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THE GEOLOGY OF THE CARNARVON BASIN, WESTERN AUSTRALIA

Part 2: PERMIAN STRATIGRAPHY

BY

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GEOLOGY OF THE CARNARVON BASIN, W.A.

Part 2 : PERMIAN STRATIGRAPHY

DEPARTMENT OF NATIONAL DEVELOPMENT

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Addition

P. 39 last line add " and the east side of the Wandagee Ridge between Lyndon and Wooramel Rivers and the west side of that ridge in the Exmouth Gulf region."

Corrections

Page 39 line 4 " few pectinids " instead of " new".

Page 54 line 15 " from " instead of " form".

Page 60 Fig. 62 Heading on right-hand column should be BILUNG NOT BILUNA CREEK.

Page 62 Heading of distribution chart " Species OR genus".

Page 68 line 37 " 273 feet " instead of " 230 feet".
line 38 Column 5 instead of Column 4.
line 39 " 282 feet " instead of " 210 feet ".
and Column 6 instead of Column 5.
line 8 180 feet instead of 175 feet.
and Column 7 instead of Column 6.

Page 69 line 8 240 feet instead of 235 feet.
line 9 Column 10 instead of Column 9.
line 12 Column 11 instead of Column 10.

Page 87 line 18 Moogooloo instead of Moogoloo.

Page 101 line 8 $6\frac{3}{4}$ instead of $8\frac{3}{4}$.

Page 124 Fig. 101 Heading of second column—Donellys Well instead of Donollys Well.

Page 140 Fig. 110 Donellys Well instead of Donollys Well.

Page 143 Fig. 113 (Column 4) Donellys Well instead of Donollys Well.

Page 174 line 26 " his " instead of " this".

CONTENTS

FIGURES

FIGURES—*continued* Page

PREFACE

The report on the Geology of the Carnarvon Basin is issued in three separate and relatively independent Parts. Each Part treats an individual section of the subject and is accompanied by a Summary and an appropriate list of References.

Part 1 deals with the Pre-Permian Stratigraphy and also includes a General Summary and other introductory information. Part 2 deals with the Permian Stratigraphy and Part 3 details the Post-Permian Stratigraphy and also contains information on Regional Structure, Palaeogeography, and Economic Geology.

These Parts are being published separately, but, as they are parts of a single report, text-figure numbers are continued through the Parts. The regional map of the basin is included in Part 1.

GENERAL SUMMARY

The Carnarvon Basin is an epicontinental basin of Proterozoic, Palaeozoic, Mesozoic, and Tertiary sediments. On land it extends from Onslow in the north to near Geraldton in the south and eastwards from the coast for about 130 miles.

Proterozoic and Lower Palaeozoic sediments crop out at the south end of the basin. Silurian dolomite has been found in bores; marine Devonian sandstone, limestone, and siltstone crop out at the north-eastern edge of the basin and are found in bores in the central coastal area. Lower Carboniferous marine limestone and greywacke overlie the Devonian in outcrop; the limestone is doubtfully recognized in coastal bores. Permian marine sediments, including marine glacial sediments, rest unconformably on Lower Carboniferous, Devonian, and Precambrian rocks. Jurassic rocks are known in outcrop only on the far northern and southern margins, but form an important part of the subsurface sequence in the northern coastal area. Cretaceous marine sediments rest unconformably on Precambrian, Permian, and Jurassic rocks, mainly in the western part of the basin. Tertiary sandstone rests unconformably on Permian and Cretaceous rocks in a belt running north-south in the centre of the basin; Tertiary limestones cover the Cretaceous rocks near the coast. Maximum known thicknesses are: Proterozoic, about 30,000 feet; Lower Palaeozoic, 10,600 feet plus possibly 10,000 feet; Devonian, 4800 feet; Lower Carboniferous, 2300 feet; Permian, 15,200 feet (Sakmarian 7200 feet, Artinskian 5500 feet, and Kungurian 2500 feet); Jurassic, 11,460 feet; Cretaceous, 2670 feet; and Tertiary, 1500 feet.

The Palaeozoic sediments were laid down on a surface of Precambrian rocks with strong relief. Minor basins sagged as sediments were laid down, and increased the original major structural relief. No evidence has been found of tangential stress in the sediments of the basin: all structures from the largest to the smallest are depositional structures affected only by large-scale down-warping.

The geological history of the basin is related to intermittent transgression and regression of the sea which may have been caused by large eustatic rises of sea level or by epeirogenic movements of the continent or its margin.

The basin is regarded as likely to contain commercial accumulations of petroleum, because of the combination of source beds in Devonian, Permian, Jurassic, and Cretaceous formations, reservoir beds in Devonian, Permian, Jurassic, and Cretaceous formations, and structural relief which has been present since deposition of the sediments.

The underground water resources of the basin are indicated: several good artesian aquifers are established.

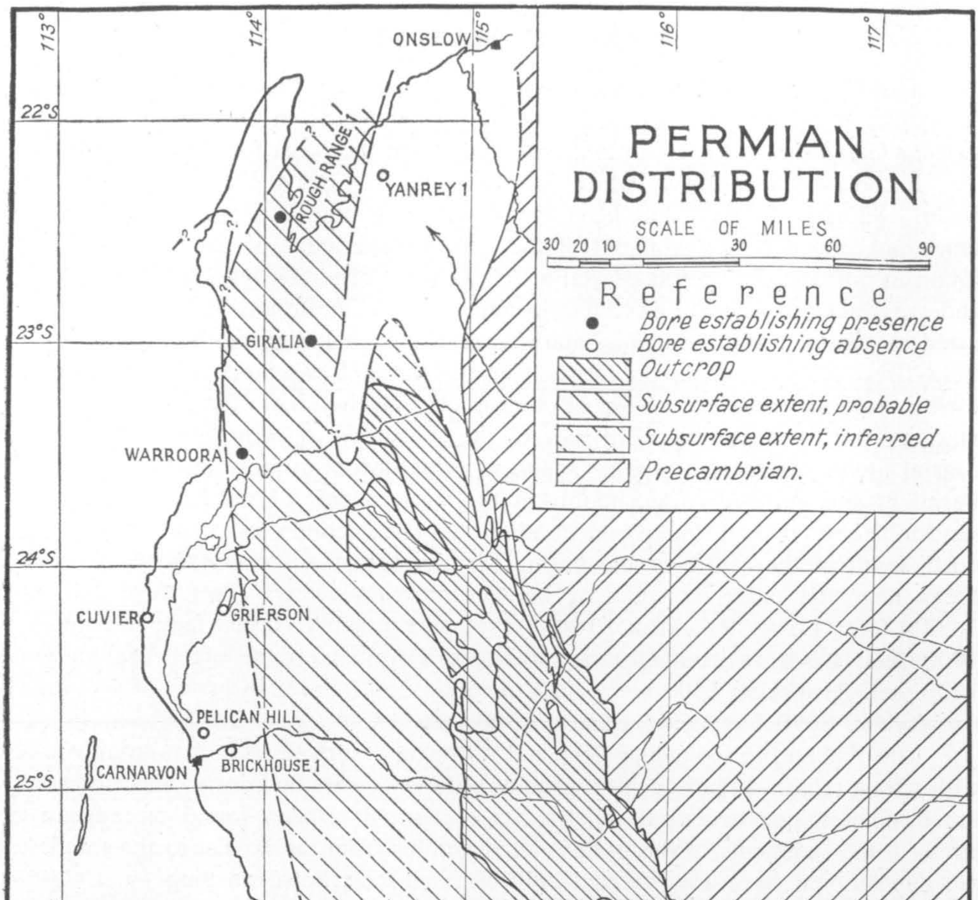


Fig. 33. Distribution of Permian rocks.

PERMIAN STRATIGRAPHY

SUMMARY

Permian sediments crop out over a very large area of the eastern part of the Carnarvon Basin and are known in bores in the northern part of the Gascoyne Basin (Fig. 33). The lithological units and their correlation are shown in the Table (at the back of this Bulletin) and Figure 34. In general, the Permian sediments rest unconformably on Lower Carboniferous, Devonian, Lower Palaeozoic, and possibly Upper Proterozoic sedimentary rocks and on Precambrian schist, gneiss and granite. They are overlain unconformably by Cretaceous and Eocene sediments in outcrop and by Jurassic and Cretaceous sediments in outcrop and by Jurassic and Cretaceous sediments in the subsurface. The Permian sediments are mainly structurally concordant among themselves, although there are several important erosional unconformities within the sequence. They range in age from Sakmarian to Kungurian (Nalivkin, 1938). The Upper Permian is not represented.

Sakmarian sedimentary rocks crop out from the Lyndon River to the Murchison River and are widespread below the surface. They are mainly glacigene and deposited in the sea or in lakes. They rest unconformably on Carboniferous, Devonian, Lower Palaeozoic, and Proterozoic sedimentary rocks and on Precambrian schist, gneiss, granulite and granite. In places the underlying surface is striated by ice erosive action. The Sakmarian sediments are overlain disconformably or unconformably by Artinskian, Jurassic, Cretaceous, and Tertiary sedimentary rocks.

The Sakmarian sequence included sediments deposited in a succession of glacial and interglacial periods. Both marine fossils and varves occur sporadically through the sequence, which has a maximum known thickness of 7900 feet.

Because it includes marine shales and porous sandstone and calcarenite formations, the sequence must be regarded as prospective for oil exploration. It probably has not yet been drilled on a closed structure.

The Artinskian and Kungurian Stages comprise dominantly terrigenous marine sediments of a maximum thickness of about 12,000 feet. Three significant hiatuses are known within the sequence, which rests disconformably or unconformably on the Sakmarian sedimentary rocks and the Precambrian crystalline basement. Jurassic and Cretaceous marine sediments unconformably overlie the Permian.

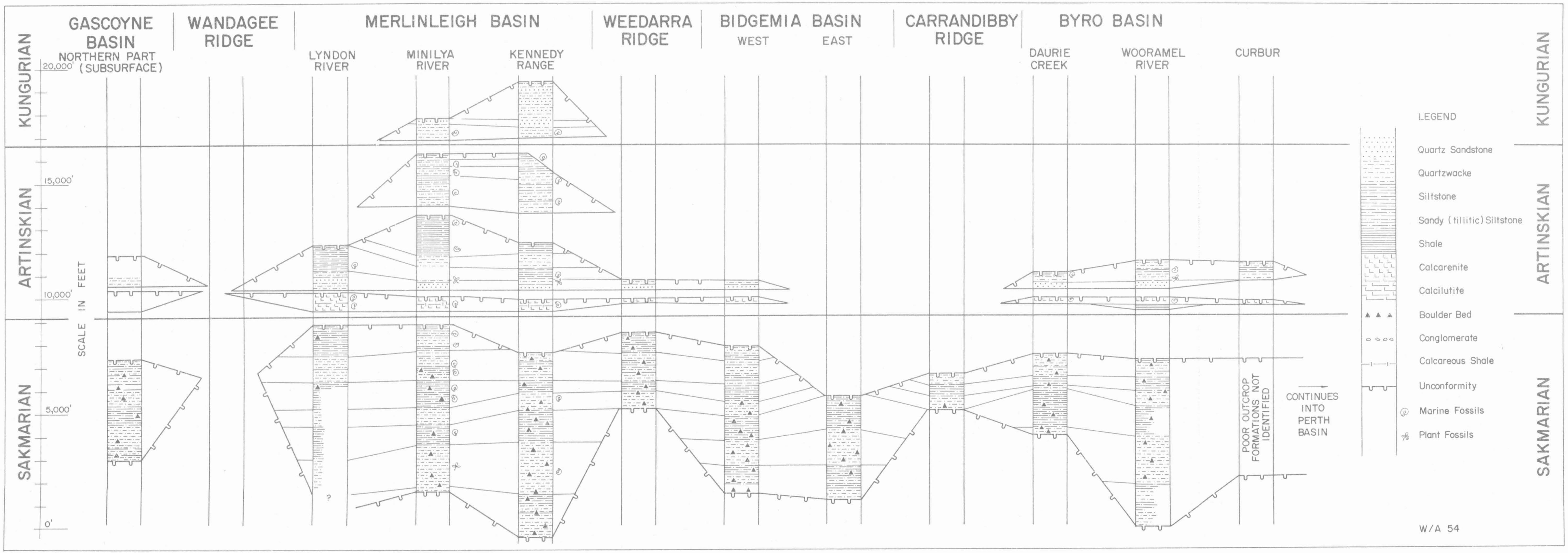


Fig. 34. Permian stratigraphy.

SAKMARIAN

The Sakmarian is accepted here as the oldest stage of the Permian (Nalivkin, 1938). The Carnarvon Basin sequence has been correlated with the Sakmarian on the basis of the affinities mainly of brachiopods and pelecypods in this sequence and in the Sakmarian of India and Russia. None of the established zonal foraminifera has been found in the Carnarvon Basin rocks.

The sequence consists of a restricted basal quartz sandstone with plant fossils (Harris Sandstone) and the glacigene Lyons Group, comprising, from the base upwards, Austin Formation, Coyango Greywacke, Dumbardo Siltstone, Koomberan Greywacke, Mundarie Siltstone, Thambrong Formation and Weedarra Shale.

Harris Sandstone

The Harris Sandstone (Condon, 1954, p. 31) is the formation of clean quartz sandstone resting disconformably on the Yindagindy Formation and conformably beneath and grading laterally with the Austin Formation of the Lyons Group. It contains some Lepidodendroid plant fossils.

A re-examination of the areas included (Condon, 1954, p. 32) in the Harris Sandstone has shown that the outcrops north and south of Moogooree should not be included in this formation, as the lithology is different from that in the type locality—it is dominantly of silty quartzwacke, with siltstone and tillitic beds. The outcrop of the Harris Sandstone, therefore, is restricted to the belt running from ½ mile north to 4 miles south of the type locality (Fig. 36) which is 3½ miles north of the Middalya-Williambury road and 5 miles north-west of Williambury (at Lat. 23° 48¼′ S., Long. 115° 5¾′ E.).

The type section (Fig. 37) runs from near the base of an east-facing scarp; the boundary of the Harris Sandstone and the Yindagindy Formation is not well exposed, but can be located by the shed of ferruginous material from the top of the Yindagindy. The lower part of the Harris is well exposed in the upstanding hill, but the upper part is well exposed only in a very small watercourse in the plain to the west of the hill. The boundary with the Austin Formation is fairly well exposed about 50 yards west of the western base of the hill.

Formation Boundaries.—The base is at the sharp change of lithology from ferruginous greywacke to clean quartz sandstone; the top is taken at the change from clean quartz sandstone with pebbles to quartz greywacke with pebbles and cobbles. This boundary is gradational, but can be established readily because of the absence of silty matrix, feldspar, and mica from the Harris Sandstone and their presence in the Austin Formation.

Relationships.—In the outcrop area the ferruginous top of the Yindagindy Formation and the sharp change in lithology to a clean quartz sandstone at the base of the Harris Sandstone indicate a disconformity, which is confirmed by the erosional unconformity that develops in this stratigraphical position farther south.

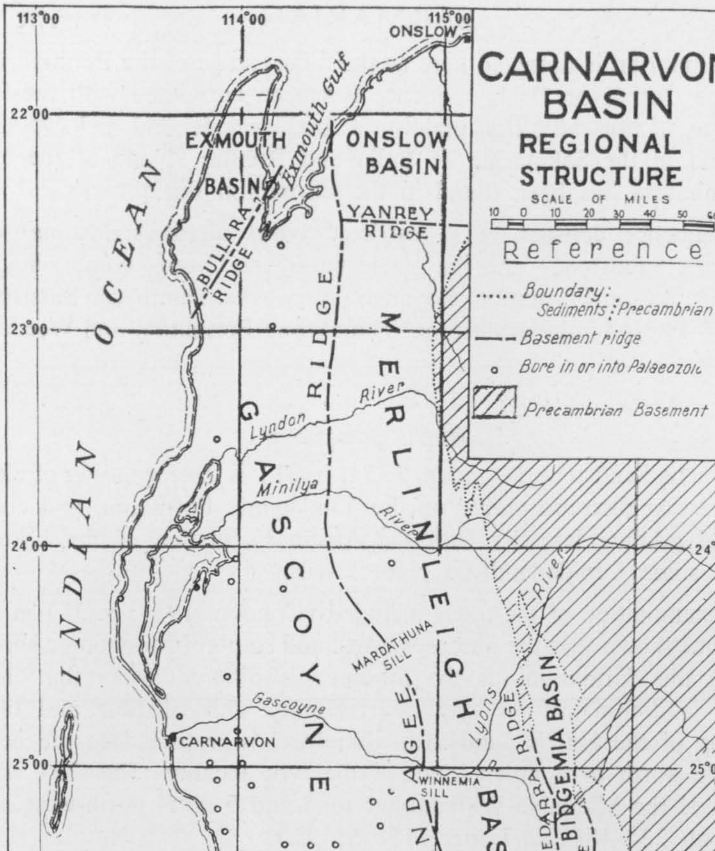


Fig. 35. Regional structure of the Carnarvon Basin.

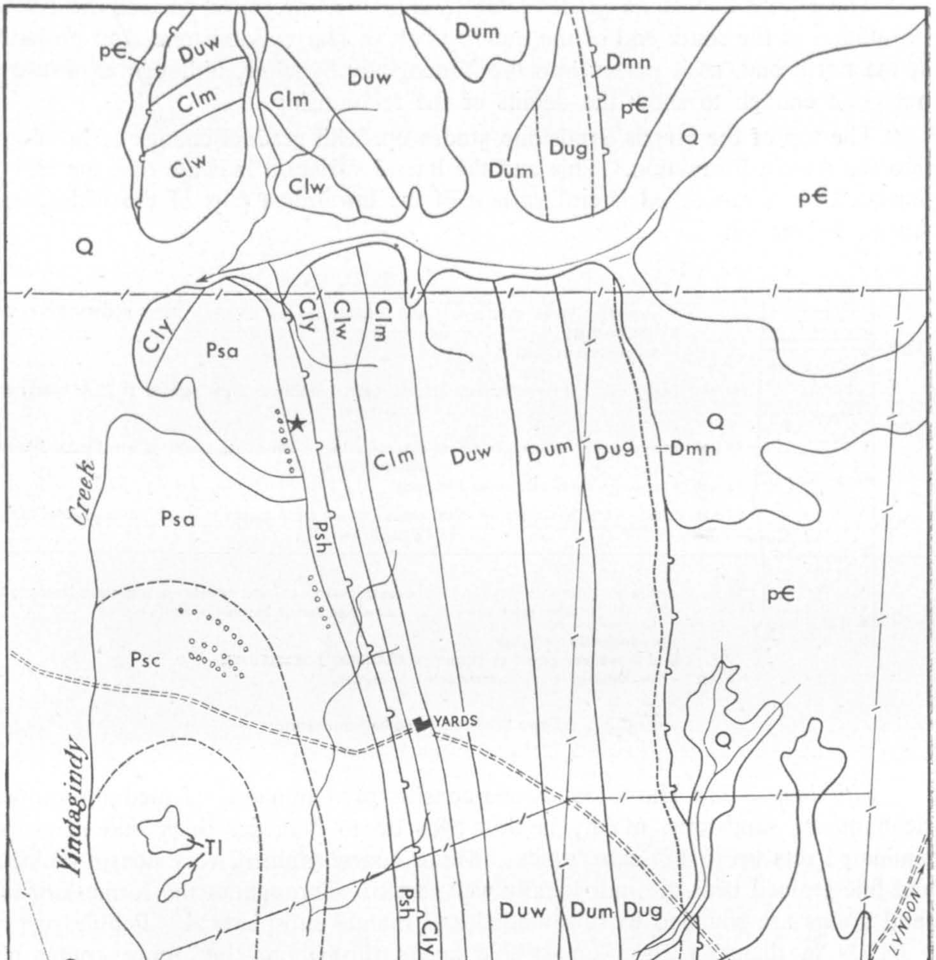
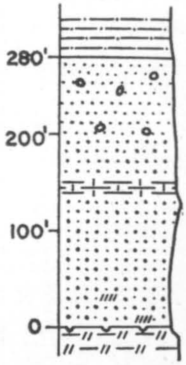


Fig. 36. Type Locality, Harris Sandstone. Q-Quaternary; Tl-Tertiary laterite; Psk-Koomberan Greywacke; Psd-Dumbardo Siltstone; Psc-Coyango Graywacke; Psa-Austin Formation; Psh-Harris Sandstone; Cly-Yindagindy Formation; Clw-Williambury Formation; Clm-Moogooree Limestone; Duw-Willaraddie Formation; Dum-Munabia Sandstone; Dug-Gneudna Formation; Dmn-Nannyarra Greywacke; pC-Precambrian schist; * Type sections.

The Harris Sandstone grades laterally into the lowermost part of the Austin Formation at the south end of the outcrop belt of Harris Sandstone, and probably at the north end, as it passes into the Yindagindy Syncline, although exposure is not good enough to show the details of the relationship.

The top of the Harris Sandstone grades up, with gradual change of lithology, into the Austin Formation. This and the lateral variation indicate that the Harris Sandstone is a re-worked lateral variant of the lowermost part of the widespread Austin Formation.



Friable light brown quartzwacke with pebbles and few cobbles (AUSTIN FORMATION of the LYONS GROUP)
conformably overlying:

80 feet friable light brown medium-grained quartz sandstone with pebbles to 3" of quartz and quartzite;

47 feet friable white medium-grained to coarse-grained clean quartz sandstone with hard red-brown siliceous skin;

13 feet soft yellow-brown calcareous siltstone;

90 feet friable white medium-grained to coarse-grained clean quartz sandstone, cross-bedded in thin sets (Sample MG/166);

50 feet friable white medium-grained to coarse-grained clean quartz sandstone with chert lenses to 18 inches thick and with lepidodendroid fossils (Sample G/225);

disconformably overlying
hard brown ferruginous greywacke (YINDAGINDY FORMATION).

280 feet - thickness of Harris Sandstone in type section.

Fig. 37. Type section, Harris Sandstone.

Lithology.—The Harris Sandstone consists predominantly of medium-grained clean quartz sandstone, mainly in thin beds up to 3 inches thick and in cross-laminated sets up to 12 inches thick. Minor coarse-grained, very coarse-grained, and fine-grained beds are individually well-sorted. Throughout the formation, the sand grains are rounded to subrounded and mainly subspherical. Pebbles up to 3 inches in diameter form one-pebble layers throughout, but more commonly in the upper part. The sandstone consists predominantly of grains of clear quartz, commonly ironstained and many with crystal overgrowth. Minor constituents include chert (black and grey), fine-grained quartzite, muscovite or bleached biotite, feldspar, blue and brown tourmaline, and garnet. The pebbles consist of white quartz, quartzite, and chert, generally rounded and ovoid to spherical. The porosity of the sandstone is very high (estimated at about 20 to 25 percent) and the permeability is also high.

In the middle of the formation is a thin member of soft yellow-brown calcareous siltstone, generally poorly exposed but forming a prominent bench in the hills of the Harris Sandstone.

In the lowermost part of the formation are lenses up to 18 inches thick of chert, cementing the grains of sand; some of these lenses cross bedding-planes—the chert is definitely postdepositional. As the formation is not strongly dissected, it was not possible to tell whether the chert is a surface effect only or extends into the formation at depth.

The only other rock type is in a bed about 5 feet thick; it is pebbly quartz sandstone in which the pebbles make up about 30 percent of the rock. There are also a few cobbles about 6 inches across. The pebbles and cobbles are of quartzite and quartz.

There are no obvious lithological variations in the outcrop area of the Harris Sandstone, but to north and south the lithology changes quite abruptly into the quartzwacke and siltstone of the Austin Formation. This gradation was not observed; at the south end there is a soil-covered area about 700 yards wide between outcrops of the Harris Sandstone and Austin Formation in the same position relative to the unconformity. At the north end, exposure is better but still poor: the Harris Sandstone appears to lens out, the lowermost beds persisting farther towards the syncline than the upper beds. Pebbly quartzwacke is poorly exposed about 50 to 100 yards along strike from exposed quartz sandstone.

Distribution and thickness.—The Harris Sandstone is known only from the outcrop belt in which the type locality is placed. This belt is very even in width, probably reflecting a very uniform thickness of about 280 feet. It stands up as a strike ridge of reddish sandstone with very little vegetation. In air-photographs, the formation outcrop shows a dark tone, but where covered by thin residual sand has a very light even tone.

Fossils.—The only fossils found in the Harris Sandstone are stem fragments and pieces of trunks of *Lepidodendron* sp. (White, 1959).

Age.—White (1959) regards the *Lepidodendron* species as being of Permian type. This agrees with the evidence from the marine fauna of the Austin Formation, which is considered by Dickins & Thomas (1959) to be similar to the Sakmarian fauna of the upper parts of the Lyons Group. The disconformity below the Harris Sandstone is shown to develop southward into an important erosional unconformity, which implies a lengthy period of emergence between the Lower Carboniferous Yindagindy Formation and the Harris Sandstone.

Correlation.—The Harris Sandstone is firmly correlated with the lower part of the Austin Formation by their stratigraphical position, by the lateral intergrading, and by the presence in both of the same species of *Lepidodendron.* Considering the thickness of the Lyons Group in its general environment of deposition, the base of the Lyons Group and the equivalent Harris Sandstone are likely to be very close to the base of the Sakmarian, the lowermost stage of the Permian.

Structure.—The Harris Sandstone is known only in a west-dipping homocline on the east flank of the Yindagindy Syncline. It apparently does not continue into the syncline.

Palaeogeography.—The Harris Sandstone was deposited in a restricted area, where the action of waves and currents was able to sift the finer and less resistant materials from the incoming sediment and effectively to round the sand grains. The occurrence of unsorted sediments in close lateral association probably indicates that the Harris Sandstone is a near-littoral deposit, and that the equivalent sediments in the syncline were deposited in deeper water whereas those on the anticlinal crest were terrestrial. This is supported to some extent by the relative abundance of plant fossils in the unsorted material to the south and east and their rarity in the Harris Sandstone.

It seems, then, that the present structural relief mirrors that of the time of deposition of the Harris Sandstone and its equivalents: land to the north-east, a sloping bottom from the sea coast, and a basin to seaward. The shoreline probably followed the present outcrop and the structural contour of the pre-Permian unconformity fairly closely, though it was somewhat to the south and west of the present outcrops of the unconformity.

Economic Geology.—Although the lithology of the Harris Sandstone suggests that it would be an excellent aquifer and oil reservoir sand, it does not extend far from outcrop and therefore would be only of local importance as a groundwater aquifer. It does indicate, however, that any of the quartzwacke formations in the sequence may readily be sorted into good reservoirs for petroleum where the conditions were suitable during deposition. The indications of relief in the bottom during sedimentation imply that such conditions may have developed in places other than the main shoreline: any of the basement ridges may have been so placed at one or more times during the deposition of the sedimentary sequence to develop such a clean quartz sandstone. Like the Harris Sandstone, such a sandstone is likely to have been rapidly buried by relatively impermeable sediments and, particularly where close to an unconformity, to be able to accumulate migrating petroleum almost from the time of deposition.

LYONS GROUP

Glacigene sediments were first reported from the Carnarvon Basin by Woodward (1891) and were named 'Lyons Conglomerate' by Maitland (1912, p. 16). Raggatt (1936) found that many boulder beds were contained in a thick sequence of varied rock types and called it 'Lyons Series'. Teichert (1950) first used the term 'Lyons Group', and Condon (1954, p. 34) revised Raggatt's definition of the Lyons Group but did not name the formations, although, in his 'type section', he indicated formation boundaries. The large amount of additional work since 1954 has very greatly increased the knowledge of the Lyons Group and requires that the definition of the group be once more revised, as follows (revision in italics):

The LYONS GROUP is the sequence of formations, related genetically to glaciation and consisting of siltstone, quartzwacke, *and boulder beds,* with few beds of marine *and of plant* fossils, resting conformably on the Harris Sandstone *and unconformably on Carboniferous, Devonian, ?Ordovician, and Proterozoic sediments and Precambrian schist and granite and disconformably or unconformably beneath Carrandibby Shale, Callytharra Formation, Wooramel Group, and the lowermost part of the Byro Group.* The formations of the Lyons Group, in ascending order, are: Austin Formation, Coyango Greywacke, Dumbardo Siltstone, Koomberan Greywacke, Mundarie Siltstone, Thambrong Formation, and Weedarra Shale.

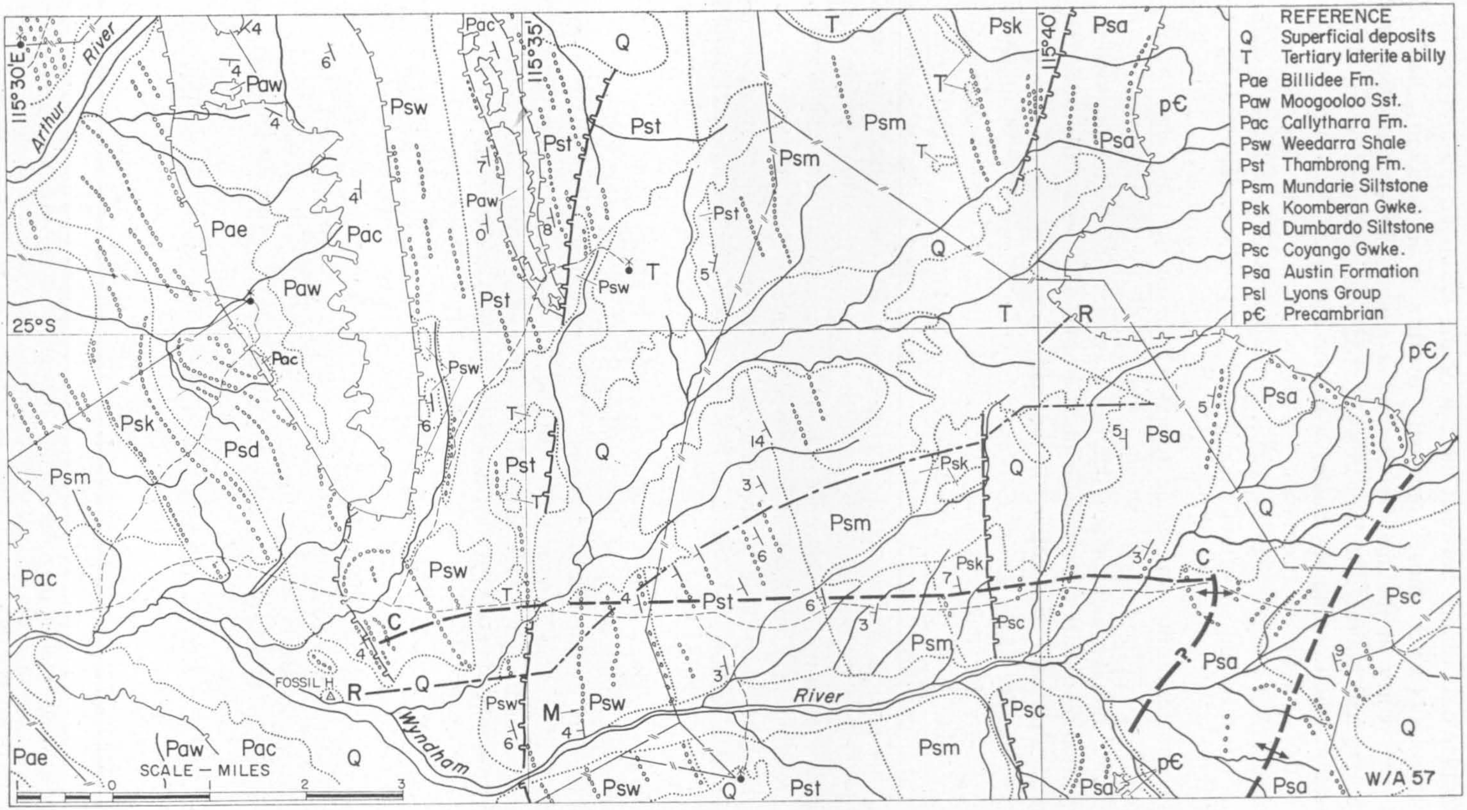


Fig. 38. Type locality, Lyons Group. M-Maitland's Lyons Conglomerate; R-R-Raggatt's section C-C—Revised Type Section.

An angular discordance between the top of the Lyons Group and the Callytharra Formation (which most commonly overlies it in outcrop) had been recognized very early in the field work, and a slightly ferruginous top in the Moogooree area had indicated a disconformity that was confirmed when an additional formation (the Carrandibby Shale) was found between the top of the Lyons Group and the Callytharra Formation. Only when the map compilation was being checked was it realized that the trends in the Lyons Group in the Wyndham River area indicated an important unconformity. This was followed by close checking on the air-photographs of the whole of the outcrop area of the Lyons Group. The unconformity was found to extend almost right through the group and in some places to have a very strong relief. With the help of abundant field notes, recording lithology and a few detailed traverses, it was found possible to follow formation boundaries on the air-photographs with very little uncertainty. A few critical areas were re-examined in the field.

The type locality of the Lyons Group is shown in Figure 38. Maitland gave no precise locality for the 'section of the boulder bed in the Wyndham River' (1912, fig. 5) but it is probably that shown in Figure 38. Raggatt's traverse was obtained from his original field book (pers. comm.); his stratigraphical column in this area is revised as shown in Figure 40, the revised type section of the Lyons Group. Condon's (1954) 'type section', (Fig. 39), which should more correctly be termed a 'reference section', is compared with the Wyndham River type section in Figure 40; it is revised to include only the main section since it is thought undesirable to include sections from two different areas in a type or reference section. In any case it is now clear that the complete section is present in the Coyango locality, although the lower part is very poorly exposed.

Distribution.—The Lyons Group has a very extensive outcrop (Fig. 41) extending from 5 miles north of the Lyndon River to the Murchison River in a belt broken only by superficial deposits. The greatest width of the belt is 28 miles in the Curbur and Narryer area. In the subsurface the Lyons Group has been established in Rough Range Bore No. 1 (from 6235 to 10,705 feet depth*, in Giralia Bore No. 1 (WAPET) from 3965 to T.D. 4080 feet, in Warroora Bore No. 1 (WAPET) from 1125 to 4951 feet, in Deep Bore, Byro Station (Oil Search) from 2018 to T.D. 2218 feet, and in Quail No. 1 (WAPET) from 1940 to 6892 feet (Pearson, 1964). It is proved absent in the Cape Cuvier, Grierson, Pelican Hill, Dirk Hartog, Shark Bay, Marrilla, Minderoo, and Wandagee bores.

The Lyons Group is continuous with the Nangetty Formation (Clarke et al., 1951) of the Irwin Basin. Playford & Willmott (1958, p.75) state that the Nangetty Formation is recognized in the valleys of the Irwin, Lockier, Greenough, and Murchison Rivers. The Lyons Group has been mapped, in almost unbroken outcrop except for a lateritized area west of Byro homestead, from the Lyndon River to the Murchison River. The rock body of the earlier-named Lyons Group continues into the Irwin Basin and therefore the Nangetty Formation may be regarded as part of the Lyons Group.

*McWhae *et al.* (1958) gives the thickness as 3000 feet, but my examination of cuttings supplied by West Australian Petroleum Pty Ltd shows quartzwacke and siltstone with tillitic texture down to 10,705 feet.

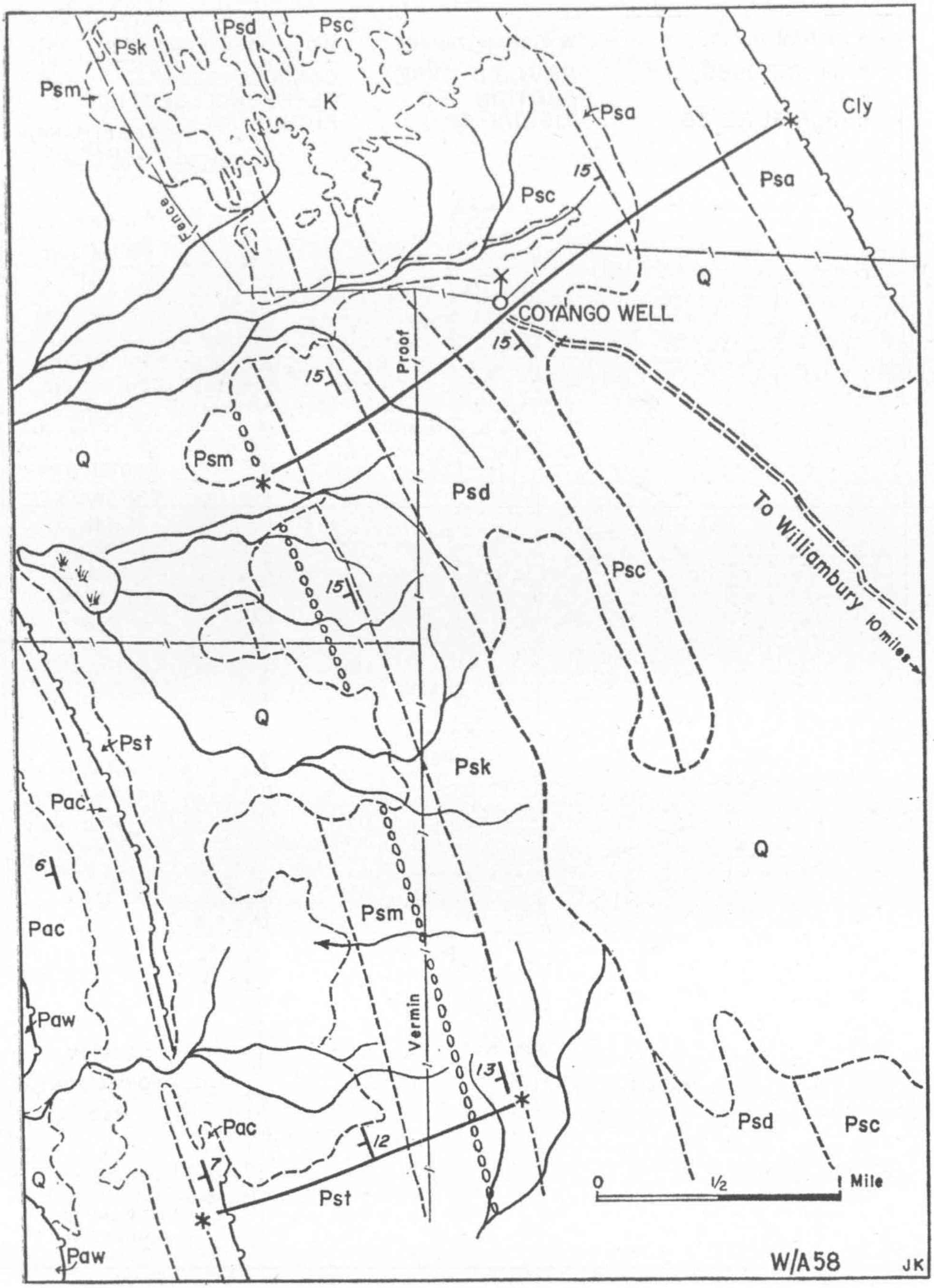


Fig. 39. Locality of reference section of Lyons Group and type sections of Coyango Greywacke (Psc), Dumbardo Siltstone (Psd), and Koomberan Greywacke (Psk).

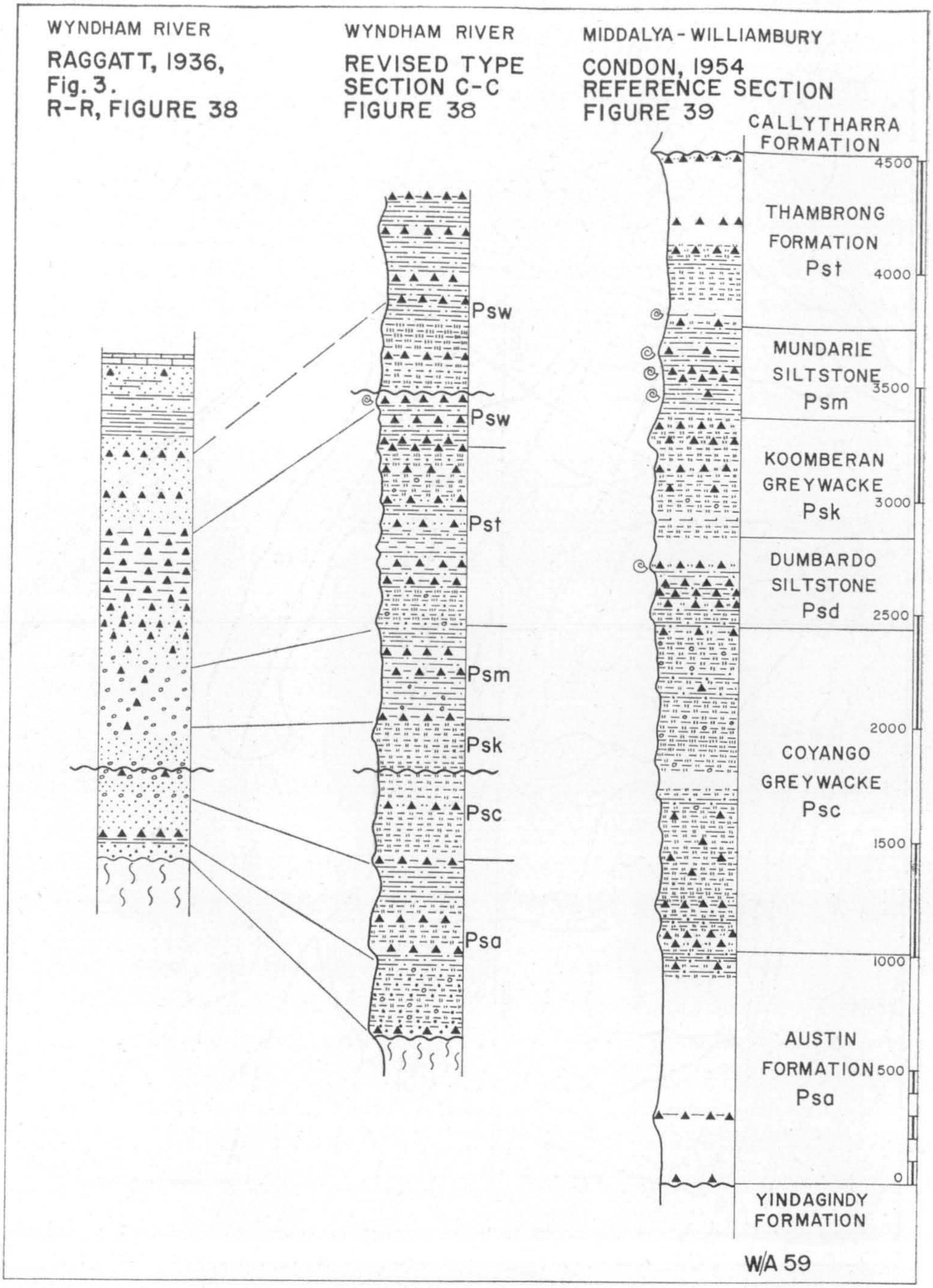


Fig. 40. Type and reference sections, Lyons Group.

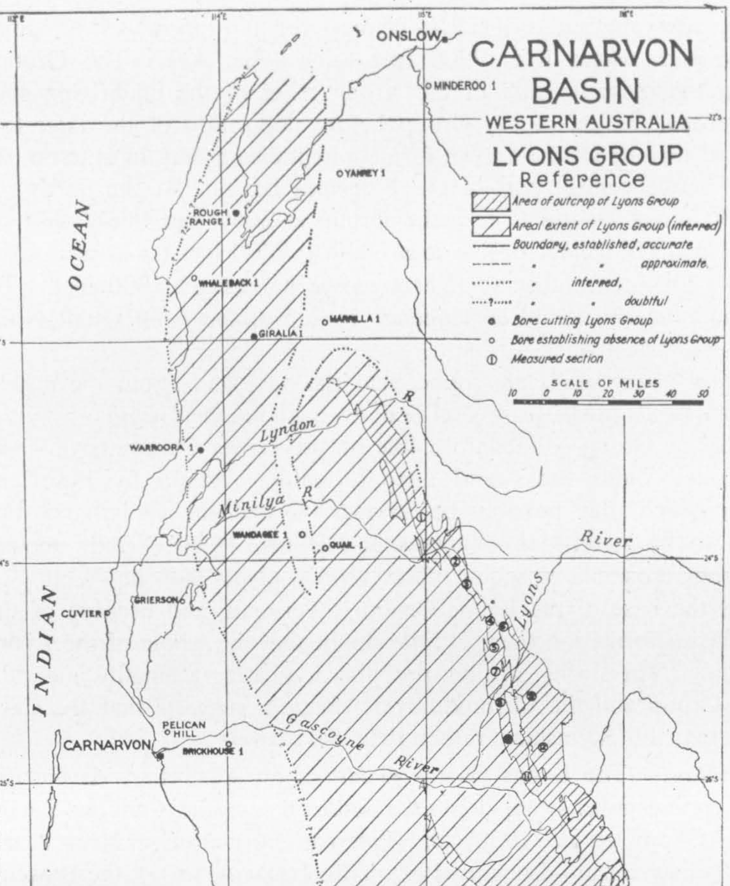


Fig. 41. Distribution, Lyons Group.

The greatest measured thickness of the Lyons Group is west of Mount Sandiman homestead, where it is 7900 feet thick (Fig. 42). The Group is very variable in thickness because of the strong relief of the underlying surface and the very strong erosion of the Group before deposition of the later formations. Sections that include all the known formations indicate that, in outcrop, the Group is thickest in the central part of the Bidgemia Basin. At the north end of the Byro Basin (along Daurie Creek) the Group is 2660 feet thick, west of Arthur River woolshed (Bidgemia Basin) it is 6000 to 7200 feet thick, near Lyons River homestead 6300 feet, and west of Moogooree homestead 4800 feet. The thickest and more nearly complete sequence in subsurface is in Quail No. 1 Bore, where it is 4952 feet thick.

Lycopod plant fossils are found near the base and about the middle of the Group and marine fossils in several beds throughout the Group.

The Lyons Group is unconformable on the Lower Carboniferous Yindagindy Formation and older rocks and unconformably overlain by the Carrandibby Formation, which may possibly be Sakmarian, and the Callytharra Formation, considered to be Artinskian (Thomas & Dickins, 1954). Both unconformities indicate strong erosional episodes. The lycopod plants indicate (White & Condon, 1959) that the base of the Lyons Group is Permian, and because of the age of the Callytharra Formation there is little doubt that the whole of the Lyons Group is Sakmarian. The strong erosion, probably indicating a lengthy interval between the Lyons Group and the Carrandibby Formation, suggests that the Carrandibby Formation may be Artinskian rather than Sakmarian.

Correlation.—The Lyons Group is part of an Australia-wide glacigene sedimentation, with similar water-deposited sediments in the Canning Basin—Grant Formation (Guppy et al., 1958) and Paterson Formation (Traves et al., 1956, p.19); the Sydney Basin—Lochinvar Formation (David, 1907); the Bowen Basin—Dilly and Cattle Creek Formations (Hill, 1952); and Tasmania—lower part of Woody Island sequence (Banks, Hale, & Yaxley, 1955). Terrestrial tillites and fluvioglacial sediments that are probably equivalent are known from the Pilbara Region—the Braeside Tillite (Traves et al., 1956); the Lake Carnegie region (Talbot & Clarke, 1916 and 1917); Inman Valley, Hallett Cove (Howchin, 1926; Glaessner & Parkin, 1958), and elsewhere in South Australia; Werribee Gorge, Heathcote, and Beechworth in Victoria; and the Northern Territory and western Queensland (Condon & Smith, 1959).

Structure.—The Lyons Group is disposed mainly in regional synclines probably formed by downwarping of the basins mainly during sedimentation. Such large synclines are known in the Gascoyne Basin, where a synclinal axis in the Lyons Group underlies the Giralia anticlinal axis in the younger Permian and Cretaceous sediments (Fig. 43) and in the Merlinleigh Basin, the Bidgemia Basin, and the Byro Basin. Anticlines formed probably by draping over basement ridges between developing basins are known over the south end of the Weedarra Ridge, the north end of the Carrandibby Ridge, and the Exmouth Ridge, and probably over the Wandagee Ridge and the north part of the Yallalong Ridge (Fig. 35). Minor anticlines plunge south into the Merlinleigh Basin on Williambury station.

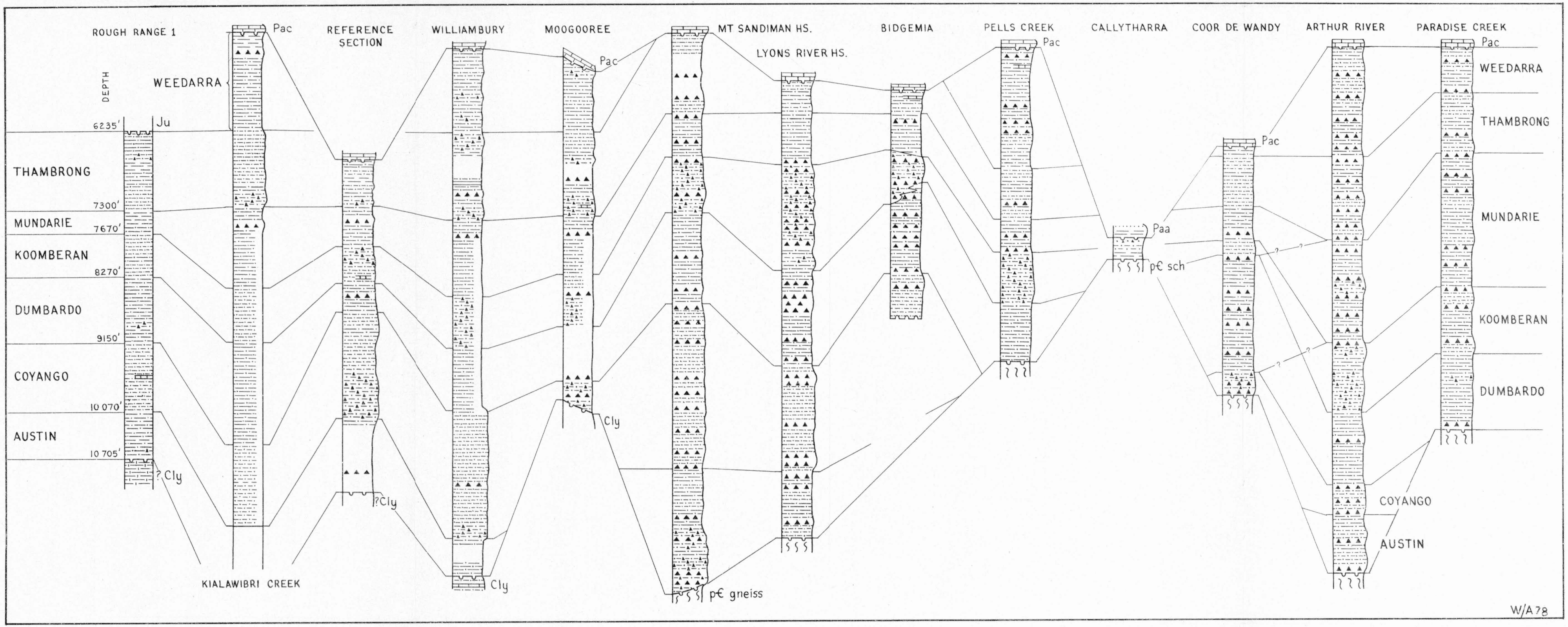


Fig. 42. Stratigraphic columns, Lyons Group. .

Although the Lyons Group rests on a small angular and strong erosional unconformity, it is generally structurally concordant with the older sediments. The unconformity above the Group has produced structural discordance between it and the younger sediments: the best example of this is the Giralia Anticline, which is developed in Artinskian and Cretaceous sediments. Although Bore BMR5, Giralia, did not reach the Lyons Group, the information obtained from it and the reflection seismic traverse (Chamberlain et al., 1954) indicates that the main structural unconformity is between the Lyons Group and the Callytharra Formation. The anticlinal structure continues downward from the surface to an unconformity at about 3500 feet depth which has a shape similar to the overlying structure; below this unconformity the structure is quite discordant; below the axis of the surface anticline the strata dip westward in the flank of a fold with anticlinal axis about 7500 feet to the east and synclinal axis 3000 feet to the west. The anticlines in the Artinskian sediments at Mount Madeline and 9 miles east of Lyons River homestead may also be developed by deposition over an unconformity of strong relief on the Lyons Group.

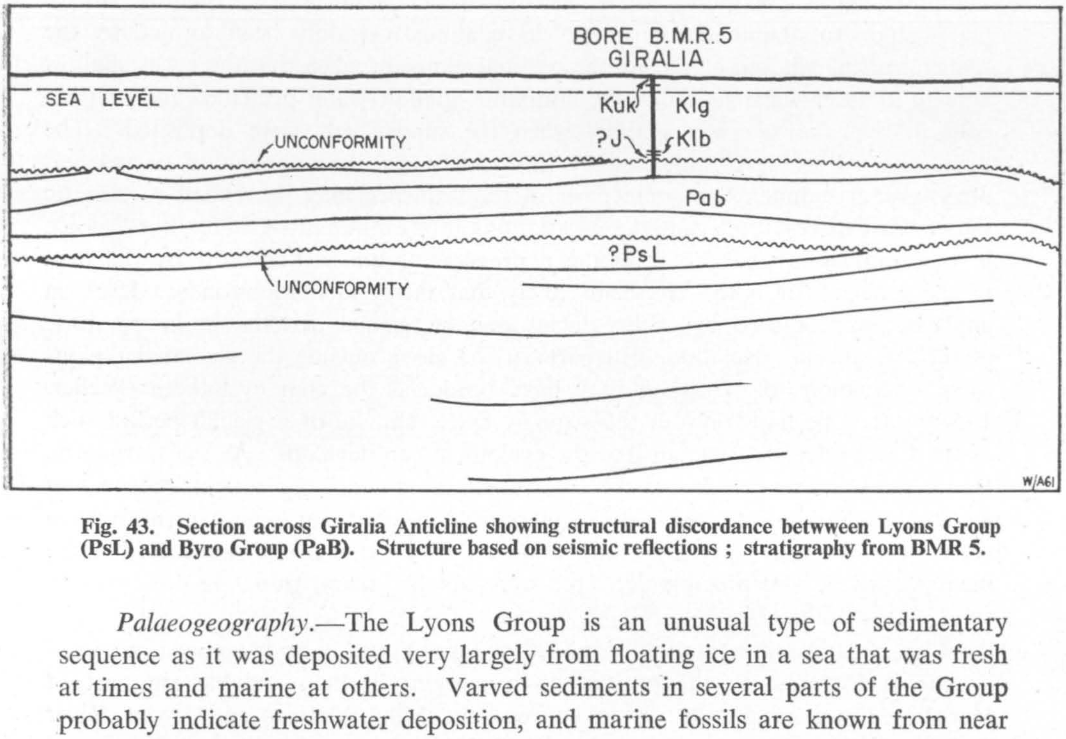


Fig. 43. Section across Giralia Anticline showing structural discordance betwween Lyons Group (PsL) and Byro Group (PaB). Structure based on seismic reflections ; stratigraphy from BMR 5.

Palaeogeography.—The Lyons Group is an unusual type of sedimentary sequence as it was deposited very largely from floating ice in a sea that was fresh at times and marine at others. Varved sediments in several parts of the Group probably indicate freshwater deposition, and marine fossils are known from near the base and the upper two-thirds of the sequence; in the upper part of the sequence marine fossils are found very close to varved sediments. The sequence is characterized by the presence of erratic boulders, as isolated individuals or thick boulder beds; they cover a wide range of rock types mainly of Precambrian igneous and metamorphic rocks with some pre-Permian sediments; striation is common on the finer-grained boulders and many are faceted; they are dominantly subround to round, but of a wide range of shapes. The dominant roundness may indicate lengthy englacial abrasion in thick ice (von Engeln, 1930). The ice containing the sedimentary material was probably part of a continental icesheet which may have covered a large part of Australia: ground moraine probably of Permian age is known over a vast area from near Lake Carnegie in Western Australia to the Georgina River in Queensland and southward to Tasmania; the epicontinental and intracratonic basins are indicated to contain aqueo-glacial sediments of the same age, deposited from icebergs derived from the continental icesheet.

The Lyons Group was deposited on a surface of strong relief: in the Arthur River woolshed area and in the Daurie Creek area near the margin of the basin the local relief is at least 300 feet and there is indication, particularly in the Bidgemia Basin, of major relief of about 3000 feet. Glacial pavements are known in the Daurie Creek area and on the west side of the Carrandibby Range: the icesheet was eroding in these areas before deposition began and part of the relief may have been produced by glacial scour.

The Lyons Group consists of alternations of sandy and silty sequences; the sandy sequences commonly include shallow-water sedimentary structures (ripple marks and cross-lamination), so they have almost certainly been formed by the removal of the silt and clay from the original sediment when the water was shallow enough to allow wave action on the bottom. Shallow-water pectenids and bryozoa confirm that the sea was shallow when the sandy beds were deposited. The fluctuation of sea level indicated by this and by the development of varves and fluvio-glacial sediments in some parts of the sequence may be related to eustatic fluctuations in sea level caused by variations in the amount of water fixed as ice in the continental icesheet or in the depression of the earth's crust by the load of the icesheet, or both. It seems likely that these fluctuations in sea level, in any case, were caused by cyclic glacial and interglacial periods similar to those of the Pleistocene glaciation. In parts of the globe outside the glaciated regions these fluctuations of sea level may have produced the coal cyclothem (Weller, 1958). It is perhaps only in the strongly cyclic climate of a glacial period such as the Carboniferous-Permian that the cyclothem can develop. As the Carnarvon Basin, the Canning Basin, and the Irwin Basin all contain very thick sequences of aqueo-glacial sediments, the western margin of the Permian Continent must have been the main outlet area for the continental icesheet; this may indicate that the main ice divide and precipitation area were not far inland from the present west coast of Australia.

The area of sedimentation of the Lyons Group appears to have been restricted on the east almost to the present basin margin; in the south-eastern part of Moogooree station, on the divide between the Minilya River and Lyons River drainage, a ground moraine, probably left by the last ice retreat, rests on truncated Devonian strata dipping at about 30° west; the present eastern edge of outcrop of the aqueo-glacial sediments is only a mile to the west. The westward extent of sedimentation of the Lyons Group is unknown. Its present extent is determined by its unconformity with pre-Permian rocks, but it may have originally extended over and beyond the pre-Permian rocks of the coastal area. It is extremely likely that sedimentation over the basement ridges was much thinner and the sediments much sandier than in the synclinal basins: this is indicated on the Weedarra and Carrandibby Ridges and has been confirmed by drilling in a few places on the buried ridges—Yanrey No. 1, Marrilla No. 1, and Wandagee No. 1—where the Permian is absent beneath the Mesozoic.

Austin Formation

The Austin Formation (Condon, 1962), is the sequence of members of quartzwacke and sandy siltstone, with several boulder beds, resting unconformably on Lower Carboniferous, Devonian, and Precambrian rocks and conformably overlain by the Coyango Greywacke; it is the lowermost formation of the Lyons Group in outcrop. It rests conformably on and grades laterally into the Harris Sandstone.

The name is taken from Austin Creek, a south-flowing right-bank tributary of the Lyons River that joins it 10 miles south of Mount Sandiman homestead, at Lat. 24° 33′ S., Long. 115° 23′ E.

The type locality (Fig. 44) is immediately north of Mount Sandiman homestead, where the Austin Formation is 1240 feet thick (Fig. 45). The base of the formation rests unconformably on Precambrian schist and gneiss, Devonian Gneudna Formation and Munabia Sandstone, and Lower Carboniferous Moogooree Limestone and Yindagindy Formation. Because of the irregularity of the surface of unconformity and the onlap of the Lyons Group on this surface, any part of the Austin Formation may be resting on the unconformity and in many places it is absent, overlapped by the younger formations. Its upper boundary is taken at the change from alternating arenaceous and lutite members to a dominantly arenaceous formation, the Coyango Greywacke; the boundary is placed at the top of the uppermost lutite member.

The Austin Formation is characterized by its alternation of arenaceous and lutite members; quartzwacke is dominant but there are several lutite members over 100 feet thick. The only other formation of the Lyons Group that has this character is the Thambrong Formation. It results in a banded dark and light pattern in air-photographs.

The lowermost member known consists of clean quartzwacke mainly medium-grained, with a silty matrix commonly less than 20 percent of the rock; pebbles and cobbles of quartz, quartzite, and crystalline metamorphic and igneous rocks are scattered through the member and concentrated in one bed, near the middle of the member, that also has a few granite boulders. In places the outcrop of this and other arenaceous units in the Lyons Group is strongly silicified into a hard quartzitic rock by Tertiary weathering processes related to lateritization. Much of the clay fraction (both interstitial and interbedded) has been removed, igneous pebbles and boulders completely decomposed, and quartz grains corroded so that it is difficult to recognize the original rock type in the weathered residual that forms a hard cap on mesas.

The higher quartzwacke members have higher proportions of silty matrix (25 to about 35 percent) and are more variable in grainsize. The lutite members are mainly laminated sandy micaceous siltstone (of tillitic texture, i.e., the sand grains of varying size are scattered through the siltstone, not in laminae or evenly dispersed). Pebbles, generally small, are scattered throughout, and boulder beds, generally somewhat lenticular, are present in the lowermost siltstone member and in the upper part of the formation.

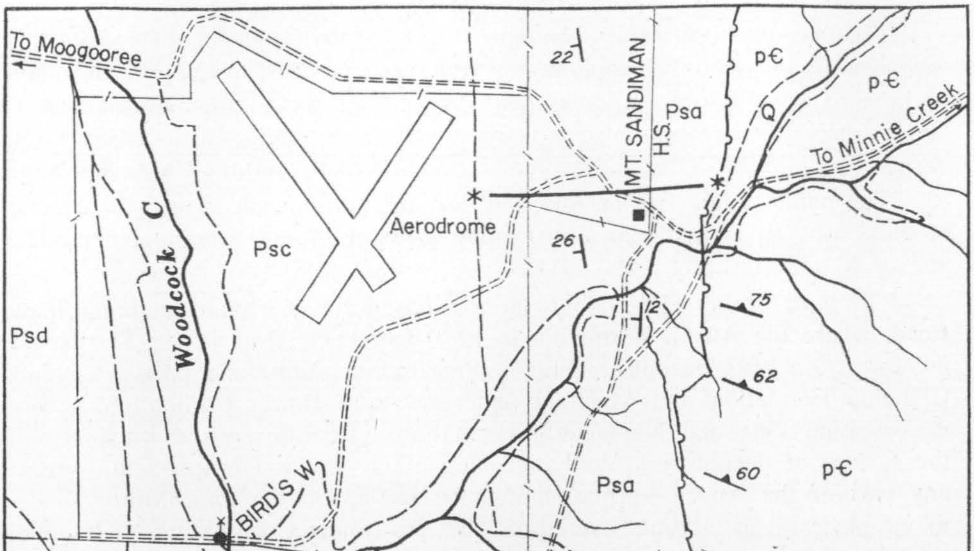


Fig. 44. Type locality, Austin Formation. Q-Quaternary; Psd-Dumbardo Siltstone; Psc-Coyango Greywacke; Psa-Austin Formation; pC-Precambrian schist. *——* Type Section.

Friable grey-green medium-grained quartzwacke with tillitic boulder beds (GOYANGO GREYWACKE), conformably overlying:

60 feet soft dark grey sandy siltstone with scattered pebbles and cobbles;

20 feet friable grey fine-grained quartzwacke; few pebbles;

20 feet soft dark grey sandy siltstone;

10 feet friable grey fine-grained quartzwacke;

40 feet soft dark grey sandy siltstone with few scattered pebbles; tillitic boulder bed at base;

70 feet of medium-hard grey medium-grained and fine-grained quartzwacke with few scattered pebbles;

60 feet soft dark grey sandy siltstone with scattered pebbles and cobbles and a boulder bed;

70 feet medium-hard grey medium-grained quartzwacke with few pebbles, a sandy boulder bed, and thin sandy siltstone;

40 feet soft dark greenish grey sandy siltstone with few pebbles; tillitic boulder bed near the top;

15 feet friable grey fine-grained quartzwacke;

25 feet soft dark greenish grey sandy and pebbly siltstone;

45 feet medium-hard grey fine-grained quartzwacke; coarse-grained quartzwacke at top;

50 feet medium-hard pale grey medium-grained quartzwacke; few pebbles;

85 feet medium-hard pale grey fine-grained quartzwacke; few scattered pebbles;

25 feet medium-hard pale grey medium-grained quartzwacke;

25 feet friable grey fine-grained quartzwacke with scattered pebbles;

30 feet soft dark greenish grey sandy siltstone;

15 feet friable grey fine-grained and medium-grained quartzwacke;

80 feet soft dark greenish grey sandy siltstone with few scattered pebbles;

5 feet dark grey boulder bed; siltstone matrix;

40 feet dark grey sandy siltstone with few pebbles;

90 feet hard pale grey medium-grained quartzwacke; silicified;

30 feet soft dark grey sandy siltstone; few pebbles;

65 feet hard cream silicified medium-grained quartzwacke;

5 feet boulder bed; quartzwacke matrix;

200 feet hard silicified medium-grained and fine-grained quartzwacke with scattered pebbles and cobbles;

20 feet friable light grey fine-grained quartzwacke with pebbles and few angular fragments of quartz;

unconformably overlying soft weathered schist (Precambrian).

