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THE UNIVERSITY OF ADELAIDE

THE STRATIGRAPHY AND FACIES OF THE LATE PRECAMBRIAN LOWER GLACIAL SEQUENCE, MOUNT PAINTER, SOUTH AUSTRALIA

by

A.P. BELPERIO

1973

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This thesis is submitted as partial fulfilment of the course requirements of the Honours Degree of Bachelor of Science in Geology at the University of Adelaide, 1973.

ABSTRACT

The sediments described in this thesis represent a total of some 4,400 metres thickness which display evidence of varying degrees of glacial activity. They are of the Yudnamutana Sub-Group and the basal member of the Farina Sub-Group. They record the onset and subsequent retreat of the Sturtian glacial period, one of two glacial periods to affect Australia during the Late Precambrian. The geological formations have been subdivided into various sedimentological facies, most of which are probably not sufficiently continuous to be mappable units over very great distances, but which are critical to the correct interpretation of the climatic and sedimentological history of the region.

ACKNOWLEDGMENTS

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CONTENTS

	Page
Abstract	(i)
Acknowledgments	(ii)
Introduction	1
Descriptive and Interpretative Stratigraphy	2
General	2
Fitton Formation	2
Bolla Bollana Formation	4
Lyndhurst Formation	9
The basal Tapley Hill Formation	10
Other possible stratigraphic relationships	15
Overall Interpretation	17
Relation to the World-Wide Late Precambrian Glacials	18
Conclusion	20
Bibliography	21

Appendices:

I	Structure, metamorphism and metasomatic alteration	A1
II	Detailed section descriptions	A3
III	Thin section and binocular rock examinations	A9

List of Figures and Plates:

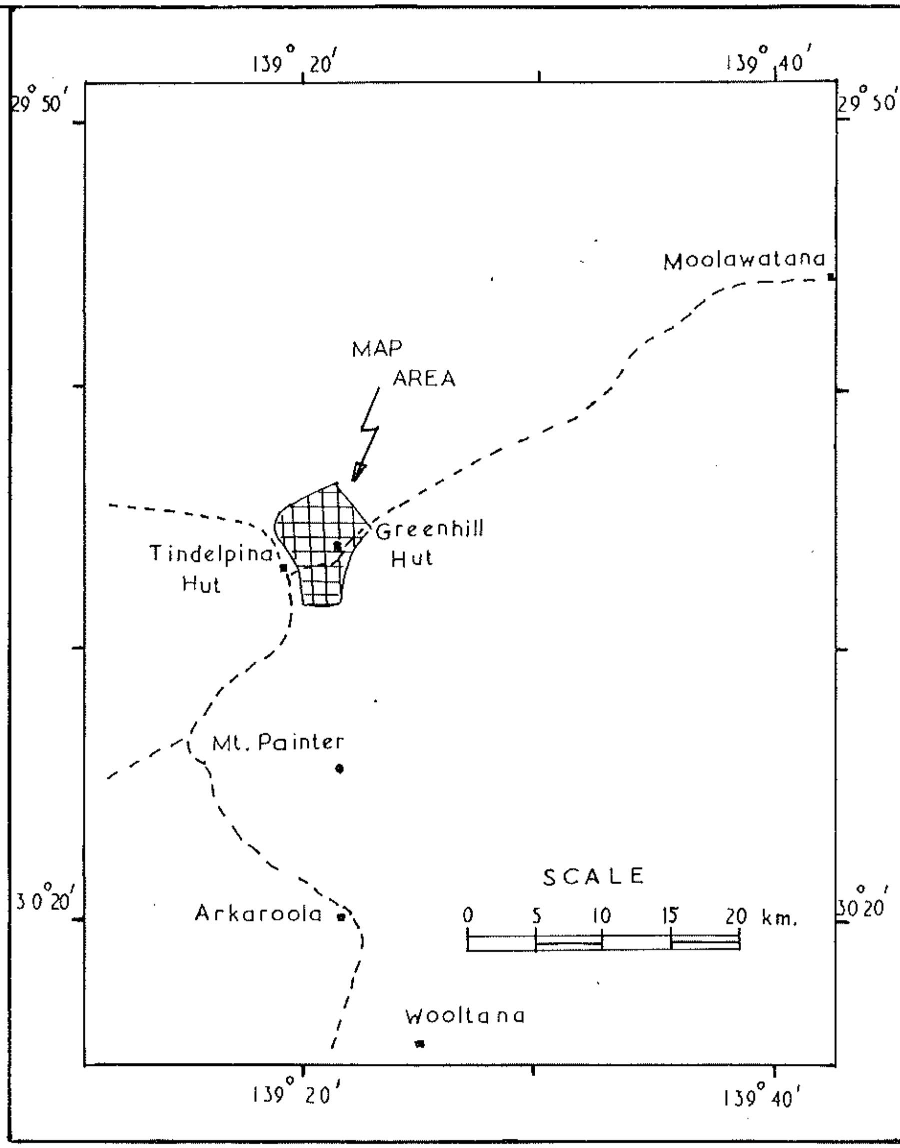
Figure 1 : Locality Sketch
Figure 2 : Regional Geology
Figure 3 : General geology of the map area
Figure 4 : Stratigraphic column
Figure 5 : Interpretative cross section of Serle Conglomerate Member
Figure 6 : Structural map.
Figure 7 : Section 2
Figure 8 : Sections 1 and 3
Figure 9 : Latest age interval limits of Precambrian glaciogenic rocks
Figure 10 : Main geological and lithofacies map (in pocket)
Plates 1 and 2 : Selected Photographs.

INTRODUCTION

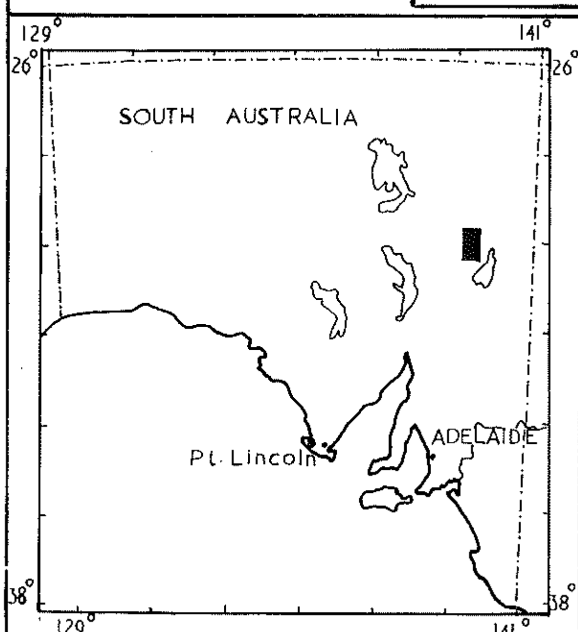
The area mapped lies in the northern-most extension of the Flinders Ranges, about 15 kilometres immediately north of Mount Painter, and is approximately 30 square kilometres. (See locality sketch, Figure 1.) Outcrop in the area is excellent for reliable mapping. The detailed mapping of lithofacies would not have been possible without the good outcrop and the high quality aerial photographs provided by North Flinders Mines N.L. Topography is rugged with steep drainage gradients, actively degrading streams and youthful valleys. The climate is semi-arid and vegetation is stunted and sparse. Rainfall is erratic and averages 230 millimetres per annum. The streams are ephemeral, the major drainage component being the MacDonell Creek which flows northwards. A few semi-permanent waterholes exist in the map area. A good account of the geomorphology and vegetation of the region is given by Twidale and Ruchel (in Corbett (Edit), 1969).

The geological setting of the map area is part of the sedimentary succession of the Adelaide Geosyncline in which more than 15,000 metres thickness of sediment was deposited under relatively shallow water, intra-cratonic basin conditions in Proterozoic times. The map area has been previously covered by R.P. Coats of the South Australia Department of Mines (Coats and Blissett, 1971) as part of the regional mapping of the Mount Painter Province. The lower glacial sequence (Campana and Wilson, 1955) was formerly defined by Coats (1964) as the Yudnamutana Sub-Group in the Mount Painter area where it reaches its greatest known thickness of approximately 5,500 metres. According to Coats, evidence for the glacial origin of the unit is provided by the occurrence of facetted and striated exotic boulders and its large areal extent. An assumed glacial pavement at the base of the unit near Wooltana, reported by Mirams (1964), has now been reappraised as being of tectonic rather than sedimentary origin (Daily et.al., 1973).

The formation names used by Coats (1971) have been retained for use in this thesis although some changes in their boundaries have been made. The regional geology is summarized in Figure 2.



GEOGRAPHIC SKETCH
MOUNT PAINTER PROVINCE



LOCALITY SKETCH
MOUNT PAINTER PROVINCE

FIGURE I.

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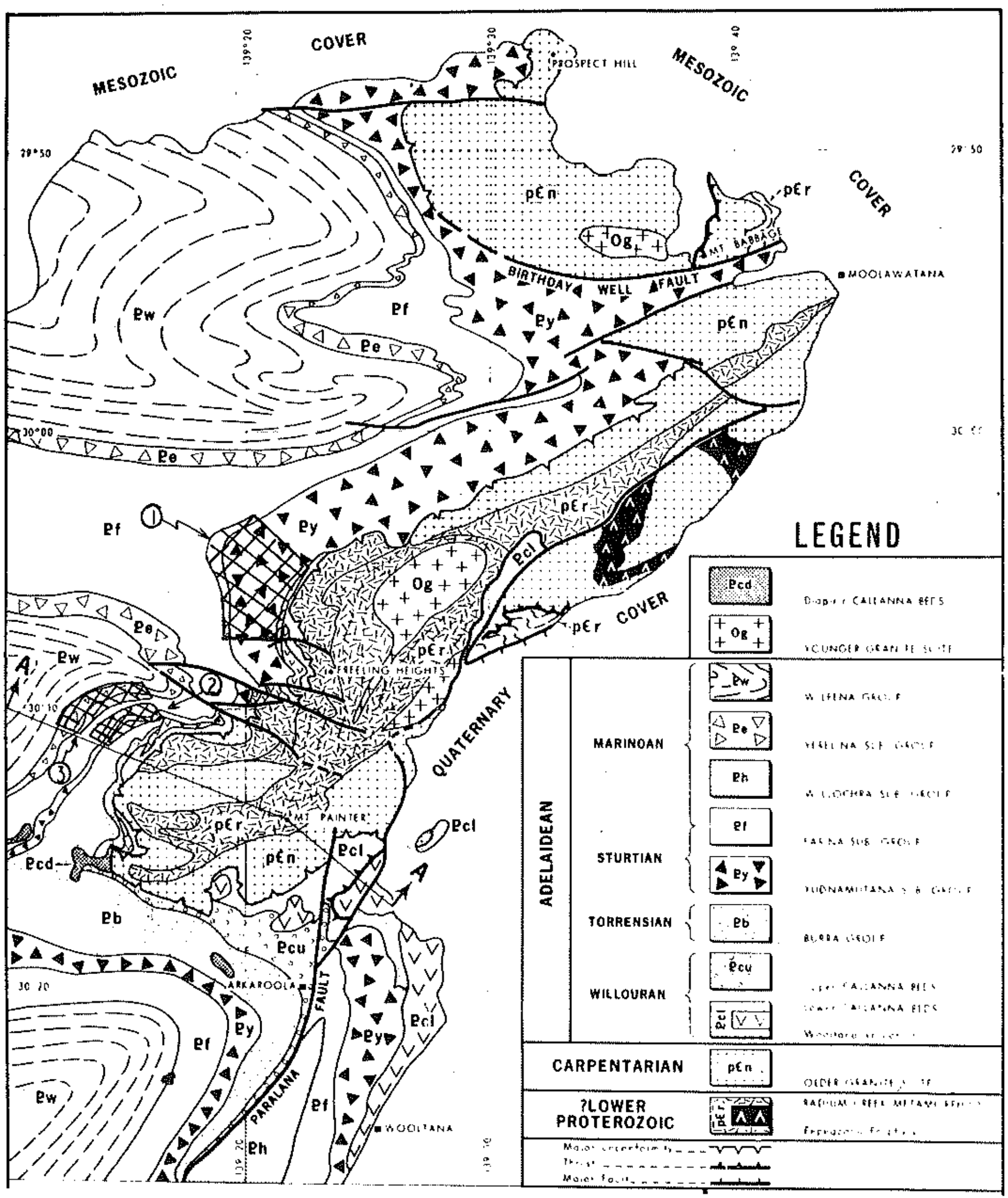

REGIONAL GEOLOGY OF THE
MOUNT PAINTER PROVINCE

MAP AREAS

1. Author
2. S. Ashton
3. G. Ambrose

FIGURE 2.

