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THE CAMBRIAN GEOLOGY OF

T H E N E P A B U N N A A R E A

SOUTH AUSTRALIA.

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INTRODUCTION:

Cambrian strata in the Nepabunna area were studied with a view to elucidating the geological history of the area and to correlate the established sequence with Cambrian sediments in other regions of South Australia.

The Nepabunna Mission is situated in the heart of the northern Flinders Ranges, 40 miles east of Leigh Creek. The Cambrian sediments in this area were first observed by Sir Douglas Mawson in 1924 who subsequently discussed two measured sections, the Nepabunna and Italowie sections, in 1937, (Mawson, 1937). The western portion was subsequently mapped on a regional scale by Sprigg andWilson, being consequently included in the Angepena sheet (1953) of the South Australian Department of Mines geolgical map series.

The area of outcrop studied is about 50 square miles being almost completely surrounded by rugged quartzite ranges which provide a convenient physiographic and stratigraphic boundary. The softer Cambrian sediments generally form a low topography which is in some areas deeply incised by water courses. A more rugged topography is found near the Italowie Gorge where the Cambrian limestones are thicker and more massive. A striking geographic feature is the occurrence of elevated flat areas which are found scattered throughout the region. These may be 100' above the adjacent creek beds that dissect them.

The average annual rainfall is only 10 inches which together with high average temperatures limits vegetation to isolated small trees and bushes. Consequently the soil is easily removed during the isolated periods of heavy precipitation. This results in generally good outcrops.

The mapping was carried out with the assistance of aerial photographs.

ACKNOWLEDGEMENTS

I am indebted to Dr. M. F. Glaessner for suggesting this study and for the subsequent supervision of it. Also I would like to express my appreciation to Dr. B. Daily for substantial material assistance as well as many helpful discussions of the project. My thanks are also due to the Bureau of Mineral Resources for financial assistance to complete this work.

STRATIGRAPHY:

Below will be described two detailed sections to be used as a basis for further discussion. The first section is taken from a traverse made across the strike about ¼ mile west of the Nepabunna - Balcanoona boundary fence. This will be referred to as the Nepabunna section. The second section described is situated about 5 miles by road west of the Italowie Gorge and will consequently be referred to as the Italowie section. A more detailed description of the sediments encountered by Sir Douglas Mawson is herein given.

A. The Nepabunna Section

The following sequence is tabulated from the youngest to oldest sediments.

(17) 400' of blue grey limestones with rhythmically interlaminated calcareous shales.

(16) 1150' of dark grey slates. These are calcareous and display several cleavages. The most prominent being parallel to the axial plane of the syncline.

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(15) 860' of massive bedded blue grey limestones, grading into argillaceous or rubbly limestones in the lower section.

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(14) 330' of calcareous shale with minor slate bands. Grades into rubbly limestone.

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(13) 400' of rubbly limestone interspersed with beds up to 1' in thickness containing small Archaeocyathia and hyolithids

(12) 700' of rubbly limestone with some thin bands containing Archaeocyatha. The brachiopod, Kutorgina, was found in a lensing band 150' above the base of this section.

(11) 50' of massive fossiliferous limestones with argillaceous limestone and calcareous shales. The fossiliferous beds contain Archaeocyatha, sections of an unidentified calcareous brachiopod, and a chitino-phosphatic brachiopod referred to as Kutorgana.

(10) 1300' of algal limestones, intraformationally brecciated limestones and calcareous shale bands similar to items, 9, 8, 7. The large algal bands, those that exceed 1' in thickness, are on the average about 100' apart. The abovementioned algae are referred to Collenia.

(9) 3' massive algal limestone (Collenia).

(8) 50' of thin bedded limestones and calcareous shales - each band being of the order of 1" - 2" thick. Many of the limestone bands are intraformationally brecciated.

(7) 6' bed of blue-grey algal (Collenia) limestone.

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(6) 580' of yellow and white shales and siltstones. The upper 100' being ferruginous in part.

(5) 110' of dense dark reddish brown ferruginous beds - probably a surface enrichment of iron rich shales.

(4) 470' of light coloured shales and sandstones with rare ripple marks.

(3) 50' of massive white to grey quartzite.

(2) 115' of soft light grey shales with some quartzite bands.

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(1) >5000' of bedded quartzites showing abundant ripple-marks and cross-bedding. This formation is referred to Pound quartzite which is regarded as uppermost Precambrian. Sprigg and Wilson have reported fossil jellyfish from this formation on their map (1953).

B. The Ttalowie Section

The following sequence is detailed in descending order.

(17) Approximately 2000' of dark grey, weathering to greenish grey, calcareous shales grading into rubbly and banded limestones at the top.

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(16) 750' of massive banded limestones passing into calcareous slates at the top.

(15) 875' of banded and softer argillaceous limestones with some bands of intraformational breccia.

(14) 30' of blue-grey limestones rich in Archaeocyatha.

(13) 850' of banded limestones showing small folds and compressional structures similar to slump structures. Intra-formational breccia common.

(12) 640' of banded limestone with some intraformationally brecciated bands.

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(11) 650' of dark grey shales, argillaceous limestones, and calcareous slates.

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(10) 1375' of banded limestones with some softer argillaceous bands. Cubic crystals of limonite after pyrite are prominent throughout this s ection.

(9) 350' of rubbly limestones with some small bands containing Archaeocyatha and hyolithids.

(8) 90' of limestones, argillaceous in part, and bands rich in Archaeocyatha and Kutorgina.

(7) 870' of Algal limestones with argillaceous bands and also beds of intraformational breccia. The blue-grey limestones change to a buff colour toward the base of this section.

(6) 2' massive algal limestone (Collenia).

(5) 49' of soft calcareous shales and thin (averaging 6" in thickness) algal bands. A ferruginous band including yellow ochrous shales, about 17' thick, is found at the top of this section.

(4) 50' of calcareous shales with thin limestone beds at the top of which occurs the lowest algal bed found in the sequence.

(3) The above limestone here begins with a 1' thick bed of intraformationally brecciated limestone. This limestone weathers pink in places but the usual colour is buff.

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(2) 1010' of yellow and white shales and siltstones interspersed with some thin quartzite beds in the basal 300'. The shales are calcareous in part and fine laminations of siderite were found. The whole is capped by 40' of concretionary limonite which may only be a surface enrichment.

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(1) The Pound Quartzite here occurs on the side of a dome structure consequently the actual thickness is unknown but the minimum would be 6000'. It consists of massive bedded quartzites showing ripple marks and cross-bedding. Worm castings appear in a narrow zone within 50' of the top.

The Pound Quartzite.

