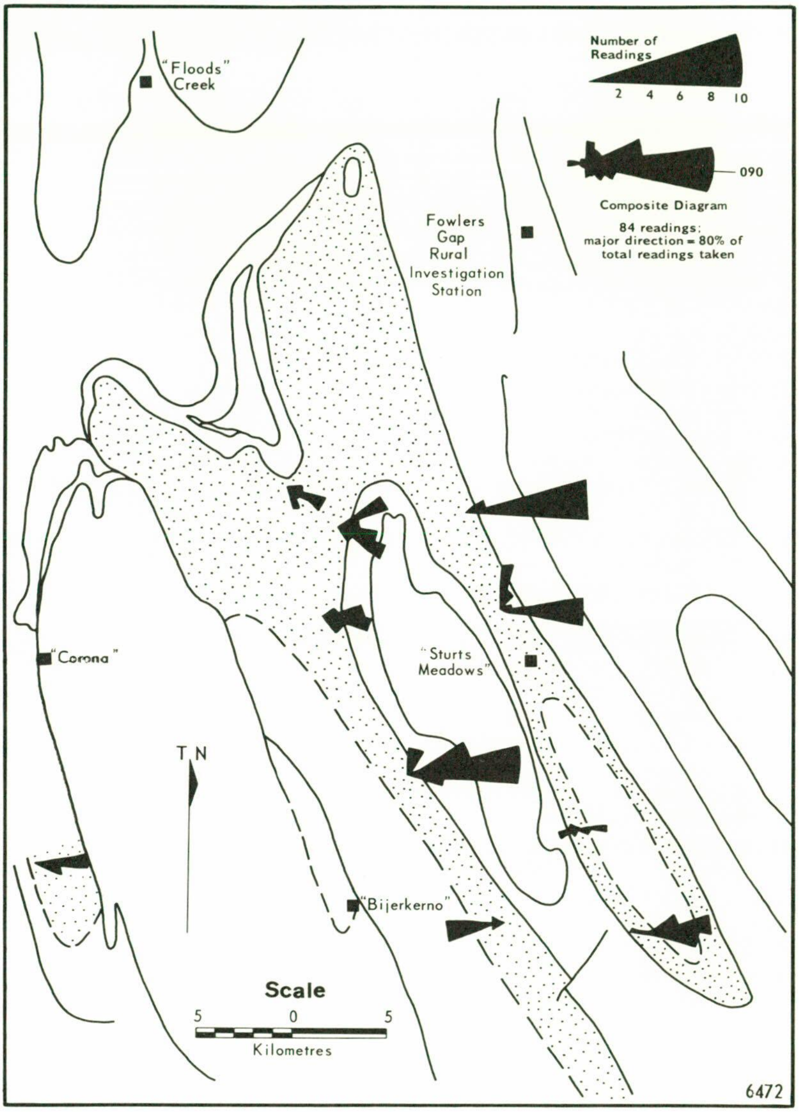


Figure 30. Current direction — Floods Creek Formation (measured on crossbeds and crossbedded ripple marks)

Palaeocurrent directions taken from ripples in the Dering Siltstone show a bipolar concentration, indicating currents flowing in opposite senses (figure 31). The ripples occur in well-delineated horizons, indicating quiet conditions with cessation of turbidity action and reworking of the sediments by bottom currents. The opposed current directions can be explained by the action of tides in a large but shallow-water enclosure (Shelley 1968). Further evidence of stable conditions is given by a thin but uniform layer of fine sediments over the ripple marks. This layer probably settled from suspension which would have also required quiet water conditions.

In figure 32 two schematic sequences have been constructed to help explain the processes which gave rise to the structures seen within the Dering Siltstone. (It was not within the scope of the present study to delineate the horizons of ripples and graded and laminated siltstone, but this could probably be done with more detailed mapping). Sequences 1 and 2 are typical of the sequences found within the Dering Siltstone, which consists predominantly of graded siltstone with some horizons of ripples. It is thought that the features seen in these rocks indicate deposition from turbidity currents in shallow water. The underlying Alberta Conglomerate and the overlying Nunduro Conglomerate are interpreted as large slumped bodies, and the Dering Siltstone is attributed to a similar process (repeated turbidity currents) in finer sediments.

In sequence 1, structures can be attributed to turbidite deposition. Unit E was directly deposited from a turbidite; however, in any one turbidite flow, effects from the flow will wane towards its edges and the characteristics of the sediments deposited will differ more and more from those of a true turbidite.

Figure 33 schematically illustrates the relative distribution of the types of sediment deposited by a turbidity current:

Zone A. True turbidite deposition: units show grading and are scoured at the base; soft sediment deformation is often present; units exceed 0.25 m in thickness.

Zone B. Zone of graded units without basal scouring; usually less than 0.25 m thick.

Zone C. Zone of deposition of finely laminated sediments; this zone is formed at the edge of the flow.

Zone D. Zone of deposition of fine material from suspension; the area of suspension deposition would also occur over zones A, B, and C after their deposition.

This morphology can be used to explain the two schematic sequences shown on figure 32.

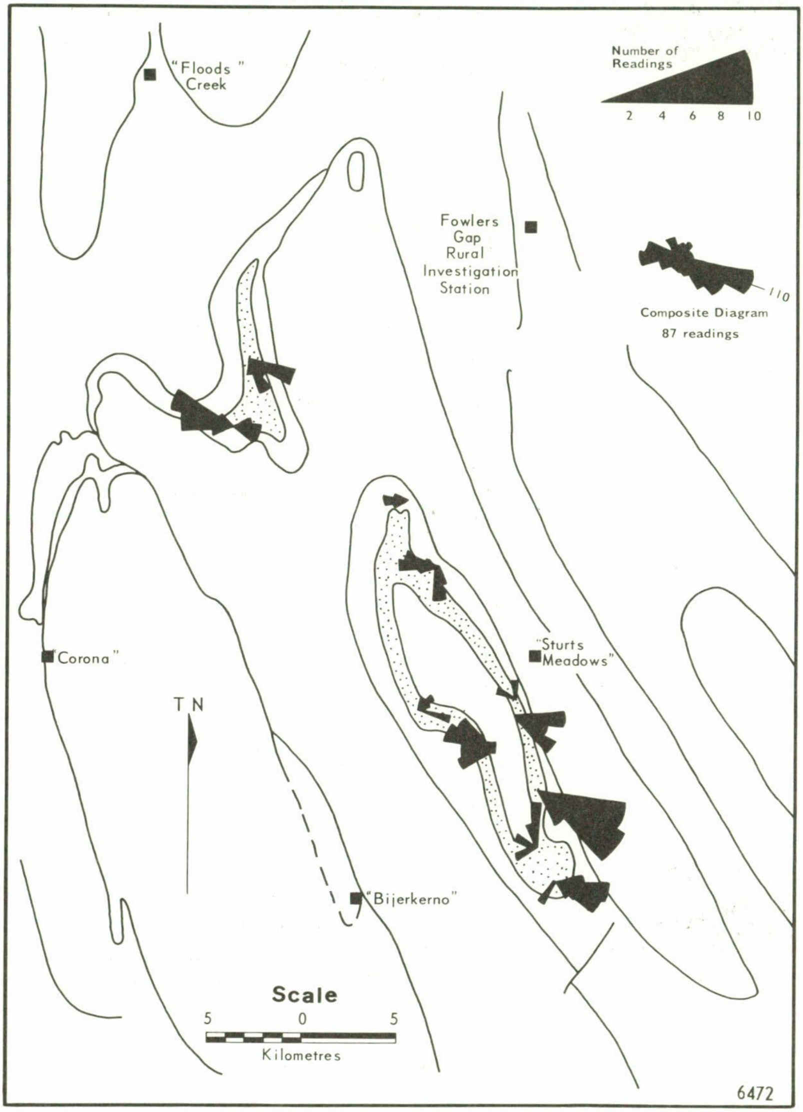


Figure 31. Current direction — Dering Siltstone (measured on crossbedded ripple marks)

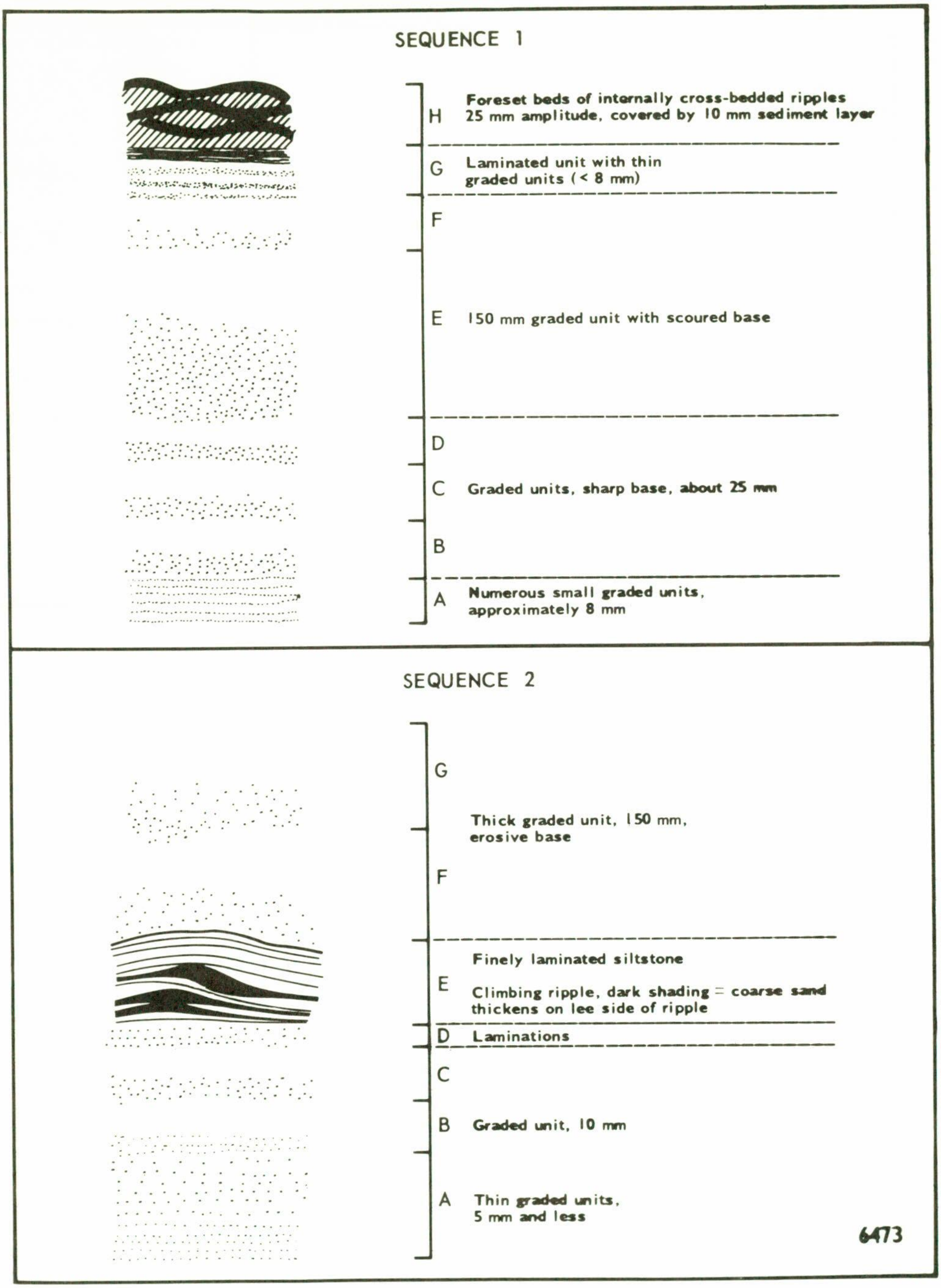


Figure 32. Two schematic sequences in the Dering Siltstone

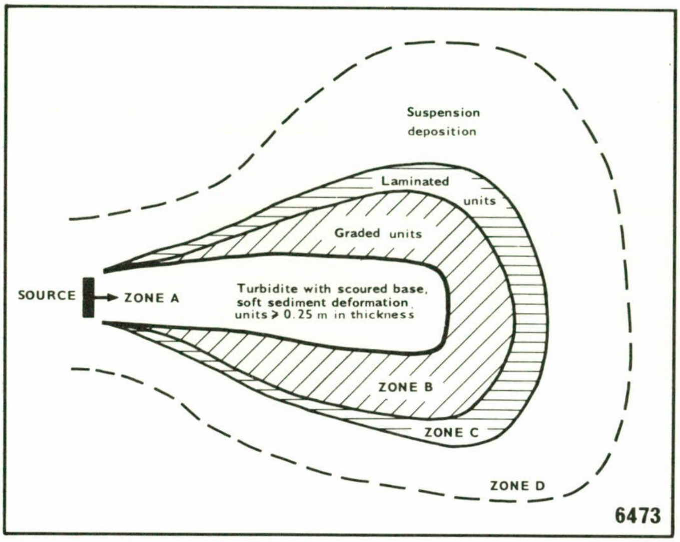


Figure 33. Morphology of a turbidity current

Schematic Sequence 1

Unit A — deposited in zone C of a turbidity current.

Units B, C, D — deposited in zone B of successive distal turbidity currents.

Unit E — deposited in zone A of a turbidity current.

Unit F — deposited in zone B of a turbidity current.

Unit G — zone B and C deposition.

After unit G was deposited there was a pause in turbidity current activity and bottom currents modified the units, producing the internally crossbedded ripples seen in unit H. After the deposition of each set of ripples, quiet conditions prevailed and a 10 mm thick fine sediment layer settled from suspension.

Each one of the graded units represents a turbidity flow which was either proximal or distal to the place of deposition. The location of the area of deposition with respect to the initiating point of the turbidity flow determined the type of sediment laid down.

Schematic Sequence 2

Unit A — deposition from the outer part of zone B.