A. Belperio 1973 : After R.P. Coats 1968

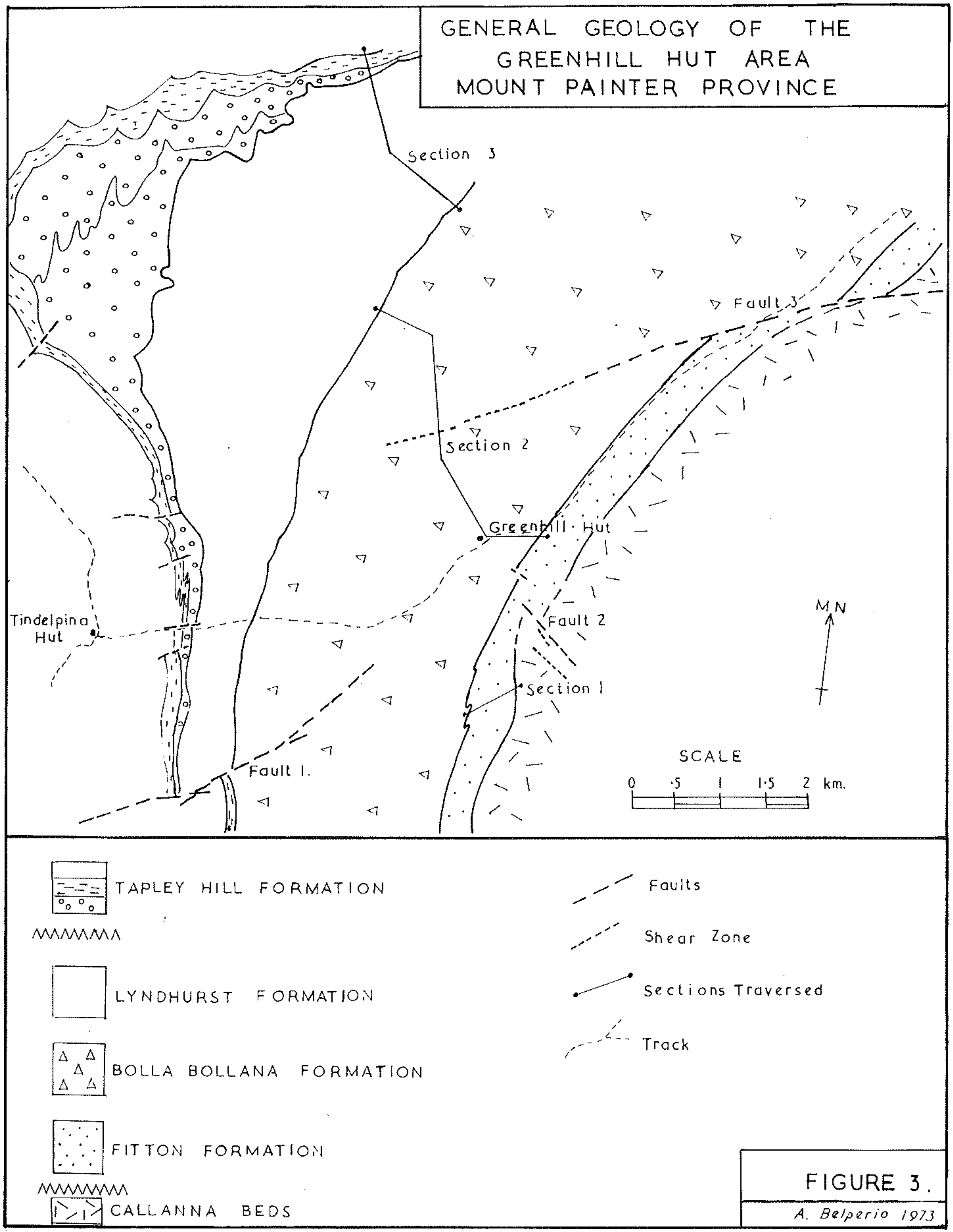

FIGURE 3.

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STRATIGRAPHIC COLUMN

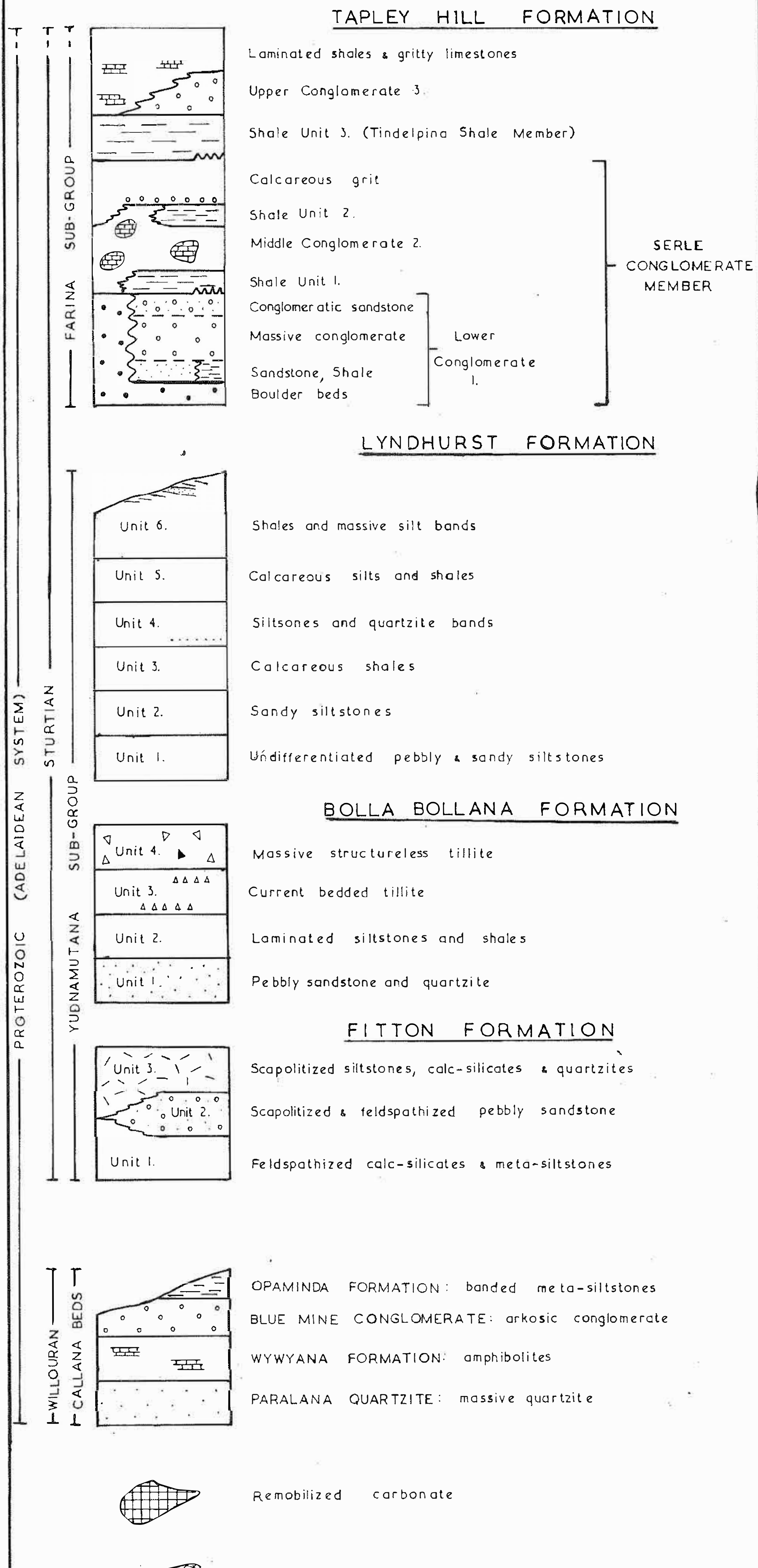

FIGURE 4

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DESCRIPTIVE AND INTERPRETATIVE STRATIGRAPHY

General

The Yudnamutana Sub-Group rests unconformably on Upper and Lower Callana Bed meta-sediments. To the north of Greenhill Mine they comprise the Paralana Quartzite and Wywyana Formation and to the south the Blue Mine Conglomerate and Opaminda Formation. (Figure 10.) The entire Burra Group is absent and the lower glacials overlap the Callana Beds from the north so that only the upper-most part of Fitton Formation is represented in the map area. The great thickness of the lower glacials in this area is due to the deposition of the sediments in a local sub-basin between Daly Mine and Union Trig (Coats, 1971), formed by complex faulting in the early Sturtian.

Fitton Formation

The upper part of this formation outcrops in the map area and consists predominantly of calc-silicate meta-sediments and scapolitized silts with a recurrence of massive quartzites and pebbly litharenites. Its maximum thickness is 430 metres, just south of Greenhill Mine (Figure 3, Section 1), where facies mapping indicates a local erosional depression. It is equivalent to the upper-most Unit 5 of Coats (1971). Sedimentary structures are almost totally obscured by medium and low grade metamorphism, the grade of metamorphism decreasing rapidly to the west. Apparent glacial conditions can only be recognized towards the upper-most part of the sequence, where presumably ice-rafted erratics, up to 60 centimetres in diameter, sit in relatively even grained calcareous silts. The pebbles are predominantly quartzite but dolomite, quartz-feldspar, shale and strained metamorphic quartz are also present.

Three distinctive units can be recognized based generally on present metamorphic characteristics but thought to reflect original compositional differences. The lower unit consists predominantly of feldspathized amphibolites, often pebbly, with minor occurrences of kaolinitic and cherty laminated siltstones. Lenses of quartzites and pebbly litharenites recur occasionally. A predominance of water-laid pebbly litharenite beds over a stratigraphic thickness of between 70 and 160 metres was used to define Unit 2. The lenticular beds are feldspathized in the vicinity of Fault 2 but become scapolitized further to the north and south (Fig. 6). The occurrence of the pebbly beds decreases northwards and they become insignificant north of Fault 3. Quartzite boulders up to 60 centimetres in diameter occur in these beds. Unit 3 consists predominantly of scapolitized siltstones, often calcareous and micaceous and pebbly in places. Numerous thin, well sorted and equigranular quartzite lenses and polymictic boulder beds occur through the sequence, the number and size of the boulders increasing towards the top of the sequence. The quartzites lens out into the silts and are occasionally slightly scapolitized and feldspathized. Strong current bedding and crossbedding can be observed in places. The thickness of this unit varies from 100 to 220 metres because of large scale intertonguing with the Bolla Bollana Formation south of Greenhill Hut.

The transgressive nature of the Fitton Formation is indicated by the presence of basal, well bedded, clean sands to the north (L39)* as well as by regional mapping (Figure 2). The thinning of Unit 2 northwards, the angularity of the matrix constituents and the predominance of quartzite pebbles indicate a local southerly provenance for the sediments. The poor sorting of the sediments implies little current activity, increasing though during the deposition of Unit 3. A predominance of the minerals scapolite, tremolite and actinolite and the occurrence of a clean, siderite rich marble lens (L5), exemplify the original highly calcareous nature of the sediments. Since the presence of dropped boulders indicates cold, floating ice conditions, the origin of the carbonate is most likely due to the mixing of cold, carbonate saturated waters with the warmer waters of the protected shelf onto which they transgressed from the north. It is also likely that the same cold currents which brought in the floating ice were

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* References prefixed by the letter L refer to localities marked on Figure 10.

responsible for precipitating the carbonate. The minor occurrence of dropped clasts, their relatively small size, roundness and lack of exotics suggests that the glacial conditions prevailing at this time were due to seasonal formation of shore ice and that glacial transport played only a minimal role. Strictly speaking, the Fitton Formation sediments should not be referred to as tillites since this is a genetic term implying deposition mainly by ice with little transportation by water.

Bolla Bollana Formation

The calcareous Fitton Formation meta-sediments pass conformably upwards into the relatively unaltered and poorly sorted arenaceous sediments of the Bolla Bollana Formation. The sudden change in lithologies is accompanied by an equally dramatic decrease in the amount of scapolitization across the contact. Because of this, the contact, the minor interfingerings and the larger scale intertonguings between the two formations can be followed quite reliably. The formation was subdivided into four facies by textural observations of the rock types. Four basic arenaceous rock types are present, namely;

(1) Pebbly sandstones and quartzites. (predominantly sandy matrix.)
(2) Silts and shales.
(3) Current bedded pebbly siltstones. (predominantly silty matrix.)
(4) Massive pebbly mudstones. (predominantly muddy matrix.)

Furthermore, each rock type has a distinctive outcrop pattern. The rock types are not mutually exclusive and all four types occur throughout the formation, therefore a predominance of any one rock type over the others was used as the basis for facies subdivision, namely Units 1, 2, 3 and 4 respectively. Subsequent binocular microscope examination of field samples has confirmed the basic differences in matrix types between Units 1, 3 and 4, even though lithologically they can all be classed as sub-litharenites. (Appendix III)

The top of the Bolla Bollana Formation is regarded by Coats (1971) as the first occurrence of blue shales of the overlying Lyndhurst Formation. Consequently, he places this boundary at the base of Unit 2B

(Figure 10). However, mapping of facies by the above criteria shows definitely that Units 2B and 3A are characteristic of the Bolla Bollana Formation and not of the Lyndhurst Formation. The base of the Lyndhurst Formation has therefore been placed at the top of Unit 3A, 160 metres stratigraphically higher than that mapped by Coats.