The most striking feature of this formation is its remarkable consistency over the whole area. Such features as the dull reddish buff colour, average thickness of beds proportion of finer grained sediments, and internal features including grain size, sorting and cross-bedding are sufficiently similar to make unnecessary any comment upon major local changes within this massive sedimentary body. Therefore as this formation was not studied in detail except near its top a generalised description will be given. The Pound Quartzite lies abruptly but conformably upon Marinoan silty shales and limestones. The transition at the top, is very often just as abrupt but in several areas the formation does tend to grade into limestones and shales over a thickness of several hundred feet. An attempt to define the top of the Pound quartzite formation in these areas will be made in the next section. Between the base and the top the 5000' thick formation consists almost wholly of reddish buff quartzite in beds from 6" to several feet in thickness. Cross-bedding and ripple marks are ubiquitous. Massive pavements of ripple marks maybe found over 50' square. An orientation of these ripple marks of about 120° is common but layers of these structures less than ¼ inch apart maybe directed at an angle of 30° relative to each other.

Random thin sections made of quartzites near the top of the formation indicates that the quartz grains are well sorted and rounded while in some cases they are completely cemented by optically continuous quartz. The only heavy minerals noted were iron oxides and rounded grains of tourmaline. The grain size in different beds ranges from a medium sand to coarse silt.

Within 30' of the topmost massive member of the Pound Quartzite formation is found a consistant series of beds somewhat more argillaceous than the rest (arkosic) and several feet in total thickness containing abundant worm castings.

The Passage Beds

In the same manner that the Pound Quartzite is so consistent the passage beds are noted for their remarkable inconsistency due to lateral facies changes. This inconsistency presents some difficulties in placing the lower and upper boundaries, so this aspect will be discussed immediately.

(a) The lower Boundary of the Passage Beds

As stated above, the Pound Quartzite passes abruptly into the softer shales of the passage beds in most areas. Here one can place the boundary precisely within several feet in any given locality. Difficulties arise in several localities due to massive quartzite bands with intervening shales and coarse grained limestones, extending several hundred feet above the massive homogeneous formation. Fortunately, here as elsewhere, a prominent horizon containing worm castings were found. This horizon is persistent laterally as well as being very close to the top of the more homogeneous quartzite formation. As this boundary is also a prominent topographic feature, (the foot of the surrounding ranges) it is easily ascertained. Consequently it is a rock formation boundary and also probably a time stratigraphic horizon. Thus it seems to be a useful marker horizon for the upper boundary of the Pound Quartzite.

(b) The Upper Boundary of the Passage Beds.

Difficulties are experienced everywhere a gradual transition from one lithologic type to another is found; especially when no laterally persistent marker horizon occurs. The passage beds at their upper boundary generally grade from calcareous shales into shaley limestone and more massive algal or intraformational breccia beds. Unfortunately all variations occur in adjacent areas. Sometimes the passage beds end abruptly in a massive algal limestone, at others breccias lie 50-100' below the first algal horizon. Perhaps the most perplexing transition is that from quartzites, oolitic limestones, and shales, to breccia and algal limestones with shales. There is no marker horizon as the algal beds lense out rapidly along the strike and need not be structually a time equivalent. Consequently this boundary was drawn locally on lithologic distinctions with due regard to regional aspects. In other words those areas where the boundary is reasonably clear were joined by an appropriately curved line. This proved quite satisfactory as no ambiguities were found.

General Discussion -

The type sections given above cut across what has come to be regarded as typical passage beds and indeed at least 75% of their lateral extent in the Nepabunna area could be thus described. In this 75% one finds the normal transition from massive pound quartzite through light coloured shales, mudstones, and quartzites, to white and yellow soft shales or mudstones with frequently a ferruginous horizon at the top. Minor variations occur due to lateral lensing out of lithologic types, especially the quartzites and ferruginous horizons leaving the white and yellow shales predominant. The quartzites show excellent cross-bedding and frequently contain lenses of coarse grained illsorted material. This would suggest local shallow water conditions open to localised currents. Associated localised and minor red shales may support this view but could be the surface weathering product of reduced marine iron oxides.

The white and yellow mudstones are extremely soft and crumbly containing mica in some cases. The yellow colour is definitely due to iron oxide as it could be leached with nitric acid and reprecipitated as the hydoxide. Minor bands of siderite were found. Consequently these shales maybe considered as the leached or weathered remnants of former iron rich (Possibly pyrite) and in part at least calcareous mudstones. Coarse grained beds are generally non existent in this horizon.

At the upper boundary south of the Italowie Gorge is found a prominent horizon of concretionary limonite. Lesser occurrences were found in the middle of the passage beds both at Nepabunna (north and south limbs of the syncline) and Italowie. Similar and much more diminutive lenses of similar material are located in and at the top of the overlying limestone formation. The concretionary structures maybe several feet in diameter and upon weathering are large enough to provide shelters for kangaroos.

The remaining 25% of the passage beds exhibit a marked facies change. These occur in two main areas (a) At the southernmost part of the area where the Big John Creek cuts through the Pound Quartzite. (b) In an area extending from the Italowie Gorge, northwards to the vicinity of Mt. McKinlay. In these areas the massive underlying quartzite gives way to a thin shale member (usually less than 100' thick) followed by cross-bedded quartzite beds (1' - 2' thick). Interbedded with these are crossbedded (in part) oolitic limestones and varying amounts of shale. These may pass directly into algal limestones and calcareous shales. The oolitic limestones carry numerous quartz grains (10-15%) of similar size to the individual oolites. The total thickness of passage beds in these areas is about 750' in contrast with more than 1000' elsewhere.

Unfortunately the lateral transition from normal passage beds to the coarse grained equivalents is nowhere clearly visible as water courses or high level boulder gravels tend to cover these transition zones. However enough was visible to show that the lateral facies change is characterised by a gradual increase of quartzite beds at the base and extending further up toward the top, followed by a gradual lensing in of oolitic limestone beds. Some of these limestones contain quartz grains in a fine grained carbonate matrix which is probably a result of recrystallisation. In extreme cases the Passage beds may consist almost entirely of interbedded quartzites and oolitic limestones. The transition zone maybe from a few hundred yards to over 1 mile long.

<u>Nepabunna Limestone</u>

This limestone formation ranges from 2000' to almost 3000' in thickness and has been termed in this paper as the Nepabunna limestone. The lower boundary has already been discussed. The upper boundary is taken to be at the transition into calcareous shales just above the uppermost prominent bed of limestone containing hyolithids and small Archaeocyatha. The transition is gradual and the boundary often cannot be placed more accurately than ± 30'. This division was established after examination of the Nepabunna section where no fossils were found above this argillaceous member. Consequently these relatively thin shales and slates formed a convenient boundary between the underlying fossiliferous formation and the overlying non fossiliferous limestones. However further east towards the Italowie Gorge, Archaeocyatha were subsequently found within the slates and the overlying limestone. Consequently the grounds for separating this group into three formations must remain purely lithological.