1240 feet - thickness of AUSTIN FORMATION in type locality.

Fig. 45. Type section, Austin Formation.

The Austin Formation crops out in a narrow belt 11 miles long from 13 miles north-west to 6 miles west-south-west of Williamsbury homestead: the exposure is poor but the thickness can be estimated at about 1000 feet (Column 9, Fig. 46). In a belt 8½ miles long in the Harris Syncline from 5½ miles north-west of Williambury homestead to Dumbardo Bore 4¾ miles south-south-west of the homestead, the Austin Formation rests conformably on and grades laterally into the Harris Sandstone and is about 1200 feet thick (Column 8). In the Williambury Syncline from 3 miles east of north of the homestead to 3 miles south-east the exposure is very poor and only the upper part of the formation, about 500 feet thick, crops out; it is overlapped from that place to 12 miles west of north of Mount Sandiman homestead. It crops out in a belt 17 miles long and about ½ mile wide from there to 5 miles south of the homestead; apart from the overlap wedge-out at the north end it varies from 800 to 1240 feet in thickness (Column 6). The lowermost member crops out only for 2 miles north from the homestead. In a belt half a mile wide 11 miles southward from 3½ miles south-south-east of Mount Sandiman homestead the Austin Formation is about 900 feet thick. It is overlapped from there southward, on the west side of the Weedarra basement ridge. In the Bidgemia Basin it crops out from 12 miles north to 6 miles east of Mount Sandiman homestead, where it is 1100 feet thick and rests unconformably on Munabia Sandstone and Gneudna Formation. The formation crops out in a north-south belt that crosses Paradise Creek 12 miles west-north-west of Arthur River woolshed. It is about 1080 feet thick and is unconformably overlain to the east by Mundarie Siltstone. From 1 mile north-west to 8 miles south-west of Arthur River woolshed it is deposited on a very uneven surface of Precambrian schist and gneiss. In this area it ranges up to about 1500 feet thick. It crops out in the type locality of the Lyons Group on the Wyndham River and in the northern part of the Byro Basin, but the outcrop is poor and thicknesses have not been determined. Farther south in the Byro Basin, the Austin Formation is overlapped by the Coyango Greywacke between Congo Creek and Daurie Creek, and south of Daurie Creek the very poor outcrop and widespread lateritization prevent recognition of the formation except on the east side of Earilier Hill, where the upper part of the Austin Formation is exposed under the Coyango Greywacke. The interval from 10,070 feet to 10,705 feet depth in Rough Range No. 1 Well (WAPET) consists of alternating members of quartzwacke and lutite and overlies ?Carboniferous calcilutite; it is overlain by a thick quartzwacke formation and is probably equivalent to the Austin Formation: on this basis the formation sequence in the bore is comparable with the outcrop sequence. McWhae et al. (1958, p. 51) regard the rocks of the interval between 9200 feet and 10,705 feet as not part of the Lyons Group, but I find tillitic siltstones down to 10,705 feet, accompanied by the speckled quartzwacke characteristic of the Lyons Group. In several places, as at 10,160 feet, 10,300 feet, and 10,550 feet, there are coarse quartz and quartzite grains in the cuttings, suggesting boulder beds.

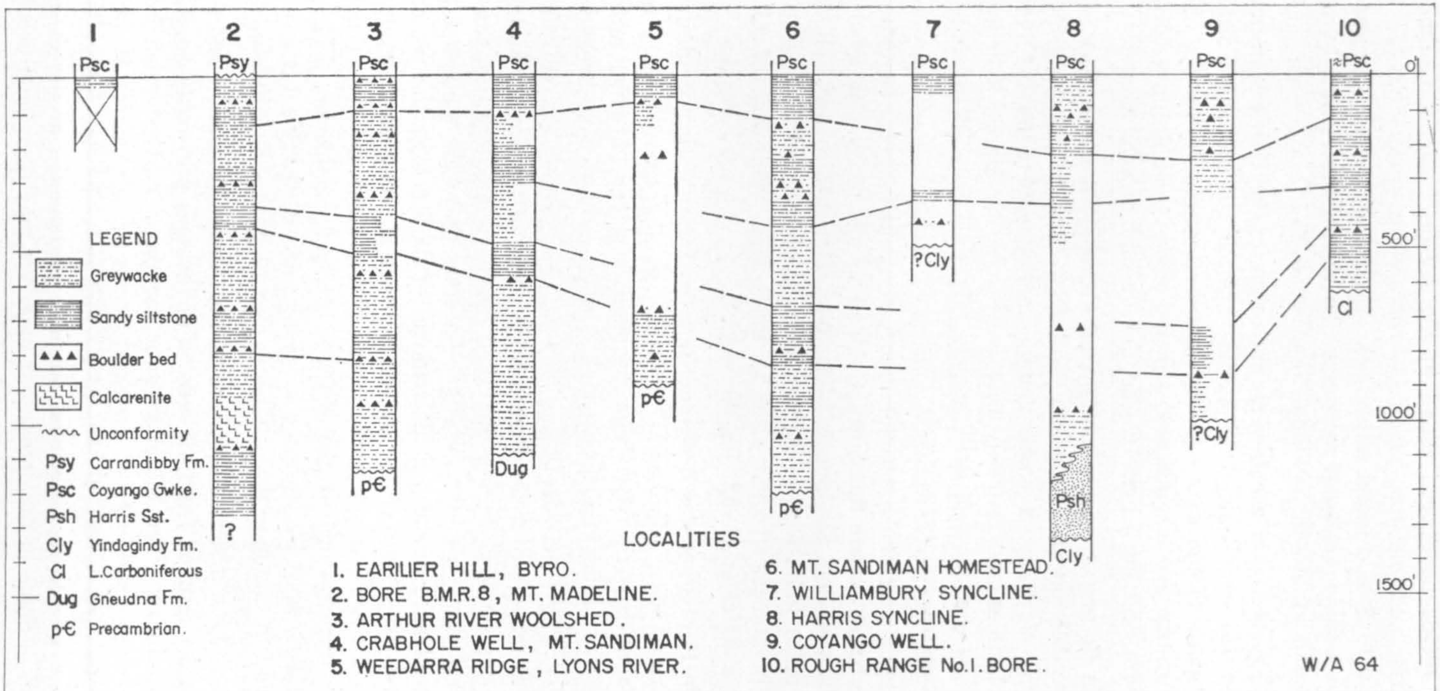


Fig. 46. Stratigraphic columns, Austin Formation.

No plant fossils have been found in the Austin Formation, although the equivalent Harris Sandstone has *Lepidodendron* (White, 1959). C. E. Prichard found fenestellid and batostomellid bryozoa, a streptorhynchid brachiopod, and pelecypods in a pebbly limestone bed near the top of the Austin Formation 5 miles east of south of Mount Sandiman homestead.

White (1959) considers the *Lepidodendron* sp. of the Harris Sandstone to be of Permian type and on this basis the Austin Formation is probably Permian and, like the higher parts of the Lyons Group that contain marine fossils, Sakmarian in age. The Permian age is consistent with the strong unconformity between the Austin Formation and the Lower Carboniferous and older formations.

The Austin Formation and its lateral equivalents are down-warped into basin-synclines in the Merlinleigh, Bidgemia, and Byro Basins and probably in the Gascoyne Basin. It forms a south-plunging anticline between the Harris and Williambury Synclines and probably to the west of the Harris Syncline. It is probably anticlinal over parts of the basement ridges (Bullara, Wandagee, Carrandibby, and Weedarra Ridges).

Its bedding is commonly parallel to or at a small angle from the unconformity surface below; where that surface sloped steeply at the time of deposition the bedding abuts against the slopes. The two relationships are well displayed in the areas 4 miles south-west of Arthur River woolshed and 2½ to 6 miles east of Coordewandy homestead, and also 5½ miles west-south-west of Glenburgh homestead (Konecki et al., 1958, fig. 4).

The Austin Formation was deposited in water from floating ice derived from continental glaciers or a continental icesheet. In the Coordewandy area the underlying Precambrian schist has been glaciated; a glacial pavement with north-south striations was found in Daurie Creek 4 miles east of Coordewandy homestead (Condon, 1962b).

The ice was moving over the Precambrian rocks of the present basin margin before the Austin Formation was deposited in the same area: deposits older than the known Austin Formation are likely in areas that were topographic basins during the first advance of the ice; the removal of the ice from the present basin margin, allowing deposition of the Austin Formation, may have resulted from a retreat of the ice or, more probably, a sag of the crust under the load of the ice resulting in the floating of the seaward margin of the ice. The Austin Formation includes varved siltstone/shale/sandstone in the Coordewandy area. This suggests that in this area the sediments were deposited in a freshwater lake.

The dominantly arenaceous sequence of the Austin Formation and Coyango Greywacke possibly resulted from the erosion of the soils previously developed on the Precambrian rocks. The tillitic siltstone members must be related to local or ephemeral events: local or temporary increase in the pulverizing of the eroded material, or temporary retreat of the ice so that only the fine-grained material reached the lake or sea in periglacial streams, particularly in the case of the varved sediments. Some of the arenaceous members may have been brought into the environment of deposition by large periglacial streams.

In suitable positions the arenaceous members of the Austin Formation have been re-worked into a clean quartz sandstone (as the Harris Sandstone). Such sandstones, which may be expected in places like the basement ridges, are excellent reservoirs for water or petroleum and as they are suitably related to the unconformity above the pre-Permian rocks which include petroleum source beds, sandstone lenses in the Austin Formation on the basement ridges may contain accumulations of petroleum. Much more information about the subsurface distribution of the formation is required before suitable locations can be indicated for test drilling for petroleum.

Coyango Greywacke

The Coyango Greywacke (Condon, 1962a) is the formation, consisting predominantly of quartzwacke with several boulder beds and minor tillitic siltstone, that is conformable between the Austin Formation below and the Dumbardo Siltstone above. In places it is unconformable on Carboniferous, Devonian, and Precambrian rocks.

The name is taken from Coyango Well, Williambury station (12 miles west-north-west of the homestead, at Lat 23° 47′ S., Long. 114° 58′ 20″ E.). The type locality (Fig. 39) is in the head of the gully that flows westward past Coyango Well. The type section (Fig. 47) starts 1000 yards north-west of the well and continues along the south side of the gully past the well and westward to 90 yards west of the right-angled corner of the vermin-proof fence.

The base of the Coyango Greywacke is placed at the change from alternating arenaceous and siltstone members to predominantly greywacke lithology; the top is placed at the change from quartzwacke to siltstone at the base of a predominantly siltstone formation.

The Coyango Greywacke consists dominantly of greywacke (about 55 percent) and quartzwacke (about 20 percent), with minor siltstone and boulder beds. The greywacke consists of poorly-sorted angular to subround grains of quartz, rock fragments (quartzite, chert, igneous rocks, limestone, schist), feldspar, and mica, in a silty matrix. It is commonly bedded but rarely graded, although in places silty partings between beds are noticed. The quartzwacke consists dominantly of moderately sorted subangular to subround grains of quartz, chert, and quartzite, with minor igneous and metamorphic rock fragments, feldspar, and mica, and a silty matrix. The siltstone is present in members up to 40 feet thick and as interbeds with greywacke. It is mainly greenish grey, laminated, with angular to subround sand grains of varied size scattered throughout (not in laminae or regularly dispersed). In all three of these rock types isolated pebbles, cobbles, and boulders are encountered. The boulder beds have a matrix of greywacke or siltstone in which pebbles, cobbles, and boulders are scattered at random. These large fragments are commonly subround to subangular; they include granite (coarse-grained and fine-grained), gneiss, schist, quartzite, laminated jasper, limestone, quartz (clear and milky), and hematite. The finer-grained rocks are commonly striated, and some are faceted. The boulder beds are generally somewhat lenticular, although in places individual boulder beds can be followed in outcrop for several miles.

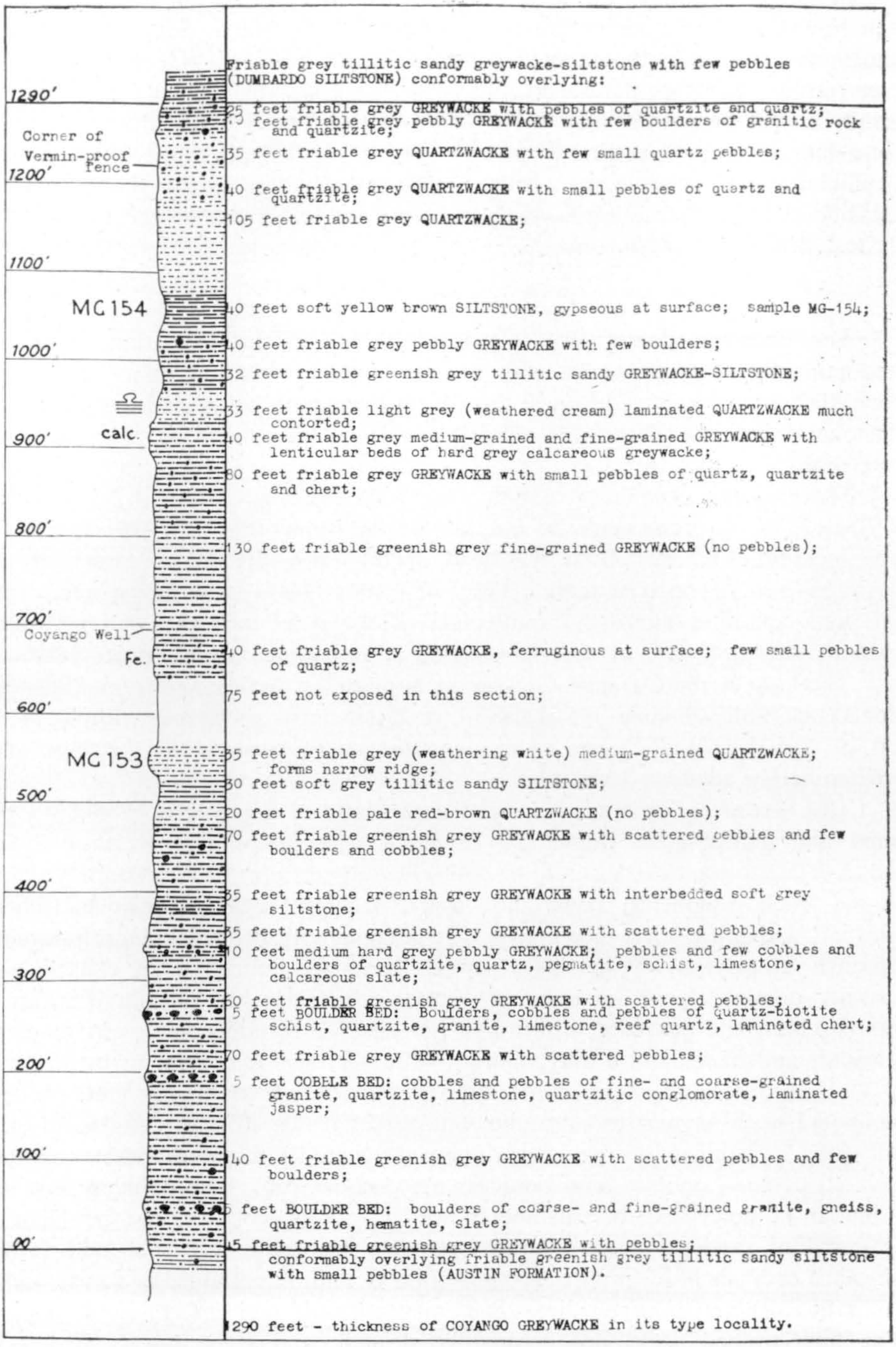


Fig. 47. Type section, Coyango Greywacke.

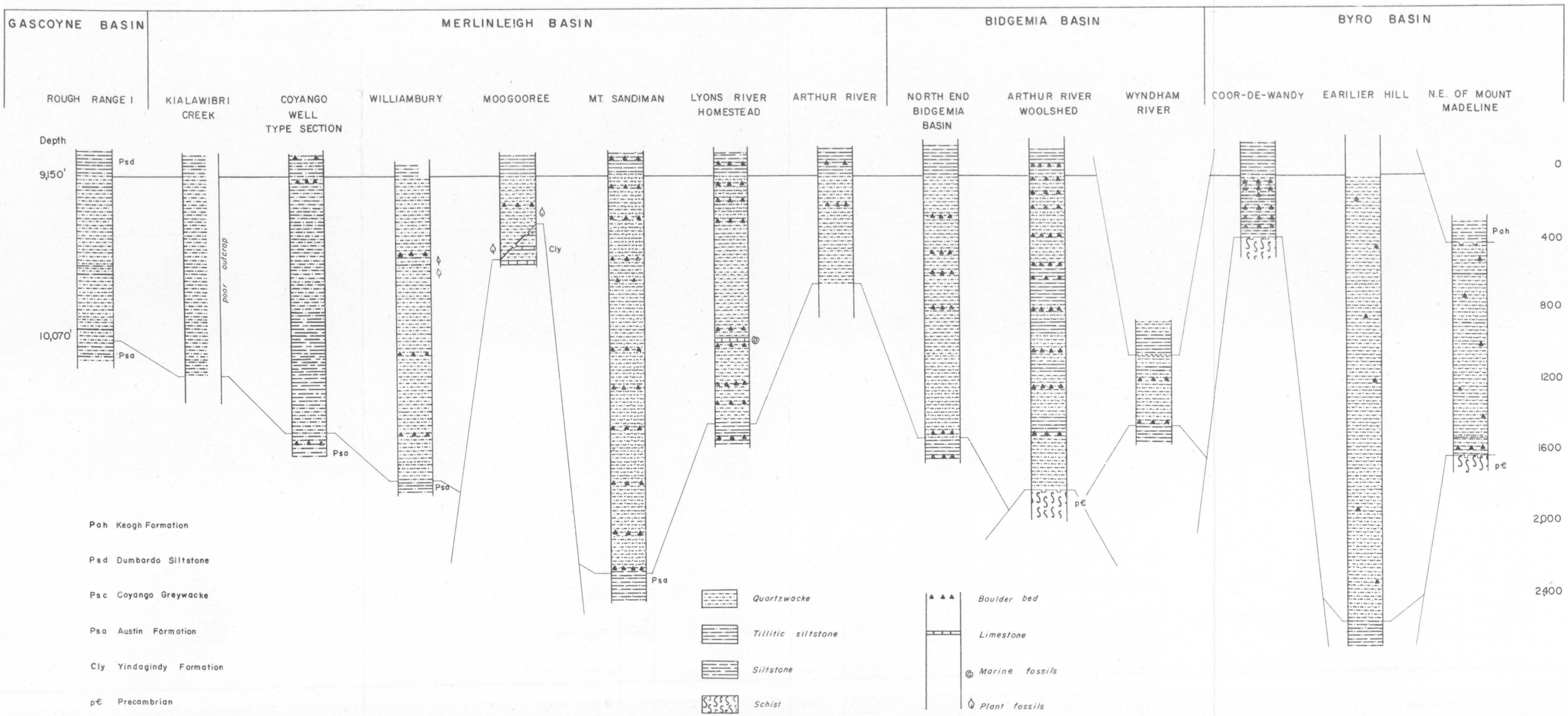


Fig. 48. Stratigraphic columns, Coyango Greywacke.

W/A66

The Coyango Greywacke crops out for only about 5 miles north-north-west from the type locality, but extends southward at least as far as Earilier Hill (Byro station). (See Fig. 48 for stratigraphical columns.) The outcrop belt that includes the type locality is 16 miles long, ending at Yindagindy Creek. In the Harris Syncline 4 miles west of Williambury homestead the Coyango Greywacke crops out from 1½ miles north of Harris Well to Dumbardo Bore. In the Williambury Syncline the large mesa east of the homestead is developed in the Coyango Greywacke, which is about 1700 feet thick and contains several beds with lycopod plant fossils. On the east flank of the syncline the Coyango Greywacke overlaps the Austin Formation, and near New Well (Moogooree, 7 miles north of the homestead) rests unconformably on Moogooree Limestone and Yindagindy Formation. From there to 15 miles south-south-east of Moogooree homestead it rests unconformably on the Carboniferous formations and in this area its exposed thickness is variable but generally about 200 to 400 feet. It continues southward on the east side of Woodcock Creek to the Lyons River. In this area it is about 2920 feet thick and contains rather more and thicker siltstone members than in the type locality. At the north end (12 miles west of north of Mount Sandiman homestead) it overlaps the Austin Formation, but from there to the Lyons River is conformable on the Austin. It overlaps the Austin Formation also 6 miles east-north-east of Lyons River homestead, where it rests unconformably on Precambrian schist of the Weedarra Ridge. In the small embayment in the Weedarra Ridge between Sandiman Well and Four-mile Well, Lyons River station, the Coyango Greywacke is 1420 feet thick and contains one bed with marine fossils. Along the west flank of the Weedarra Ridge the exposed thickness is about 200 feet at the north end. The Coyango Greywacke is overlapped by the Dumbardo Siltstone 10 miles south-east of Lyons River homestead. It crops out at the south end of the Merlinleigh Basin, about 15 miles north-east of Carey Downs homestead, where it is about 1200 feet thick.

In the Bidgemia Basin it crops out in the north end, 8 miles north of Mount Sandiman homestead, where it is 1480 feet thick, and from there to the Lyons River. There is no outcrop between the Lyons River and Onslow Creek. The Coyango Greywacke crops out at or near the margin of the basin from Onslow Creek, 2 miles south of Eudamullah homestead, for 30 miles to 4 miles north-west of K-32 where it rests unconformably on the Austin Formation; in the Arthur River embayment the Coyango Greywacke rests conformably on the Austin Formation and is overlain by the Dumbardo Siltstone; it is 560 to 960 feet thick, the variation being related to deposition over a surface of strong relief on the Precambrian schist. Elsewhere in this belt the Coyango Greywacke rests unconformably on the Precambrian schist; 6 miles south of Eudamullah homestead it is 1150 feet thick; the abutment unconformity on the Precambrian schist is well exposed. The Coyango Greywacke crops out in a north-south belt crossing Paradise Creek about 12 miles west of Arthur River woolshed; it is about 940 feet thick. The formation is not unequivocally identified, but it is the only predominantly arenaceous thick formation in the Lyons Group in this area. In the Byro Basin the most northerly outcrop is near Congo Creek, where the top part of the Coyango Greywacke rests unconformably on the Precambrian schist. In the Daurie Creek embayment the Greywacke is 300 feet thick and contains five prominent boulder beds. It rests unconformably on a surface of strong relief in the Precambrian schist. It is not exposed in most of the Wooramel embayment because of the widespread and deep lateritization, but crops out at the south side of the embayment in Earilier Hill (8 miles north-west of Byro homestead). Konecki et al. (1958, p. 10) considered the quartzwacke of Earilier Hill to be similar to the Badgeradda Group, but in 1959 I found tillitic siltstone underlying the quartzwacke, and quartzite boulders in the quartzwacke. Because of its positon towards the bottom of the Lyons Group and because it is a thick formation (2500 feet) of quartzwacke with boulder beds, the main mass of Earilier Hill is considered to be Coyango Greywacke. I have not examined Mount Rebecca (10 miles south of west of Byro homestead), but the photo-pattern and structural trends suggest that it is similar to Earilier Hill and therefore also Coyango Greywacke. Outcrop is very poor in the Lyons Group south of Mount Rebecca and the Coyango Greywacke has not been established in outcrop there.

On the west side of the Byro Basin 4½ miles north-east of Mount Madeline, Konecki et al. (1958, pl. 2) mapped as Monument Formation a triangular area of arenaceous sediment. I examined this outcrop in 1959 and found it to consist predominantly of quartzwacke with many pebbly beds, a few boulder beds, and thin tillitic siltstone beds, the whole silicified by weathering processes. The sequence is unconformable on the Precambrian schist of the Carrandibby Range and dips eastward at 55° (near that unconformity) to 30° in the upper part; it is about 1200 feet thick and is overlain unconformably by the Keogh and Madeline Formations. This outcrop is definitely part of the Lyons Group and very similar in its surface expression to the outcrop of the Coyango Greywacke six miles south of Eudamullah homestead. Because of the thickness predominantly of quartz-wacke this sequence is considered to be Coyango Greywacke, as no other grey-wacke formation of the Lyons Group has such thickness or uniformity of lithology.

In Rough Range No. 1, I consider that the equivalent of the Coyango Grey-wacke is the predominantly quartzwacke sequence from 9150 feet to 10,070 feet depth (thickness 920 feet): it is the only very thick quartzwacke sequence within the Lyons Group in the bore, is in the lower part of the Lyons Group sequence, and is underlain by alternating siltstone and quartzwacke and overlain by siltstone.

The only fossils reported from the Coyango Greywacke are the marine fossils from G-176 (5¾ miles south-south-east of Mount Sandiman homestead) where a pebbly calcareous quartzwacke contains abundant bryozoa and poorly preserved shelly fossils, and the lycopod plant fossils from CC101 (0.8 mile south of Williambury homestead), CC106 (1.1 mile south-south-west of the homestead), CC108 (0.7 mile west of north of the homestead) and TP210 (1.3 mile north of Moogooree homestead). White (White & Condon, 1958) determined these fossils as *Lepidodendron* sp. of Permian type. CC108 is near the bottom and

TP210 near the top of the Coyango Greywacke; all CC localities are close to an abutment unconformity with Precambrian schist and TP210 is near the unconformity with Lower Carboniferous rocks.

The *Lepidodendron* sp. establishes the Coyango Greywacke as Permian (White, loc. cit.), and since the upper part of the Lyons Group is Sakmarian, this formation is also Sakmarian.

The Coyango Greywacke can probably be correlated with part of the Grant Formation of the Canning Basin and of the Nangetty Formation of the Irwin Basin, but the detailed sequence of those formations is not well enough known to indicate which parts may be stratigraphically equivalent.

The presence of *Lepidodendron* in the Coyango Greywacke indicates that there must have been ice-free land in the vicinity throughout the deposition of this formation. This perhaps gives a hint of the palaeogeographical control of the type of sedimentation in the Lyons Group: the arenaceous formations may represent material transported mainly by periglacial streams with the addition of small amounts from floating ice (floes, and bergs derived from valley glaciers); the siltstone units may represent direct deposition from floating ice without sorting by stream action and thus would indicate periods of advance of the ice to the edge of the continent. Parts of the Coyango Greywacke are locally contorted (e.g. 1000 feet west of Coyango Well, and in the left bank of Minilya River 0.5 miles east of Williambury homestead); these contortions, which are quite strong with overturned folds and small thrust faults, are believed to have been produced by the impact of large icebergs on the unconsolidated sediment of the sea floor.

The Coyango Greywacke in outcrop is generally homoclinal, conforming to the regional westward dip. In the Harris, Williambury, and Gap Well Synclines it plunges southward. Anticlines are developed, probably over ridges of basement, 2 miles west of Arthur River woolshed (5 miles long, north-south) and 17 miles west of Dairy Creek homestead (5 miles long, north-south). The only outcrop showing homoclinal east dip is that near Mount Madeline; this suggests that the Coyango Greywacke, in subsurface, extends across the basins, although it is likely that in the central parts of the basins the Coyango Greywacke varies into a more silty formation derived from fine-grained material winnowed from the Coyango Greywacke before its deposition. The presence of an arenaceous equivalent in Rough Range No. 1 indicates its wide spread; it may be present in subsurface over the large basement ridges in anticlinal form and, possibly, in somewhat cleaner lithology than in outcrop.

The Coyango Greywacke has been used only as a source of underground water, and that in only a few places: Harris Well (Williambury) most probably is sunk in the Coyango Greywacke, not in Harris Sandstone as previously thought (Condon, 1954, p. 31); Coyango Well (Williambury), Woodcocks Well, Birds Bore, Austin Well and Crabhole Bore (Mount Sandiman), Eight-mile Well and Four-mile Well (Lyons River station), and the well 2½ miles south of the homestead, Steads Well, Windlass Well, Corktree Well and the well 4½ miles west-north-west of K-32 (Eudamullah station). It is generally of only moderate porosity and permeability, although in some places where it has been deeply weathered the silt has been removed and it is then a good shallow aquifer.

It is likely to develop into a fair to good intergranular reservoir for oil in locations that were within reach of wave and current action during deposition. Such locations may be found on the larger basement ridges (as Wandagee Ridge). It is marine in the Merlinleigh Basin, and has marine shale above it and perhaps below it, so that it must be considered as a possible oil sand in locations suitable for accumulation. Apart from the anticlinal areas above the basement ridges traps may be developed at the abutment unconformity against the Precambrian, especially where the Coyango is overlapped by the impermeable Dumbardo Siltstone, as on the west side of the Bidgemia Basin, Byro Basin, and the Weedarra Ridge, and possibly on the west side of the Merlinleigh Basin.

Dumbardo Siltstone

The Dumbardo Siltstone (Condon, 1962a) is the formation, consisting mainly of tillitic siltstone with minor quartzwacke and boulder beds, that is conformable between the Coyango Greywacke below and the Koomberan Greywacke above. In places it grades laterally into the Koomberan Greywacke.

The name is taken from Dumbardo Bore, Williambury station (Lat. 23°55′S., Long. 115°06′E.), which cuts the lower part of the formation. The Dumbardo Siltstone crops out 2 to 4 miles east-north-east of the bore. The type locality (Fig. 39) is 700 to 1350 yards west of Coyango Well, Williambury (12 miles west-north-west of the homestead), and there the Dumbardo Siltstone is 500 feet thick (Fig. 49).

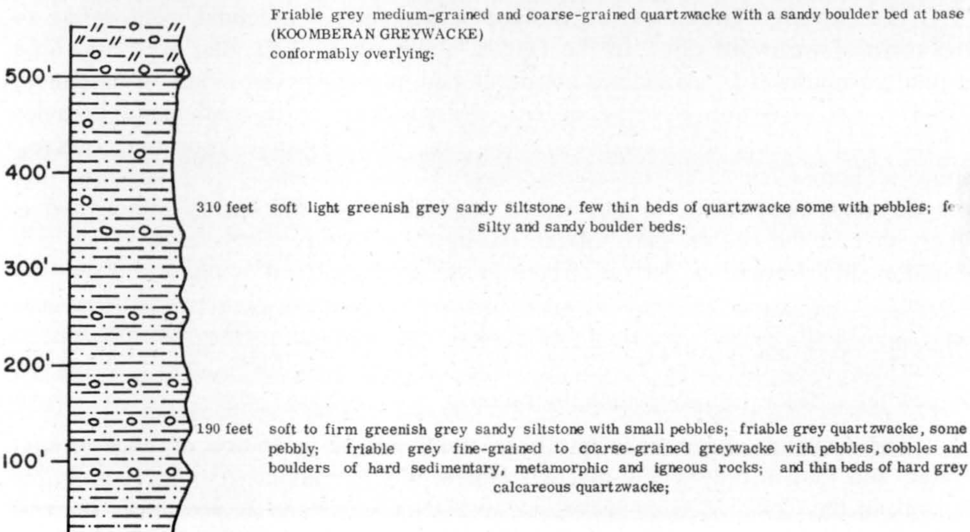


Fig. 49. Type section, Dumbardo Siltstone.

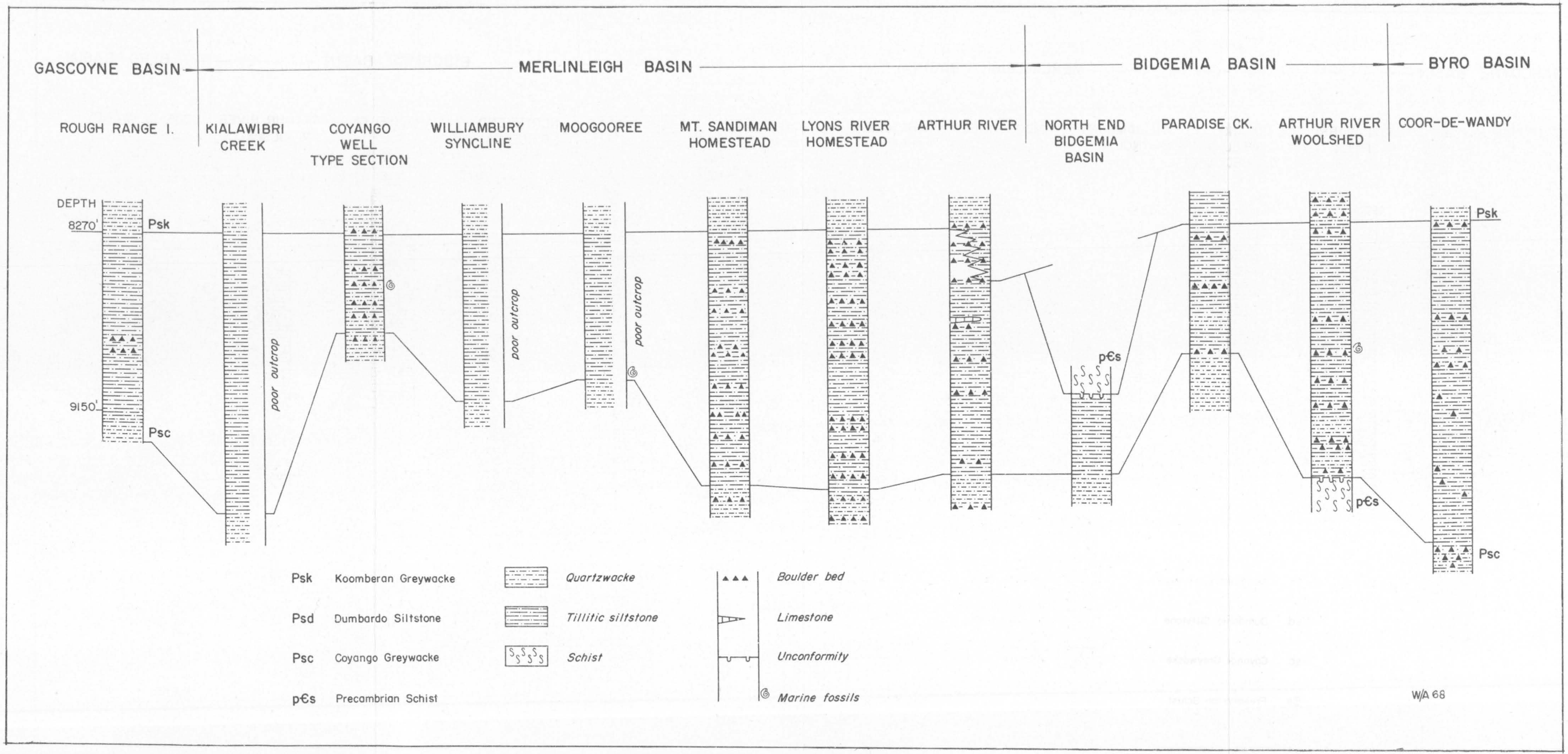


Fig. 50. Stratigraphic columns, Dumbardo Siltstone.

The base of the Dumbardo Siltstone is placed at the marked change in lithology from predominantly quartzwacke to dominantly siltstone (the lower part of the Dumbardo Siltstone contains several quartzwacke members but is dominantly siltstone). At the top of the formation there is a marked change in lithology from siltstone to quartzwacke.

The Dumbardo Siltstone is characterized by its position between the two greywacke formations of the Lyons Group and by having several thin quartzwacke members in its lower part, some of which have hard calcareous beds. The boulder beds mainly have a greywacke matrix and some include hard calcareous beds.

The dominant lithology of the Dumbardo Siltstone is dark greenish grey sandy siltstone of tillitic texture (the sand grains of all sizes are scattered through the rock, not evenly dispersed or in laminae) which contains few scattered pebbles and larger rock fragments. It is commonly thin-bedded to laminated.

The arenaceous members are mainly greywacke of very uneven grainsize (commonly coarse-grained to fine-grained) with a large proportion (30 to 40 percent) of silt matrix, and mica and feldspar, and commonly pebbles and larger fragments. The sand grains and larger fragments include a large proportion of rock fragments (dominant in some beds): rock types include (roughly in order of abundance) quartzite, granite, schist, gneiss, limestone, ironstone, hornfels, pegmatite, and amphibolite.

Most of the boulder beds are less than 10 feet thick, have a greywacke matrix, and include boulders, cobbles, and pebbles of rocks of the same lithology as the fragments in the greywacke and also milky quartz and slate. Many of the boulders are striated and a few are faceted; most are subrounded to rounded with a polished surface even on re-entrant surfaces.

Quartzwacke forms a minor proportion of the arenaceous beds; it consists mainly of quartz (uneven-grained, subangular to subrounded) and silt matrix with minor mica, feldspar, and rock fragments; it contains very few pebbles.

A very minor rock type is hard dense fine-grained limestone with cone-in-cone structure.

Distribution, Thickness, & Relationships (Fig. 50).—The most northerly definite outcrop of the Dumbardo Siltstone is about 8 miles north of the type locality. It is probably present in the area east of Kialiwibri Creek and immediately west and north-west of the Pleiades Hills, where a 'crab-hole' surface is covered by gibbers of billy* derived from the Tertiary landsurface. The outcrop belt extends southward from the type locality for 12 miles to Yindagindy Creek. The thickness varies markedly: it increases regularly from 500 feet at the type locality to 1150 feet at the Williambury-Middalya road, and decreases sharply, at a bend in strike 1 mile south of the road, to 850 feet. From this area to Yindagindy Creek the Dumbardo Siltstone is unconformably overlain by the Callytharra Formation and the full thickness cannot be measured.

In the Harris Syncline the Dumbardo Siltstone is very poorly exposed in the area west of Dumbardo Bore and east of Yindagindy Creek. No estimate of

*'Hard opaline quartzite formed in the mature soil profile either in concretions or as a continuous layer up to about 5 feet thick' (Dunstan, B., 1900, *Geol. Surv. Qld Bull.* 148, 5-6).

thickness can be made, as formation boundaries and dips cannot be determined satisfactorily.

In the Williambury Syncline outcrop is poor also, but formation boundaries can be established and dips measured (mainly in the adjoining formations). The thickness is estimated at 840 feet. Here the Dumbardo Siltstone abuts unconformably against the Devonian Gneudna Formation (and probably against younger Devonian formations also, that are covered by alluvium).

The Dumbardo Siltstone crops out (generally with poor exposure) for half a mile west from Moogooree homestead; it is 740 feet thick. This outcrop belt is narrow (½ mile)and extends from the South Minilya River for only 7 miles southwards before it is interrupted by the wide alluvial area around Longreach and Wilson's Bores, Moogooree station. Outcrop reappears about 7 miles southward and continues with minor interruptions by alluvium for 27 miles to the alluvium of the Lyons River. In this outcrop belt the Dumbardo Siltstone maintains a thickness of 1200 to 1300 feet, and dips at 10° to 13° westward. From 5½ miles north-west to 3½ miles west of Mount Sandiman homestead, Callytharra Formation and Moogooloo Sandstone rest unconformably on the Dumbardo Siltstone in an asymmetrical valley eroded in that formation.

South of the Lyons River the Dumbardo Siltstone crops out in a belt 2½ miles wide and 18 miles long. It dips at 4° to 6° westward and is 1300 feet thick. It overlaps the Coyango Greywacke 10 miles south-east of Lyons River homestead and rests unconformably on Precambrian schist of the Weedarra inlier.

The outcrop is interrupted at the south end of the Weedarra inlier and recommences 4 miles east-south-east of the end of the previous outcrop belt. From there it continues (interrupted by the alluvium of the Arthur River) for 10 miles to where it is overlapped by the Koomberan Greywacke 6 miles south-east of K-35; there the Callytharra Formation abuts unconformably against it. In this belt the thickness of the Dumbardo Siltstone ranges from 500 feet to about 1250 feet. This variation appears to be related to the lateral variation of a large part of the Koomberan Greywacke into the Dumbardo Siltstone (in the area 3 to 6 miles north-eastward from K-35): several boulder beds that pass from the Koomberan Greywacke into the Dumbardo Siltstone establish the relationship.

The Dumbardo Siltstone crops out very poorly at the south end of the Merlinleigh Basin 10 to 15 miles north-east of Carey Downs homestead. It unconformably overlies the Precambrian schist of the Carrandibby Range. Its thickness there is estimated at about 800 feet.

In the Bidgemia Basin the Dumbardo Siltstone crops out at the north end near Crabhole Bore in a belt 4 miles long; on the west side it abuts unconformably against Precambrian schist. The maximum thickness there is 400 feet. An outcrop belt about a mile wide and 7 miles long extends southward from the left bank of the Lyons River 7 miles south-east of Mount Sandiman homestead. The Dumbardo Siltstone is 660 feet thick; at its north end it probably abuts unconformably against Precambrian schist (the contact is under the alluvium of the Lyons River but the regional structure suggests this relationship); at the south end it is overlain by Koomberan Greywacke and Dumbardo Siltstone on an angle of rest unconformity (Condon, 1956). This overlying Dumbardo Siltstone extends in outcrop for 12 miles southward from 7 miles south-south-west of Eudamullah homestead; in this belt the thickness is very uniformly 850 feet. At the south end of the belt the Dumbardo Siltstone is overlain by Mundarie Siltstone on an angle of rest unconformity. An outcrop of Dumbardo Siltstone ranging in width up to 3 miles extends from 6½ miles south of Eudamullah homestead for 30 miles. Two Dumbardo Siltstone sequences meet on an angle of rest unconformity. The western sequence ranges up to 2000 feet thick and the eastern to 1400 feet. At its southern end the eastern sequence abuts unconformably against the Austin Formation.

In the Byro Basin no outcrop of Dumbardo Siltstone is known in the north end (north of Congo Creek); it crops out in a belt 1½ miles wide and 6 miles long north and south of Daurie Creek. There it is 1600 feet thick. Farther south the Dumbardo Siltstone does not crop out because of the deep lateritization or a cover of Recent deposits.

In West Australian Petroleum Limited's Rough Range No. 1 Well, I consider that the siltstone formation between depths of 8270 and 9150 feet is the equivalent of the Dumbardo Siltstone.

In outcrop the thickness of the Dumbardo Siltstone ranges from 500 feet to 2000 feet with an average of about 1000 feet. It appears to be thicker in the Bidgemia and Byro Basins than in the Merlinleigh and Gascoyne Basins.

Fossils.—Several beds of marine fossils have been found in the Dumbardo Siltstone. In the type section one bed (M.G. 156) contains Fenestellidae, *Deltopecten lyonsensis* Dickins, spiriferid, and *Calceolispongia* sp. ML6, from near the base of the Dumbardo Siltstone 3¼ miles west of north of Moogooree homestead, contains *Trigonotreta*(?) sp. ind., *Neospirifer* sp. ind., *Linoproductus lyoni* (Prendergast), Rhynchonellaceae gen. ind., Rostrospiraceae gen. ind., and *Deltopecten lyonsensis* Dickins (G. A. Thomas,, pers. comm.). GW62, from about the middle of the Dumbardo Siltstone 6¼ miles west-north-west of Arthur River woolshed, contains *Kiangsiella* sp. nov. A. (Thomas, 1958), *Aviculopecten* cf. *A. tenuicollis* (Dana) and Fenestellidae (J. M. Dickins, pers. comm.). In the dissection embayment 2 miles north of Coyango Well CC123 contains *Streptorhynchus* sp. nov. and fenestellids, CC125 from the same bed contains *Pseudosyrinx* sp. nov. aff. *nagmargensis, Streptorhynchus* sp. nov., *Neospirifer* sp., martiniopsid gen. et sp. nov., dielasmatid, *Deltopecten lyonsensis* Dickins, fenestellids, and worm trails, and CC124, from slightly above the other two, contains *Linoproductus lyoni* (G. A. Thomas, pers. comm.).

Age and Correlation.—All the determined species appear to range through the Lyons Group from the Dumbardo Siltstone upwards, and some, e.g. *Linoproductus lyoni,* are found also in the Artinskian Callytharra Formation. No species so far found in the Dumbardo Siltstone is known to range into the Carboniferous.

As no restricted species have been found in the Dumbardo Siltstone it cannot be correlated with particular formations of the Lower Permian elsewhere.

Structures.—Throughout the outcrop belt, the Dumbardo Siltstone mainly has a westward dip ranging from about 25° near Moogooree to about 5° west of the Weedarra Inlier. Synclinal structure is developed in the Williambury Syncline and in the eastern of the two adjoining belts of Dumbardo Siltstone 6 miles west of Arthur River woolshed. The Dumbardo Siltstone forms a north-plunging anticline over the Weedarra Ridge immediately north of the Precambrian inlier of the Carrandibby Range (17 miles north-eastward from Carey Downs homestead). It is probably anticlinal in the Dumbardo Bore area (Williambury).

Palaeogeography.—The Dumbardo Siltstone is predominantly tillitic but bedded. It was deposited in seawater from icebergs derived from a continental icesheet, and indicates a period of advance of the icesheet beyond the margin of the continent. The detrital material includes many rocks, all of which are similar to rocks at present cropping out on the Western Australian Plateau east of the Basin. Some of the differences in thickness of the formation may be related to routes of movement of icebergs by ocean currents.

Economic Geology.—The Dumbardo Siltstone has no present use apart from the very low-value grazing land on its outcrop. It is probably suitable for brick shale.

As it is a fossiliferous marine siltstone deposited in seas adjoining a continental icesheet it may be a source of oil: it is well established that the present Southern Ocean is one of the most prolific producers of plankton, which probably provides raw material for oil forming. It would certainly be a good caprock to the Coyango Greywacke.

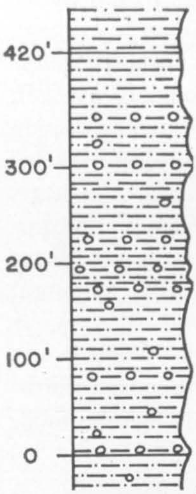
Koomberan Greywacke

The Koomberan Greywacke (Condon, 1962a) is the formation of greywacke, quartzwacke, and boulder beds, with minor tillitic siltstone, conformable between the Dumbardo Siltstone below and the Mundarie Siltstone above. In places it grades laterally into the upper part of the Dumbardo Siltstone.

The name is taken from Koomberan Bore, Middalya station (Lat. 23°42¾′S., Long. 114°51¾′E.). The formation crops out along the Vermin-proof Fence which is the eastern boundary of Koomberan Paddock.

The type locality (Fig. 39) is 1½ miles south-south-west of Coyango Well, Williambury station, and 8¾ miles south-east of Koomberan Bore. The type section (Fig. 51) starts at the Vermin-proof Fence where a small watercourse crosses it 1 mile south of the fence corner 700 yards west of Coyango Well; it extends south-westward for 2000 feet. The Koomberan Greywacke in this section has a uniform dip of 15° westward (apart from contorted beds); it is 420 feet thick.

The base of the Koomberan Greywacke is placed at the change of lithology from tillitic siltstone to quartzwacke and greywacke, the top at the change from greywacke to tillitic siltstone. The Koomberan Greywacke is characterized by members of greywacke (about 70 percent of the formation), quartzwacke (10 percent), siltstone (12 percent), and boulder beds (6 percent), which give a strongly banded air-photo pattern with bands of even grain and medium tone alternating with mottled bands. It crops out as rounded strike ridges commonly slightly higher than the country on either side.



Friable light green-grey sandy siltstone with few scattered cobbles (MUNDARIE SILTSTONE) conformably overlying:

30 feet thin-bedded friable grey medium-grained quartzwacke;

17 feet firm grey-green sandy siltstone;

63 feet thin-bedded friable grey medium-grained quartzwacke with a bed of pebbly greywacke; sandy boulder bed at base (boulders of granite, limestone, quartzite, chert);

10 feet firm grey-green siltstone;

50 feet friable grey medium-grained quartzwacke;

55 feet friable grey medium-grained and coarse-grained quartzwacke with friable and hard calcareous beds of pebbly greywacke with cobbles and few boulders;

75 feet friable grey medium-grained and coarse-grained quartzwacke with a bed of pebbly greywacke with few boulders at base;

80 feet friable grey medium-grained and coarse-grained quartzwacke with a sandy boulder bed at base;

conformably overlying soft greenish grey sandy siltstone (DUMBARDO SILTSTONE).

420 feet - thickness of Koomberan Greywacke in type section.

Fig. 51. Type section, Koomberan Greywacke.

Lithology.—The Koomberan Greywacke consists dominantly of friable greenish grey medium-grained greywacke composed of uneven angular and subangular rock fragments and grains of quartz, feldspar, and mica with a silty matrix and commonly containing scattered pebbles particularly of quartzite and quartz. Some beds of greywacke are coarse-grained. Quartzwacke, composed of subangular to subrounded grains of quartz and quartzite with minor white mica and feldspar, and a silty matrix, forms members 5 to 20 feet thick and is interbedded with greywacke in one member. It was probably formed by the sorting of the typical greywacke by wave and current action. The siltstone members 10 to 25 feet thick are sandy (tillitic) and micaceous with scattered small pebbles. The boulder beds are commonly less than 5 feet thick and consist of boulders, cobbles, and pebbles of quartzite, granite, limestone, hornfels, biotite schist, and ironstone in a greywacke matrix.

Distribution, thickness and relationships (Fig. 52).—The Koomberan Greywacke is known in outcrop between Lyndon River and Bilung Creek; farther south generally poor outcrop prevents its identification.

On the Lyndon River, the Koomberan Greywacke is exposed between 3½ and 4½ miles downstream from Windalia Pool; it has a thickness of about 760 feet and contains more siltstone than in the type locality. In the area 4½ miles south of east of Koomberan Bore, the Greywacke is 580 feet thick. At the Williambury to Middalya road 9 miles west of Williambury, it is 850 feet thick; 2 miles south of the road it is unconformably overlain by Callytharra Formation. In the

Williambury Syncline 3 to 4 miles south of Williambury homestead the Koomberan Greywacke is very poorly exposed; it is estimated to be about 700 feet thick. It crops out on the plain $\frac{1}{2}$ to $\frac{3}{4}$ mile west of Moogooree homestead: it is 720 feet thick there. The outcrop is interrupted by Recent deposits from 4 to 10 miles southward from Moogooree homestead and then continues to the Lyons River; in this outcrop belt it is 760 feet thick west of Mount Sandiman homestead and 1440 feet immediately north of Lyons River homestead. For 20 miles southward from that homestead the Koomberan Greywacke is unconformably overlain by the Callytharra Formation; 8 miles south of the homestead the outcropping part of the Koomberan Greywacke is 560 feet thick. At the south end of this outcrop belt the Greywacke outcrop is offset about 4 miles to the east and starts at an abutment unconformity at the south end of the Weedarra Inlier of Precambrian schist and continues southward for 16 miles to 1 mile north of the Wyndham River; the thickness is variable, from 360 to 720 feet, mainly because of lateral variation into the underlying Dumbardo Siltstone but also because of a minor erosional unconformity against the overlying Mundarie Siltstone. At the south end of the Merlinleigh Basin the Koomberan Greywacke is poorly exposed north-west of the Carrandibby Range, where it is about 700 feet thick and includes more quartzwacke than farther north.

In the Bidgemia Basin the Koomberan Greywacke crops out from the left bank of the Lyons River (7 miles south-east of Mount Sandiman homestead) southward for 7 miles to a depositional unconformity; in this belt it is 600 feet thick. It is offset half a mile north across the unconformity and continues southward for 25 miles to another depositional unconformity; in this belt it is 300 to 600 feet thick and includes much more siltstone than in the Merlinleigh Basin. To the east of the unconformity Koomberan Greywacke crops out from 9 miles south of Eudamullah homestead southward for 40 miles. In this belt it is 300 to 700 feet thick and includes much siltstone. Nine miles north of Wyndham River it grades laterally into the Mundarie Siltstone. At this place shallow water was present during the deposition of the Mundarie, allowing the detrital material to be sifted. The Koomberan Greywacke is probably present in the south end of the Bidgemia Basin, but poor outcrop because of lateritization prevents the identification of the formation.

In the Byro Basin the outcrop of the Koomberan Greywacke is known only near Daurie Creek, where it is 185 feet thick. The top of the Koomberan is exposed at Bilung Pool on Bilung Creek. Elsewhere in the basin the outcrop of the Lyons Group is insufficient to allow identification of formations.

In Rough Range No. 1, I consider that the interval between 7670 and 8270 feet depth may be the equivalent of the Koomberan Greywacke: it is calcareous and dolomitic greywacke and quartzwacke with minor tillitic siltstone and few pebble beds.

The Koomberan Greywacke in outcrop ranges in thickness from 185 feet in the Byro Basin to 1440 feet in the central part of the Merlinleigh Basin. It is generally thinner in the eastern basins than in the Merlinleigh.

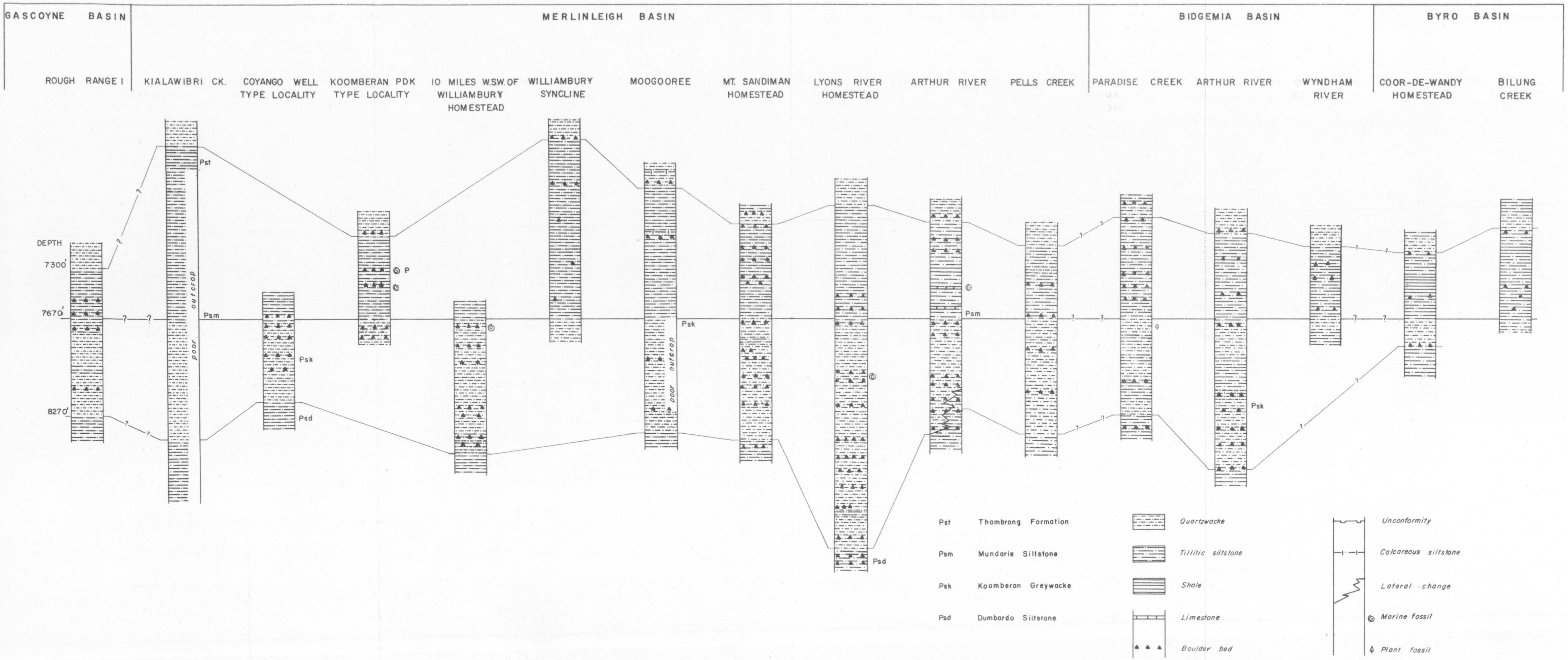


Fig. 52. Stratigraphic columns, Koomberan Greywacke and Mundarie Siltstone.

W/A70

Fossils.—Only three fossil localities are known in the Koomberan Greywacke: MG133, 2000 feet north-east of the right-angled corner of the Verminproof Fence, 10 miles south of west of Williambury homestead—this is near the top of the Formation and contains new pectinids; a locality 5½ miles south-east of Grays Well, Lyons River station, near the bottom of the formation, where M. H. Johnstone found pectinids, brachiopods (mainly spiriferids), crinoid stem ossicles, bryozoa, and corals in a hard pebbly calcareous greywacke bed; and a boulder bed about the middle of the formation 1 mile north of Lyons River homestead, which contains brachiopods.

Age and correlation.—The fauna has not been determined, but as Permian (Sakmarian) fossils are found in underlying and overlying formations the Koomberan Greywacke is certainly Sakmarian. It cannot be correlated with any particular part of Sakmarian sequences elsewhere as the faunas are insufficiently known.

Structure.—The Koomberan Greywacke dips generally westward along the east side of the Merlinleigh Basin. The structural continuity is broken by the basement ridges south and west of Williambury homestead, which have produced minor anticlines, south-plunging synclines, and unconformities in the Greywacke. A similar break, mainly an unconformity, is developed south and south-west of the Weedarra Inlier. North of the Carrandibby Inlier of Precambrian schist the Koomberan Greywacke forms a north-plunging anticline over the Weedarra Ridge and dips gently north-west into the Merlinleigh Basin and north-east into the Bidgemia Basin. In the Byro Basin it is known only in the central part of the east side of the basin, where it dips westward at about 10°.

Palaeogeography.—The Koomberan Greywacke is different from the Coyango Greywacke in having less quartzwacke and more siltstone. This difference reflects a difference in origin: the Koomberan Greywacke probably was deposited directly into the sea from icebergs derived from a continental icesheet. Either the detritus was coarser than usual, or the sea was shallower, allowing removal by waves and currents of much of the finer-grained material. Some beds show severe contortion probably caused by the impact of a grounding iceberg—an indication of relatively shallow water.

Economic geology.—The only use made of the Koomberan Greywacke to date is as an aquifer for stock water: New Well and Wilsons Well, Moogooree, obtain somewhat brackish water from it. The quartzwacke members are porous and permeable enough to be reservoirs for oil and gas. As there are siltstone members in the Koomberan, and marine siltstone formations below and above, there is a reasonable prospect of primary migration into it and of accumulation in any suitable structure. Areas where closed anticlines may be present in the Koomberan Greywacke include the Wandagee Ridge between the Lyndon and Wooramel Rivers and perhaps the Bullara Ridge (Fig. 35); stratigraphic traps may be present at the unconformities against the east side of the Weedarra Ridge and the east side of the Carrandibby Ridge.

Mundarie Siltstone

The Mundarie Siltstone (Condon, 1962a) is the formation, consisting mainly of sandy (tillitic) siltstone with minor greywacke and boulder beds, that is conformable between the Koomberan Greywacke below and the Thambrong Formation above.

The name is taken from Mundarie Well, Middalya station (Lat. 23° $54\frac{1}{3}'$ S., Long. 114° $55\frac{1}{2}'$ E., Minilya 4-mile Sheet). The formation crops out across the north-eastern corner of Mundarie Paddock, which is north-east from Mundarie Well. The type locality (Fig. 39) is in the north-eastern corner of Mundarie Paddock (at Lat. 23° 49′ S., Long. 114° $57\frac{3}{4}'$ E.) and the type section (Fig. 53) is 520 feet thick.

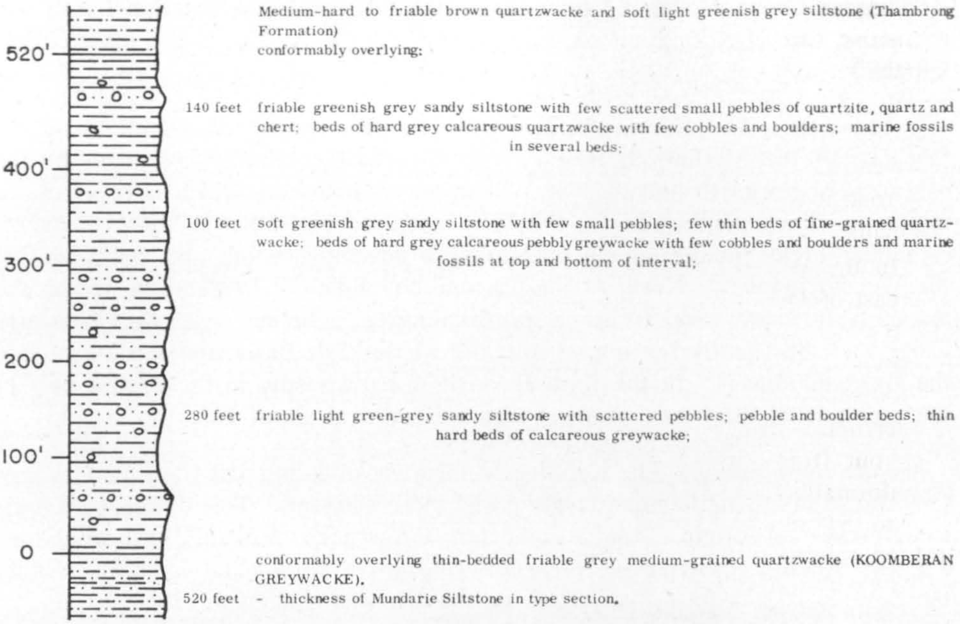


Fig. 53. Type section, Mundarie Siltstone.

The base of the Mundarie Siltstone is placed at the change of lithology from greywacke (with minor siltstone) to sandy siltstone (with minor greywacke); the top is placed at the change from sandy siltstone to quartzwacke at the bottom of a formation of alternating members of quartzwacke and siltstone.

The Mundarie Siltstone is characterized as predominantly siltstone: the individual greywacke and boulder bed members are not more than 5 feet thick. In this respect it differs from the Dumbardo Siltstone, which has thicker arenaceous members, but is similar to the shaly members of the Weedarra Shale.

The Mundarie Siltstone mainly has a reduced topographic expression and well-exposed complete sections are rare. The air-photograph pattern is smooth and even and moderately dark, but commonly includes black patches caused by dense vegetation in 'gilgais'—small swamp areas.

Lithology.—The predominant lithology of the Mundarie Siltstone is soft dark greenish grey sandy siltstone with scattered small pebbles. The sand and small pebbles are of uneven size and are scattered irregularly through the rock, not evenly dispersed or in laminae. The boulder beds commonly have a silty matrix and include pebbles, cobbles, and boulders of the types common throughout the Lyons Group. A few of the boulder beds have a greywacke matrix. The greywacke beds are friable grey and hard grey calcareous greywacke, the detrital fraction of which consists of rock fragments, quartz, feldspar, and mica in a silty matrix. Thin beds of hard calcilutite and of cone-in-cone limestone are a very minor part of the formation.

Distribution, thickness, and relationships (Fig. 52).—In the Merlinleigh Basin, the Mundarie Siltstone crops out at the north end on the Lyndon River, and along Kialawibri Creek from Gnarrea Pool southward. In this area it is about 1100 feet thick: only its upper part is well exposed. The outcrop is interrupted by a cover of sand south to 4 miles east of Koomberan Bore; from there the Mundarie Siltstone crops out for 17 miles southward almost to the Minilya River. At the north end of this belt the Siltstone is 280 feet thick; at the Middalya to Williambury road it is 560 feet thick; farther south its boundaries are covered by Recent sediments.

In the Williambury Syncline the Mundarie Siltstone crops out from half a mile east of Dumbardo Bore south-eastward to the South Branch, Minilya River. In this syncline it is about 1120 feet thick and generally not well exposed. Across the South Branch the outcrop continues southward for 8 miles; in this area, west of Moogooree homestead, the Mundarie Siltstone is 800 feet thick. Its outcrop is interrupted by the Recent deposits around Longreach Bore, Moogooree. It crops out from 10 miles south of Moogooree homestead for 6 miles and is unconformably overlain by Callytharra Formation from 11½ miles north-north-west to 5½ miles north of west of Mount Sandiman homestead. The same outcrop trend reappears and continues southward for 6 miles. In this area the Mundarie Siltstone is 600 feet thick. Recent deposits obscure the outcrop for 5½ miles. It then continues south for 8 miles to half a mile west of Lyons River homestead, where it is 720 feet thick and is unconformably overlain by Callytharra Formation. It does not crop out for 16 miles southward of Lyons River homestead. At the south-western end of the Weedarra Inlier the Mundarie Siltstone abuts unconformably against the Precambrian schist and Dumbardo Siltstone. From there it continues southward for 14½ miles to the Wyndham River. North of the Arthur River in this belt the Mundarie Siltstone is 480 to 600 feet thick and rests with a minor erosional unconformity on the Koomberan Greywacke.

At the south end of the Merlinleigh and Bidgemia Basins the Mundarie Siltstone crops out, dipping away from the Carrandibby Inlier and forming a north-plunging anticline (possibly with a little closure) over the Weedarra Ridge. In this area the exposure is poor and formation boundaries not easily placed. The Mundarie Siltstone is estimated to be about 460 feet thick but may be much thicker.