The four subdivisions recognized are very similar to the descriptive terms used by Mawson (1949) in describing the detailed stratigraphy of the Bolla Bollana Formation at Mount Jacob and Mount Warren Hastings, about 30 kilometres to the south. Mawson illustrated the interbedding of "true tillites" with "glaciofluvial sands and siltstones." The general resemblance between the sections described by Mawson and the facies mapped, despite the difference in thickness are;

(i) The lower one-third of the successions described by Mawson consist of "glaciofluvial sandstones, siltstones and sandy tillite" with only thin bands of "typical tillite." This is similar to the basal Units 1 and 2 of the map area.

(ii) The second one-third of the sections described consists of intercalations of "typical tillite, sandy tillite and mud base tillites." In the map area, the middle part of the formation is characterized by complex intertonguing between facies types.

(iii) The upper one-third of the sections described by Mawson consists of continuous, massive "typical tillite." In the map area, massive tillite (Unit 4) is restricted to the upper half of the formation.

The general similarities between the successions of the two areas suggests that, despite the complex intertonguing relations between them, these four facies types could be used for regional facies mapping. Quartzite is by far the most predominant megaclast, often exceeding 80% of the pebble count. In the lower half of the formation, the other 20% are often metamorphic rock types, namely quartz-muscovite and quartz-feldspar boulders and minor granite boulders. In the upper half, angular shale fragments account for 10% to 20% of the clasts as well as minor dolomite and quartz-biotite gneiss boulders. Other minor clast types are Blue Mine Conglomerate and amphibolite boulders. A red weathering, fine grained quartz porphyry pebble similar to that described by Mawson (1949) was seen at the top of the formation.

Unit 1: This basal facies was mapped by the predominance of poorly sorted pebbly sandstones (413-23)* with minor interbeds of bedded pebbly siltstones and laminated siltstones. The largest ice-dropped clast seen was a one metre quartz-muscovite boulder but the average pebble size associated with the current bedded, sandy, gritty matrix was less than 10 cms. This unit shows a concentration of large boulders in the basal 20 metres throughout the map area, which is more poorly sorted and approximates Unit 3 in composition and texture. This facies recurs higher in the sequence where it is generally more quartzitic and less continuous than at the base of the formation.

Unit 2: The basal unit is overlain by a sequence of interbedded, well laminated shales and sandy, micaceous silts (413-42), with a minor occurrence of thin pebbly lenses (413-35) and silty arenites. The siltstones are well bedded, show crossbedding and are occasionally ripple marked. This facies also recurs higher in the sequence as discrete lenses in the more massive deposits and as a continuous thin blanket of sediment towards the top of the Bolla Bollana Formation (Unit 2B).

Unit 3: This facies is characterized by current bedded, silty matrixed, blue-grey sublitharenites (413-40). The maximum clast size observed was a 90 cm. quartzite boulder and the average pebble size was one to two centimetres. Minor interbeds of calcareous shale and thick interbeds of massive, structureless, pebbly mudstones with an average pebble size of 10 to 15 cms. also occur.

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* References prefixed by 413- or TS.413- refer to hand specimen and thin section material described in Appendix III.

Unit 4: This facies is similar in composition to Unit 3 except that it has a higher mud content in the matrix. The matrix is dark and pyritic (413-50), in places containing up to 5% disseminated pyrite, and is often calcareous. Outcrop is massive with only poor stratification and minor current bedding. The clasts are much greater in number and size, the average pebble size is 8 to 30 cms. and the maximum erratic seen being a 125 cm. quartzite boulder. This facies forms complex intertonguing relations with the other rock types throughout most of the map area but is absent south of Fault 1.

The massive pebbly mudstones of the Unit 4 facies are undoubtedly primary subglacial deposits. The total range of particle size and angularities, the presence of rock flour, the freshness of the shale and schist fragments (TS.413-47), the lack of internal structure, the size of the erratics and the lateral thickness variations all indicate that this is a true glacio-marine deposit which has undergone very little current reworking. The wet based glacier model of Reading and Walker (1966) adequately explains the features of this facies. The period of ice cover was probably fairly continuous and extensive and may have allowed stagnating sub-glacial conditions to precipitate pyrite. Unit 3 is also primarily a glaciogenic sequence except that here the ice cover must have undergone periods of advance and retreat, sufficient to enable currents to rework the sub-glacial deposits, resulting in current bedding and a poor degree of sorting. The degree of current sorting and reworking must have been much greater for the sandy Unit 1 facies, so much so that this should now be classed as a secondary glacio-marine sequence. This type of sedimentation is adequately explained by the existence of an incomplete ice-shelf cover. The texture and lithology of the silts and the minor distribution of erratics in the Unit 2 facies implies that this is a normal, immature, shallow marine facies with a secondary, minor contribution of sediment from either intermittent sea ice, ice-floes or drifting icebergs. Facetted, striated and flat-iron shaped boulders are not common. Where present the facetting is not well enough developed to be considered diagnostic of ice transportation. However the author does not consider facetting and striations to be necessarily developed at all in the ice-shelf environment. From the facies mapping it is evident that Fault 1 must have been active at least by the end of the deposition of the main phase of Unit 3. Unit 4 is absent south of the fault and the facies present indicate there was much current activity and relatively little glacial influence. The thick occurrence of the silts and shales of Unit 2 at the top of the formation south of the fault has, however, a greater number of intra-stratified pebbly mudstone beds than elsewhere. Geochemical measurements by S. Ashton show that the Rb/Sr ratio of these silts plot within the Bolla Bollana field so they are not the equivalents of the Lyndhurst Formation silts and shales which they somewhat resemble. The southern block was apparently uplifted allowing only minor formation of ice.

Sedimentological evidence from the Fitton Formation and the Lyndhurst Formation (see later) points to a local southerly source for the detrital component* of the sediments. The obvious source is the stripped Burra Group and Callana Bed sediments associated with contemperaneous block faulting of the Mount Saturday radial fault complex and the Paralana Fault. Furthermore, the absence of detrital feldspar in the samples examined from the Bolla Bollana Formation must refute the idea that the Mount Painter Complex was a source of sediment at this time. The fact that the "true tillite" facies of Unit 4 thickens northward towards the deeper part of the sub-basin casts doubt on the theory of a massive continental glaciation similar to that now covering Antarctica. Such a glaciation would deposit a consistent, massive blanket of glaciogenic sediments irrespective of topographic variations. The lateral variations of the sediments in the map area are much more suggestive of a massive, ice-shelf type glaciation which can be affected by small topographic variations, water depth and current activity.

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* In contrast to the ice-transported component.

Lyndhurst Formation

This formation is predominantly an argillaceous sequence of alternating laminated siltstones and shales, calcareous and non-calcareous, with a recurrence of glacial drop-boulders and reworked tillite bands which decrease in number and thickness towards the top of the sequence. Quartzite and gneissic boulders predominate through much of the sequence but dolomite, porphyry and granite clasts begin to appear towards the top. The predominant detrital rock fragments are quartzite and shale. The sediments become finer grained, better sorted and laminated, firstly towards the top of the sequence, changing from sandy siltstones at the base to well laminated shales at the top, and northwards away from Fault 1. This is clearly seen from the facies mapped.

Unit 1 is an area of exceptionally pebbly and sandy siltstone beds (413-69), decreasing in pebble content westward and northward and with only minor shale interbeds towards the top. This reflects, a second phase of movement of Fault 1, resulting in further uplift of the southern block and no deposition on this side. There was also only a little erosion because no coarse conglomerates are present. Unit 2 represents the sudden but gradational change from the glaciogenic sub-litharenites of the Bolla Bollana Formation to the quieter water, limited glacial conditions of the Lyndhurst sediments. Sedimentation was continuous except at locality L40 where a minor unconformity is evident. This unit is a sequence of massive sandy silts with interbeds of well laminated blue shale and current reworked, pebbly tillite lenses up to 3 metres thick. The tillite lenses consist predominantly of quartzite clasts up to 60 cms. in diameter and decrease in number and thickness towards the top of the sequence. They show current bedding and slumping and a variety of rock types from quartzite to gneiss and granite gneiss. Ice dropped boulders up to 2 metres in diameter recur throughout this unit. The shale interbeds increase northwards. They are virtually absent in the south but make up 50% of the unit in the northern-most part of the map area. The siltstones also become better laminated northwards.

This same situation is reflected in the deposition of the next two units. The calcareous shales of Unit 3 were deposited to the north while the massive but well bedded slightly calcareous silts of Unit 4 predominated in the south. Quieter water conditions are evidenced by the predominance of shales in Units 5 and 6, although glacial dropstones and sand and silt interbeds still recur through the sequence. A limited amount of quiet, varve-like sedimentation also occurred (413-72) and some sandy carbonate lenses are also present. The coarse, sandy beds show ripple marks, cross bedding, heavy mineral banding and other evidence of strong current activity. Lenticular, medium grained and well sorted quartzites are numerous, especially in Unit 4. The lensing out of these beds implies that the depositional floor was not deep enough for blanket sedimentation and an interplay of currents was involved.

A large regional unconformity with the overlying Tapley Hill Formation is evident from the mapped beds in the north. Here the contact shows scouring and channelling (Plate 1, P2). At locality L41, however, sedimentation was paraconformable and apparently continuous since the boulder beds of the Serle Conglomerate Member contain a large number of angular fragments of blue shale from the directly underlying Lyndhurst Formation.

<u>The basal Tapley Hill Formation</u>

The Serle Conglomerate Member was defined by Coats (1971) in its thickest occurrence in the area mapped as the basal member of the Tapley Hill Formation, which, he considered, reflected the prolonged period of erosion at the end of the glaciation that deposited the Yudnamutana Sub-Group. In the extreme northern-most and southern-most occurrences mapped, this member outcrops as a distinctive, relatively thin (50 metres) boulder bed consisting principally of a chaotic mixture of well laminated dark shales, interbedded sands and conglomerates, and huge quartzite, dolomite and birdseye limestone erratics up to 2 metres in diameter. In between, over most of the map area, the equivalent sediments were found to be a highly complex interfingering of two directly opposing rock types, namely massive conglomerates and very well laminated, fine carbonaceous shales. There are no less than three distinct conglomerate units, a calcareous grit unit and three distinct shale units. (Including the Tindelpina Shale Member.)) The relationship between these is shown in Figure 4 and schematically in Figure 5.

The Lower Conglomerate (1) was divided into three facies; a thin, basal, kaolinized sandstone unit, a main, massive, water-laid conglomerate and an upper thin, conglomeratic sandstone. All three units thicken northwards. The principle boulder types are well rounded, quartzite, dolomite, quartz porphyry and shale with occasional boulders of arkose, sandstone, muscovite schist, granite gneiss and feldspar porphyry. The matrix is almost exclusively a very poorly sorted sand but is occasionally dolomite based. This is in marked contrast to the Middle Conglomerate (2) which is highly calcareous, very often dolomite based and containing large numbers and sizes of angular dolomite boulders. A good comparison occurs along the creek at locality L31. Here the Lower Conglomerate contains about 50% well rounded quartzite and 10% to 20% well rounded porphyry boulders. The Middle Conglomerate, bounded above and below by Shale Units 2 and 1 respectively, contains in parts up to 50% angular dolomite boulders and in parts up to 50% angular shale fragments. The Upper Conglomerate (3) is limited in outcrop but also contains very large angular blocks of birdseye limestone, often pebbly and up to 3 metres in width, concentrated in reworked carbonate conglomerate horizons in what is predominantly a massive water-laid conglomerate. The Calcareous Grit unit is stratigraphically part of the Middle Conglomerate. At locality L32 it is a 10 metre thick, distinctively outcropping, highly calcareous, coarse sandstone. It changes variously along strike into calcareous conglomerate, with up to 50% of the immediately underlying Shale Unit 2, into sandy limestone and bedded dolomite. When followed to the east and the west, it intertongues with the Middle Conglomerate after the Shale Unit 2 lenses out. It thickens to the west, though this appears partly exaggerated due to topographic effects, and then rapidly thins out to locality L42 where it directly overlies the Lower Conglomerate and is unconformably overlain by Shale Unit 3.

The Shale Units 1 and 2 are lenses of very well laminated calcareous and carbonaceous shales within the Middle Conglomerate. At locality L43, these two units are in contact with each other due to large scale interfingering with the Middle Conglomerate. East of Locality L31, the Shale Unit 1 unconformably overlies the Lower Conglomerate, but to the west an interfingering and gradational contact is evident. (Plate 1, P1.) This shale is characterized by increased interbedding upwards with carbonate conglomerate beds until it is overlain by carbonate rich Middle Conglomerate. It also contains numerous thin (10 cms.), discontinuous, pebbly lenses, the base of which show penetration and contortion of the underlying laminated shales by the larger pebble constituents. This could only be interpreted as slumped glacial debris from floating ice (Plate 2, P1.) Shale Unit 3 (Tindelpina Shale Member of Coats (1971).) is also a well laminated, fine, calcareous shale with minor sandy limestone bands. It has been argued by Coats (1971) that the Tindelpina Shale Member forms a very distinctive marker bed at the base of the Tapley Hill Formation throughout the Adelaide Geosyncline. This is not true in the area mapped, for here the Shale Unit 3 is, in parts, not exceptionally different to the overlying continuous sequence of shales, especially where it is not an interbed in the conglomerates. However it is only in the northern-most and southern-most occurrence that this difficulty arises, and in these cases the top of the Tindelpina Shale Member is taken as just below the first major occurrence of sandy limestone lenses in the shales. Shale Unit 1 shows a much greater lithological resemblance to the description of the Tindelpina Shale Member given by Thomson (1969). South of Tindelpina Hut, Shale Unit 3 becomes less carbonaceous, less well laminated and more calcareous and appears transitional with the underlying boulder beds. At two other localities (L42 and L30), local unconformities are evident beneath the shales.