The discussion will again be necessarily generalised as lateral transitions and lensing out dominate the sedimentary sequence. It is not a particularly massive formation as at least 80% consists of interlaminations of limestone and calcareous shale, each lamination being about 1" thick. The various more massive beds (1' - 6') are usually fossiliferous and distributed unevenly throughout the formation. These massive beds lie predominantly in the lower section beneath the Archaeocyatha, enabling the formation to be divided into two roughly equal members. (a) The algal limestone (b) The Archaeocyatha bearing limestones.

The algal limestone usually attributed to <u>Collenia</u> occurs from the base upwards, in massive beds from a few inches to 6 feet in thickness, to within 50' of the lowermost Archaeocyatha horizon. None have been found higher in the sequence. In the upper part of the algal limestone and below the Archaeocyatha the horizon massive beds containing vague algal structures different from <u>Collenia</u> are found. Throughout the algal members beds of intraformational breccia ranging from 2" to 1' in thickness are found. Softer beds of interlaminated calcareous shales and limestones form the greater part of this sedimentary sequence.

In its broader characteristics, the algal limestone member is comparatively uniform i.e. the thickness and number of algal beds does not vary greatly. In detail however variations occur. Thus the base is characterised by algal and breccia structures at Nepabunna - by homogeneous buff coloured limestones near the Italowie Gorge - and by breccia followed by algal structures at various intermediate localitied. At Italowie the last algal horizon is about 150' below the first Archaeocyatha while at Nepabunna the interval may be less than 50'. As noted above these algal beds lens out, seldom extending more than a few hundred yards along the strike. Consequently some areas have fewer massive algal beds and are compensated by a higher proportion of interlaminations of calcareous shales and limestones. The algal limestones are extremely fine grained, with some re-crystallisation, and contain about 10% acid insolubles of an argillaceous nature. No magnesium was found in the several representative samples examined.

The upper Archaeocyatha limestone shows marked variations in thickness and lithology. The thickness varies from 1100' at Nepabunna to 1800' near the Italowie Gorge. The corresponding localities on the north limb of the syncline have similar thicknesses so one may assume a general increase in this property toward the east. In studying the fossil horizons one can suggest where in the stratigraphic sequence this extra limestone was deposited. The basal Archaeocyatha limestone beds are the only large and prominent fossiliferous units in the whole Cambrian sequence in this area. These are usually $<$100' in total thickness so as they can be traced continuously throughout the area, except for some lensing out on the northern limb of the syncline, they form a valuable datum horizon. No easterly thickening can be detected in the strata below this horizon. Above this Archaeocyatha horizon a rubbly limestone is ubiquitous. Throughout this sequence maybe found lenses of Archaeocyatha, Hyolithes, and brachiopod bearing limestones. At Nepabunna a particularly rich horizon of small Archaeocyatha associated with hyolithids occurs about 50' below the narrow slate member. This can be followed intermittently along the strike to the vicinity of the Italowie section. Interest in this horizon stems from the fact that it is the uppermost fossil horizon found in this formation and roughly parallels the lower Archaeocyatha horizon. It also becomes progressively further below the slate member toward the east. So if this can be taken as a datum horizon it seems that the extra thickness of limestone was deposited above it. Unfortunately this horizon is not as well defined as the above discussion indicates and is lost eastwards as the rubbly limestones thin rapidly toward the Italowie Gorge. The overlying massive banded limestones probably represent a lateral facies change from the uppermost rubbly limestones. It seems that the uppermost horizon of hyolithids at Nepabunna has its equivalent horizon in the lower portion of the above-mentioned massive banded limestones. It is worthy to note that some of the thickening in the Italowie area may be tectonic. Much incompetent folding was observed i.e. beds of limestone were folded and contorted between other beds which were only slightly distorted. Some minor overthrusting was found.

From the above observations it seems probable that conditions changed in the east at about or just before the uppermost fossils occurred at Nepabunna, allowing the deposition of a much greater thickness of limestones in an equivalent time. It maybe significant in this connection to note the large amount of cubic crystals of limonite, which are pseudomorphs after pyrite, that occur in the limestones presently discussed around the Italowie section. These are somewhat rare at Nepabunna. As these crystals represent the concentrated portions of the finely disseminated iron sulphides which give the characteristic colour to all the Cambrian Limestones in this area, it seems that the presence of these crystals indicates either that a greater percentage of Fe sulphides occur in the Italowie limestones or greater tectonic activity caused the localised concentrations. The iron was not analysed but the percentage ca - carbonate (88%) and acid insoluble (11%) are very similar in limestones from both Italowie and Nepabunna. As the remainder when precipitated was iron in both cases it maybe assumed that the iron sulphide concentrations are similar in the two areas. Thus one may assume a reasonably constant bottom environment during the deposition of the analysed limestones. The limestones analysed occur near the Lower Archeaocyatha horizon. As the crystals are most prominent in the banded limestones which have no equivalent at Nepabunna it cannot be proved that the bottom environment was not constant over the area during their deposition. A greater concentration of iron in the east would represent more severe reducing conditions and probably deeper sinking which would allow greater thicknesses of sediments to accumulate.

The Narrow Slate Member

This horizon extends over the whole area ranging in thickness from 300' to over 600'. It is not a formation with very definite boundaries, nor is the lithology within these very consistent. The main purpose of making this division is to separate two limestones, one fossiliferous, the other largely devoid of fossils.

Where rubbly limestones occur at the Lower boundary a gradual transition takes place from laminated calcareous shales and limestones to calcareous shales with layers of limestone nodules and finally to calcareous shales and slates. The upper boundary exhibits a similar transition. The transition zone maybe over 50' thick so the boundary was often drawn at the change in topography rather than the observed change in lithology. This formation is usually softer than the surrounding limestones and forms a well defined valley when it outcrops. In the Italowie section however the boundaries are more definite as massive banded limestones lie on either side.

The overall change in lithology is from calcareous shales and slates at Nepabunna to predominatly dark grey calcareous slates between Nepabunna and Oocaboolina. In the Italowie region an intermediate limestone lenses in becoming quite massive with an horizon of Archaeocyatha.

This formation exhibits the general thickening toward Italowie noticed in the underlying strata. The presence of abundant Archaeocyatha in the thickest section may indicate more rapid filling than sinking.

Big John Creek Limestone

This is a generally massive bedded and somewhat argillaceous limestone lying conformably upon the abovementioned slates, and is herein termed Big John Creek Limestone. The top of this formation also passes conformably into slates.