In the Bidgemia Basin the Mundarie Siltstone crops out from the Lyons River 13 miles north-east of Lyons River homestead southward for 7 miles to a depositional unconformity. In this belt it is 640 feet thick. The outcrop is offset about ½ mile north at the unconformity and then continues southward for 28 miles to another depositional unconformity; in this outcrop belt the Mundarie Siltstone is 400 to 650 feet thick: it is thicker near the western unconformity and thins near the eastern. The outcrop is offset along the unconformity: to the east of the unconformity it extends from 11 miles north-west of Arthur River woolshed to the Gascoyne River (40 miles); for 21 miles its western boundary is the unconformity, and thicknesses are partial only: in this belt the thickness increases southward to 3½ miles west of Gibidi Well, Bidgemia, where the Thambrong Formation appears. There the Mundarie Siltstone is 1200 feet thick. Immediately to the south the lower part of the Mundarie Siltstone changes laterally into the Koomberan Greywacke, and at the Wyndham River the Mundarie is only 500 feet thick. This is the ninth unit from the base of Raggatt's Wyndham River section (1936, p. 117) '325 feet of white quartz pebble conglomerate with boulders'. Southward the thickness continues constant towards the Gascoyne River to where the upper part of the formation is truncated by the unconformity beneath the Callytharra Formation.

In the Byro Basin the Mundarie Siltstone is known in outcrop only for 5 miles north and 2½ miles south of Coordewandy homestead, where it is 430 feet thick and includes a varved member 110 feet thick, and from Bilung Creek to Wooramel River, where it is 580 feet thick and has a varved member 60 feet thick.

In Rough Range No. 1 the interval between 7300 and 7670 feet depth is probably the equivalent of the Mundarie Siltstone: it is mainly sandy (tillitic) siltstone with a few pebble beds.

In outcrop the Mundarie Siltstone ranges in thickness from 280 feet to 1200 feet. The thickness appears to be related to structural position: all the very thick sections are in synclines.

Fossils.—In the type section three fossil localities were found: MG158 contains bryozoa, crinoid ossicles and plates, *Calceolispongia* sp., echinoderm spines, *Neospirifer* sp. ind., *Pseudosyrinx* sp. nov., and *Deltopecten lyonsensis* Dickins; MG159 contains bryozoa, *Neospirifer* sp. ind., *Deltopecten lyonsensis* Dickins, *Keeneia carnarvonensis* Dickins, *Platyschisma*? sp. nov., and cf. *Omphalotrochus*; and MG160 contains bryozoa (batostomellidae), crinoid ossicles and plates, *Linoproductus lyoni* (Prendergast) and *Permorthotetes* sp. (determinations by G. A. Thomas and J. M. Dickins).

In the area 12½ miles east-north-east of Bidgemia homestead D. Johnstone found crinoid ossicles, fenestellid bryozoa, and pectinids in a calcilutite bed low in the formation.

Dr. I. Crespin determined *Reophax tricameratus* and *Hyperamminoides* sp. in GW10, collected by D. Johnstone from the Mundarie Siltstone 16½ miles south of west of Dairy Creek homestead.

Age.—The known assemblage is similar to that from other parts of the Lyons Group and the Mundarie Siltstone therefore is Sakmarian in age.

Palaeogeography.—The Mundarie Siltstone was deposited in the sea, in fairly deep water directly from icebergs derived from a continental icesheet. There is no evidence of re-working of the material by waves or currents, and the beds of fine dense calcilutite confirm the generally deep, quiet environment. In the Byro Basin the environment was similar except that the water was probably fresh, perhaps because the Byro Basin was landlocked or icelocked: the varved member at Coordewandy and Wooramel River probably could form only in fresh water.

The relationship between the thickness of the Mundarie Siltstone and structural position suggests that the present regional structure reflects the topography of the bottom during deposition: silt and clay washed from sediments in shallow water would tend to collect in the hollows and there may have been some tendency for ocean currents to follow such bottom features, to direct the preferred course of iceberg movement into the areas of maximum deposition of material from the ice.

Economic Geology.—Apart from grazing on the outcrop no use is made of the Mundarie Siltstone. It is probably suitable for brick shale if ever that is required in this area.

Its main prospective economic significance is as a source bed for petroleum and a caprock to the Koomberan Greywacke. In the Merlinleigh Basin several fossil beds are known and the general environment of deposition of the Mundarie Siltstone is known to be very favourable for the growth of micro-organisms. It is very likely that organic matter was incorporated in the Mundarie Siltstone and converted into petroleum. It has porous formations above and below and grades laterally into the lower one in places.

Thambrong Formation

The Thambrong Formation (Condon, 1962a) is the sequence of alternating members of quartzwacke and siltstone conformable between the Mundarie Siltstone and the Weedarra Shale.

The name is taken from Thambrong Pool on the Minilya River 8 miles downstream from Williambury homestead (at Lat. 23° 57½′ S., Long. 115° 04′ E., on Minilya 1:250,000 Sheet). The formation crops out along the South Branch, Minilya River, upstream from its mouth, which is just upstream from Thambrong Pool.

The type locality (Fig. 54, Photo. 5013, Run 15, Minilya) is on both sides of South Branch from its junction with the Minilya River to the Williambury-Moogooree road. The type section (Fig 55) is in two parts because the South Branch crosses the formation outcrop so that no continuous complete section is available. The lower section is in the area about 2 miles north-north-west of South Branch Well, Williambury; it starts 800 feet east of the steep hill 2½ miles west of north of South Branch Well and ¾ miles east of Minilya River; extends for 2000 feet along the south side of that hill; is transferred along strike for 1500 feet, and continues south of west for half a mile over a group of hills to the western edge of outcrop. The upper part starts at the edge of the alluvium on the south side of South Branch 2000 yards east-south-east of South Branch Well and runs west of south for half a mile. A small part of the sequence, estimated to be about 200 feet thick, is not exposed between these two sections. The Thambrong Formation is about 1200 feet thick in the type locality.

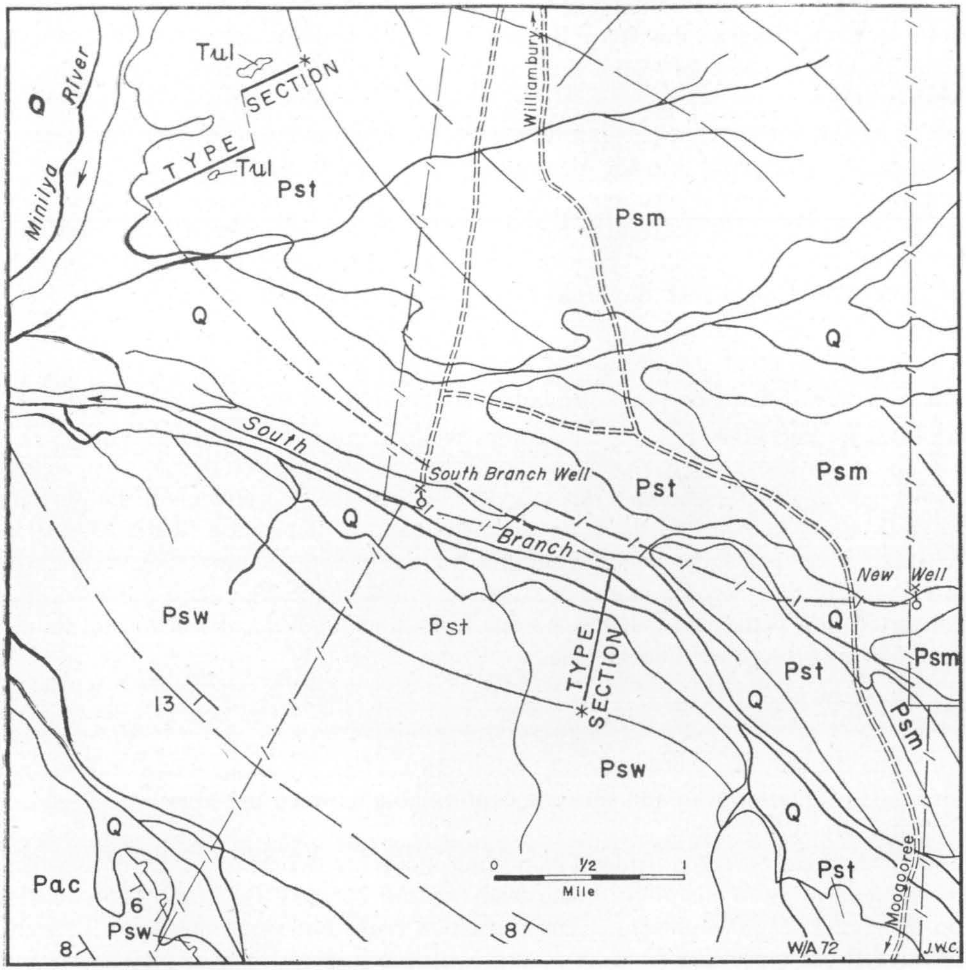


Fig. 54. Type locality, Thambrong Formation. Psm-Mundarie Siltstone; Pst-Thambrong Formation; Psw-Weedarra Shale; Pac-Callytharra Formation; Tul-laterite.

The base of the Thambrong Formation is placed at the change from dominant siltstone to the basal quartzwacke of a sequence of alternating quartzwacke and siltstone. The top is placed at the change from quartzwacke to tillitic siltstone in a formation of dominant siltstone and shale.

The Thambrong Formation is characterized by alternating members of tillitic siltstone and tillitic quartzwacke. They give a strongly banded air-photo pattern with alternate bands of moderately dark smooth pattern and light or mottled light and dark pattern.

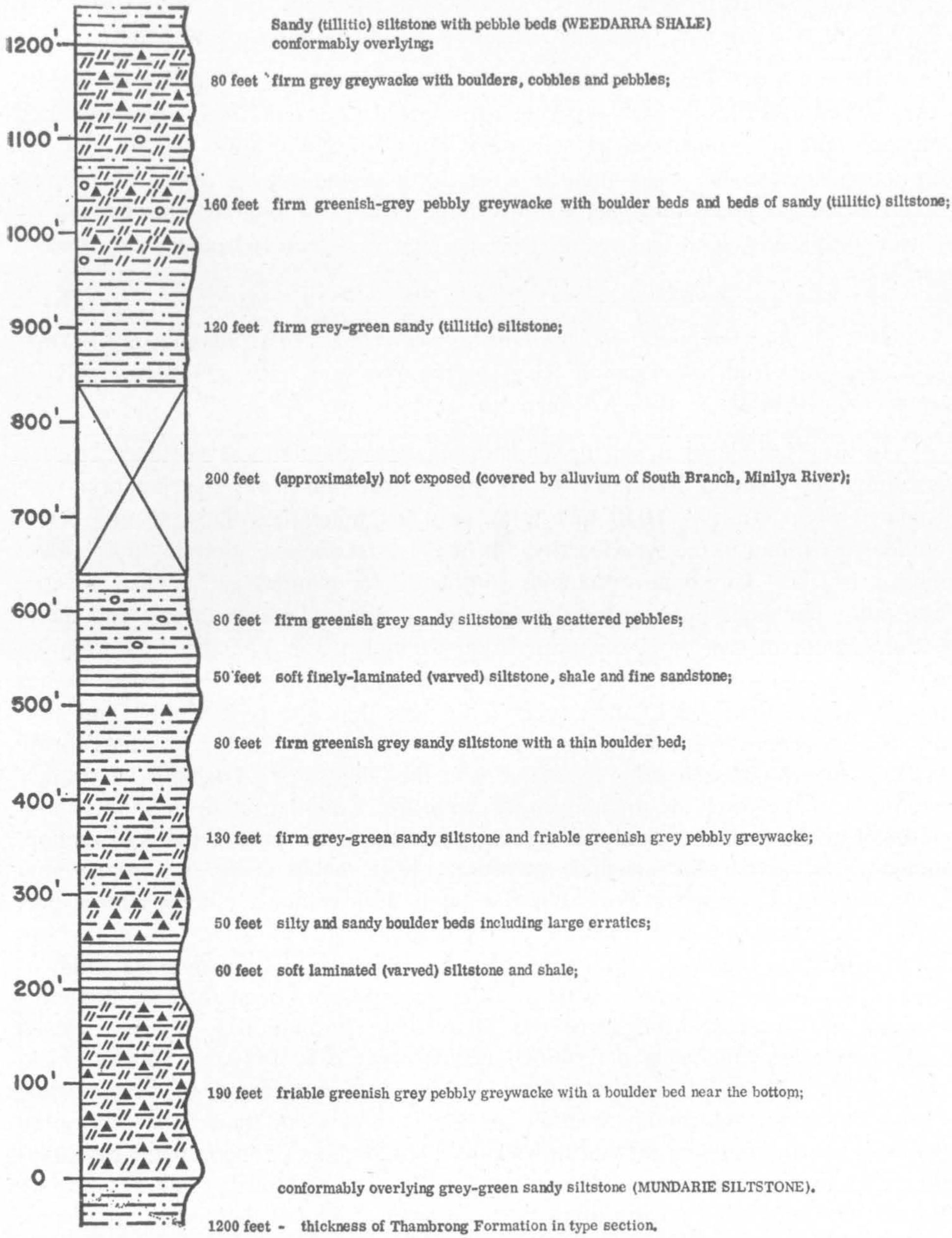


Fig. 55. Type section, Thambrong Formation.

Lithology.—The Thambrong Formation in the type locality consists of about 25 percent greywacke, 20 percent quartzwacke, 15 percent siltstone, 10 percent varved siltstone, 10 percent sandy boulder beds, 5 percent silty boulder beds, and 15 percent not exposed (siltstone suggested by photo pattern and soil).

The rocks are similar to those in the older formations of the Lyons Group. The varved siltstone, in two separate members, consists of finely interlaminated siltstone and fine sandstone. The boulder beds above the lower varved member crop out between the road and the river north of the road crossing of Minilya South Branch. There they include very large erratics of granite; one, broken by recent weathering, is at least 20 feet by 10 feet by 8 feet high above the present surface.

Distribution, thickness, and relationships (Fig. 56).—The Thambrong Formation crops out from the Lyndon River to the Wooramel River and probably its equivalent is present in Rough Range No. 1.

In the Merlinleigh Basin the Thambrong Formation's most northern outcrop is along the Lyndon River 1½ to 2¾ miles upstream from the junction with Kialawibri Creek; it is 1040 feet thick and has much less siltstone and fewer boulder beds than in the type locality. It has at least six beds containing abundant marine fossils. This outcrop extends southward for 6 miles and is then covered by sand. The same outcrop trend reappears 24 miles south-south-east and there, 3 miles south of east of Koomberan Bore, Middalya, the Thambrong Formation is 600 feet thick and overlain unconformably by Callytharra Formation; it has more siltstone than the Lyndon section but less than the type section and very few pebble beds. From there the outcrop extends southward for 12 miles to the Williambury-Middalya road. Near the road the Thambrong Formation is poorly exposed except near the unconformity with the Callytharra Formation; about 650 feet of the formation includes a section like the lower part of the type section, including a varved siltstone-shale member. It probably crops out in the area south-west of Thambrong Pool, but the small discontinuous outcrops have prevented identification of Lyons Group formations in this area. It crops out southward from the type locality for 13 miles; southward from 5 miles south of Moogooree homestead it is truncated by the unconformity beneath the Callytharra Formation. West of Moogooree the Thambrong Formation is poorly exposed and boundaries cannot be determined accurately: it is 1150 ± 50 feet thick. From 8½ to 14 miles southward from Moogooree homestead the Thambrong Formation is unconformably overlain by Callytharra Formation and Moogooloo Sandstone: no complete section crops out. The outcrop is interrupted by Callytharra Formation and younger formations for 8 miles southward. The Thambrong Formation crops out from 6¼ miles north of west of Mount Sandiman, southward for 15 miles to 2½ miles north-west of Lyons River homestead; in this area it is unconformably overlain by Callytharra Formation and the complete sequence of the Thambrong Formation is not exposed; at the north end 1120 feet of the formation is exposed (probably nearly the full sequence) and at the south end

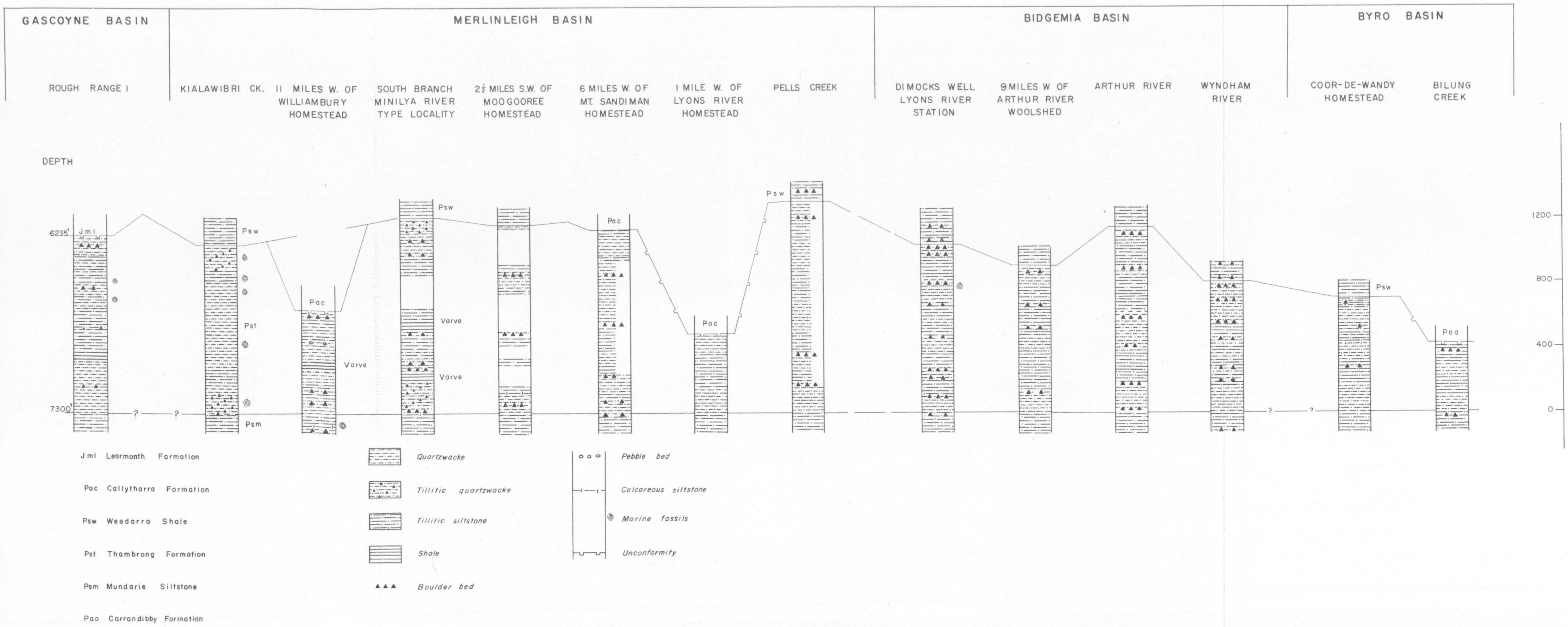


Fig. 56. Stratigraphic columns, Thambrong Formation.

W/A 74

not more than 440 feet. There is no outcrop for 18½ miles southward from Lyons River homestead: the Callytharra Formation unconformably overlaps the Thambrong. The Thambrong Formation is unconformably overlain by Callytharra Formation for 6 miles northward from K-35; a maximum thickness of 320 feet of the Thambrong is exposed. It reappears between the Arthur River and Wyndham River and at the Wyndham is overlapped by the Callytharra Formation. At the south end of the Merlinleigh Basin the Thambrong Formation crops out southwards from Pells Range for 20 miles to 7 miles north-east of Carey Downs homestead, where its outcrop is covered by superficial deposits; it is 1300 feet thick and, at the north end, unconformably overlain by Callytharra Formation.

In the Bidgemia Basin the most northerly outcrop of the Thambrong Formation is on the east side of the Lyons River 12 miles upstream from Lyons River homestead. From there it crops out southward for 16 miles, where it is offset ½ mile northward at a depositional unconformity; in this outcrop belt it is 1300 feet thick. East of the unconformity an outcrop belt of the Thambrong Formation runs from 12 miles south-south-west of Eudamullah homestead for 30 miles southward to another depositional unconformity near the Wyndham River. In this belt the thickness of the Thambrong Formation ranges from 1000 feet 4 miles west of Gibidi Well, Bidgemia, to 1300 feet 4 miles north-west of Coondoo Well, Eudamullah. At the south end it forms part of Raggatt's Lyons Group section (1936, p. 117): the 3rd to 5th units from the top. At the unconformity the outcrop is offset 6 miles north and continues southward for 9 miles to where it is truncated by the unconformity beneath the Callytharra Formation; in this belt it is 800 feet thick: in Raggatt's section of the Lyons Group (1936, p. 117) the Thambrong Formation is the 10th, 11th, 12th, and part of the 13th unit from the base.

In the Byro Basin the Thambrong Formation crops out only from Congo Creek to Wooramel River in a belt that is ½ to 1½ miles west of Coordewandy homestead. At Daurie Creek the formation is 700 feet thick, and at Bilung Creek, where it is unconformably overlain by Carrandibby Formation, it is 400 feet thick.

In Rough Range No. 1, the equivalent of the Thambrong Formation is probably 1065 feet thick, from 6235 to 7300 feet depth, and is unconformably overlain by the 'Learmonth Formation' (McWhae et al. 1958, p. 91).

Complete sequences of the Thambrong Formation are from 1040 to 1300 feet thick in the Merlinleigh Basin, from 800 to 1300 feet thick in the Bidgemia Basin and 700 feet thick in the Byro Basin. The thinner sequences have a higher proportion of arenaceous sediments than the thicker sequences.

Fossils.—Abundant marine fossils are found in several beds in the Thambrong Formation. On the right (north) bank of Kialawibri Creek from 1½ to 2¼ miles upstream from its junction with the Lyndon River there are at least six fossil beds, some including coquinoid lenses of large pectinids. In this area (localities M75 & 76, ML105 to 110) the following fossils have been found:

Pelecypods (determined by J. M. Dickins):
- *Deltopecten lyonsensis* Dickins (abundant)
- *Aviculopecten* sp. ind.
- *Stutchburia variabilis* Dickins
- *Astartila condoni* Dickins
- *Cleobis* sp.
- *Eurydesma* sp. ind.
- *Schizodus crespinae* Dickins

Gastropods (determined by J. M. Dickins):
- *Ptychomphalina umariensis* (Reed)
- *Mourlonia(?) lyndonensis* Dickins
- *Keeneia carnarvonensis* Dickins

Brachiopods (determined by G. A. Thomas):
- *Neospirifer* sp. nov.
- *Pseudosyrinx* sp. nov.
- *Linoproductus (Cancrinella) lyoni* (Prendergast)
- *Trigonotreta* sp. nov.

Foraminifera (determined by Irene Crespin):
- *Calcitornella stephensi* (Howchin)

Crinoids:
- Calceolispongidae sp. nov.

Bryozoa:
- Fenestellidae
- Batostomellidae

Conulariidae:
- *Conularia* sp.

MG136, from 700 yards south of the Middalya to Williambury Road 12½ miles east of Middalya, contains Fenestellidae, pectinids, and orthotetids. At locality TP53, 2½ miles west of Moogooree homestead, G. A. Thomas found:

- *Aviculopecten tenuicollis* (Dana) (Dickins, 1957, p.45)
- *Nuculana lyonsensis* Dickins
- *Astartila condoni* Dickins
- *Cleobis* sp.
- *Parallelodon*(?) sp. ind.
- Spiriferacea gen. et sp. ind.
- Scaphopoda and wood fragments

in a calcareous pebbly greywacke in the Thambrong Formation.

D. Johnstone found brachiopods and bryozoa in a pebbly limestone in the Thambrong Formation three miles north-north-west of K-35.

Age.—The fauna of the Thambrong Formation is very similar to that of the other fossiliferous formations of the Lyons Group, which, because of faunal affinities with the Umaria Beds of India, the Nagmarg Beds of Kashmir, and Speckled Sandstone of Salt Range, is regarded (Dickins & Thomas, 1959) as Sakmarian (Lower Permian).

Correlation.—Details of ranges of species present in the Thambrong Formation are not established, so that correlation cannot be made with units smaller than the Sakmarian Stage. *Eurydesma playfordi, Schizodus crespinae, Stutchburia variabilis, Astartila condoni, Nuculana lyonsensis, Mourlonia(?) lyndonensis,* and *Peruvispira umariensis* are not known below the Thambrong Formation, so there appears some possibility of local zoning within the Sakmarian.

Structure.—The Thambrong Formation crops out best in the synclines at the north and south ends of the Merlinleigh Basin, in the Williambury Syncline, and in the west-dipping homoclines of the Bidgemia Basin. Elsewhere the formation is overlapped, wholly or in part, by the Callytharra Formation, which rests on a surface of unconformity of strong relief eroded in the sediments of the Lyons Group.

Much of the structural relief inherited from the pre-Permian surface is eliminated by the relatively greater sedimentation in the hollows in the lower formations. In a few areas the structural expression of this relief persists into the Thambrong Formation: the Williambury Syncline and the anticline adjoining to the west are strongly expressed by the offset of the outcrop trend at the Minilya River—local outcrop is very poor and no structural detail has been obtained; the depositional unconformities in the western part of the Bidgemia Basin persist although the structural relief on the western one is very small (about 50 feet) and on the next one to the east about 150 feet.

The Thambrong Formation and its lateral equivalents almost certainly follow the regional synclinal structure of the Merlinleigh and Byro Basins and of the northern part of the Gascoyne Basin. Because of the established erosional unconformity below the Callytharra Formation it is unlikely that the Thambrong Formation remains in the anticlines over the basement ridges. Seismic profiles of West Australian Petroleum Pty Ltd indicate that the Thambrong Formation equivalent in Rough Range No. 1 does not pass over the Bullara Ridge but is truncated by the pre-Jurassic unconformity to the west of Rough Range.

Palaeogeography.—The alternation of lithology between sandy and shaly and the occurrence of quartzwacke and varved sediments suggest a period of rapid fluctuation of icesheet advance and retreat, with the tillitic siltstone and greywacke deposited during periods of advance and the fluvioglacial quartzwacke and varves during period of retreat.

Varved siltstone-shale is found 75 feet vertically below marine fossils, near the Middalya-Williambury road. The varved sediment is in a quartzwacke sequence which is either fluvioglacial or, more probably, formed of sediment transported by periglacial streams and deposited in a lake or sea. The marine fossils are in a greywacke/tillitic siltstone/boulder bed sequence of sediments deposited into the sea directly from icebergs. Apparently an alternation between marine and freshwater lake environment was related to the advance and retreat of the ice. As the ice retreat is accompanied by a rise of sea level the contrary indication of non-marine conditions associated with ice retreat is probably related to formation locally of a restricted basin in which a freshwater lake developed intermittently. This may be related to crustal movement as the ice load changed with its advance and retreat.

Economic geology.—Dymocks and Meeda Wells on Lyons River station obtain stock water (somewhat brackish) from quartzwacke members in the Thambrong Formation.

The combination of fossiliferous marine members, porous quartzwacke, and impervious shaly members makes the Thambrong Formation potentially a good source-migration-reservoir-cap formation for petroleum, but it is likely that it has been eroded from synchronous anticlines (Scholten, 1959). Where the synclinal areas were further warped after the unconformity was covered, traps may have developed at the unconformity or in basal sands above the unconformity, along the basement ridges—Bullara Ridge, Wandagee Ridge from Lyndon River to Gascoyne River (both flanks but particularly the eastern), and Weedarra Ridge between Wyndham River and Pells Range.

Problems.—As zoning may be possible within the Lyons Group larger collections of fossils from the known localities are required for study and additional fossil localities should be sought, so that all species can be determined or described, and their ranges established.

Additional detailed work is required to determine the number of climatic-environmental fluctuations within the formation, the characteristics of the sediments within each type, and whether the varved sediments necessarily indicate freshwater environment.

Practically nothing is known about the variations in thickness and lithology of the Thambrong Formation and its lateral equivalents in the subsurface nor about the areas where it has been removed by erosion at unconformities..

Its economic possibilities for underground water and petroleum have not been examined at all.

Weedarra Shale

The Weedara Shale (Condon, 1962a) is the formation, consisting dominantly of tillitic shale and siltstone with lenticular members of quartzwacke and calcarenite, conformably overlying the Thambrong Formation and overlain disconformably or unconformably by the Carrandibby Formation and unconformably by the Callytharra Formation.

The name is taken from Weedarra Paddock, Bidgemia station, the north-eastern corner of which is 7½ miles east of K-34, at Lat. 24° 47½′ S., Long. 115° 39′E. The Weedarra Shale crops out in a north-south belt across Weedarra Paddock 4 to 6 miles west of the eastern fence of the paddock.

The type locality (Fig. 57) is in this same outcrop belt 2 miles north of the north fence of Weedarra Paddock and 3¼ to 6 miles south of west of Coondoo Well, Mount Clere station. The type section (Fig. 58) is 1240 feet thick and includes three members: a lower tillitic shale 400 feet thick with several boulder beds, a middle quartzwacke member 320 feet thick with two boulder beds, and an upper tillitic shale member 520 feet thick with three boulder beds and minor greywacke. This section finishes at the axis of a syncline; elsewhere in the same area the Weedarra Shale is thinner and is unconformably overlain by the Callytharra Formation.

The base is placed at the change from alternating thin members of greywacke and siltstone to a thick member predominantly of siltstone and shale; the top at the change from tillitic siltstone and shale to non-tillitic sediments (shale of the

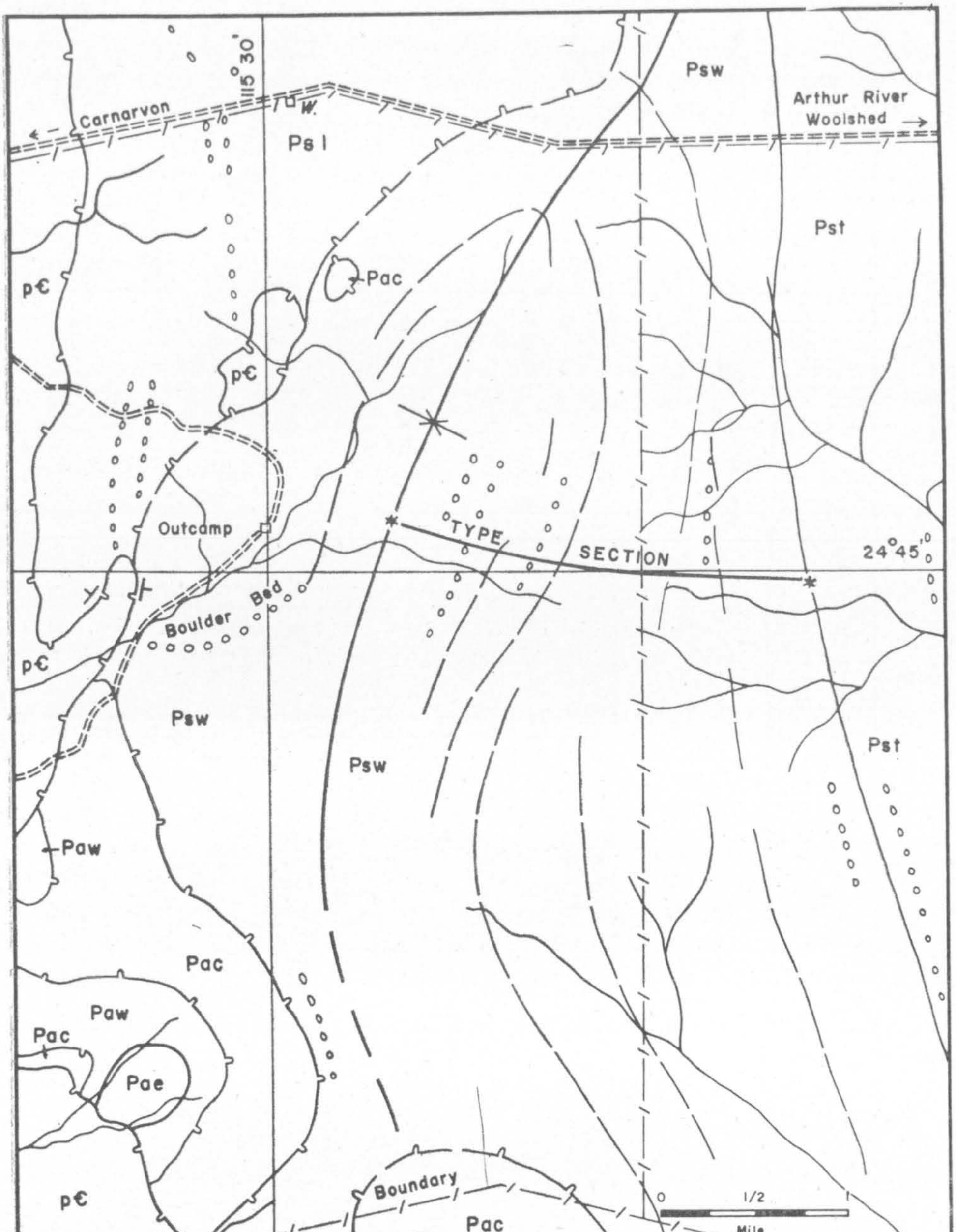


Fig. 57. Type locality, Weedarra Shale. Pst-Thambrong Formation ; Psw-Weedarra Shale ; Pac-Callytharra Formation ; Paw-Moogooloo Sandstone ; Pae-Billidee Formation ; pC-Precambrian.

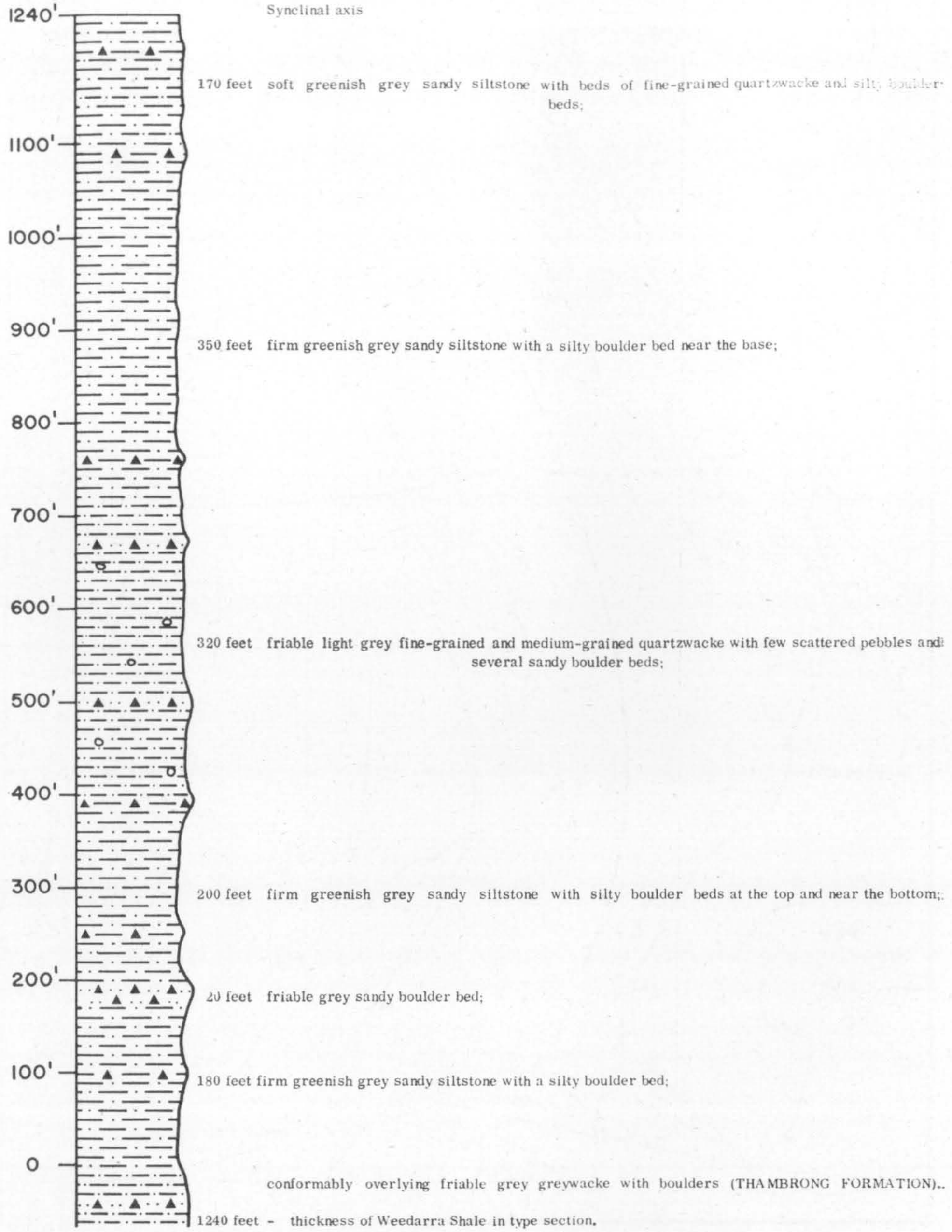


Fig. 58. Type section, Weedarra Shale.

Carrandibby Formation or calcareous sediments of the Callytharra Formation). The Weedarra Shale is characterized by thick members of uniform lithology giving an air-photo pattern of very wide bands of similar tone: the shaly members commonly mottled, the quartzwacke member of light even tone.

A calcarenite member was encountered in Bore BMR9, Daurie Creek (1325 to 1405 feet depth), 50 feet below the top of the formation, but this has not been seen in outcrop.

Lithology.—The dominant rock is sandy (tillitic) shale and siltstone, dark greenish grey, laminated to thin bedded, with few scattered small pebbles. Varved siltstone-shale occurs in the lower shaly member.

The lenticular member of quartzwacke is completely absent in some sections, but elsewhere it forms an important part of the formation. It is friable pale bedded (and cross-bedded) medium-grained and fine-grained quartzwacke consisting of subangular to subrounded grains of quartz, chert, and quartzite with minor feldspar and white mica (?leached biotite) and a small proportion of kaolinitic silty matrix.

Boulder beds form a small part of the sequence in both the shaly and sandy members. The rock types represented are similar to those in boulder beds in the older formations of the Lyons Group. Particular note was taken of boulders throughout the outcrop area, but only local differences in rock types were found.

Distribution, Thickness, and Relationships (Fig. 59).—The Weedarra Shale crops out from the Lyndon River to Carey Downs, but the outcrop is discontinuous because the formation is commonly overlapped by the Callytharra Formation.

The Weedarra Shale crops out along the Lyndon River for one mile upstream from the junction with Kialawibri Creek: it is 1360 feet thick and has no sandy member and only one boulder bed. The outcrop continues for 4½ miles south of the Lyndon River. In the area between the two outcrop belts of Callytharra Formation from Round Hill, Winning station, to Karilla Well, Middalya station, there are many disconnected outcrops of the Weedarra Shale.

The Weedarra probably crops out in the area between Koorakootharra Well, Minilya River, and Donellys Well, Williambury, but the outcrops are too disconnected and poorly exposed for identification.

In the area east of Thambrong Pool, Minilya River, the Weedarra Shale is 1160 feet thick and includes a quartzwacke member. It is overlain unconformably by the Callytharra Formation. Outcrop continues south-eastward, but the formation is truncated by the unconformity: 5 miles south of Moongooree homestead it is completely overlapped by the Callytharra Formation and does not crop out in the Merlinleigh Basin between there and the Pells Range area. There a wide outcrop extends, from the Bidgemia/Dairy Creek boundary 24 miles west of Dairy Creek homestead, westward to Winderie homestead and southward to 2 miles north of Carey Downs homestead. Exposure is generally poor, but there is no indication of a quartzwacke member and the thickness is estimated at 1100 feet ± 100 feet.

In the Bidgemia Basin the Weedarra Shale crops out from 8½ miles east of south of Mount Sandiman homestead, where it abuts unconformably against the Precambrian schist of the Weedarra Ridge southward for 14 miles to a depositional unconformity. In this area the Weedarra Shale is truncated by the unconformity beneath the Callytharra Formation and the maximum thickness exposed is 750 feet at the south end of the belt.

The outcrop is offset about half a mile north at the depositional unconformity and then continues southward to another depositional unconformity at the Wyndham River. In several areas Callytharra Formation rests unconformably on the Weedarra Shale and between the areas of Callytharra Formation the Weedarra Shale rests unconformably against Precambrian schist or older formations of the Lyons Group. The Weedarra Shale (like the Callytharra Formation) is synclinal. This belt includes the type locality, where a thickness of 1240 feet is exposed. The quartzwacke member is well displayed and shows some lensing within this outcrop belt. At the south end of the belt the Weedarra Shale forms part of Raggatt's (1937) section: the shale in the uppermost unit (as shown in his fig. 3) and the upper part of the sixth unit form the top (p. 117); this is part of an outcrop belt offset by a depositional unconformity. The outcrop continues southward for 5 miles, where it is overlapped by the Callytharra Formation.

In the Byro Basin the Weedarra Shale is not known in outcrop but was drilled from 1405 feet to T.D. 2299 feet in BMR9, Daurie Creek, where it is overlain by Carrandibby Formation. The quartzwacke member is present (1740 to 2115 feet), but the bottom of the formation was not penetrated. Varved siltstone-shale was cut from 2200 to 2225 feet.

The equivalent of the Weedarra Shale is not represented in Rough Range No. 1.

The Weedarra Shale is known only in synclinal areas, and thicknesses are related to the position of the unconformity in the formation as well as to variations in the original thickness of the formation.

Fossils.—Fossils have been found in the Weedarra Shale only in the Kialawibri Creek, Minilya South Branch and Pells Range areas and in BMR9 Bore, Daurie Creek.

At locality ML90, 400 yards south of the junction of Kialawibri Creek and Lyndon River, marine fossils are found in several beds associated with a boulder bed; the fauna includes Fenestellidae, Batostomellidae, *Deltopecten lyonsensis* Dickins, *Stutchburia variabilis* Dickins, and a spiriferid.

Fragmentary marine fossils were found by C. Teichert and G. A. Thomas at two localities, TP114 and 115, 220 yards apart, 2 miles south-south-west of South Branch Well, Williambury. The material has not yielded any determinable species.

M. H. Johnstone reported but did not collect fossils from a locality in the Pells Range area in the western part of Dairy Creek station. The locality is 12½ miles south-west of the junction of Pells Creek and Gascoyne River. Grey crystalline limestone with large fenestellid bryozoa and crinoid stems is interbedded with and overlain by boulder beds; 2¼ miles north-west of this locality is another outcrop of similar lithology which may be the same bed or may be

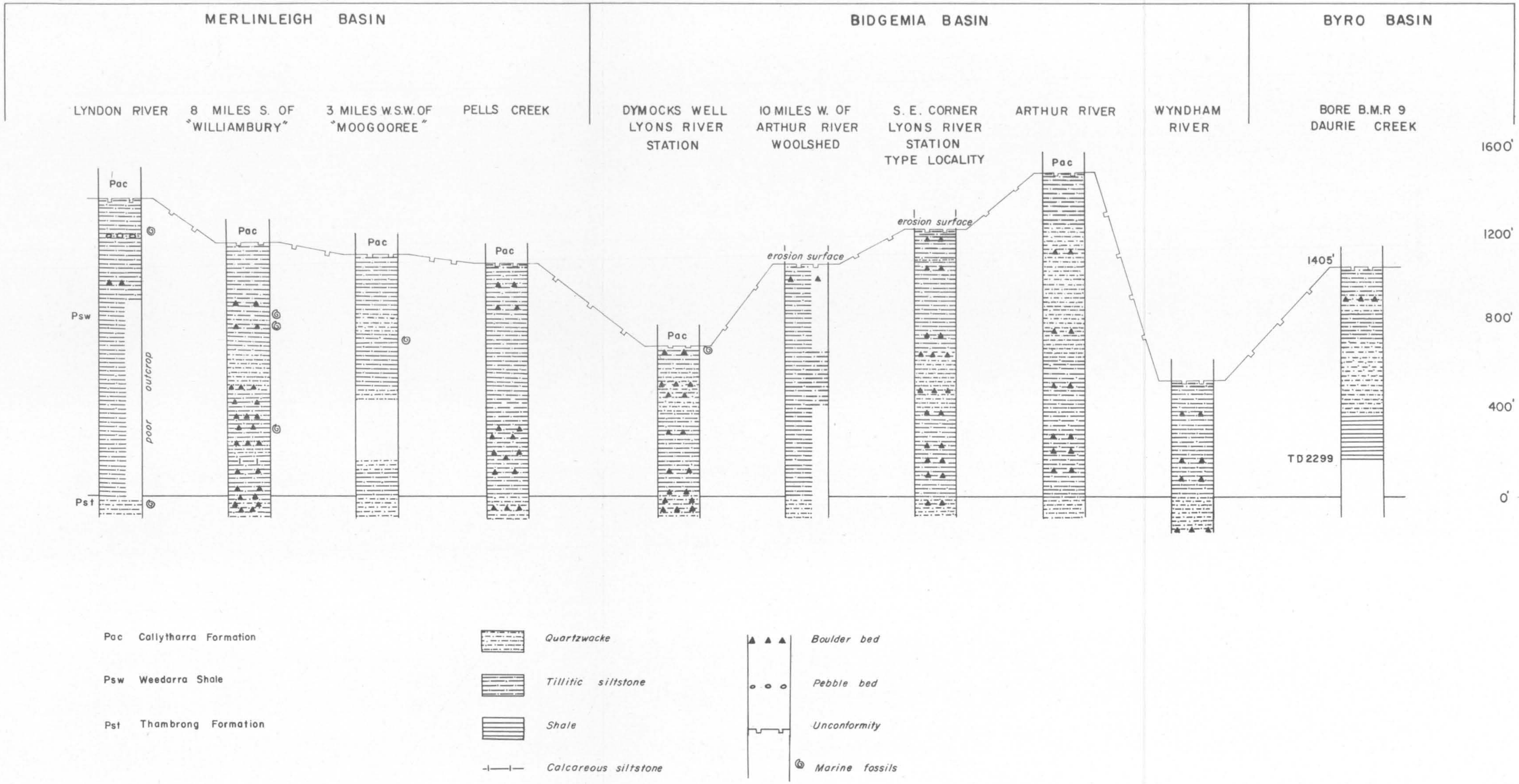


Fig. 59. Stratigraphic columns, Weedarra Shale.

W/A77

the basal bed of the Callytharra Formation with derived boulders; at that place fossils include fenestellid bryozoa, phrycidothyrid and spiriferid brachiopods, and crinoid stem ossicles. At locality GW52, an excavated tank 12 miles south-west of the Pells Creek/Gascoyne River junction, is yellow-green siltstone in which Dr I. Crespin found *Hyperammina callytharrensis* Crespin.

Mr L. M. Waterford found fossils at locality W41, reported to be about ¼ mile east of Winderie homestead, and D. Johnstone found two fossil beds half a mile east of the homestead; these may be the same locality. Crespin (1937) identified *Polypora australis, 'Derbyia' sp.* (since described as *Permorthotetes crespinae* Thomas, 1958), and *Linoproductus 'cancriniformis'* (determined by G. A. Thomas as *L. lyoni*) from Waterford's collection, and Johnstone reported fenestellid and polyporid bryozoa, productid and spiriferid brachiopods, ?pectinid. These localities are in the Weedarra Shale.

Fragmentary marine fossils were reported by Mercer (1959) in cuttings from 1355 feet in BMR9.

Age.—At present the fauna of the Weedarra Shale is inadequately known. The few species determined range from older formations into the Carrandibby Formation. Several species known from the Carrandibby Formation have not been found in the Weedarra Shale or older formations: *Nuculana darwini, Pachymyonia occidentalis,* and a martiniopsid gen. et sp. nov. This suggests that a faunal break may be associated with the erosional unconformity between the Lyons Group and the Carrandibby and Callytharra Formations.

The Weedarra Shale is gradational with the underlying Thambrong Formation and regionally conformable with it; it has no obvious faunal differences from the other higher formations of the Lyons Group and therefore may be regarded as of Sakmarian Age.

Correlation.—Faunal correlation of the Weedarra Shale with particular parts of the Sakmarian Stage elsewhere is not possible. In the Irwin Basin, the Holmwood Shale (Clarke et al., 1951) contains the goniatites *Metalegoceras jacksoni* and *M. campbelli,* considered by Teichert & Glenister (1952) to establish its Sakmarian age. This formation has been 'correlated' on the basis of 'lithology and stratigraphical position' with the Carrandibby Formation. The stratigraphical position referred to is relative to the Callytharra Formation and the correlated Fossil Cliff Formation: it assumes that the Holmwood/Fossil Cliff and Carrandibby/Callytharra sequences are each conformable and continuous. From the description of the sequence by Clarke et al., it appears that their 'Lower Holmwood Shale' (p. 46), including the *Metalegoceras* bed near the top, is tillitic shale, whereas the 'Upper Holmwood Shale' (p. 49) is not tillitic and, like the Carandibby Formation, includes reddish brown ferruginous matter, secondary selenite, calcilutite, and beds of marine fossils of species similar to those in the Fossil Cliff Formation. It seems quite possible that two separate sequences are present, and in this case the 'Upper Holmwood Shale' is likely to be equivalent of the Carrandibby Formation, and the 'Lower Holmwood Shale' to the Weedarra Shale (or to some other part of the Lyons Group).

Structure.—The Weedarra Shale crops out only at the synclinal north and south ends of the Merlinleigh Basin, in the Williambury Syncline and in the synclines at the western side of the Bidgemia Basin. Elsewhere it has been eroded, and overlapped by the Carrandibby and Callytharra Formations.

In the subsurface it has been identified only in Bore BMR9, Daurie Creek. The Weedarra Shale and its lateral equivalents probably extend over the structurally lower parts of the Merlinleigh, Bidgemia, and Byro Basins and perhaps in the low northern part of the Gascoyne Basin. It is unlikely that it extends over the basement ridges except perhaps in areas like the Winnemia Sill where the ridge is structurally low.

Palaeogeography.—The lithology and fossils indicate a continuation of the alternation of environment characteristic of the Thambrong Formation. The lower shaly member is mainly tillitic and was probably deposited in fairly deep water directly from icebergs during a period of advance of the continental icesheet. The quartzwacke member and the varves in the Byro Basin probably were deposited in water and their sediments transported by periglacial streams and glacier icebergs. The upper member is tillitic and marine and was deposited into deep sea direct from icebergs formed from an advancing continental icesheet.

Economic geology.—The quartzwacke member is porous and permeable and is a potential groundwater aquifer.

The shaly members are likely to be good source beds for petroleum and where warping subsequent to pre-Artinskian or pre-Jurassic erosion could cause migration of the formation fluids may have supplied petroleum to porous formations above those unconformities.

Problems.—The fauna of the Weedarra Shale is insufficiently known. Better collections need to be made at the known localities and new localities sought. The outcrop of the fossiliferous limestone encountered in Bore BMR9 would provide useful additional material: it may even be the equivalent of the *Metalegoceras* bed of the Irwin Basin. Areas where it may crop out are between Carey Downs, Winderie, and Pells Creek, particularly the calcareous boulder beds with fossils reported by M. H. Johnstone 12¼ miles east-north-east of Towrana homestead and 2¾ miles farther north-east (which were not sampled) and the fossil beds reported by L. W. Waterford and D. Johnstone ¼ and ½ mile east of Winderie homestead.

The subsurface extension of the Weedarra Shale is not known, nor is anything known of its lateral variations in the subsurface. There was almost certainly additional sequence deposited between the uppermost known part of the Weedarra Shale (in BMR9) and the Carrandibby Formation, and this may be preserved in the central parts of the basins. Only drilling could ascertain this, although seismic survey may indicate it.

More careful mapping may provide useful information on the Weedarra Shale in the area between Pleiades Outcamp, Winning station, and Donellys Well, Williambury, where the very uneven unconformity beneath the Callytharra Formation was wrongly mapped as faulting.

ARTINSKIAN

The Artinskian is here accepted as the second oldest stage of the Permian (Nalivkin, 1938). The Carnarvon Basin sequence has been correlated with the Russian stage on the basis of the affinities of its goniatites, brachiopods, and pelecypods with those of the Artinskian sequences of India and Russia.

The sequence consists of a restricted basal shale (Carrandibby Formation), a widespread calcareous-terrigenous formation (Callytharra) an arenaceous sequence (Wooramel Group) and a sand-shale sequence (Byro Group).

Carrandibby Formation

The Carrandibby Formation (Konecki, Condon, Dickins, & Quinlan in McWhae et al., 1958, p. 72) consists of shale, calcilutite, and sandstone unconformable on the Lyons Group and conformably overlain by the Callytharra Formation.

From the time that I discovered the Carrandibby Formation and its characteristic *Eurydesma* fauna in 1953 during a visit to the type locality of the Callytharra Formation, I have always believed that its lower boundary represented an important stratigraphic break because of the extremely sharp change of lithology there from greenish grey bouldery tillitic siltstone to dark grey shale. This is confirmed by the formation mapping of the Lyons Group, which has established the presence of a large erosional unconformity between the Lyons Group and the Carrandibby and Callytharra. The Carrandibby Formation rests on bouldery tillitic siltstone in the type locality, on a quartzwacke formation 2 miles to the east, on tillitic siltstone with few erratic boulders 1 mile north of Gap Pool, on bouldery greywacke of the Thambrong Formation in Bilung Creek near the junction with Wooramel River, on tillitic siltstone of the Austin Formation in Bore BMR 8, Mount Madeline, and on tillitic siltstone of the Weedarra Shale in Bore BMR 9, Daurie Creek. Dickins (1957) and Dickins & Thomas (1959) included the Carrandibby Formation in the Lyons Group, although Konecki, Condon, Dickins, & Quinlan (1958) defined it as resting 'with apparent conformity on the Lyons Group'.

The name is taken from the Carrandibby Range, which rises north-eastward from the type locality. The type locality (Fig. 60, Photo 5075, Run 14, Glenburgh) is on the south side of the Wooramel River ½ to 1½ miles west of Callytharra Spring. The type section (Fig. 61) starts on an outcrop flat beside the river channel where the boundary with Lyons Group tillitic siltstone is well exposed; exposure is continuous in several small gullies, and the section finishes at the Callytharra Formation in a deep gully 700 yards south-south-east of the starting point. The Carrandibby Formation is 193 feet thick in the type section.

The base of the Carrandibby Formation is at the sharp change in lithology from bouldery tillitic siltstone (or other rocks of the Lyons Group) to soft dark grey shale with red phosphatic nodules; the top is gradational into the Callytharra Formation and the boundary is placed at the uppermost of several

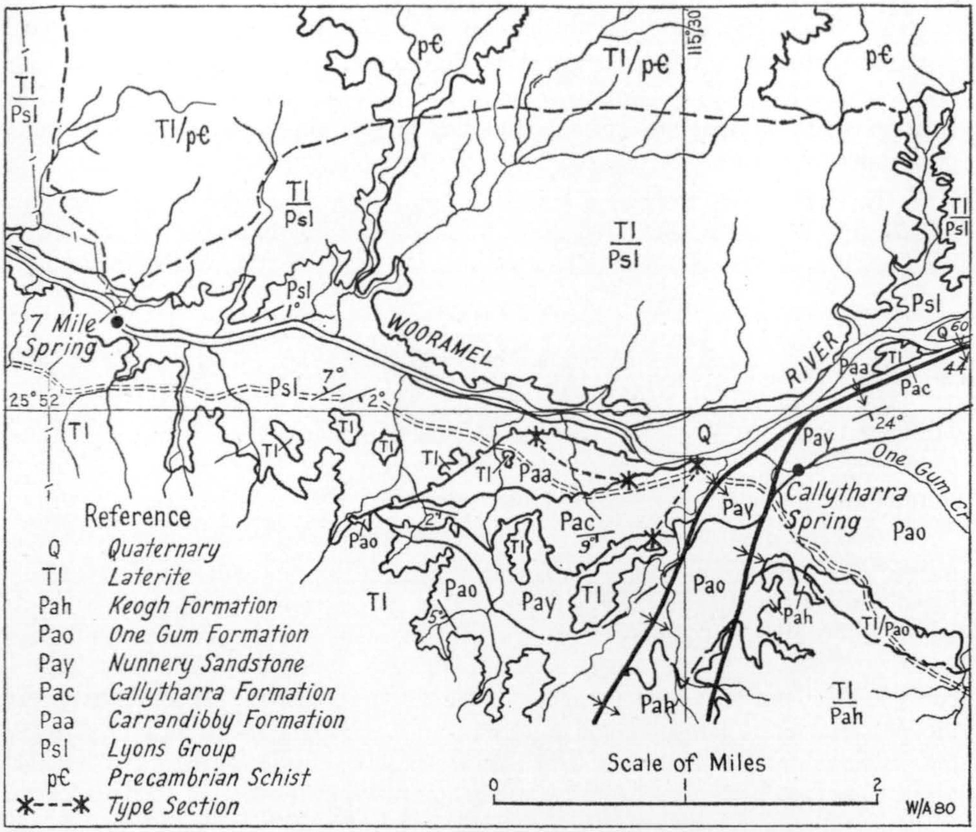
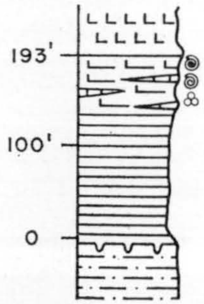


Fig. 60. Type locality, Carrandibby Formation and Callytharra Formation.



Friable grey bryozoal silty calcarenite with abundant fossils; few thin hard calcarenite beds (CALLYTHARRA FORMATION)

? conformably overlying:

53 feet firm thin-bedded pale grey silty calcilutite and calcareous siltstone with few beds of hard calcilutite and hard calcareous sandstone; contains pelecypods including Eurydesma;

90 feet soft dark greenish grey shale with red phosphatic calcareous lenses;

50 feet soft dark shale with phosphatic lenses; few thin beds of laminated fine-grained calcareous quartzwacke;

unconformably overlying firm grey-green sandy siltstone with scattered pebbles (LYONS GROUP).

193 feet - thickness of Carrandibby Formation in type section.

Fig. 61. Type section, Carrandibby Formation.

beds of calcareous quartz sandstone, intercalated in soft brownish grey calcilutite and calcareous siltstone, which is overlain by friable grey bryozoal calcarenite with abundant fossils and few thin beds of hard calcarenite.

The Carrandibby Formation is characterized by a generally shaly lithology with sandstone beds increasing towards the top. It includes the red phosphatic nodules of the 'network bed' type (Condon, 1954, p. 70) that are characteristic of the shaly formations of the Artinskian of the Carnarvon Basin. The sand included in the formation is in laminae or evenly dispersed in the lutite. The Carrandibby is very much less fossiliferous than the Callytharra Formation and the fossils are mainly pelecypods, in lenses.

Lithology.—The Carrandibby Formation is composed dominantly (about 50 percent) of soft dark grey shale, slightly carbonaceous and with a little disseminated fine pyrite and red phosphatic nodules from 3 inches to 9 inches long. Calcilutite makes up about 30 percent; it is mainly soft, brownish grey, laminated, and silty, but also includes lenticular beds of hard grey calcilutite. About 10 percent of the formation is soft dark grey laminated calcareous siltstone, interbedded with the calcilutite; about 10 percent is medium-hard pale thin-bedded to laminated fine-grained quartzwacke intercalated in the shale and calcilutite; and a few thin beds near the top are of calcareous quartz sandstone. The shale is predominant in the lower part of the formation and the calcilutite in the upper.

Distribution, Thickness, and Relationships (Fig. 62).—The Carrandibby Formation is known only in the Byro Basin; it crops out in several separate small areas. The type locality outcrop is separated from a small narrow outcrop along the south side of the Wooramel River by the channel and alluvium of the river. This outcrop is 1000 yards north-east of Callytharra Spring on the north side of a steep north-dipping monocline; about 25 feet of sandstone, calcilutite, and siltstone rests on pebbly quartzwacke of the Lyons Group and is overlain by Callytharra Formation. There is a small outcrop 1400 yards north of Gap Pool, Wooramel River: 150 feet of soft dark grey laminated siltstone of the Carrandibby Formation is exposed between tillitic siltstone of the Lyons Group and fossiliferous Callytharra Formation. The only other known outcrop is in Bilung Creek just upstream from the junction with the Wooramel River, where 8 feet of fine-grained quartzwacke and 25 feet of soft dark shale underlie the Callytharra Formation, probably with minor disconformity, and unconformably overlie a silty boulder bed of the Thambrong Formation.

In Bore BMR 8 the Carrandibby Formation was penetrated for 235 feet, between 1465 feet and 1700 feet, and in Bore BMR 9 for 110 feet, from 1400 to 1510 feet depth (Mercer, 1959). In both bores there is a limestone member at the bottom of the Carrandibby Formation. The Carrandibby rests on the basal formation of the Lyons Group (the Austin Formation) in BMR 8 and on the topmost formation (the Weedarra Shale) in BMR 9.

Fossils.—The Carrandibby Formation has many marine fossils; *Eurydesma playfordi* Dickins is very abundant in some places. Other pelecypods, small brachiopods, blastoids, crinoids, bryozoa, and foraminifera have been found.

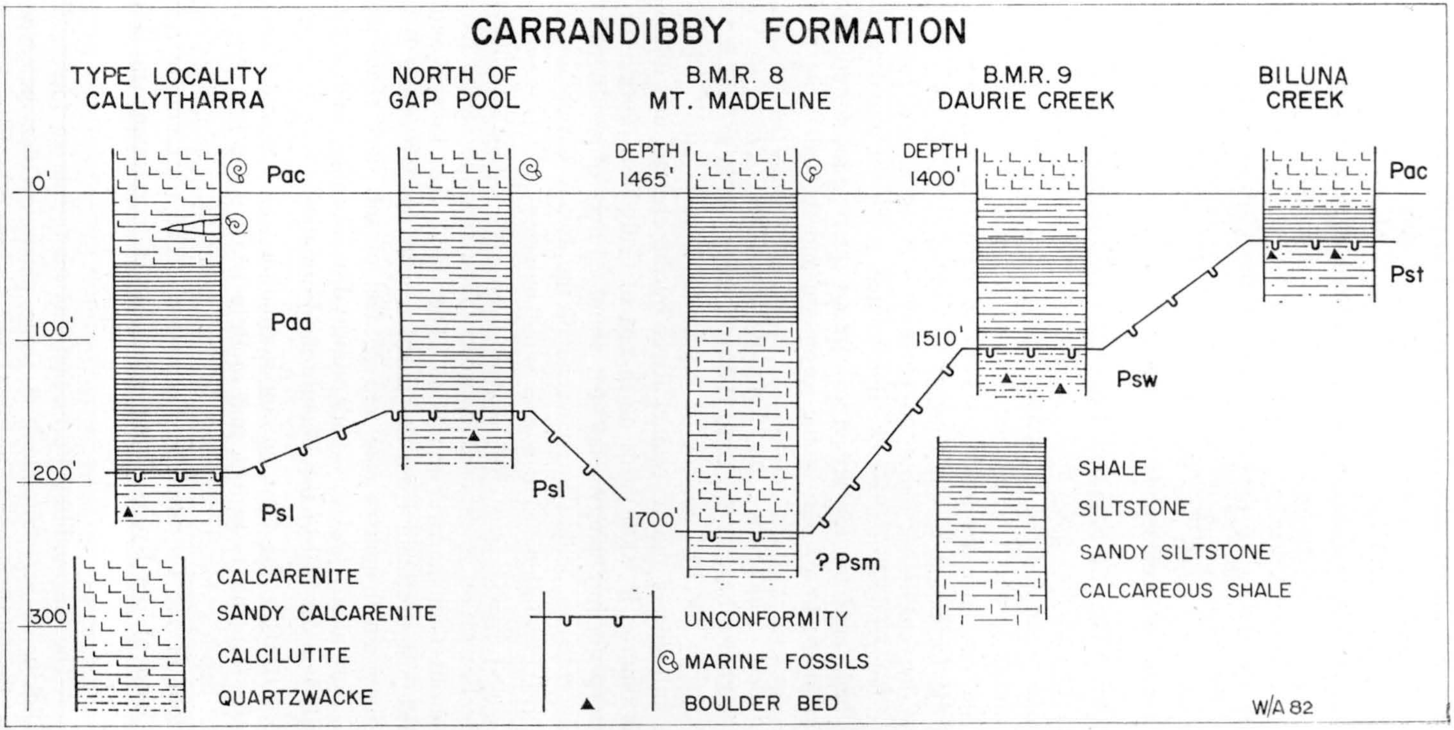


Fig. 62. Stratigraphic columns, Carrandibby Formation. Pac-Callytharra Formation ; Paa-Carrandibby Formation ; Psl-Lyons Group ; Psw-Weedarra Shale ; Pst-Thambrong Formation ; Psm-Mundarie Siltstone.