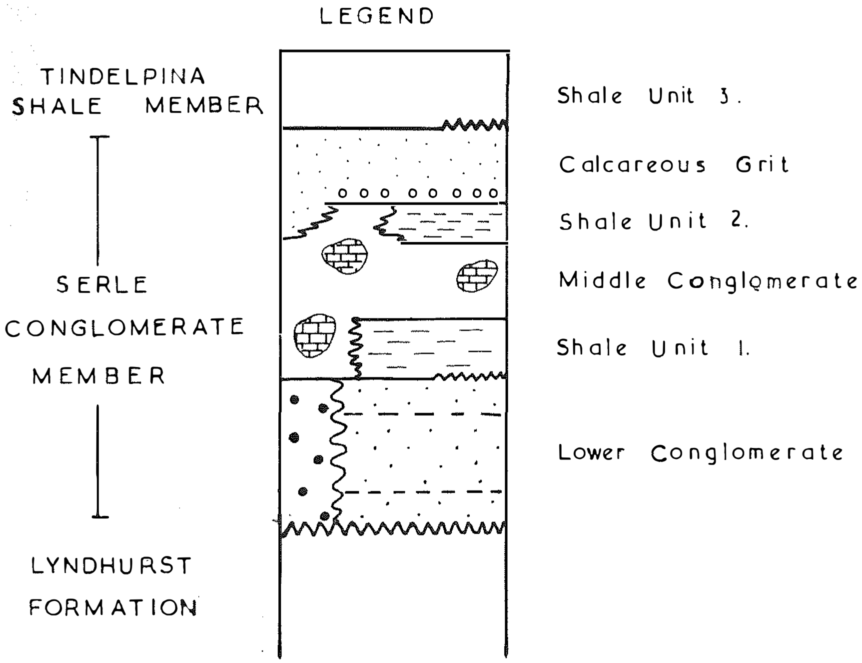
The thickening of the Serle Conglomerate Member from 50 to 480 metres in the nose of the anticline is due to the culmination of clastic deposition from two sources into a local erosional depression. The fact that the maximum thickness of these sediments corresponds with the zone of maximum thickness of the Lyndhurst Formation implies that this was also an area of greater relative subsidence. Facies mapping clearly shows that the sediments of the Lower Conglomerate were derived from the south and that these were overridden by the sediments of the Middle Conglomerate and the Calcareous Grit, brought in from an apparent northerly direction. This is shown diagrammatically in Figure 5. Since only a minor unconformity is present (east of L31.), the time interval between the deposition of these two successions must have been fairly small. The change in provenance direction from south to north also adequately explains the sudden change in lithologies and pebble suites between the Lower and Middle Conglomerates.

The dolomite and birdseye limestone boulders and shale fragments are invariably angular but the quartzite and porphyry boulders are mostly well rounded, these having been transported much further. The most widely accepted interpretation of a birdseye limestone is deposition in a near shore or supra-tidal environment. Another directional component for the sediments may be the east, where quite obviously a shore line must have existed over, or further east of, the present day outcropping Mount Painter Block. The porphyry and other exotics need not necessarily have come from the Gawler Ranges as argued by Coats (1971) because we have no idea what basement rock types may have been exposed to the east, even possibly over what is now the Frome Embayment, and between the Mount Painter and Willyama Blocks. The shape of the sediment body can be likened to the deposits of a coarse deltaic fan spreading out from the east, but the lithology and structure of the sediments does not support this.

Although the conglomerates show definite evidence of being laid under strong current activity, the fact that contemporaneous glacial activity existed is adequately supported by the following observations:

(1) The association of interfingering, finely laminated shales and

DIAGRAMATIC REPRESENTATION OF THE DEPOSITION OF THE SERLE CONGLOMERATE BETWEEN TINDELPINA HUT AND MACDONALD CREEK.



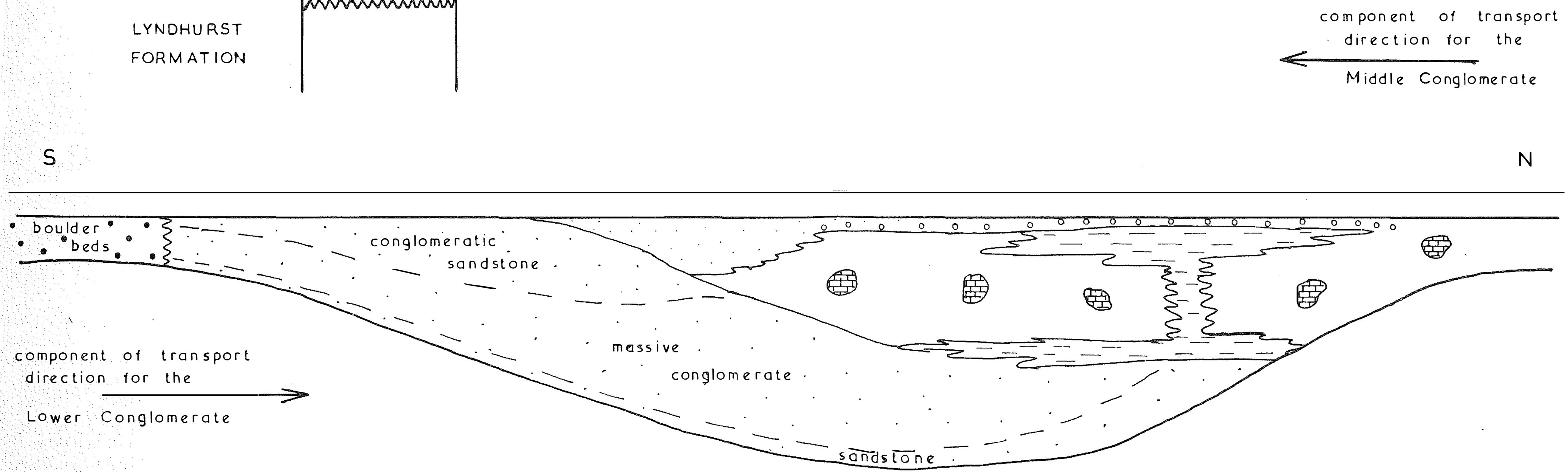


FIGURE 5.

A. Belperio 1973.

very coarse, massive conglomerates (Plate 1, Pl.) cannot have co-existed over such a large area without a physical barrier to separate the two opposing hydrodynamic systems. An advancing and retreating, protective ice-sheet cover adequately explains this.

(2) The boulder beds consist of a chaotic mixture of huge quartzite and dolomite boulders up to 2 metres in width, sitting in fine, blue shales (Plate 2, P4. and 413-7). Since submarine slumping and turbidity current models do not agree with the widely accepted theory of a shallow water environment for the Adelaide Geosyncline and the occurrence of birdseye limestone boulders, the only other plausible hypotheses are contemporaneous fault movement or ice rafting. If fault movement to the south was responsible, we would expect this to be reflected in the matrix type (i.e. not fine shales) and for such large clast sizes to decrease rapidly northwards. Neither of these was observed. However, this does not rule out the possibility that contemporaneous fault movement, postulated at this time by Coats (1971), provided the primary source of sediments, to be subsequently transported and deposited by ice and reworked by strong currents.

(3) As mentioned previously, Shale Unit 1 contains numerous thin, discontinuous pebbly lenses, the base of which show penetration and contortion of the underlying shales (Plate 2,Pl.) and interpreted as slumped supra-glacial material from floating ice

An elaborate interpretation of the Serle Conglomerate Member cannot be made because insufficient time was available to examine the fabric and internal structures of the conglomerates. In general, it appears that the conglomerates are a result of strong current reworking of a massive influx of partly glacially transported coarse detritus. Tectonic uplift at this time may have contributed by exposing unconsolidated Yudnamutana Sub-Group glacials, coastal limestone deposits and new areas of basement rocks, (the porphyries are distinctively associated with the Lower Conglomerate.) and the debris was preferentially shed down an elongate, westerly trending, shallow submarine valley. The fact that the reworked, coarse conglomerate beds occur in the centre of this depression while boulder beds with well laminated shales occur on the flanks is difficult to explain, except perhaps that the flanks were ice covered and protected, whilst at the same time bringing in material from the north and south and dumping it in the erosional depression.

Other possible stratigraphic relationships

By discussion with G. Ambrose and S. Ashton, other hypotheses were put forward and examined.

(1) The possibility that the Lower Conglomerate in the area mapped is the stratigraphic equivalent of the thin Bolla Bollana Formation across the faults in the map areas to the south. (Figure 2.) This is supported by the fact that;

(i) Both sequences contain distinctive quartz porphyry pebbles which are almost totally absent in the Bolla Bollana sediments of the author's map area.

(ii) The sequences are both related, in varying degrees, to glacial sedimentation.

(iii) The two sequences are both overlain by Tapley Hill Formation shales with gritty limestone beds.

This idea was rejected from the evidence available because;

(i) The porphyry pebbles in the Bolla Bollana Formation to the south are considered rare compared with 10% to 20% in the Lower Conglomerate of the map area.

(ii) The Bolla Bollana Formation to the south is a massive tillite, whereas the Serle Conglomerate Member, in the deeper part of the basin, is totally reworked and water-laid.

(iii) The Bolla Bollana Formations in the two areas show general lithological similarities. (S. Ashton, pers. comm.)

(iv) The Serle Conglomerate boulder beds are absent south of Fault 1.

(2) The possibility that Shale Unit 1 is the Tindelpina Shale Member and forms the base of the Tapley Hill Formation, with the Lower Conglomerate belonging to the Yudnamutana Sub-Group. The evidence for this was;

(i) The excellent lithological similarities of Shale Unit 1 to the description of the Tindelpina Shale, given by Thomson (1969).

(ii) An unconformity present at the base of this shale, east of locality L31.

(iii) Apparent continuous sedimentation between the Lyndhurst Formation shales and the Lower Conglomerate boulder beds at locality L41.

(iv) The great difference in pebble suites between the Lower and Middle Conglomerates and the opposing source areas, the source direction for the Lower Conglomerate being consistent with that of the Yudnamutana Sub-Group.

This idea was also rejected because;

(i) Shale Unit 1 also interfingers, in parts, with the Lower Conglomerate, and minor unconformities are wide-spread throughout the Serle Conglomerate Member.

(ii) The main unconformity occurs at the top of the Lyndhurst Formation and the existence of continuous sedimentation at L41 is not definite.

(iii) The difference in pebble suites and source areas can be easily related to other causes such as tectonics.