Again notable lithologic changes may be noticed along the strike. In the vicinity of Nepabunna these limestones are massive with very little argillaceous material and occur in beds up to 1' in thickness. This may pass into an argillaceous limestone along the strike and then back into massive limestones. Towards the Italowie section the limestone becomes more argillaceous resulting in a hard laminated rock forming rugged ranges where it outcrops. These laminations are usually between 1" and 2" in thickness with the calcareous and argillaceous layers of equal thickness. Crystals of limonite, which are pseudomorphs after pyrite, are abundant in this section and are largely confined to the carbonate layers. The two layers are so similar in colour, grain size, and hardness that it would be difficult to differentiate them in the field if the argillaceous layer did not weather to a distinctive buff colour. In a thin section the boundary between the two layers is seen to be very abrupt although a small amount of calcite does continue throughout the argillaceous layer. The gradation from laminated limestone to massive limestone with little argillaceous material, was found to be through a thickening of the limestone laminations with consistent thinning of the argillaceous bands.

Similarly to the underlying strata this formation thickens significantly from 1000' at Nepabunna to 3000' near the Italowie Gorge. The latter thickness may not be true as notable amounts of incompetent folding, similar to that described in a previous section, occurs. This could add greatly to the thickness but even so it seems probable that the Italowie section is at least twice as thick as the Nepabunna section.

Random analyses show no dolomitisation.

The Oocaboolina Slate

This so far has been found to be an unfossiliferous formation of dark grey slates weathering to green-grey. These slates grade into argillaceous limestones at both the upper and lower boundaries. Several cleavages are always present but the cleavage which is parallel to the axis of the syncline is usually most prominent. These calcareous slates are soft and weather easily forming a generally low undulating topography except where deeply dissected by water courses. Crystals of pyrite are rare in these sediments but it seems likely that the dark grey colour is due to finely disseminated iron sulphides rather than organic matter.

Again a general thickening toward the east is indicated but may be unreliable due to tectonic thickening. This formation is referred to as the Oocaboolina Slate and attains a thickness of approximately 2000'.

Unnamed Limestone

This formation which is not formally named occurs along the axis of a syncline and being the uppermost horizon in the Cambrian sequence at Nepabunna its upper members have been lost by erosion. The lower boundary cannot be fixed precisely as the argillaceous limestone passes gradually into calcareous slates below. The generally low dips at the base also hamper fixing of this boundary.

No fossils have as yet been found in this formation. The proportion of argillaceous bands is generally rather high and only the upper section becomes predominantly limestone. Minor amounts of pyrite crystals are present, many of which have undergone only a slight replacement by limonite.

On the highest flat lying parts of this limestone was found a dissected capping of kunkar, several inches in thickness. The lower portion of this kunkar has a finely brecciated structure. This may represent a remnant of a former shallow soil which has been removed since the most recent uplift of the area.

more massive, thicker, and harder carbonates in this region which did not allow erosion to gouge out a smooth basin shaped surface in the given time. It also seems probable that the Italowie Gorge had not been cut at this stage so this area would have been surrounded on three sides by a hard wall of quartzite which would hamper deep erosion.

The Kunkar deposits probably represent a surface of no deposition near the centre of the basin where a shallow residual soil developed during the equilibrium which preceded the recent cycle of deeper erosion.

A more spectacular example of these elevated flat surfaces is found extending several miles eastward from the Italowie Gorge toward Lake Frome. This feature seems certainly to be of the same age as those within the Nepabunna area. Therefore the latter are not the result of a closed basin erosion cycle but are intimately related to re gional tectonic movements which increased the height of the Flinders Ranges relative to the Lake Frome Plains. These movements must have occurred in recent geological history as the subsequent erosion cycle is still at a very juvenile stage. The down cutting of the water courses after these movements is well displayed in the Italowie Creek where marooned creek conglomerates are found hanging on steep slopes up to 40' above the present creek bed. These marooned creek conglomerates are common over most of the Northern Flinders Ranges.

Thus the distribution of these high level gravels is controlled locally by topography but their formation is due to regional stability followed by relative block movements.

CONDITIONS OF SEDIMENTATION:

After the general stability which was characterised by the uniformly well sorted sandstones, there followed a period of renewed sinking. This sinking allowed the deposition of finer grained material. Some areas must have remained in shallow water environments as the sediments, such as sorted sandstoned and crossbedded oolites, indicate. It may have been that the whole area was under a shallow water environment with the oolites confined to areas of localised currents. In this connection the siderite found in the normal passage bed areas indicates a shallow water environment of deposition (Chillingar 1955). The lesser thickness of the Passage Beds in the oolitic limestone areas may be due to the sifting action of the localised currents which carried the elastic material to more stagnant areas of the depositional basin.

General stability or slow sinking with a dearth of clastic material resulted in the formation of shallow water limestones (algal and intraformational breccia) over the whole area studied at about the same time. This contemporaneity is established on several factors each of which is not individually sound but together they may have some significance. These factors are (a) the widespread appearance of algal limestones attributed to Collenia at or near the base of the limestones. These are not zone fossils but facies fossils and therefore probably only establish uniform shallow water conditions throughout this area at this time (b) a horizon containing Archaeocyatha and the brachiopod Kutorgina parallels this boundary perfectly over the whole area - there may also be facies fossils to some degree but they do suggest the sudden appearance of a certain environment over the whole area parallel to and conformably above the lower uniform boundary environment. Thus by extrapolation the lower boundary may be considered roughly equivalent in time over its whole extent. This shallow water environment continued until at least the time of deposition of the lowermost Archaeocyatha horizon. Sometime after the lower Archaeocyatha beds but before the uppermost hyolithid bed was deposited, sedimentation became more rapid toward the east allowing more than twice the thickness of equivalent strata to form. The change in thickness is gradual and not abrupt at any locality. As sinking was previously uniform over the whole area as indicated by uniform contemporaneous environments and there is no evidence of a line of flexure it seems reasonable to postulate a continued uniform sinking after the time of the Lower Archaeocyatha deposit. Thus an increase of clastic sediment supplied to the eastern section would be responsible for the increased thickness in that area. The argillaceous character of the Big John Ck. limestone in the east compared with the massive relatively pure limestone at Nepabunna supports this conjecture. The disappearance of fossils (ending with the pelagic? hyolithids) at this change may indicate a general sinking more rapid than the contemporaneous sedimentation resulting in a bathyal environment. Such an environment probably did not support organisms that secrete hard parts in Cambrian times and would explain the absence of fossils in the Nepabunna area where this bathyal environment prevailed. Near Italowie sedimentation was greater and a shallow water environment again prevailed resulting in Archaeocyatha and intraformational breccia being found in the middle limestone. It is interesting to note that limonite pseudomorphs after pyrite become prominent only above the Lower Archaeocyatha horizon. This may indicate more severe reducing conditions or a deeper water environment during deposition above the Archaeocyatha horizon.