In the type locality the following fauna has been determined:

Foraminifera (determined by Dr Irene Crespin):
Hyperammina cf. *hadzeli* Crespin
Bryozoa:
Fenestellidae
Batostomellidae
Crinoidea (Dickins & Thomas 1959):
Calceolispongidae gen. et sp. nov. (cup and stem ossicles)
Blastoidea:
cup ossicles
Brachiopoda (determined by G. A. Thomas):
martiniopsid gen. et sp. nov.
Mollusca (determined by J. M. Dickins):
Pelecypoda:
Phestia darwini (de Koninck)
Stutchburia variabilis Dickins
Astartila condoni Dickins
Astartila? obscura Dickins
Pachymyonia occidentalis Dickins
Chaenomya sp. nov.
Praeundulomya elongata Dickins
Leiopteria? carrandibbiensis Dickins
Eurydesma playfordi Dickins
Deltopecten lyonsensis Dickins
Aviculopecten tenuicollis (Dana)
Gastropoda:
Mourlonia (*Mourlonia*) *lyndonensis* (Dickins)
Peruvispira umariensis (Reed)

This list corrects lists in Dickins & Thomas (1959), which include forms from the Callytharra Formation (F17, 238), Weedarra Shale (¼ mile east of Winderie homestead and ML90), and Thambrong Formation (GW105, MG136 and MG161).

The four species at present restricted to the Carrandibby Formation are *Astartila? obscura, Pachymyonia occidentalis, Praeundulomya elongata,* and *Leiopteria? carrandibbiensis.*

Some of the species that are characteristic of the Lyons Group, e.g. martiniopsid gen. et sp. nov., *Deltopecten lyonsensis, Aviculopecten tenuicollis,* and Calceolispongidae gen. et sp. nov., range up into the Carrandibby Formation, and the characteristic species of the Carrandibby, *Eurydesma playfordi,* ranges down into the Lyons Group.

Phestia darwini, Stutchburia variabilis, Chaenomya sp. nov., and *Aviculopecten tenuicollis* are known to range into higher formations.

Peruvispira umariensis, Eurydesma playfordi, and *Deltopecten lyonsensis* are not known to range above the Carrandibby Formation.

Atomodesma, Oriocrassatella, Pseudomyalina, Heteropecten, and *Girtypecten* are known only from formations younger than the Carrandibby Formation.

Age.—Dickins & Thomas (1959) include the Carrandibby Formation in the Lyons Group. The arguments used to justify this are in part based on formation misidentifications by the field geologists (including myself). The 'Carrandibby equivalent' in the Jimba Jimba area was so called because it is the uppermost part of the pre-Callytharra section and at the time the unconformity at the top of the Lyons Group had not been recognized. This formation is *not* equivalent to the Carrandibby but to one of the arenaceous formations of the Lyons Group (possibly the Thambrong Formation). The faunal list Ib should therefore be included in the list IIIa which contains all the species of Ib. This requires a revision of the relationships of the faunas of the Lyons Group, Carrandibby Formation, and Callytharra Formation, and this revision includes the distribution information given by Dickins (1963).

Sixteen forms have been specifically identified from the Carrandibby Formation (all in the type locality). Of these, seven are known elsewhere only from the Lyons Group, two are known from both the Lyons Group and Callytharra Formation, four are known only from the Carrandibby Formation, and three only from the Nura Nura Member (correlatable with the Callytharra) or higher. Dickins' distribution chart (his Fig. 3) needs to be revised as follows:

Species of genus	Lyons (Sakmarian)	Carrandibby	Callytharra or equivalents (Artinskian)
Kiangsiella sp A. Thomas	x		
Permorthotetes crespinae Thomas	x		
Streptorhynchus sp. nov. A. Thomas	x		
Trigonotreta sp. nov.	x		
Schizodus crespinae	x		
Platyschisma? sp.	x		
Keenia carnarvonensis	x		
Calceolispongidae gen. et sp. nov.	x	x	
Martiniopsid gen. et sp. nov.	x	x	
Astartila condoni	x	x	
Eurydesma playfordi	x	x	
Deltopecten lyonsensis	x	x	
Mourlonia lyndonensis	x	x	
Peruvispira umariensis	x	x	
Stutchburia variabilis	x	x	x
Aviculopecten tenuicollis	x	x	x
Astartila? obscura		x	
Pachymyonia occidentalis		x	
Leiopteria? carrandibbiensis		x	
Praeundulomya elongata		x	
Hyperammina cf. *hadzeli*		x	x
Phestia darwini		x	x
Chaenomya? nuraensis		x	x
Permorthotetes callytharrensis			x
Permorthotetes camerata			x
Streptorhynchus plicatilis			x
Atomodesma			x
Oriocrassatella			x
Girtypecten			x

There are faunal breaks both between the Lyons Group and the Carrandibby Formation and between the Carrandibby and the Callytharra Formation. The Callytharra Formation is established as early Artinskian in age (see p. 72) and the Lyons Group as Sakmarian. The fauna of the Carrandibby Formation is distinctive. It contains a larger element that ranges down into the Lyons Group and a smaller part that ranges up into the Callytharra Formation; but this may be controlled in part by environment—the Lyons Group and Carrandibby faunas are dominated by pelecypods, which are a minor part of the Callytharra fauna.

The Lyons Group and Carrandibby Formation are separated by a large unconformity; the Carrandibby and Callytharra Formations by a sharp change in lithology and, in Bilung Creek, some suggestion of a disconformity. The Carrandibby Formation is not lithologically like the lower Holmwood Shale, which contains the Sakmarian *Metalegoceras jacksoni* and *M. campbelli*, although it is similar to the upper Holmwood Shale (see p. 55).

On present evidence the Carrandibby Formation could belong in either the Sakmarian or the Artinskian Stage. Because of the nature of its two boundaries it is likely to be closer in age to the Callytharra Formation than to the Lyons Group, and therefore is referred to as possibly Artinskian in age.

Correlation.—As its precise age cannot be decided correlation with other formations is not possible. It may be equivalent to the upper Holmwood Shale (Clarke et al., 1951, p. 49) of the Irwin Basin, as it is similar in lithology and is between glacigene sediments below and Artinskian fossiliferous sediments above.

Structure.—The Carrandibby Formation crops out only in very small areas, so that no indication of regional structure is available except its concordance with the overlying Callytharra Formation, which mainly overlaps the Carrandibby Formation. As it is present in Bores BMR 8 and BMR 9 it is likely that it continues throughout the central, structurally low and synclinal part of the Byro Basin.

Palaeogeography.—The Carrandibby Formation was deposited mainly in moderately deep quiet sea; the uppermost part of the formation was deposited in a shallow sea. The sediment was probably derived mainly from the erosion of the Lyons Group, although deposition did not begin in the Wooramel River/ Daurie Creek area until the Permian erosion of the Lyons Group had almost ceased.

The shoreline of the sea cannot be determined; the top of the formation was close to shoreline at the south end of the Carrandibby Range.

After the uplift and erosion of the sediments of the Lyons Group the area must have been suddenly and deeply submerged; no transgressive basal sand is known; the lowermost sediments were deposited in deep water. After a short period of stability the water began to shallow until at the top of the formation shallow-water sands and shellbanks were deposited.

The deep submergence may well have affected the whole of the Carnarvon Basin; so equivalents of the Carrandibby Formation may be present in the central part of the Merlinleigh Basin and the northern part of the Gascoyne Basin.

Economic Geology.—The Carrandibby Formation has no present economic significance. It is a petroleum source bed with sufficient sandstone intercalations to allow primary migration. It is overlapped by the Callytharra Formation and therefore drainage from it would be mainly along the basal unconformity or, where the Callytharra equivalent is permeable, into that formation. It may form an unconformable impermeable cap to some of the permeable formations of the Lyons Group, since it must overlie the whole sequence, for example, between Bores BMR 8 and BMR 9.

Callytharra Formation

Dee & Rudd first separated the 'Callytharra Limestone Group' in an unpublished report (1932). Condit (1935) first published the name Callytharra Limestone and gave a very brief description of the formation. Condit, Raggatt, & Rudd (1936, p. 1040) and Raggatt (1936, p. 123) called the unit 'Callytharra Stage', named the type locality Callytharra Spring, and defined it (as a rock unit) as consisting of 'rather argillaceous limestone or highly calcareous mudstone, including foraminiferal, crinoidal and shelly types' between the Lyons 'Series' and the Wooramel 'Stage'.

Condon (1954, p. 47) changed the name to Callytharra Formation; the lower boundary was still regarded as conformable, but a hiatus was recognized at the upper boundary, which was called a disconformity. Konecki, Dickins, & Quinlan (1958) did not alter these relationships except to record the conformable lower boundary with the Carrandibby Formation.

Condon (1962a) redefined the Callytharra Formation 'as the formation of fossiliferous hard and friable sandy and silty calcarenite and calcilutite unconformably overlying the Weedarra Shale or older Permian formations and overlain unconformably by formations of the Wooramel Group'. This definition needs to be enlarged to include the relationships with the Carrandibby Formation and Precambrian metamorphic rocks.

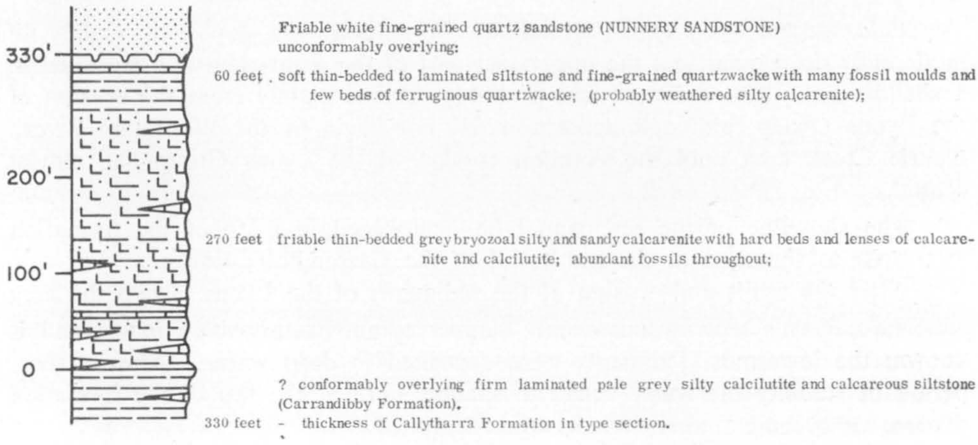


Fig. 63. Type section, Callytharra Formation.

The Callytharra Formation is redefined as the formation of fossiliferous hard and friable sandy and silty calcarenite and calcilutite, siltstone, and quartzwacke conformably (?disconformably) overlying the Carrandibby Formation or unconformably overlying formations of the Lyons Group and Precambrian schist and overlain unconformably by formations of the Wooramel Group.

The name is taken from Callytharra Spring (Lat. 25° 52′ 20″ S., Long. 115° 30′ 25″ E.) on One Gum Creek 500 yards upstream from its junction with Wooramel River. The type locality is half a mile west of Callytharra Springs (Fig. 60); I measured a section (Fig. 63) in this locality. The thickness (330 feet) is quite different from that reported by Dee & Rudd (1932)—85 feet 'immediately west of Callytharra Spring': at this place a fault or monocline cuts out the upper part of the formation.

Condon (1954, p. 50) proposed a section 765 feet thick near the Lyndon River as the 'amended type section' of the Callytharra Formation. It is not desirable to have a type section not in the type locality and this section therefore may be regarded as a reference section for the northern part of the Carnarvon Basin.

The lower boundary of the Callytharra Formation is placed at the sharp change in lithology from tillitic sediments or calcilutite with thin beds of quartz sandstone below to richly fossiliferous calcareous sediments (calcarenite or calcarenaceous quartzwacke mainly); in places there is a basal conglomerate, which may include boulders derived from the underlying Lyons Group; the upper boundary is at the sharp change in lithology from richly fossiliferous calcareous sediments to quartz sandstone with, in places, a basal conglomerate and derived fossil fragments.

Lithology.—In the type section the dominant lithology is friable fossiliferous silty calcarenite, made up of small fragments of fossils, particularly bryozoa, with a silt matrix; this makes up about 75 percent of the sequence. Soft thin-bedded to laminated fossiliferous siltstone and fine-grained calcarenaceous quartzwacke at the top of the section form about 14 percent of the sequence; in the outcrop the fossils are mainly moulds, the carbonate having been leached out by weathering. Soft grey laminated carbonaceous pyritic siltstone forms a thin member between the calcarenite and the interbedded siltstone-quartzwacke. Hard brown and grey fossiliferous calcarenite in lenticular beds up to about a foot thick characterizes the lower part of the sequence and forms about 5 percent of the sequence. Hard grey fossiliferous calcilutite in lenticular beds up to one foot thick forms about 3 percent.

Elsewhere the proportion of terrigenous sediment is higher, although everywhere in outcrop the formation is richly fossiliferous. In the Lyndon River reference section the dominant rock (53 percent of the sequence) is friable grey fossiliferous fine-grained to coarse-grained sandy calcarenite made up of fragments of fossils (mainly bryozoa and crinoids) with 5 to 15 percent rounded quartz sand grains; 30 percent of the sequence is friable grey fine-grained calcarenaceous quartzwacke in which the fossil-fragment material makes up 10 to 30 percent of the rock; 11 percent is friable dark grey silty calcarenite; 6 percent is hard grey and brown fossiliferous calcarenite (some sandy) in lenticular beds up to 2 feet thick; and there are a few lenticular beds of hard grey fossiliferous calcilutite.

In the area between the north end of the Kennedy Range and Moogooloo Hill, there is a persistent member in the lower part of the formation consisting of soft dark grey fossiliferous calcareous siltstone with few thin lenticular beds of hard grey calcilutite.

Sixteen miles west of Gascoyne Junction the sequence is predominantly friable calcarenite with thin beds of fine-grained quartzwacke near the base and thin lenses of hard calcarenite and calcilutite throughout.

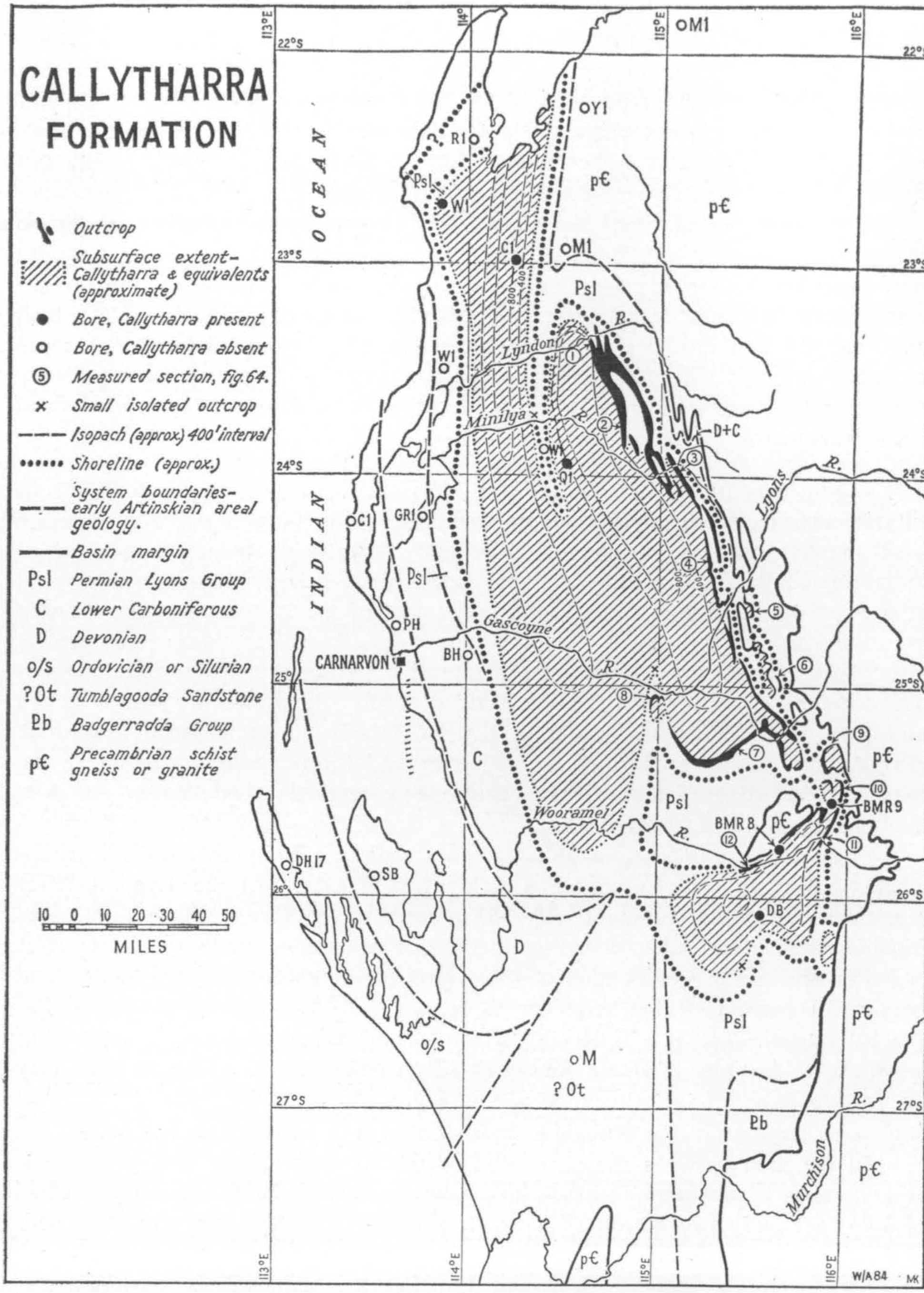


Fig. 64. Callytharra Formation and equivalents : distribution and thickness.

In Bores BMR 8, BMR 9, and Giralia 1, the Callytharra Formation equivalent is firm black carbonaceous pyritic calcareous siltstone with coquinite beds and a few thin beds of calcarenite.

Distribution (*Fig. 64*), *Thickness, and Relationships* (*Fig. 65*).—The outcrop of the Callytharra Formation extends southward for 240 miles from the Lyndon River to 30 miles south of the Wooramel River. The Callytharra Formation equivalent has been penetrated in West Australian Petroleum Ltd Giralia No. 1 Bore (McWhae et al., 1958, p. 65), and Quail No. 1 (Pearson 1964), in Bores BMR 8 and BMR 9, and in O.S.L. Deep Bore, Byro station.

On the Lyndon River (Locality 1, Fig. 64) the Callytharra Formation is 800 feet thick (not 765 feet as stated in Condon, 1954); it is unconformable on the Weedarra Shale and is disconformably overlain by the Cordalia Greywacke. For 12 miles south from the Lyndon River the Callytharra Formation crops out in a rather complicated pattern determined by the irregular surface of the Lyons Group. At Moogooloo Peak the formation is 590 feet thick, unconformable on Lyons Group and disconformable under Cordalia Greywacke: the upper friable calcarenite member of the Lyndon River section is absent, probably removed by erosion before the Cordalia Greywacke was deposited. In the east scarp of K-55 the Callytharra Formation is 575 feet thick (Column 2, Fig. 65). The rocks of the eastern outcrop belt 8 to 9 miles east of K-55 occupy an asymmetrical strike valley in the surface of the Lyons Group; the formation is 535 feet thick 10 miles north-east of K-55: coarse quartz sand is present near the base, and a basal conglomerate with few boulders is developed sporadically. The Callytharra Formation rests unconformably on the Thambrong Formation and is overlain unconformably by the Moogooloo Sandstone. Near K-52 the outcrop belts run together, but separate again south of the Williambury-Middalya Road and continue across the Minilya River to near Donellys Well, Williambury. In the eastern outcrop belt the Callytharra Formation, 575 feet thick, rests unconformably on Thambrong Formation and is unconformably overlain by Moogooloo Sandstone. In the western belt 2½ miles south-south-east of K-52 it is overlain unconformably by Cordalia Greywacke. From Donellys Well the outcrop of the formation is offset 13 miles northward and then continues southward to the Gascoyne River. Five miles southward from Moogooree homestead the formation is 425 feet thick; it rests unconformably on the Thambrong Formation and is unconformably overlain by the Moogooloo Sandstone. Between there and the Lyons River the Callytharra Formation rests on Thambrong Formation, Mundarie Siltstone, or Koomberan Greywacke; north-west of Mount Sandiman homestead there are two outcrop belts, in the eastern of which the rocks occupy a valley eroded in the Lyons Group. At Lyons River homestead the Callytharra Formation occupies a valley in the surface of the Koomberan Greywacke; it rests on the Koomberan for 20 miles southward from the homestead. There its outcrop is offset 1½ miles northward and from there to the Wyndham River it is unconformable on the Thambrong Formation.

South of the Wyndham the unconformity between the Callytharra Formation and the Lyons Group truncates the upper formations of the Group: at the Gascoyne River the Callytharra rests unconformably on the Mundarie Siltstone. In this area the unconformity with the overlying Moogooloo Sandstone is very striking: the Callytharra is eroded into rock-stack form and the Moogooloo Sandstone is deposited between and over the stacks. In the Pells Range area at the south end of the Merlinleigh Basin a similar unconformity is exposed; there the Callytharra Formation is 175 feet thick (Column 6, Fig. 65). In the ridge 14 miles west of Gascoyne Junction on the south-western side of the Merlinleigh Basin the Callytharra Formation, 260 feet thick, rests on undifferentiated Lyons Group quartzwacke and siltstone and is overlain by Moogooloo Sandstone. There are two small isolated outcrops of Callytharra Formation along the western side of the Merlinleigh Basin: one, 1½ miles north of the Minilya River 10 miles west of Wandagee homestead, is of fossiliferous hard grey fine-grained calcarenite dipping 5° eastward; the other, 5 miles north of the Gascoyne River and 16 miles west-north-west of Gascoyne Junction, is hard greenish grey fossiliferous sandy fine-grained calcarenite.

Information on the Callytharra Formation and its equivalents in the subsurface of the Merlinleigh Basin is provided by the Bureau seismic traverse from Middalya past Wandagee Hill and by WAPET's Quail No. 1 well (Pearson, 1964). In the area 5 miles south of Wandagee homestead the seismic profile shows a continuous reflector with gentle synclinal structure. Its maximum depth, at the syncline, is 3700 feet. About 800 feet below this is a weaker reflection. These two reflections may be from the top and base of the Callytharra Formation. The reflections continue only for 3 miles west. In Quail No. 1, the Callytharra equivalent was penetrated between 1330 feet and 1943 feet depth. Pearson (1964) shows 1465 to 1943 feet, but the 135 feet above is of similar lithology to the Callytharra. It is not present on the Wandagee Ridge in the vicinity of WAPET's Wandagee No. 1, although it crops out 1½ miles north of the Minilya River, possibly within the area of a saddle on the Wandagee Ridge.

In the Bidgemia Basin the Callytharra Formation crops out in synclines at the western side of the basin from 8 miles north-east of Lyons River homestead to Wyndham River and in a small embayment from the Merlinleigh Basin extending southward to 12 miles south-west of Dairy Creek homestead. Nine miles east of Lyons River homestead the Callytharra rests unconformably on the Weedarra Shale on the east flank of the syncline and on Precambrian schist on the west flank. It is overlain by the Moogooloo Sandstone and is 230 feet thick (Column 4, Fig. 65). In an isolated outcrop belt between the Arthur and Wyndham Rivers the Callytharra rests unconformably on the Thambrong Formation and is overlain by Moogooloo Sandstone; it is 210 feet thick (Column 5, Fig. 65).

In the Byro Basin the Callytharra Formation crops out around the north, west, and south sides of the Bush Creek syncline (Konecki et al., 1958, p. 72) and on the east side appears as lenses between the Wooramel Group and the Precambrian schist. Three miles east of Dairy Creek homestead the formation

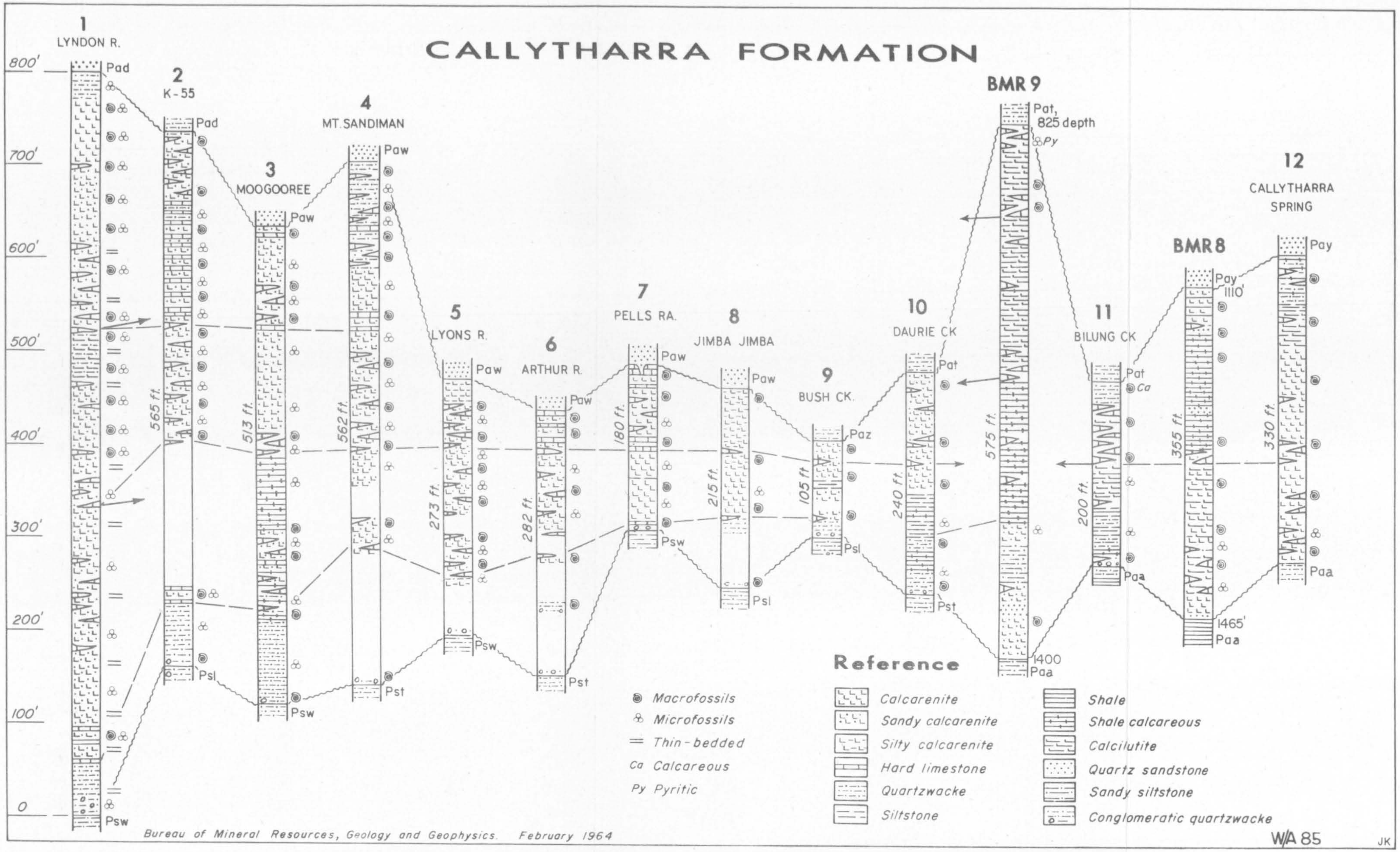


Fig. 65. Callytharra Formation (Pac)—stratigraphic columns. Column numbers refer to localities shown in Fig. 64. Paw-Moogooloo Sandstone ; Paz-Congo Formation ; Pat-Monument Formation ; Pay-Nunnery Formation ; Pad-Cordalia Greywacke ; Paa-Carrandibby Formation : Psw-Weedarra Shale ; Pst-Thambrong Formation ; Psl-Lyons Group.

is only 85 feet thick; it rests unconformably on the Lyons Group (undifferentiated) and is unconformably overlain by the Congo Formation. It crops out in two south-plunging synclines from 1 mile south of Congo Creek; the western outcrop runs south for 4 miles on the east flank of the syncline and then is cut off by an unconformity. The eastern outcrop is mainly obscured by younger formations at the north end; it is well exposed from 6 miles north of Coordewandy homestead to 3 miles south-west, where it is obscured by deep weathering and laterite. In this outcrop belt west of Coordewandy the Callytharra Formation is 235 feet thick (Column 9, Fig. 65). It is unconformable on the Thambrong Formation and unconformably overlain by the Monument Formation. It crops out in a small area north and south of the Wooramel River downstream from the junction with Bilung Creek; there it is 200 feet thick (Column 10, Fig. 65). On the west side of Byro Basin the Callytharra crops out in several separate areas: near Plant Well, Daurie Creek, and from there southward for 5½ miles; in a narrow belt from 4 to 8 miles south-west of Plant Well; 1½ miles north-west of Gap Pool, Wooramel River, where it is 380 feet thick and rests conformably on the Carrandibby Formation and unconformably under the Nunnery Sandstone; and in the type locality ½ mile west of Callytharra Spring. The only other outcrop in the Byro Basin is a small isolated one 30 miles west of Curbur homestead, where lateritized fossiliferous Callytharra Formation rests on undifferentiated Lyons Group and is unconformably overlain by ?Eocene Pindilya Formation. In Coolyun Well 22 miles west-south-west of Byro homestead Callytharra Formation was encountered under the outcropping Nunnery Sandstone.

Fossils.—The Callytharra Formation is richly fossiliferous both in numbers of species and, particularly, in abundance of individuals. The following forms have been determined to date:

Plantae:
- Calcareous algae
- *Gangamopteris cyclopteroides* Feist. (Teichert, 1942b)

Foraminifera (Crespin, 1958, p. 18):
- *Ammobaculites eccentrica* Crespin
- *Ammobaculites wandageensis* Crespin
- *Calcitornella heathi* Cushman & Waters
- *Calcitornella stephensi* (Howchin)
- *Earlandia condoni* Crespin
- *Frondicularia hillae* Crespin
- *Frondicularia woodwardi* Howchin
- *Geinitzina triangularis* Chapman & Howchin
- *Giraliarella angulata* Crespin
- *Glomospirella nyei* Crespin
- *Hemigordius schlumbergi* (Howchin)
- *Hyperammina callytharrensis* Crespin
- *Hyperammina elegantissima* Plummer
- *Hyperammina hadzeli* Crespin
- *Nodosaria tereta* Crespin
- *Nodosaria irwinensis* Howchin
- *Orthovertella protea* Cushman & Waters
- *Placopsilina wooramelensis* Crespin
- *Tetrataxis conica* Ehrenberg
- *Trepeilopsis australiensis* Crespin

Bryozoa (Crockford, 1944a, b):
- *Fenestella horologia* Bretnall
- *Fenestella affluensa* Bretnall
- *Fenestella chapmani* (Crockford)
- *Fenestella sparsigemmata* (Crockford)
- *Fenestella alia* (Crockford)
- *Hexagonella australis* (Bretnall)
- *Minilya ampla* Crockford
- *Minilya* cf. *duplaris* Crockford
- *Penniretepora fossata* Crockford
- *Penniretepora granulata* Crockford
- *Penniretepora triporosa* Crockford
- *Rhabdomeson bispinosa* Crockford
- *Rhombocladia minor* Crockford
- *Rhombocladia spinulifera* Crockford
- *Septopora ornata* Crockford
- *Streblocladia excavata* Crockford
- *Streblotrypa marmionensis* Etheridge
- Batostomellidae not yet described

Corals (Hill, 1937, 1942, 1957):
- *'Amplexus'*
- *Cladochonus*
- *Euryphyllum*
- *Plerophyllum*
- *Tachylasma*
- *Thamnopora*
- *Verbeekiella*
- *Wannerophyllum*

Blastoidea:
- *Rhopalablastus* (not yet described)

Crinoidea:
- Numerous stem and cup ossicles
- *Calceolispongia digitata* Teichert
- *Calceolispongia spinosa* Teichert

Brachiopoda:
- Productacea (Coleman, 1957):
  - *Aulosteges baracoodensis* Eth. fil.
  - *Aulosteges spinosus* Hosking
  - *Dictyoclostus callytharrensis* Prendergast
  - *Dictyoclostus magnus* Coleman
  - *Krotovia micracantha* (Hosking)
  - *Krotovia senticosa* (Hosking)
  - *Linoproductus cancriniformis* (Tschernyschew)
  - *Linoproductus cora foordi* (Eth. fil.)
  - *Linoproductus lyoni* (Prend.)
  - *Strophalosia prideri* Coleman
  - *Strophalosia (Heteralosia) etheridgei* Prend.
  - *Strophalosia (Heteralosia) prendergastae* Coleman
- Orthotetacea (Thomas, 1958):
  - *Streptorhynchus plicatilis* Hosking
  - *Permorthotetes callytharrensis* Thomas
  - *Permorthotetes camerata* Thomas
  - *Kiangsiella?* sp.
- Spiriferacea:
  - *Neospirifer*
  - *Spiriferella*
  - *Spiriferellina? cristata* Schl.
- Rostrospiracea
  - *Cleiothyridina*
  - *Phricidothyris*
- Terebratulacea (Campbell, 1965):
  - *Fletcherithyris* cf. *hardmani* Campbell
  - *?Aulosteges*
  - *?Chonetes*
  - *Pseudosyrinx*

Mollusca
  Pelecypoda (Dickins, 1963):
    Streblopteria sp.
    Megadesmus sp.
    Stutchburia variabilis Dickins
    Aviculopecten tenuicollis (Dana)
    Deltopecten waterfordi Dickins
    Myonia sp. nov.
    Cypricardinia? elegantula Dickins
    Plagiostoma? sp. nov.
    Acanthopecten? sp.
    Girtypecten ovalis Dickins
    Parallelodon bimodoliratus Dickins
    Edmondia prichardi Dickins
    Euchondria callytharraensis Dickins
    Chaenomya sp.
    Schizodus sandimanensis Dickins
    Astartella obliqua Dickins
    Oriocrassatella sp.
    Atomodesma mytiloides Beyrich
    Atomodesma cf. *timorense* (Wanner)
    Praeundulomya sp.
    Modiolus koneckii Dickins
  Gastropoda (Dickins, 1963):
    Mourlonia (*Mourlonia*) sp. nov.
    Platyceras sp. nov.
    Platyceras cf. *abundans* (Wanner)
  Cephalopoda:
    Nautiloidea (Teichert, 1951, p. 83), not yet described:
      Pseudorthoceras
      Mooreoceras
      Brachycycloceras
      Domatoceras
      Stearoceras
    Ammonoidea (Thomas & Dickins, 1954):
      Metalegoceras sp.

The rich fauna of the Callytharra Formation has been described only in part. The most abundant forms are bryozoa, crinoid fragments, and brachiopods. The bryozoa are commonly fragmental.

The foraminifera suggest a cool to temperate shallow marine environment. Thomas (1958) considered that the faunal association indicates a water depth of about 100 feet to 180 feet.

Age and Correlation.—Within the Carnarvon Basin the Callytharra Formation may be correlated with the following subsurface sequences. The rocks of the sequence 870 feet thick between 3095 feet and 3965 feet depth in Giralia No. 1 (West Australian Petroleum Pty Ltd) are similar to those of the Callytharra Formation, and the foraminifera—*Calcitornella stephensi* (Howchin), *Earlandia condoni* Crespin, *Geinitzina triangularis* Chapman & Howchin, *Giraliarella angulata* Crespin, *Hyperammina elegantissima* Plummer, and *Tetrataxis conica* Ehrenberg (Crespin, 1958)—establish the correlation. The sequence of 318 feet of black calcareous carbonaceous siltstone, black shale, calcarenite and sandstone with few coquinite beds, between 1110 feet and 1428 feet in BMR 8, Mount Madeline, is considered a deeper-water lateral variant of the Callytharra Formation. Between 825 feet and 1090 feet in BMR 9, Daurie Creek, black carbonaceous calcilutite with coquinite beds is considered to be the lateral variant of the Callytharra Formation that crops out only one mile to the south-west and 3½ miles to the east. Both of these outcrops are finer-grained than the typical Callytharra Formation.

Fossiliferous dark pyritic carbonaceous siltstone and shale, equivalent to the Callytharra, was penetrated between 1330 and 1943 feet in WAPET's Quail No. 1 well (Pearson, 1964). The faunal assemblage of the Callytharra Formation has strong affinities with those of the Fossil Cliff Formation of the Irwin Basin and the Nura Nura Member of the Poole Sandstone in the Fitzroy Basin. Teichert (1942a) found *Metalegoceras clarkei, M. striatum,* and *Thalassoceras wadei* in the Nura Nura; these have sutures resembling typical Artinskian species and are decidely more advanced than the Sakmarian *Metalegoceras jacksoni.* The *Metalegoceras* from the Callytharra Formation is closely related to *M. clarkei* (Thomas & Dickins, 1954). The brachiopods and pelecypods have strong affinities with those from the Artinskian Bitauni Beds of Timor and with those of the Artinskian Lower Productus Limestone of the Salt Range, India.

Correlation with particular parts of the Permian sequence in Eastern Australia is difficult: there are very few good faunal links. The bryozoa and brachiopods (Banks, 1957) of the Darlington Limestone of Tasmania indicate correlation with the Callytharra Formation. *Pseudogastrioceras* in the Farley Formation of the Dalwood Group is the lowermost Artinskian index fossil in the Permian sequence of New South Wales (Teichert, 1953); on this basis the Farley Formation must correlate approximately with the Callytharra Formation, although Banks' (1957) correlation of the Rutherford Formation with the Callytharra is not impossible. The Queensland succession and faunas are incompletely known: the Ingelara Shale, containing *'Martiniopsis'* spp., *Spiriferella, Cleiothyridina, Neospirifer, Spiriferellina,* and *Pseudosyrinx* (Campbell, 1953), is close to the Callytharra Formation in its generic assemblage of brachiopods and may therefore be correlated, approximately, with it.

Structure.—In outcrop the structure of the Callytharra Formation is controlled by the shape of the surface of unconformity on which it was deposited. The Lyons Group was deeply dissected and in places completely removed before the Callytharra Formation was laid down. The tilted strata of the Lyons Group were truncated down to a surface fairly close to the present and a strong cuesta-topography was developed, with mainly westerly dip slopes and east-facing scarps. The Callytharra Formation was deposited more or less parallel to the dip-slopes and abutted against the scarps. Long narrow asymmetrical synclines are developed over the homoclinal Lyons Group. Where the slopes on the underlying surface are gentle, depositional anticlines are developed over the ridges; for example, the Giralia Anticline (Fig. 43), Weedarra Ridge between Wyndham and Gascoyne Rivers, the anticline 7 miles east of Lyons River homestead, and Mount Madeline and Ballythanna Hill anticlines (Callytharra Formation not exposed).

Apart from the valley-filling areas, the Callytharra Formation and its lateral variants rest on the upper surface of the Lyons Group, disconformably in central areas of synclines and basins and unconformably on the homoclinal flanks of the basins.

The lateral variation from mainly arenite at outcrop to mainly lutite in synclines is considered to indicate that much of the present structural relief was in being during deposition of the Callytharra Formation: the present synclines and basins were hollows in the sea floor and anticlines were ridges. The topographic relief probably was much less than the present regional structural relief, but must have been sufficient (about 500 feet) to remove the low areas from the zone of action of waves and currents. The depositional unconformities so characteristic of the Artinskian strata of the Merlinleigh Basin originated at scarp edges (Condon, 1956) in the unconformity surface on the Lyons Group.

The regional structure of the Callytharra and equivalents consists of synchronous basin-synclines deepened by later downwarping in the Byro, Merlinleigh, and Gascoyne Basins, and a synchronous anticline over the Wandagee Ridge. There may be an anticlinal connexion between the Gascoyne and Byro Basins in the Wooramel Sill.

Palaeogeography.—The Callytharra Formation was deposited in shallow water on a bottom of strong relief. The eastern shoreline probably was not far removed from the present outcrop, and areas like the Weedarra Inlier and Carrandibby Range were almost certainly islands and the basement ridges were shoals and peninsulas. The Byro Basin was either practically landlocked except for a narrow entrance at the Wooramel Sill or, more probably, was connected to the Merlinleigh Basin by a very shallow sea over the Carrandibby and Weedarra Ridges; in any case the central part of the basin contained stagnant water producing a black-mud sediment under very reducing conditions, as the lateral variant of the Callytharra Formation. The Merlinleigh Basin was open to the west but somewhat barred by the Wandagee Ridge. The Gascoyne Basin took the form of a large gulf open to the north but probably not open to the west.

Organic banks or reefs may have developed on the shoal ridges; although no colonial corals or algae have been found in the outcrop area, solitary corals and small calcareous algae and the abundant bryozoa suggest that reefs or banks may have developed in areas where the sea was shallow and terrigenous material absent.

Economic Geology.—The only economic use of the Callytharra Formation to date is as a source of supply of limestone for local building stone for station homesteads (e.g. Lyons River).

The friable calcarenite of the Callytharra Formation is permeable enough to form aquifers, but as the overlying sandstone produces good supplies of excellent water there is no reason to explore the Callytharra Formation, the water in which is likely to be hard and in some cases not potable because of sulphides.

The silty members of the Callytharra Formation and the lutite lateral variants indicated in bores contain fixed carbon and pyrite and abundant fossils: they are almost certainly source beds for petroleum. Some of the calcarenite beds are permeable enough for primary migration and for accumulation.

The anticlinal areas of the Callytharra equivalents are likely to include clean calcarenites which, if not cemented, would be porous and permeable. The synclinal areas of Callytharra equivalents are probably unfavourable for primary migration: in this case migration from these areas may have been delayed until compaction by weight of overlying sediment and tilting by downwarping of the basins caused lateral drainage, at a time when the permeable Callytharra equivalents and the permeable Wooramel Group sandstones were covered by adequate caps of the Byro Group. These considerations make the Wooramel-Callytharra equivalents good targets for exploration drilling in any of the anticlinal areas where Byro Group sediments remain.

The hard calcarenite and calcilutite beds at the outcrop could be used for road and concrete aggregate and, with the siltstone, as a source of material for the manufacture of Portland Cement. Some parts may be pure enough for burning for lime.

Problems.—The outstanding deficiency in our knowledge of the Callytharra Formation and its equivalents is its extent, lithology, and cover in the anticlinal areas. Drilling is required to obtain this information.

Much palaeontological work remains to be done on the rich fauna of the Callytharra Formation: this will help to establish correlations with formations in other parts of Australia and to refine correlations with sequences in other parts of the world.

The subsurface boundary between the Callytharra Formation and its lutite equivalent is unknown: it would define the limits of possible petroleum accumulation in the Callytharra Formation and Wooramel Group from this source; subsurface information on the lithology of the Callytharra equivalent on the western side of the Gascoyne Basin is required in order to establish whether or not a shoreline existed in this area: the results from Giralia No. 1 Bore suggest that this is so, but more definite information on the western edge of subcrop, beneath the Mesozoic, is desirable as the Giralia occurrence may be related to a topographic ridge during deposition.

Wooramel Group

The Wooramel Group (Condit, 1935; revised Konecki et al., 1958) is the predominantly arenaceous sequence disconformably or unconformably overlying the Callytharra Formation, Lyons Group, or Precambrian schist, and overlain conformably by, or changing laterally into, the Byro Group.

In the type locality (Gap Pool to One Gum Creek junction, Wooramel River) the Wooramel Group consists of three formations: Nunnery Sandstone at the bottom, One Gum Formation, and Keogh Formation. Elsewhere in the Carnarvon Basin the following formations are included in the Wooramel Group; Monument Formation, Congo Formation, Curbur Formation, Cordalia Greywacke, Moogooloo Sandstone, Jimba Jimba Calcarenite, and Billidee Formation.

The base of the Wooramel Group is at the sharp change in lithology from fossiliferous calcareous sediments to arenaceous sediments containing very few fossils; the top at the change in lithology, commonly gradational, from arenaceous sediments to dominant lutite sediments.

The Wooramel Group includes quartz sandstone, quartzwacke, and minor siltstone (in laminae, beds, and members up to about 50 feet thick) and conglomerate. In a few places it also includes a calcarenite formation.

Distribution (Fig. 66), Thickness, and Relationships (Fig. 67).—The outcrop of the Wooramel Group extends with some interruptions from Lyndon River to Curbur station (230 miles); in the subsurface a similar sequence has been encountered in Giralia No. 1 Bore (West Australian Petroleum Pty Ltd), in Deep Bore and Bogadi Bore (Byro station), in BMR 8, Mount Madeline, and BMR 9, Daurie Creek (Mercer, 1959), and in WAPET's Quail No. 1 Bore.

Over most of the area it rests with erosional unconformity on the Callytharra Formation and is conformably overlain by the Byro Group.

It varies in thickness (Fig. 67) from 230 feet at the south end of the Merlinleigh Basin 20 miles south of Gascoyne Junction to 1115 feet in bore BMR 8, Mount Madeline. The greatest thicknesses are on the flanks of basement ridges; the thinner sections are in the major synclines and in the eastern-most outcrops, probably close to the original limits of deposition.

The lowermost formation, the Cordalia Greywacke, crops out only between the Lyndon and Minilya Rivers; it overlies the thickest and most complete section of the Callytharra Formation disconformably and has a fine-grained conglomerate at the base with fossil fragments derived from the Callytharra. The Cordalia Greywacke is overlain by a quartz sandstone formation, the Moogooloo Sandstone, which south of the Minilya River and in the eastern outcrop belt north of that river is the basal formation of the group. In the Byro Basin the equivalent formations are the Monument Formation and Nunnery Sandstone. Twelve miles west of Gascoyne Junction and in bore BMR 8 a fossiliferous calcarenite formation overlies the sandstone; in the northern area it is the Jimba Jimba Calcarenite. Elsewhere the sandstone formation is overlain by a mixed formation of quartzwacke and siltstone; it seems likely that the calcarenite is the littoral equivalent of the basal siltstone member of these formations (Billidee Formation in the Merlinleigh and Bidgemia Basins; One Gum Formation in the Byro Basin). The One Gum Formation is the lateral equivalent of the lower part of the Billidee Formation, but the Congo and Curbur Formations are equivalent of the whole. The Keogh Formation is the equivalent in the Byro Basin of the upper part of the Billidee Formation. The basal formation of the Byro Group (Madeline in the Byro Basin and Coyrie in the Merlinleigh and Bidgemia Basins) conformably overlies the uppermost formation of the Wooramel Group.

In the central part of the Byro Basin and probably also in the Merlinleigh Basin the upper formations pass laterally into siltstone and shale of the Byro Group.

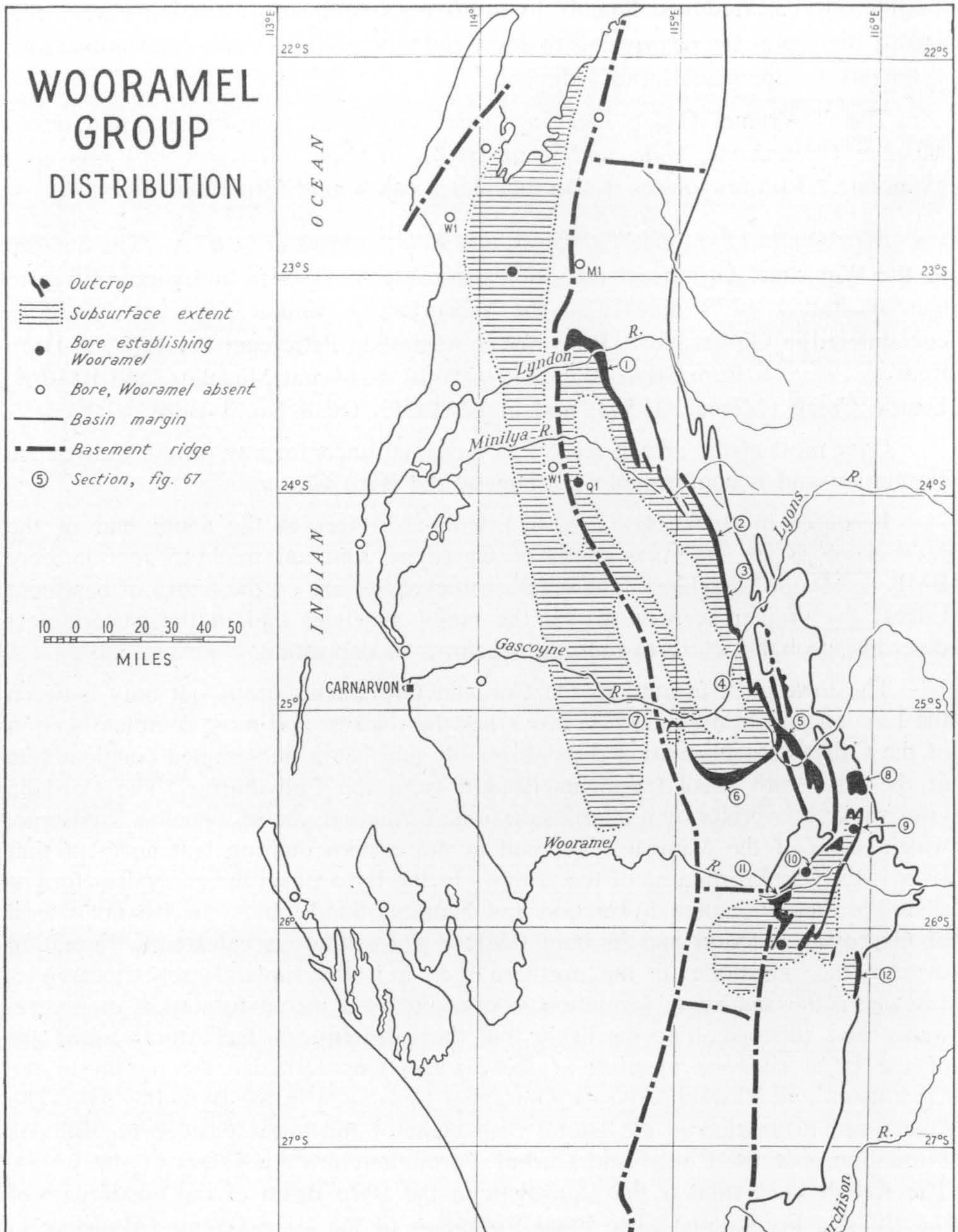


Fig. 66. Distribution of Wooramel Group.

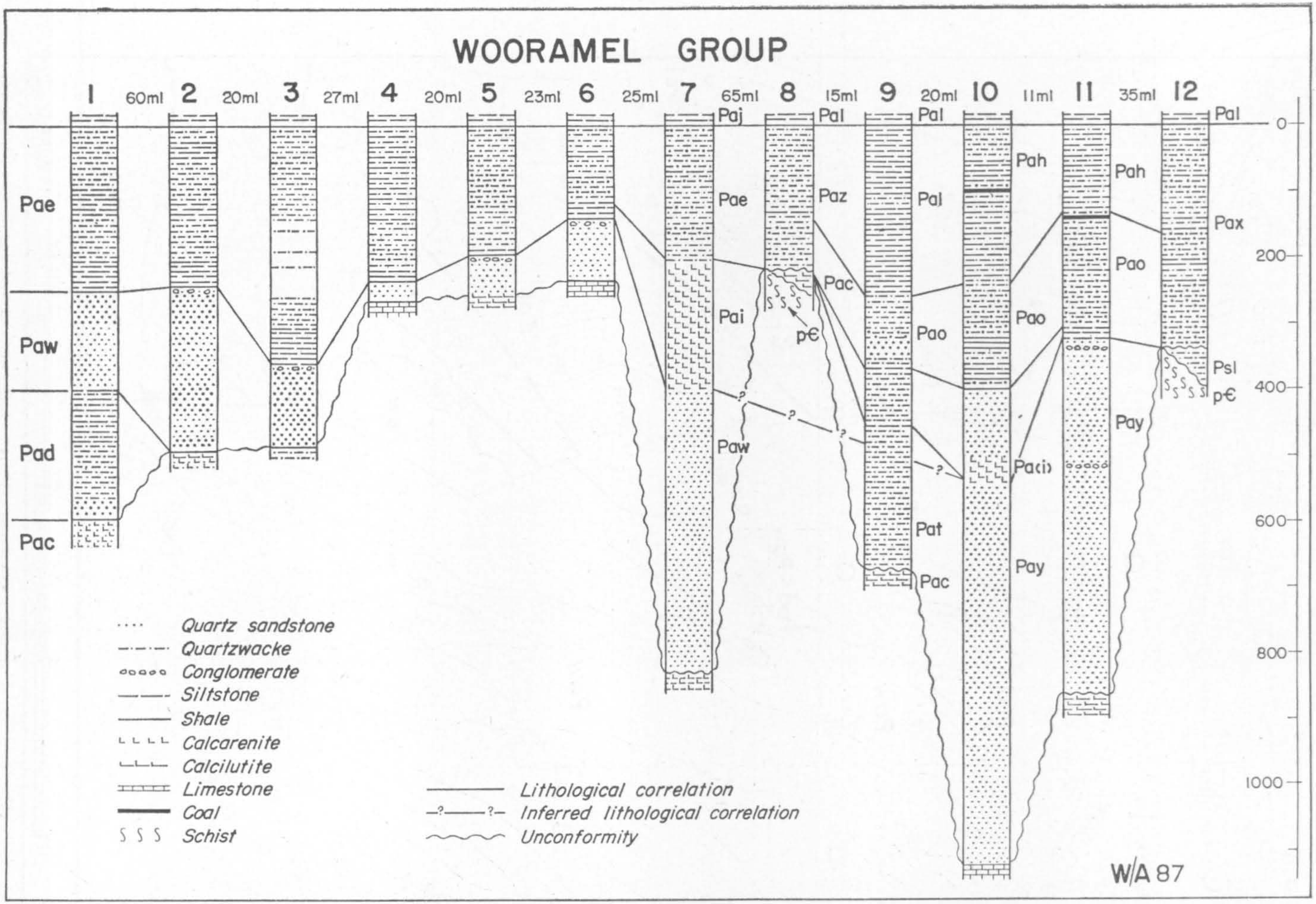


Fig. 67. Stratigraphic columns, Wooramel Group. Column numbers refer to localities shown in Fig. 66. Paj-Coyrie Formation, Pal-Madeline Formation, Pae-Billidee Formation, Paz-Congo Formation, Pah-Keogh Formation, Pax-Curbur Formation, Pao-One Gum Formation, Pai-Jimba Jimba Calcarenite, Paw-Moogooloo Sandstone, Pat-Monument Formation, Pay-Nunnery Sandstone, Pad-Cordalia Greywacke, Pac-Callytharra Formation, pC-Precambrian metamorphics.

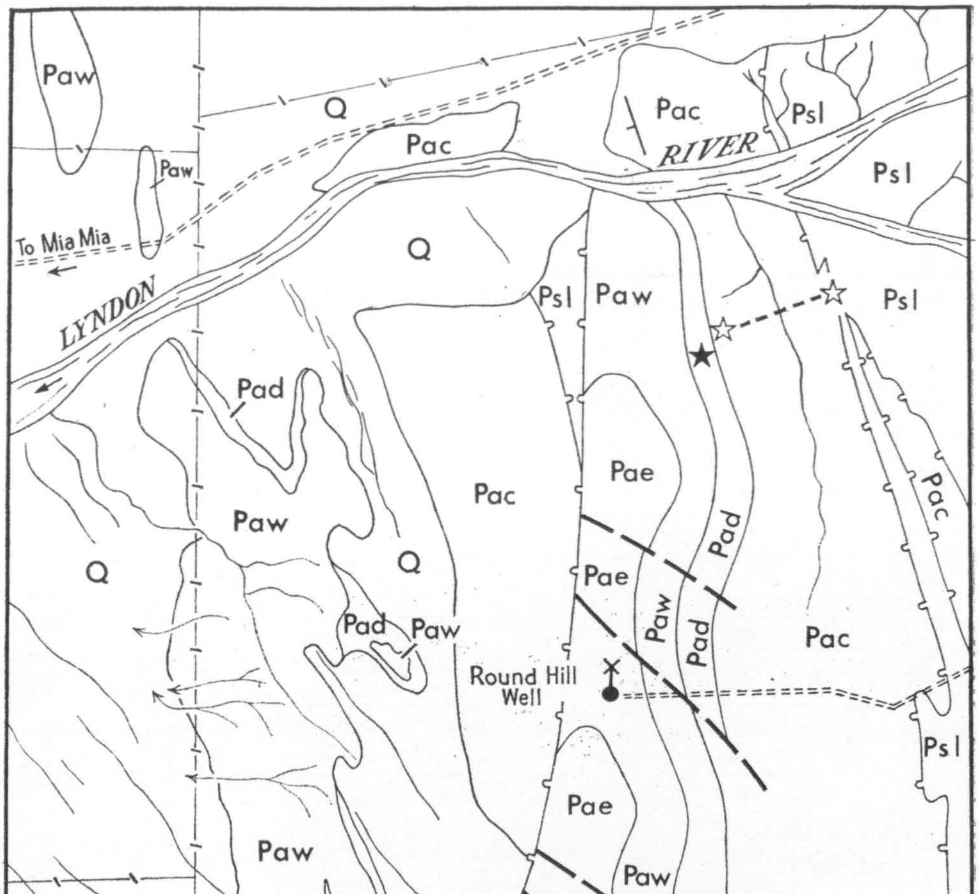


Fig. 68. Type locality, Cordalia Greywacke (Pad) ; reference section locality, Callytharra Formation (Pac). Q-Quaternary deposits ; Pae-Billidee Formation ; Paw-Moogooloo Sandstone ; Psl-Lyons Group.

In some areas the formations of the Wooramel Group rest unconformably on rocks older than the Callytharra Formation: in the Mount Sandiman area, they rest on formations of the Lyons Group in asymmetrical valleys eroded in the sediments of the Lyons Group; east of Lyons River homestead they rest on Precambrian gneiss on the eastern side of the Weedarra inlier; between Arthur River and Wyndham River they rest unconformably against an erosion scarp in the Lyons Group; between Congo and Daurie Creeks they rest unconformably against Lyons Group on the west flank of the Daurie and Monument Synclines.

Fossils are plentiful only in the Jimba Jimba Calcarenite, and these have not been specifically determined. The age of the Wooramel Group is fixed as Artinskian by its position between the Callytharra Formation and the Byro Group.

The Wooramel Group was deposited as a basal sand during a marine transgression that followed a minor regression; all phases from lagoonal (Keogh Formation) to completely marine (Jimba Jimba Calcarenite) are included.

The sediments of the group are thickest and most permeable high on the flanks of basement ridges, where, also, they are in good structural position to receive hydrocarbons migrating from the basins: source beds are known in the shale equivalents of the Group and in the shale equivalents of the underlying Callytharra Formation. The siltstone and shale of the overlying Byro Group provide adequate cover for petroleum accumulation. Few anticlines are known that include the Wooramel Group, but stratigraphic traps along the western side of the Merlinleigh and Byro Basins and perhaps along the east side of the northern part of the Gascoyne Basin may provide useful accumulations.

The subsurface extent of the Wooramel Group is not known precisely and as it is one of the obvious stratigraphic targets for oil exploration this needs to be determined, by drilling and seismic surveys.

Cordalia Greywacke

The Cordalia Greywacke (Condon, 1954, p. 53-56) is the formation of quartzwacke with calcareous lenses, disconformable or unconformable on the Callytharra Formation and conformable beneath the Moogooloo Sandstone. The name is taken from Cordalia Well on Mia Mia station, 14½ miles south of east of the homestead. The formation crops out in the scarp below Trig. Point A-51 one mile west of Cordalia Well. The type section (Fig. 69), was measured 4½ miles north of Cordalia Well at latitude 23° 21′ S., longitude 114° 40′ E. (Fig. 68).

The base of the Cordalia Greywacke is at the sharp change in lithology from richly fossiliferous calcareous sediment below to quartzose sediments above. In most places there is a coarse sandstone, commonly calcareous and with fragmental fossils, and probably derived from the Callytharra Formation, at the base. The top is at the gradational change from laminated micaceous fine-grained quartzwacke, commonly with siltstone interlaminated, to medium-grained quartz sandstone.

The outcrop distribution of the Cordalia Greywacke is shown in Figure 70.

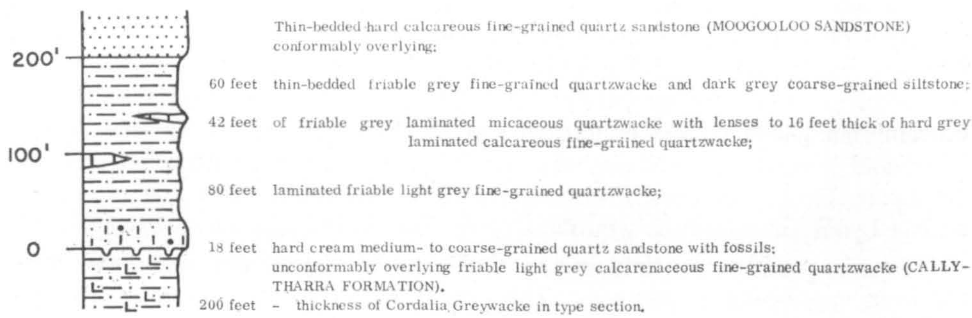


Fig. 69. Cordalia Greywacke type section.

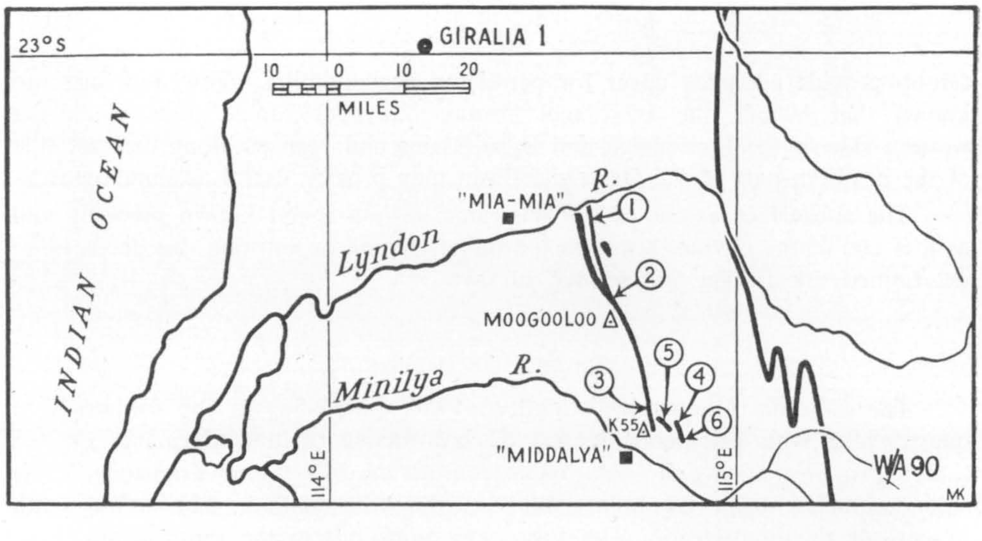


Fig. 70. Outcrop distribution of Cordalia Greywacke. Numbers refer to columns in Fig. 71.

The Cordalia Greywacke crops out only between the Lyndon and Minilya Rivers and only in the western outcrop belt of Callytharra Formation and Wooramel Group. It is thickest at the north end and wedges out about 5 miles south of K-52. Its equivalent, quartzwacke and calcareous sandstone 453 feet thick above the Callytharra equivalent, was encountered in Giralia No. 1 (West Australian Petroleum Pty Ltd) between 2642 and 3095 feet. In WAPET's Quail No. 1, 198 feet of quartzwacke and siltstone, equivalent to the Cordalia, was penetrated between 1267 and 1465 feet (Pearson, 1964).

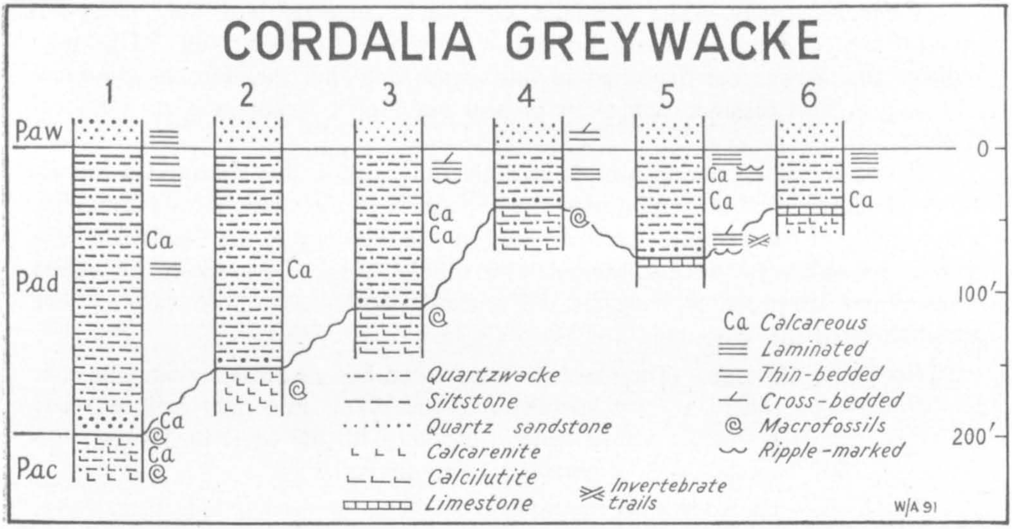


Fig. 71. Stratigraphic columns—Cordalia Greywacke. Paw-Moogooloo Sandstone ; Pad-Cordalia Greywacke ; Pac-Callytharra Formation.