OVERALL INTERPRETATION

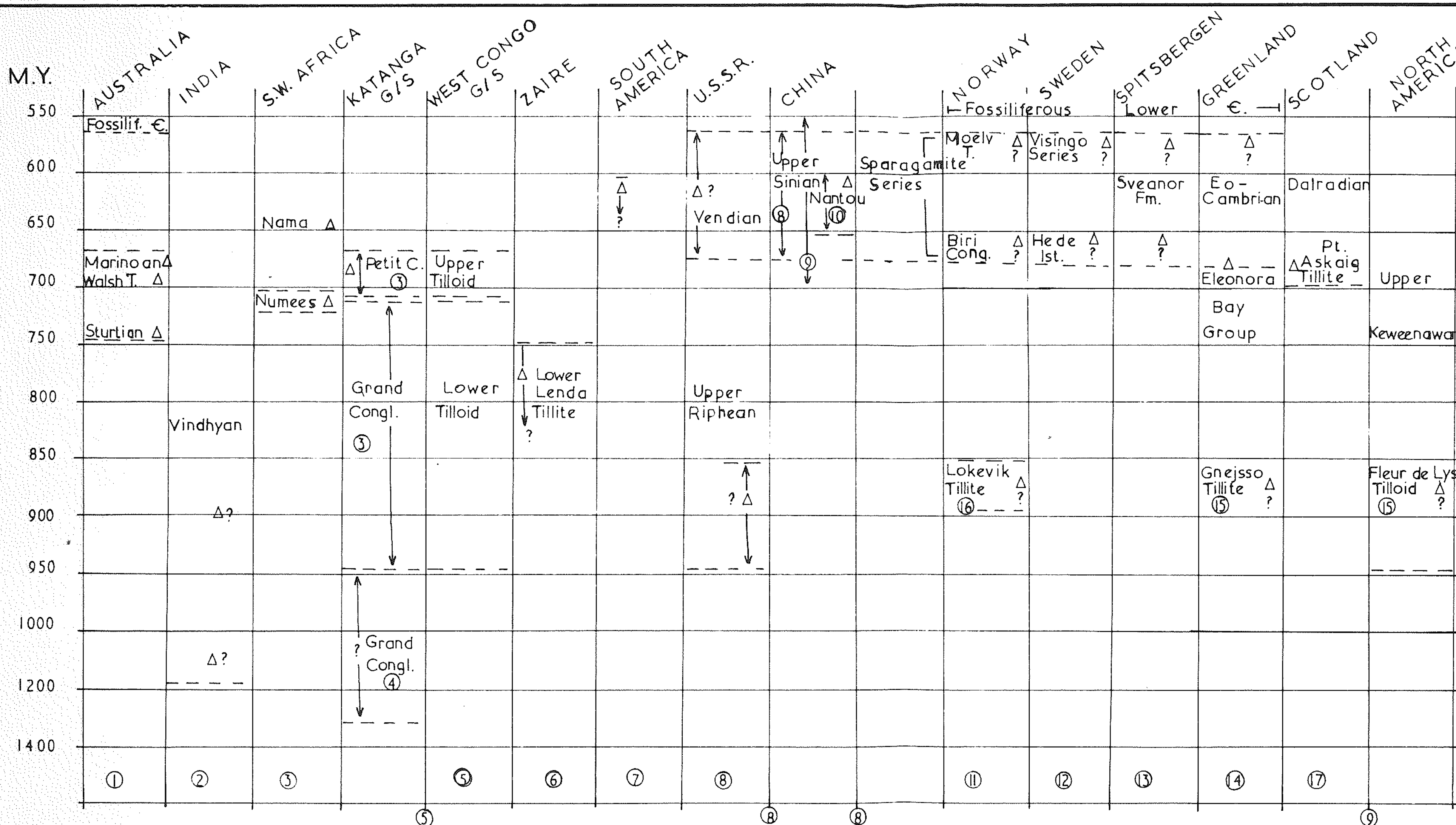
The Yudnamutana Sub-Group sediments quite clearly record the progressive onset and retreat of a major glacial event. This is much more indicative of a circumpolar continental glaciation, brought about by polar wandering or continental drift, than a sudden, "catastrophic," world-wide glaciation. From the seasonal formation of sea ice during Upper Fitton time, glacial intensity increased to the massive, possibly grounded, ice-shelf conditions of Middle to Upper Bolla Bollana time and then decreased rapidly at the beginning of Lyndhurst time. The thickness of the primary tillite is not exceptionally great, of the order of 1,300 metres if we consider only Units 3 and 4 of the Bolla Bollana Formation. The detrital element of the sediments was derived, on the whole, from a local southerly source. Both the Mount Saturday Fault system and the Paralana Fault were active at this time (Coats, 1971). The fact that there is a lack of detrital feldspar in the Bolla Bollana Formation sediments indicates that there was no feldspathic basement rocks in the source area to the south, but the occurrence of quartz-muscovite, quartz-feldspar and granite gneiss erratics in the sediments means that the ice transported material came from further afield. There was a minor resurgence of glacial activity during Serle Conglomerate time, and contemporaneous fault movements, associated with the unconformity, resulted in the stripping of poorly consolidated tillite. A subsequent rapid influx of coarse detritus, associated firstly with a southerly and then a northerly component of direction and possibly a palaeocoast not far to the east, was shed into a shallow subaqueous valley or trough before the quiet water conditions of the interglacial period set in.

RELATION TO THE WORLD-WIDE LATE PRECAMBRIAN GLACIALS

The Yudnamutana Sub-Group represents the lower part of a double glaciation of Australia during the Late Precambrian. The latest age estimates by Dunn, Thomson and Rankama (1971) are that the older (Sturtian) glaciation began about 750 M. years ago and the younger (Marinoan) about 670 M. years ago, with the total duration of the two glaciations being about 100 M. years. As well as in South Australia, the ice-age left immense deposits of glaciogenic sediments in other widespread localities throughout Australia, from the Kimberlys in north-western Western Australia (Dow, 1965), to northwest Queensland (De Keyser, 1969) and probably to King Island and Tasmania as well as throughout the central Australian Proterozoic basins (Thomson, 1969).

Harland (1964) postulated a world-wide Infra-Cambrian ice age of great severity to explain the occurrence of glaciogenic horizons below fossiliferous Cambrian rocks in both the northern and southern hemispheres. More recently, it has been argued that a world-wide synchroneity of Late Precambrian glaciations is unlikely on polar wandering considerations (Crawford and Daily, 1971), and that the glaciations involved were essentially a circumpolar feature. The latest age interval limits obtained from recent references (Figure 9) show, that with the exception of the 650 to 670 M. year interval, the glacials of the southern and northern hemispheres are far from isochronous.

Assuming circumpolar continental glaciation, a time span of 100 M. years for the double glaciation of Australia, and a relative polar wander rate of .3 degree of latitude per million years (Brock and Piper, 1972), Australia would have had to be within 20 degrees of latitude of the pole during the interglacial period. Considering the huge thickness of interglacial sediments in the Adelaide Geosyncline and the fact that the Kimberly Basin is almost 20 degrees of latitude away, we can conclude that the glaciation within Australia was non-synchronous if we assume only circumpolar glaciation. Using the Gondwanaland reconstruction of Wilson (1963), the tillite occurrences of Australia and Africa are spread over 80 degrees of latitude. Using the above estimates, this



LATEST AGE INTERVAL LIMITS OF PRECAMBRIAN GLACIOGENIC ROCKS

REFERENCES

① Dunn, Thomson and Rankama (1971)
② Crawford and Compston (1970)
③ Kroner and Rankama (1972)
④ Brock and Piper (1972)
⑤ Schermerhorn and Stanton (1963)
⑥ Cahen and Lepersonne (1967)
⑦ Isotta et al. (1969)
⑧ Salop (1968)
⑨ Sokolov (1964)
⑩ Saito (1969)
⑪ Spjeldnaes (1964)
⑫ Harland (1963)
⑬ Wilson and Harland (1964)
⑭ Berthelsen and Noe-Nygaard (1965)
⑮ Harland (1969)
⑯ Siedlecka and Roberts (1972)
⑰ Johnson (1969)

FIGURE 9.

A. Belperio 1973.

would require 240 M. years of polar wandering if we assume only circum-polar glaciation. Since the latest age estimates narrows the age of the two tillite horizons of these two continents to within 100 M. years (Figure 9), we can conclude that the Late Precambrian glaciation must have been much more extensive than merely a circumpolar glaciation and that either a waxing and waning ice age occurred as well as polar wandering or that any essentially circumpolar glaciation would have covered at least 40 degrees of latitude at any one time.

CONCLUSION

Modern glacial models can be applied quite generally to the Late Precambrian lower glaciogenic sediments in the map area. The glaciation appears to have shown at least one period of resurgence before the interglacial period set in. The true primary tillite thickness is not exceptionally great because there was a large contribution from normal shallow marine deposition. A majority of this sediment was locally derived from the south. Because this local source of sediment predominates, this area is not particularly suited for a regional study of the glacial sediments with reference to the Adelaide Geosyncline as a whole.

Plate 1

P1. Interfingering between the Lower Conglomerate and finely laminated Shale Unit 1. Serle Conglomerate Member. Locality L44.

P2. Scoured contact between Lyndhurst Formation shales and massive Serle Conglomerate. Locality L30.

P3. Evidence of glacial activity in the Serle Conglomerate Member. A 10 cm. clast showing truncation of finely laminated shales. Shale Unit 1. Locality L31.

P1.

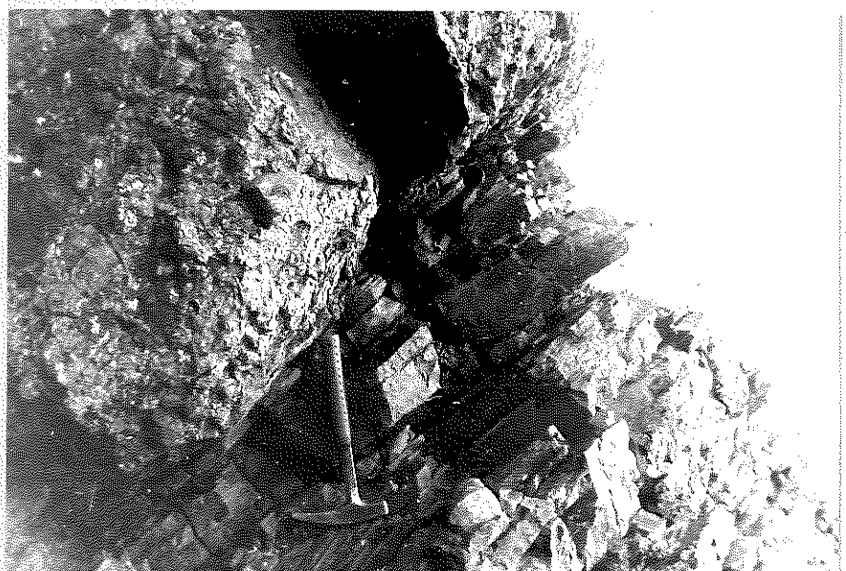


PLATE I.

P2.

P3.

Plate 2

Evidence of glacial activity in the Serle Conglomerate Member.

P1. A 5 cm. lenticular pebble lens with an 8 cm. clast showing penetration and contortion of underlying finely laminated shales. Shale Unit 1. Locality L43.

P2. A pebble lens in finely laminated shales of Shale Unit 1. Locality L43.

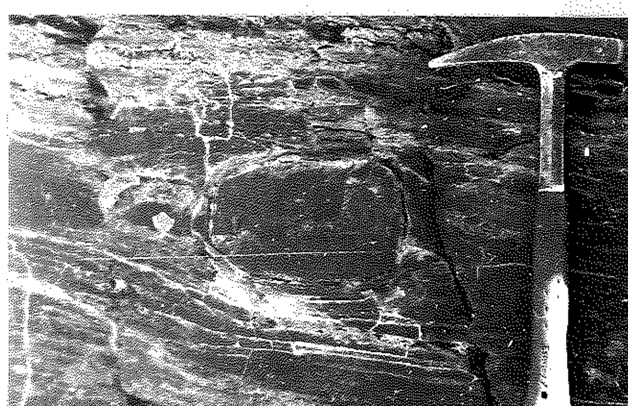
P3. A 15 cm. quartzite boulder occurring in well laminated shales. Shale Unit 1. Locality L31.

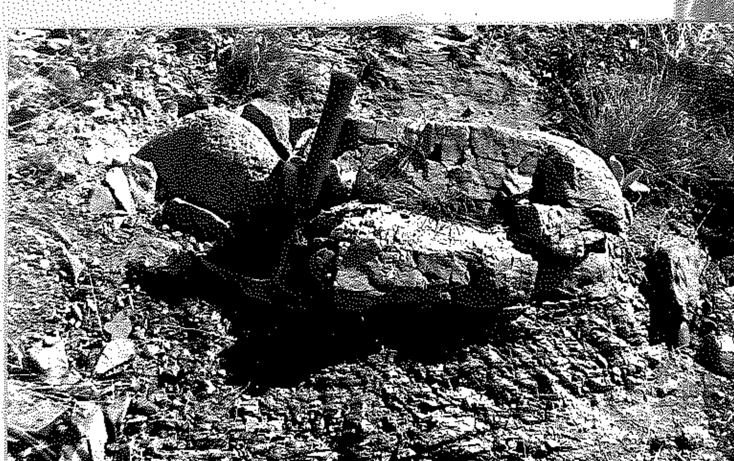
P4. A 50 cm. quartzite boulder sitting in well laminated blue shales. Boulder beds, Locality L27.

P1.

P2.

P3.





P4.

PLATE 2.

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APPENDIX I

Structure, Metamorphism and Metasomatic Alteration

The sediments of the map area are openly folded about the Gladstone Anticline which plunges shallowly to the west. The dip of the beds decreases rapidly from 70 degrees in the east to 10 degrees in the west. From the sedimentation pattern on the two sides of Fault 1, it is obvious that this fault has undergone a long, complex period of movement whereas Faults 2 and 3 are apparently the result of meta-sediment and basement décollement. Intrusions of remobilized and recrystallized carbonates (413-13) and jasperized meta-breccia are associated with Fault 1.

The metamorphic minerals present are typical of regional, high pressure metamorphism as would be expected from such a great thickness of sediment as exists in the Adelaide Geosyncline. The metamorphic grade decreases to the west, from amphibolite facies (microcline, hornblende, tremolite) and greenschist facies (chlorite, muscovite, biotite, scapolite, actinolite) in the Fitton Formation to zeolite facies (laumontite, thomsonite) in the Bolla Bollana Formation.

Metasomatic alteration is also widespread (c.f. microcline veinlets in 413-56) and is quite obviously structurally controlled. Control is by;

(1) Faults.
(2) Porosity of the beds.
(3) Unconformities.