The appearance of calcareous slates above the limestones probably represents increased supplies of clastic material rather than more rapid sinking. Thus there is a great thickness of Cambrian sediments (9000' maximum) with alternations of clastic and non clastic material. Actually the whole series represents a series of transitions between argillaceous and carbonate sediments this suggests an unstable environment with sporadic sinking. These sediments are typical of miogeosynclines and the thickness is of the right order for the time interval they represent.

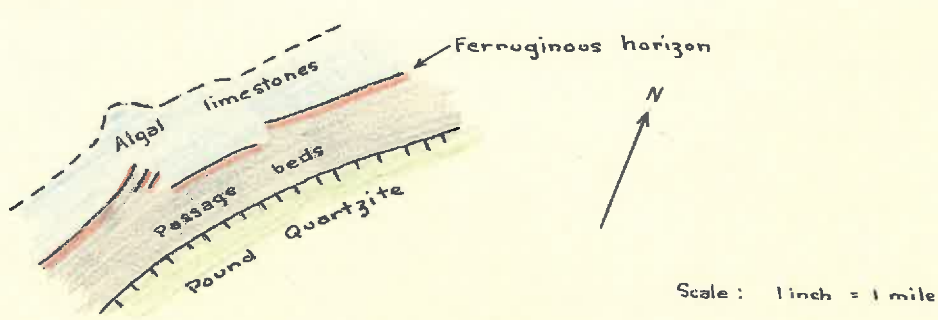
The sediments decrease in thickness toward the west suggesting the old craton lay in that direction. It seems that much of the clastic sediments came from positive areas within the postulated eugeosyncline in the east. Argillaceous material was probably carried from the craton to this area also.

STRUCTURE:

After the deposition of the Cambrian sediments described above, compressive forces caused folding of these strata. These movements resulted in a series of anticlines and synclines with their axes orientated east-west. Buckling occurred at right angles to this deformation resulting in a subordinate series of synclines and anticlines with their axes orientated in a north-south direction. This resulted in a series of basin and dome structures to which the Nepabunna Basin owes its origin. It is this folding which enabled the uppermost deposits in the geosyncline to be preserved in the synclinal areas. The Nepabunna structure is part of a major syncline stretching almost across the northern Flinders Ranges from east to west and known as the Angepena Syncline.

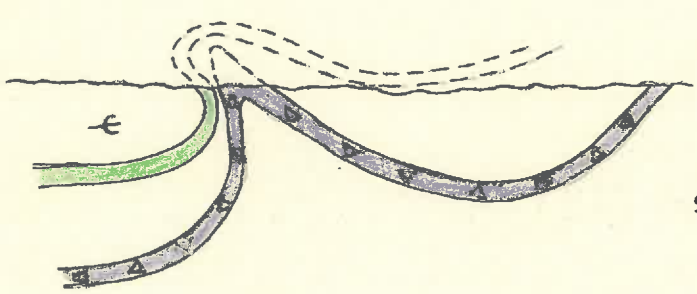
The Nepabunna structure is essentially a major east-west syncline in which is contained a smaller anticline. The growth of this anticline was hampered by forces parallel to its axis which buckled and flattened it forming the present basin shaped structure. The plasticity of the strata was such that this deformation proceeded without any major dislocations. The strong quartzite formation probably acted as a firm support for the softer overlying strata which were able to conform with the comparatively open folding of the former. It will be shown later that there is evidence of movement between the Pound Quartzite formation and the underlying strata.

The softer incompetent passage beds yielded during the folding resulting in some internal folding and over-thrusting. The best examples of these occur along the north-west side of the Hawker Hill Range Dome.

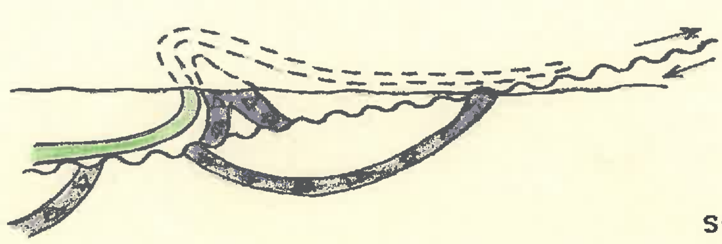


The major dislocation is illustrated above as it appears in outcrop. It is evident that the compressive forces caused a buckle which ruptured resulting in the upper ferruginous horizon of the passage beds being forced into the overlying limestones. This dislocation was accommodated in the overlying limestones by small scale folding and buckling. An Archaeocyatha horizon 1000' stratigraphically above this dislocation is displaced less than 30' corresponding to the several hundred feet of the thrust itself. This was a complementary movement allowing the relief of localised stresses within both formations.

Immediately east of the Italowie Gorge a thick tillite is found separated from the greatly decreased thickness of quartzite by about 200' of strongly stressed green slates which probably belong to the Marinoan. Obviously some faulting and pinching out of beds has occurred, perhaps similarly to the north-west fault on the western side of the ranges. North of the gorge a dome structure in the Pound Quartzite formation has been cut in half along a north-south line. The outcropping sediments have the same relationship to each other along this line as they do at the Italowie Gorge. Similarly to the south of the gorge the eastern side of the Hawker Hill Range Dome is truncated. Regional structure shows that this fault is the continuation of a major feature known as the Paralana fault.



Stage I



Stage II

As there appears to be a fault on both sides of the tillite outcrop the structure may be as depicted above, i.e. in stage one an anticline is formed in which the softer shales and slates were pinched out between the harder quartzite and tillite. With further compression a rupture occurred between the hard quartzite and the underlying strata resulting in a low angle thrust fault.

North of Wooltana and Paralana fault consists of a low angle thrust which has displaced Torrensian sediments some distance onto Archean rocks. Consequently there is no reason why a low angle thrust should not occur in the area now under discussion. In connection with this fault an area approximately 5 miles to the west of the Italowie Gorge maybe significant. This area has been described on the map as a crush zone.

This is a roughly rectangular area surrounded on three sides by massive quartzite ranges and on the fourth by Cambrian strata. The area was not studied in great detail but sufficient is known to comment on the general structure. A syncline with a N-S axis runs through the middle of the area flattening out toward the south. Almost at 90° to this/an anticline plunges at a low angle to the west. Covering the area, where not eroded away, is a flat undulating layer of highly metamorphosed quartzitic rock containing angular and rounded (by melting) quartzite fragments, the whole having a characteristic dark reddish brown colour. The contact of this zone with the overlying unmetamorphosed quartzites may be seen for about 1½ miles where the Big John Creek cuts in close against the Hawker Hill Range. Here is found a sharp contact between unaltered but highly cleaved quartzite and the red brown metamorphosed rock below. Within the metamorphosed zone is a gradation from non-brecciated above to highly brecciated near the creek bed. Below the breccia were found highly metamorphosed purple and green slates with a near vertical dip and NE-SW strike in contrast to the 15° dip to the south of the overlying quartzite. This high angle of dip and N-S strike was noted in many and widespread localities in the area. These facts indicate that relative movement other than a bedding plane slip has occurred between the Pound Quartzite and the underlying strata. From south to north the fault cuts firstly the transition bed then down through the Quartzite (probably over 1000'), and finally disappears beneath the top of the Pound cutting transition beds near the axis of the syncline. Therefore the fault plane is very nearly flat or mildly domed.