The only fossils found in the Cordalia Greywacke are fragmental bryozoa and brachiopods near the base of the type section. These may be remanié, from the Callytharra Formation.

The age of the Cordalia Greywacke is Artinskian by reference to the Callytharra Formation below and the Coyrie Formation above, both of which are Artinskian; the faunal differences between these two formations are sufficient to suggest the possibility of the separation of local stages within the Artinskian. As the Cordalia Greywacke is separated from the Callytharra Formation by a disconformity or erosional unconformity, but is in conformable sequence with the Coyrie Formation, it would probably belong with the stage of the Coyrie fauna rather than that of the Callytharra (but see Jimba Jimba Calcarenite, p. 91).

Structure.—The Cordalia Greywacke at outcrop is part of the main west-dipping homocline on the north-eastern flank of the Merlinleigh Basin. As its equivalent is present in the Giralia Bore the Cordalia and its equivalents probably extend in subsurface over much of the Merlinleigh Basin and the north central part of the Gascoyne Basin. It is unlikely to extend across the Wandagee Ridge except perhaps in the saddles.

The unconformity between the Cordalia and Callytharra is not very obvious: there is commonly a 'basal conglomerate' of very coarse quartz sand or very fine-grained quartz conglomerate at the base of the Cordalia, and this rests on different parts of the Callytharra sequence, which has been differentially eroded in the hiatus between the deposition of the two formations.

Palaeogeography.—The Cordalia Greywacke extends into the 'valley-fill' outcrop area of the Callytharra Formation only near Cordalia Well. This may indicate that it was not deposited in this region and that therefore its shoreline was only a short distance east of its present outcrop; it is not in itself a littoral deposit.

It was deposited during a rapid marine transgression that followed a regression and short period of erosion after the deposition of the Callytharra Formation. The rapidity of the transgression is attested by the lithology of the Cordalia Greywacke: its sediments were deposited with little sorting or reworking by waves or currents. It probably indicates the renewal of the basin downwarping that accommodated the Wooramel and Byro Groups.

Economic Geology.—The Cordalia Greywacke has no present economic use. Its sediments are likely to vary laterally into the basins into finer-grained types that may include petroleum source beds in contact with the overlying Moogooloo Sandstone, which certainly is a potential reservoir bed.

Problems.—The subsurface extent and thickness of the Cordalia Greywacke and its equivalents are not known and can be determined only by drilling. The extent of the Callytharra-Cordalia regression is unknown—drilling might show whether there is a conformable sequence between Callytharra and Cordalia equivalents within the Carnarvon Basin or whether there is everywhere a disconformity indicating a complete regression.

Moogooloo Sandstone

The Moogooloo Sandstone (Craig, 1950, amended Condon, cited in McWhae et al., 1958, p. 66) is the formation consisting predominantly of medium-grained quartz sandstone resting conformably on the Cordalia Greywacke or unconformably on the Callytharra Formation and conformably below the Billidee Formation. In a few places its rests unconformably on Lyons Group or Precambrian schist.

Raggatt (1936, p. 129) called this unit Wooramel Stage because of the similarities of lithology and sequence in the Wooramel area and in the area north of the Gascoyne River. However, our mapping has shown that the unit named Wooramel by Dee & Rudd (1932, unpublished) and Condit (1935) is not the same as that named Wooramel by Raggatt, nor is there any sensible continuity of outcrop between the Wooramel area and the Merlinleigh Basin area. As Craig (1950) had used the name Moogooloo for the unit called Wooramel by Raggatt and by Condon (1954), this name was adopted (Condon, 1962a). The definition is amended slightly to include additional relationships.

The name is taken from Moogooloo, a large mesa with a trigonometrical station at latitude 23° 36′ S., longitude 114° 44′ E. Moogooloo Sandstone forms the western slope and eastern scarp of the range on which the Moogooloo mesa stands. The mesa consists of Billidee Formation, capped by Eocene Merlinleigh Sandstone with a laterite surface. As this area can be reached only with difficulty, the type section (Fig. 73) is located at the south end of the Moogooloo Range in the scarp east of Trig. point K55, and west of Mongie No. 2 Well, Middalya station at latitude 23° 51′ S., longitude 114° 49′ E. (Fig. 72).

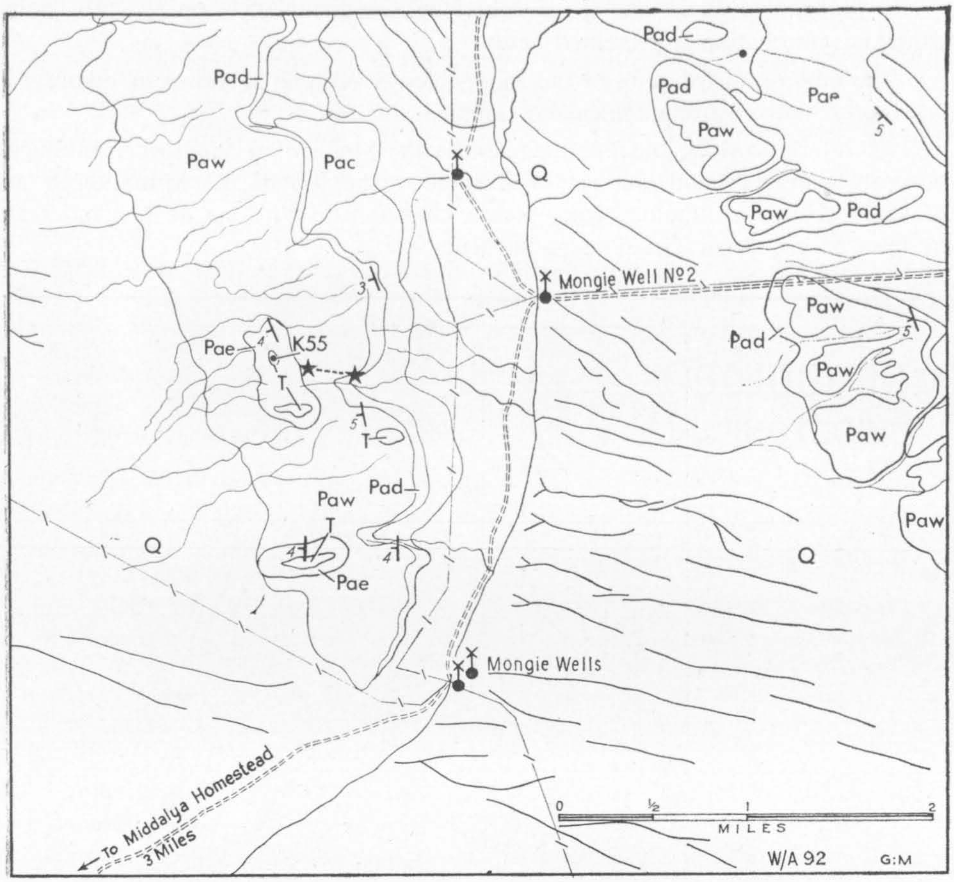
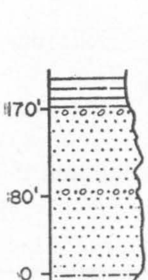


Fig. 72. Type locality, Moogooloo Sandstone. Q-Quaternary; T-Tertiary; Pae-Billidee Formation; Paw-Moogooloo Sandstone; Pad-Cordalia Greywacke; Pac-Callytharra Formation.



Soft dark to light grey laminated carbonaceous siltstone and shale (Billidee Formation) conformably overlying:

90 feet medium hard and friable white and red-brown medium-grained quartz sandstone with beds of coarse-grained and fine-grained sandstone and of siltstone; beds of very coarse quartz sandstone with pebbles at top and bottom;

80 feet thin-bedded medium hard white medium-grained quartz sandstone with a little white silt matrix; cross-bedded and ripple-marked; worm burrows and inverterbrate trails and fossil wood near base;

conformably overlying friable thin-bedded to laminated fine-grained quartzwacke (CORDALIA GREYWACKE).

170 feet - thickness of Moogooloo Sandstone in type section.

Fig. 73. Type section, Moogooloo Sandstone.

The Moogooloo Sandstone is described by Condon (1954, pp. 56-60); only additional information is presented here.

The outcrop distribution of the Moogooloo Sandstone is shown in Figure 74 and representative stratigraphical columns in Figure 75.

There are no thick siltstone members in the Moogooloo Sandstone, although there are thin beds and laminae of siltstone. The top of the formation is at the sharp change in lithology from quartz sandstone to siltstone in a member at the base of a quartzwacke-siltstone sequence.

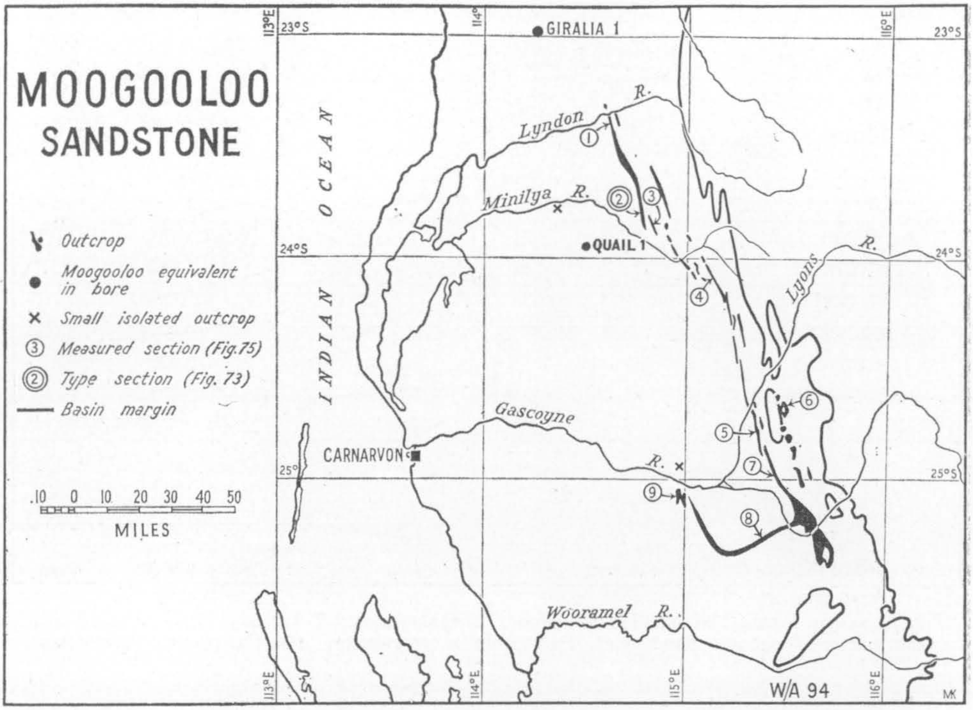


Fig. 74. Outcrop distribution of Moogooloo Sandstone.

The thickness of the Moogooloo Sandstone is related in part to the local relief on the eroded surface of Callytharra Formation: in areas where the unconformity is flat the thickness is fairly uniform between 150 and 180 feet (Fig. 75, sections 1, 2, 3, and 5); where there is a hollow in the surface the Moogooloo is thick (section 4), and where there is a ridge or rock stacks (sections 7 and 8) or where the section is probably close to the Moogooloo littoral (sections 6 and 9) the formation is thin.

The Moogooloo Sandstone is conformable on the Cordalia Greywacke: the junction is gradational from laminated fine and very fine-grained quartzwacke and siltstone to thin-bedded medium-grained quartz sandstone. It is unconformable on the Callytharra Formation: in many places there is little difference in dip and strike, but a varying amount of the upper part of the Callytharra Formation has been removed by erosion; in other places, as near the Arthur and Wyndham Rivers and in Pells Range, the Moogooloo Sandstone is deposited on a surface including pinnacles or rock stacks of Callytharra limestone: the sandstone is commonly unbedded near the pinnacles, dips away from them for a short distance and, at some 10 to 20 feet above the level of the tops of the pinnacles, achieves a plane regional dip generally several degrees less than the dip of the Callytharra Formation below. In a few places, e.g. 13, 11½, and 10½ miles north-north-west, 5½, 4½, and 4 miles north of west, and 4 miles west of Mount Sandiman homestead, and 20 miles north-east, 21 miles east-north-east, and 21 miles east of Bidgemia homestead, the Moogooloo Sandstone abuts unconformably against erosional scarps in sediments of the Lyons Group. On the east side of the Weedarra Precambrian inlier the Moogooloo Sandstone abuts unconformably against the Precambrian schist 16, 17½, 18½, 25½, 26, 27, and 29 miles southward from Mount Sandiman homestead.

The Moogooloo Sandstone almost everywhere is overlain by the same siltstone member of the Billidee Formation. The sharp change in lithology and the common strongly ferruginous top of the Moogooloo Sandstone suggested a disconformity, but there is no regional evidence to support this. The relationship is almost certainly conformable. In the area 12 miles west of Gascoyne Junction the Moogooloo Sandstone is conformably overlain by the Jimba Jimba Calcarenite; in this area the Moogooloo Sandstone has its greatest known thickness—420 feet. The Moogooloo Sandstone was penetrated between 895 and 1267 feet in WAPET's Quail No. 1 Well (thickness 372 feet); the sequence included traces of coal (Pearson, 1964).

Fossils.—No fossil species from the Moogooloo Sandstone have been determined. I found fenestellid bryozoa and *Neospirifer* sp., *Strophalosia* sp. ind., cf. *Strophalosia* sp., and *Parallelodon* sp. (determined by G. A. Thomas), in ferruginous sandstone at the top of the Moogooloo Sandstone 11 miles west-south-west of Williambury homestead (MG 147), and Glenister is reported to have found 'brachiopods and bryozoans in the basal medium- to coarse-grained cross-bedded sandstones'—no locality is given (McWhae et al., 1958, p. 66). At M40, 15½ miles north-north-east of Middalya homestead, M. H. Johnstone found a shark's tooth, small crinoid stem ossicles, bryozoa, and brachiopods in the basal part of the Moogooloo Sandstone: these of course may have been derived from the Callytharra Formation.

Fossil wood has been found in a few places: M51, 4 miles south-west of Lyndon-Kialawibri junction (collected by C. E. Prichard); TP.251, seven miles west-north-west of Moogooree homestead (collected by C. E. Prichard); and in the bottom part of the type section.

Age.—As the underlying Callytharra Formation and the Coyrie Formation, which is higher in sequence, are both Artinskian, the Moogooloo Sandstone is certainly of that age also. As an erosional break separates the Callytharra from the Moogooloo, whereas the Moogooloo and Coyrie are in an unbroken sequence, the Moogooloo is likely to belong to a stage including the Coyrie Formation rather than the Callytharra Formation.

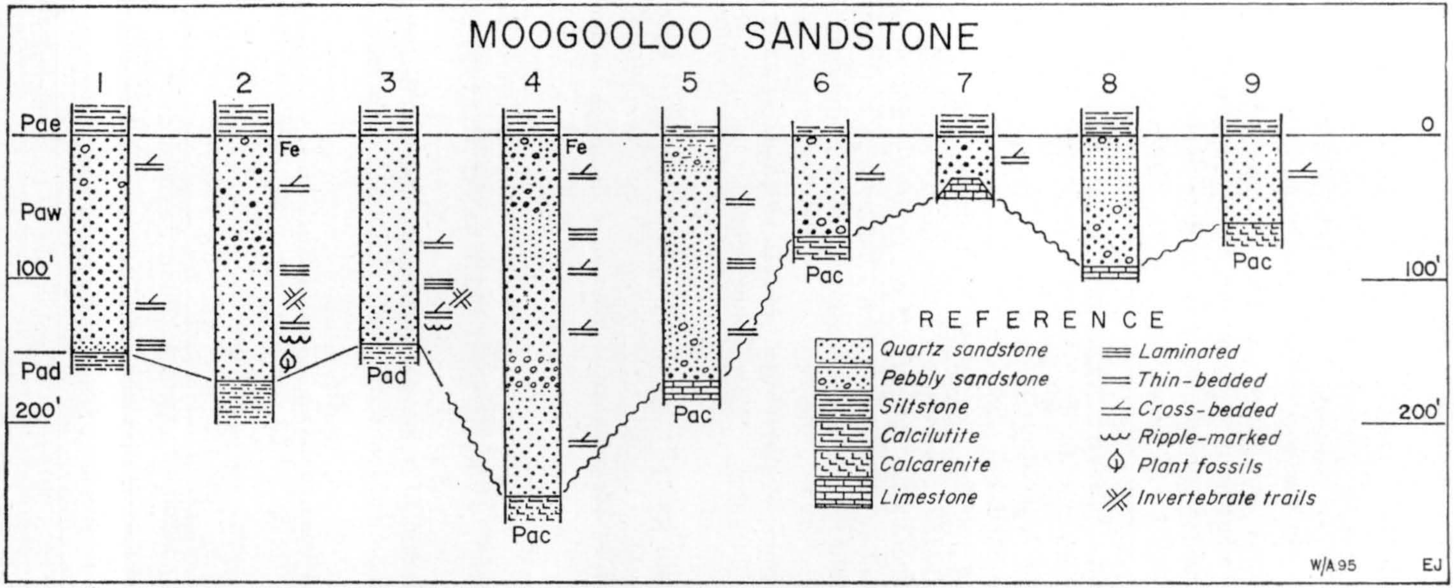


Fig. 75. Stratigraphic columns, Moogooloo Sandstone. Location of columns shown in Fig. 74. Pae-Billidee Formation ; Pad-Cordalia Greywacke ; Pac-Callytharra Formation.

Correlation.—The Moogooloo Sandstone is correlated, by lithology and stratigraphic position relative to fossiliferous formations, with the Nunnery Sandstone of the Byro Basin and with the sandstone in the interval from 2263 feet to 2642 feet in Giralia No. 1 Well (West Australian Petroleum Pty Ltd). It probably correlates with the High Cliff Sandstone of the Irwin Basin (Clarke et al., 1951) and with the upper part of the Poole Sandstone of the Fitzroy Basin (Guppy et al., 1958). Konecki et al. (1958, p. 73, and 1958a, p. 34) equated the One Gum Formation with the upper part of the Moogooloo Sandstone. Both formations include beds of quartz pebbles but the Moogooloo Sandstone has no siltstone members and few siltstone beds and is much cleaner than the One Gum. The Nunnery Sandstone, like the Moogooloo Sandstone, has no siltstone members, and has quartz pebbles in its upper part. Both are overlain by a calcarenite formation in one place.

Structure.—In outcrop the Moogooloo Sandstone is part of the west-dipping homocline on the east side of the Merlinleigh Basin; this passes into a north-plunging syncline at the south end of the basin. The outcrop at the north end of the basin is obscured by sand cover, but probably forms a south-plunging syncline. East of the main homocline the Moogoloo Sandstone overlies the Callytharra Formation in several of the valley-fillings (in valleys eroded in the Lyons Group sediments).

In the Bidgemia Basin the Moogooloo Sandstone crops out in synclines close to the west side of the basin.

The subsurface extent of the Moogooloo Sandstone is unknown. The equivalent Nunnery Sandstone extends across the Byro Basin and therefore it is likely that the Moogooloo Sandstone extends across the Merlinleigh Basin in a broad syncline. It probably does not extend across the Wandagee Ridge generally, although it may cross the Ridge in the Winnemia Sill (Fig. 35).

The only anticline known in outcrop in the Moogooloo Sandstone is the very gentle one where it occupies a saddle in the Weedarra Ridge south of the Wyndham River.

Palaeogeography.—The Moogooloo Sandstone was deposited in a shallow sea on a stable floor. The eastern shoreline was probably very close to the present outcrop: its form was determined by the major relief of the unconformity surface on the Lyons Group, modified by the deposition of the Callytharra Formation. Minor features were determined by the nature of the eroded surface of the Callytharra Formation. The basement ridges formed islands, peninsulas, and shoals. The sea was open to the north at the north end of the Gascoyne Basin but possibly was not open to the west in the area between Rough Range and Carnarvon. There was probably a shallow connexion with the Byro Basin across the Carrandibby Ridge south of Dairy Creek homestead and possibly one between the Byro Basin and the Gascoyne Basin at the Wooramel Sill (see p. 112, Nunnery Sandstone).

Economic Geology.—The Moogooloo Sandstone is a useful aquifer providing large supplies of potable water. It has been developed only near outcrop (e.g. Mundarie Well, Middalya; Shed Bore, Mount Sandiman; Tabletop Well, Lyons River); it can provide much more water in the area close to outcrop and may provide artesian water in the area of outcrop of the Byro and Minilya Groups, where groundwater is saline or insufficient.

It is a potential reservoir bed for petroleum, lying between source formations (Callytharra equivalents and Byro Group). Few anticlinal structures are known in the Moogooloo Sandstone, but these and stratigraphic traps may be present. As it is likely that the present structural relief did not develop until after the deposition of the Byro Group cap to the Moogooloo Sandstone, petroleum would have migrated into the Moogooloo under good conditions for retention. Stratigraphic traps are very likely to have developed on the west side of the Merlinleigh Basin against the Wandagee Ridge. In the Gascoyne Basin, the Moogooloo equivalent is anticlinal in the Giralia Anticline (Fig. 41) but closure has not been determined.

Problems.—Much can be learned of the details of the palaeogeography of the Moogooloo Sandstone by a quantitative study of the sedimentary structures (particularly cross-bedding).

The subsurface extent of the Moogooloo Sandstone and whether it changes laterally, in the central part of the Merlinleigh Basin, into a different lithology can be determined only by drilling. Seismic surveys are needed to supplement drilling to determine the structure of the formation and to indicate areas of possible petroleum accumulation.

Hydrological data are required to determine the flow net of the fluids contained in the Moogooloo Sandstone, to help in exploring structural and stratigraphic traps, and to indicate possible hydrodynamic traps for petroleum. When bores are drilled into the Moogooloo Sandstone adequate information on pressure, temperature, and salinity of the water and porosity and permeability of the aquifer should be obtained.

Jimba Jimba Calcarenite

The Jimba Jimba Calcarenite (Condon, 1965b) is the formation of fossiliferous friable calcarenite with minor beds of hard calcilutite conformable between the Moogooloo Sandstone below and the Billidee Formation above.

The name is taken from Jimba Jimba station. The type locality (lat. 25° 02¾′ S., long. 114° 58½′ E.) is on Jimba Jimba station 9½ miles west of the homestead (Fig. 76). The type section (Fig. 77) was measured on the north-western flank of the syncline, where the south-easterly dip ranges from 23° at the base to 12° at the top.

Lithology.—The Jimba Jimba Calcarenite is predominantly a friable fossiliferous calcarenite; this consists mainly of fragments of organic tests, mainly bryozoa and crinoids. There are many lenticular thin beds of hard calcilutite, generally with few brachiopods. In the lowermost 30 feet of the formation there are thin beds of fine-grained fossiliferous quartzwacke, but there is generally less terrigenous matter in this formation than in the Callytharra Formation, which it resembles.

Distribution, Thickness, and Relationships.—The Jimba Jimba Calcarenite is known to crop out only in the type locality, where it is 200 feet thick, and 8½ miles east of south of that. In bore BMR 8, Mount Madeline, a calcarenite formation similar in lithology and stratigraphic position to the Jimba Jimba Calcarenite is certainly its equivalent; it is 60 feet thick (470 to 530 feet depth in the bore).

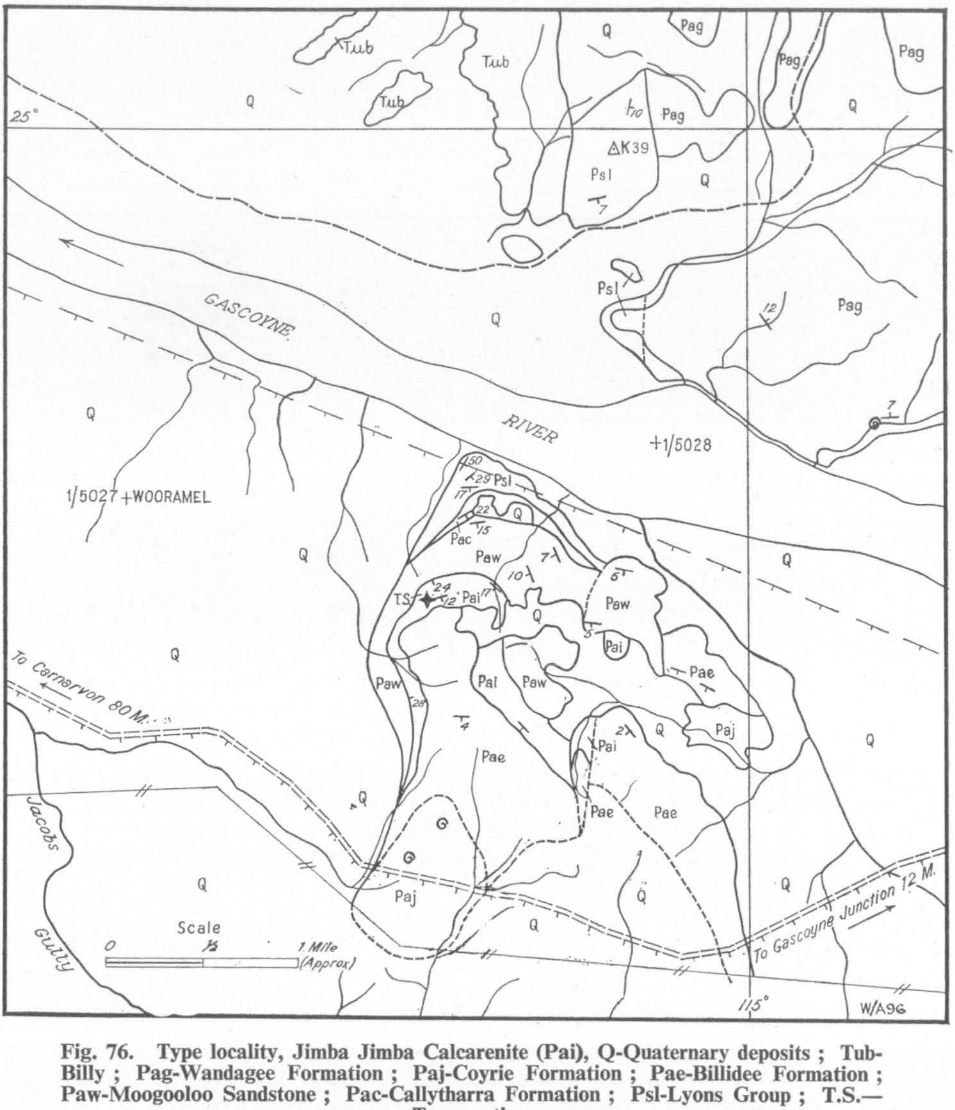


Fig. 76. Type locality, Jimba Jimba Calcarenite (Pai), Q-Quaternary deposits ; Tub-Billy ; Pag-Wandagee Formation ; Paj-Coyrie Formation ; Pae-Billidee Formation ; Paw-Moogooloo Sandstone ; Pac-Callytharra Formation ; Psl-Lyons Group ; T.S.—Type section.

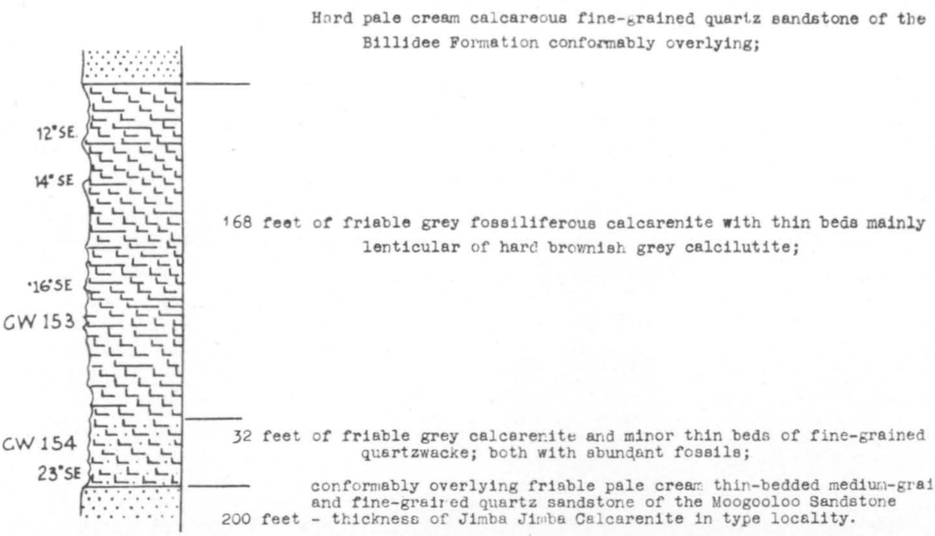


Fig. 77. Type section, Jimba Jimba Calcarenite.

The Jimba Jimba Calcarenite is in conformable sequence with the underlying Moogooloo Sandstone and the overlying Billidee Formation. Its equivalent in BMR 8 is conformable between One Gum Formation above and Nunnery Sandstone below. It is the equivalent of either the top of the Moogooloo and Nunnery Sandstones or the bottom of the Billidee and One Gum Formations. It establishes the equivalence of the Moogooloo and Nunnery Sandstone (whereas Konecki, Dickins, & Quinlan, 1958, p. 31 and 34, equated the Nunnery and One Gum with the Moogooloo).

The fossils in the Congo Formation on the east flank of Bush Creek Syncline ¼ mile north of Bush Creek suggest a correlation between the Jimba Jimba Calcarenite and the lower part of the Congo Formation.

Fossils.—The Jimba Jimba Calcarenite is richly fossiliferous, but its fauna has not been critically examined. The assemblage is, superficially, very like that of the Callytharra Formation. In the field I listed the following fossils (these have not been checked by palaeontologists): Bryozoa, crinoid ossicles, *Linoproductus* spp., *Neospirifer* spp., *Cleiothyridina, Phricidothyris, Dictyoclostus, 'Chonetes', 'Derbyia'*.

Age.—By its stratigraphic positon between Callytharra Formation and Byro Group the Jimba Jimba Calcarenite is established as Artinskian. Its fauna appears to be very like that of the Callytharra Formation. This may be related to similarity of facies, but suggests that there is no large interval between the two (in spite of the established unconformity between the Callytharra and the Wooramel Group).

Correlation.—Apart from general correlation with other lower Artinskian formations no particular correlations can be suggested outside the Carnarvon Basin. It suggests that the Wooramel Group belongs, in any time-rock classification, with the Callytharra Formation rather than the Byro Group.

Structure.—The Jimba Jimba Calcarenite is folded into a south-plunging asymmetrical syncline (with steep west flank) in the type locality and 1 mile to the east. The outcrop is on the east flank of the Wandagee Basement Ridge, but appears to be related to geomorphology of west-dipping sediments in the Lyons Group sediments in this area. The shallow marine sediments of the formation indicate that this area was topographically high during their deposition, compared with the relatively deep-water sediments of the lowermost One Gum and Billidee Formations, and that the present regional structure is inherited from pre-Artinskian structure.

Palaeogeography.—As only two well-separated areas of occurrence of the Jimba Jimba Calcarenite and its lithological equivalent are known, very little can be said of its palaeogeography. Indubitably, the type locality area and the area around Mount Madeline were shallow seas with an abundant fauna and little terrigenous sediment. In the Byro Basin, it seems likely that the calcarenite changes to carbonaceous siltstone with marine fossils within 9 miles. If this is so the sea must have deepened away from Mount Madeline. This is confirmed by the slump structures in the basal siltstone of the One Gum Formation, which indicate a sloping sea floor or strong penecontemporaneous folding.

The lithological equivalent of the Jimba Jimba Calcarenite has not been seen in outcrop on the eastern side of the Merlinleigh or Byro Basins; a siltstone member is present in its stratigraphic position. This suggests that the shoreline at this time was well to the east of the present outcrop area of the Wooramel Group.

A change in environment ended the deposition of the Moogooloo and Nunnery Sandstones. Much less terrigenous detritus was deposited: this indicates less erosion of the hinterland, which could result from lowering of the hinterland, or a rise of sea level, or a more equable and humid climate; the organic detritus indicates supply of nutrients favouring growth of organisms. Taken together these suggest a warmer more humid climate producing a dense cover of vegetation on the hinterland and little terrigenous detritus but abundant nutrients in the runoff to the sea. The dense vegetation is confirmed by the coaly layers in the Keogh Formation above (in bore BMR 8).

Economic Geology.—In its only known outcrop the Jimba Jimba Calcarenite is a potential source of friable limestone 20 and 30 miles from the nearest similar sources. Its greatest economic significance, however, is in indicating that the Wooramel Group, obviously a possible reservoir for petroleum, also has fossiliferous marine formations that in places probably are of source-bed type.

Problems.—During much of the field mapping it was not realized that there were two fossiliferous calcareous formations—the Callytharra Formation and the Jimba Jimba Formation. It is possible, therefore, that in some of the structurally complex areas (as on Mount Sandiman and Lyons River stations, in the Donellys Well area, Williambury station, and along the Carrandibby Range unconformity) Jimba Jimba Calcarenite may crop out, having been wrongly mapped as Callytharra Formation.

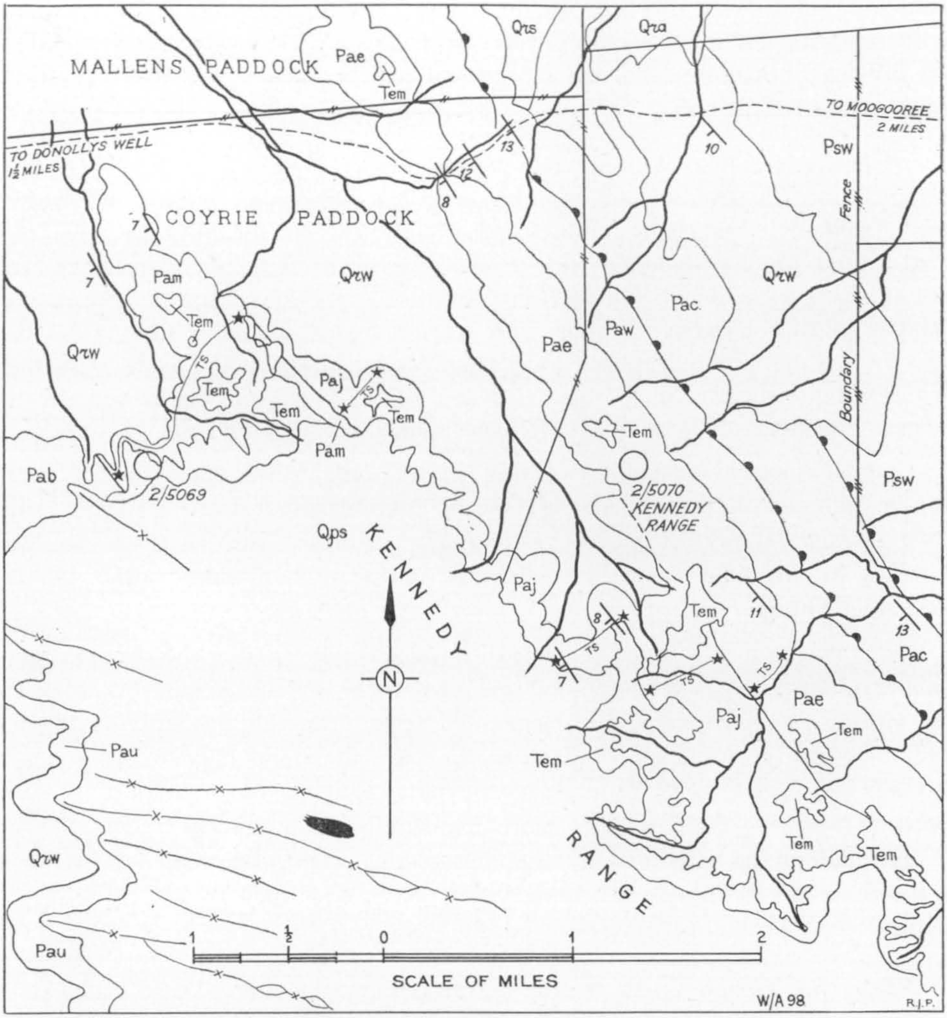


Fig. 78. Type locality, Billidee Formation (Pae), Coyrie Formation (Paj), and Mallens Greywacke (Pam). Qra-Alluvium ; Qrw-Recent wash ; Qrs-Recent sand ; Qps-Pleistocene sand ; Tem-Merlinleigh Sandstone ; Pau-Cundlego Formation ; Pab-Bulgadoo Shale ; Paw-Moogooloo Sandstone ; Pac-Callytharra Formation ; Psw-Weedarra Shale.

The fauna of the Jimba Jimba Calcarenite has not been studied separately from that of Callytharra Formation. Additional collection is required in the type locality (and in the nearby Callytharra Formation for local comparison).

Billidee Formation

The Billidee Formation (Condon, 1962a) is the formation of quartzwacke and siltstone with minor conglomerate resting conformably between the Moogooloo Sandstone below and the Coyrie Formation above. In the south-western part of the Merlinleigh Basin it rests conformably on the Jimba Jimba Calcarenite. Condon (1962a) named the lower, arenaceous, part of his (1954) Coyrie Formation the Billidee Formation and included it in the Wooramel Group.

The name is from Billidee Well, Moogooree station, 5½ miles south of the homestead; the well is sunk in the outcrop of the formation. The type locality (Fig. 78) is 3 miles north-west of Billidee Well, at the original type locality of the Coyrie Formation. The type section (Fig. 79) starts 4¼ miles south-east of Moogooree homestead in a small watercourse running north-east. The basal siltstone is not exposed in the watercourse, but is well exposed in small scours in scarps running back from the stream. The section was measured for about 100 yards up the main stream then for about 450 yards up a left (north) bank tributary stream.

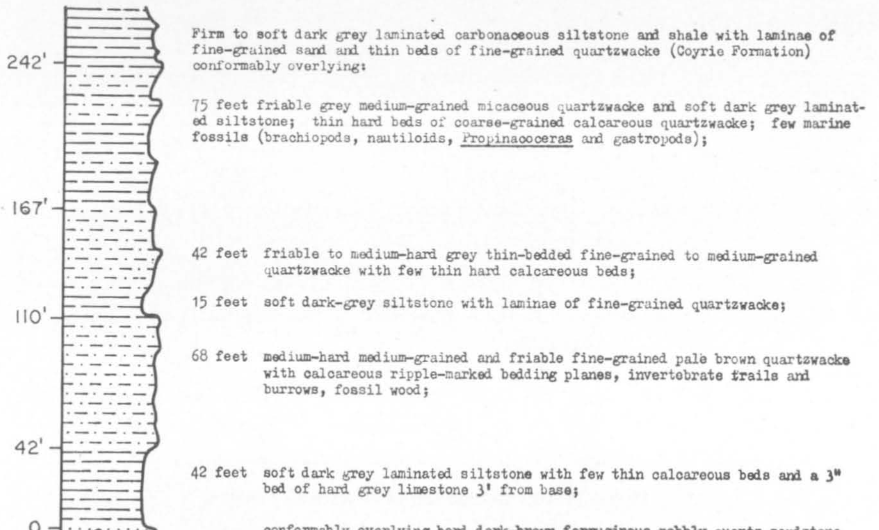


Fig. 79. Type section, Billidee Formation.

The base of the Billidee Formation is placed at the sharp change in lithology from quartz sandstone to siltstone in a thick member; the uppermost part of the underlying quartz sandstone is commonly ferruginous. The top of the Billidee Formation is placed at the change from quartzwacke (medium-grained and coarse-grained calcareous) and siltstone to dominant siltstone.

The Billidee Formation is characterized by an alternation of quartzwacke and siltstone members giving a strong dip slope and scarp topography in hilly outcrop and a strike-ridge plains outcrop. The air-photo pattern is banded dark grey and light grey to white in hilly country and strongly banded grey in plains outcrop. Vegetation is sparse.

Lithology.—The dominant rock of the Billidee Formation is thin-bedded fine-grained to medium-grained quartzwacke with ripple marks, invertebrate trails and burrows, fossil wood, and silt biscuits. Soft dark grey laminated siltstone forms thick members, thinner beds, and laminae; it commonly contains laminae of fine sand and calcareous beds. In the upper part of the formation are beds of calcareous coarse-grained quartzwacke, with sporadic marine fossils.

Distribution, Thickness, and Relationships.—The Billidee Formation crops out from Lyndon River to south of the Gascoyne River, a distance of 150 miles (Fig. 80). The equivalent of the Billidee Formation was encountered in Giralia No. 1 and Quail No. 1 Wells (West Australian Petroleum Pty Ltd).

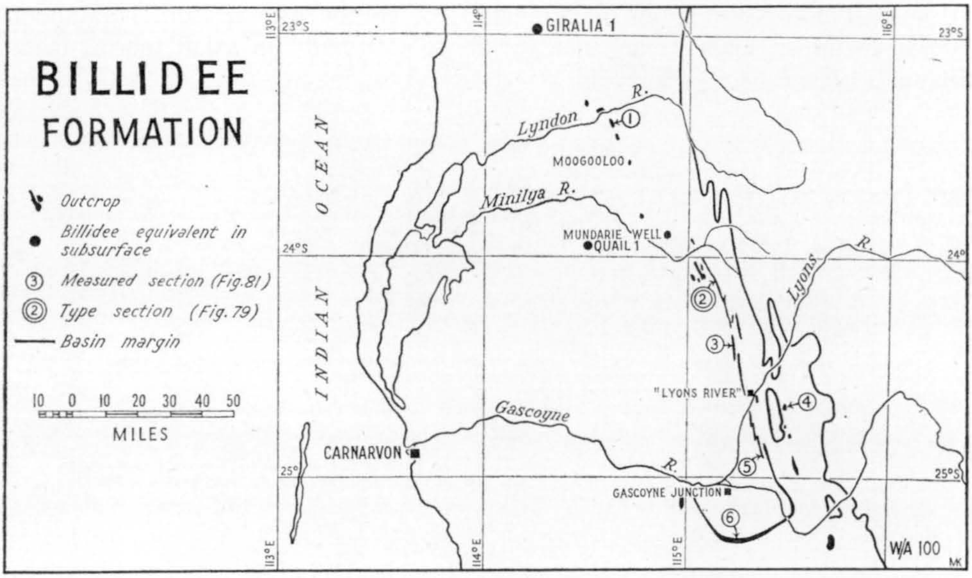


Fig. 80. Outcrop distribution of Billidee Formation.

The Billidee Formation crops out on the right bank of the Lyndon River about 10 to 12 miles east of Mia Mia homestead, where it is about 500 feet thick; the boundaries with the Moogooloo Sandstone and Coyrie Formation are not exposed (Fig. 81, column 1). No other complete section of the formation crops out north of the Minilya River; part sections are exposed in the scarp of Moogooloo mesa, at K55, and 9 miles west-south-west of Williambury homestead. South of the Minilya River the Billidee Formation crops out more strongly. In the Donellys Well area 8 to 12 miles west of Moogooree homestead there are several discrete outcrop belts of Billidee Formation separated by depositional unconformities. The main outcrop belt starts 8½ miles west-north-west of Moogooree homestead; at the type locality the Billidee Formation is 242 feet thick and the outcrop continues for a total length of 25 miles to 4½ miles north of Mount Sandiman woolshed, where the formation is cut by an unconformity: the outcrop starts again 2 miles north of the woolshed and continues south for 8 miles; in this area the Billidee Formation is 360 feet thick (Fig. 81, column 3). The outcrop is offset 4 miles north by an unconformity and then extends 15 miles south, where it is covered by alluvium of the Lyons River; in this outcrop the Billidee Formation is about 200 feet thick; the upper boundary is not exposed. East of the Lyons River the Billidee Formation crops out from 3 miles south of Lyons River homestead for 24 miles southward to the Arthur River; the outcrop is offset in several places by unconformities. In this belt the thickness ranges from about 200 feet to about 300 feet—the top boundary is not well exposed (Fig. 81, column 5). South of the alluvium of the Arthur River the Billidee crops out for 14 miles southward to the alluvium of the Gascoyne River: it is 230 feet thick in this area. In the Pells Range, west of the Gascoyne River alluvium the outcrop extends in an arcuate belt, largely obscured by sand cover, to 7 miles east-south-east of Winderie homestead. The thickness 18 miles east of Winderie homestead is about 250 feet (the upper boundary is poorly exposed). There are several small areas of outcrop, 5, 11, and 17 miles south of K39 on the south-western side of the Merlinleigh Basin.

East of the main outcrop belt in the Mount Sandiman area, and south of Lyons River homestead, there are several outcrops where Billidee Formation overlies the Moogooloo Sandstone conformably and abuts unconformably against the Lyons Group. These outcrops form part of the valley filling of valleys eroded in the Lyons Group before the deposition of the Callytharra Formation.

In the Bidgemia Basin the Billidee Formation crops out in several synclines to the east of the Weedarra Precambrian inlier. In the northern outcrop, 9 miles south of east of Lyons River homestead, the Billidee Formation is 190 feet thick (Fig. 81, column 4).

In Giralia No. 1 Well the Billidee equivalent is probably represented in the interval between 2263 feet and 2642 feet described by the Company geologists as 'sandstone and subgreywacke'; this interval also includes the Moogooloo Sandstone equivalent. In Quail No. 1, the Billidee is 675 feet thick (from 220 to 895 feet); it contains a few thin coal seams (Pearson, 1964).

The Billidee Formation is somewhat more variable in thickness than these figures indicate: measurements were not made close to the depositional unconformities, but at several of these the formation is very thin (less than 100 feet) and has no siltstone members on the higher side, and is thicker (up to about 500 feet) on the low side, close to the unconformity.

The thickness on the Lyndon River is related to its closeness to the regional syncline at the north end of the Merlinleigh Basin.

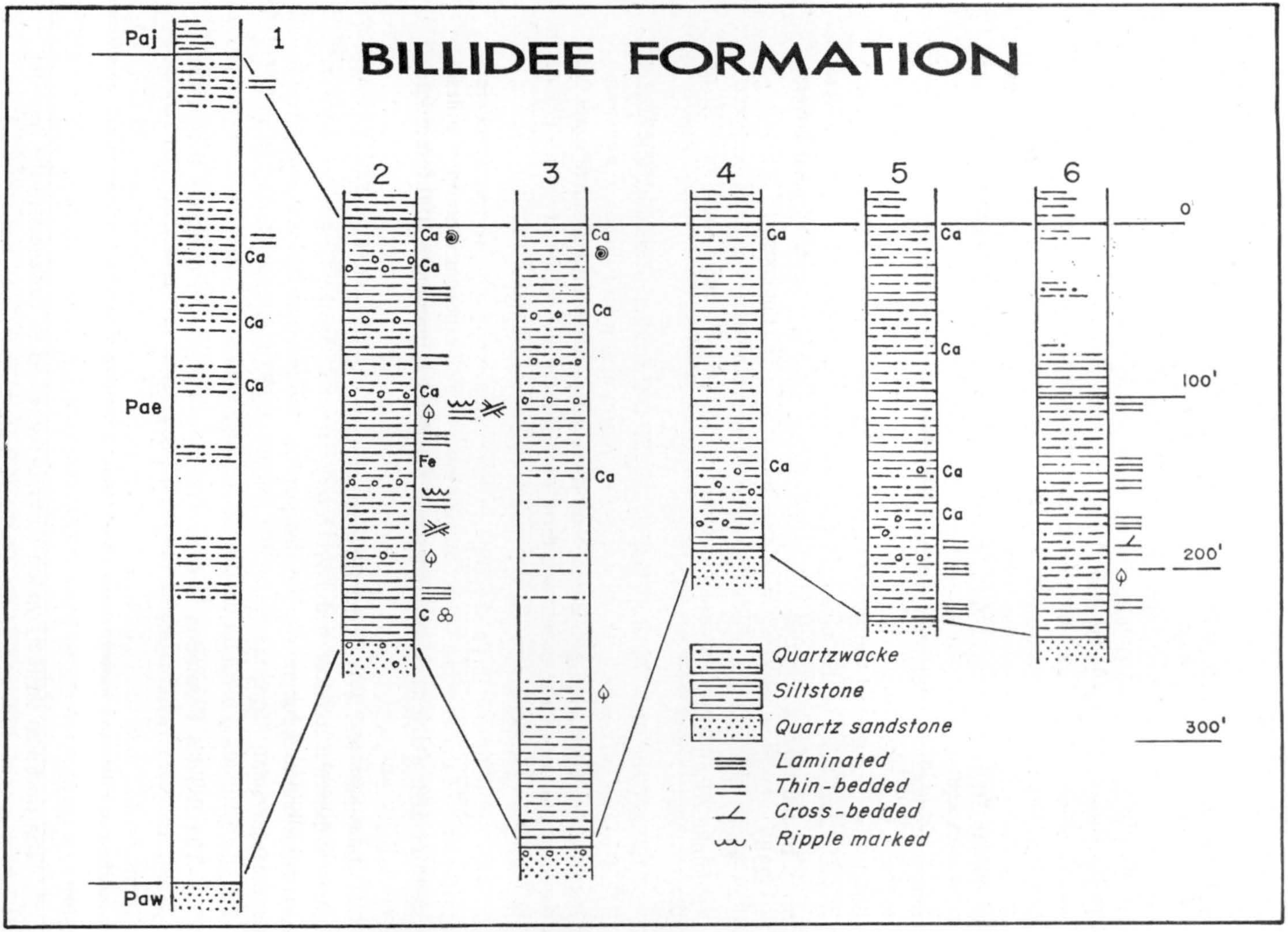


Fig. 81. Stratigraphic columns, Billidee Formation. Paj-Coyrie Formation ; Pae-Billidee Formation; Paw-Moogooloo Sandstone. Location of columns shown in fig. 80.

No information is available on the extension of the Billidee Formation into the central part of the Merlinleigh Basin. As its lithology indicates that the environment of deposition had become unstable, it is likely that the Billidee Formation changes basinward into a finer-grained equivalent.

Fossils.—Silicified fossil wood (*?Araucaria*) is common in the lower part of the Billidee Formation, but invertebrate trails and burrows and a few poorly preserved foraminifera, pelecypods, and brachiopods establish the marine environment of deposition.

In the upper part of the formation marine fossils are found in a few localities: 4½ miles west of Moogooree homestead and ½ mile north of the Moogooree/Donellys Well road, Dr C. Teichert, G. A. Thomas, and C. E. Prichard found a bed with abundant fossils (TP323), in which the following have been determined:

Crinoids: *Calceolispongia* cup and brachial ossicles.
Brachiopods: Dielasmatid, small productid.
Mollusca: Pelecypoda: *Nuculana* sp.
Gastropoda: *Pleurotomaria*, bellerophontid.
Nautiloidea: *Permonautilus* sp.
Ammonoidea: *Propinococeras* sp.

In the type section brachiopods and gastropods were found near the top (G238).

Five hundred yards north of Mount Sandiman woolshed, a pelecypod coquinite contains the following forms (identified by J. M. Dickins):

Pelecypoda:
- *Nuculopsis* (*Nuculanella*) sp.
- *Oriocrassatella* sp.
- *Aviculopecten* sp.
- *Schizodus* cf. *kennedyensis* Dickins
- *Stutchburia* sp. nov.

Gastropoda:
- *Mourlonia* (*Pseudobaylea?*) sp. nov.?
- *Macrochilina* sp.
- *Warthia* sp.

Ammonoidea (Glenister, 1961):
- *Neocrinites* sp.

D. Johnstone found bryozoa, *Neospirifer, Aulosteges,* and a pectinid at locality G144, 8½ miles south of east of Lyons River homestead (4, Fig. 80); 1¼ miles east-north-east of Congo Well (on Congo Creek 8 miles west of Dairy Creek homestead), he found but did not collect *Neospirifer* spp., *Strophalosia* sp., a chonetid, and a productid.

Age.—The Billidee Formation is Artinskian, by reference to the Artinskian Callytharra below it and the Artinskian Coyrie Formation above. It is conformable and gradational with the Coyrie, but there is an erosional hiatus between the Callytharra and the Billidee: if the Artinskian of the Carnarvon Basin were subdivided the Billidee should probably be in the same substage as the Coyrie and in a different one from the Callytharra.

Correlation.—The Billidee Formation is probably the lateral equivalent of the Congo Formation, all or part of the Monument Formation, the One Gum and Keogh Formations, and the Curbur Formation of the Byro Basin. These formations are, like the Billidee, dominantly of quartzwacke with siltstone members and beds and are in similar stratigraphic position between the fossiliferous Callytharra Formation and Byro Group. Konecki et al. (1958A, p. 73 and 1958b, p. 34) equated the One Gum Formation with the upper part of the Moogooloo Sandstone, but this is unlikely (p. 87).

Structure.—The main outcrop of the Billidee Formation is on a west-dipping homocline on the east side of the Merlinleigh Basin. At the south end of the basin the Billidee Formation plunges gently (1°-2°) north in a broad syncline and at the north end plunges south in a narrowed syncline (the outcrop is covered but younger formations indicate the structure).

Isolated synclines are developed in valley-fillings in the Donellys Well area, Williambury, in the Mount Sandiman station area, and south of Lyons River homestead.

In the Bidgemia Basin the Billidee Formation is preserved in synclines along the west side between Lyons River and Arthur River and at the south end (8 miles west of Dairy Creek homestead).

The Billidee Formation probably does not extend into the central part of the Merlinleigh Basin: it most probably changes laterally into the lithology of the Byro Group.

No anticlines, other than very minor ones on the high side of depositional unconformities, are known. Faulting is not known to affect the Formation. Slump folds and slump breccias are present in the siltstone members in several places. Ripple marking is common in the lower arenaceous members. Cross-lamination is rare.

Palaeogeography.—The deposition of the Billidee Formation followed a marked change in environment from that of the Moogooloo Sandstone: from a shallow sea over a stable shelf the environment changed abruptly to a moderately deep sea over an unstable shelf which continued unstable, causing varying water depth, throughout the deposition of the Billidee Formation and for a long time afterwards.

The siltstone members of the Billidee Formation were deposited in moderately deep water (perhaps 50 fathoms or more) whereas the arenaceous members were deposited in shallow water (indicated by invertebrate trails and burrows, and ripple marks), but quickly buried so that the sediment had little marine reworking or sorting.

The abundant fossil wood indicates near-shore conditions for the arenaceous members, in outcrop. The thin coal seams in WAPET's Quail No. 1 bore suggest paralic conditions and may indicate that the Wandagee Ridge was a land area during the deposition of the Billidee.

The shoreline probably fluctuated from very close to the present outcrop to some miles to the east. In the first case the old ridges and valleys of the pre-Callytharra surface formed the peninsulas and rias of a drowned topography; on further subsidence these were completely submerged but remained as irregularities of the sea floor.

The instability was the expression of the renewal of downwarping of the basins and is indicated by the evidence of sloping floor in the slump structures that are not uncommon in the siltstone members. The parts of the basins that now are structurally low became the deeper parts of the sea, where finer-grained sediments were deposited.

Some of the fluctuations in sea level may have been eustatic, related to climatic fluctuations of a glacial epoch, and a cause of cyclic sedimentation (Wanless & Shepard, 1936) including the cyclothems of the Sydney Basin (Booker, in Hill, 1955), the Byro Basin (Mercer, 1959), and Kansas-Nebraska (Moore, 1950, Wanless, 1950).

Economic Geology.—The Billidee Formation has a very limited present economic use as a low-grade aquifer: Billidee Well, Moogooree, and Shed Bore No. 2, Mount Sandiman, obtained small supplies of brackish water from it. In addition the basal siltstone member acts as a cap to the high-grade aquifer, the Moogooloo Sandstone.

The Billidee Formation is marine, and the alternation of siltstone of source-bed type with arenaceous members provides good conditions for primary migration. The basinward equivalents of the Billidee Formation are likely to contain a higher proportion of source-bed sediments. The quartzwacke of the Billidee Formation is generally not porous or permeable enough to form a good petroleum reservoir, although it may be adequate for secondary migration. The only reservoir beds likely to be in hydraulic contact with the Billidee Formation are the Cretaceous Birdrong Sandstone and, possibly, a cleaner sand that may have developed against the east side of the Wandagee Ridge as a lateral variant of the Billidee Formation. The basal siltstone is an adequate cap to the Moogooloo Sandstone reservoir bed.

The continued downwarping of the Merlinleigh Basin would favour secondary migration after adequate cover had been deposited. Only on the west side of the Basin is this cover likely to be intact.

Problems.—The fauna of the Billidee Formation has not been collected or studied adequately to compare with the Callytharra and Coyrie faunas. The basinward extent of the Billidee Formation and its extent along the west side of the Merlinleigh Basin are not known, except at Quail No. 1, and drilling will be required to determine them. The extent of Billidee equivalents in the Gascoyne Basin is unknown—its presence is established only at Giralia No. 1 Well.

Congo Formation

The Congo Formation (Konecki et al., 1958) is the sequence of quartzwacke, with thin beds of conglomerate and thin to thick beds of siltstone, resting unconformably on Callytharra Formation, Lyons Group, or Precambrian schist and gneiss, and conformably overlain by the Madeline Formation. The name is taken from Congo Creek, which enters the Gascoyne River at latitude 25° 14′ S., longitude 115° 39½′ E.

The type locality (Fig. 82) is on the north bank of Bush Creek, at latitude 25° 18′ S., longitude 115° 57′ E., 7 miles upstream from Dairy Creek homestead.

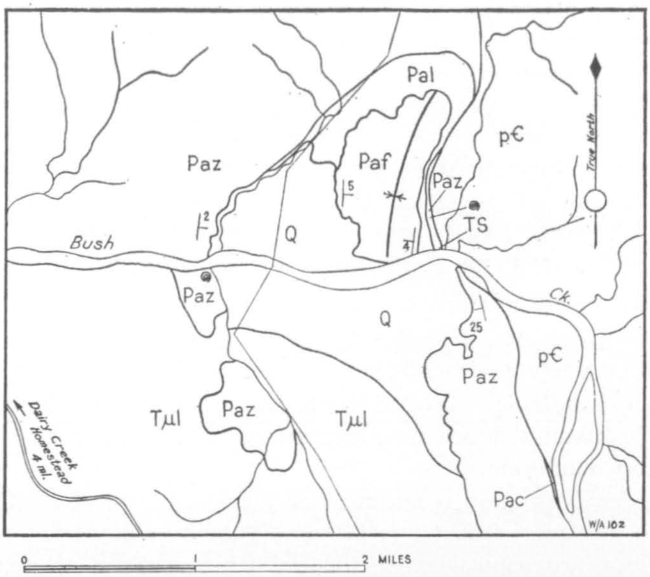


Fig. 82. Type locality, Congo Formation. Q-Quaternary deposits ; Tul-laterite ; Paf-Bogadi Greywacke ; Pal-Madeline Formation ; Paz-Congo Formation ; Pac-Callytharra Formation ; pC-Precambrian metamorphics ; T.S.—Type section.

The type section (Fig. 83) starts in a well-exposed bluff where sediments dipping 80° westward overlie decomposed Precambrian gneiss of reduced topography, and continues westward along the face of the bluff to its west end, where the dip is 35° west, and the outcrop meets alluvium.

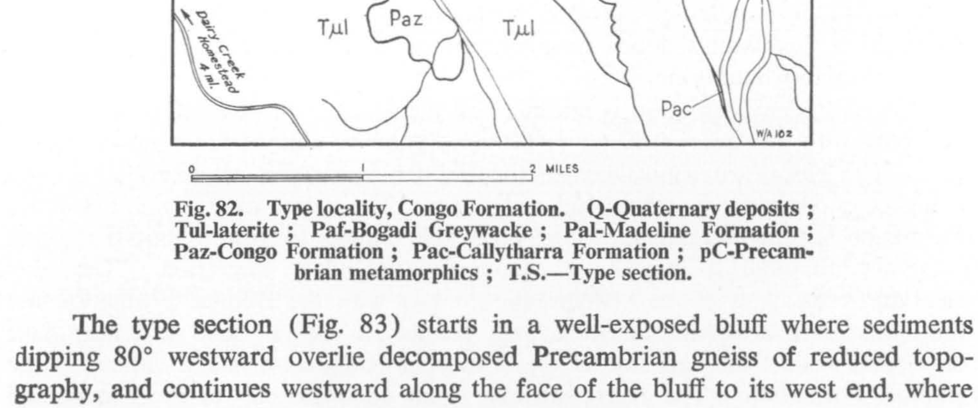


Fig. 83. Type section, Congo Formation.

The base of the Congo Formation is placed at the bottom of the pebbly quartzwacke-siltstone sequence which overlies Callytharra Formation, Lyons Group, or Precambrian schist and gneiss; the top at the gradational change from dominant quartzwacke to predominant siltstone.

Lithology.—The dominant rock of the Congo Formation is pebbly to conglomeratic medium-grained quartzwacke, commonly cross-laminated and ripple-marked. Fine-grained quartzwacke, cross-laminated and ripple-marked in some beds, characterizes the upper part of the formation. Siltstone in units from laminae to members 10 feet thick forms about 15 percent of the formation.

Distribution (*Fig 84*) *and Relationships.*—The Congo Formation crops out only in the Bush Creek Syncline (Konecki et al., 1958, p. 72). Undulating dips and poor exposure because of lateritization made impracticable the determination of the thickness of the formation elsewhere than in the type locality.

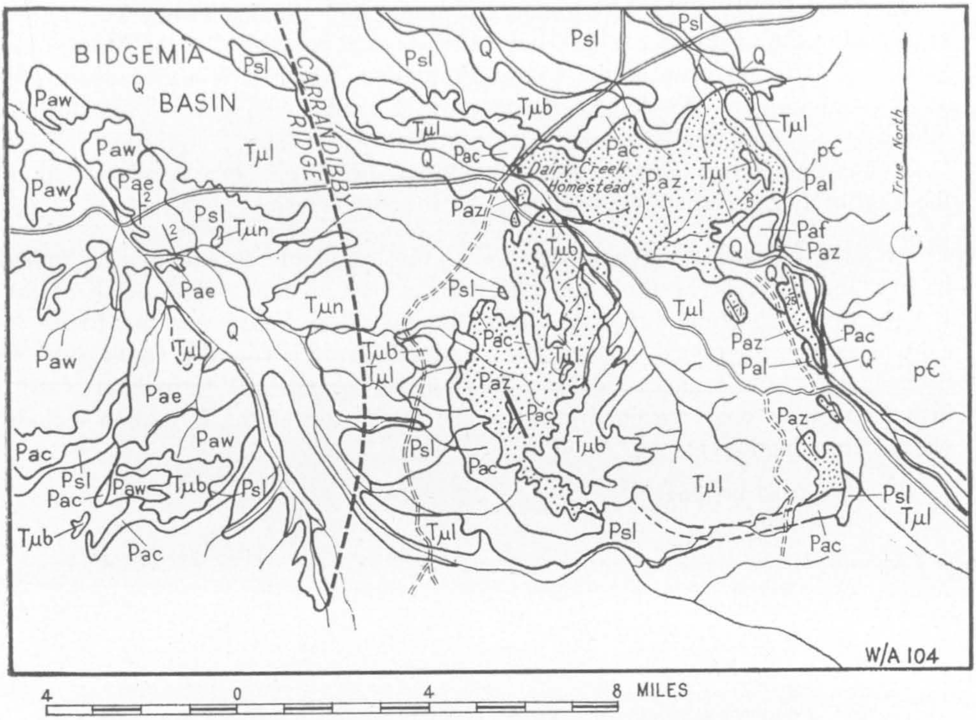


Fig. 84. Outcrop distribution of Congo Formation. Q-Quaternary deposits; Tub-Billy; Tul-Laterite; Paf-Bogadi Greywacke; Pal-Madeline Formation; Pae-Billidee Formation; Paz (stippled)-Congo Formation; Paw-Moogooloo Sandstone; Pac-Callytharra Formation; Psl-Lyons Group; pC-Precambrian metamorphics.

The Congo Formation rests unconformably on the Callytharra Formation on the north, west, and south sides of the Bush Creek syncline and in a small outcrop at the south end of the outcrop. The Callytharra has a rock-stack surface with a relief of about 50 feet under the Congo Formation, 8¾ miles south of Dairy Creek homestead. In places the Callytharra has been completely eroded and the Congo rests unconformably on the Lyons Group (the poor exposure prevents determination of the formations of the Lyons Group in this area); this relationship is exposed at the north and south ends of the Bush Creek syncline. Along the east side of the syncline the Congo Formation rests unconformably on a weathered surface of Precambrian schist and gneiss. Even where, as in the type locality, the unconformity is very steep, the bedding of the Congo Formation is nearly parallel to that surface.

The Congo Formation is overlain conformably by the Madeline Formation in the low part of the Bush Creek Syncline. Elsewhere it is overlain by Tertiary laterite and billy developed by weathering of the surface of the formation, and by Quaternary superficial deposits.

It is separated from the Wooramel Group of the Bidgemia Basin by the Carrandibby Ridge. The Moogooloo Sandstone and Billidee Formation can be separated to the west of the Ridge, but no lithological equivalent of the Moogooloo Sandstone is found beneath the Congo Formation, which is regarded, therefore, as the equivalent of the Billidee Formation: it is much more conglomeratic but otherwise contains similar rocks. It is probably the lateral equivalent of the One Gum and Keogh Formations of the Wooramel Group type locality, and of the Curbur Formation of the south end of the Byro Basin.