(1) The meta-sediments around Greenhill Mine are feldspathized and contain minute crystals of tourmaline. The pebbly Unit 2 of the Fitton Formation is feldspathized in the vicinity of Fault 2 but becomes scapolitized further to the north and south. (Figure 6)

(2) The Serle Conglomerate Member, Serle Sandstone unit is kaolinized at the Daly Mine (3 kms. south of Fault 1.) and just east of

Tindelpina Hut. The degree of kaolinization decreases northwards away from the Mount Saturday Fault system. According to Blissett (Coats and Blissett, 1971), the kaolinization of the Serle Conglomerate is due to Tertiary weathering beneath the Freeling Heights peneplain. If this were so, we would expect the degree of kaolinization to vary vertically and not laterally. The occurrence of copper mineralization and tourmaline at the Daly Mine and the fresh, unweathered occurrence of Lyndhurst Formation and Tindelpina Shale above and below the conglomerate, also support the author's belief that the kaolinization of the Serle Conglomerate is due to the movement of metasomatic fluids, firstly along faults and then along the highly porous conglomerate. Most of the quartzite beds, especially those in the vicinity of the southern fault, are metasomatically silicified.

(3) The control of mineralization by unconformities is clearly seen on the regional scale by the localization of mines along the basement-cover contact in the Mount Painter Province. In the map area, the unconformity between the Fitton Formation and the Callana Beds is marked by kaolinization and feldspathization, by silicification of the sandy sediments (413-33) and by minor copper mineralization along the contact.

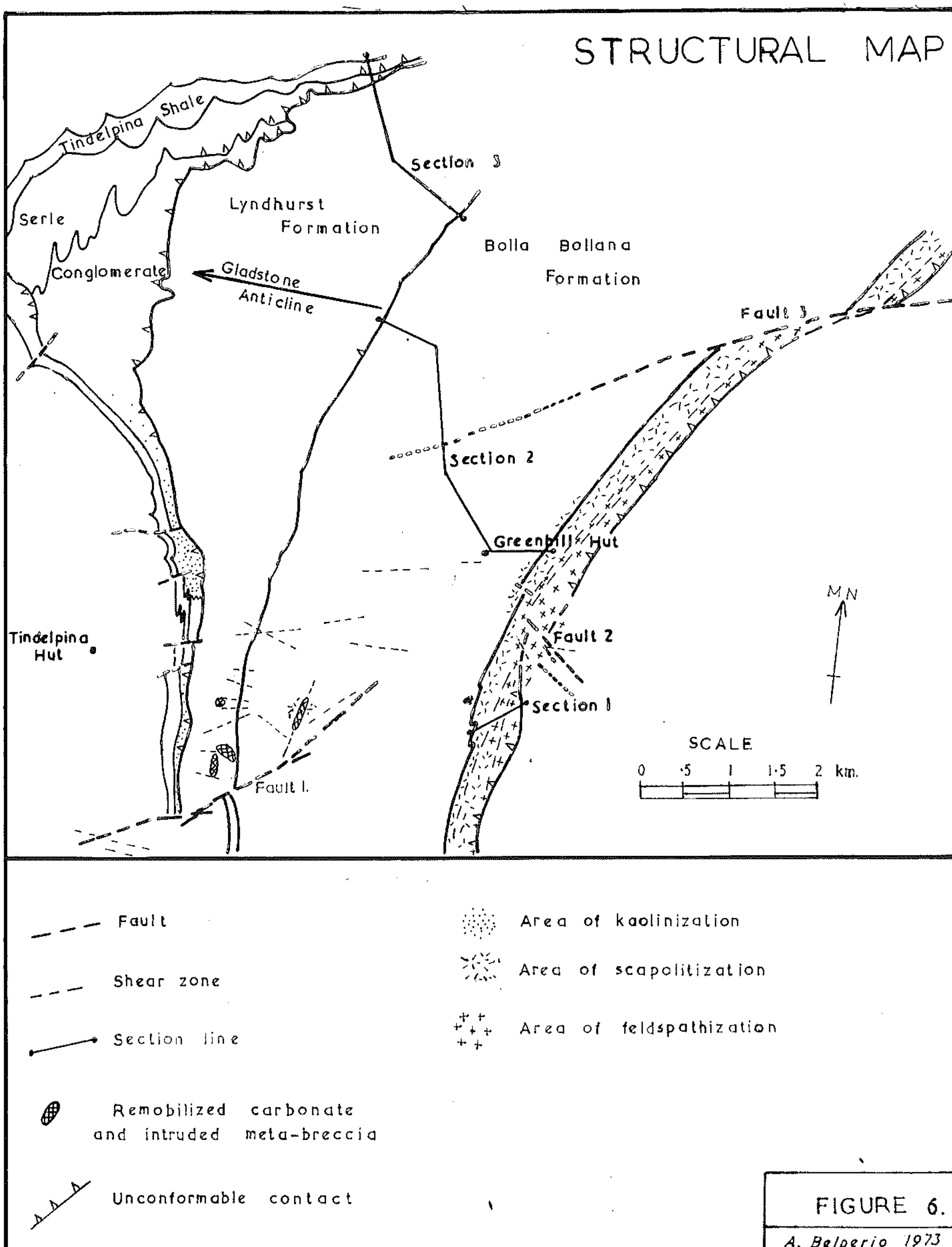

FIGURE 6.

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APPENDIX II

Detailed Section Descriptions

Detailed section traverses through the various formations were carried out by pace and compass using marker pegs. The accuracy of the pacing was well within 10%. The sections are shown in Figure 3 and in detail in Figures 7 and 8.

Section 1 ; Fitton Formation

metres	
0 to 10	Highly sheared and kaolinized quartzose arkose of the Blue Mine Conglomerate.
10 to 50	Blue Mine Conglomerate scree.
50 to 230	Creek alluvium.
230	Feldspathized quartz-actinolite calc-silicate rock.
230 to 270	Interbedded siderite rich marble, dolomite and calc-silicate rock.
270 to 300	Pebbly quartz-feldspar-actinolite-tremolite rock.
300 to 355	Metamorphic banded quartz-feldspar-actinolite rich pebbly silts and sandstones (413-56). Increase in scapolite up the sequence. Quartzite erratics up to 60 cms.
355 to 400	Scapolitized calcareous silts with minor lenses of pebbly sandstones.
400 to 480	Scapolitized and feldspathized pebbly sands and silts.
480 to 500	A massive, kaolinized feldspathic quartzite.
500 to 700	Scapolitized silts and pebbly sandstone lenses and interbeds of amphibole rich arkoses towards the top.
700 to 720	Blue, current bedded, sub-greywacke with a sudden increase in the number and size of erratics and a sudden decrease in the amount of scapolitization (Bolla Bollana Formation).

True thickness of Fitton Formation at this locality is 430 metres.

Section 2 ; Bolla Bollana Formation

metres	
0 to 17	Interfingering contact between scapolitized calcareous silts (Fitton Formation) and blue, water-laid sub-greywacke rock.
17 to 20	Blue sub-greywacke rock.
20 to 90	Non calcareous well laminated sandy silts with pebbly sandstone and sub-greywacke lenses. Quartzite erratics up to 30 cms.
90 to 240	Poorly sorted, well bedded, laminated sands with pebbly and laminated silt interbeds up to 5 metres.
240 to 245	Non calcareous, current bedded, sandy sub-greywacke.
245 to 300	Massive sandy silts.
300 to 550	Interbedded sandy silts and shales with a recurrence of dropstones of average diameter about 15 cms. and interbeds of current bedded sub-greywacke.
550 to 770	Massive, bedded micaceous silts, often sandy with pebbly bands.
770 to 850	Massive, fine grained, poorly sorted quartzite with coarse sand and pebbly sand interbeds and quartzite dropstones up to 60 cms. In parts shows good lamination, heavy mineral lamination, current bedding and evidence of strong current activity.
850 to 900	Bedded, water-laid sub-greywacke with a muddy matrix. Has an average pebble size of 1 to 2 cms. and a maximum dropstone (quartzite) of 90 cms. at the base. Thin interbeds of well laminated calcareous shales.
900 to 1360	Poorly bedded pebbly silts and sub-greywacke with minor silt interbeds. Average pebble size is 2 cms. and consist of 80% quartzite and 20% shale, granite, amphibolite and Blue Mine Conglomerate pebbles. Thick interbeds of massive structureless greywacke rock with an average boulder size of 10 to 15 cms.
1360 to 1380	An interbed of well laminated shales and silts.

1380 to 1575	Continuation of poorly bedded sub-greywacke rock becoming increasingly massive.
1575 to 1900	Massive, structureless, unbedded greywacke tillite with an average boulder size of 15 cms. Generally muddy matrixed but quartzitic in places. Numerous thin interbeds of water-laid sandy shale.
1900 to 2000	Quartzitic, massive greywacke tillite with very little stratification. A poorly sorted sand and mud matrix.
2000 to 2600	Back into muddy matrixed greywacke tillite with interbeds of water-laid pebbly siltstones.
2600 to 2850	Interbedded, partly calcareous silts, shales, pebbly sands and quartzites.
2850 to 2925	Back into massive, structureless greywacke tillite.
2925 to 2965	Alternating silts, shales and pebbly sands.
2965 to 3500	Back into massive greywacke tillite.
3500 to 3580	Change in pebble suite. Shale fragments increase to 10 to 20% and quartzites decrease to about 70%. Also about 5% quartz-muscovite and quartz-biotite gneiss pebbles. Also minor pebbly dolomite lenses with fragments of greywacke tillite. The greywacke becomes very massive, pyritic and calcareous (413-50) and also contains minor granules of blue quartz.
3580 to 3600	A massive pyritic and arkosic quartzite.
3600 to 3700	Massive greywacke tillite with a 1 metre gneissic granite erratic.
3700 to 3710	Current bedded pebbly siltstones.
3710 to 3750	Massive greywacke tillite.
3750 to 3850	Well laminated blue silts and shales with minor pebbly bands, decreasing upwards.
3850 to 3900	Massive but bedded greywacke tillite with a 1 metre quartzite erratic.
3900 to 4000	Well laminated blue silts and shales.
4000 to 4100	Well bedded, slightly calcareous sub-greywacke. An exotic red weathering, fine grained quartz porphyry pebble.

4100	Well laminated blue shales and sandy silts with a recurrence of ice dropped boulders. (Lyndhurst Formation)

True thickness of the Bolla Bollana Formation calculated from this traverse is 2,500 metres.

Section 3 ; Lyndhurst Formation and Tapley Hill Formation

metres	
0	Gradational change from bedded sub-greywacke to sandy and pebbly shales to well laminated sandy silts and shales.
0 to 10	Well laminated (1 mm.) fine, even grained blue shales with minor massive silt interbeds and occasionally pebbly bands and dropstones up to 30 cm. in diameter.
10 to 90	Massive, pyritic blue siltstones with gritty and pebbly sand bands.
90 to 145	Well laminated blue shales.
145 to 155	Massive, sandy blue silts, crossbedded and current laminated with a 1 metre quartzite erratic.
155 to 190	Well laminated blue shales.
190 to 210	Massive, sandy blue silts.
210 to 255	Well laminated blue shales with quartzite interbeds up to 2 metres.
255 to 290	Massive siltstone.
290 to 345	Well laminated calcareous blue shales.
345 to 380	Massive, calcareous siltstone with interbeds of well laminated shale.
380 to 640	Well laminated, calcareous shales with minor sand and silt interbeds up to 2 metres thick and a recurrence of drop-boulders. Numerous thin silt bands lens out rapidly and show heavy mineral laminations, cross bedding and minor slump rolls.
640 to 780	Calcareous, silty blue shales with occasional dropstones of average diameter 10 cms. About one pebble per two metres square of outcrop. Minor thin (30 cms.) quartzite bands.

780 to 810	Massive, well bedded siltstones.
810 to 870	Calcareous, silty blue shales.
870 to 1200	Massive, poorly laminated, blue-grey silts with shale interbeds of about 2 metre thickness. Shale interbeds increase in number and size up the sequence and the silts become progressively better laminated.
1200 to 1280	Shale float.
1280 to 1330	Massive, grey, brown and red sandy silts, very poorly laminated and poorly bedded. Irregular shale interbeds.
1330 to 1525	Alternating, well laminated, calcareous and non calcareous shales and well bedded silt interbeds of pebbly sand and quartzite.
1525 to 1600	A predominance of massive, poorly bedded silts and gritty and sandy quartzite-sandstone beds.
1600 to 1700	Alternating shales (2 metres) and silts (1 metre) with medium grained, well sorted and sub-rounded sandstone bands and minor sandy carbonate lenses.

True thickness of Lyndhurst Formation from this traverse is 960 metres.

1700 to 1702	Scoured contact with Serle Conglomerate Member, Middle Conglomerate 2. The conglomerate consists of a basal pebbly sandstone (413-51) for the first two metres with an average pebble size of 2 cms. Pebbles are 50% quartzite, 30% shale, 10% dolomite and 5% calc-silicates.
1702 to 1740	Typical calcareous, sandy conglomerate with an average pebble size of 8 cms and a maximum boulder size of 1 metre.
1740 to 1768	Calcareous, sandy conglomerate with bedded conglomeratic carbonate lenses and large angular blocks of pebbly carbonate.
1768 to 1773	Reworked, intraformational, carbonate matrixed conglomerate. Pebbles include (413-55) well rounded quartz and feldspar porphyries, rounded and angular quartzite, angular shale and very angular dolomite fragments.