Consequently although the structure is that of a syncline cutting across an anticline localised upwarping especially along the western primeter where the strata dip outwards instead of inwards, indicates some vertical force acted within or below the strata. This upwarping could be explained as being due to a horizontal stress converted to a vertical stress in order to relieve the compressive forces (buckling). But the relative movement between two different formations suggests that the underlying sediments were forced upward into the quartzite formation. The relatively mild upwarping of the Pound quartzite is hardly responsible for the great thickness (at least 50') of metamorphosed material between the two formations. Consequently some lateral movement is indicated. Therefore it is possible that this crush zone is a window into the low angle? Paralana Fault. It has been observed further north that the low angle Paralana fault thrust has an undulating fault plane. This structure may have appeared because it lies on an upwarped section of the fault plane.

This explanation is purely hypothetical and will require a large amount of regional study to prove or disprove.

COMPARISON WITH OTHER AREAS:

Comparison with other Cambrian strata in the Flinders Ranges.

The nearest Cambrian strata to the Nepabunna section occur in a syncline south of the Hawker Hill Range. As this syncline bears a simple structural relationship to the Nepabunna area it is evident that the two areas were once a continuous depositional basin with only the normal variations in environment which are characteristic of such an area.

The faunal succession and lithology are sufficiently similar that a fossil horizon missed on the outward traverse was found after sundown on the way back because its exact position could be ascertained from the abovementioned characteristics.

In detail:

(a) Passage Beds: These consist of soft shales followed by cross-bedded quartzite and oolite beds with minor argillaceous bands. Algae (Collenia) appear about 400' above the base. As a shale with ferruginous bands appears above the algae some difficulty is experienced in correlating the upper boundary here with that at Nepabunna. But above this shale band intraformationally brecciated limestone appears together with algae and therefore by analogy with Nepabunna. The boundary of the Passage Beds would be placed between these two horizons. This section is very similar to the passage beds around the Big John Creek just north of the crush zone. The thickness of these southern Passage Beds is 1100' compared with 700'-800' for comparable strata in the Nepabunna area.

(b) Nepabunna Limestone: Above the Passage beds the limestones (algae and breccia) are highly argillaceous but within 200' they grade into massive limestones in beds 6" to 1' thick. Generally the limestones up to the Archaeocyatha horizon are much more massive than corresponding strata at Nepabunna. The Archaeocyatha horizon lies just above the last algal bands and contains the brachiopod Kutorgina, similarly to the corresponding strata further north. As at Nepabunna immediately above this Lower Archaeocyatha horizon there appears the ubiquitous rubbly limestone containing small bands of Archaeocyatha and hyolithids. The rubbly limestone grades into banded limestones which appear identical to those at a corresponding horizon on the northern limb of the syncline north of the Italowie section. These have bands of Archaeocyatha and hyolithids to within several hundred feet of a shale and slate horizon which probably corresponds to the narrow slate horizon at Nepabunna. The Archaeocyatha limestone is 3900' thick compared with 2800' at Italowie. As at the latter location the extra thickness of sediments occurs above the Lower Archaeocyatha horizon.

(c) The light coloured calcareous shales and slates are 1100' thick compared with 700 at Italowie. They also contain a conspicuous quartzite band 2' thick.

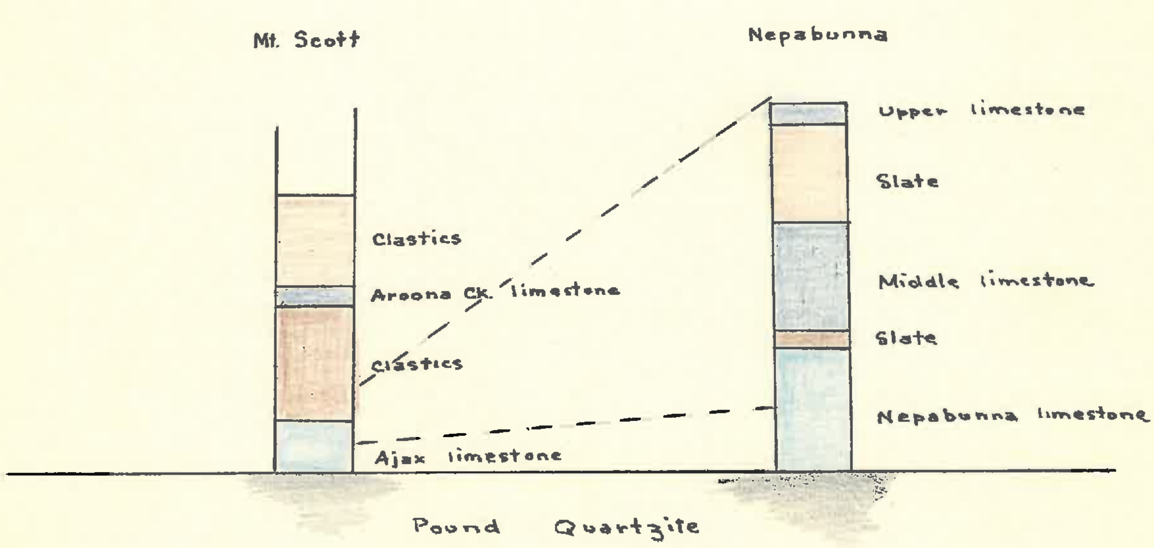
(d) Above the shales, bedded limestones (The Nepabunna Lmst.) with thin argillaceous layers occur which are not unlike those of the middle limestones (Big John Ck. Lmst.) directly to the north. These occur in the axial part of the syncline and are of unknown thickness.

Conclusions

The two areas discussed above do have marked similarities in faunal succession and lithology. Therefore it is practicable to correlate the corresponding formations even to the extent of using the same names in both areas. An interesting feature is the comparable thickness of corresponding strata in the two areas up to the Archaeocyatha horizon above which thicknesses of corresponding strata are considerably less at Nepabunna. There is no evidence of tectonic thickening along the section studied in the Wertaloona syncline. The true significance of this sudden increase in thickness will only be elucidated by further measured sections across the Wertaloona syncline.