Fossils.—Fossil wood has been found in several places and marine fossils in four localities: near the basal unconformity about half a mile north of the type section fragmental bryozoa, *Calceolispongia,* and *Neospirifer* are found in calcareous coarse-grained quartzwacke, and at GW129 (on the south side of Bush Creek 4¾ miles upstream from Dairy Creek homestead) ferruginous fossils in a ferruginous coarse-grained quartzwacke at the top of the formation include (field determinations):

- Fenestellid bryozoa
- Brachiopods
  - *Neospirifer* spp.
  - *Linoproductus* sp.
  - *Aulosteges* sp.
  - *Strophalosia* sp.
  - *Kiangsiella condoni* Thomas
  - *Phrycidothyris* sp.
  - *Streptorhynchus* sp.
  - *?Dielasma* sp.
  - *Permorthotetes* sp. (det. G. A. Thomas)
  - *Martiniopsid*
  - *Chonetid*
- Pelecypods:
  - *?Astartila* sp.
  - *Undulomya* sp.
  - *Pseudomyalina* sp.
  - *Atomodesma* sp.
  - pectinid
- Gastropods:
  - Trochoid
- Nautiloids:
  - Coiled nautiloid

T. Quinlan found another marine fossil locality probably in the same bed as GW 129 but 2 miles south-east of there.

D. Moore found fenestellid bryozoa, *Neospirifer, Cleiothyridina,* an orthotetid, and a small pelecypod at a locality 9½ miles south-east of Dairy Creek homestead.

Age.—As the fossils have not been determined as species no comparison can be drawn with other assemblages. The general appearance of the assemblage and the lithology are very like those from the top of the Billidee Formation at

Moogooree. In any case the assemblage is certainly Permian and probably Artinskian: this is supported by its position above the Callytharra Formation and the absence of forms of Kungurian or younger aspect.

Correlation.—As indicated above there is probably a faunal (and lithological) correlation between the top of the Congo Formation and the top of the Billidee Formation of the Merlinleigh Basin. The Congo Formation, by similarities in lithology and sequence, may be correlated with the One Gum and Keogh Formations of the Wooramel River area and with the Curbur Formation of the south-eastern Byro Basin. This does not necessarily mean that these units are of precisely the same age.

Structure.—The Congo Formation occurs in the Bush Creek Syncline (Konecki et al., 1958), an asymmetrical syncline with steep east flank and gentle west flank. The west flank includes a terrace that develops into a shallow anticline in places. The junction with the Precambrian schist has been mapped as a fault (Konecki et al., 1958, pl. 2). Although for a short distance north of Bush Creek the contact is nearly vertical, the sediments of the Congo Formation are stratified parallel to the contact and show no evidence of movement relative to the Precambrian. Slump-folds in quartzwacke beds indicate a moderately steep slope during sedimentation. The unconformity, originally strongly sloping, has been tilted, together with the rocks on either side, to its present position. The location of the hinge of this tilting has not be established, although the steep tilt at Bush Creek suggests that it may be nearby, to the east.

Palaeogeography.—The Congo Formation was deposited in a small structural-topographic basin separate from the rest of the Byro Basin and from the Bidgemia Basin. The shoreline probably varied from close to the present margin of outcrop to a short distance to the east. The sloping floor of the basin produced slumping in the newly deposited sediments. Probably the Congo Formation was deposited in the shallow water at the edge of the basin, and finer-grained sediments in the deeper part.

Economic geology.—The Congo Formation has no present or foreseeable economic use.

Problems.—The Congo Formation contains a rich marine fauna in one place. This has yet to be studied: as it is one of the few good assemblages in the Wooramel Group its study is required for comparison with Callytharra and Byro assemblages.

Monument Formation

The Monument Formation (Konecki et al., 1958, p. 34) is the sequence of quartzwacke and quartz sandstone with minor siltstone unconformably overlying the Callytharra Formation and conformably overlain by the Keogh Formation.

The name is taken from Monument Bore (lat. 25° 35′ S., long. 115° 55¾′ E.) on Coordewandy station 3 miles west-north-west of the homestead. The bore is in the Monument Formation. The type section (Fig. 86) was measured along the right bank of Daurie Creek from 2 to 3 miles downstream from Coordewandy homestead (Fig. 85); it is revised to include an additional 50 feet of coarse-grained to fine-grained quartzwacke and siltstone that certainly is not part of the Keogh Formation. The ripple-laminated interbedded fine-grained quartzwacke and siltstone of the Keogh Formation overlies this sequence. The Monument Formation as thus revised is 450 feet thick in the type locality. This revision agrees with the formation boundary as mapped: the boundary separates dominantly coarse-grained quartzwacke below from dominantly fine-grained quartzwacke above.

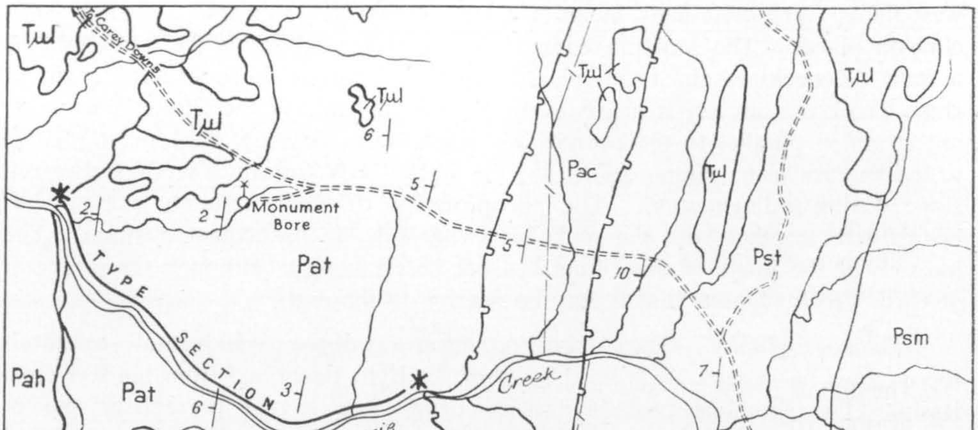


Fig. 85. Type locality, Monument Formation. Tul-Laterite ; Pah-Keogh Formation ; Pat-Monument Formation ; Pac-Callytharra Formation ; Pst-Thambrong Formation ; Psm-Mundarie Siltstone.

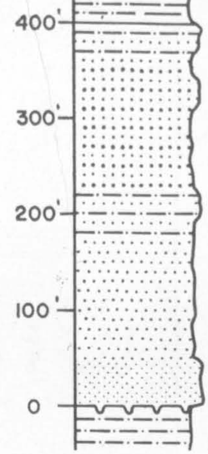


Fig. 86. Type section, Monument Formation.

The base of the Monument Formation is placed at the sharp change in lithology from fossiliferous calcareous sediments of the Callytharra Formation to quartzwacke. Outside the type locality the underlying rock may be sediments of the Callytharra Formation or Lyons Group, or Precambrian schist and gneiss. The top is placed at the change from dominant medium-grained to coarse-grained quartzwacke with laminae and thin members of siltstone to interbedded fine-grained quartzwacke and siltstone of the Keogh Formation.

The lithology is described by Konecki et al. (1958, p. 35). At the north end of the Monument Syncline the upper part of the Monument Formation contains scattered pebbles of white quartz to 2 inches in diameter and a few quartz and quartzite boulders to 1 foot in diameter. The distribution of outcrop is shown in Figure 87.

In addition to the thicknesses previously determined (Konecki et al., 1958, p. 35) the Monument Formation was found to be 435 feet thick (390 feet to 825 feet) in BMR 9 Daurie Creek (Fig. 88), and to be overlain by the Madeline Formation. In the Wooramel River $\frac{3}{4}$ to $1\frac{1}{2}$ miles downstream from the mouth of the Bilung Creek, the Monument Formation is about 270 feet thick; it rests unconformably on Callytharra Formation and is overlain conformably by Keogh Formation.

The Monument Formation probably has a wider subsurface extent than any of the other formations of the Wooramel Group: it is shown to continue into the synclinal areas (in BMR 9 and probably in Bogadi Bore) and therefore probably forms the lower part of the Wooramel Group over a large part of the basins down-dip from outcrop.

Fossils.—The only fossils found in the Monument Formation are plant stems 8 miles north and 6 miles north-west of Coordewandy homestead.

Age.—As the Monument Formation is in sequence between the fossiliferous Artinskian Callytharra Formation and Madeline Formation, it is Artinskian in age.

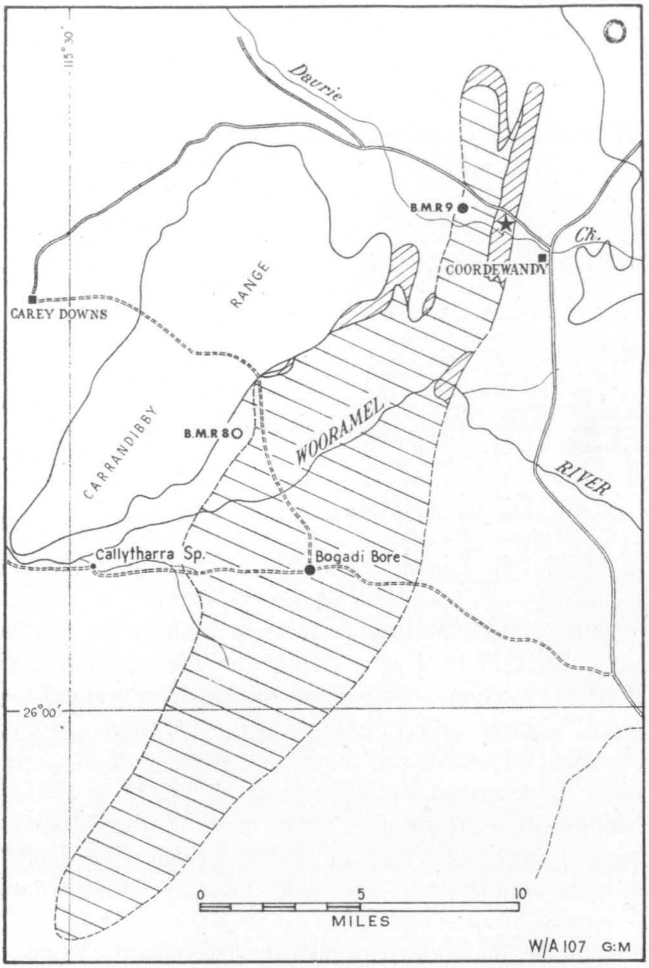


Fig. 87. Outcrop (fine hatching) and subsurface distribution of Monument Formation.

Correlation.—The Monument Formation was regarded by Konecki et al. (1958) as a lateral variant of the Nunnery Sandstone and One Gum Formation, of part of the Congo Formation, and of the Moogooloo Sandstone.

Comparison between the revised type section and the composite log of bore BMR 9 (Mercer, 1959) and between BMR 9 and BMR 8 confirms the lateral equivalence of the Monument Formation and the Nunnery Sandstone and One Gum Formation. The lower parts of the Congo Formation and Curbur Formation are likely to be lateral variants of the coarser upper part of the Monument Formation. The Moogooloo Sandstone is probably equivalent to the lower medium-grained part of the Monument Formation; the upper coarse-grained part of the Monument Formation is probably equivalent to the lower part of the Billidee Formation—both sequences include coarse-grained quartzwacke and siltstone members.

Structure.—The Monument Formation crops out along the north-eastern flank of the Bogadi Syncline, along the east flank and northern plunge of the Monument and Daurie Synclines and along both flanks and northern plunge of the Plant Well Syncline. Bore BMR 9 indicates that the Monument Formation continues without significant variation across the synclines.

At the north end of the Monument Syncline and in the small syncline 7 miles south of west of Coordewandy homestead small slump-folds were reported by J. M. Dickins. Both occurrences are near the centre of a syncline and suggest that there was some slope on the floor of deposition of the Monument Formation, in places.

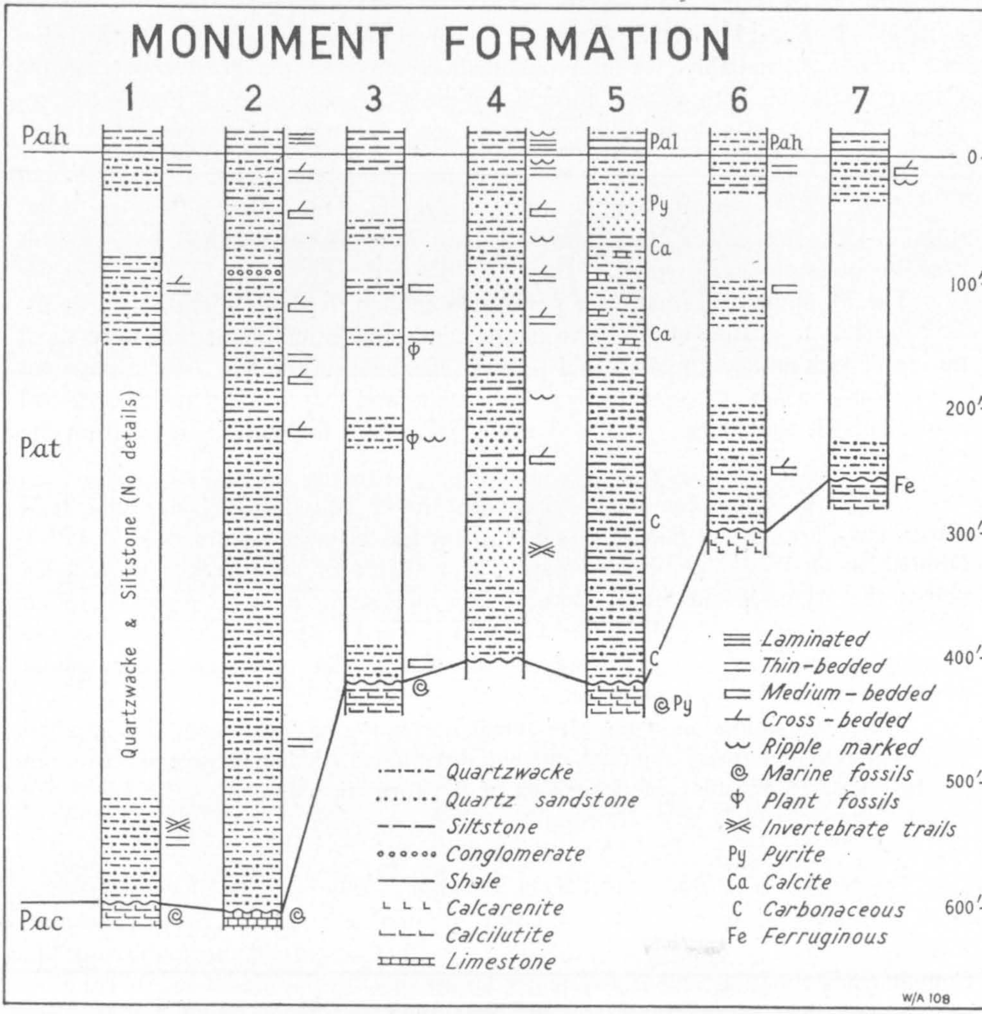


Fig. 88. Stratigraphic columns, Monument Formation. Pal-Madeline Formation ; Pah-Keogh Formation ; Pat-Monument Formation ; Pac-Callytharra Formation. Location of columns : 1 and 2-north end of Daurie Syncline ; 3-east flank Daurie Syncline, 4-Type section Daurie Creek, 5-BMR 9, 6-Monument Syncline east flank, 7-Wooramel River.

Cross-lamination in sets up to 7 feet thick (commonly less than 2 feet) is characteristic of the Monument Formation. The foresets mainly face down-dip, but some face up-dip, suggesting that the floor of deposition had very little slope in most places. Ripple marking occurs in the middle and upper parts of the formation.

Palaeogeography.—The Monument Formation was deposited in a shallow sea on a floor that was generally flat but with some slopes into the present synclinal areas. The sediment was moved into its place of deposition mainly by currents, but was very little reworked: the depth of water remained constant during deposition by gradual subsidence of the basin or gradual rise of sea level.

The present outcrop area was outside the area of strong wave action and therefore the shoreline probably was at least several miles away from the present outcrop. It seems likely that there was no direct connexion with the Perth Basin, but there was probably a continuous shallow sea over the greater part of the Carnarvon Basin, with islands formed by the Carrandibby inlier and Weedarra inlier. This sea was probably open to the north but not to the west.

Economic Geology.—Underground water is obtained from the Monument Formation in Monument Bore, Coordewandy, and Dilba Bore, Pindilya Bore, Bogadi Bore, Breakaway Bore, and Wandarie Bore, Byro station. The water is brackish but suitable for stock.

The Monument Formation is permeable enough to allow migration of fluids; as it is likely to change into a clean quartz sandstone in any areas that were shoal during deposition such areas would provide adequate reservoirs. The Monument Formation overlies the Callytharra Formation and its finer-grained sourcebed equivalents; it should have provided a migration path for hydrocarbons from the Callytharra equivalent.

Problems.—The Monument Formation (or its equivalent) does not extend across the Carrandibby Ridge. Its equivalent has been encountered in WAPET Giralia No. 1 Well, but no information is available on its presence or absence across the Ajana-Wandagee Ridge. If it is present it must be regarded as an excellent target for oil exploration; if absent it will be necessary to determine its distribution on either side of the ridge—this may provide beach-sand or erosional pinch-out targets for oil exploration.

The cross-lamination of the Monument Formation in outcrop could be studied statistically to determine regional current directions: this may give information on the shape of coastline of deposition of the formation.

Nunnery Sandstone

The Nunnery Sandstone (Konecki, Condon, Dickins, & Quinlan in McWhae et al., 1958, p. 72) is the formation, consisting predominantly of quartz sandstone with minor conglomerate and siltstone beds, that rests unconformably on the Callytharra Formation and is overlain conformably by the One Gum Formation or the equivalent of the Jimba Jimba Calcarenite.

The name is taken from Nunnery Pool, Wooramel River (lat. 25° 51′ S., long. 115° 32½′ E.), which is within the outcrop area of the formation.

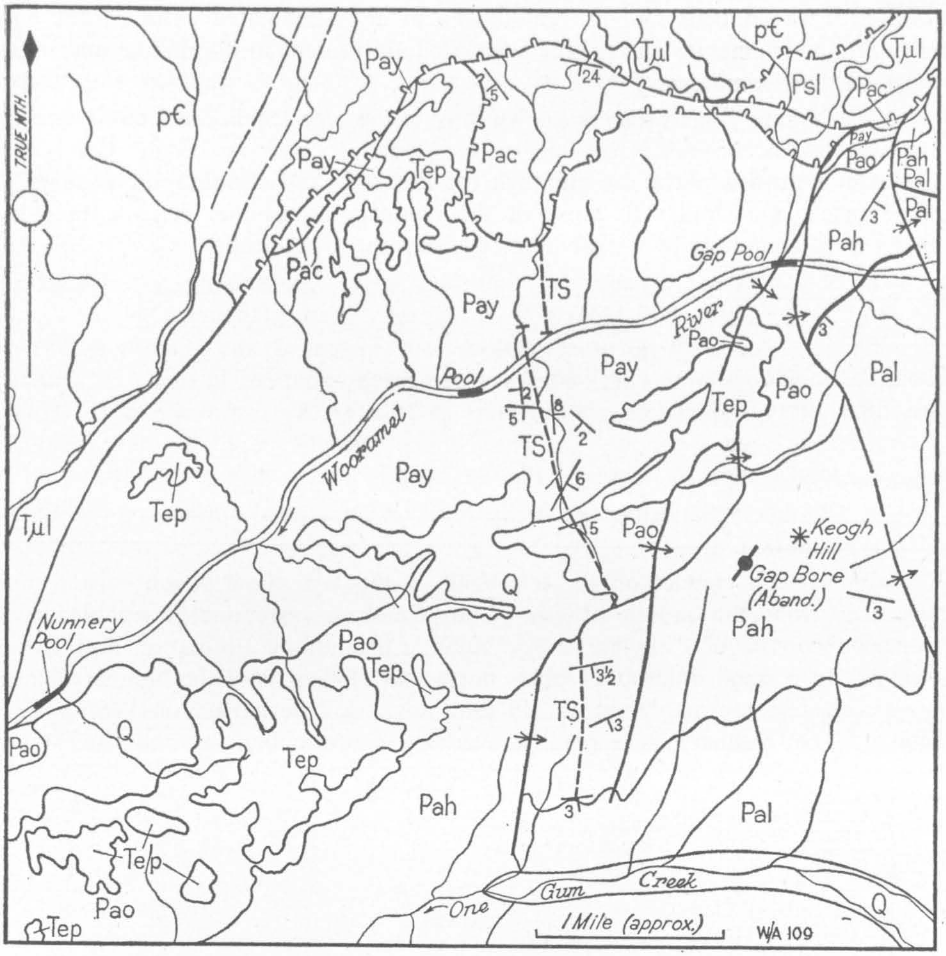


Fig. 89. Type locality, Wooramel Group. Nunnery Sandstone (Pay), One Gum Formation (Pao) and Keogh Formation (Pah). Q-Quaternary deposits ; Tul-Laterite ; Tep-Pindilya Formation ; Pal-Madeline Formation ; Pac-Callytharra Formation ; pC-Precambrian metamorphics ; T.S.—Type section.

The type locality (Fig. 89) is 2 miles upstream from Nunnery Pool. The type section (Fig. 90) was measured along a small northern tributary and a small southern tributary of the Wooramel River. There is no outcrop in the river bed, but the river runs obliquely to the strike and therefore a complete sequence can be examined.

The lithology of the Nunnery Sandstone is very uniform, but there are some minor variations. Predominantly the rock is white, cream, or yellow friable to medium-hard medium-grained quartz sandstone consisting of 80 to 90 percent quartz grains (even-grained within each lamina, equant, subround to subangular), 10 to 20 percent silt (mainly quartz with more or less kaolin), partly disseminated (intergranular) and partly in silt balls 0.5 to 2.00 mm in diameter, with or without small amounts of feldspar, mica, chert, and quartzite. Siltstone is present as thin partings between beds and as bottom-sets to cross-laminated beds. Thin beds of quartz conglomerate and pebbly sandstone are present in the middle and upper parts of the formation.

The Nunnery Sandstone is known only in the type locality and close vicinity. Its reported occurrence (Konecki et al., 1958, p. 31) at Bilung Creek and Coolyun Well is doubtful as, although the lithology and stratigraphic position at these places are similar to those of the Nunnery Sandstone, there is no good evidence of continuity of similar lithology from the type locality.

The Nunnery Sandstone is 545 feet thick in the type section (Fig. 91, section 3) and 580 feet thick (530-1110 feet) in BMR 8, Mount Madeline (Mercer, 1959) (section 4). Although no other sections were measured, the outcrop pattern in the Gap Pool/One Gum Creek area suggests large variations in thickness (mainly less than the type thickness); a thickness of 300 feet was estimated in the Callytharra Spring area (section 2). The Nunnery Sandstone lenses out about 2½ miles west of Callytharra Spring (Fig. 91, section 1).

The Nunnery Sandstone generally rests on an eroded surface of the Callytharra Formation.

On a steep contact on the left bank of the Wooramel River ½ to 1 mile upstream from the mouth of One Gum Creek it rests unconformably on a truncated surface of Callytharra Formation, Carrandibby Formation and Lyons Group. In a small outcrop 2½ miles north-east of Gap Pool the Nunnery Sandstone rests unconformably on an old terra rossa soil developed on Precambrian schist. The Nunnery is generally overlain, conformably, by the One Gum

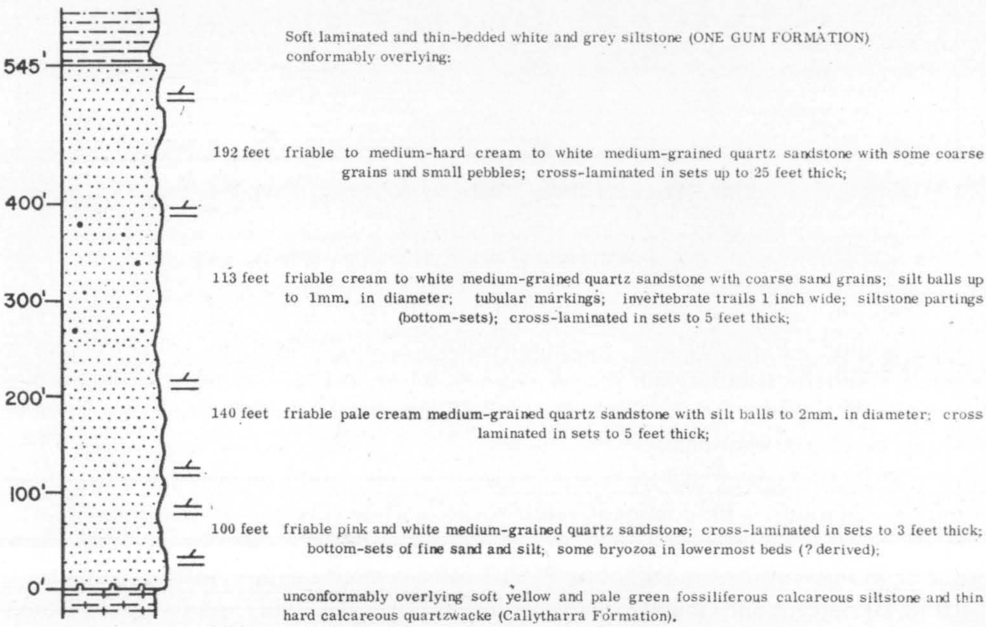


Fig. 90. Type section, Nunnery Sandstone.

Formation. In places, the basal siltstone of the One Gum and the uppermost beds of the Nunnery are slumped together in a coarse slump breccia. Immediately north of Gap Pool the Nunnery is in contact with the Keogh Formation at a steep monocline. In BMR 8 Mount Madeline, the Nunnery Formation is overlain by a fossiliferous calcarenite formation, equivalent to the Jimba Jimba Calcarenite. No fossils have been found in the Nunnery Sandstone apart from fragmental bryozoa in the basal beds, almost certainly derived from the Callytharra Formation, and invertebrate trails and burrows.

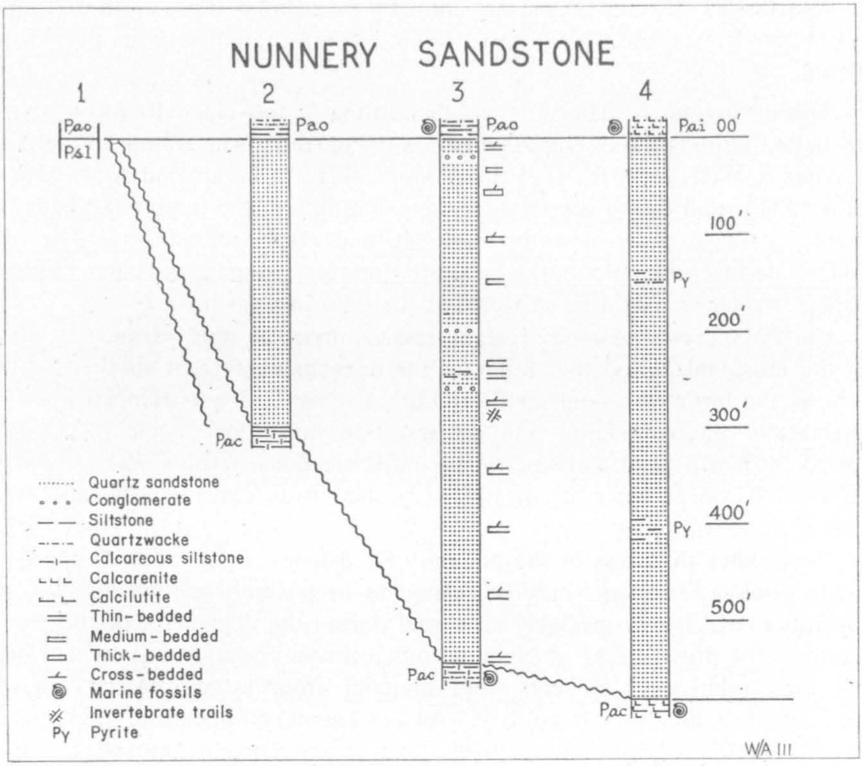


Fig. 91. Stratigraphic columns, Nunnery Sandstone. Pao-One Gum Formation ; Pai-Jimba Jimba Calcarenite ; Pac-Callytharra Formation ; Psl-Lyons Group.

Because of its position between the Artinskian Callytharra and Madeline Formations, the Nunnery Sandstone is Artinskian in age.

Correlation.—The Nunnery Sandstone is the lithological and stratigraphical equivalent of the Moogooloo Sandstone of the Merlinleigh and Bidgemia Basins. Konecki et al. (1958, p. 31) and J. R. H. McWhae (pers. comm., 1957) considered the Nunnery Sandstone equivalent to only the lower part of the Moogooloo, but the equivalence of the two formations is established by the Jimba Jimba Calcarenite, which overlies the Moogooloo Sandstone, and its equivalent in BMR 8, which overlies the Nunnery Sandstone. The Nunnery Sandstone is a lateral variant of the lower part of the Monument Formation.

The Nunnery Sandstone is of similar lithology and approximately similar stratigraphical position to the High Cliff Sandstone (Clarke et al., 1951) of the Irwin Basin and the upper part of the Poole Sandstone (Guppy et al., 1958) of the Fitzroy Basin.

Structure.—The Nunnery Sandstone in its outcrop area is part of a homocline dipping south, off the southern end of the Precambrian inlier of the Carrandibby Range. The homocline is interrupted by several east-dipping steep monoclines that are developed on the projection of steeply dipping unconformities. North-east of Gap Pool the Nunnery Sandstone dips south-east off the Carrandibby Range and forms part of the subsurface sequence in the Madeline Anticline.

Palaeogeography.—The Nunnery Sandstone is too clean to form part of a river delta, although the cross-lamination is of the form found in delta-lobes (McWhae & Weir, 1952). It is much more likely to be an undaform-edge sand (Rich, 1951), and this is supported by the slumping of the uppermost beds which probably grade laterally downdip into siltstone of the clinoform. The almost complete absence of ripple marks in a fairly mature sediment indicates moderately deep water such as would be expected at the edge of a shelf.

The Nunnery Sandstone is transgressive, marking the advance of the sea after the erosional period that followed the deposition of the Callytharra Formation. As the terra rossa soil on Precambrian schist was not stripped during this transgression, the subsidence and transgression must have been very fast, but followed by a period of stability, when the terrigenous detritus was abraded and winnowed by waves and currents and deposited from currents near the edge of the shelf.

The greater thickness of the Nunnery Sandstone, compared with the equivalent Moogooloo Sandstone, may be related to its position relative to the Carrandibby Inlier, which was probably an island during the deposition of the Nunnery Sandstone: the present area of Nunnery outcrop was probably a protected depositional area relative to currents, and material from more exposed areas was moved into this area and deposited. As the Nunnery appears to thin markedly west of Callytharra Spring it is likely that strong currents moved around the south end of the Carrandibby Island from the west perhaps through a strait in the area of the Wooramel Sill (Fig. 35).

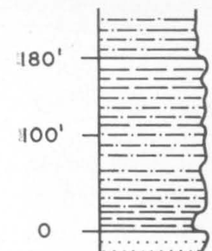
Economic Geology.—The Nunnery Sandstone at its outcrop is a useful freshwater reservoir that keeps several semipermanent pools in the Wooramel River (Nunnery, Gap, and another unnamed) and Callytharra Spring supplied with groundwater. These are used as watering points for cattle on Byro station. This water could be developed by bores into the Nunnery Sandstone. Gap Bore was abandoned because the water was too saline for stock: if the bore (123 feet deep) had been taken a little deeper (perhaps to 250 feet) into the Nunnery Sandstone a good supply of good water would almost certainly have been obtained.

Although the Nunnery Sandstone has adequate porosity-permeability for an oil reservoir there are few places where it has adequate cover; one of these is the Madeline Anticline, but bore BMR 8 gave no indication of hydrocarbon in the Nunnery Sandstone there. It is possible, however, that the bore is outside the area of closure of the structure; no seepage has been reported on the Madeline Unconformity at the spill point of the closure, but it was not examined carefully and not at all with seepage particularly in mind.

Problems.—The subsurface extent of the Nunnery Sandstone and the nature of its immediate lateral variants in the central part of the Bogadi Syncline are not known; drilling would be required to establish these. Drilling would have an immediate use in establishing waterbores for use of cattle; as a start Gap Bore might repay deepening to about 250 feet (after casing or cementing off the saline water). The presence or absence of hydrocarbons has not been determined. The provenance of the sandstone has not been determined: if it derived from Carrandibby Range its heavy mineral assemblage should be close to that in the present watercourse sands. A statistical study of the foreset directions should indicate the direction(s) of the depositing current(s) and help to indicate the provenance and to suggest areas of extension of the Formation.

One Gum Formation

The One Gum Formation (Konecki, Condon, Dickins, & Quinlan, in McWhae et al., 1958, p. 73) consists of quartzwacke, quartz sandstone, and siltstone, with minor pebble conglomerate or pebbly quartzwacke beds, resting conformably on the Nunnery Sandstone and overlain conformably by the Keogh Formation.



	Firm to medium-hard ripple-laminated fine-grained quartzwacke and siltstone (KEOGH FORMATION)
	conformably overlying:
10 feet	hard bedded ferruginous uneven-grained quartzwacke;
15 feet	soft thin-bedded siltstone and fine-grained ripple marked quartzwacke;
40 feet	friable uneven-grained quartzwacke, strongly cross-laminated with siltstone bottom-sets; pebble conglomerate at base;
5 feet	soft laminated siltstone;
68 feet	friable white and cream medium-grained to very coarse-grained quartzwacke, strongly cross-bedded;
22 feet	friable medium-grained quartz sandstone and quartzwacke;
18 feet	soft dark laminated and thin-bedded siltstone with fossils;
	conformably overlying hard ferruginous medium-grained quartz sandstone (NUNNERY SANDSTONE).
180 feet	- thickness of One Gum Formation in type section.

Fig. 92. Type section, One Gum Formation.

The type section (Fig. 92) continues southward from that of the Nunnery Sandstone (Fig. 89); the south-south-easterly dip is fairly constant—5° at the base to 3° at the top.

The One Gum Formation is characterized by members of quartzwacke, quartz sandstone, and carbonaceous siltstone. The quartzwacke is commonly coarse-grained, with quartz and quartzite pebbles, and the quartz sandstone is mainly medium-grained; both are thin-bedded, cross-bedded, and in places ripple-marked. The base of the formation is marked by a siltstone member and its top by a change from bedded coarser sandstone to laminated fine-grained quartzwacke and siltstone. In bore BMR 8 some coaly shale beds are present in the place of siltstone members of the outcrop sequence (Mercer, 1959).

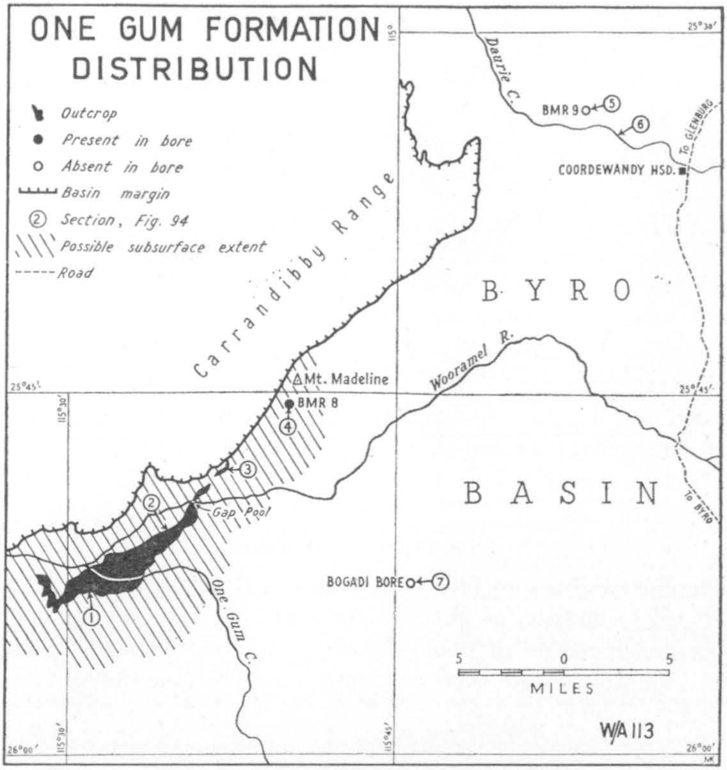


Fig. 93. Distribution of One Gum Formation.

Distribution (Fig. 93), Thickness (Fig. 94) and Relationships.—The One Gum Formation crops out mainly in the area south of the Carrandibby Range; the thickness is 285 feet immediately south of Callytharra Spring, 180 feet in the type section, and about 250 feet 2 miles north-east of Gap Pool, Wooramel River. The One Gum Formation rests unconformably on Lyons Group 2½ miles west of Callytharra Spring, but from 2 miles west of the Spring to Gap Pool it is conformable between Nunnery Sandstone and Keogh Formation. In BMR 8 a calcarenite formation equivalent to the Jimba Jimba Calcarenite underlies the One Gum, which is overlain by the Keogh Formation; the One Gum Formation is 235 feet thick (235 feet to 470 feet depth). Between Mount Madeline and Daurie Creek the One Gum Formation is not identified as the equivalent sequence does not contain siltstone members. It is not present in BMR 9, Daurie Creek.

Fossils.—Marine fossils (bryozoa, *Neospirifer,* and streptorhynchid) are found in the basal siltstone in the type section, and these and crinoid stems, *Cleiothyridina, Strophalosia, Aulosteges,* and pectinids are found in the basal siltstone elsewhere. Plant fossils (wood and *Glossopteris* leaves) are found south of Callytharra Spring in the upper siltstone members.

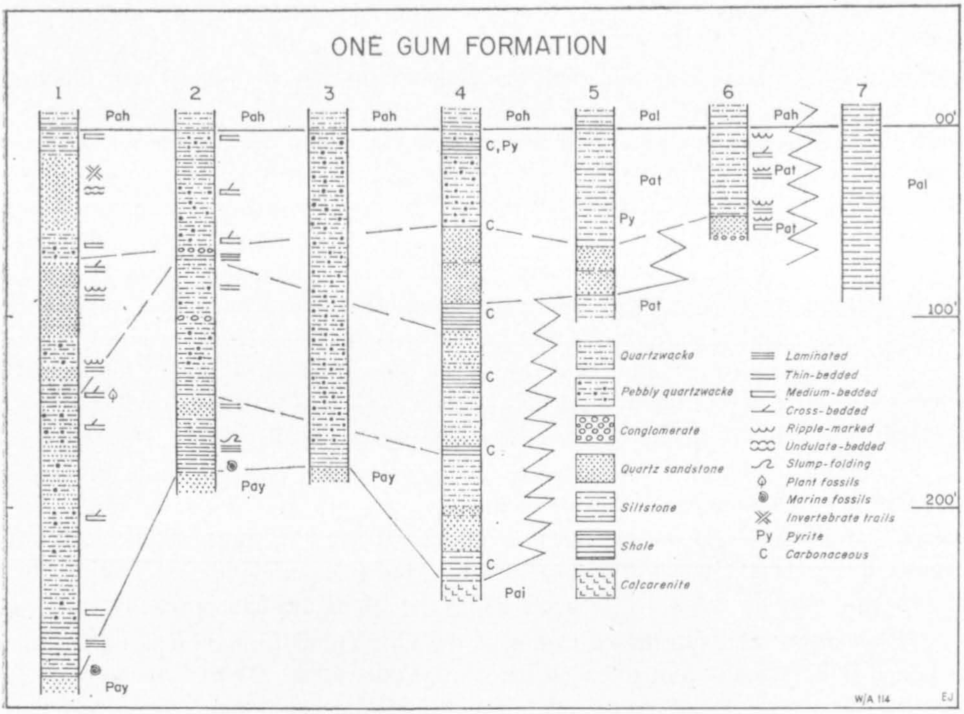


Fig. 94. Stratigraphic columns, One Gum Formation. Pah-Keogh Formation ; Pal-Madeline Formation ; Pat-Monument Formation ; Pai-Jimba Jimba Calcarenite ; Pay-Nunnery Sandstone. Location of columns shown in Fig. 93.

Age.—The fossils are insufficient to establish the age of the formation, but its position between the Callytharra and Madeline Formations fixes its age as Artinskian.

Correlation.—The One Gum Formation is correlated with the lower part of the Billidee Formation by reason of their overlying the Jimba Jimba Calcarenite and its equivalents. It is a lateral variant of the upper part of the Monument Formation and a part, probably the lower part, of the Congo and Curbur Formations. The One Gum Formation apparently passes laterally into the Madeline Formation in the central part of the Byro Basin, as the Bogadi Bore passed through about 1050 feet of shale before reaching sandstone probably of the Monument Formation. The presence of coaly shale in BMR 8 suggests a correlation with Irwin River Coal Measures.

Structure.—The southern outcrop forms a south-dipping homocline with several north-trending steep monoclines crossing it. At Mount Madeline the One Gum Formation is probably included in the Madeline anticline. In the Daurie Creek area it forms an asymmetrical syncline with steep west flank.

In several places, the best exposed at Callytharra Spring, the basal siltstone bed of the One Gum Formation is contorted and brecciated by slumping.

Palaeogeography.—The repeated succession of siltstone, quartzwacke, and quartz sandstone in the One Gum Formation is strongly suggestive of cyclothems and of the fluctuating sea level that accompanies the development of cyclothems (Wanless & Weller, 1932; Wanless & Shepard, 1936; Wanless, 1950; Wheeler & Murray, 1957). As in the United States these One Gum cyclothems are associated with coaly beds (in BMR 8) and with marine beds including limestones (Jimba Jimba equivalent in BMR 8): the environment ranged, at one place, from terrestrial to moderately deep marine several times. The local shoreline changed from basinward of the present outcrop to high on the Carrandibby Range island; or that island may have been submerged, when the nearest shoreline would be far to the east, well beyond the present eastern margin of the Byro Basin.

The One Gum Formation was apparently deposited on a sloping floor that caused slumping of the basal siltstone. The central area of the Byro Basin was a marine basin in which fine-grained sediments were deposited.

Economic Geology.—The association of marine and coaly shales with sandstone provides source beds for petroleum and dry gas and adequate migration and reservoir beds. However, the only structural traps in the probable area of extent of the One Gum Formation are the Madeline anticline and the monoclines; stratigraphic traps are possible along the Madeline Unconformity.

Problems.—The subsurface extent of the One Gum Formation is unknown, although it is indicated not to reach the central part of the Basin. It is possible that the coaly shale members may develop into coal seams in some areas, perhaps the Bush Creek syncline, Minthalla syncline, and the western arm of the Byro Basin between the Wooramel River and Woodleigh station. The fauna and flora have not been adequately collected or studied; they may provide a useful correlation between faunal and floral (including spore) assemblages.

Keogh Formation

The Keogh Formation (Konecki, Condon, Dickins, & Quinlan *in* McWhae et al., 1958, p.73) consists mainly of interlaminated fine-grained quartzwacke and siltstone with few beds of coarse-grained greywacke some of which are calcareous. In the type locality it is conformable between the Madeline Formation above and the One Gum Formation below. Elsewhere it rests conformably on the Monument Formation or unconformably on Precambrian schist and Lyons Group or grades laterally into Madeline Formation.

Soft dark grey laminated micaceous carbonaceous siltstone and laminated to thin-bedded fine-grained quartzwacke (Madeline Formation)
? conformably overlying:
16 feet friable and hard medium- and coarse-grained quartzwacke;
62 feet dark laminated siltstone and firm laminated fine-grained quartzwacke, ripple-marked in parts;
67 feet firm to medium-hard ripple-laminated fine-grained quartzwacke and dark laminated siltstone;
? conformably overlying thick-bedded hard ferruginous medium- to very coarse-grained quartzwacke (One Gum Formation).
145 feet - thickness of Keogh Formation in type section.

Fig. 95. Type section, Keogh Formation.

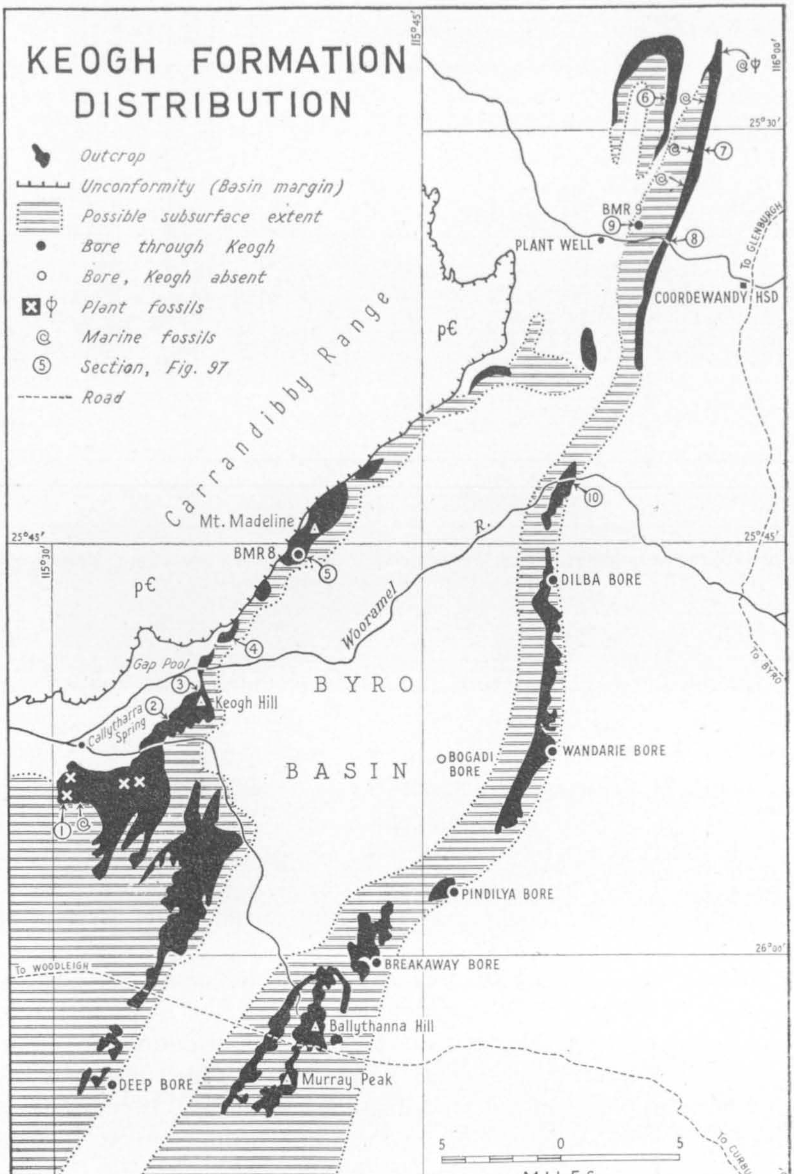


Fig. 96. Distribution of Keogh Formation.

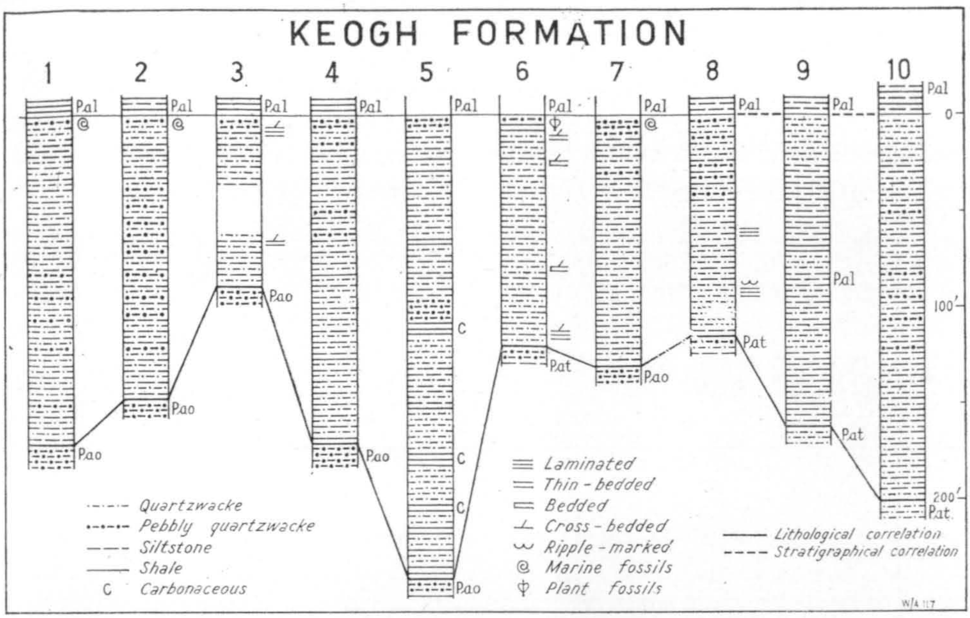


Fig. 97. Stratigraphic columns, Keogh Formation. Pal-Madeline Formation ; Pao-One Gum Formation ; Pat-Monument Formation.

The type section (Fig. 95) runs southward from near the end of the One Gum type section. The dip is fairly uniform (3° to 2° south). The type locality is shown in Figure 89.

The Keogh Formation is characterized by the interlamination of fine-grained quartzwacke and siltstone. The lamination is commonly ripple-lamination. There are a few thin beds of coarse quartzwacke usually ferruginous at outcrop and probably calcareous where not weathered. It is transitional between the dominantly arenaceous Wooramel Group and the dominantly silty Byro Group.

Distribution (Fig. 96), Thickness (Fig. 97), and Relationships.—The Keogh Formation is more widespread in outcrop than any of the other formations of the Wooramel Group in the Byro Basin. Its westernmost outcrop is one to two miles south of Callytharra Spring, where it is about 170 feet thick and has less siltstone and more medium-grained sandstone than typically. It crops out southward to Deep Bore but, as the underlying formation is not exposed, its thickness is not known; to the north-east, past the type locality and Keogh Hill the complete formation is exposed: it is 90 feet thick at Keogh Hill. Two miles north-east of Gap Pool, Wooramel River, the Keogh Formation is 170 feet thick. It is enclosed in the Mount Madeline anticline: bore BMR 8 was spudded in the Keogh Formation about 5 feet below its top and remained in it to 235 feet, giving a thickness of 240 feet for the Keogh at that place. In the bore the Keogh includes 8 feet of coal shale at 100 feet depth. South-west and north-east of the Madeline Anticline there are several outcrops of part of the Keogh Formation against the Madeline Unconformity. Ten miles north-east of Mount Madeline the Keogh Formation is 100 feet thick. In the Daurie Syncline the Keogh is 120 feet thick; in both of these areas it is conformable between Monument and Madeline Formations.

At the north end of the Monument Syncline the Keogh Formation is 130 feet thick, and at Daurie Creek it is 112 feet thick, between Monument and Madeline Formations. It is present in BMR 9 between 230 and 390 feet, but is somewhat more fine-grained than typical. Between Daurie Creek and Wooramel River its outcrop is masked by laterite. At the river the Keogh Formation, between Monument and Madeline Formations, is about 200 feet thick. The base of the Keogh is not exposed south of this area, but the upper part crops out in and near the scarp from the Wooramel River southward to Pindilya Bore and then south-west past Murray Peak.

Fossils.—The Keogh Formation contains a few marine and plant fossils. The marine fossils are found mainly in the topmost bed of coarse quartzwacke: Bryozoa, *Chonetes, Neospirifer, Conularia,* pectinids, *Astartila, Atomodesma, Undulomya,* and gastropods have been reported. The plant fossils, which are found low in the sequence, include *Glossopteris* and stem impressions.

Age.—The fossil species have not been determined, but the assemblage is like that of the Madeline Formation. The age of the Keogh Formation is established as Artinskian by its position between the Callytharra and Madeline Formations.

Correlation.—The Keogh Formation is correlated with the upper part of the Billidee Formation and with the upper part of the Congo Formation; like them it has a coarse-grained quartzwacke bed at the top with marine fossils. The uppermost beds of the Curbur Formation are not known to contain fossils but are almost certainly equivalent to the Keogh Formation. In the deeper parts of the Byro Basin the Keogh Formation is absent, having graded laterally into shale and siltstone of the Madeline Formation. As it contains coaly shale beds in BMR 8, and has a similar stratigraphical position relative to marker formations, the Keogh probably may be correlated with the Irwin River Coal Measures.

Structure.—The Keogh Formation at outcrop is mainly homoclinal on the flanks of the Bogadi Syncline, and on the east flank of the Daurie and Monument Synclines. It is synclinal at the north end of the Daurie and Monument Synclines and in the south part of the Plant Well Syncline. In the area south of One Gum Creek the outcrop is interrupted by several monoclines which form part of the steep flanks of small north-plunging anticlines. The Madeline Anticline is expressed in outcropping Keogh Formation; at each end the anticline abuts against the Madeline Unconformity. On the east flank of the Bogadi Syncline south of Wooramel River the outcrop of the Keogh Formation is interrupted by small faults. North of Murray Peak the Keogh Formation is folded into the Ballythanna Hill Anticline, which plunges north.

Palaeogeography.—The Keogh Formation was laid down in a paralic environment; shallow-water marine and lagoonal. Much less terrigenous material was supplied than to the One Gum Formation. The shoreline probably was close to the present outcrop area, mainly basinward but occasionally towards the basin margin. The reduction of sand content basinwards suggests that a basin, probably marine, was present during its deposition. It seems likely that littoral deposits of coarse quartz sandstone may have developed basinwards from the present outcrop with the marine shale beyond; such deposits may be exposed in the anticlines south of One Gum Creek, where medium-grained quartz sandstone, conglomerate, and calcarenite are reported in the upper part of the Keogh Formation (J. M. Dickins, field book).

Economic Geology.—As the Keogh Formation grades laterally into marine shale of the Madeline Formation and was probably updip from that equivalent during or shortly after deposition it was favourably placed to receive petroleum from the shale. The suggested littoral sands would be adequate traps for migrating petroleum, especially as they were capped by the Madeline Formation, and as migration out of them would be reduced by the porosity barrier between these littoral sands and the finer-grained lagoonal Keogh Formation. No definite locality where such littoral sands are indicated to be present with adequate cover is known, but some of the structural undulations in the Madeline Formation on the west side of the Bogadi Syncline (e.g. the northward extension of the Ballythanna Hill Anticline, at the Wooramel River upstream from Gap Pool, and 1½ miles east of Mount Madeline) may have formed over such sand banks.

There seems little likelihood that usable coal seams are developed in the Keogh Formation: the only area where there is any possibility is under the sandplain south of Callytharra Spring.

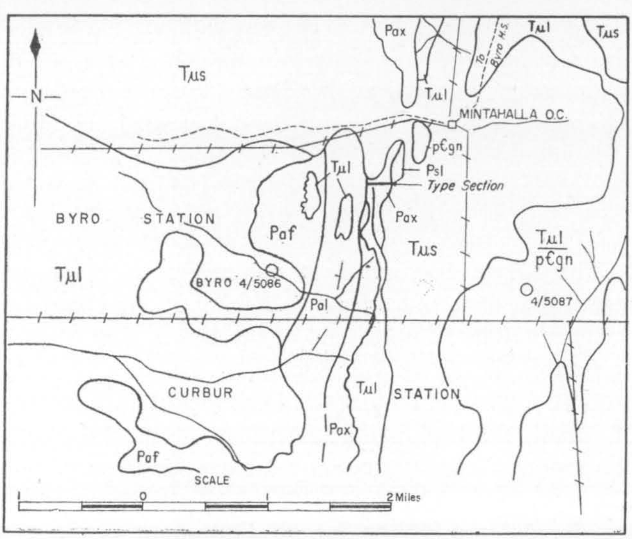


Fig. 98. Type locality, Curbur Formation. Tus-lateritic soil ; Tul-laterite ; Paf-Bogadi Greywacke ; Pal-Madeline Formation ; Pax-Curbur Formation ; Psl-Lyons Group ; pC-Precambrian gneiss.

Problems.—Additional collections of fossils are required to establish whether there are any faunal distinctions between the Keogh and adjoining formations. Comparison of faunal and floral (including spore) assemblages may help to give stratigraphic precision to the floral sequence. The subsurface extent of the Keogh Formation and the location of littoral sands equivalent to the Keogh require subsurface investigations.

Curbur Formation

The Curbur Formation (Konecki, Dickins, & Quinlan 1958, p.39) consists of interbedded quartzwacke, siltstone, and conglomerate resting unconformably on Lyons Group or Precambrian gneiss and overlain conformably by Madeline Formation equivalent.

The type locality (Fig. 98) is 16½ miles south-west of Byro homestead. The type section (Fig. 99) was measured across the ridge and along a north scarp where exposure is very good. At the unconformity the Curbur Formation dips 62° west; it gradually flattens to 25° west at the top of the formation.

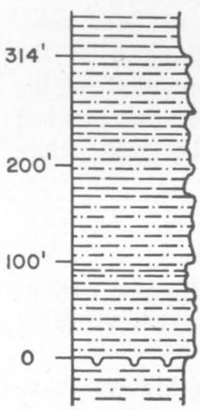


Fig. 99. Type section, Curbur Formation.

The Curbur Formation is characterized by alternations of quartzwacke, pebbly or conglomeratic in the lower part, and siltstone. It is known only in the outcrop belt north and south of the type locality (Fig. 98) and only the type section was measured.

No fossils have been found in the Curbur Formation or in the adjoining formations. About 6 miles north of Mintahalla Bore there is a lateritized outcrop possibly of Callytharra Formation between the Curbur Formation and the Lyons Group. The overlying sequence is similar to that of the Byro Group in the Bogadi Syncline, and therefore the Curbur Formation is identified as part of the Wooramel Group, probably equivalent to the One Gum Formation and Keogh Formation, to the Congo Formation, and to the Billidee Formation.

Structure.—The Curbur Formation crops out on the steep eastern flank of the Mintahalla Syncline (Konecki et al., 1958). The underlying unconformity is very steep (70° to 80° dip westward) and the Curbur Formation meets it at an acute angle (about 10°). Cross-lamination and ripple marking attest the original flatness of the bedding, although slump folding indicates that the floor of deposition had some slope. A short distance east of the unconformity the Lyons Group dips 15° west. The unconformity and the beds in the near vicinity were folded together in a steep monocline probably over a hinge in the gneiss, at the eastern edge of the downwarped area of the Byro Basin.

Problems.—The details of the structure in the gneiss beneath the monocline is not known: it may help to explain the mechanism of such hinges.

The Curbur Formation is likely to contain plant fossils: these would help to confirm the correlation of the formation.

BYRO GROUP

The Byro Group was first named, as 'Byro Limestone Group', by Dee & Rudd (1932, unpublished). Condit (1935, p. 870) used the name 'Byro Formation' for the 'largely calcareous to shaly sandstone' overlying 'the Wooramel Sandstone'. Raggatt (1936) used the name 'Byro Stage' for the sequence north of the Gascoyne River that he regarded as equivalent to the 'Byro Formation' of the Wooramel River area, but used the name for two different sequences: that between the present Moogooloo Sandstone and Coolkilya Greywacke in the Lyons River station area and that between the Moogooloo Sandstone and the Cundlego Formation in the Minilya River area.

The Byro Group crops out from the Lyndon River in the north to Curbur station, south of Wooramel River, in the south (Fig. 100). It has been penetrated in WAPET Giralia No. 1, Learmonth No. 1, and Quail No. 1, and probably in bore BMR 5, Giralia.

The full sequence of the Byro Group is preserved only in the Minilya River and Kennedy Range areas (Fig. 101). In the Minilya River area the Byro Group is about 4650 feet thick, at the north end of Kennedy Range 3925 feet, east of Kennedy Range (in Lyons River station) 2275 feet, and south of Kennedy Range 3120 feet. Only the lower part of the sequence (720 feet thick) is known in the Byro Basin, and the full sequence of the Group has not been penetrated by a bore.*

The sediments of the Byro Group have been deposited in a sea varying in depth between about 100 and about 1000 feet, under conditions of moderately large supply of terrigenous sediment and uneven but fairly rapid subsidence. The seas had restricted circulation, except at the north end of the Gascoyne Basin, which was probably open to the ocean. The basement ridge areas formed shoals or islands and their low parts formed sills into the Merlinleigh and Byro Basins.

* WAPET's Kennedy Range No. 1 Well (1967) penetrated a complete sequence of the Byro Group between 1180 feet and 6168 feet depth (thickness 4988 feet) (WAPET, pers. comm.).

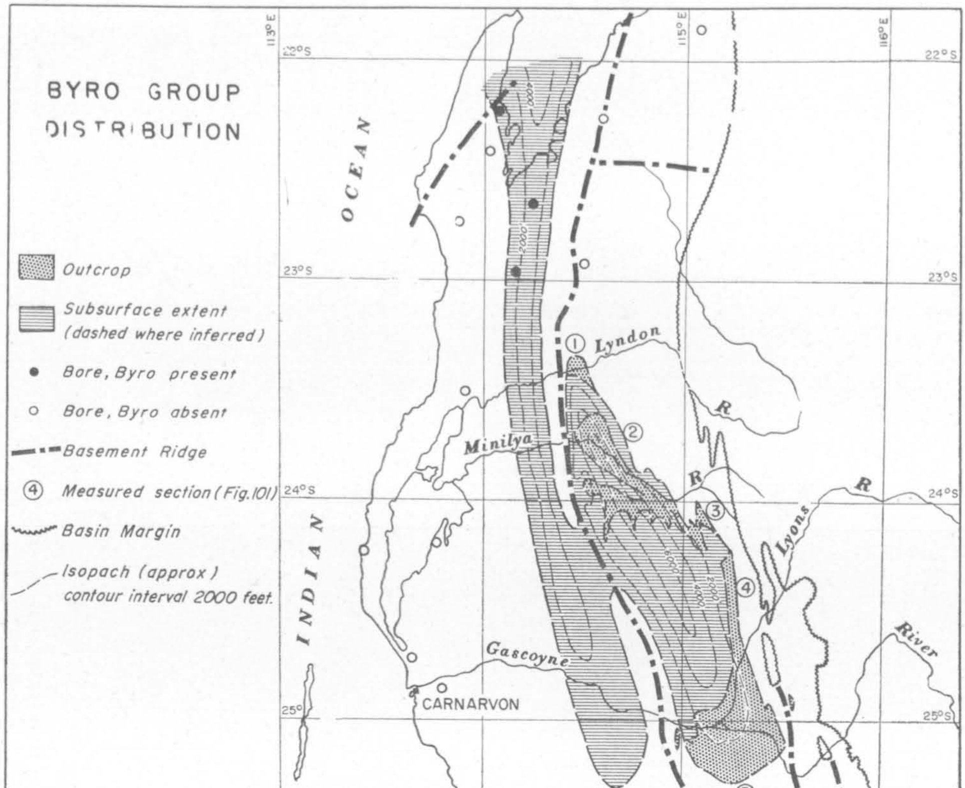


Fig. 100. Distribution of Byro Group.

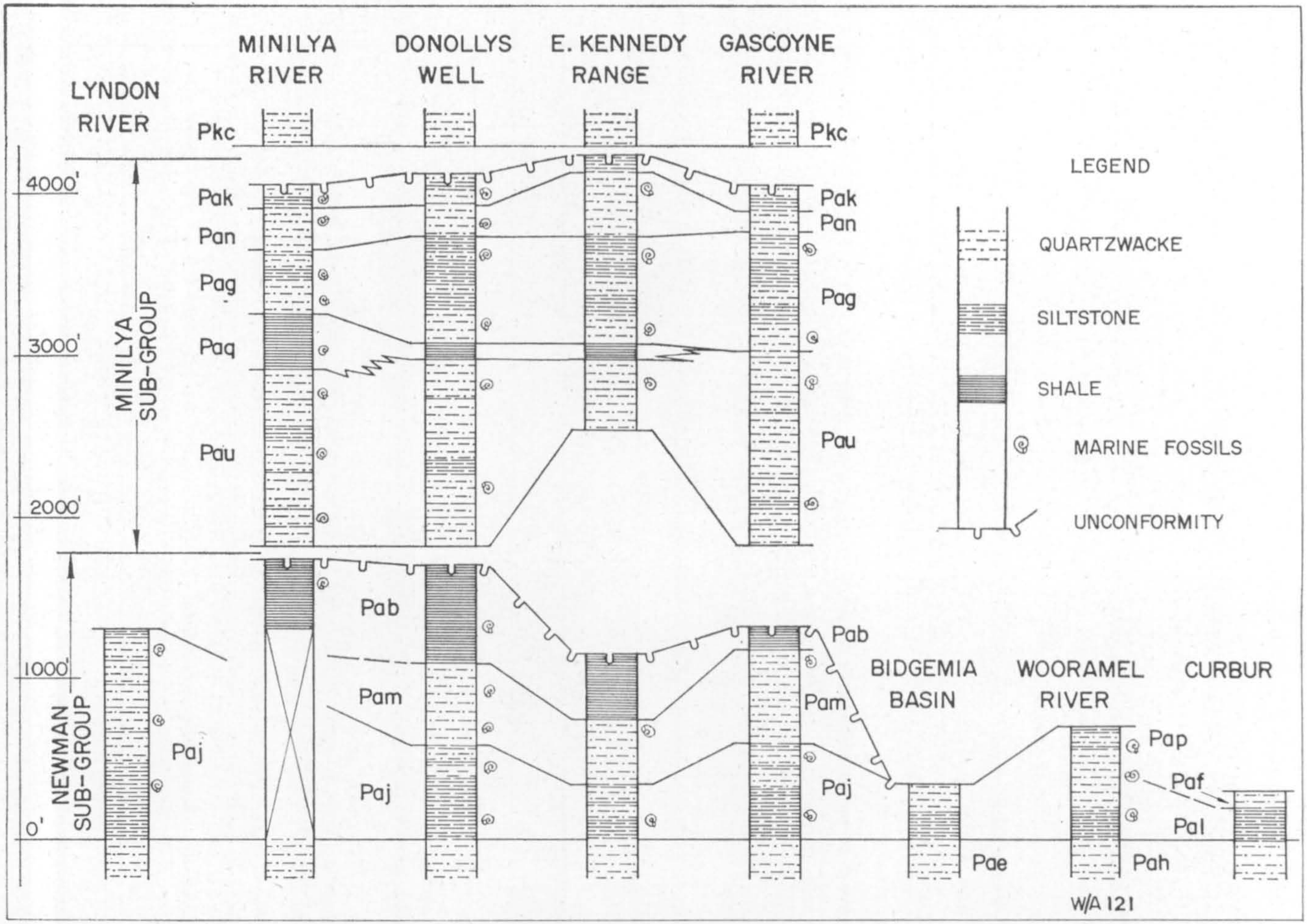


Fig. 101. Stratigraphic columns, Byro Group. Pkc-Coolkilya Greywacke; Pak-Baker Formation; Pan-Norton Greywacke; Pag-Wandagee Formation; Paq-Quinnanie Shale; Pau-Cundlego Formation; Pab-Bulgadoo Shale; Pam-Mallens Greywacke; Paj-Coyrie Formation; Pap-Warra Warringa Formation; Paf-Bogadi Greywacke; Pal-Madeline Formation; Pae-Billidee Formation; Pah-Keogh Formation.