Units B,C — deposition from zone B.

Unit D — deposition from zone C.

Unit E — action of the bottom current producing climbing ripples.

Unit F — further deposition from zone A of a turbidite.

Erratically distributed limonite cubes (pseudomorphic after pyrite) occur towards the top of the Dering Siltstone and also within the Nunduro Conglomerate. This pyrite is authigenic, and probably formed in small areas of restricted circulation under reducing conditions.

Overlying the Dering Siltstone is the Nunduro Conglomerate which has an erosional base and shows some excellent slump features containing clasts of Dering Siltstone. Numerous, closely packed lenticular horizons of boulders occur within this unit, and these also appear to have been formed by submarine slumping. The Nunduro Conglomerate thins rapidly to the east and northeast, indicating that the source area lay somewhere to the west.

FARNELL GROUP

At the base of the Farnell Group is a thin, finely laminated dolomite which, because of its fine lamination, great lateral extent, and thinness, is considered to be a chemical precipitate. The widespread distribution of dolomitic rocks in association with glacial sediments strongly suggests that the deposition of dolomite was a natural occurrence in glacio-marine environments. There is little doubt that dolomite deposition was due to the decrease in solubility of calcium and magnesium carbonates with increasing temperature (Carey and Ahmad 1961).

Fairbridge (1964, p.456) stated that

> "Primary or *syngenetic* dolomites ... are found interstratified in immense anhydrite, magnesite and saline sequences ... But as one goes back into the Palaeozoic they seem to become more and more frequent, even in basins not obviously barred, and there seems a good possibility of precipitation in shallow platform facies, where slightly elevated temperatures and salinities may occur, but in a sea where the partial pressure of CO_2 was appreciably above the present level ..."

The presence of authigenic pyrite noted in the top of the Teamsters Creek Sub-Group, and even in the dolomite itself, suggests a restricted environment — possibly a barred shallow bay where there was very little interchange of sea water.

The remainder of the Farnell Group consists mainly of fine-grained, very finely laminated siltstones which contain very few sedimentary structures. Towards the top of the sequence siltstones become coarser, and massive quartzites begin to appear. The sequence at this point consists of interbedded quartzites and siltstones; however, some carbonate is present towards the top.

The Farnell Group is essentially the same to the southwest of Floods Creek. However, here the upper part of the Sturts Meadows Siltstone is quite calcareous. This calcareous facies does not occur in the Sturts Meadows Siltstone to the east of "Sturts Meadows" or in the Caloola Syncline.

In general the Farnell Group becomes coarser towards the top, where it contains some minor carbonate facies. The nature of the sediments indicates quiet marine conditions and generally deeper water than that for the rest of the Adelaidean sequence, but shallowing occurred towards the top as indicated by the presence of carbonates and an upward coarsening of the principal silty/sandy facies.

The trace fossils found and described by Webby (1970a) suggest a similar environment, where suspension-feeding worms lived comfortably in slightly agitated conditions.

Structural Geology

Two periods of deformation have been recognized within the Adelaide System rocks (see table 7). The first period, F_1, caused the development of major broad, open, synclinal and anticlinal structures with their associated penetrative slaty cleavage. These structures have been named the *Floods Creek, Eight Mile Creek, Caloola,* and *Torrowangee Synclines* and the *Sturts Meadows Anticline*. The second period, F_2, produced a minor folding of the slaty cleavage in areas adjacent to the northern and eastern portions of the Euriowie Block and the northern portion of the Nardoo Inlier. A strain slip axial plane cleavage was developed during this deformation.

F_1 Folding

F_1 mesoscopic folds are not developed to any great degree, but are more prevalent to the west of the Euriowie Block. Here the style of the folds is very dependent upon lithology so that it is impossible to generalize about the shape of F_1 folds. Folds in layered rocks which possess a very strong competence contrast, and folds in competent rocks (sandstone, quartzite), are both concentric in style. Similar style folds occur in the finer grained and less competent materials — siltstone, shale, and thin limestone horizons.

Slaty cleavage, S_1, is penetrative on all scales of observation and is well developed in all rocks except sandstone and quartzite.

TABLE 7

FABRIC ELEMENTS OF THE ADELAIDE SYSTEM

Episode	Element	Symbol	Components/ results	Remarks
F_1	Bedding	S_o		
	Slaty cleavage	S_1		
	Fold axis	B_1	$B_1 = B^{S_1}_{S_o}$	Axis F_1 folds
	Lineation	L_o	$L_o = S_o \wedge S_1$	
F_2	Crenulation cleavage	S_2		Crenulates S_1
	Fold axis	B_2	$B_2 = B^{S_2}_{S_1}$	Axis F_2 folds
	Crenulation lineation	L_1	$L_1 = S_1 \wedge S_2$	
	Lineation	L_2	$L_2 = S_o \wedge S_2$	Not detected

$\wedge$ = intersection

F_2 Folding

F_2 folds are restricted to areas indicated by black shading in figure 34. These areas are all adjacent to basement blocks, and superimposed F_2 deformation is probably due to movement of these blocks with respect to the Adelaidean cover.

The axis of F_2 folds east of the Euriowie Block is near horizontal or plunges gently in a southerly direction. The folds themselves are gently undulations of S_1 slaty cleavage with a strongly developed crenulation lineation (L_1) developed parallel to $B^{S_2}_{S_1}$. However, north of the Euriowie Block and the Nardoo Inlier, the folds plunge steeply northwards.

The crenulation cleavage (S_2) is subvertical and generally parallels the regional trend of S_1.

STRUCTURAL ANALYSIS

The areas of Adelaidean strata were divided into nine domains homogeneous with respect to the fold axes $B^{S_1}_{S_o}$ of F_1 folds. The distribution of these domains is shown in figure 34, and the poles to S_o for each domain in figure 35. The poles to bedding are plotted

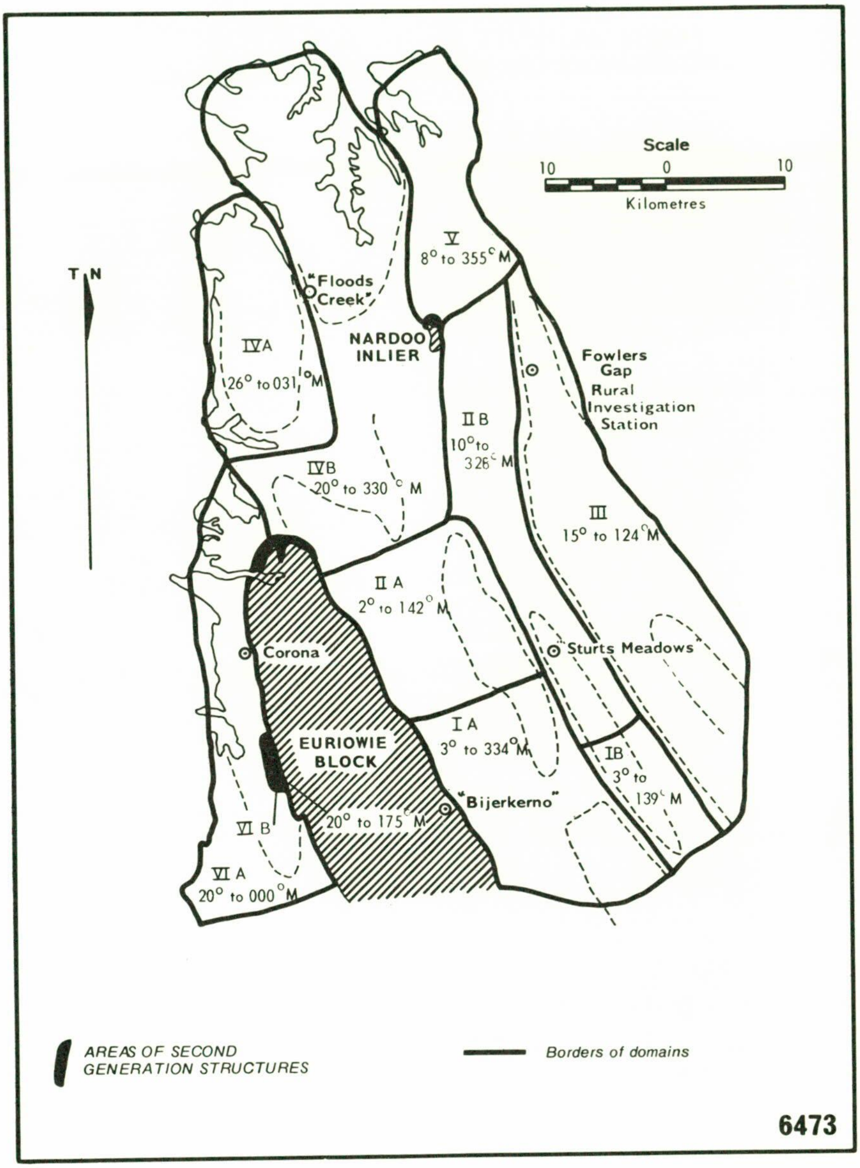


Figure 34. Domains for the Adelaidean showing variation in statistical β

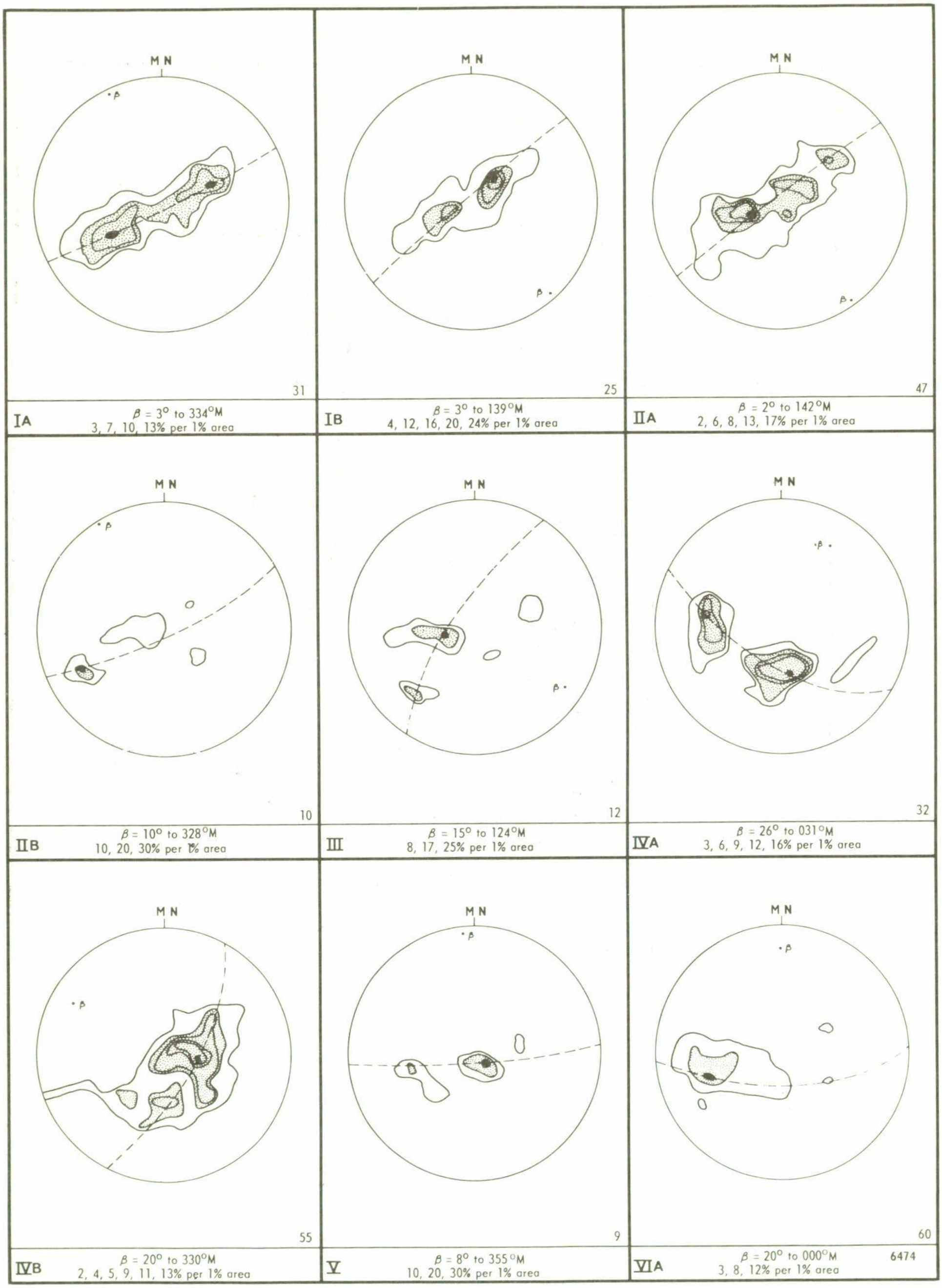


Figure 35. Poles to S_o for each domain in the Adelaidean

for each domain to define the statistical fold axis for that domain.

It can be seen that between domains I A and II A, and also I B and II B, a reversal of plunge occurs, but the strike of the F_1 structures is quite constant. The plunges of the statistically defined fold axis are all quite shallow. Domain II B does indicate a slightly steeper plunge but this could be misleading as only a small number of readings could be obtained.

Domain III indicates a statistical fold axis plunging at 15° towards 124°M, but outcrop is poor in this area and readings were difficult to obtain. If more readings could be obtained the stereogram would probably show a spread of points because it can be seen on the aerial photographs that there is an easterly swing in the fold from the northern to the southern part of the domain.

There is a significant change in the direction of the fold axis between domains IV B and IV A. The axis swings from 330°M to 031°M respectively, with little change in the plunge of the structures. This change in strike of the structure could be due to compression of the cover rocks against rigid basement (the Euriowie Block), accompanied by thrusting of the Adelaidean over the basement. It is important to note that this domain borders on the northeastern corner of the Euriowie Block and consequently stress trajectories would differ about this corner.