Other areas of Cambrian sediments in the Flinders Ranges have many lithologic similarities with the Nepabunna section but lack of good faunal succession in the latter area hampers any precise correlation. The only distinctive fossil found at Nepabunna is the brachiopod, Kutorgina peculiaris. This occurs in Daily's faunal assemblage No 2 which places it in the Lower Lower Cambrian. As this assemblage occurs in the lower part of the Ajax Limestone at Mt. Scott, the Nepabunna limestone may be correlated with this. The Big John Creek limestone is very similar lithologically to the Parara Limestone. As the upper part of the Nepabunna sequence is largely a transitional series of carbonaceous and argillaceous beds it seems that the whole sequence above the Nepabunna limestone maybe a somewhat more argillaceous equivalent of the Parara Limestone. Consequently the Oocaboolina slates may be equivalent to the lower part of the clastics below the Aroona Creek Limestone.

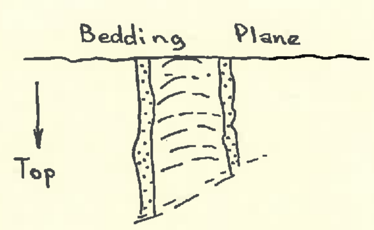
Therefore the sediments above the Pound Quartzite at Nepabunna all belong to the Lower Cambrian. As the uppermost strata have been eroded away, sedimentation probably continued to the upper Lower Cambrian at least.



Fossils present in the Cambrian Strata of Nepabunna

Firstly it may be appropriate to mention the evidence of life in strata immediately below the lowermost Cambrian. Near the upper boundary of the Pound Quartzite Formation there occurs a series of siltstone beds whose total thickness would be less than 15'. No bedding or other sedimentary structure may be distinguished within these beds. But organic structures which appear to be worm castings are prominent. These casts may be cylindrical and segmented, being orientated perpendicular to the bedding plane. Basically the same structures may be observed in coiled or randomly curved attitudes on the bedding planes (see specimen No. 1). In a cross section of the rock perpendicular to the bedding plane, these structures may be observed to be parallel to the latter turning sharply to a position perpendicular to the bedding. These worm casts are usually less than $\frac{1}{8}$" in diameter and may be more than 2" in length.

Another structure found in this same horizon is also attributed to worms. Here there are two vaguely segmented casts (similar to the above) parallel to each other and about $\frac{3}{4}$" apart. Between these two tubes is a vageuly layered structure as illustrated below.

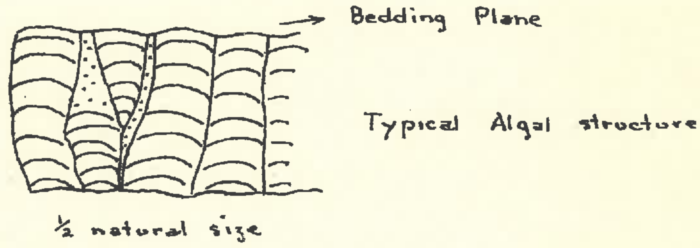


See Specimen No. 2.

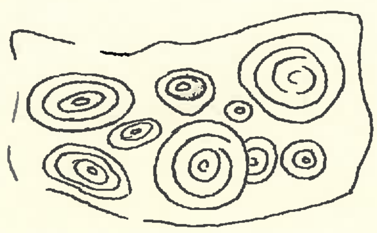
A thin section of this rock revealed that it is riddled with similar structures. The rock is a feldspathic siltstone containing silt sized angular grains of fresh feldspar and quartz with iron oxides interspersed between and surrounding them but concentrated outside of the worm casts. Otherwise there is no petrological difference between the worm cast and matrix.

Indefinite worm casts were found in ferruginous siltstones of the lower Passage Beds. (Specimen No. 3).

The next evidence of organic life is found in the lower half of the Archeaocyatha limestone. Here there are beds up to 6' in thickness containing structures usually attributed to the algae known as Collenia. These form in vertical laminated cylinders.



The laminations are separated by more argillaceous fine grain limestone as are the individual columns.



In cross section the columns are found to consist of concentric rings, light and dark material.
These algal limestones range from the base of the Archaeocyatha limestone to within 50' of the lowest Archaeocyatha horizon.

From several hundred feet above the base of the Archaeocyatha limestone up to the Lower Archaeocyatha horizon there occurs another structure which could have been formed by another type of algae or may be inorganic. These show irregular columnar structures with equally irregular cross sections. A thin section reveals a laminar or concretionary interval structure (see spec. No. 10).

Another structure which may be attributed to algae is found weathered out on the surface of fine grained blue grey limestones about 50' below the lowest Archaeocyatha near the Italowie section. The surface exposure appears to be as depicted below. The complete structure is never found (specimen No. 11).

Many other small structures described as micro breccia found throughout the Lower Archaeocyatha limestone are probably inorganic sedimentary structures (Specimen No. 9).

The first Cambrian fossils occur over 1000' above the base of the basal Cambrian limestone. Here there is a highly fossiliferous horizon containing Archaeocyatha, two species of brachiopods and another gastrapod-like fossil of unknown affinities.

The individual fossil beds in this horizon are 1'-5' thick being composed almost entirely of fossil remains with infilling of fine grained limestone.

Archaeocyatha are the most numerous fossils present. Although silicification is rare many specimens may be found weathered out on the surface of the rock within rarer cases the internal structure clearly distinguishable. It was found that all the fossils studied belong to the class Archaeocyathea with a predominance of representatives from the Family Coscinocyathidae Taylor. One specimen studied allowed classification to genus level. This is Coscinocyathus Born, consisting of a funnel shaped structure with normal perforated walls and radial parieties. The intercallum is crossed by perforate, horizontal tabulae.

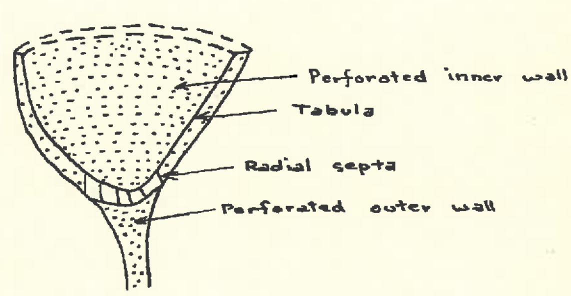


Diagram of Coscinocyathus Born.

Specimen No. 12.

Together with the first appearance of Archaeocyatha there occurs the inarticulate chitinophosphatic brachiopod, Kutorgina peculiaris Tate . This fossil does not appear along the whole lower Archaeocyatha horizon but occurs in localised areas where it maybe found 150' stratigraphically above its first appearance.