There may have been access (through the Wooramel Sill) between the Gascoyne and Coolcalalaya Basins. Clean sands may have been deposited over the basement ridges and around the sills at the same time as the Byro Group was laid down.

The Byro Group includes several formations of petroleum sourcebed type, sandy beds and formations suitable for primary migration of petroleum, and some sandy formations of porosity and permeability high enough to form second-class reservoirs. There is also the possibility that the Group may grade laterally into permeable quartz sandstones on the top and flanks of the basement ridges.

Condon (1954) accepted the Lyons River sequence as the Byro Group without direct reference to the type locality. Konecki, Dickins, & Quinlan (1958, p. 43) did not discuss the content of the Group outside the type locality, but named three formations of the Byro Group in the Wooramel River area: Madeline Formation (lowermost), Bogadi Greywacke, and Warra Warringa Formation. As it is extremely unlikely that the Byro Group of the Wooramel River area has any present continuity with equivalent sequences elsewhere in the Carnarvon Basin I should have preferred to restrict the name to the sequence in the Byro Basin. This proposal was not approved by the Western Australian Sub-committee on Stratigraphical Nomenclature; the name is used, therefore, in the established sense of the sequence of siltstone, shale, and quartzwacke between the Wooramel Group below and Kennedy Group above.

Because there is a disconformity within the Byro Group, Condon (1962a) subdivided the Byro Group into the (lower) Newman Subgroup and the (upper) Minilya Subgroup.

BYRO GROUP : ROCK UNITS AND RELATIONSHIPS

	BYRO BASIN	MERLINLEIGH BASIN Lyons R. Minilya R. Lyndon R.
		KENNEDY GROUP
		unconformity
MINILYA SUBGROUP		Baker Formation
		Norton Greywacke
		Wandagee Formation Quinnanie Shale
		Cundlego Formation
		disconformity
NEWMAN SUBGROUP		Bulgadoo Shale
		Mallens Greywacke
	Warra Warringa Formation Bogadi Greywacke Madeline Formation	Coyrie Formation
WOORAMEL GROUP		

The Byro Group is Artinskian (Lower Permian) in age. The two subgroups have distinctive faunas that may provide a basis for the subdivision of the Artinskian in Australia.

NEWMAN SUBGROUP

The Newman Subgroup (Condon, 1962a) is the lower part of the Byro Group; it consists of siltstone, shale, and quartzwacke, with marine fossils, and rests conformably on the Wooramel Group and disconformably (in places unconformably) beneath the Minilya Subgroup. It includes the Coyrie Formation, Mallens Greywacke and Bulgadoo Shale in the Merlinleigh Basin, the Coyrie Formation in the Bidgemia Basin, and the Madeline Formation, Bogadi Greywacke and Warra Warringa Formation in the Byro Basin.

Although its rock types are similar to those of the overlying Minilya Subgroup it is separated as a unit because it has a distinctive fauna and its top is a disconformity (see p. 141).

The Newman Subgroup is 1300 feet thick in its exposed portion on the Lyndon River, about 2000 feet thick (500 feet exposed) in the Minilya River area, 1750 feet at the north end of Kennedy Range, 1000 feet east of Kennedy Range (Lyons River station), 1360 feet south of the Gascoyne River, and 720 feet in the Wooramel River area (Fig. 101).

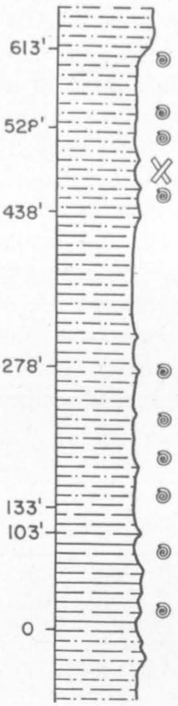
Coyrie Formation

The Coyrie Formation (Condon, 1954, revised Condon, 1962a) consists of siltstone and fine-grained quartzwacke, with marine fossils, conformable between the Billidee Formation below and the Mallens Greywacke above. It is the lowermost formation of the Byro Group in the Merlinleigh Basin and the only remaining formation of the group in the Bidgemia Basin.

As originally defined (Condon, 1954) the Coyrie Formation included a dominantly arenaceous lower part and an upper part dominantly of siltstone. Condon (1962a) separated the lower part as the Billidee Formation and restricted the name Coyrie Formation to the upper part.

The type section (Fig. 102) was measured in the floor and northern scarp of an erosion embayment at the north-eastern end of the Kennedy Range (Fig. 78).

The base of the Coyrie Formation is at the change of lithology from quartzwacke with minor siltstone beds and members to siltstone with minor quartzwacke beds and members: the upper part of the Billidee Formation has many beds of calcareous coarse-grained quartzwacke; the lowermost part of the Coyrie Formation is predominantly siltstone and shale. The top of the Coyrie Formation is at the change from laminated fine-grained quartzwacke with calcareous beds and beds and members of siltstone to thin-bedded medium-grained quartzwacke of the Mallens Greywacke. Although the lithological change is small there is at this place a marked change in resistance to erosion and in air-photo pattern. Whereas the Coyrie Formation is easily eroded down to the local base level, the Mallens Greywacke tends to stand up in low sand-covered hills. The upper part of the Coyrie Formation is characterized by calcareous beds which in many places are the only beds cropping out.



Firm pale brown medium-grained scavenged quartzwacke (MALLENS GREYWACKE) conformably overlying:

85 feet friable laminated and finely cross-laminated light grey fine-grained micaceous quartzwacke with thin hard calcareous beds; sparse marine fossils;

90 feet friable thin-bedded to laminated fine-grained quartzwacke with thin hard calcareous beds and lenses; marine fossils and invertebrate trails and burrows;

160 feet soft very dark laminated siltstone and friable greenish grey laminated fine-grained quartzwacke with lenses and beds of hard calcareous quartzwacke; few marine fossils;

145 feet thin-bedded soft dark siltstone and friable grey fine-grained quartzwacke; many fossiliferous beds;

30 feet firm dark grey laminated siltstone with thin beds of hard calcareous quartzwacke;

103 feet firm to soft dark grey laminated carbonaceous siltstone and shale with laminae of fine-grained sandstone and thin beds of fine-grained quartzwacke and network beds of phosphatic siltstone; several fossil beds;

conformably overlying soft dark grey laminated siltstone, friable grey medium-grained quartzwacke and thin hard calcareous coarse-grained quartzwacke with fossils (BILLIDEE FORMATION).

613 feet - thickness of Coyrie Formation in type section.

Fig. 102. Type section, Coyrie Formation.

The dominant lithology of the Coyrie Formation and the predominant lithology of its lower part is dark grey laminated carbonaceous micaceous siltstone, commonly with laminae of fine sand, shale, and calcilutite, and thin network-beds of phosphatic siltstone. Quartzwacke is dominant in the upper part of the Coyrie Formation: it is fine-grained and medium-grained, laminated to thin-bedded, and contains calcareous beds and lenses, and laminae and beds of dark grey siltstone. The quartzwacke consists of about 60 to 70 percent quartz grains, angular to subrounded and poorly sorted, 0 to 5 percent feldspar, mainly orthoclase, 1 to 3 percent biotite (including leached biotite), and about 25 percent silty matrix. Porosity and permeability are generally low. In the calcareous beds the calcite takes the place of the silt matrix. In a few beds the calcite is dominant, resulting in a sandy limestone.

Distribution (Fig. 103), *Thickness (Fig.* 104), *and Relationships.*—The Coyrie Formation commonly crops out very poorly, so complete sections are very few. The thickness can be estimated in many other places by reference to distance between the base and top and to dips on a few outcropping calcareous beds and in the underlying and overlying formations. Outcrops of the Coyrie Formation are spread over a distance of 145 miles from the Lyndon River to Pells Range.

On the Lyndon River east of Mia Mia homestead between Warringoona Pool and Salt Pool, the Coyrie Formation has its thickest expression in outcrop. The sequence is incomplete, as it ends in a south-plunging syncline, but about 1300 feet of the Coyrie Formation is exposed. The lower siltstone member is about 500 feet thick and has several richly fossiliferous beds; the upper quartz-wacke member is more than 800 feet and includes several fossil beds and many calcareous beds. The Coyrie Formation in the syncline is probably close to its top. On the Minilya 4-mile sheet (B.M.R., 1954) these members were mapped as Bulgadoo Shale and Cundlego Formation, but examination of the fossils by J. M. Dickins established the identity of the lower member with the Coyrie Formation. This outcrop is overlapped by Cretaceous Windalia Radiolarite on the western side and disappears under superficial deposits to north and south. The Coyrie Formation does not crop out between the Lyndon River outcrop and the Minilya River, but there is a suggestion of outcrop in the low ridges of travertine on the main Middalya-Williambury road between Coodawarra and Mundarie Wells. WAPET'S Quail No. 1 bore demonstrated that both Teichert (1952, p. 124) and Bureau geologists (Minilya Sheet, 1954) had misidentified

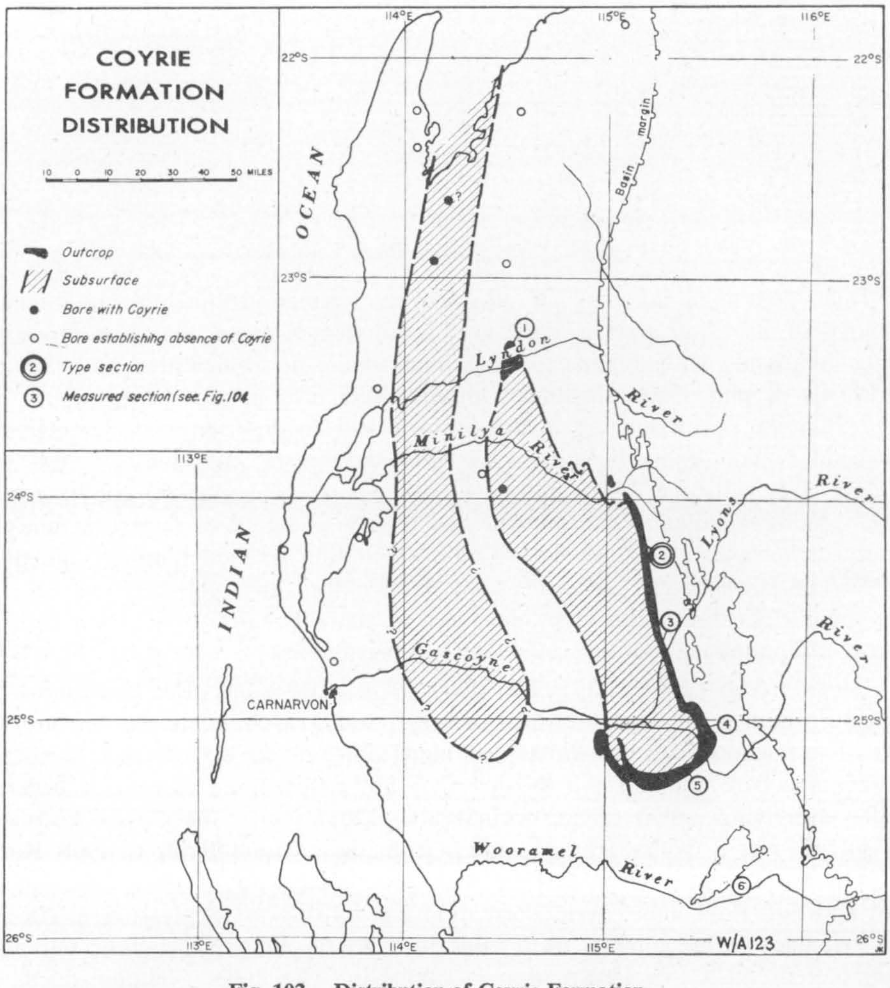


Fig. 103. Distribution of Coyrie Formation.

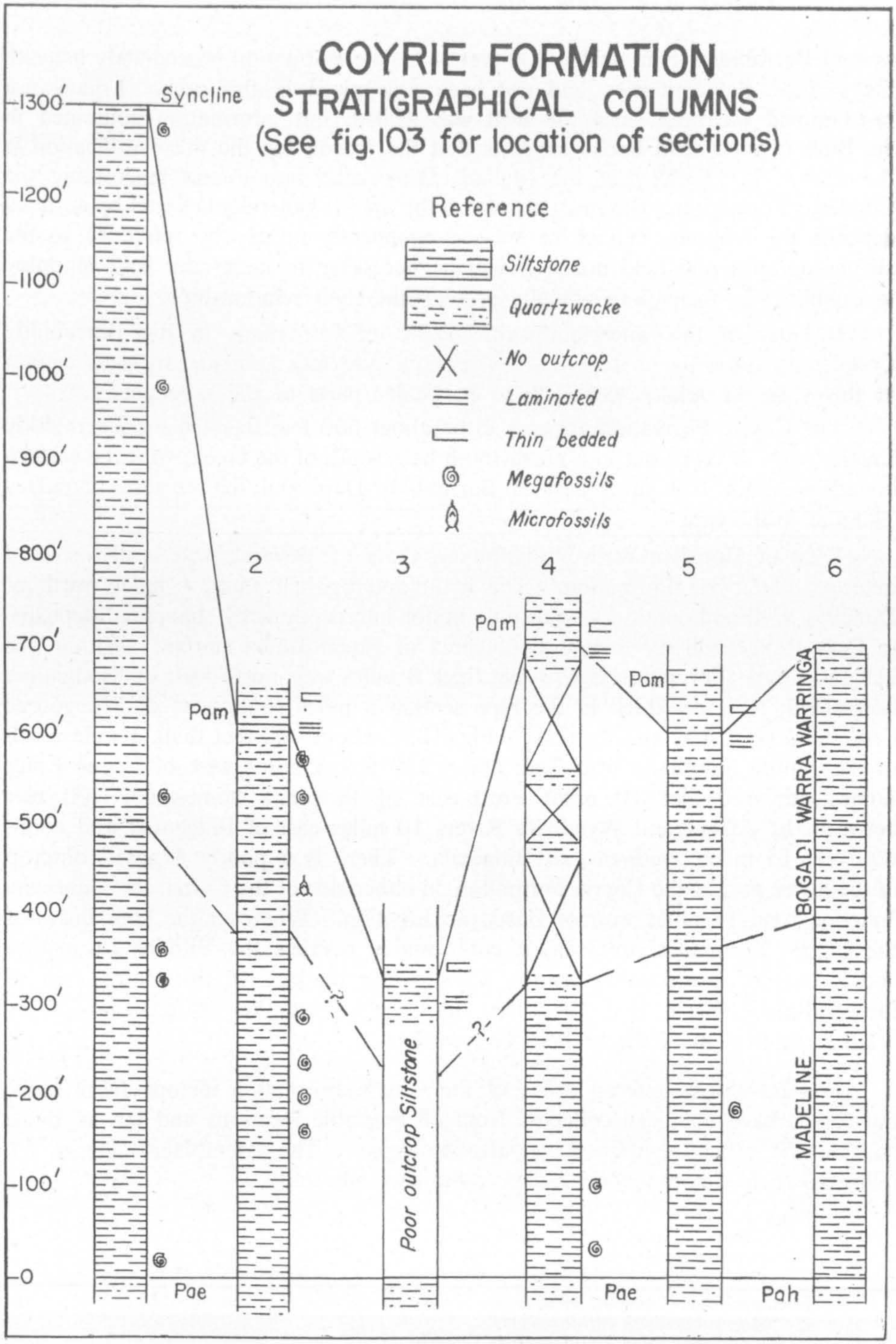


Fig. 104. Stratigraphic columns, Coyrie Formation. Pam-Mallens Greywacke ; Pae-Billidee Formation ; Pah-Keogh Formation.

formations in the Barrabiddy Creek area. Quail No. 1, 2000 yards west-north-west of Barrabiddy dam, drilled 200 feet of Coyrie Formation immediately beneath the surface; the formation had not been recognized in this area. I have not re-examined the area since the well was drilled, but information contained in the Bureau party field books suggests that the reason for the misidentification is the change in lithology of the Mallens Greywacke into a unit resembling the Cundlego Formation. Because outcrop in the area is generally covered by surficial deposits the mapping cannot be revised confidently merely by reference to the air-photographs and field notes; it will be necessary to undertake field mapping to establish the formations actually present and their relationships.

Because of this uncertainty thicknesses of formations in the Barrabiddy Creek area can only be regarded as tentative and any fossil occurrences cannot at this stage be related definitely to particular parts of the sequence.

The Coyrie Formation appears to be about 600 feet thick in the Barrabiddy Creek area. It crops out in a north-south belt, south of the creek, with the eastern boundary about 100 yards east of Barrabiddy Dam and the western boundary 2½ miles to the west.

West of Donellys Well, Williambury, there are several structurally isolated outcrops of Coyrie Formation. The main outcrop belt starts 4 miles north of Donellys Well and continues, with only minor interruptions by superficial deposits, to Pells Range and the Jacobs Gully area of Jimba Jimba station. Within this belt the Coyrie Formation is 470 feet thick 8 miles west-north-west of Moogooree homestead; 613 feet thick in the type section 5 miles south-west of Moogooree homestead (Fig. 102 and Section 2, Fig. 104); about 400 feet thick ½ mile north of the Mount Sandiman woolshed; about 330 feet 3 miles west of Lyons River homestead; 420 feet 10 miles north-east of Bidgemia homestead; 700 feet between the Arthur and Wyndham Rivers 10 miles east of Bidgemia; and about 600 feet 15 miles south-east of Bidgemia. There is a poorly exposed outcrop of the lower part of the Coyrie Formation on either side of the Carnarvon-Gascoyne Junction road 15 miles west of Gascoyne Junction. Wherever the boundaries of the Coyrie Formation are seen, it conformably overlies the Billidee Formation and is overlain conformably by the Mallens Greywacke. In the central part of the Merlinleigh Basin, it is likely that the Coyrie Formation extends upwards as a lateral equivalent of the Mallens Greywacke.

Fossils.—Most outcrop areas of the Coyrie Formation include fossil beds, but fossils have not been collected from all available locations and few of those collected have been examined by palaeontologists. The assemblage includes the following (field determinations unless otherwise indicated):

Plantae:
- Silicified wood *?Araucaria* (det. C. E. Carter)
- *Gangamopteris*
- *Glossopteris*

Foraminifera (Crespin, 1958):
- *Ammobaculites nitidus* Parr
- *Ammobaculites wandageensis* Crespin
- *Hyperammina acicula* (Parr)
- *Hyperammina coleyi* Parr

Hyperammina elegans (Cushman & Waters)
Hyperammina fusta Crespin
Reophax ellipsiformis Crespin
Reophax fittsi (Warthin)
Reophax minutissimus Plummer
Reophax tricameratus Parr
Sacculinella australae Crespin
Spiroplectammina carnarvonensis Crespin
Textularia improcera Crespin
Thurammina phialaeformis Crespin
Thuramminoides sphaeroidalis Plummer

Bryozoa:
Fenestellid
Batostomellid

Crinoidea:
Calceolispongia barrabiddiensis Teichert*
Stem ossicles

Brachiopoda:
Aulosteges ingens Hosking (det. P. J. Coleman)
Aulosteges lyndonensis Coleman (incorrectly described by Coleman (1957 p.46) as from the Bulgadoo Shale).
Neospirifer
Linoproductus cancriniformis (Tschernyschew) (det. P. J. Coleman)
Chonetid
Kiangsiella condoni Thomas, 1958
Strophalosia

Pelecypoda (Dickins, 1963):
Anthraconeilo sp.
Astartila blatchfordi (Hosking)
Atomodesma mytiloides Beyrich
Aviculopecten spp.
Nuculopsis (*Nuculanella*) sp.
Nuculopsis (*Nuculopsis*) sp.
Oriocrassatella sp.
Palaeosolen? sp.
Pectinid gen. et sp. A.
Praeundulomya concentrica Dickins
Schizodus kennedyensis Dickins
Stutchburia sp. nov.

Gastropoda (Dickins, 1963):
Euphemites sp.
Glyptoleda sp. nov.
Macrochilina sp.
Mourlonia (*Mourlonia*) sp. nov. A.
Mourlonia (*Platyteichum*) sp.
Mourlonia (*Pseudobaylea*) sp. nov.
Naticopsis? sp.
Ptychomphalina sp.
Stachella sp. nov.
Straparolus (*Leptomphalus*) sp.
Warthia sp.

Nautiloids

Ammonoidea:
Propinacoceras
Pseudoschistoceras simile Teichert*

Conulariids:
Conularia

Trilobita:
? Ditimopyge

Vermes.

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* Teichert (1952, p.124) misidentified the formations in the Barrabiddy Creek area and wrongly included *Calceolispongia barrabiddiensis* and *Pseudoschistoceras simile* in the fauna of the Bulgadoo Shale. WAPET Quail No. 1 established that the formation in which these fossils occur near Barrabiddy Dam is the Coyrie.

Age.—The assemblage of genera merely indicates the Permian age and not enough species have been determined to establish indubitable local correlations. From its position in sequence between the Callytharra and Wandagee Formations the Coyrie Formation is certainly Artinskian.

Correlation.—The Coyrie Formation has a few determined species in common with the Madeline Formation of the Byro Basin, and this and their position above the Wooramel Group and similarity of lithology indicate a probable correlation between the two. Konecki, Dickins, & Quinlan (1958, p.46) equate the whole of the Coyrie with the Madeline Formation, but a comparison of the lithological sequences indicates that the Madeline may be the equivalent of only the lower part of the Coyrie Formation.

Structure.—In the Lyndon River outcrop the Coyrie Formation is folded into a south-plunging syncline and anticline. In the Donellys Well area the several outcrops of Coyrie Formation are in west-dipping blocks separated by unconformities or faults. Between the Minilya and Gascoyne Rivers the Coyrie Formation outcrops form part of a west-dipping homocline; south of the Gascoyne this passes into a broad north-plunging syncline. Regionally, the main structure of the Coyrie Formation is synclinal, roughly concordant with the shape of the Merlinleigh Basin. There are some small anticlines and synclines on the western side of the Basin.

Palaeogeography.—Sedimentation of the Coyrie Formation was preceded by a rapid subsidence of the sea floor so that only siltstone, shale, and fine sand were deposited in the present outcrop area, where, immediately before, coarse sand had been deposited. The dominance of pelecypods in the fauna and the presence of terrestrial plants indicate that shallow water and the shoreline were not far removed; this implies that the subsidence was local and probably resulted from downwarping of the Merlinleigh Basin. A period of structural stability followed the initial subsidence and as the depression was filled with sediment the sediment deposited became more sandy.

A small part of the structural relief resulting from deposition over the surface of the Lyons Group remained at the start of deposition of the Coyrie, but was largely eliminated by selective infilling by the silts of the Coyrie Formation.

Economic Geology.—The Coyrie Formation has no present use. It is probably a source formation for oil and would certainly be an adequate cap for reservoirs in the underlying Wooramel Group. The local downwarping that preceded the deposition of the Coyrie Formation should have favoured migration of petroleum in underlying sequences; the Coyrie would have provided cover wherever it was deposited. The eastern slope of the Wandagee Ridge between the Minilya and Gascoyne Rivers is indicated as an area where the Wooramel Group may be overlapped by the Coyrie.

Fig. 105. Type section, Mallens Greywacke.

Problems.—The subsurface extent of the Coyrie Formation is unknown, particularly on the western side of the Merlinleigh Basin and over or around the Wandagee Ridge. Additional collections of fossils are required, particularly of zonally useful forms such as ammonites and *Calceolispongia.* Examination and description of the fauna and flora are needed.

Mallens Greywacke

The Mallens Greywacke (Teichert, 1950; amended Condon, 1954) is the formation, predominantly of quartzwacke, conformable between the Coyrie Formation below and the Bulgadoo Shale above.

The type locality (Fig. 78) is in the scarp at the north end of Kennedy Range. The type section (Fig. 105) was measured across a spur south of the Moogooree/Donellys Well road; the Mallens Greywacke dips at 5° to 7° south-west. The base is placed at the change from friable laminated fine-grained quartzwacke to medium-hard bedded medium-grained quartzwacke: although there is only a small change in lithology it is well marked topographically and in air-photo pattern. The top of the Mallens Greywacke is placed at the change from predominant quartzwacke to interbedded siltstone and quartzwacke, which are transitional between the dominant rock types of the Mallens Greywacke and Bulgadoo Shale but are included with the Bulgadoo because the selected boundary is readily mappable.

The Mallens Greywacke consists mainly of medium-hard thin-bedded medium-grained quartzwacke consisting of 70 to 80 percent quartz (subangular to subrounded, moderately well-sorted) 5 to 10 percent feldspar, 2 to 5 percent black chert, 1 to 5 percent red garnet, 1 to 2 percent white mica, and 10 percent to about 20 percent silty matrix. Towards the top of the formation the Mallens is fine-grained and laminated but otherwise similar to the lower part. It generally has less silt than a normal quartzwacke, but in texture and composition is quartzwacke rather than quartz sandstone.

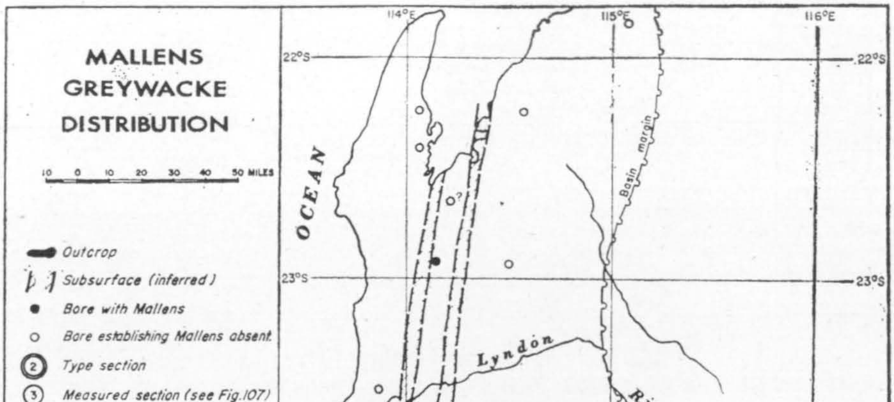


Fig. 106. Distribution of Mallens Greywacke.

Distribution (*Fig.* 106) *and Thickness* (*Fig.* 107).—The northernmost outcrop of the Mallens Greywacke is in the Burna Burna Hills, 8 miles north of Wandagee homestead, where 125 feet of medium-grained quartzwacke rests on friable laminated fine-grained quartzwacke with calcareous beds (Coyrie Formation); the upper part of the Mallens is not exposed—the Bulgadoo Shale crops out 1½ miles to the south. The areas on the Lyndon River shown as Mallens on the Minilya 4-mile sheet (BMR, 1954) were incorrectly identified: they are Billidee Formation. No Mallens Greywacke was recognized by the Bureau

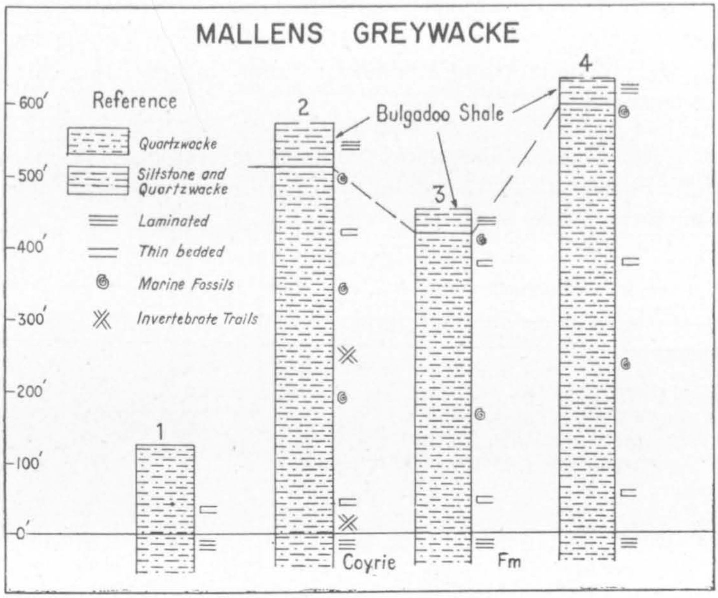


Fig. 107. Stratigraphic columns, Mallens Greywacke.

party in the Barrabiddy Creek area south of Wandagee Hill. Following the identification of Coyrie Formation at the surface in WAPET Quail No. 1 it appears likely that the outcrop belt west of Quail Quail Creek, identified by Bureau geologists as Cundlego Formation, is in fact equivalent to the Mallens but in lithology more like the Cundlego. This 'Mallens equivalent' is about 450 feet thick and consists of fine-grained quartzwacke, calcareous in places, and dark siltstone. South of the Minilya River there is an outcrop trend from 2 miles west to 3 miles south-south-west of Donellys Well, Williambury, and several isolated outcrops from 3 miles north to ¾ mile east of the well. The type section outcrop, 2½ miles east-south-east of the well, is the northernmost complete outcrop section, 517 feet thick. The outcrop is masked by superficial deposits on the plateau surface of the Kennedy Range; the same trend reappears in outcrop in the eastern scarp of the Kennedy Range 9 miles south of Moogooree homestead and continues with minor interruptions by superficial deposits to the Gascoyne River. Five miles north of Mount Sandiman woolshed the Mallens Greywacke is 600 feet thick; it is 420 feet thick 4½ miles west of Lyons River homestead, about 600 feet 7 miles north-east of Bidgemia homestead, and about 600 feet 7 miles south-east of Bidgemia. Farther west poor outcrop and very gentle undulating dip prevent measurement of thickness; there are isolated outcrops of Mallens in a sand plain westward to 7½ miles south-west of Gascoyne Junction.

Relationships.—Almost everywhere the Mallens Greywacke is conformable between Coyrie Formation below and Bulgadoo Shale above. In the area around Donellys Well, Williambury, it is unconformable on older formations: west and north of the well it rests on Callytharra Formation and probably it is unconformable on Lyons Group 3 miles north of the well: the Lyons Group does not crop out near the Mallens outcrop but is almost certainly present under the superficial deposits.

Fossils.—The Mallens Greywacke contains several beds of marine fossils, many beds of invertebrate trails and burrows, and many disturbed beds probably resulting from invertebrate scavenging.

The fossil fauna is dominated by pelecypods, which have been described by Dickins (1963). There are also a few brachiopods and small gastropods. Forms present (field determinations, not checked by palaeontologists, except as indicated) include:

Foraminifera (Crespin, 1958):
- *Ammodiscus nitidus* Parr
- *Hyperammina acicula* (Parr)
- *Thuramminoides sphaeroidalis* Plummer

Crinoidea:
- *Calceolispongia*

Brachiopods:
- *Neospirifer*

Pelecypods (Dickins, 1962):
- *Oriocrassatella* cf. *stokesi* Eth. fil.
- *Schizodus* sp.
- *Stutchburia* sp. nov.
- *Astartila blatchfordi* (Hosking)
- *Atomodesma mytiloides* Beyrich
- *Pseudomonotis* sp.
- *Heteropecten* sp. nov.
- *Allorisma* sp. nov. (Dickins, 1956)
- *Aviculopecten* sp. nov.

Gastropods

Age.—The age of the Mallens Greywacke is fixed, by its position in sequence between the Callytharra and Wandagee Formations, as Artinskian.

Correlation.—The Mallens Greywacke has been correlated by Konecki, Dickins, & Quinlan (1958, p. 48) with the Bogadi Greywacke of the Byro Basin, but I consider that this correlation is not established and that the Mallens may have no equivalent formation in the Byro Basin.

Structure.—Over most of its outcrop the Mallens Greywacke is part of a west-dipping homocline. South of the Gascoyne River it is part of the broad gentle north plunge at the south end of the Merlinleigh Basin. In the Donellys Well area it is structurally displaced by unconformities related to the relief on the surface of the Lyons Group.

Palaeogeography.—The sediments of the Mallens Greywacke were deposited in a shallow sea resulting from the infilling of the downwarp that preceded the deposition of the Coyrie Formation. It is likely that the shoreline remained stationary and not very far from the present outcrop. There was probably still a marine basin in the central part of the Merlinleigh Basin in which the finer sediment winnowed from the sand was deposited. It is likely that, basinwards, the Mallens changes laterally into an upward extension of the Coyrie Formation.

Economic Geology.—The Mallens Greywacke has moderate porosity (estimated at 10 to 15 percent) and fair permeability (estimated at 20 to 100 millidarcies). It is a source of shallow underground water (White Well, Moogooree; Baker Bore, Merlinleigh; Binthabooka Bore, Mount Sandiman; Bissets Well and Johnsons Well, Lyons River; Karranooka Well, Ram Paddock Bore, and several bores and wells south of Bidgemia homestead). The aquifer could be much more utilized near the outcrop, but it is not known how far it will extend subsurface before it loses its good aquifer characteristics. It is likely to become less permeable and its water more saline away from outcrop.

The Mallens Greywacke would be a good reservoir formation for petroleum where it is covered by the Bulgadoo Shale and in suitable structure; it overlies a probable source formation and may grade laterally into its upward extension. There was probably some structural relief during sedimentation, favouring early migration of petroleum. No structural or porosity traps can be indicated in the outcrop area: the only possibility there is for wax seal at the water table. On the flank of the Wandagee Ridge there is good possibility for structural and wedge-out traps in the area between Minilya River and Gascoyne River; similar traps may be present in the northern Gascoyne Basin on the west flank of the Wandagee Ridge and the east flank of the Bullara Ridge in the area between Minilya River and Exmouth Gulf.

Problems.—The subsurface extent of the Mallens Greywacke, and whether or not it changes into the lithology of the Coyrie Formation basinwards, are almost completely unknown.

Few fossil localities have been found, but additional collections are required; the molluscan fauna has been described by Dickins (1963); the other elements, particularly the *Calceolispongia,* require description. This fauna provides a means of establishing the molluscan assemblage characteristic of the Newman Subgroup for comparison with assemblages of similar environment, e.g. Billidee Formation and Norton Greywacke.

No structural or stratigraphic traps in the Mallens Greywacke have been established: subsurface exploration is necessary to look for them.

Bulgadoo Shale

The Bulgadoo Shale was named by Teichert (1941), and because insufficient field work had been done it was described as resting on what is now called the Moogooloo Sandstone and as probably correlating with the lowermost formation of the Byro Group. Condon (1954) revised the definition of the Bulgadoo Shale to correct its position in outcrop sequence. Later work requires slight modification of that definition.

The Bulgadoo Shale is the formation of shale and siltstone with minor quartzwacke and calcilutite conformable on the Mallens Greywacke and disconformably (locally unconformably) overlain by the Cundlego Formation.

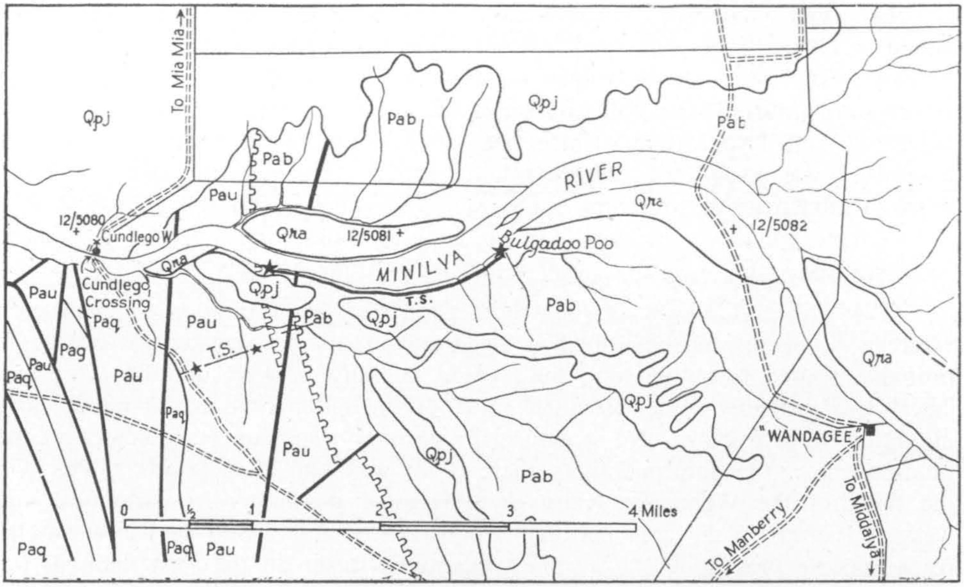


Fig. 108. Type locality, Bulgadoo Shale (Pab) and Cundlego Formation (Pau). Qra-alluvium ; Qpj-Joolabroo Formation ; Pag-Wandagee Formation ; Paq-Quinnanie Shale.

The type locality of the Bulgadoo Shale (Fig. 108) is along the Minilya River downstream from Wandagee homestead for about 12 miles; Bulgadoo Pool is in this part of the river about 5 miles downstream from the homestead. Only the upper part of the formation (Fig. 109) is exposed there. The sequence is broken by many strike faults of probably small but indeterminate throw. Condon (1954, p. 68) proposed an amended type locality in the north scarp of the Kennedy Range 43 miles east-south-east of Teichert's type locality: this amendment is not valid—the complete section should be regarded as a reference section where the relationships, thickness, and full sequence can be demonstrated. Outcrop is not continuous between the two areas and therefore the original type locality must be retained. The reference section is 7½ miles south of west of Moogooree homestead and 2 miles south-east of Donellys Well, Williambury (at lat. 24° 05½′ S., long. 115° 05′ E.) in the northern scarp of Kennedy Range (Fig. 110). The reference section (Fig. 111) is 626 feet thick: the exposure is masked by a scree of silcrete, but a complete sequence can be examined in the

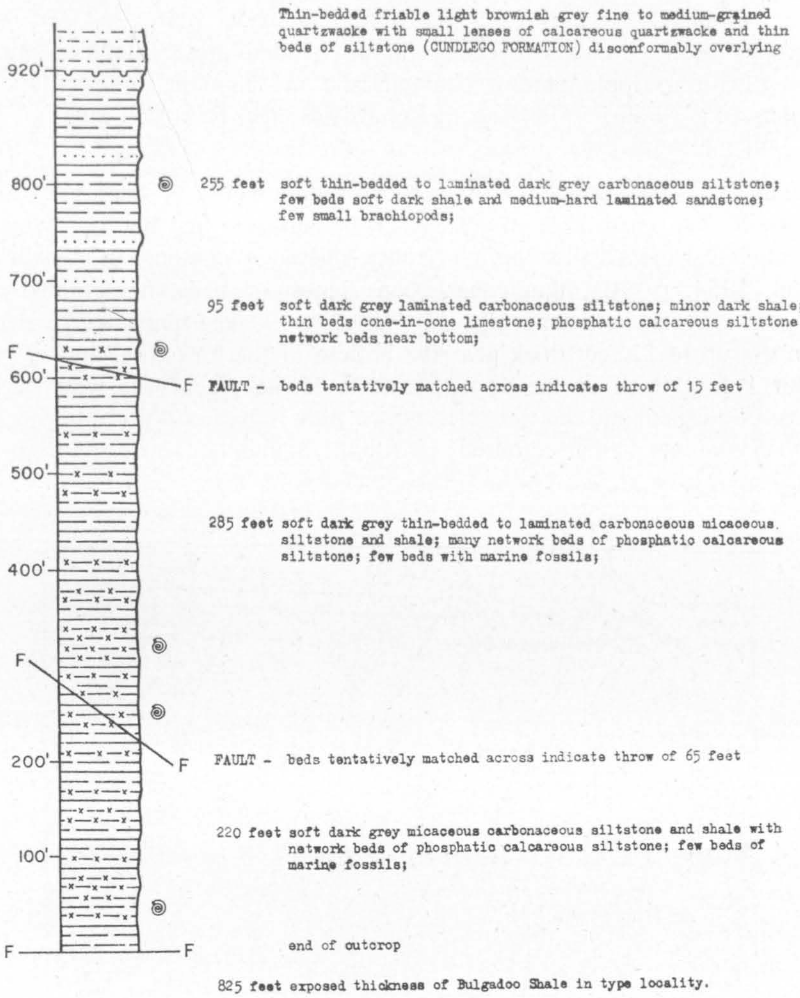


Fig. 109. Type section, Bulgadoo Shale.

many small scoured gullies in the scarp. The bottom of the formation is gradational from the Mallens Greywacke: it is taken at the bottom of the lowermost siltstone member in the sequence of alternating siltstone and quartzwacke members above the quartzwacke of the Mallens. The top of the Bulgadoo Shale is eroded: it is marked by a lag-gravel of phosphatic-nodule pebbles, remanié fossils, and coarse quartz grains; below the boundary the sequence is dominantly lutite, above the boundary it is alternating fine-grained quartzwacke and siltstone. The top boundary is very well exposed in the bed of the Minilya River 300 yards upstream from Cundlego Crossing (Fig. 108) and in the area 5 to 10 miles south-east of Wandagee homestead (Minilya 4-mile Sheet, BMR, 1954). The base of the Bulgadoo is not exposed on the Minilya River; it is well exposed in the reference section and also 5 miles north-north-west of Mount Sandiman woolshed (Kennedy Range 1:250,000 Sheet). It is well expressed on air-photographs as a boundary between faintly banded grey (Mallens) and very pale grey with a ripple pattern characteristic in this area of silty and shaly formations (e.g. Photo. 5008, Run 6, Kennedy Range; R.A.A.F. Survey 728, 9th June 1949, photo. centre).

Lithology.—The Bulgadoo Shale consists dominantly of dark grey to black carbonaceous shale with a small amount of disseminated fine pyrite. Minor rock types include calcareous siltstone, phosphatic siltstone commonly in 'network beds' (Condon, 1954, p. 70), thin cone-in-cone limestone beds, fine-grained quartz-wacke, and evaporite gypsum (probably anhydrite). The quartzwacke is present in members up to 12 feet thick near the bottom of the formation and in beds up to about 1 foot thick in the upper part. In some places (as west of Mount Sandiman woolshed and in the reference section) gypsum of evaporite type—coarsely crystalline, amber-coloured—is found in undulate beds up to 6 inches

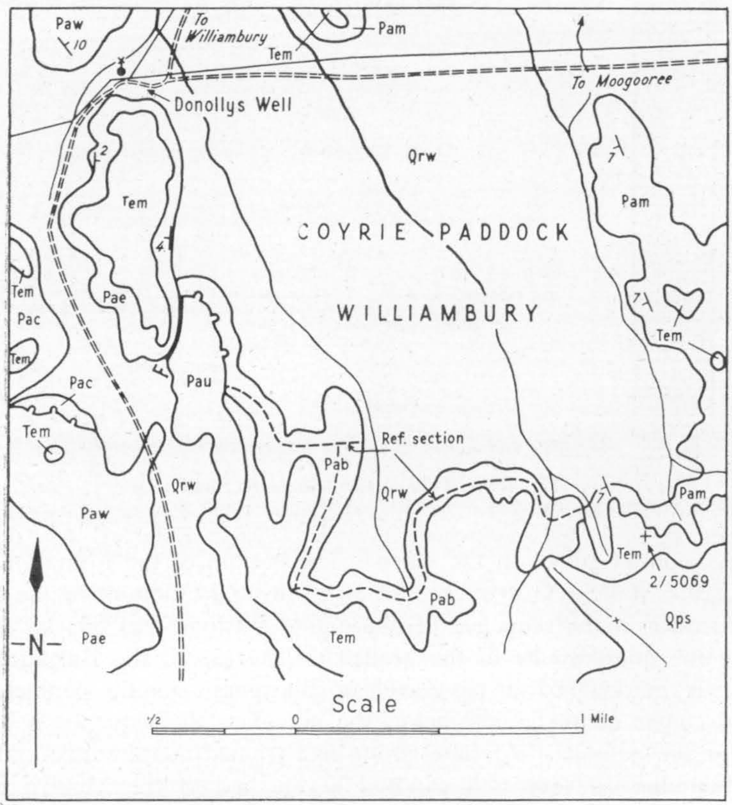


Fig. 110. Reference section locality, Bulgadoo Shale. Qrw-Recent deposits ; Qps-Pleistocene sand ; Tem-Merlinleigh Sandstone ; Pau-Cundlego Formation ; Pab-Bulgadoo Shale ; Pam-Mallens Greywacke ; Pae-Billidee Formation ; Paw-Moogooloo Sandstone ; Pac-Callytharra Formation.

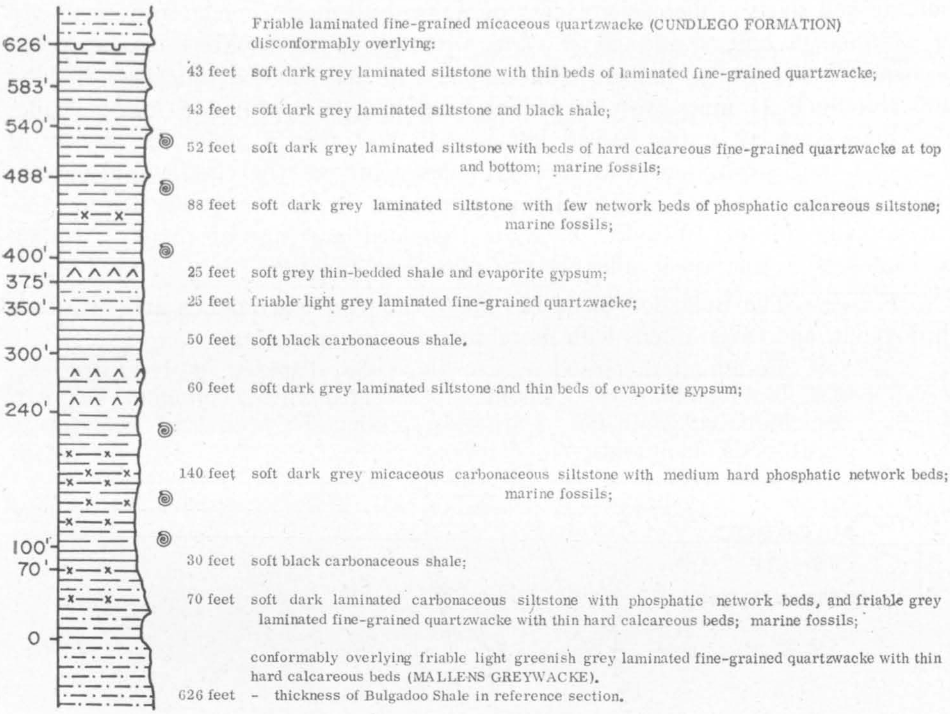


Fig. 111. Reference section, Bulgadoo Shale.

thick intercalated in shale and siltstone. This is quite distinct from the selenite produced by weathering (McWhae et al., 1958, p. 67), which is characteristic of the outcrop of the shale.

Distribution (*Fig.* 112 & 113).—The Bulgadoo Shale crops out from just north of the Minilya River to just south of the Gascoyne—over a distance of 115 miles. The upper part only of the formation is exposed along the Minilya River from near Cundlego Crossing upstream to Middalya homestead: the river roughly follows the strike of the formation. The middle part of the formation is exposed along the creek flowing into the Minilya River from the north-east 2 miles north of Wandagee homestead and the lower part crops out but is poorly exposed in the plain 5½ to 8½ miles north-east of the homestead. The lowermost part of the formation is covered by sand. The sequence is broken by many small faults and the total thickness outcropping cannot be determined. It crops out in several fault blocks in the Barrabiddy Creek area; the sequence is very poorly exposed, but there appears to be about 1700 feet below the Cundlego in the fault block containing the Barrabiddy Dam. It crops out between Kimbers Well, Williambury, and the northern scarp of Kennedy Range; in this area it is 520 feet thick. The formation is exposed in an erosion embayment 4 miles east of Kimbers Well. In this area there is an angular unconformity between the Bulgadoo Shale, dipping at between 2° and 6° south-south-west, and the Cundlego Formation dipping at between 3° and 8° west-south-west. The main outcrop belt starts at the eastern scarp of Kennedy Range 3 miles north-north-east of Merlinleigh homestead and extends, with many interruptions by superficial deposits, to Salt Gully, Jimba Jimba station. In this belt the Bulgadoo Shale is 400 feet thick 2½ miles west of Mount Sandiman woolshed; 245 feet 6½ miles west-south-west of Lyons River homestead; 260 feet 5 miles north-east of Bidgemia homestead; and 160 feet 5½ miles south-east of Gascoyne Junction. Only the lower part of the formation is present in the Gascoyne River area. An anticline in the Bulgadoo Shale is truncated and unconformably overlain by Cundlego Formation 9 miles west of Gascoyne Junction.

Fossils.—The Bulgadoo Shale has many chonetid brachiopods and ostracods throughout, and several beds with more varied fauna including:

> Foraminifera (listed by Crespin, 1958, Table V, p. 18); Bryozoa; Corals: *Thamnopora;* Crinoidea: *Calceolispongia acuminata* Teichert; Brachiopoda: chonetids, spiriferids, productids; Mollusca: pelecypods, gastropods, nautiloids; *Helicoprion.*

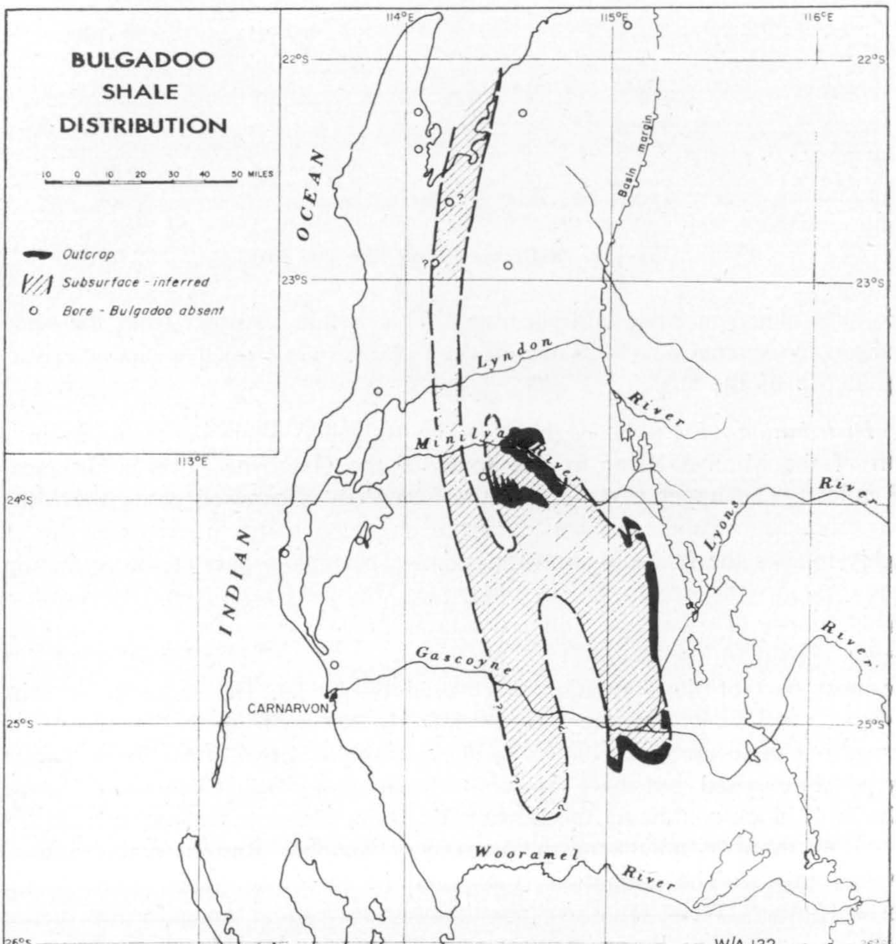


Fig. 112. Distribution of Bulgadoo Shale.

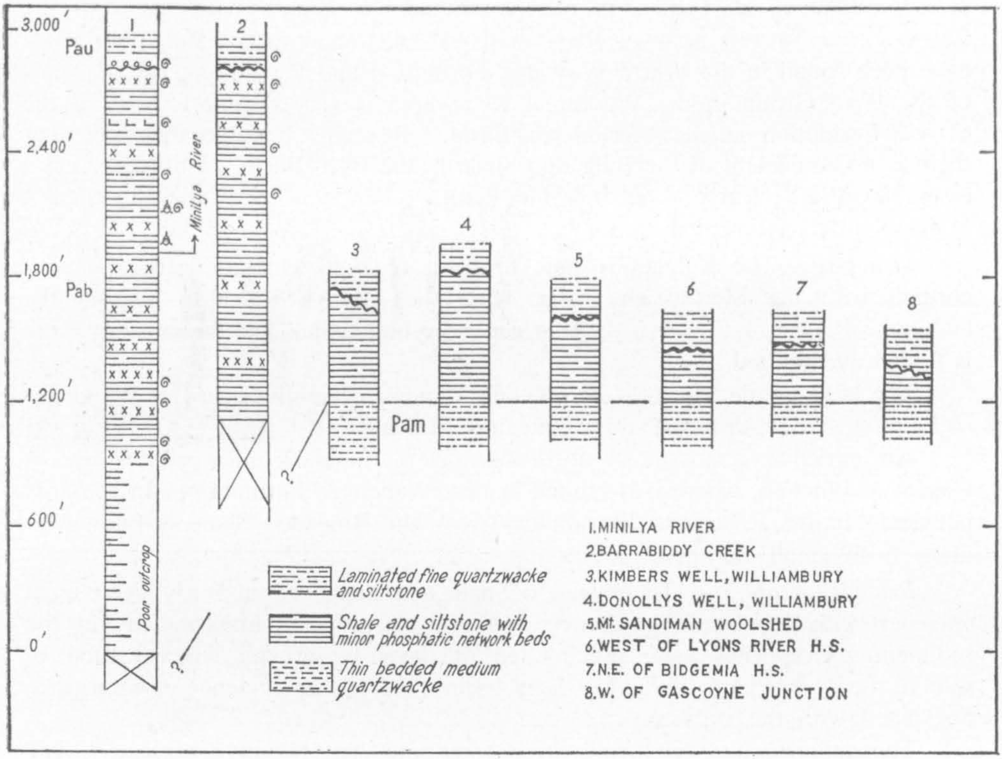


Fig. 113. Stratigraphic columns, Bulgadoo Shale. Pau-Cundlego Formation ; Pab-Bulgadoo Shale ; Pam-Mallens Greywacke.

Teichert (1957, p. 65) stated that the two species of *Calceolispongia* were 'rather widely separated stratigraphically'—*C. acuminata* restricted to the top of the Bulgadoo Shale, *C. barrabiddiensis* with *Pseudoschistoceras simile* 'about 2100 feet below the top of the formation'. Teichert did not recognize that the Barrabiddy area is very closely faulted so that the sequence is not easily established, or that the Bulgadoo Shale in outcrop is nowhere thicker than about 1700 feet. It is now clear that the Barrabiddy Dam locality with *C. barrabiddiensis* and *P. simile* is in the Coyrie Formation, not the Bulgadoo. These two species may or may not be of zonal significance, but until their occurrence is established in sequences where relative positions can be firmly established no significance can be given to Teichert's claims.

Age.—The Bulgadoo Shale is Artinskian by reason of its position between the Callytharra Formation and the Wandagee Formation. Its fauna has more elements in common with the Coyrie Formation than with the Cundlego or Wandagee Formations.

Correlation.—The Bulgadoo Shale cannot be correlated precisely with any other formation. Konecki, Dickins, & Quinlan (1958, p. 43) stated that the Warra Warringa Formation is probably of the same age as the Bulgadoo Shale, and McWhae et al. (1958, p. 68) correlated the Warra Warringa with the Bulgadoo. However, none of the few species restricted to the Bulgadoo Shale have been found in the Warra Warringa Formation and the lithological sequence of the Byro Group in the Wooramel River area is very similar to that of the Coyrie Formation in the Merlinleigh Basin. It seems possible therefore that there is no equivalent of the Bulgadoo Shale in the Byro Basin. Until the faunal assemblages are clearly defined in the Permian basins of Australia no attempt at detailed correlations can be made.

Structure.—The Bulgadoo Shale forms a regional syncline, generally concordant with the Merlinleigh Basin, from the Minilya River to beyond the Gascoyne River. Its eastern flank is generally homoclinal but the western flank is folded and faulted.

The large gentle 'Barrabiddy Syncline' trends east-south-east from Wandagee Hill and swings south past Paddys Outcamp, Middalya.

An anticline trends north-north-west in the area 7 miles south-west of Gascoyne Junction, where it is faulted against Wandagee Formation. In the area between Minilya River and Barrabiddy Creek the Bulgadoo Shale is faulted by many fairly small meridional faults.

Palaeogeography.—The Bulgadoo Shale was deposited in fairly deep quiet seawater with restricted circulation, and with a reducing environment in the sediment. Evaporites were precipitated at times by gravity concentration of salts in the deeper parts of the restricted basin: there is no evidence of emergence associated with the gypsum.

The submergence producing these conditions was regional, at least. The shoreline must have been far away from the present outcrop area so that little coarse terrigenous sediment could reach it. Within this area there probably was only minor topographic relief, although the indication of restricted circulation suggests that the regional relief of the sea floor was large.

Economic Geology.—The Bulgadoo Shale has no present economic significance. It is of petroleum source-bed type and includes evaporite beds that may contain useful salts. It would form a good cap to the Mallens Greywacke or older sands.

Problems.—The faunal assemblage of the Bulgadoo Shale requires definition, and additional collections will probably be required for this. Only in small areas is the nature of the surface between the Bulgadoo Shale and Cundlego Formation revealed. There may be much more relief in this than is indicated at present. The presence (or absence) of the Bulgadoo Shale has not been established in the Gascoyne Basin.

Madeline Formation

The Madeline Formation (Konecki, Condon, Dickins, & Quinlan, 1958, p. 73) consists of siltstone, shale, and fine-grained quartzwacke (calcareous in places), with marine fossils, conformably between and grading laterally into the Keogh Formation and the Bogadi Greywacke. In places it conformably overlies the Monument Formation.

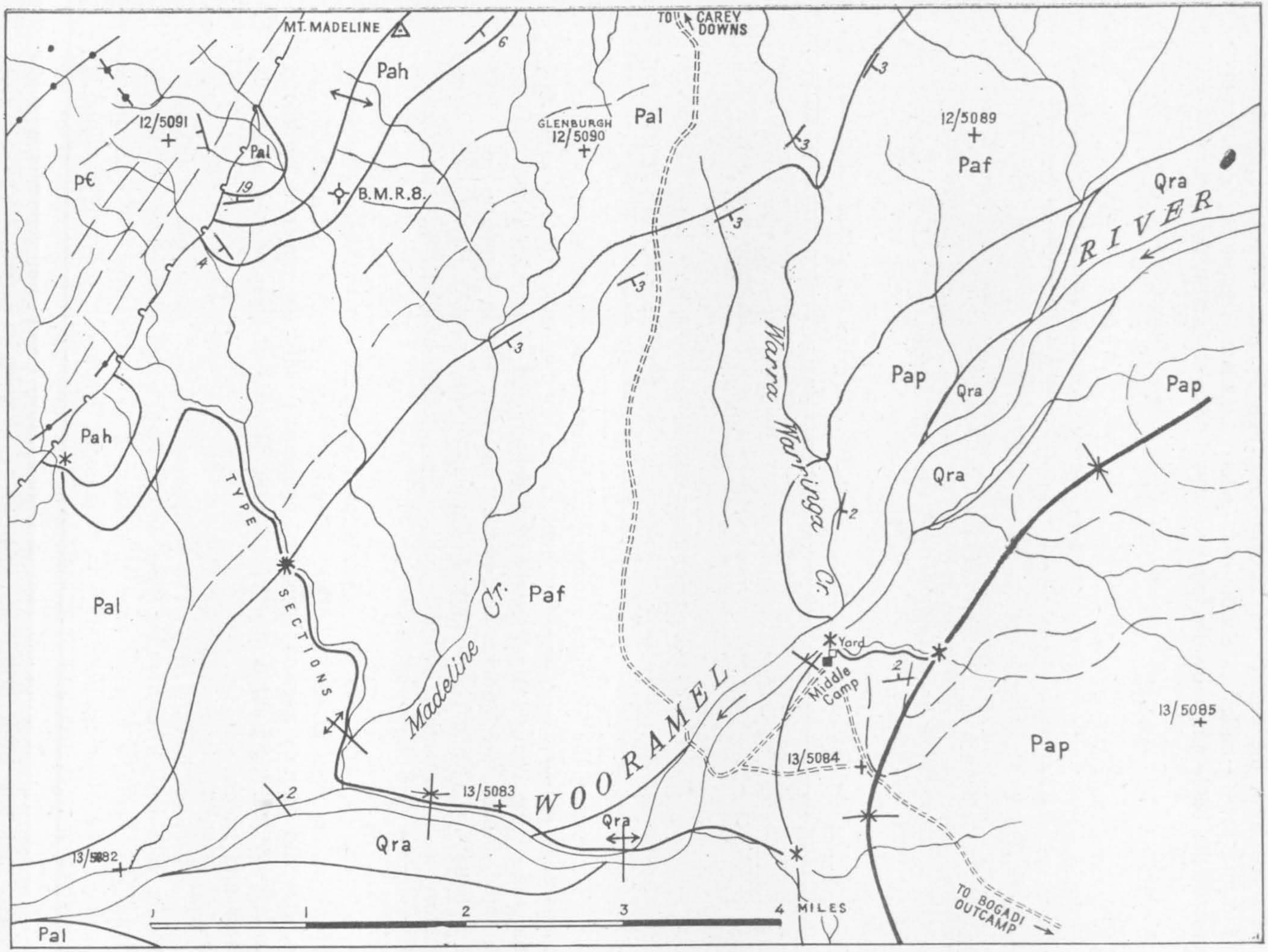
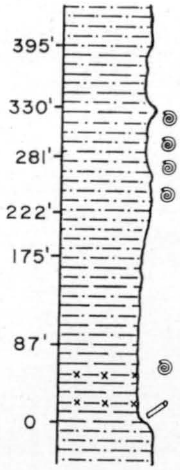


Fig. 114. Type locality, Madeline Formation (Pal), Bogadi Greywacke (Paf) and Warra Warringa Formation (Pap). Qra-alluvium ; Pah-Keogh Formation ; pC-Precambrian metamorphics.

The type locality (Fig. 114) is in the area west of Madeline Creek, a northern tributary of Wooramel River. The type section (Fig. 115) was measured from the outcrop of Keogh Formation 3 miles south-west of Mount Madeline for 1¼ miles east-south-east. The sequence dips at 9° south-south-east at the base, gradually dropping to 4° south-south-east at the top.



Friable thin-bedded fine-grained quartzwacke (BOGADI GREYWACKE) conformably overlying:

65 feet friable green-grey fine-grained quartzwacke interlaminated with dark grey micaceous siltstone;

49 feet friable thin-bedded fine-grained quartzwacke with lenticular hard calcareous beds at top; marine fossils;

59 feet friable laminated to thin-bedded fine-grained quartzwacke with calcareous beds; several fossil beds;

47 feet friable laminated fine-grained quartzwacke with siltstone laminae;

88 feet soft dark grey laminated siltstone and fine-grained micaceous quartzwacke, the proportion of siltstone increasing downwards;

87 feet soft dark grey laminated micaceous carbonaceous siltstone with few thin network beds of phosphatic fine-grained quartzwacke; few beds of ferruginous coarse-grained quartzwacke; marine fossils; fossil wood;

? conformable on hard medium- to coarse-grained quartzwacke (KEOGH FORMATION).