The thickness of the Serle Conglomerate Member at this locality is 48 metres compared with 480 metres further to the west.

1773	Unconformable contact between Serle Conglomerate Member and Tindelpina Shale Member (Shale Unit 3.)
1773 to 1780	Interbedded, poorly laminated silty shales and well laminated, dark "carbonaceous" shales. To the east, these shales strike into the underlying conglomerate.
1780 to 1781	A small band of water laid pebbly carbonate similar to the carbonate conglomerate and with a similar pebble suite.
1781 to 1900	Very well laminated, dark "carbonaceous" shales with minor thin calcareous pebbly lenses.
1900 to 2000	Well laminated silts and silty shales. Sandy limestone bands suddenly become more noticeable and the shales become calcareous and lighter in colour.

The thickness of the Shale Unit 3 at this locality is 62 metres.

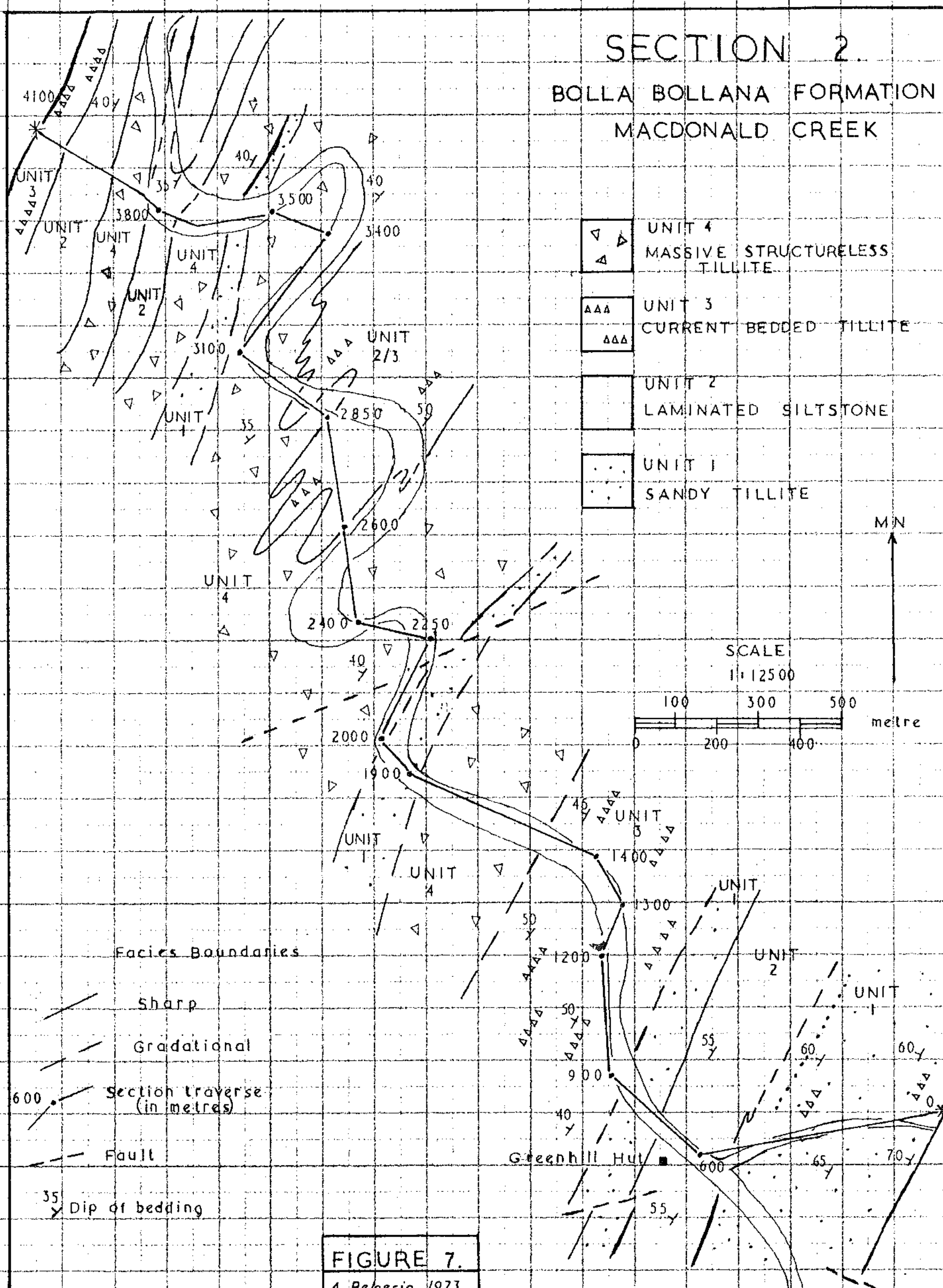
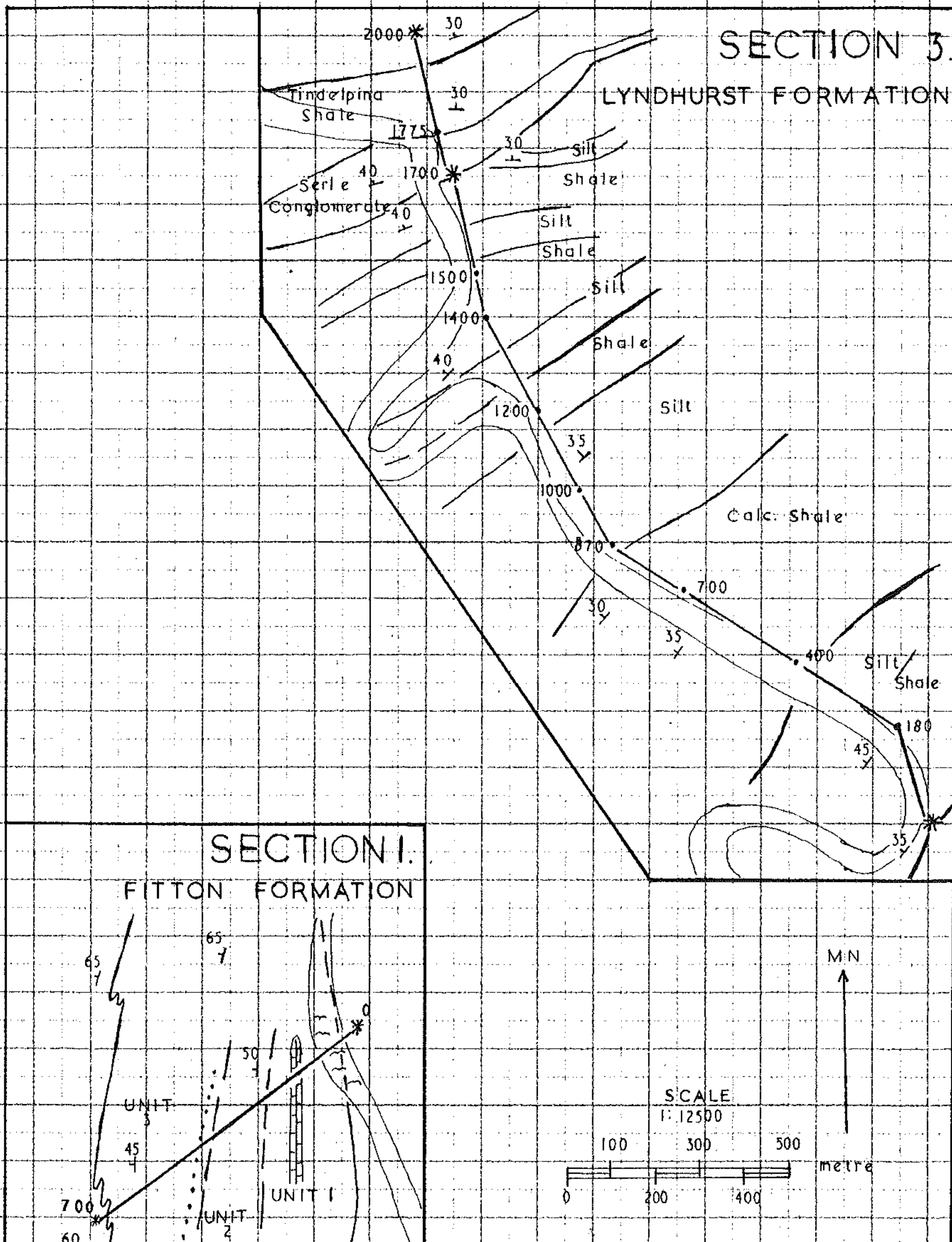


FIGURE 7.
A. Belperio 1973



SECTION 3.
LYNDHURST FORMATION
Tindelpina Shale
Serle Conglomerate
Silt
Shale
Calc. Shale
2000
1775
1700
1500
1400
1200
1000
870
700
400
180
SECTION I.
FITTON FORMATION
UNIT 3
UNIT 2
UNIT I
700
0
MN
SCALE
1: 12500
metre
FIGURE 8.
A. Belperio 1973

APPENDIX III

Rock and Thin Section Descriptions

Binocular rock examination and thin section description (TS) of selected specimens held under the accessum number 413- by the Geology Department.

413-25 Blue Mine Conglomerate, Locality L1.
A massive feldspathized and silicified pebbly sandstone. Contains angular and very poorly sorted quartz, feldspar, phyllite and gneissic fragments and minor granules of blue quartz.

413-28 Fitton Formation, Unit 1, Locality L2.
A massive, very poorly bedded and feldspathized pebbly sandstone. Contains large granules of quartz in a quartz-feldspar-amphibole-chlorite matrix.

413-30 Fitton Formation, Unit 1, Locality L2.
A massive calc-silicate rock containing quartz, feldspar, actinolite and tremolite.

413-33 Fitton Formation, Unit 1, Locality L3.
A massive silicified pebbly sandstone with subrounded quartz grains and quartzite pebbles and fine grained opaque heavy minerals.

TS.413-48 Fitton Formation, Unit 1, Locality L4.
A medium grained, equigranular recrystallized rock with a relict gritty sand structure.

Contains
- 10% poikoblastic scapolite
- 5% euhedral tremolite
- 25% bladed and fibrous actinolite
- 10% hornblende
- 10% microcline perthite feldspar
- 15% large quartz granules showing strain extinction

25% fine quartz-feldspar matrix.

Macro: a massive quartz-actinolite-tremolite rock.

413-18 Fitton Formation, Unit 1, Locality L5.

A poorly bedded dolomitic tremolite marble..

Contains 40% fine, well rounded quartz grains
20% tremolite porphyroblasts
40% marble matrix.

TS.413-15 Fitton Formation, Unit 2, Locality L6.

An unsorted, weathered, chlorite rich pebbly sandstone.

Contains 45% fine to coarse quartz grains
10% rock fragments; quartzite, siltstone and shale
35% fresh and altered chlorite
10% sericite and sericitized feldspar
minor actinolite and opaques.

TS.413-56 Fitton Formation, Unit 2, Locality L7.

A massive, poorly sorted, feldspathized pebbly sandstone.

Contains 25% coarse sand size quartz and minor detrital feldspar. Show sutured contacts and overgrowths.
25% fine sand size quartz
25% actinolite
5% biotite
5% scapolite
15% microcline-perthite feldspar as veinlets and replacement intergrowths.

413-17 Fitton Formation, Unit 2, Locality L8.

A massive medium grained quartzite showing a relict well sorted equi-granular structure. Accessories are actinolite and fine grained iron oxides.

413-0 Fitton Formation, Unit 3, Locality L9.

A bedded and pebbly highly scapolitized siltstone.

TS.413-19 Fitton Formation, Unit 3, Locality L10.

A well bedded, scapolitized calcareous siltstone.

Contains 20% scapolite; poikoblastic porphyroblasts
15% fine sand size quartz and occasional coarse grains concentrated in bands.
65% silt size calcite, clay and quartz matrix.

413-22 Bolla Bollana Formation, Unit 1, Locality L11.

A massive, poorly sorted, pebbly, silty sandstone; argillaceous sublitharenite. Shows poor stratification and a current lineation perpendicular to strike.

Contains 50% fine sand and silt size quartz matrix
40% medium and coarse sand size quartz granules
10% rock fragments; quartzite and phyllite
minor scapolite crystals.

413-23 Bolla Bollana Formation, Unit 1, Locality L12

A bedded, poorly sorted, conglomeratic sandstone; siliceous sublitharenite. Shows a poor current lineation at 45 degrees to strike.

Contains 50% siliceous matrix
40% well rounded sand size quartz grains
10% rock fragments; well rounded quartzite and quartz-feldspar.

TS.413-39 Bolla Bollana Formation, Unit 1, Locality L13.

A weakly bedded and poorly sorted pebbly, silty sandstone. Shows a strong lineation parallel to strike.

Contains 50% fine quartz and micaceous clay matrix
40% sub-angular sand size quartz granules
10% rock fragments; meta-quartzite and siltstone.

413-41 Bolla Bollana Formation, Unit 2, Locality L14.

A massive, well sorted, fine sandy siltstone. Shows good stratification but poor internal bedding.

Contains 40% very fine sand size quartz
60% micaceous silt.