In domain V the statistically defined fold axis is indicated as plunging 8° to 355°M, but this must be regarded as only a guide as an insufficient number of readings has been taken.

West of the Euriowie Block, in domain VI A, the statistically indicated fold axis plunges 20° to 000°M. The folds here are generally tighter than those elsewhere in the cover rocks, and tend to have a better development of slaty cleavage S_1. This may be due to "sandwiching" of the cover rocks between the Euriowie Block and basement in the west (the Poolamacca Horst and Wilangee Platform).

In domain VI B the statistically indicated fold axis plunges 20° to 175°M.

There is little variation in cleavage direction throughout the domains except in the areas shaded black in figure 34. The composite plot of poles to S_1 in figure 36 indicates a statistical cleavage striking 349°M and dipping 86°E. The plot of S_1 cleavage in domain VI B indicates that the cleavage is flat lying, and the plot of S_2 from domain VI B indicates a vertical north - south cleavage, axial plane to folds in S_1.

JOINT AND FAULT ANALYSIS

Because of the poor outcrop of the Adelaidean, only a limited number of measurements of the orientation of joints, faults, and

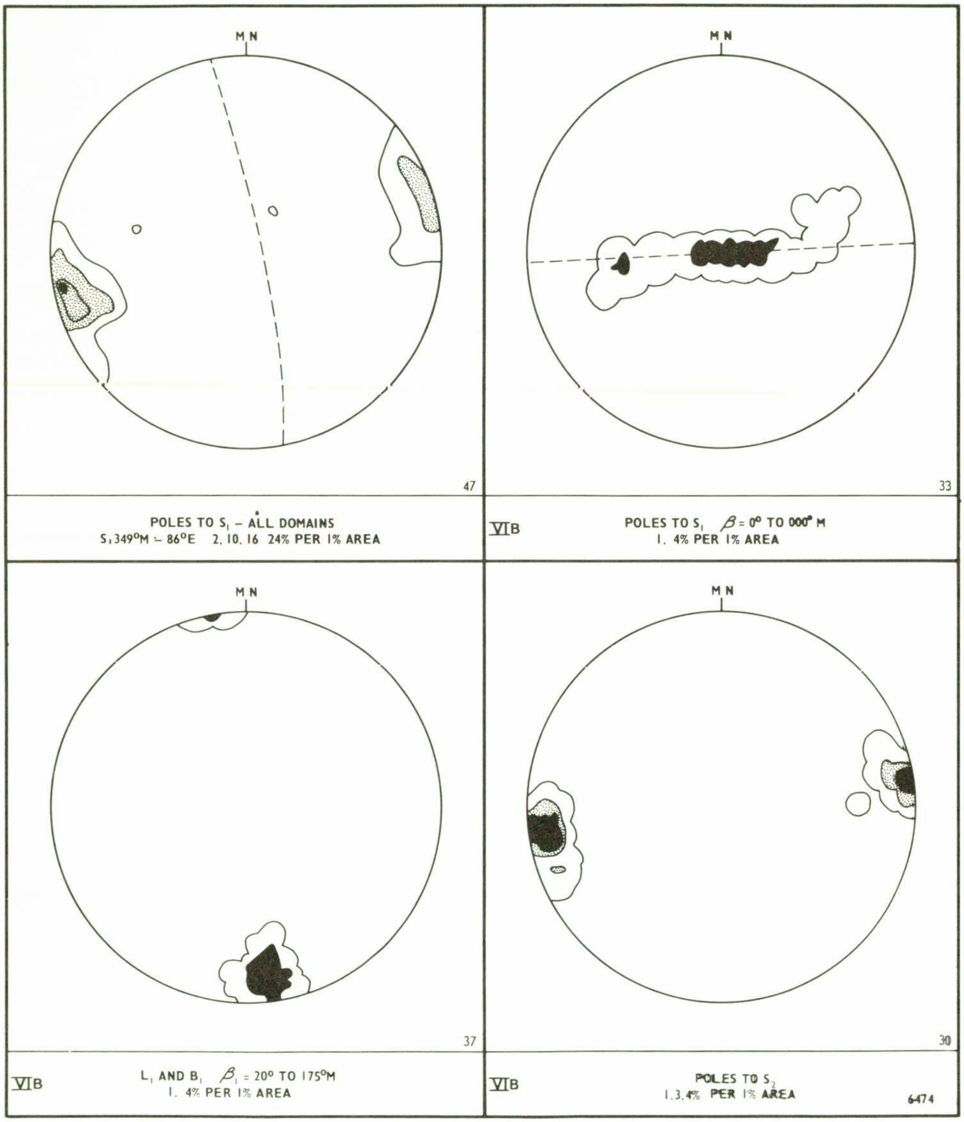


Figure 36. Generated structural elements for the Adelaidean

igneous dykes could be made. Insufficient data were collected to give a statistical orientation for each domain, so a composite rose diagram was prepared for the area due east of the Euriowie Block (figure 37).

An analysis of this diagram reveals the following:

1. The best developed direction of failure in the cover rocks is between 020°M and 040°M.

2. The secondary direction of failure in the cover rocks is 150°M - 160°M. (e.g., the *Corona* and *Nundooka Creek Faults*)

Joints possessing the orientation of 020°-040°M were often open fractures, sometimes quartz or carbonate filled. Where lateral movement has taken place along failure planes, it is invariably sinistral.

The dominant fold axis direction is around 150°M, which coincides with the orientation of the Euriowie Block.

The major joint direction (020° - 040°M) is consistent with the theoretical position of an oblique joint with respect to the regional fold axis (figure 38).

The reason why only one of the paired shear joints is well developed is uncertain, but it may be a function of the orientation of the stress field with respect to the rigid Euriowie Block. This interaction could have led to the development of a rotational shear couple with subsequent opening of the major (020° - 040°M) fracture direction.

The secondary joint direction (150° - 160°M) is parallel to the fold axes and is probably a failure pattern related to the development of longitudinal or "ab" joints.

Chronology of Basement Activity

Because of the continuous nature of Poolamacca Group sediments and their equivalents in South Australia and the Northern Territory, it is probable that during the early Late Precambrian the entire area was a stable block covered by shallow seas. The minor fluctuations in the sea level that resulted in erosion of some of the sequences may have been caused by slight vertical movements of the craton.

The first major uplift involved movement on the Mundi Mundi and Corona Faults and other similar structures, leading to the formation of the Euriowie Block and Campbells Creek High (see figure 28 and map sheet cross section). This movement evidently occurred after deposition of the Poolamacca Group, and resulted in widespread erosion of much of this sequence. Deeper sedimentary basins — such as the Wilangee Platform and Torrowangee Trough (initially as one unit), and the Caloola Trough — began forming at the start of

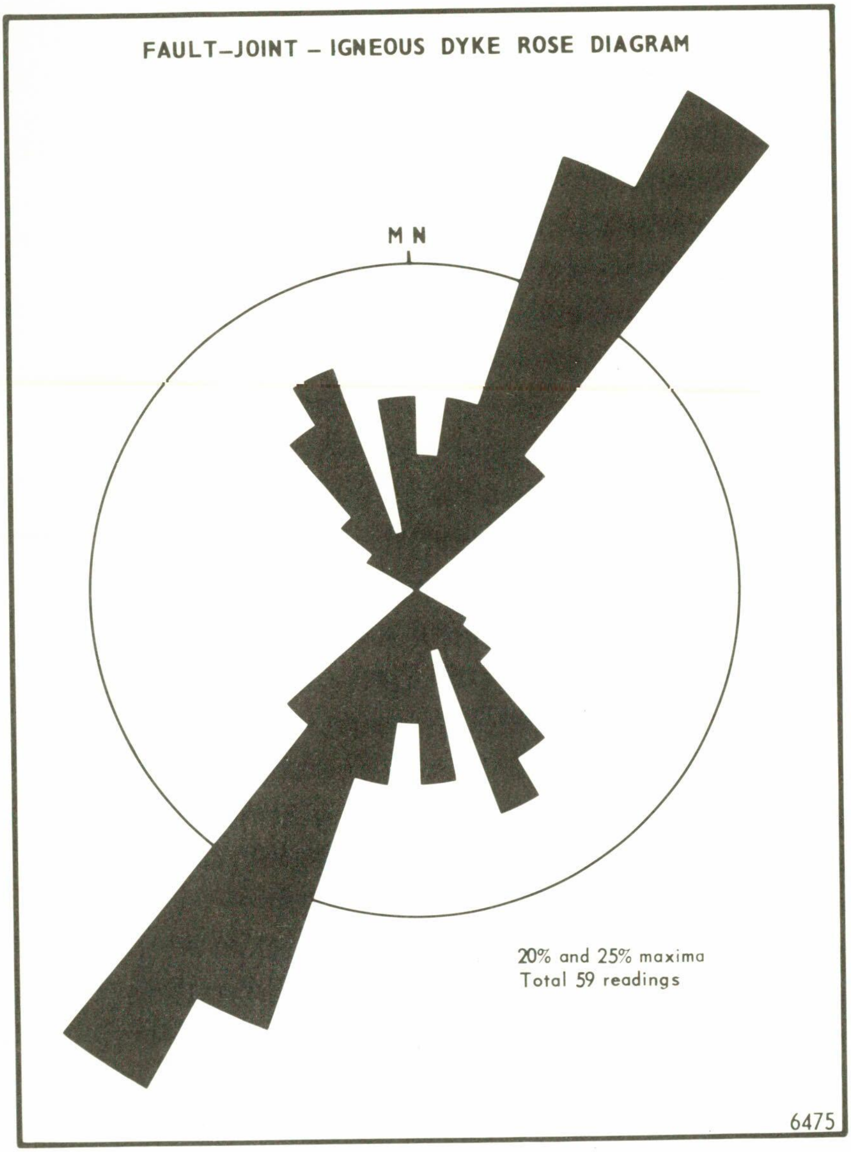


Figure 37. Composite rose diagram for orientation of joints, faults, and igneous dykes

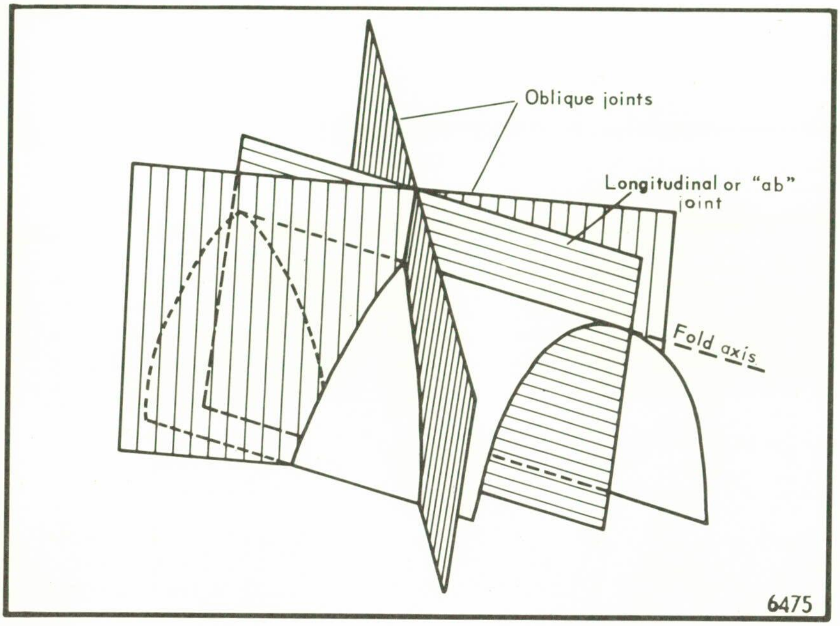


Figure 38. Classification of joints with respect to a fold

deposition of the Torrowangee Group. This would have involved the subsidence of areas on either side of the Euriowie Block, which moved upwards (relatively) along basement faults (e.g., the Corona Fault, see map sheet cross section).

During deposition of the Waukeroo Formation, the Poolamacca Horst began to be uplifted, causing termination of sedimentation of the Mulcatcha Formation east of the horst, and the formation of the now distinct Torrowangee Trough.

Deepening of the Wilangee Platform, Torrowangee Trough, and Caloola Trough occurred during almost the entire period of Yancowinna Sub-Group deposition. The Torrowangee Trough and the Caloola Trough underwent slow subsidence during deposition of the Euriowie Sub-Group, although minor, more violent, activity is evidenced by slump structures and other larger deformational structures in this sequence.

A period of more intensive uplift is indicated by the Teamsters Creek Sub-Group sediments which are very coarse grained. Uplift of the Euriowie Block during this period involved exposure of the Poolamacca Group, Yancowinna Sub-Group, and some Euriowie Sub-Group sediments to erosion, and clasts of these sequences were incorporated in the Teamster Creek Sub-Group.

The commencement of deposition of the Farnell Group signified the end of basement instability, and the initiation of sedimentation in a stable shelf environment.

Correlation with the Adelaidean of South Australia

General correlations with the Adelaidean of South Australia may be seen in table 8. However, more specific correlations are made in table 9.

The Poolamacca Group is correlated with the Lower Callanna Beds. The Paralana Quartzite is lithologically similar and has a stratigraphically similar position (both overlie basement) to the Pintapah Sub-Group. The Heavitree Quartzite in the Amadeus Basin may be a northern equivalent of the Pintapah Sub-Group (see section on the "Poolamacca Group"). If these correlations are correct then extremely similar conditions must have existed over large areas of deposition during lower Willouran times. The type of sedimentation which deposited the Poolamacca - Lower Callanna sediments must have been quite different from that which produced the remaining sediments of the Adelaide Aulacogene (Scheibner 1972). The area of sedimentation was characterized by a long period of stability which enabled the deposition of thick, well-sorted sandstones (later to become quartzites).