An unidentified calcareous brachiopod is found within the lower Archaeocyatha horizon at Nepabunna becoming e xtremely abundant locally but extremely rare elsewhere. This brachiopod has b een found only as sections in rocks. It is confined stratigraphically to t he lower part of the Kutorgina beds.

Various unidentified Hyolithids occurs stratigraphically above Kutorgina and below the Narrow Slate Member.

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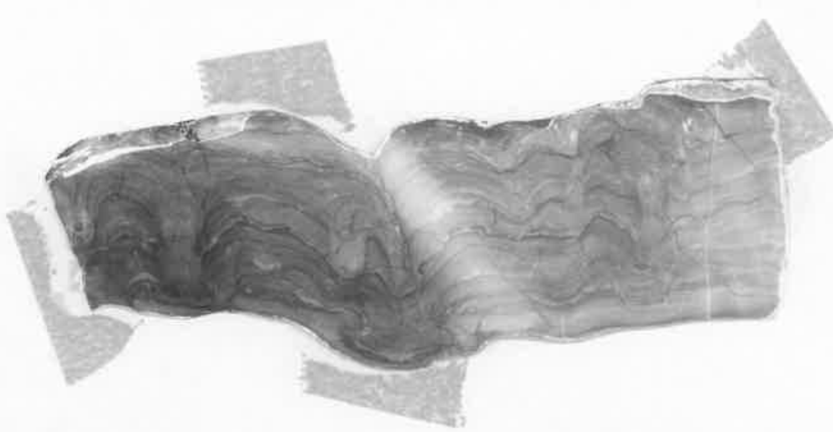
P L A T E   I

Intraformational Breccia from base of Lower Limestone at ITALOWIE. ¾ Natural Size.

Cross section of Algal (Collenia) Limestone. 2/3 Natural Size.



Vertical section of Algal Limestone., 2/3 Natural size.

PLATE 2

Small scale folding in the middle limestones near Oocaboolina.

Typical large high level boulder gravel dissected by the Italowie Creek.

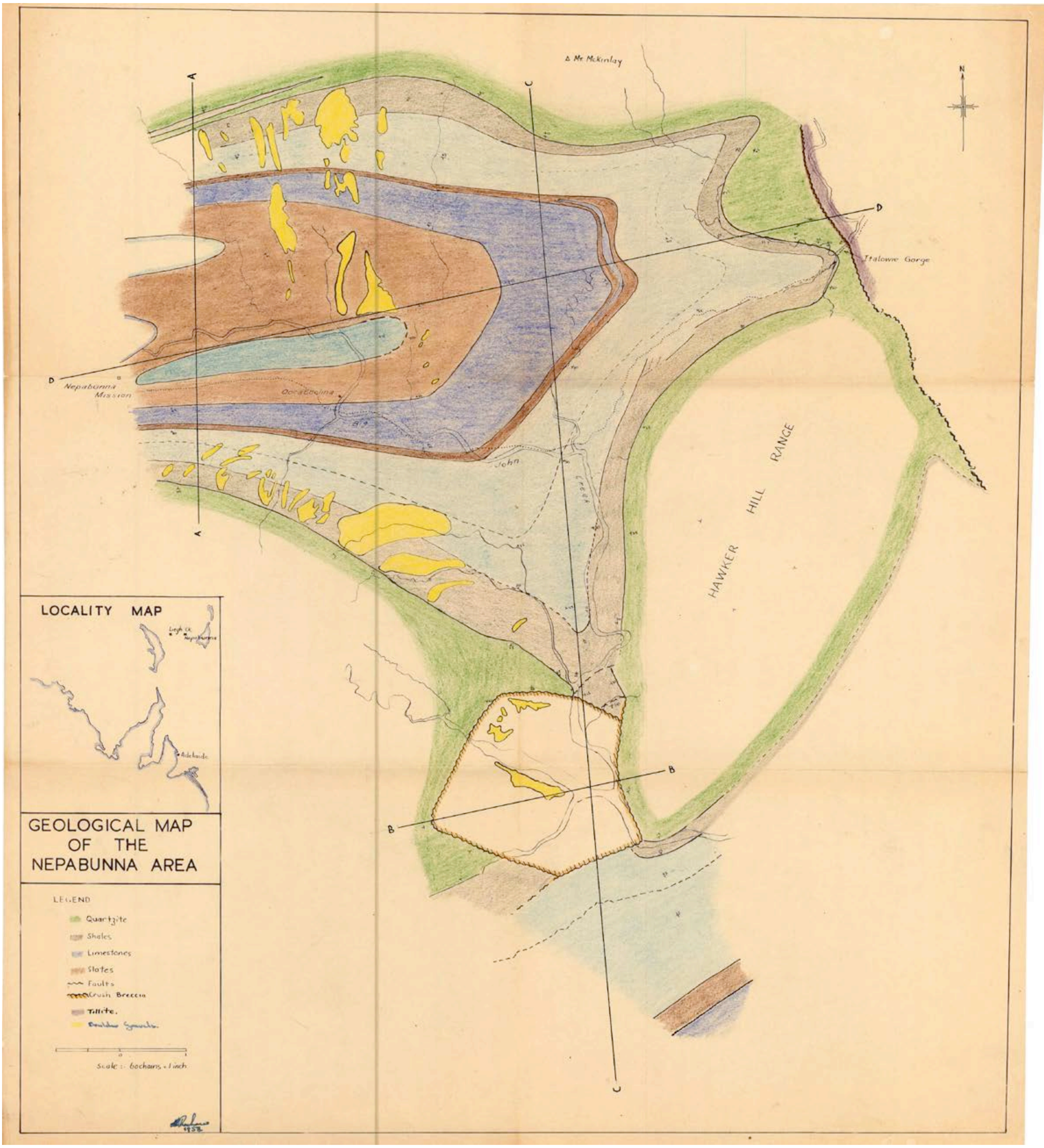
Passage beds in Foreground, Nepabunna limestones in background. Photo taken on side of Hawker Hill Range 2 miles South of Italowie Gorge.

PLATE 3

Outcropping slates at their lower boundary, north east of Oocoboolina.

Crush breccia in centre foreground, Passage beds in centre left, Pound Quartzite of Hawker Hill Range in Background.

Limestones just above the lowest Archaeocyatha horizon with the Italowie Gorge almost hidden in the background.



GEOLOGICAL MAP
OF THE
NEPABUNNA AREA
LOCALITY MAP
Leigh Ck.
Nepabunna
Adelaide
LEGEND
Quartzite
Shales
Limestones
Slates
Faults
Crush Breccia
Tillite.
Scale :- 60chains = 1 inch
Mt McKinlay
Nepabunna Mission
Ooratoolina
John Creek
Italowie Gorge
HAWKER HILL RANGE
A
B
C
D
N
1953

STRATIGRAPHY & STRUCTURE OF THE NEPABUNNA AREA