<u>413-35</u> Bolla Bollana Formation, Unit 2, Locality L15.

A poorly sorted pebbly siltstone from a pebble lens in this unit. A massive rock with contorted bedding.

Contains 80% matrix similar to rock 413-41
20% well rounded rock fragments; quartzite and shale.

<u>TS.413-42</u> Bolla Bollana Formation, Unit 2, Locality L15.

A cross-bedded and banded sandy siltstone with roughly 50% coarse silt bands and 50% fine silty sand bands.

The silty matrix contains

- 50% fine sub angular quartz
- 40% undifferentiated phyllosilicates
- 10% fine calcite grains.

The sand bands contain

- 40% angular quartz grains
- 40% silty matrix (as above)
- 5% opaques and iron oxides
- 10% interstitial and granular calcite
- 5% pennine mainly in cavities and interstitial.

<u>TS.413-40</u> Bolla Bollana Formation, Unit 3, Locality L16.

A poorly sorted and crudely bedded pebbly sandy siltstone consisting of an unsorted aggregate of very angular to well rounded grains of sand, coarse silt and rock fragments set in an abundant argillaceous matrix.

Consists of

- 40% argillaceous matrix
- 40% fine to coarse quartz grains with angularities ranging from very well rounded to very angular
- 10% rock fragments; quartzite and quartz-muscovite
- 5% biotite, muscovite and sericite
- 5% zeolites; Laumontite vein fill and thomsonite radiating fibres.

<u>413-38</u> Bolla Bollana Formation, Unit 3, Locality L17.

A poorly sorted and current bedded pebbly siltstone with an ice dropped pebble showing truncation and contortion of bedding.

Consists of 60% silty matrix
35% sand size quartz grains and shale fragments
5% rock fragments; quartzite, shale and quartz-feldspar gneiss.

<u>413-72</u> Bolla Bollana Formation, Unit 4, Locality L18.

A 5 cm. quartz-feldspar glacial dropstone penetrating and truncating a poorly bedded sandy siltstone.

<u>TS.413-50</u> Bolla Bollana Formation, Unit 4, Locality L19.

A massive, unsorted and unbedded pebbly sandy siltstone; argillaceous, calcareous and pyritic sublitharenite.

Contains 25% medium and fine grained quartz
20% very fine sand size quartz
35% clay and silt
10% rock fragments; quartzite, siltstone and schist
10% calcite; disseminated and replacing quartzite boundaries
2% pyrite; disseminated and replacement.

<u>TS.413-47</u> Bolla Bollana Formation, Unit 4, Locality L20.

A very poorly sorted pebbly mudstone, an argillaceous phyllarenite consisting of a totally unsorted aggregate of silt, sand and gravel sized grains and rock fragments in a micaceous muddy matrix. Although there are numerous fresh schist and shale fragments, there is a total absence of feldspar. The rock shows a complete lack of internal structure but shows a poorly developed stratification in outcrop parallel to field strike.

Consists of 45% argillaceous matrix; sericite, illite, micaceous clay and silt

35% sand size quartz grains ranging from extremely angular to extremely well rounded. Also broken and fragmented grains and some overgrowths. A few volcanic grains show strain extinction and inclusions. Cross fracturing of grains is most likely due to brecciation effects of Fault 3.

20% rock fragments - mostly metamorphic quartzite, siltstone, shale and muscovite schist fragments.

Accessories; zeolites in cavities could possibly be replacing volcanic rock fragments. A sericite fragment could have originally been a feldspar. Minor iron oxides and tourmaline.

The minimum detectable quartz grains are .005 mm. in diameter. The total range of matrix grain size, angularity and freshness is indicative of rock flour.

TS.413-36A Lyndhurst Formation, Unit 1, Locality L21.

A massive, very poorly sorted, granular micaceous siltstone.

Contains 5% rock fragments; quartzite, siltstone and shale
30% fine to coarse quartz grains
65% micaceous clay and silt matrix
Minor opaques and iron staining.

413-69 Lyndhurst Formation, Unit 1, Locality L22.

A massive, very poorly bedded, pebbly sandy siltstone.

Contains 55% coarse silt matrix
30% sand size angular quartz grains
15% granule and pebble size rock fragments of quartzite and shale.

413-68 Lyndhurst Formation, Unit 2.

A bedded, calcareous sandy siltstone.

Contains 35% fine to medium sand size sub-angular quartz
65% coarse calcareous silt.

413-3 Lyndhurst Formation, Unit 4, Locality L23.
A massive, poorly bedded sandy siltstone.
Contains 25% fine sand
65% coarse silt
10% quartzite granules
minor fine mica and pyrite.

413-2 Lyndhurst Formation, Unit 4, Locality L23.
A massive silicified quartzite with about 5% scattered opaques and a relict granular structure from a quartzite interbed in Unit 4.

TS.413-45 Lyndhurst Formation, Unit 6, Locality L24.
A well laminated silty shale consisting of;
35% clay minerals
5% anthophyllite
60% fine silt size quartz
minor chlorite and opaques.

TS.413-46 Lyndhurst Formation, Unit 6, Locality L24.
A poorly sorted sandy siltstone interbed in this shale unit.
Contains 5% fine sand size quartz and feldspar
25% very fine sand size quartz
20% silt size quartz
30% micaceous clay matrix
20% iron oxides in matrix.

413-6 A medium grained leucogranite, part of a 3 metre erratic sitting in blue shales at the top of the Lyndhurst Formation at locality L25.

413-73 Lyndhurst Formation, Unit 6, Locality L26.
A float sample of a varved siltstone showing a repetitive fining upward set of laminae. A very well laminated fine micaceous siltstone.

413-7 Serle Conglomerate Member, Boulder beds, Locality L27.
An 8 cm. ice dropped sandstone clast sitting in very finely laminated blue shales.

<u>413-4</u> Serle Conglomerate Member, Lower Conglomerate 1, Locality L28.

A typical quartz porphyry pebble from this conglomerate.

<u>TS.413-51</u> Serle Conglomerate Member, Middle Conglomerate 2, Locality L29.

A very poorly sorted and poorly bedded calcareous pebbly sandstone. At this point, the pebble constituents are 50% quartzite, 30% shale, 10% dolomite and 5% calc-silicates.

Consists of 10% silt
65% fine to coarse sand size quartz
25% rock fragments.

<u>TS.413-54</u> Serle Conglomerate Member, Middle Conglomerate 2, Locality L30.

A massive, pebbly and slightly sandy, very fine grained dolomite with about 15% fine grained quartz.

<u>413-55</u> Serle Conglomerate Member, Middle Conglomerate 2, Locality L30.

A collection of the resistant pebbles from the dolomite matrixed (413-54) conglomerate.

Pebbles include quartzite, well rounded and angular
quartz porphyry, well rounded
shale, invariably angular and weathered
feldspar porphyry, sandstone, calc-silicate and dolomite.

<u>TS.413-63</u> Serle Conglomerate Member, Shale Unit 1, Locality L31.

A well laminated, dark, calcareous and carbonaceous shale consisting of

5% fine sand size quartz
35% silt size quartz
35% phyllosilicate matrix
15% fine calcite granules
10% fine carbonaceous stringers
Minor fine opaques.

<u>TS.413-71</u> Serle Conglomerate Member, Shale Unit 2, Locality L32.

A well bedded calcareous siltstone consisting of

5% very fine sand
45% coarse silt size quartz
50% fine silt, micaceous clay and calcite.

<u>TS.413-60</u> Serle Conglomerate Member, Calcareous grit unit, Locality 32.

A poorly bedded and poorly sorted highly calcareous sandstone.

Contains 30% medium and coarse, very angular quartz and quartzite grains
35% medium grained calcite and minor feldspar
35% fine carbonate matrix
Minor zeolites and iron oxides.

<u>413-62</u> Serle Conglomerate Member, Calcareous grit unit, Locality L32.

A massive, unbedded, calcareous sandy siltstone consisting of
35% medium and fine grained quartz
65% calcareous silt and clay

<u>TS.413-59</u> Tindelpina Shale Member, Shale Unit 3, Locality L33.

A well sorted and very well bedded slightly carbonaceous, calcareous siltstone.

Contains 2% very fine sand
60% silt, mostly quartz but also minor feldspar
30% clay minerals
3% fine calcite grains
5% dark, possibly carbonaceous, stringers.

<u>413-64</u> Tindelpina Shale Member, Shale Unit 3, Locality L34.

A well laminated shale with banded calcareous and non calcareous laminae.

<u>413-65</u> Tindelpina Shale Member, Shale Unit 3, Locality L35.

A very well laminated, dark calcareous shale.

TS.413-58 Tapley Hill Formation, Upper Conglomerate 3, Locality L36.

A massive, slightly sandy, birds-eye limestone.

Contains 10% angular, medium and fine grained quartz
25% very large (2 mm.) calcite grains as blebs
65% calcite mosaic.

413-1 Tapley Hill Formation, Locality L37.

A poorly bedded, coarse, sandy limestone from a gritty limestone lens in the Tapley shales.

Consists of
35% coarse sand size, subangular quartz
5% limonite specks
60% calcareous matrix.

413-13 Remobilized carbonate, Locality L38.

A massive, pebbly, siderite rich recrystallized carbonate rock. Consists of calcite, siderite, shale fragments, quartz, magnetite and pyrite and limonite.

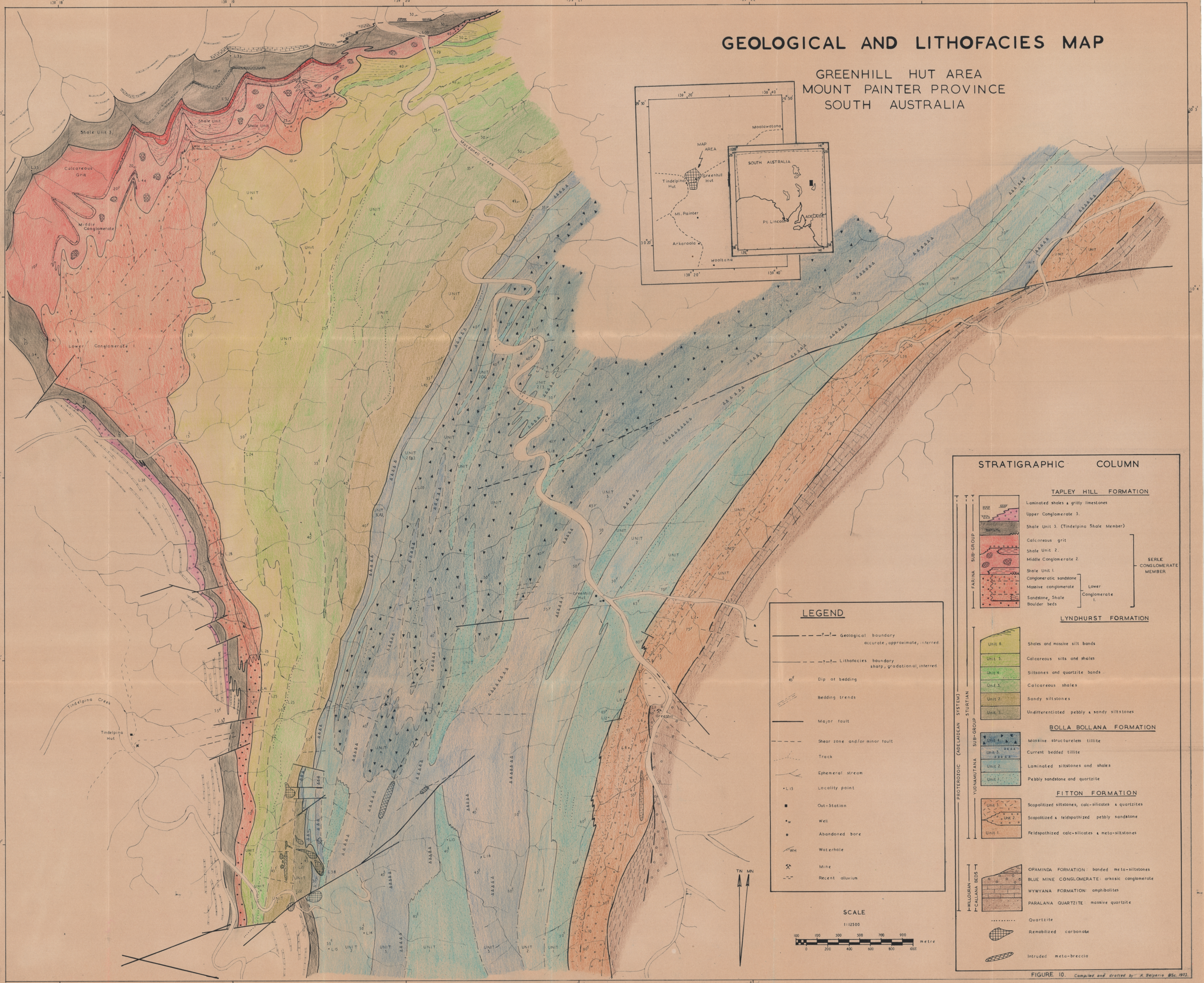


FIGURE 10. Compiled and drafted by A. Belperio BSc. 1973.