The Wendalpa Sub-Group has good lithological correlation with the upper portion of the Lower Callanna Beds — the Boco Formation with the Wywyana Formation and the Wilangee Basalt with the Wooltana Volcanics. No equivalent of the Humanity Seat Formation appears to be present.

No equivalent of the Burra Group and Upper Callanna Beds is present in the area mapped*. Some outcrops south of Broken Hill may be Burra Group in part. Extensive and thick sedimentation occurred in South Australia during the Torrensian; however, New South Wales was most likely an elevated area at this time and possibly provided detritus for the sediments of eastern South Australia.

The Yancowinna Sub-Group in general character resembles the Yudnamutana Sub-Group; both consist of glacially derived detritus.

The Euriowie Sub-Group appears to generally correspond to the Farina Sub-Group, although the Floods Creek Formation either may be correlated with the Fortress Hill Formation (basal Yerelina Sub-Group) or may be broadly equivalent to the Tarcowie Siltstone (sandy siltstone and limestone unit above the Tapley Hill Formation in the Olary region).

The Wammerra Formation and lower Tanyarto Formation would appear to be equivalent to the Tindelpina Shale Member of the Tapley Hill Formation.

The Teamsters Creek Sub-Group is equated with the Yerelina Sub-Group (or Pepuarta Tillite of the Olary region), and in particular the Gairdners Creek Quartzite and the Balparana Sandstone are extremely

* with the exception of a poor exposure of gritty calcareous sandstone west of "Poolamacca" (see also footnote on page 4).

TABLE 8

CORRELATION TABLE FOR THE LATE PRECAMBRIAN

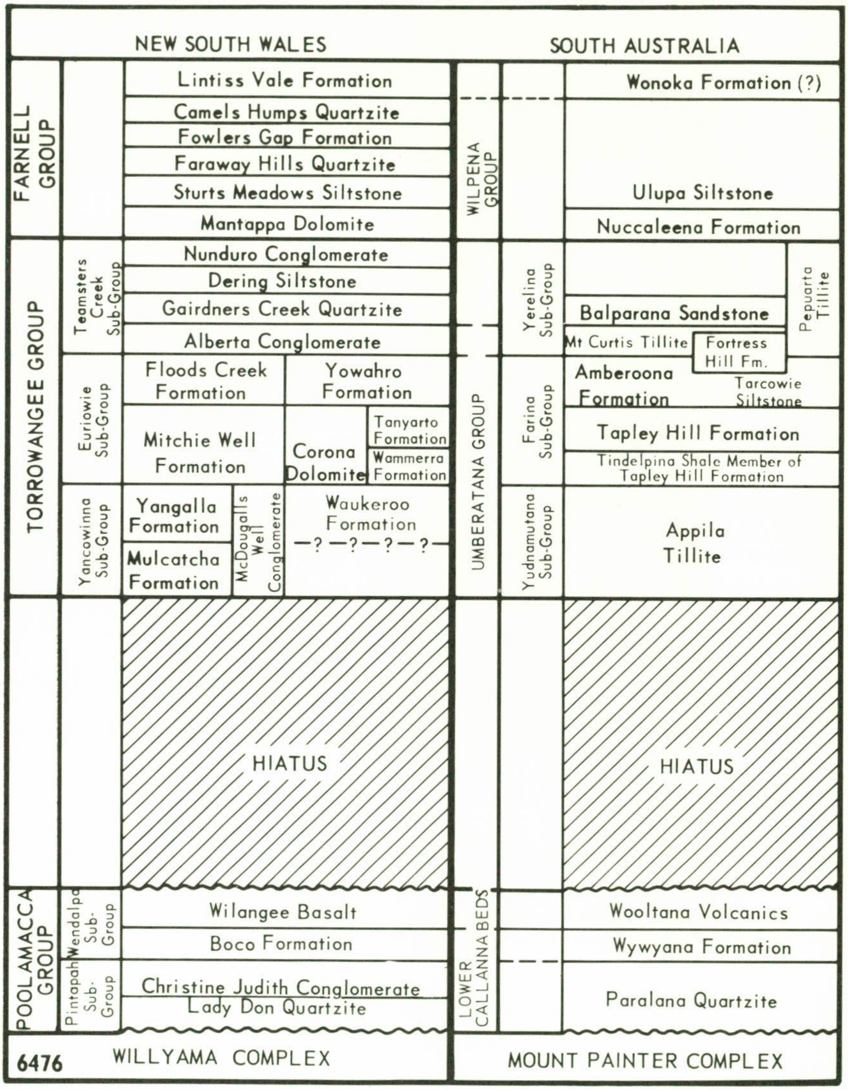
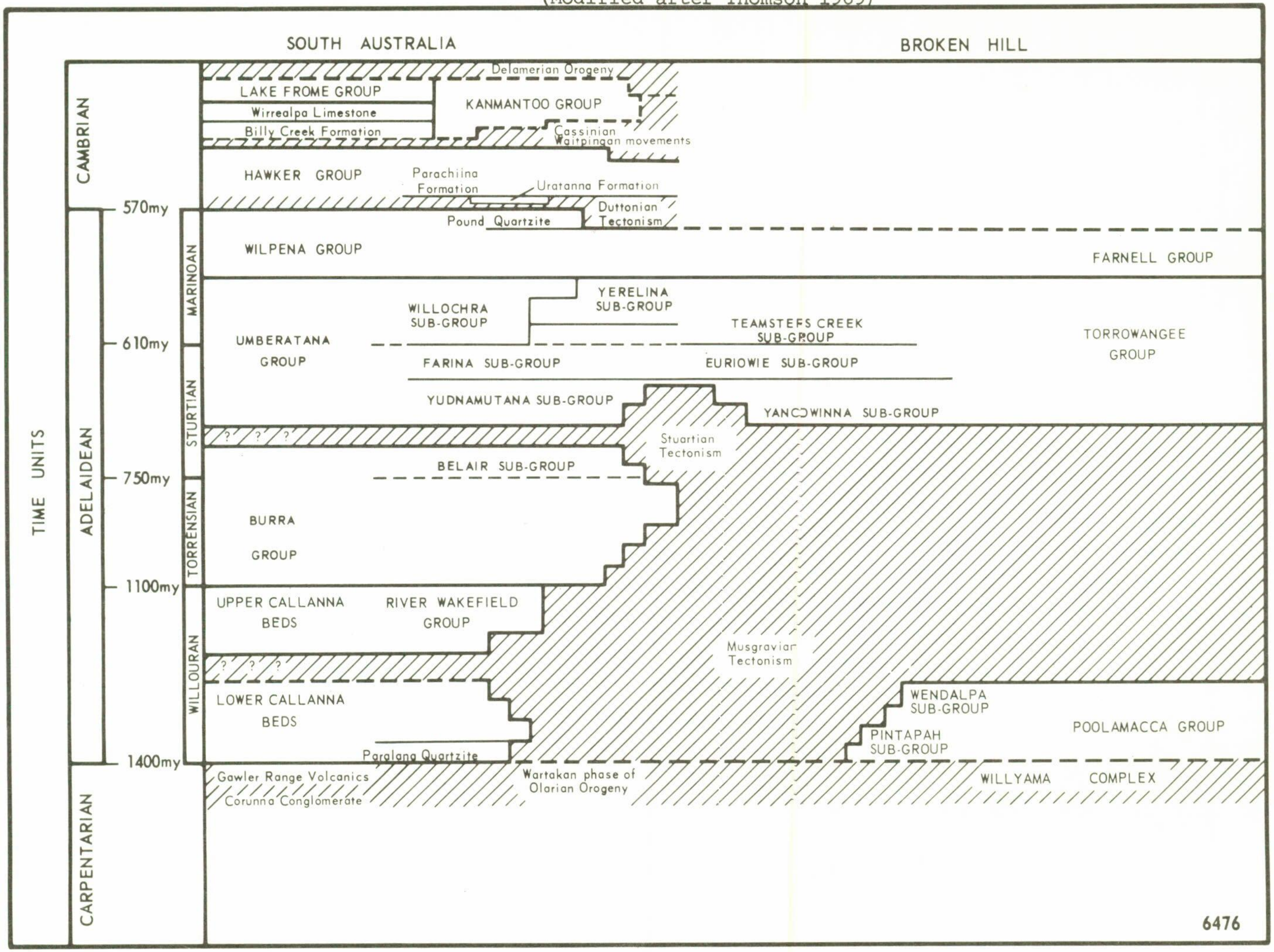


TABLE 9

GENERALIZED CORRELATION TABLE FOR THE ADELAIDEAN
(Modified after Thomson 1969)



similar.

The overlying Mantappa Dolomite and Sturts Meadows Siltstone of the Farnell Group are readily correlated with the Nuccaleena Formation and Ulupa Siltstone of the Wilpena Group.

Correlations higher up in the sequence are less readily made, but the upper part of the Lintiss Vale Formation could represent an intertonguing of the Wonoka Formation and the Pound Quartzite*.

* The work of Daily (1972, 1973) has indicated that the Lintiss Vale Formation is equivalent to the Uratanna Formation of early Early Cambrian age. He has also suggested that the Camels Humps Quartzite may be equivalent to the basal quartzites of the Uratanna Formation. However, it may alternatively represent an equivalent of the Pound Quartzite.

POST - ADELAIDEAN IGNEOUS INTRUSIONS

Quartz - bearing Norite (εn)

Several outcrops of a quartz-bearing norite occur within the Willyama Complex. The age of these intrusions is not known and their exact relation to the surrounding Willyama Complex is obscured. Identical rock types occurring around Silverton and west of Broken Hill have suffered mild retrograde metamorphism, suggesting that they were probably emplaced during the Precambrian. However, as no similar intrusions have been recorded from the Adelaidean, it can also be reasoned that they are older than approximately 870 m.y. It should be noted that the symbol given to the quartz norite implies that it is of Cambrian age.

Tuckwell (1968) considered the bodies to be granulites. Cooper (1969) was not sure if the bodies were igneous intrusion or granulites, but considered them more likely to be granulites. Watts (1971a) re-examined thin sections of the rocks and considered them to be quartz-bearing norites. On reconsideration of the problem the authors agree that the rocks are intrusive. The description of Watts (1971a) is as follows:

"The rock is reasonably coarse grained (average grainsize about 1 mm across) with an allotriomorphic granular texture. The feldspar is labradorite and is normally zoned from about An_{60} centrally to about An_{40-50} peripherally.

"Hypersthene and bronzite comprise about 50% (or very slightly greater) of the pyroxene present. The remainder is a pale greenish augite.

"Hornblende is a minor mafic constituent and is commonly moulded on the pyroxenes. Quartz occurs interstitially and comprises about 5% of the rock. Apatite is a minor accessory. Opaque phases also constitute about 5% of the rock. An approximate modal composition is as follows:

mafic constitutents	50%
plagioclase	40%
quartz and apatite	5%
opaque	5%

A chemical analysis of the quartz norite is given in table 10.

Altered Igneous Dykes

Numerous altered discordant igneous intrusions have been found within the Adelaidean sediments (e.g., GR 710198). They are in the form of dykes of what was originally porphyritic, acid to intermediate, intrusive igneous rock.

Watts (1970) described the rock as follows:

"The rock consists mainly of carbonate together with sericite, chlorite and biotite. Relict grains of plagioclase ... remain. Quartz is present in somewhat granoblastic patches. Small irregular opaque granules are scattered throughout."

The orientation of these dykes is consistently north-northeasterly (dip vertical), which is one of the directions of paired shear joints associated with the fold axes in the Adelaidean. This direction is also a direction of major brittle failure within the Adelaidean, as numerous small faults and quartz veins also have this orientation (see section on "Joint and Fault Analysis").

It is possible that these dykes, usually only 1 m thick but up to 4 km long, are related to the syenite intrusions at Packsaddle (GR 502215, Cobham Lake 1:250 000) and the quartz porphyry intrusions south of Wertago (GR 570165, White Cliffs 1:250 000). D.J. Pogson (pers. comm. 1971) considers the Wertago intrusions to be of Middle Devonian age, and, as no dykes have been observed to intrude the Late Devonian sediments, it is possible that the altered porphyritic dykes are also of Middle Devonian age.

TABLE 10

ANALYSIS OF A QUARTZ NORITE

SiO_2	49.43
TiO_2	0.60
Al_2O_3	16.57
Fe_2O_3	2.17
FeO	7.47
MnO	0.20
MgO	7.56
CaO	12.87
Na_2O	1.76
K_2O	0.16
P_2O_5	0.06
H_2O+	1.12
H_2O-	0.11
CO_2	0.05
	100.13

GR 492243. Analyst P.M. Ashley. Analysis by XRF spectroscopy except for FeO, Na_2O, H_2O, and CO_2 which were done by wet chemical methods.

DEVONIAN SEDIMENTS

Dominantly quartz sandstones of probable Late Devonian age lie unconformably upon the Adelaidean sediments on the eastern flank of the Caloola Syncline. The only fossils reported from these sediments were found by students of the Australian National University who worked under the direction of M.J. Rickard in 1968. These fossils were identified as fish plates (*Bothriolepis*). Further investigations of the reported fossil locality have failed to reveal any more fossils (G. Neef pers. comm.)

There are three main area of Late Devonian outcrop. The first is just to the east of the Fowlers Gap Rural Investigation Station, the second is around the Lintiss Vale area (GR 930180), and the third is north of Wallace Creek (GR 870340). The area to the east of Fowlers Gap has been mapped in some detail by Ward et al. (1969), who divided the sequence into two blocks separated by the Nundooka Creek Fault. The western (upthrown) block is lithologically different from the eastern block and the two units are given different names. The Nundooka Creek Fault separates the two units for the entire length of the outcrop, but Ward et al. (1969) believed them to be conformable.

Coco Range Beds (Dc)

The Coco Range Beds rest unconformably upon the Adelaidean sediments and constitute the upthrown block. They are exposed along the eastern edge of the Caloola Syncline but the best development is further to the north in Coco Range (Cobham Lake 1:250 000 sheet) where a section at least 760 m thick is exposed. Sections were measured by Ward et al. (1969), and the type section is shown in figure 39.

Ward et al. (1969, p.69) described the Coco Range as follows:

"The sandstones of the Coco Range Beds are medium grained, fairly well sorted and in places quite flaggy. They contain about 90% quartz and the rest consists of mica and rock fragments set in a matrix of white clay. Some iron oxide, probably authigenic, is also present. Many beds of orthoquartzite about four feet thick persist as distinct horizons both in the Coco Range and Nundooka sandstones. They are much harder than the sandstones described above, with a cemented nature due to secondary enlargement of quartz grains. This diagenetic precipitation of silica appears to have been confined to horizons of less clayey sandstone in the Devonian sequence.

"Small hemispherical pits one eighth to one quarter inch in diameter are often seen in the Devonian sandstones. These are left by weathering out of spherical patches, rich in clay, within the sandstone. These clayey patches may be primary or diagenetic; not unlike concretions. Flattened blebs of grey shale also occur within the sandstone. Removal of the shale on exposure leaves polygonal hollows resembling fish plates, but these impressions do not have any regular shape or ornamentation.

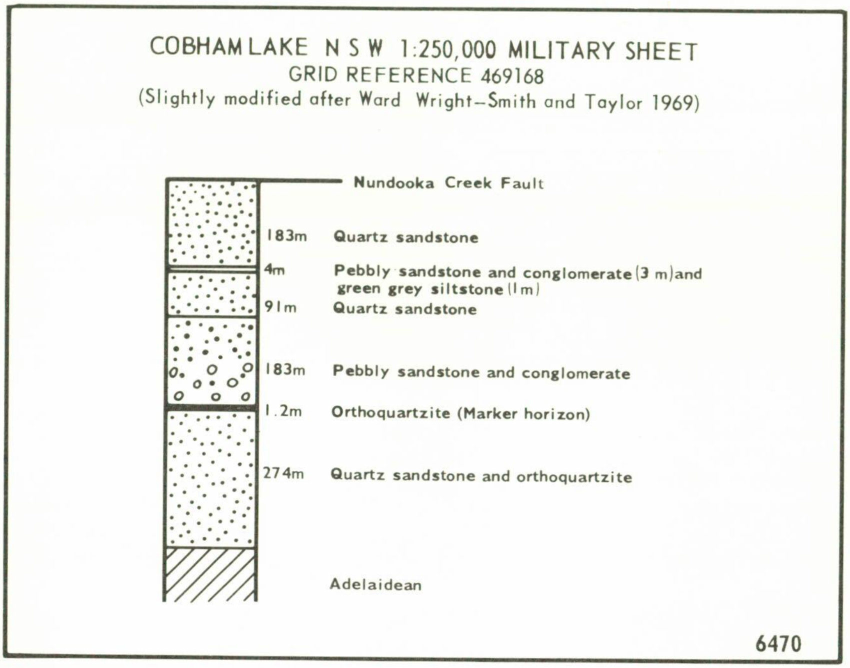


Figure 39. Type section of the Coco Range Beds

"The conglomerates contain rounded cobbles and pebbles of white vein quartz, up to four inches across, set in a sand and granule matrix. Although the proportion of pebbles varies, the bulk of the rock consists of pebbly sandstone rather than true conglomerate.

"The upper limit of the Coco Range Beds is not clearly defined due to truncation by the Nundooka Creek Fault. However photogeological interpretation of the area to the north indicates that very little more of the sequence is likely to be exposed on the western side of the fault than seen in the area mapped".

Little work has been done in the Lintiss Vale area but the sandstones here are all quite similar to the Coco Range Beds. The sequence rests unconformably upon the Adelaidean and so would probably be equivalent to the Coco Range Beds.

Nundooka Sandstone (Dn)

Ward et al. (1969, p.69) described the Nundooka Sandstone as follows:

"On the eastern side of the fault, a sequence of at least 3,500 feet of quartzose sandstone is exposed. This is called the Nundooka Sandstone after "Nundooka" Station to the north. The sandstone is very similar to that of the Coco Range Beds, but no conglomerate units were observed in the area mapped.

Pebbly bands do occur in places and one very thin bed of green shale is exposed. Orthoquartzite beds similar to those described above occur with secondary enlargement of quartz. Three of these beds are persistent enough to trace as marker horizons over many miles.

"The base of the units is obscured due to the Nundooka Creek Fault, and the top is covered by extensive deposits of alluvium to the east."

ECONOMIC GEOLOGY

Very little mining activity has taken place within the Torrowangee and Fowlers Gap sheet areas.

Pyritic limestone and dolomitic limestone were mined from the Torrowangee Quarries to provide flux for the smelters at Broken Hill. Mining ceased when the smelters were moved to Port Pirie in South Australia. In all 669 000 t were extracted.

Argentiferous galena occurs in white quartz veins on "Sturts Meadows", "Paringa" and the "Floods Creek" Rural Investigation stations. These veins consistently strike northeast - southwest and are parallel to the trend of altered igneous dykes. This fracturing and its relationship to major structure is discussed in the section on "Structural Geology". Minor copper mineralization, in the form of fine malachite and azurite fracture fillings, occurs associated with the Wilangee Basalt west of "Poolamacca".

Prominent outcrops of ironstone occur over a distance of 24 km along the Corona Fault which forms the boundary between the Euriowie Block and the Torrowangee Synclinorial Zone. Gilligan (1972) reported a considerable amount of manganese in the ironstone and high trace amounts of copper and zinc. Rayner (1960) noted an occurrence of rutherfordine (uranium carbonate) adjacent to the ironstone near Old Corona Well. Gilligan did not consider the ironstones to represent gossans, but to have formed by precipitation from groundwater moving along the fault zone.

Tin Deposits

Tin mineralization occurs associated with low-grade Willyama Complex metasediments at "Bijerkerno" and west of "Poolamacca" around Bobs Well. The following description is largely taken from Lishmund (1975).

Euriowie Tin Field

The Euriowie tin field is situated in Parish Byjerkerno, County Farnell, approximately 70 km north of Broken Hill.

Pegmatites of varying size and composition have been intruded along the bedding planes (which are well preserved in the low-grade rocks), in the axial plane cleavage of the folds produced in the first deformation (group 1 folds as defined by Meares 1969), and in other minor structural features.

The stanniferous pegmatites are mineralogically zoned, while other pegmatites present are mainly unzoned, relatively fine grained and simple. Approximately 8 km northwest of "Bijerkerno" homestead the sequence is intruded by granitic rocks which are similar to the Mundi Mundi Granite. Meares (1969) noted that the pegmatites show a distinct areal distribution according to compositional type, and K.D. Tuckwell has suggested that this distribution arises because they are genetically related to granite, their composition being dependent on their distance of emplacement from it. The apparent sequence east from the granites is:

(a) simple, unzoned pegmatites with graphic quartz-feldspar intergrowths and occasionally garnets,

(b) simple, usually unzoned but sometimes banded, pegmatites containing garnet and tourmaline, emplaced stratigraphically below the "Bijerkerno Beds" and

(c) complex, zoned stanniferous pegmatites which are almost wholly intruded into the "Bijerkerno Beds".

The stanniferous pegmatites have been emplaced both before and during the first deformation, and exhibit a sequence of zones identical to that of the Thackaringa pegmatites. This sequence is, however, largely obscured by recrystallization and shearing in most cases. Individual bodies are generally elongated and tabular, measuring a few metres thick and up to several hundred metres long, and contacts are sharp to gradational, the country rocks occasionally exhibiting a degree of silicification and feldspathization. In places, tourmalinization of country rocks can be observed on the upper contacts where the pegmatites are emplaced parallel to bedding.

The unaltered stanniferous pegmatites show varying degrees of albitization with which a number of minerals are associated, including cassiterite, amblygonite (usually as large masses adjacent to quartz cores), beryl (a rare caesium-bearing variety) tourmaline, garnet, and fluorite. The presence of fluorite is significant as in many pegmatitic tin deposits the tin is believed to have been transported from the source rock as a fluoride. The cassiterite occurs as small crystals and bunches irregularly distributed through the pegmatites, and overall grades are low.

Tin was first discovered in the area in about 1884 and most of the mining activity took place in the next 20 years, the major producing mines being the Wheal (Huel) Bijerkerno, Trident, Mount Euriowie, and Lady Don mines. In more recent years some attention has been paid to the production of feldspar, beryl, and amblygonite from the Lady Don and Trident mines, but at current prices, and considering the distance of the deposits from the nearest railhead at Broken Hill and the limited reserves available, these operations have been only marginally economic at best.

The *Lady Don* mine, in ML's 16 and 17 (now covered by ML 306) Parish Byjerkerno, County Farnell, about 3 km south of "Bijerkerno" homestead, is developed on a pegmatite emplaced parallel to bedding and subsequently deformed into a number of near-isoclinal to moderately open, steeply north-plunging folds. The country rocks are andalusite-chiastolite schist, mid-grey slate and phyllite, and grey to red-brown quartz-biotite-sericite schist which is crenulated in part. Schorl rocks are often developed near the upper contacts of the pegmatite, and in some places the country rocks are extensively feldspathized. The deposits comprise a large pegmatite approximately 200 m long and up to 10 m wide, and numerous dykes, veins, and other masses of pegmatite occurring within or near the margins of a slate-phyllite unit. The main pegmatite comprises a quartz-muscovite-minor plagioclase selvedge up to 0.3 m wide, an intermediate zone of sodic plagioclase, quartz, and minor muscovite, and a core of quartz. Large massive quartz bodies also occur in the surrounding country rocks, and a large mass of amblygonite is associated with the quartz core in the large bulge in the pegmatite near the crest of the hill.

The pegmatite has been worked by means of a number of pits, adits, and shafts to depth of approximately 30 m, mainly before the turn of the century.

Kantappa

The Kantappa tin mine (GR 379308) is situated approximately 65 km north of Broken Hill and about 11 km south-southwest of "Corona" homestead, in Parish Corona, County Farnell.

The deposit comprises a quartz-feldspar-muscovite pegmatite dyke which is up to 5 m wide, dips steeply northeast, and appears to transgress the lithological layering of the surrounding phyllite, gneiss, and schist. Outcrop is poor in the immediate vicinity of the workings, but the pegmatite is very similar to those of the Euriowie tin field and some suggestion of zoning is apparent.

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APPENDIX 1

BRIEF PETROLOGICAL NOTES ON THE WILANGEE BASALT

(Taken from Barron 1971, pp 1 - 2; for location of samples see figure 16)

169/1

Altered basic volcanic rock (Epidote - chlorite - biotite rock)

This rock is extremely altered. However, the relict texture indicates that it is a fine-grained slightly porphyritic basic volcanic rock. No original minerals remain. Large patches of epidote are common. These are extremely irregular and partly replace former igneous crystals. The other alteration minerals are extremely fine grained and include quartz, albite, green biotite, and chlorite. Large skeletal opaque grains are partly altered to leucoxene. These were probably ilmenite or titanomagnetite...

169/2

Altered vesicular(?) basalt

The texture of this rock is intergranular and is strongly vesicular. It is partly altered. Vesicles are filled with epidote, albite, quartz, chlorite, and biotite. These are commonly zoned and albite invariably occurs marginally.

The remainder of the rock consists of very fine plagioclase laths with small needles of metamorphic actinolite and abundant peppery opaque granules.

169/3

Epidote - albite - actinolite rock

This rock consists almost entirely of a granular aggregate of epidote with smaller amounts of albite, actinolite, and sphene. A small amount of chlorite is also present.

No original texture or mineralogy remains. However, the rock was probably derived from a basic igneous rock...

169/4

Altered basic igneous rock

This rock is coarser grained than 169/2 and probably represents a basic igneous rock, perhaps basaltic. It is reasonably altered to granular epidote and acicular actinolite together with sphene.

The original texture of the rock is intergranular and small albite laths are scattered throughout. Small irregular opaque grains are scattered throughout.

169/5

Altered vesicular(?) basalt

This is a reasonably fine-grained basic volcanic rock bearing sparsely distributed vesicles filled with quartz, biotite, epidote, and fine acicular actinolite needles.

The groundmass consists of ragged actinolite, granular epidote, and sphene, together with small plagioclase microlites that are now albite. Irregular opaque granules are scattered throughout...

169/6

Altered basic igneous rock

This rock is extremely similar to 169/4. It carries slightly more granular epidote and is slightly finer grained. Textural relationships are essentially identical.

APPENDIX 2

STROMATOLITES AND PROBLEMATICAL STRUCTURES FROM THE BARRIER RANGES

(Slightly modified from Preiss 1972)

Stromatolites from the Boco Formation near "Wilangee" (GR 368190), from its probable equivalent at "Mount Woowoolahra" (GR 234459), and from boulders in the Nunduro Conglomerate are described below. The origin of the "birdseye-like" limestones of the Torrowangee quarries remains problematical. The tubular structures in the Nunduro boulders are probably highly altered stromatolites. The terminology is that outlined in the glossary.

BOCO FORMATION STROMATOLITES

GROUP OMACHTENIA Nuzhnov 1967.

Collenia omachtensis Nuzhnov 1960, p. 1422

Omachtenia Nuzhnov 1967, p. 13

Type form: *Omachtenia omachtensis* (Nuzhnov), from the Omakhtin Suite of the Uchur Basin, southeastern Siberian Platform.

Diagnosis: Cylindrical and subcylindrical unwalled columns, sometimes widening upwards, with numerous cornices and bridges linking several columns. Branching is mainly alpha-parallel; columns are usually vertical, sometimes radiating or slightly curved.

Content: *O. omachtensis* Nuzhnov, *O. utschurica* Nuzhnov, and *O. givunensis* Nuzhnov.

Age and distribution: Early Riphean in the Uchuro - Maya region of the U.S.S.R., but in South Australia *O. utschurica* is probably Late Riphean (Preiss 1971b).

?*Omachtenia* f. indet.

Material: Seven specimens from two localities.

Description:

Mode of Occurrence: The stromatolites form discrete lenticular bioherms, generally 1 to 6 m wide and up to 1.5 m high. The separate bioherms are in contact both laterally and vertically, often overlapping earlier bioherms. The bioherms all stood in relief above the surrounding sediment floor. The substrate consists of flaggy, poorly laminated finely crystalline dolomite, containing tabular or lenticular white chert pods. The same sediment continued to accumulate after bioherm growth and is seen lapping up on to the bioherm margins. The stromatolites are largely pseudocolumnar, with columnar and columnar-layered intercalations; only these portions were collected for serial sectioning. Chert pods within the bioherms are broadly conformable, but in detail they cut across the lamination. On casual inspection, vertical pillars of chert give the impression of being strict replacements of stromatolite columns, but sectioning reveals that the pillars cut across continuously laminated stromatolites. At "Mount Woowoolahra" the whole bed is totally silicified, although the earlier chert pods are still visible and are distinct from the later silicification. The stromatolites occur in lenticular bioherms similar to those near "Wilangee".

Column shape and arrangement: Where truly columnar, the stromatolites consist of sub-cylindrical, vertical columns of more or less constant diameter. They are sub-parallel, except at bioherm margins where some are inclined. Bridging and coalescing occur very frequently at all levels and columns rarely maintain their identity for more than 10 cm in height. Such columns are frequently covered by pseudocolumnar or undulatory stromatolites. Columns vary in width from 1 to 15 cm.

Branching: Branching is rare, except for the initial branching of columns from a laterally linked stromatolite substrate. Where branching does occur it is sub-parallel, except near bioherm margins where columns tend to be radially arranged.

Margin structure: Margins of columns are commonly obscured by recrystallization, so that the column interspace contact is hazy. In places long overhanging peaks are observed but in other areas column margins appear smooth to bumpy, as far as can be ascertained. No continuous cornices as in Russian specimens of *Omachtenia* can be observed. Laminae sometimes appear to coat the margins for very short distances, but columns are generally unwalled.

Lamina shape: The stromatolites are characterised by gently convex lamination. Laminae are smooth, occasionally gently wavy. The degree of convexity is very uniform for both wide and narrow columns; in specimens from near "Wilangee", 49 per cent of the 105 laminae measured have h/d in the range 0.2 - 0.3, with only 1 per cent between 0.4 and 0.5. The distribution of lamina convexities for a "Mount Woowoolahra" specimen is similar: 68 per cent of the 31 measured lie between 0.2 and 0.3.

Microstructure: Lamination is rarely well preserved. Where visible, it is indistinctly but continuously banded, with alternating predominantly dolomitic laminae 0.5 to 2.0 mm thick, and thinner, partly calcitic laminae. The dolomitic laminae are very continuous, but pinch and swell slightly along their length. They consist of equigranular hypidiotopic dolomite of grain size ranging from 0.01 to 0.04 mm. The calcitic laminae are much less continuous, and frequently consist only of irregular stringers of sparry calcite separating the dolomitic laminae. Small apophyses of sparry calcite frequently project from them into the dolomitic laminae. The calcitic laminae vary in thickness up to 1.2 mm, and frequently consist of coarse sparry calcite in crystallographic continuity. In places dolomitic laminae alternate with laminae composed mainly of dolomite but containing finely dispersed sparry calcite. Such laminae tend to be as continuous as the dolomitic laminae, and may reach a thickness of 2 mm. The totally silicified stromatolites from Mount Woowoolahra have a similar microstructure, but laminae are poorly visible in thin section. Cut slabs show alternating relatively paler and darker grey laminae, which cannot be differentiated in thin section. These specimens consist of a granoblastic quartz mosaic of grain size ranging from 0.02 to 0.15 mm.

Interspaces: The spacing of adjacent columns varies from 0.5 to 5 cm. Interspaces are frequently bridged in the columnar-layered poorly bedded sediments. These consist either of dolomitized micrite or intraformational breccia. Flat, tabular dolomite clasts up to 3 cm long are randomly stacked in the interspaces, and are grain-supported at least in part. In places upturned clasts act as high points on which new column growth commences. Intraclasts are entirely dolomitic, while the surrounding matrix consists of dolomite plus void-filling sparry calcite. The original nature of this matrix could not be determined; it may have been lime and mud or sparry cement, in each case later dolomitized. The clasts may have been eroded as dolomite.

Secondary alteration: These sediments are extensively altered, and the original nature of the stromatolitic laminae is not clear. The uniform hypidiotopic equigranular texture of the dolomite suggests that this is formed by replacement of a limestone, but it is uncertain whether or not the sparry calcite is a recrystallized remnant of the original limestone. It is equally possible that the sparry calcite has filled void spaces, which may be either primary (cf. fenestral structures of modern intertidal and supratidal carbonates) or a secondary porosity due to dolomitization and/or dissolution. When traced into a silicified area, the sparry laminae appear as slightly coarser grained chert (up to 0.15 mm grain size). The silicification is crosscutting and post-dates the formation of the whole structure. Chert is white, relatively coarse-grained, of grain size 0.02 to 0.05 mm and of granoblastic texture. Its contact with the carbonate is gradational and slightly sutured; relics of dolomite within the chert suggest that silicifcation post-dated dolomitization, and probably also the differentiation of the dolomitic and calcitic laminae. This difference is preserved in the chert only as a slight difference in grain size (as above) or as concentrations of carbonate inclusions. The sequence of events could be interpreted as follows:

1. Growth of stromatolites with calcitic laminae, possibly with fenestral fabric.

2. Filling of the interspaces in places with lime mud and partly with flat pebbles which were possibly already dolomitized.

3. Replacement of calcium carbonate of the stromatolites and interspaces by dolomite.

4. Filling of void spaces (either primary or secondary) with coarse sparry calcite.

5. Replacement of parts of the rock by silica.

6. Metamorphic recrystallization.

Comparisons: These stromatolites are provisionally placed in the group *Omachtenia* although the preservation does not allow exact comparisons with any particular form. The shape of columns, the predominantly columnar-layered structure and the banded lamination closely resemble Russian representatives of the group. They apparently lack the cornices characteristic of most of these, but long, downward directed peaks are common. The consistently gently domed laminae without sharply deflexed margins most resemble those of *O. omachtensis*.

Distribution: In the U.S.S.R., *O. omachtensis* and *O. utschurica* occur in the Lower Riphean Gonam and Omakhtin suites, while *O. givunensis* occurs in the lowermost Middle Riphean Ennin Suite, all in the Uchuro-Maya region. In South Australia, *O. utschurica* occurs in the Brighton Limestone, (Preiss 1971b). In the Barrier Ranges, *?Omachtenia* f. indet. occur in the Boco Formation, probably equivalent to part of the Lower Callanna Beds of South Australia.

Age: Lower Riphean to lowermost Middle Riphean in the U.S.S.R. In South Australia, *O. utschurica* is Late Adelaidean, probably equivalent to the upper part of the Upper Riphean.

STROMATOLITES FROM THE NUNDURO CONGLOMERATE

Boulders of creamish-white dolomite are common in the Nunduro Conglomerate, and some contain probable stromatolites. These are visible only by the alternation of dolomite laminae with fine stringers of sparry calcite (cf. the laminae of specimens from the Boco Formation). On cut slabs the stromatolites are barely visible even when etched, and although column-like structures occur, their margins cannot be discerned. Laminae in these columns are frequently steeply domed to sub-conical and thus differ from the stromatolites of the Boco Formation; the laminated, column-like structures in places are almost in contact, and in places grade into less laminated sediment in which the sparry patches are coarser and more equidimensional. This may represent original interspace sediment. The stromatolites are too poorly preserved to allow reconstruction or comparision. The specimens may have suffered tectonic deformation; indeed some of the curvature of laminae may be due entirely to folding.

"BIRDSEYE-LIKE" LIMESTONE, TORROWANGEE QUARRIES

There are both massive and laminated varieties of this rock in the Wammerra Formation of the Torrowangee quarries (GR 463228). Field occurrence suggest that they all occur as slumped blocks. The massive type consists of randomly oriented irregular polygonal spar-filled vughs, 0.5 to 10 mm in diameter. The vughs are filled with several generations of carbonate: (1) some have an outer drusy rim of dolomite (radiaxially oriented elongated crystals), partly spalled off towards the centre of the vugh; (2) many have a rim of equigranular mosaic calcite; (3) all have a central cavity filled usually with a single large calcite crystal. The host sediment consists of an equigranular mosaic of xenotopic to hypidiotopic dolomite, itself containing some quartz silt and scattered xenotopic calcite crystals.

The laminated varieties have vughs which are enlongated and aligned parallel to a lamination in the intervening carbonate. This lamination is of uniform, banded appearance, and sinuously folded, and is possibly stromatolitic, but no direct evidence of this was observed. The folding of laminae is probably sedimentary, but is unlikely to be the original shape of algal laminae. This sediment grades into the massive variety.

The origin of the vughs remains problematical; the textures of the generations of carbonate infilling suggest that the vughs were indeed void spaces; they are not the result of recrystallization. They could be either primary (i.e., "birdseye" structures of Shinn 1968) or secondary, due to solution of carbonate and later infilling by sparry cement. If they are "birdseyes" and the associated laminae are stromatolitic, then these rocks would indicate deposition in very shallow water, possibly in a littoral environment.

TUBULAR STRUCTURES FROM BOULDERS IN THE NUNDURO CONGLOMERATE

Dolomite boulders from the Nunduro Conglomerate at GR 487511 contain chert-walled tubular structures not seen anywhere in situ. Thus their relation to the original bedding is not known. In transverse section the tubes are strongly elongated, their longer dimension being up to five times the shorter. In thin section a slight foliation is seen in the dolomite parallel to the direction of elongation, and attenuation of the cherty walls parallel to the foliation shows that the tubes have been tectonically deformed. Cross sections of the tubes commonly measure 0.5 to 1.5 cm by 2 to 4 cm. The carbonate inside the tubes consists of roughly equigranular hypidiotopic dolomite of grain size 0.008 to 0.015 mm, with scattered isolated xenotopic (xenomorphic) calcite crystals. Contacts of the matrix and the cherty walls are gradational, with the chert containing varying amounts of carbonate interstitial between quartz grains. In rare cases a curved transverse lamination is seen within the tubes.

A specimen collected by R.P. Coats in 1970 (F 182/70) was large enough to allow serial sectioning and three-dimensional reconstruction. The tubular structures were seen to be only partially silicified, and the reconstruction revealed their branching habit. This, together with the internal convex lamination occasionally observed, suggests that these structures are highly altered columnar branching stromatolites with locally silicified column margins. The suggested original orientation is as shown. The areas shown by cross-hatching are coarsely recrystallized.

These probable stromatolites are too highly altered to permit identification, and in their unaltered state they could have resembled any of a number of columnar branching forms. They are therefore not of stratigraphic value.

GLOSSARY

Axis. The centre-line of a column.

Bioherm. A circumscribed organo-sedimentary structure whole minimum width is less than or equal to one hundred times its maximum thickness, embedded in rocks of different lithology.

Tabular bioherms have parallel upper and lower surfaces, while domed bioherms have gently convex upper surfaces. Subspherical bioherms had the highest growth relief relative to their width.

Tonguing bioherms are bioherms which had little or no growth relief, and therefore intertongue at their margins with the surrounding sediment.

Branching. The division of a column into new, discrete columns. The columns become discrete when they are first separated by an interspace. In parallel branching, the axes of the new columns are parallel (most commonly they are also parallel to the axis of the original column). α -parallel branching is parallel branching in which the width of the individual remains constant. In β -parallel branching the original column widens gradually before branching, while in γ -parallel branching, it widens abruptly before branching. In slightly divergent branching, the axes of the new columns diverge at less than 45°, while in markedly divergent branching they diverge at more than 45°. Dichotomous branching into more than two columns at approximately one level.

Bridge. A stromatolitic lamina or set of laminae linking adjacent columns.

Bump. A low, rounded protrusion on the side of a column.

Coalescing columns. Adjacent columns which join and continue growth as one column.

Column. A discrete stromatolite structure, with the dimension in the direction of growth greater than at least one of the transverse dimensions. Column shape and arrangement often vary according to the position in the bioherm.

Columnar-layered stromatolite. A stromatolite in which short columnar and laterally linked (usually pseudocolumnar) portions alternate.

Cornice. Peripheral overhanging portion of a lamina or set of laminae, elongated transversely to the column axis.

Crestal zone. The crestal zone is specifically the zone of thickening and contortion of the laminae; the width of the crestal zone is the width of the thickened and/or contorted portions of laminae.

Cumulate stromatolite. A rounded protruding non-columnar stromatolite.

Flat-laminated stromatolite. Non-columnar stromatolite with flat continuous laminae.

Gently convex lamina. A lamina whose ratio of height to diameter is less than or equal to 0.5. Measurements of this ratio are best treated statistically by plotting on a histogram.

Hypidiotopic. A mineral texture intermediate between xenotopic and idiotopic.

Idiotopic. A texture in which the mineral grains are bounded by crystal faces.

Individual. A single discrete stromatolite within which the laminae are continuous or which comprises a group of columns from a single basal column.

Interspaces. The space between columns, usually filled with sediment.

Lamina. The smallest unit of layering in a stromatolite.

Laterally linked stromatolite. Stromatolite with wavy laminae which are continuous between crests.

Microstructure. The fine-scale structure of the stromatolite lamination, in particular the distinctness, continuity, thickness, and composition of the laminae.

Banded microstructure is characterized by very continuous laminae with sharp, distinct, more or less parallel boundaries. In streaky micro-structure less distinct and continuous laminae frequently grade into one another. The darker laminae are usually more distinct.

Striated microstructure consists of primary chains of lenses, oriented parallel to the lamination (this excludes cases where originally continuous laminae are disrupted by recrystallization).

Vermiform microstructure consists of narrow, sinuous, pale coloured areas (usually of sparry carbonate) surrounede by darker, usually finer grained areas.

Peak. Overhanging portion of a lamina or set of laminae with a small dimension transverse to the column.

Platy column. A strongly transversely elongated column.

Projection. A small columnar or conical outgrowth from the side of a column.

Pseudocolumnar stromatolite. Laterally linked stromatolite in which successive crests are superimposed, forming column-like structures (pseudocolumns).

Steeply convex lamina. A lamina whose ratio of height to diameter is greater than 0.5.

Tuberous column. A column with prominent expansions and constrictions.

Wall. Structure at the margin of a column formed by one or more laminae from within the column bending down and coating the margin for at least a short distance.

Undulatory stromatolite. Laterally linked stromatolite in which successive crests are not superimposed.

Xenotopic texture. A texture in which the mineral grains are anhedral or irregularly shaped, i.e., not bounded by crystal faces.

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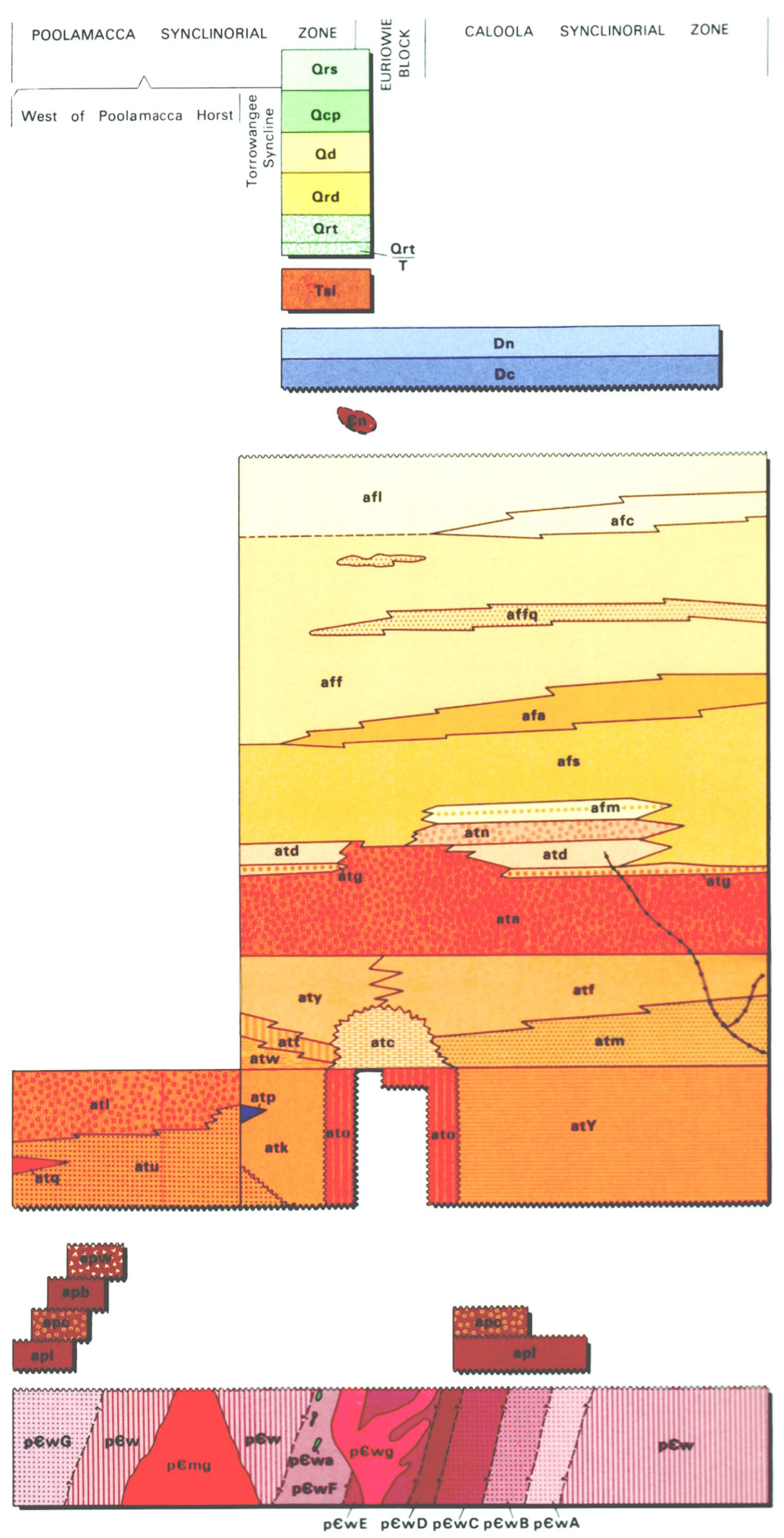
TORROWANGEE–FOWLERS GAP

GEOLOGICAL SERIES SHEETS 7135 & 7235
(EDITION 1) 1975
GEOLOGICAL SURVEY OF N.S.W. DEPARTMENT OF MINES



REFERENCE

Qrs Flood plains, outwash areas and drainage flats of red clayey silt and sand

Qcp Playas, lakes and "claypans" of black and grey silty clay and silt

Qd Flat to gently undulating plains of red and brown clayey sand, loam and lateritic soils

Qrd Dune deposits of red and brown clayey sand, loam and lateritic soils, irregular deposits of aeolian sand

Qrt Residual and colluvial deposits of angular and poorly sorted gravel

Tsi Silicified conglomerate and quartzite, diagenetic siliceous cement (greybilly)

Qrt/T Residual boulders and pebbles of silicate and iron-stained silcrete and sandstone of probable Tertiary age

Dn Nundooka Sandstone; quartz sandstone

Dc Coco Range Beds; quartz sandstone, siltstone and conglomerate

Єn Quartz norite

afl Lintiss Vale Formation; light-brown, green, grey and yellow siltstone with some quartzite and minor carbonate

afc Camels Humps Quartzite; grey, well-bedded, silicified quartzite and minor shale

aff Fowlers Gap Formation; purple, yellow shales bleached white in outcrop, interbedded with massive quartzite

affq Massive quartzite member

afa Faraway Hills Quartzite; grey, silicified, massive quartzite containing white clay as matrix

afs Sturts Meadows Siltstone; siltstone, light to dark green-grey siltstone

afm Mantappa Dolomite; brown to buff, finely laminated dolomite

atn Nunduro Conglomerate; pebble, cobble, boulder bearing siltstone, diamictite siltstone

atd Dering Siltstone; graded and laminated siltstone with abundant ripple marks

atg Gairdners Creek Quartzite; quartzite with brown, silicified, medium to coarse, well-bedded sandstone

ata Alberta Conglomerate; diamictite, pebble, boulder, cobble bearing siltstone

aty Yowahro Formation; calcareous sandstone, predominantly finely laminated. Siltstone and sandstone

atf Floods Creek Formation; brown calcareous sandstone interbedded with grey-green siltstone

att Tanyarto Formation; green-grey siltstone, limonitic pyrite cubes, minor sandstone

atw Wammerra Formation; massive and flaggy limestone with pyritic shale

atc Corona Dolomite; massive, white dolomite

atm Mitchie Well Formation; lenticular, sandy limestone interbedded with green laminated shale

atl Yangalla Formation; boulder beds, lenticular interbedded siltstone, sandstone

atk Waukeroo Formation; lenticular paraconglomerate, siltstone and sandstone

atp Mount Wallop Quartzite Member; quartzite and siltstone

atu Mulcatcha Formation; flaggy, quartzose sandstone with some lenticular boulder beds

atq Kantappa Quartzite Member

ato McDougalls Well Conglomerate; polymictic paraconglomerate

atY Yancowinna Sub-Group, undifferentiated

apw Wilangee Basalt; amygdaloidal vesicular basalt

apb Boco Formation; dolomite, limestone and minor sandstone

apc Christine Judith Conglomerate; quartzite conglomerate

apl Lady Don Quartzite; white silicified quartzite

pЄw Willyama Complex; schist, gneiss, minor pegmatite

pЄwA Zone A; quartz-mica phyllite, laminated phyllite, siltstone, shale, chert

pЄwB Zone B; andalusite-chiastolite-chloritoid schists, phyllite

pЄwC Zone C; sillimanite schist

pЄwD Zone D; quartz-sericite-muscovite schist

pЄwE Zone E; retrogressed schist, subordinate gneiss and amphibolite

pЄwF Zone F; sillimanite-garnet gneiss, abundant amphibolite, minor schist

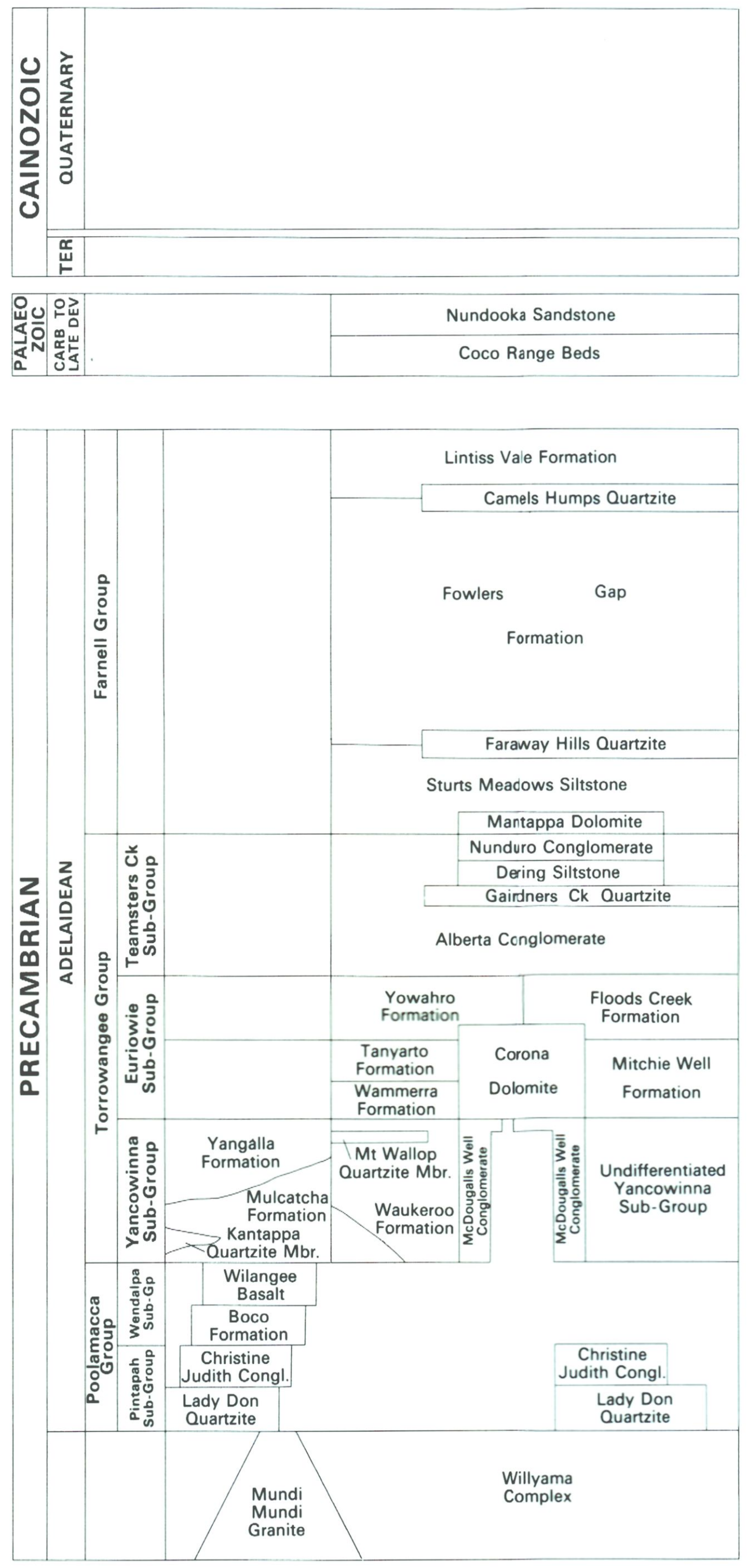
pЄwG Zone G; grey laminated phyllite and spotted quartzite

pЄwg Pegmatite with subordinate schist

pЄwa Amphibolite

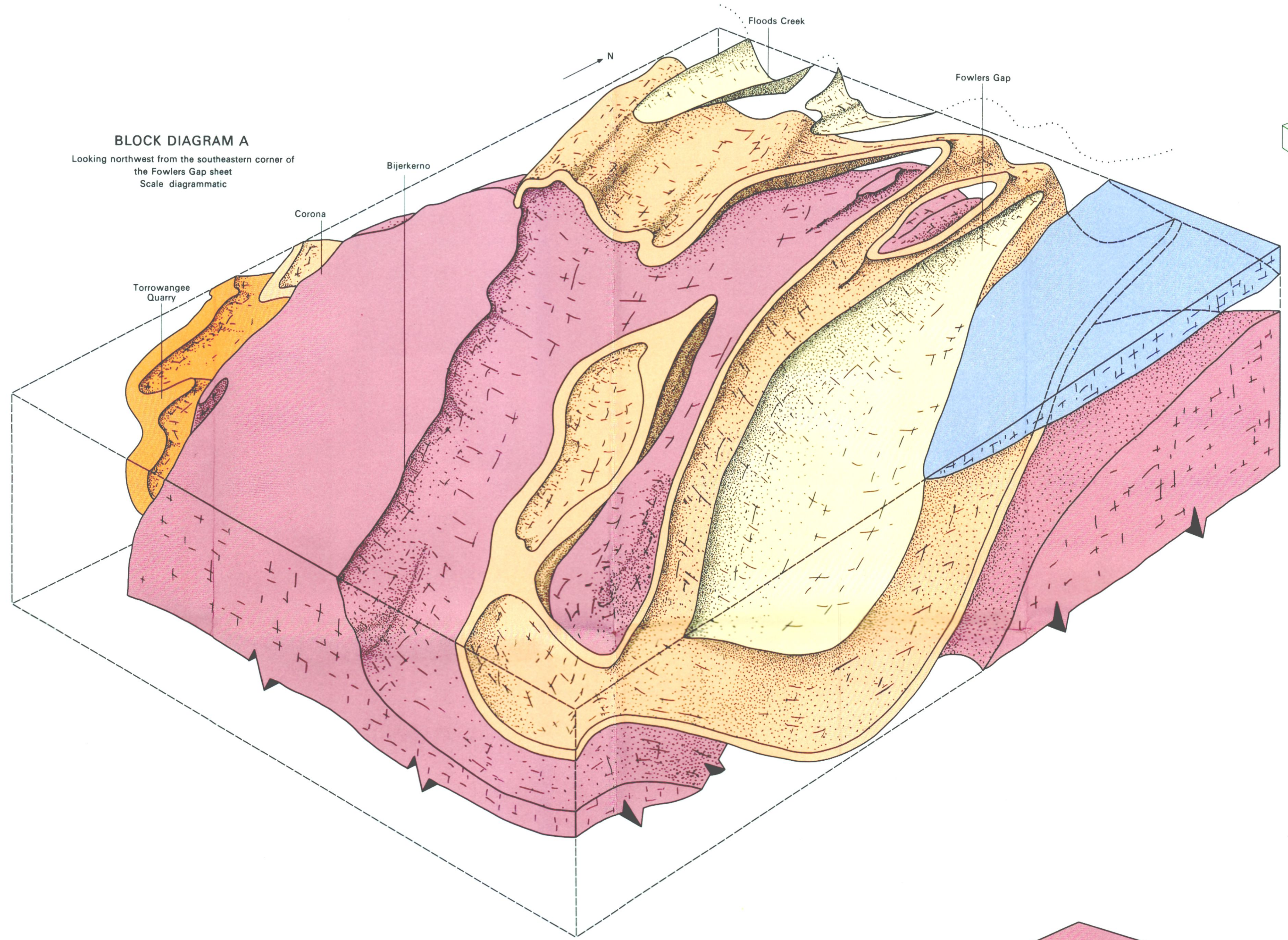
pЄwr Granite, gneiss

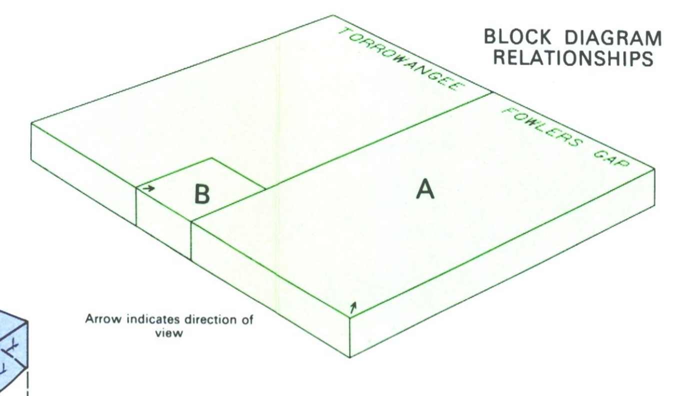
pЄmg Mundi Mundi Granite; leucocratic granite



BLOCK DIAGRAM A

Looking northwest from the southeastern corner of the Fowlers Gap sheet
Scale diagrammatic



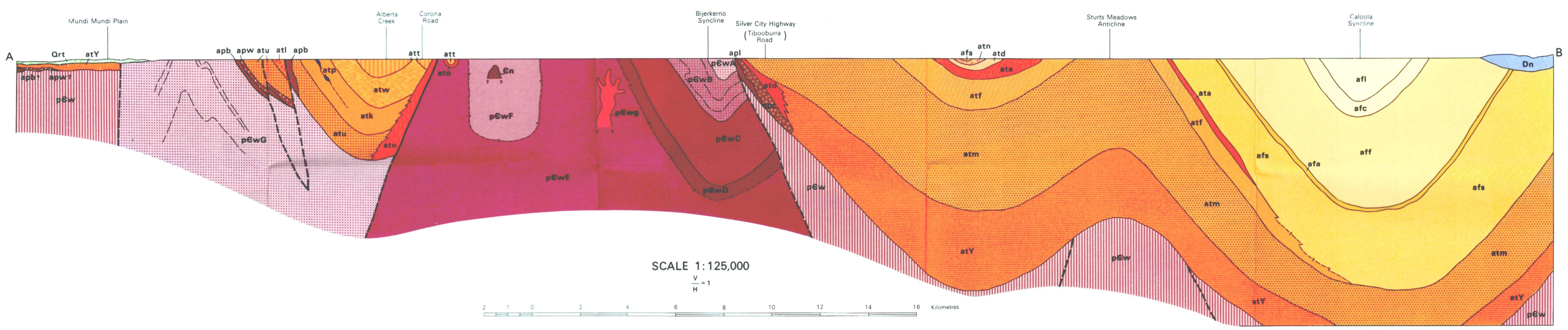


REFERENCE

- Devonian
- Base of the Fowlers Gap Formation
- Alberta Conglomerate (base of the Teamsters Creek Sub-Group)
- Wammerra Formation (base of the Euriowie Sub-Group)
- Willyama Complex including Corona Dolomite
- Fault planes

CROSS SECTION

Looking Northwest



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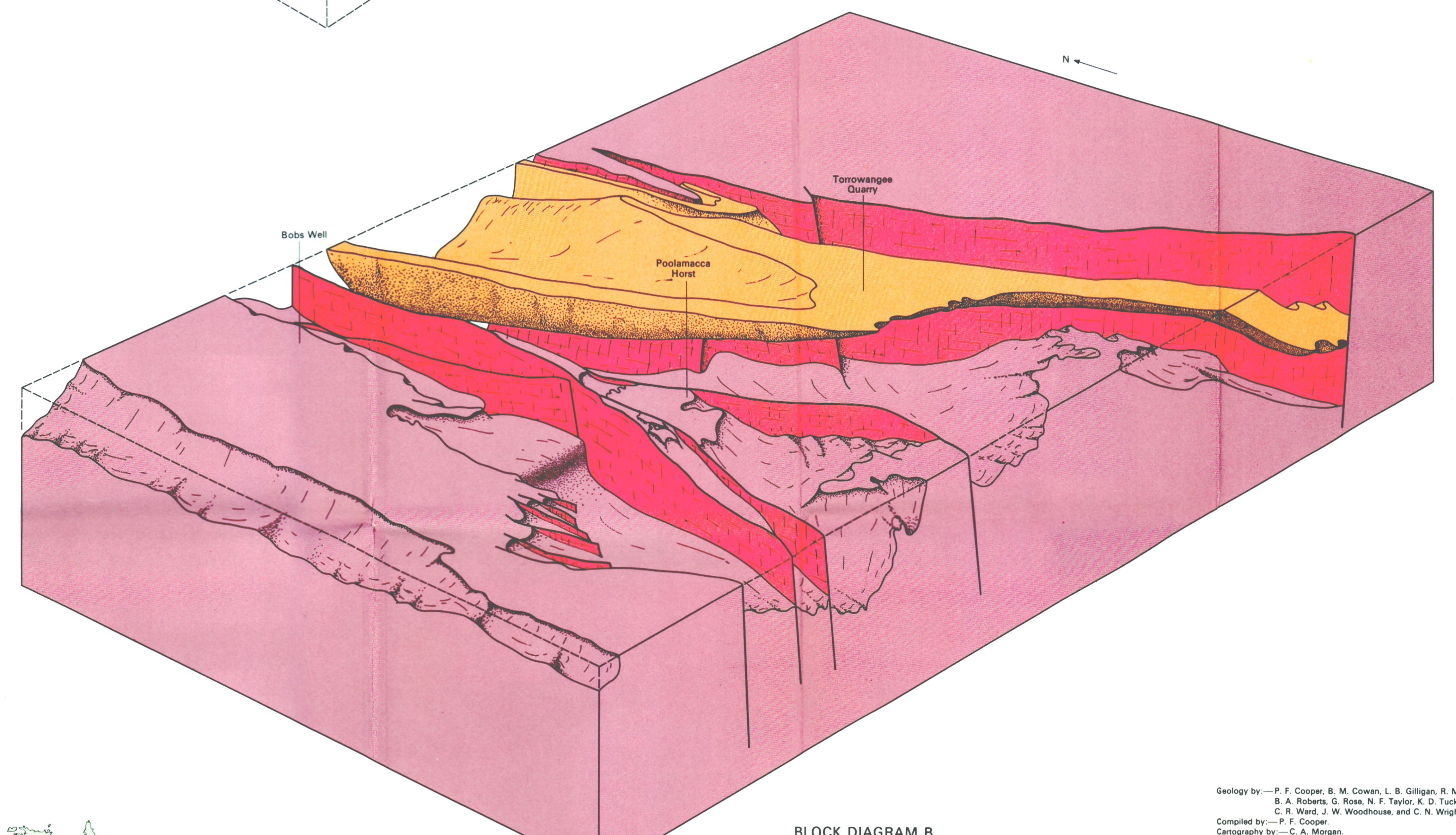

BLOCK DIAGRAM B

Looking northeast from GR340150
on the Torrowangee sheet
Scale: diagrammatic
(Modified after K. D. Tuckwell 1968)

Copies of this map may be obtained from the Geological Survey of New South Wales, Department of Mines, Sydney.

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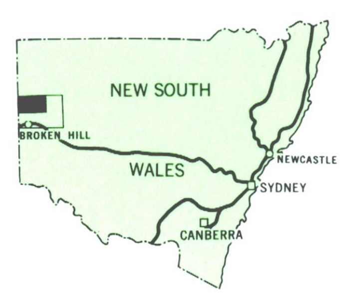
South New South Wales Australia Wales



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THE HON. WAL FIFE M.L.A.

Geology by:— P. F. Cooper, B. M. Cowan, L. B. Gilligan, R. M. D. Meares, B. A. Roberts, G. Rose, N. F. Taylor, K. D. Tuckwell, C. R. Ward, J. W. Woodhouse, and C. N. Wright-Smith.
Compiled by:— P. F. Cooper.
Cartography by:— C. A. Morgan.
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SHEET 2 OF 2

TORROWANGEE 7135 FOWLERS GAP 7235

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AUSTRALIA 1:100,000

TORROWANGEE–FOWLERS GAP

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SHEET 1 OF 2

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MINES

1	Anaconda	Cu	17	Mt Bunchikana	Sn
2		Cu	18	Caloola King	Sn
3	Kantappa	Sn	19	Rio Tinto	Sn
4	Horrie Hores gold mine	Au	20	Toogooroo	Sn
5	Triumph	Sn	21	Caloola	Sn
6	Euriowie Central	Sn	22	Caloola North	Sn
7	Lady Don	Sn	23	Adelaide	Sn
8	Ormond	Sn	24	Cosmopolitan	Sn
9	Sceptre	Sn	25	The Thistle	Sn
10	Trident	Sn	26	The Ruby	Sn
11	Cobar	Sn	27	Huel Bijerkerno	Sn
12	Mount Euriowie	Sn	28	Jubilee	Sn
13	Queen Victoria	Sn	29	Torrowangee Quarry	Limestone
14	Tincroft	Sn	30	,, ,,	,,
15	Victoria No 2	Sn	31	,, ,,	,,
16	Poolamacca	Sn	32	,, ,,	,,
			33	,, ,,	,,
			34		Cu

GEOLOGICAL SYMBOLS USED

Geological boundary, position definite
Geological boundary, position approximate
Fault position, definite
Fault position, approximate
Syncline (with plunge)
Anticline (with plunge)
Dyke
Measured section
Shear zone
Mine •26

WILLYAMA COMPLEX

Low-grade Rocks
Bedding, overturned
Cleavage

High-grade Rocks
Lithological layering
Schistosity
Crenulation schistosity

ADELAIDEAN
Bedding
Cleavage

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Australia		Wales	
MULYUNGARIE 7034	BROKEN HILL 7134	TALTINGAN 7234	TOPAR 7334

SCALE 1:100,000

2 1 0 2 4 6 8 10 12 Kilometres

CONTOUR INTERVAL 80 m

UNIVERSAL TRANSVERSE MERCATOR PROJECTION

BLACK NUMBERED GRID LINES ARE 1000 METRE INTERVALS OF THE AUSTRALIAN MAP GRID ZONE 54
GRID VALUES ARE SHOWN IN FULL ONLY AT THE SOUTHWEST CORNER OF THE MAP
MAGNETIC DECLINATION IS ABOUT 08° AT THE CENTRE OF THE MAP
MEAN ANNUAL CHANGE IS 02' EASTERLY

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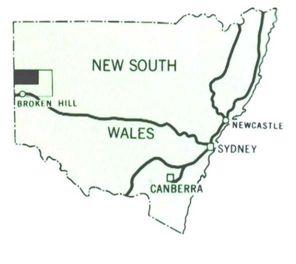

TOPOGRAPHICAL AND CULTURAL FEATURES

Secondary road, loose surface, dry weather
Minor road, unimproved earth
Vehicular track
Railway, single track (abandoned)
Building or homestead buildings
Trigonometrical station
Emergency landing ground
River or stream
Dam or tank
Bore, with windmill
Contour, value in metres

Geology by:— P. F. Cooper, B. M. Cowan, L. B. Gilligan, R. M. D. Meares, B. A. Roberts, G. Rose, N. F. Taylor, K. D. Tuckwell, C. R. Ward, J. W. Woodhouse, and C. N. Wright-Smith.
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