395 feet - thickness of Madeline Formation in type section.

Fig. 115. Type section, Madeline Formation.

The base of the Madeline Formation is placed at the change from dominantly arenaceous sediments of the Wooramel Group to dominantly pelitic sediments, the top at the change from interbedded fine-grained quartzwacke and siltstone to predominant quartzwacke, thin-bedded and fine and medium-grained. This top boundary (Konecki, Dickins, & Quinlan, 1958, p. 42) is not very satisfactory as a formation boundary although it forms a moderately satisfactory boundary on air-photographs.

Lithology.—The Madeline Formation consists of two members: the lower of laminated siltstone and shale with phosphatic 'network beds' (Condon, 1954, p. 70) and primary gypsum (probably anhydrite) beds, the upper of laminated to thin-bedded fine-grained quartzwacke with laminae of siltstone and calcareous beds and lenses.

Distribution (Fig. 116).—The Madeline Formation crops out on the Byro Plains in a belt 1 to 6 miles wide on the flanks and plunges of the Bogadi Syncline. There is a small area of outcrop 2 to 4 miles south of Callytharra Spring. The Madeline Formation in Monument Syncline is probably continuous with that at the north end of Bogadi Syncline, although it is interrupted by an area of laterite. It crops out also in Daurie, Bush Creek, and Mintahalla Synclines, and has been drilled through in bore BMR 9 (Daurie Creek) and Bogadi Bore.

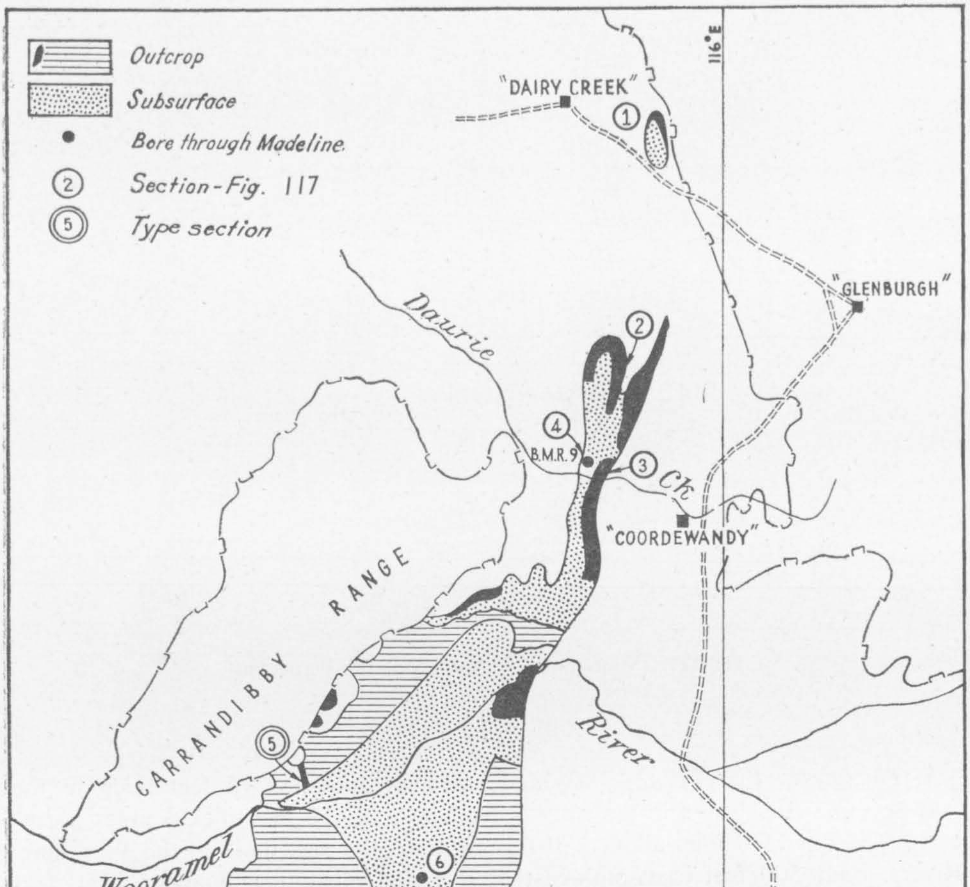


Fig. 116. Distribution of Madeline Formation.

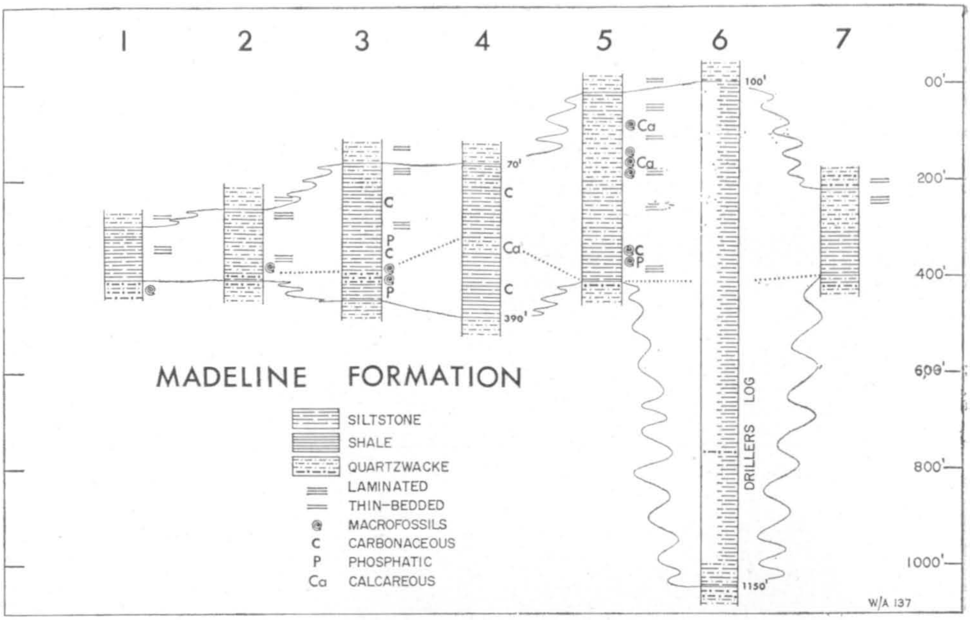


Fig. 117. Stratigraphic columns, Madeline Formation.

Thickness (Fig. 117).—The Madeline Formation is 395 feet thick in the type section. Elsewhere in the Bogadi Syncline it is 450 feet thick 4 miles north-east of Mount Madeline, about 280 feet thick on the east flank at the Wooramel River, about 500 feet east-south-east of Bogadi Outcamp, and about 1050 feet in Bogadi Bore (from about 100 feet to 1150 feet depth). It is 150 feet thick in the Daurie Syncline. In the Monument Syncline it is 285 feet thick in outcrop on Daurie Creek and 320 feet (70 to 390 feet depth) in BMR 9. In the Daurie and Monument Synclines the Madeline is conformable on the Keogh Formation, which grades laterally into the Madeline towards the synclinal axis. In BMR 9 the Madeline is conformable on the Monument Formation. In the Bush Creek Syncline the Madeline Formation varies from 50 to 110 feet thick, conformable between the Congo Formation below and Bogadi Greywacke above—the Bogadi here is probably a lateral variant of the upper part of the Madeline. In the Mintahalla Syncline the Madeline Formation is 180 feet thick, conformable between Curbur Formation and Bogadi Greywacke.

The Madeline Formation is unconformable on Precambrian gneiss and schist along the Madeline Unconformity. Four to 5½ miles north-east of Mount Madeline, it is unconformable on the Coyango Greywacke of the Lyons Group. It is unconformable on Callytharra Formation and Lyons Group 1 to 4 miles south of Plant Well. In Bogadi Bore the Madeline Formation probably includes lateral variants of the Keogh and One Gum Formation and rests on Monument Formation.

Fossils.—The Madeline Formation includes many fossiliferous beds. In the lower siltstone member the fossils are generally small; brachiopods predominate. In the upper member the assemblage is large and individual beds contain abundant specimens. The assemblages include:

Lower member

[1]Foraminifera
[1]Bryozoa : fenestellid
[1]Brachiopods : *Neospirifer*
Linoproductus
Cleiothyridina
chonetid
streptorhynchid
martiniopsid
[2]*Permorthotetes*
Strophalosia prideri Coleman
Aulosteges ingens Hosking
Kiangsiella condoni Thomas
Pseudosyrinx sp.
Hoskingia trigonopsis (Hosking)
[2]Pelecypods: *Astartila blatchfordi* (Hosking)
Glyptoleda sp. nov.
Aviculopecten cf. *subquinquelineatus* (McCoy)
Pseudomyalina sp.
Praeundulomya concentrica Dickens
Atomodesma mytiloides Beyrich
Streblochondria sp.
[2]Gastropods: *Mourlonia*? sp.
Baylea? sp.
[1]*Conularia*
[1]?*Teredo*
[2]*Glossopteris*

Upper member

[1]Foraminifera
Bryozoa: [1]fenestellid
[2]*Streblotrypa* sp.
[2]batostomellid
[2]Brachiopods: *Strophalosia* sp. nov.
Neospirifer spp. nov.
N.rostalinus (Hosking)
N.byroensis (Glauert)
Aulosteges ingens Hosking
Streptorhynchus sp.
Cleiothyridina sp.
Linoproductus (*Cancrinella*) sp.
[3]Pelecypods: *Atomodesma mytiloides* Beyrich
Astartila blatchfordi (Hosking)
Aviculopecten cf. *subquinquelineatus* (McCoy)
Stutchburia sp.
Chaenomya sp.
Heteropecten sp.
Pseudomyalina sp.
Praeundulomya concentrica Dickins
Pseudomonotis sp.
Schizodus sp.
[2]*Solenomorpha* sp.
[3]Gastropods: *Ptychomphalina maitlandi* Eth.
Mourlonia (*Pseudobaylea*) sp. nov.
Bellerophon sp.
Warthia sp.
Macrochilina sp.
[2]*Stachella* sp.
[2]*Conularia* sp.
[2]Scaphopods
[2]Worm burrows
[2]*Glossopteris*

Age.—The assemblage has such a large proportion of new or local species that in itself it is of little value for direct determination of precise age. There is no doubt that it is younger than the Callytharra assemblage, which is lower Artinskian. It has a few similarities with the Callytharra assemblage and many with the Coyrie assemblage, which is definitely Artinskian. There are no species characteristic of the Cundlego or Wandagee Formations. The age of the Madeline Formation is Artinskian and probably about middle Artinskian.

Correlation.—On the basis of faunas, the Madeline Formation may be correlated with all or part of the Coyrie Formation of the Bidgemia and Merlinleigh Basins. Lithologically it is most like the lower half of the Coyrie Formation. No equivalent fauna is known from the Fitzroy Basin or from the Irwin Basin, although a few Madeline genera are found in one or both of these basins.

[1]Field determinations; [2]Dickins, 1956, unpub.; [3]Dickins, 1963.

Structure.—The Madeline Formation is synclinal in the Bogadi Syncline: it crops out on both flanks and the southern plunge and is present, subsurface, in the central part of the syncline in Bogadi Bore. In the Daurie Syncline it crops out on both flanks and the northern plunge; in the Monument Syncline on the east flank and northern plunge; in Bush Creek Syncline on both flanks and the northern plunge; and in the Mintahalla Syncline on the eastern flank. Small synclines west and south-west of Mount Madeline contain Madeline Formation. Two miles south of Callytharra Spring is a south-plunging syncline in Madeline Formation, and a narrow syncline trends south-south-west from 5 miles east of Callytharra Spring. A parallel syncline is developed between Six-Mile Bore and Ballythanna Hill. The northern plunge of the Ballythanna Hill Anticline is developed in the Madeline Formation from 2½ miles west of Breakaway Bore, Byro station, to the Wooramel River. Two small anticlines, plunging north, are developed 5½ and 6½ miles east of Callytharra Spring.

Large slump folds and faults are developed in the Madeline Formation 3 to 5 miles south-west of Bogadi Bore, Byro.

Palaeogeography.—The Madeline Formation was deposited in a sea of moderate depth receiving detritus from a terrain of low relief. The large slump-folds and the change from arenaceous sediments of the upper Wooramel Group into lutite of the Madeline indicate a topographic basin in the present position of the Bogadi Syncline: the topographic relief during deposition was probably much less than the present structural relief (about 1100 feet). The change upwards into sandy sediment suggests that after an initial fairly deep submergence there was a stillstand during which the depositional area shallowed by accumulation of sediment without accompanying subsidence. The lower part of the outcrop sequence was probably deposited under conditions of restricted circulation, as a result of which phosphate and pyrite were laid down and evaporites precipitated: this suggests that the submergence resulted largely from a local downwarp within the Byro Basin, leaving the Wooramel Sill at relatively high level and restricting movement of water masses between the Byro Basin and the open sea. If this is so, the Madeline Formation as a continuous rock-body of similar lithology never had any extensions outside the Byro Basin.

Economic Geology.—The Madeline Formation has no present use except as a cover rock to the Wooramel Group aquifers. Although it is almost certainly a source bed formation for petroleum only the lower parts that change laterally into the Wooramel Group may have provided petroleum for migration into a covered reservoir rock.

The bedded gypsum may indicate other evaporites. The phosphatic beds are too few and too low in phosphate to be useful. The shale of the lower part of the outcrop sequence may be of use for brick manufacture, but it has not been tested.

Problems.—The fauna requires study to establish its relationships and to help in the faunal subdivision of the Permian of Australia.

The nature of the evaporite association present below the water table is unknown: trace element analysis of the gypsum at outcrop may indicate whether any of the more useful salts are present.

Bogadi Greywacke

The Bogadi Greywacke (Konecki, Condon, Dickins, & Quinlan 1958, p.74; Konecki, Dickins, & Quinlan, 1958, p. 46-48) is the formation of bedded fine-grained and medium-grained quartzwacke that is conformable between the Madeline Formation and the Warra Warringa Formation and in places grades laterally into the upper part of the Madeline Formation.

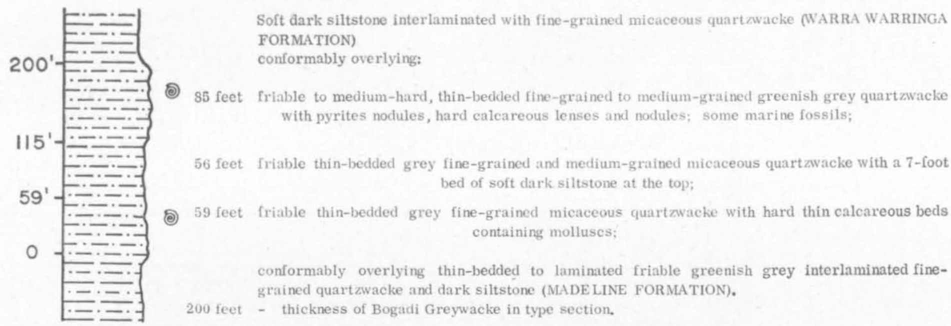


Fig. 118. Type section, Bogadi Greywacke.

The type locality (Fig. 114) is along the lower part of Madeline Creek and from its mouth upstream along the Wooramel River to near Warra Warringa Pool. The type section (Fig. 118) was measured in this locality, where the outcrop is well exposed. The dip is generally eastward at about 2°, but there are several gentle undulations along the river section. The section in this part was measured by walking individual beds through these undulations.

The base of the Bogadi Greywacke is placed at a minor change of lithology from interlaminated fine-grained quartzwacke without siltstone beds or laminae. This minor change shows clearly in air-photographs. The top of the formation is taken at the change from quartzwacke to siltstone and shale with interlaminated fine-grained quartzwacke. Both boundaries are gradational.

Distribution (*Fig. 119*).—The Bogadi Greywacke crops out in a belt from 1 to 4 miles wide around the central area of the Bogadi Syncline; and in the central parts of the Monument, Daurie, Bush Creek, and Mintahalla Synclines.

Thickness.—Only in the Bogadi Syncline can full thicknesses of the Bogadi Greywacke be determined, as elsewhere its top is the present erosion surface in the centre of the synclines. In the Bogadi Syncline the Bogadi Grewacke is 200 feet thick in the type section at the Wooramel River, 300 feet ± 50 feet on the northern plunge, 120 feet on the north-eastern flank, 350 feet on the north-western flank, 300 feet on the south-western flank, 250 feet on the southern plunge, and 200 feet at Bogadi Outcamp on the south-eastern flank. In the Bush Creek

Syncline 240 feet remains, in the Daurie Syncline only 50 feet; 200 feet of the Bogadi crops out in the Monument Syncline, where the lower part is a lateral variant of the upper part of the Madeline Formation; in the Mintahalla Syncline 120 feet of the Bogadi remains.

Fossils.—The Bogadi Greywacke has a small marine fossil fauna. Dickins (1956, unpubl.) has identified the following:

Wood fragments.
- Crinoids:
  - *Calceolispongia acuminata*(?) Teichert
  - *Calceolispongia* spp. nov.
  - Stem ossicles
- Brachiopods:
  - *Neospirifer byroensis* (Glauert)
  - *N. rostalinus* (Hosking)
  - *Hoskingia trigonopsis* (Hosking)
  - *Martiniopsis* sp.
  - *Aulosteges*
- Pelecypods:
  - *Astartila blatchfordi* (Hosking)
  - *Heteropecten* sp. nov.
  - aviculopectinids
- Gastropods:
  - *Ptychomphalina maitlandi* Eth. fil.
- Cephalopods:
  - *Propinoceras* sp. ind.
- Conularid:
  - *Conularia* sp.

All these forms, except the *Calceolispongia* spp. and *Propinoceras* sp., are known in the Madeline Formation. The *Calceolispongia* spp. have affinities with those of the Bulgadoo Shale of the Merlinleigh Basin. As no *Calceolispongia* are identified from the Coyrie Formation the range of these forms in the northern sequence is not known (but see p. 143 on Bulgadoo fauna).

Age.—As the fauna has a major element similar to forms in the Madeline Formation and a minor element like forms in the Bulgadoo Shale its age is Artinskian, probably middle.

Correlation.—Konecki, Dickins, & Quinlan (1958) correlated the Bogadi Greywacke with the Mallens Greywacke, but although this is not excluded comparison of the sequences in the Byro Basin and Merlinleigh Basin indicates that it is more likely to be equivalent to a part of the Coyrie Formation (Fig. 101). The dominance of fossils of Madeline-Coyrie type support this correlation, but the presence of a species of *Calceolispongia* of a group not known below the Bulgadoo Shale raises some doubt.

Structure.—The Bogadi Greywacke is synclinal in all its outcrops; very gentle undulations are present on the western flank of the Bogadi Syncline.

Palaeogeography.—The sandy sediment, the marine fossils, and the evidence of invertebrate scavengers together indicate a moderately shallow sea with a relation between depth and supply of sediment that prevented reworking by wave and current action. The shallowing by infilling of the basin continued from the Madeline Formation. Sedimentation may have been continuous over the areas between the Byro Basin and the Merlinleigh and Gascoyne Basins.

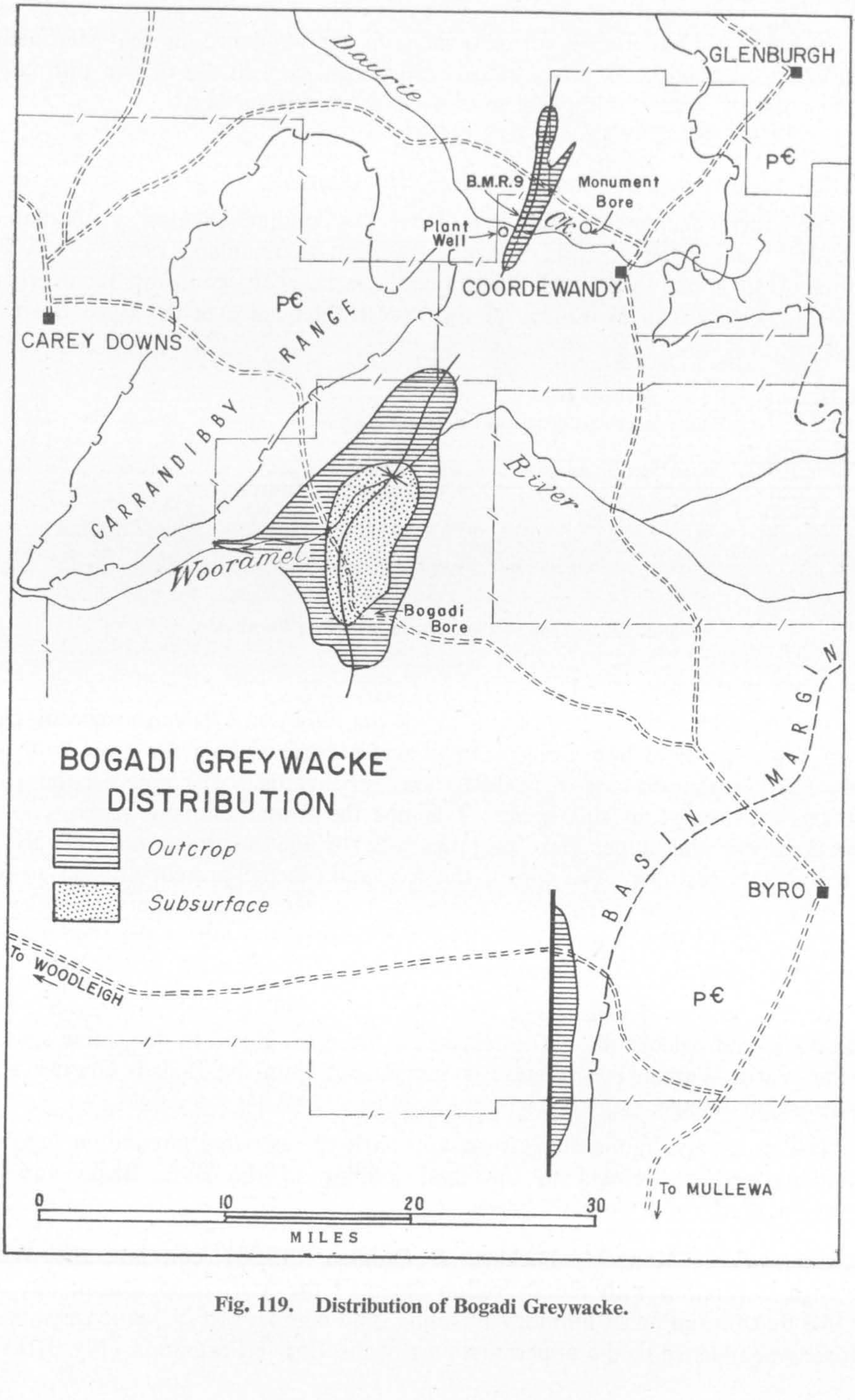


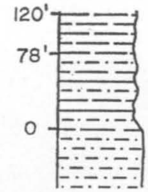
Fig. 119. Distribution of Bogadi Greywacke.

Economic Geology.—The Bogadi Greywacke has no present use and no obvious potential.

Problems.—The precise correlations with the sequence in the Merlinleigh Basin are not established: study of *Calceolispongia* spp. in the Coyrie Formation seems necessary before this problem can be examined further.

Warra Warringa Formation

The Warra Warringa Formation (Konecki, Condon, Dickins, & Quinlan *in* McWhae et al., 1958, p. 74; Konecki, Dickins, & Quinlan, 1958, p. 48-50) consists of siltstone, shale, and fine-grained quartzwacke, conformably overlying the Bogadi Greywacke at the top of the Permian sequence in the Byro Basin.



Synclinal axis

42 feet soft dark sandy siltstone with thin red phosphatic calcareous beds;

78 feet soft dark micaceous siltstone interlaminated with light grey fine-grained micaceous quartzwacke and soft black carbonaceous shale;

conformably overlying medium hard grey fine-grained to medium-grained micaceous quartzwacke (BOGADI GREYWACKE).

120 feet - thickness of Warra Warringa Formation in type section.

Fig. 120. Type section, Warra Warringa Formation.

The type locality (Fig. 114) is along the Wooramel River upstream from Warra Warringa Pool and along a small watercourse joining the river from the south 200 yards north-east of Middle Camp stockyards. The type section (Fig. 120) was measured in this area: it is not the most complete section of the formation, but the upper part cropping out to the north cannot reliably be related to this section. The top of the formation is the present erosion surface in the Bogadi Syncline. The type section is 120 feet thick, to the synclinal axis; about another 40 feet is preserved above the level of the top of the type section, in the area 1½ miles to the north-east.

A few marine fossils have been found, including foraminifera, bryozoa, gastropods, and pelecypods. These have not been examined to determine species. As the Warra Warringa Formation is transitional from the Bogadi Greywacke it is Artinskian in age.

The rocks and fauna suggest an approach to restricted circulation lagoonal conditions perhaps related to the final infilling of the Byro Basin and the regression of the sea from this area.

Correlation.—Konecki, Dickins, & Quinlan (1958) correlate the Warra Warringa Formation with the Bulgadoo Shale of the Merlinleigh Basin; but it is not like that formation in lithology or fauna, and comparison of sequence suggests a closer resemblance to the uppermost part of the Coyrie Formation (Fig. 101).

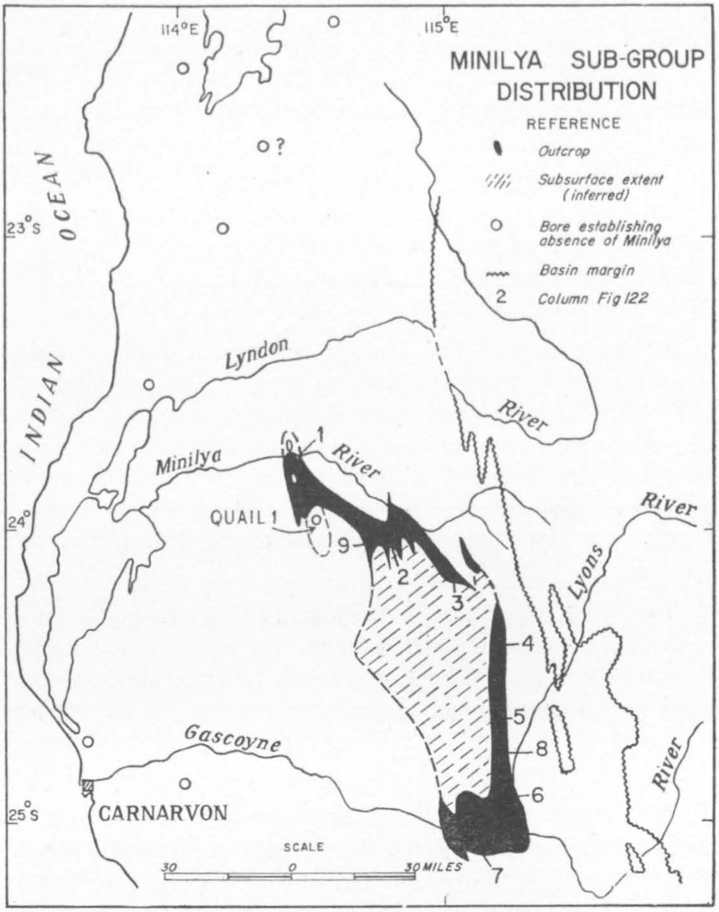


Fig. 121. Distribution of Minilya Subgroup.

Minilya Subgroup

The Minilya Subgroup (Condon, 1962a) is the upper part of the Byro Group; it consists of fine to medium-grained quartzwacke, siltstone, and shale, with marine fossils; and it rests disconformably (in places unconformably) both on the Newman Subgroup and beneath the Kennedy Group. It includes the Cundlego Formation, Quinnanie Shale, Wandagee Formation, Norton Greywacke, and Baker Formation. It is known only in the Merlinleigh Basin, where it crops out between the Minilya and Gascoyne Rivers (Fig. 121).

The Minilya Subgroup is 2190 feet thick at the Minilya River (in the type locality of the Subgroup between Cundlego Crossing and Curdamuda Well) with a sand/shale ratio of 1.73; more than 2200 feet (composite) in bores BMR 6 and 7, Muderong (sand/shale about 1.2); 2125 feet at the head of Norton Creek; 2500 feet south-west of Mount Sandiman woolshed; 1050 feet south-west of Lyons River homestead; 1400 feet in the Walbarune Peak area; and 1900 feet near Jimba Jimba (Fig. 122). Much of the thickness variation appears to be related to the shape of the surface of the Newman Subgroup. Although no sediments of the Minilya Subgroup were identified in BMR 5, Giralia, it is possible that they occur a little to the north in the deepening part of the Gascoyne Basin.

The Minilya Subgroup is lithologically similar to the Newman Subgroup, but is separated from it by a disconformity. In a few places, such as 12 miles west of Gascoyne Junction and, less certainly, north of Barrabiddy Creek near Barrabiddy Dam, Wandagee, the Minilya is unconformable on the eroded surface of folded Newman Subgroup.

The upper boundary of the Minilya Subgroup, also, is a disconformity. The Kennedy Group is lithologically distinct from the Minilya although not unlike some parts of it. In some places around Kennedy Range, e.g. north of Southern Cross Bore, Middalya, the disconformity is suggested by a sharp change in lithology, but elsewhere, where the upper part of the Baker Formation is sandy, the change is less marked. To the east of Calvary Well, Jimba Jimba, the Kennedy Group rests with angular unconformity on a truncated surface of the Minilya Subgroup.

The marine fossil assemblage is dominated by brachiopods and crinoids, but includes a wide range of forms. Many of the fossils are found in mud balls and probably were rolled to their present position. Invertebrate trails and scavenged sediment attest the presence of an abundant bottom population at times, but the general occurrence of carbon and pyrite indicates a non-oxidising environment within the sediment.

The fossils of the Minilya Subgroup show similarities with those of the Newman Subgroup below and of the Kennedy Group above. There are, however, significant differences that would probably justify the establishment of local substages, within the Artinskian.

The separation of the fossils of Teichert's 'Coolkilya sandstone' into their stratigraphical position above and below the disconformity makes the faunal break between the Byro Group and the Kennedy Group, suggested by Thomas & Dickins (1954), more obvious: *Permorthotetes teicherti* Thomas, *Marginifera gratiodentalis* (Grabau), *Krotovia spinulosa* (J. Sowerby), *Helicoprion davisii* (Woodward), and *Paragastrioceras wandageense* Teichert, all previously stated to occur in the Coolkilya, are in fact found no higher than the Baker Formation.

The absence of the Artinskian species of *Helicoprion* and *Paragastrioceras* makes more certain the Kungurian age of the Coolkilya Greywacke.

The Minilya Subgroup was deposited in a neritic to infraneritic basin with moderately to completely restricted water circulation. The location of the sill leading to open sea has not been established, but may have been in the Mia Mia area or the Mardathuna area or both. The source of sediment was distant from the area of outcrop and probably was a dominantly sedimentary rock terrain; it may have been mainly the uplifted western part of the Palaeozoic sediments of the Gascoyne Basin (see Fig. 123).

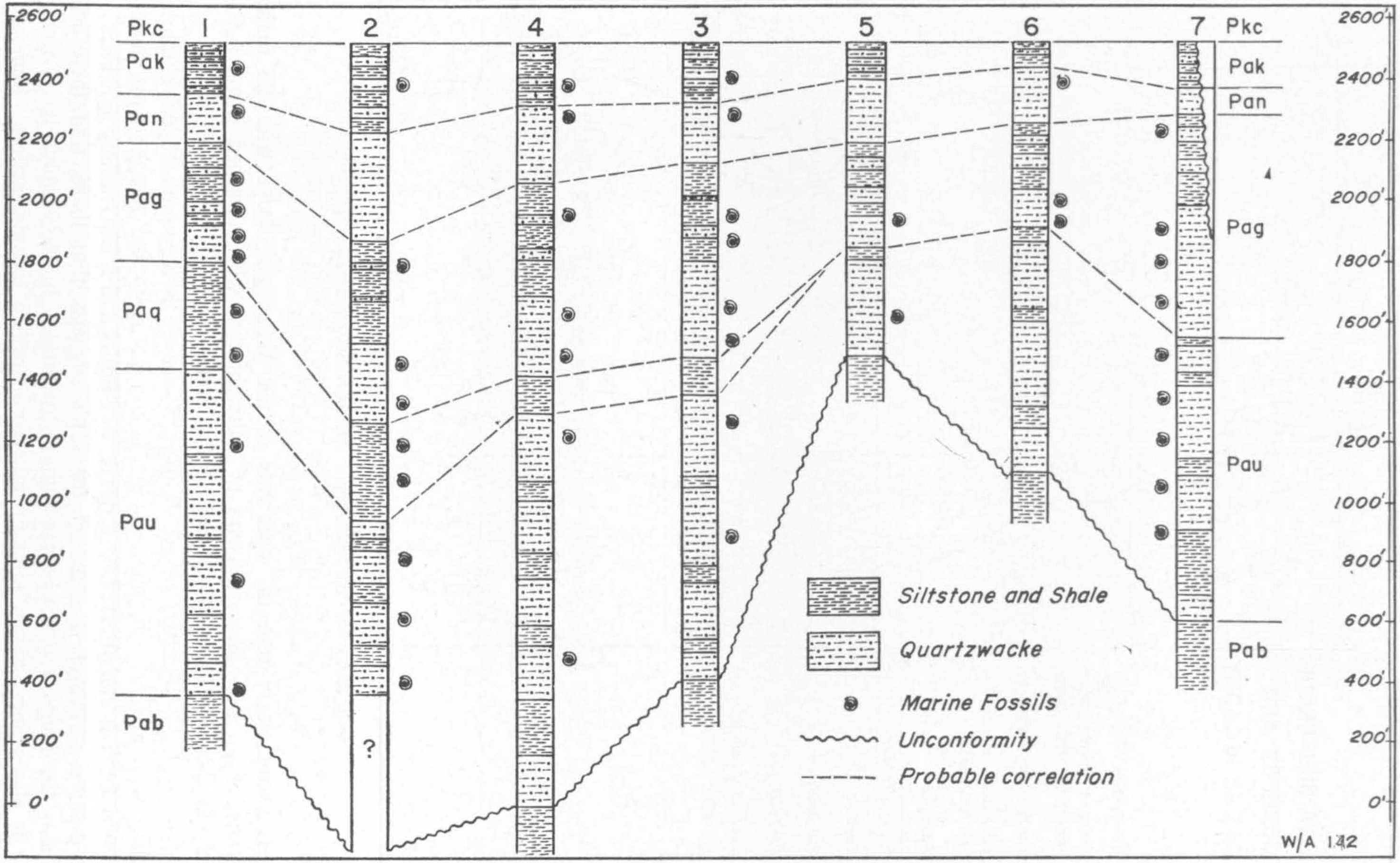


Fig. 122. Stratigraphic columns, Minilya Subgroup. Pkc-Coolkilya Greywacke; Pak-Baker Formation; Pan-Norton Greywacke; Pag-Wandagee Formation ; Paq-Quinnanie Shale ; Pau-Cundlego Formation ; Pab-Bulgadoo Shale.

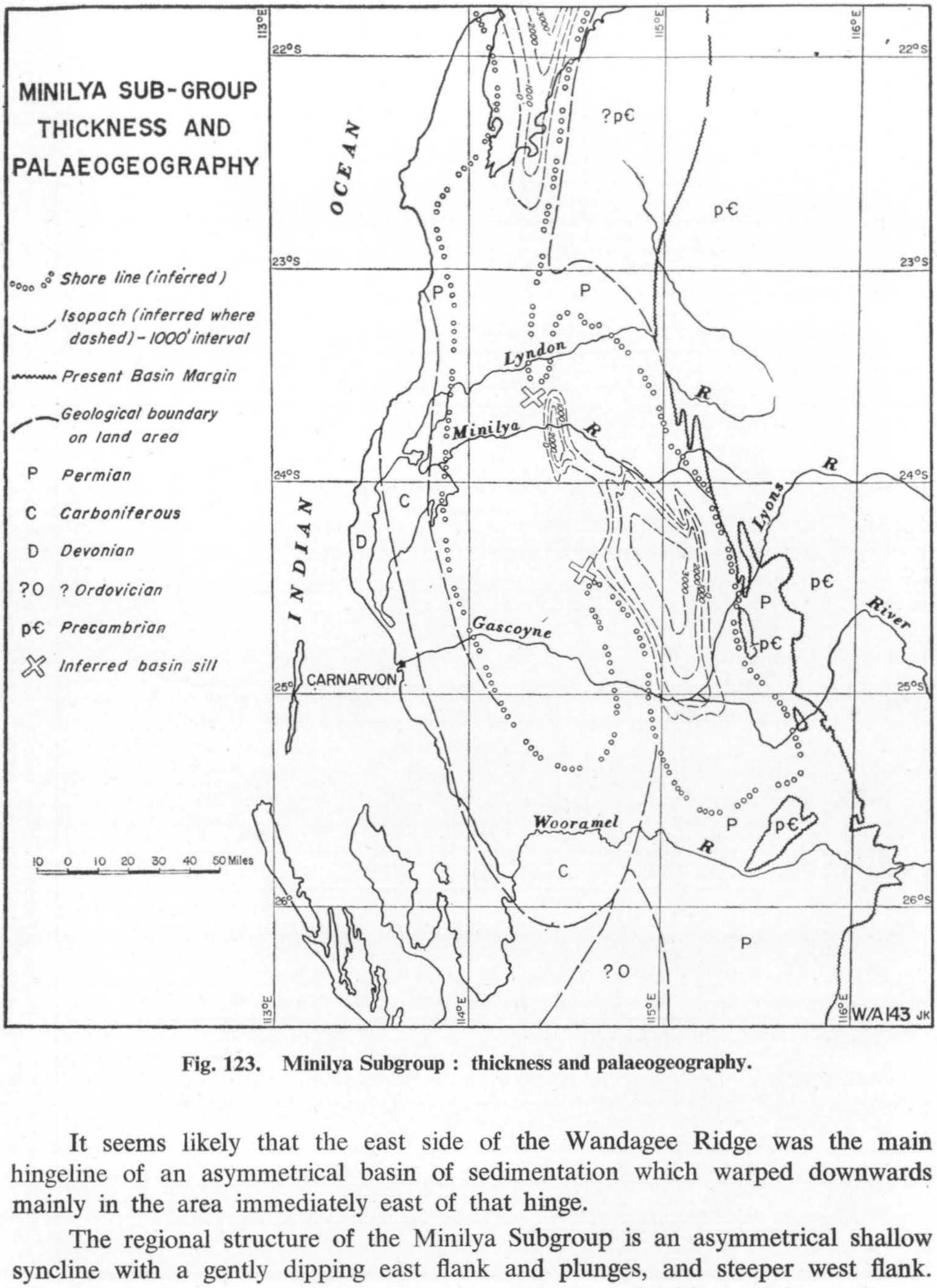


Fig. 123. Minilya Subgroup : thickness and palaeogeography.

It seems likely that the east side of the Wandagee Ridge was the main hingeline of an asymmetrical basin of sedimentation which warped downwards mainly in the area immediately east of that hinge.

The regional structure of the Minilya Subgroup is an asymmetrical shallow syncline with a gently dipping east flank and plunges, and steeper west flank. The west flank is complicated by a number of faults and folds (mainly synclines). The detailed structure in some of the folds suggests that these, and therefore probably the faults, are large-scale slump structures. In the Minilya River area, there is also compressional jointing indicating positive tectonic action. Some of the faults in the Wandagee Hills/Minilya River area (e.g. 2 miles north of Wandagee Hill, and 500 yards east of Curdamuda Well, Wandagee) are invaded by evaporites probably of diapiric form.

The Minilya Subgroup includes much shale and siltstone of petroleum source-bed type, interbedded with sands of low to moderate porosity. Petroleum was probably formed in this sequence and was able to move freely. The sedimentary structures, slump and depositional, were available to trap this migrating oil and probably have not been much deformed since. In addition the more sandy units such as the Cundlego, lower Wandagee, and Norton probably formed pinch-out traps of relatively high porosity against the hingeline and were overlain by impermeable caprocks of the same sedimentary episode. Some homoclinal stratigraphic traps may have formed, also, in the east flank of the Merlinleigh Basin, but these are less likely to have been preserved.

Problem.—Although it is almost certain that the Subgroup changes laterally to a finer-grained sequence in the central parts of the Merlinleigh Basin and to a more sandy sequence on the east flank of Wandagee Ridge the precise extent of the outcrop sequence is not known.

The detailed structure of the subgroup and its equivalents is not known at all and will require seismic surveys and drilling to determine.

Much work remains to be done on the complete description of the faunas of the subgroup; this is important as it may form the basis for a time-rock unit applicable at least to all the Western Australian basins.

Cundlego Formation

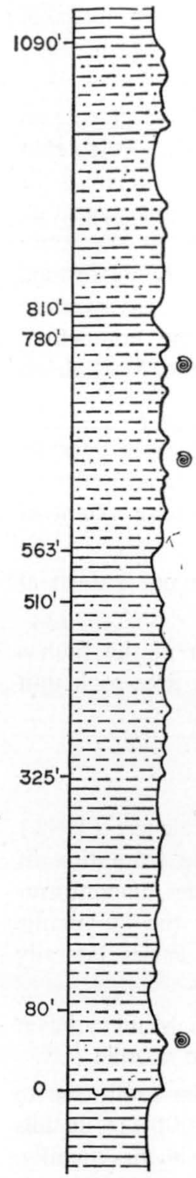
The Cundlego Formation (Condon, 1954) was named by Teichert (1941) and formally defined by Condon (1954, amended 1962a) as the formation of quartzwacke and carbonaceous siltstone disconformably (in places unconformably) overlying the Bulgadoo Shale and overlain conformably by the Quinnanie Shale or Wandagee Formation. In places the Quinnanie Shale varies laterally into the Cundlego Formation.

The type locality (Fig. 108) is at Cundlego Crossing on the Minilya River (Lat. 23° 44½′ S., Long. 114° 27¼′ E.) and upstream for about a mile.

The type section (Fig. 124) was measured from 1½ miles east-south-east to 1 mile south-east of Cundlego Well; the Cundlego Formation is 1090 feet in this section, which is one of the few complete sections of the formation in the vicinity. Generally the formation is cut by strike faults in this area.

The base of the Cundlego Formation is commonly marked by a 'lag gravel' consisting of pebbles formed from the calcareous nodules of the Bulgadoo Shale and with worn rolled fossils. Generally the underlying Bulgadoo Shale consists of carbonaceous shale, or siltstone, whereas the lower part of the Cundlego Formation is dominantly sandy.

The top of the Cundlego is taken at the change in lithology from dominant quartzwacke to either dominant shale or interbedded fossiliferous quartzwacke and siltstone.



Soft white gypsite with fragments of red phosphatic siltstone (QUINNANIE SHALE) conformably overlying:

280 feet friable light grey laminated fine-grained quartzwacke, with thin beds and thin to thick lenses of hard calcareous quartzwacke and thin beds of soft dark grey siltstone;

30 feet soft dark grey roughly bedded siltstone;

217 feet friable light greenish grey festoon-laminated fine-grained quartzwacke with beds and lenses of hard grey fine-grained calcareous quartzwacke and few beds with marine fossils;

53 feet soft dark grey carbonaceous shale and siltstone; few thin network beds of red phosphatic calcareous siltstone

185 feet friable to medium hard light greenish grey laminated fine-grained quartzwacke and hard grey festoon-laminated calcareous quartzwacke with fontainebleu structure; minor thin soft dark siltstone;

245 feet interlaminated soft dark grey siltstone and friable light grey fine-grained quartzwacke minutely cross-laminated in places;

80 feet friable light greenish grey laminated and festoon-laminated fine-grained quartzwacke; thin network of beds of phosphatic calcareous siltstone; minor soft dark grey siltstone; few marine fossils; basal bed is a conglomerate with pebbles of phosphatic siltstone;
disconformably overlying soft dark grey laminated siltstone with few thin network beds of phosphatic calcareous siltstone and very few beds of fine-grained quartzwacke (BULGADOO SHALE).

1090 feet - thickness of Cundlego Formation in type section.

Fig. 124. Type section, Cundlego Formation.

A feature of the Cundlego Formation not previously reported is the characteristic festoon bedding (Allen et al., 1960). There is still some doubt about the nature of this sedimentary structure. In the abundant examples provided by the Cundlego Formation there seems little doubt that the structure is giant ripple-lamination with ripples of a wavelength of 2 to 4 feet and amplitude of 6 to about 9 inches. The sediment is poorly sorted and certainly underwent little winnowing by the waves producing the ripples. The occurrence of this structure mainly in this one formation (not below and only occasionally above) indicates a peculiar sedimentary environment. The few available indications of the palaeogeography (the variations in sand/shale ratio and the fossils) suggests a fairly shallow gulf in which waves may have had very long reach in one direction (the present southward). This suggests that the sea (or gulf) in which the Cundlego Formation was deposited may have been open into the northern part of the Perth Basin.

The Cundlego Formation crops out between the Minilya River and the northern scarp of the Kennedy Range and intermittently from near Merlinleigh to the south side of the Gascoyne River at Gascoyne Junction. It is 1090 feet on Minilya River (sand-shale ration of 3.1); about 750 feet west of Quail Quail Creek; 780 feet 6 to 10 miles north of Paddys Outcamp, Middalya; 1150 feet at the head of Norton Creek south of Kimbers Well (sand/shale about 3.8); 450 feet east of Merlinleigh (sand/shale about 2.2); 460 feet 7 miles west of Lyons River homestead (sand/shale about 6.0)—the lower part of the formation is absent above the disconformity; 1200 feet 8 miles south-west of Lyons River homestead; 800 feet 10 miles north of Gascoyne Junction (sand/shale about 8.0); and 1350 feet south of the Gascoyne River west of Gascoyne Junction (sand/shale = 3.6).

Cundlego Formation was penetrated in bore BMR 7, Muderong, from 1215 feet to total depth of 1997 feet. Disseminated pyrite is common, slump folding and brecciation are seen in many of the cores, and thin beds of calcilutite, not observed in outcrop, are present. The sand/shale ratio is 1.4 (Fig. 125).

Thus there is a general thickening towards the main synclinal area of the Merlinleigh Basin accompanied by an increase in the proportion of siltstone—strongly suggesting that the present structural form reflects the topographic form of the basin during sedimentation.

Marine fossils occur sporadically in the Cundlego Formation: they include foraminifera (Crespin, 1958 p. 17), rare bryozoa, *Calceolispongia* (Teichert, 1949), other crinoids (Teichert, 1954), brachiopods (chonetid, spiriferid, productid, and 'martiniopsid'), *Conularia*, and mollusca (pectinids, gastropods, and nautiloids).

The age is fixed as Artinskian by reference to the well-established Wandagee Formation above and Callytharra Formation below. Although the faunas have not been described in any detail it is obvious that they have changed significantly from those of the Bulgadoo Shale and older formations. The disconformity between the Bulgadoo and Cundlego represents an important hiatus within the Artinskian which has not been reported elsewhere in Australia.

The Cundlego Formation was probably a very good oil-generating formation, with interbedded and basinally developed shales rich in organic matter deposited in a non-oxidizing environment and draining oil into interbedded sands. Porosity traps may be well developed in the sands by carbonate cement, and structural and stratigraphic traps are to be expected where the Cundlego abuts on the eastern flank of the Wandagee Ridge, for example, the anticline along Salt Gully 11 miles west of Gascoyne Junction developed in Wandagee Formation.

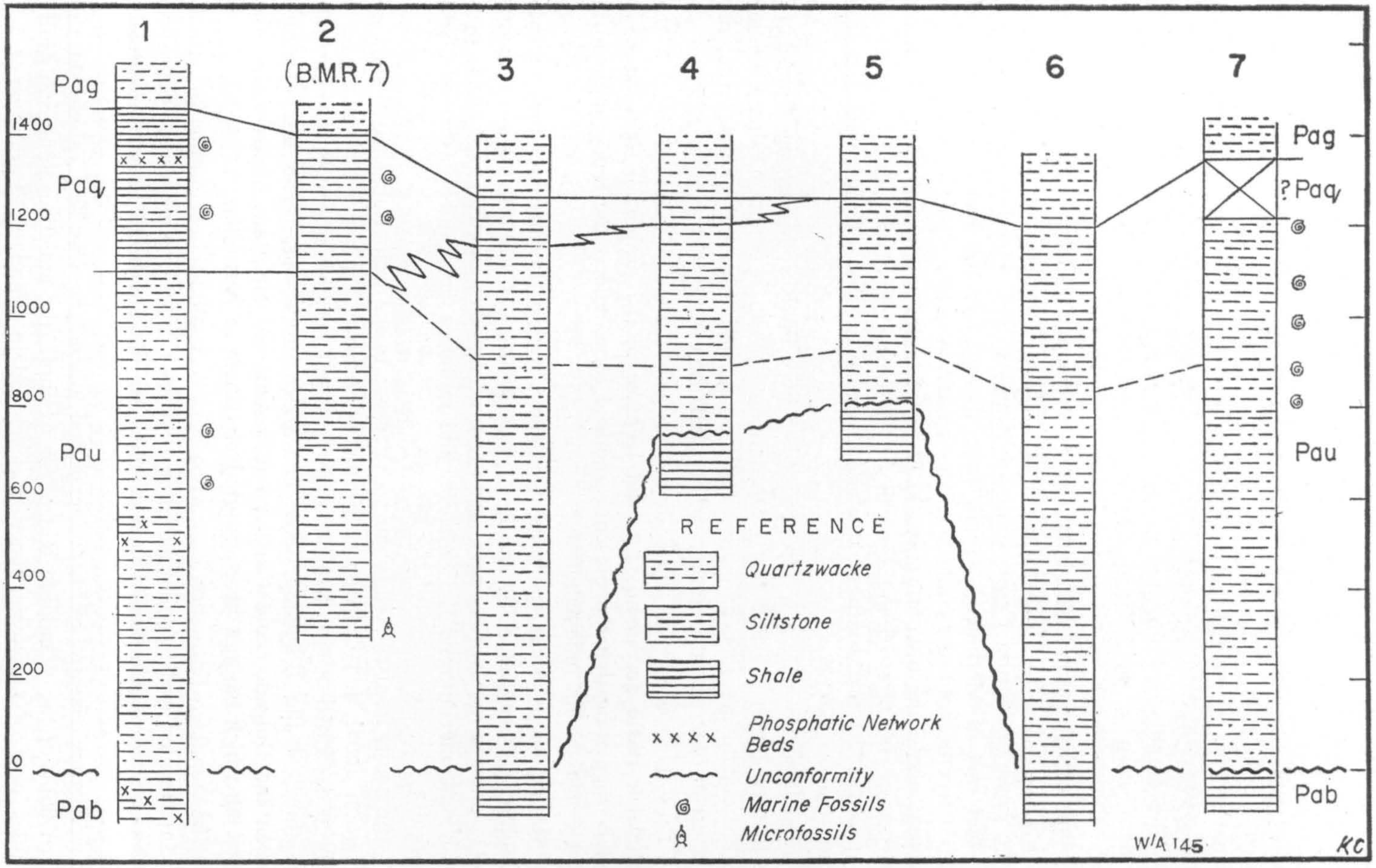


Fig. 125. Stratigraphic columns, Cundlego Formation (Pau) and Quinnanie Shale (Paq). Pag-Wandagee Formation ; Pab-Bulgadoo Shale. Location of sections shown in Fig. 121.

Quinnanie Shale

The Quinnanie Shale was named by Teichert (1950) and defined by Condon (1954). It consists predominantly of carbonaceous shale with minor siltstone and quartzwacke and phosphatic-calcareous network beds. It is conformable with the Cundlego Formation below and the Wandagee Formation above. In some places it grades laterally into the Cundlego Formation.

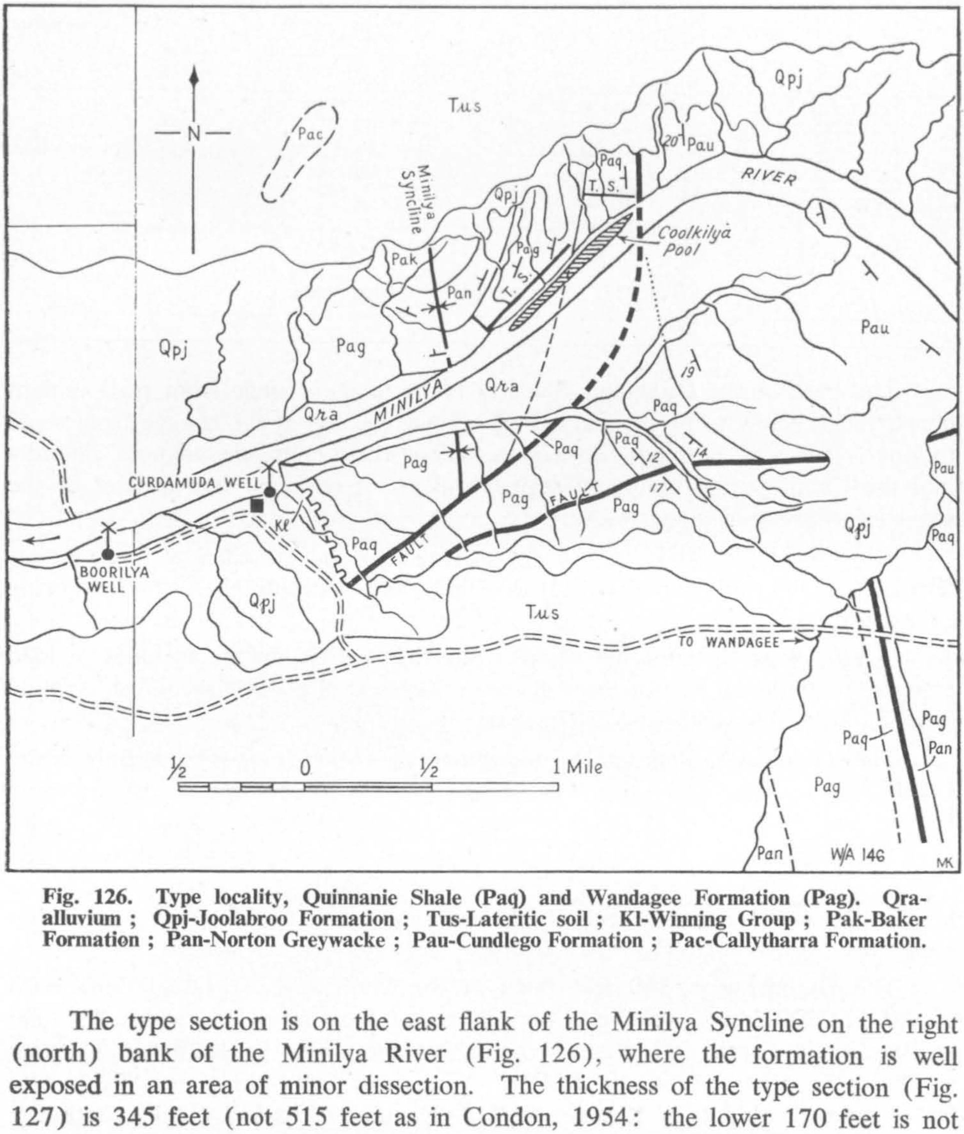


Fig. 126. Type locality, Quinnanie Shale (Paq) and Wandagee Formation (Pag). Qra-alluvium ; Qpj-Joolabroo Formation ; Tus-Lateritic soil ; Kl-Winning Group ; Pak-Baker Formation ; Pan-Norton Greywacke ; Pau-Cundlego Formation ; Pac-Callytharra Formation.

The type section is on the east flank of the Minilya Syncline on the right (north) bank of the Minilya River (Fig. 126), where the formation is well exposed in an area of minor dissection. The thickness of the type section (Fig. 127) is 345 feet (not 515 feet as in Condon, 1954: the lower 170 feet is not part of the type section and should be correlated with the lowermost part of the type section, not added below it). The fault between Quinnanie and Cundlego cuts out very little of the section of either formation: south of the river an unfaulted section of the Quinnanie (shown on Fig. 126) is 360 feet thick.

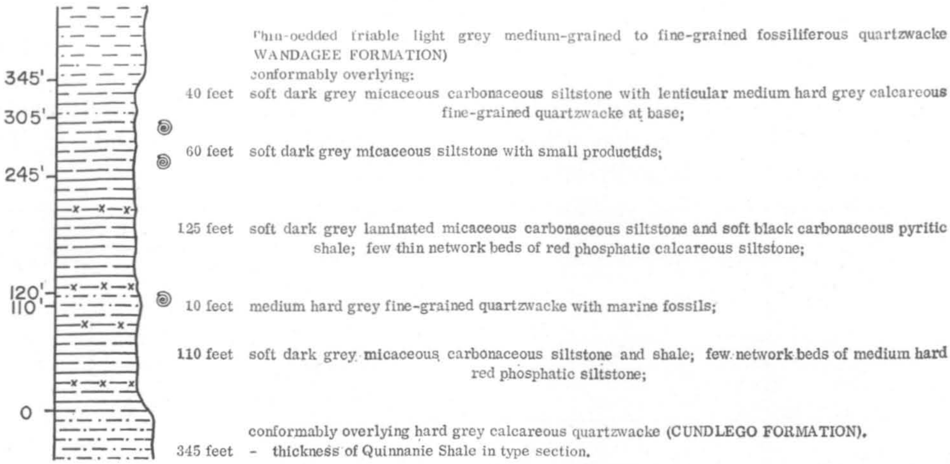


Fig. 127. Type section, Quinnanie Shale.

The base of the Quinnanie Shale is taken at the change from predominant quartzwacke below to predominant shale above; the top at the change from shale to quartzwacke with minor siltstone. Where the Quinnanie changes laterally into the Cundlego the boundary may be taken where about one quarter of the sequence consists of quartzwacke.

The Quinnanie Shale is a dark carbonaceous pyritic shale with foraminifera, ostracods, and chonetids. It was certainly deposited in a non-oxidizing environment.

On the west flank of the Minilya Syncline the Quinnanie includes bedded gypsum, probably as part of the sequence. There is also some secondary selenite formed during the weathering of the shale.

The Quinnanie Shale crops out from the Minilya River to Barrabiddy Creek, at the head of Norton Creek near the northern scarp of the Kennedy Range, and to the east of Kennedy Range near Merlinleigh. South of Merlinleigh it changes laterally into the Cundlego Formation. It has not been recognized farther south, although, to the south of Kennedy Range, the stratigraphic interval in which it would occur is very poorly exposed, and it could be present in that area.

The Quinnanie is 360 feet thick at the Minilya River (sand/shale ratio of 0.035); 390 feet 3 miles north-north-east of Wandagee Hill; about 300 feet at Barrabiddy Creek; 315 feet (900 to 1215 feet, not 195-1020 to 1215 feet as shown by Perry, 1965) in BMR 7 Muderong (sand/shale ratio 0.2); 100 feet 3 miles south-east of Kimbers Well, Williambury; 50 feet 1 mile south-east of Merlinleigh; absent from 5 miles south-east of Merlinleigh to the Gascoyne River. On the north side of the River at Jimba Jimba an area of no outcrop between the Cundlego and Wandagee, representing a stratigraphic interval of 130 feet, may be underlain by Quinnanie Shale (Fig. 125).

Fossils.—The Quinnanie Shale is not very fossiliferous, but chonetids and foraminifera (*Hyperammina acicula* (Parr) and others—Crespin, 1958, p. 7) occur sporadically throughout. In a few more fossiliferous beds a fairly abundant fauna is found, including foraminifera, solitary corals, crinoid stem ossicles, *Calceolispongia* sp., *Lingula, Neospirifer, Streptorhynchus hoskingae* Thomas, productid and chonetid brachiopods, Aviculopectinidae, *Undulomya, Permonautilus,* and gastropods including Bellerophontidae.

Age.—The assemblage is Permian and its species all range from Cundlego to Wandagee Formation. On the basis of the Artinskian age of the Wandagee and Coyrie the Quinnanie is certainly Artinskian.

Economic Geology.—The Quinnanie Shale is of source-bed type: shale with abundant carbon, pyrite, and microfossils indicating abundant organic life and non-oxidizing conditions in the sediment. The lateral variations into the more sandy Cundlego Formation would have provided opportunity for early migration of petroleum.

The primary gypsum exposed on the west flank of the Minilya Syncline suggests that other evaporite salts may also be present below the water table.

Wandagee Formation

The Wandagee Formation (Condon, 1954) was named by Condit (1935), but was not defined as a formation until 1954 (by Condon). It is the formation of quartzwacke, some calcareous, and siltstone, with abundant marine fossils, conformable between the Quinnanie Shale and Norton Greywacke. Where the Quinnanie Shale has changed into the Cundlego Formation the Wandagee is conformable on that formation.

The name derives from Wandagee station, where the formation crops out between the Minilya River and Mungadan Creek.

The type locality (Fig. 126) is along the right (north) bank of the Minilya River 9 miles west of Wandagee homestead (or 7 miles west of north of Wandagee Hill). The type section (Fig. 128) is very well exposed in the bank and minor dissection and abundant fossils strew the surface of the terrace about 20 feet above river level.

The base of the Wandagee Formation is taken at the change from dominant quartzwacke with fossils above to either siltstone or interbedded quartzwacke and siltstone below. The top is at the change from interbedded quartzwacke and siltstone below to quartzwacke above. The formation has two main parts: a lower part dominantly of quartzwacke and richly fossiliferous and an upper part of interbedded quartzwacke and siltstone with fewer fossils.

The Wandagee Formation rarely displays the festoon bedding that is so characteristic of the Cundlego; it is characterized by the deranged bedding produced by scavenger action, and by the rolled mud balls, commonly containing fossils, that appear to have been picked up by the soft mud ball rolling along the bottom.

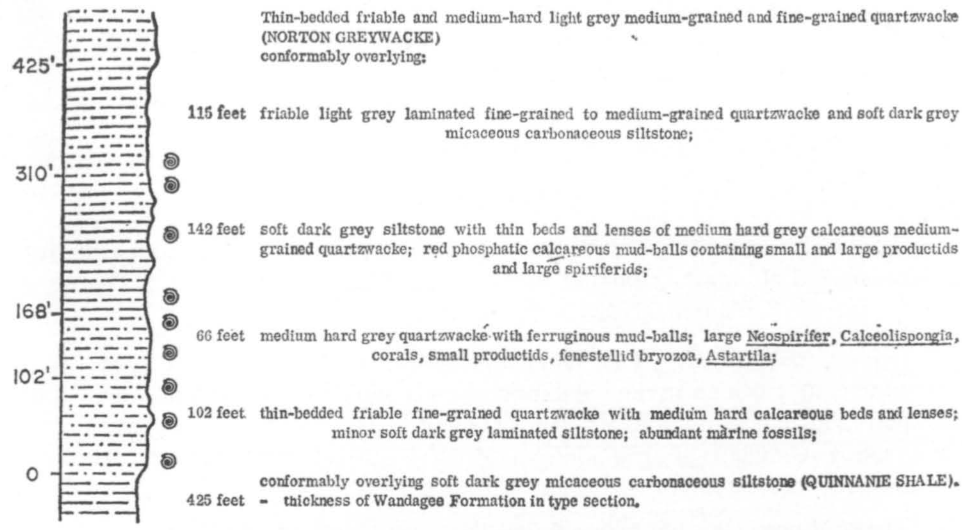


Fig. 128. Type section, Wandagee Formation.

Reduced outcrop and occasional low discontinuous ridges (of the more calcareous beds) are characteristic of the surface expression of the formation. In air-photographs, the outcrop of the formation appears as a broadly banded pattern of dark and light tones and fine grain. Soaks (gilgais) are common on the surface of the upper member.

The only variation from the rocks typical of the Byro Group is a minor development of thin beds of limestone of dense hard calcilutite type, mainly without fossils—a few beds contain sparse brachiopods.

The Wandagee Formation crops out between the Minilya River and Mungadan Creek, south of Barrabiddy Creek, in a number of synclines between Paddys Outcamp and the head of Norton Creek, and east of the eastern scarp of Kennedy Range southward from Merlinleigh. The outcrop swings around parallel to the scarp at its south end and continues to the Calvary Well area. There is a small outcrop area south of the Gascoyne River in Salt Gully.

The Wandagee Formation is 425 feet thick at the type locality on the Minilya River (sand/shale ration of 2.0: upper member 0.95, lower member 13.0); 550 feet 2 miles north of Wandagee Hill; 520 feet 1½ miles south-east of Wandagee Hill; about 540 feet at Barrabiddy Creek; 800 feet 5 miles north of Paddys Outcamp, Middalya station (sand/shale = 1.6); 380 feet (from 470 feet to 850 feet) in BMR 6 Muderong, Middalya (sand/shale = 2.4); about 520 feet in a poorly exposed outcrop 2 miles south-west of the mouth of Norton Creek; about 450 feet 2½ miles east of Bakers Bore, Middalya (sand/shale = about 3.0); 470 feet 4 miles south-west of Kimbers Well, Williambury (sand/shale = 1.8); 670 feet at the head of Norton Creek, 3 miles south-south-east of Kimbers Well (sand/shale = 0.6); 680 feet in the scarp immediately south of Merlinleigh

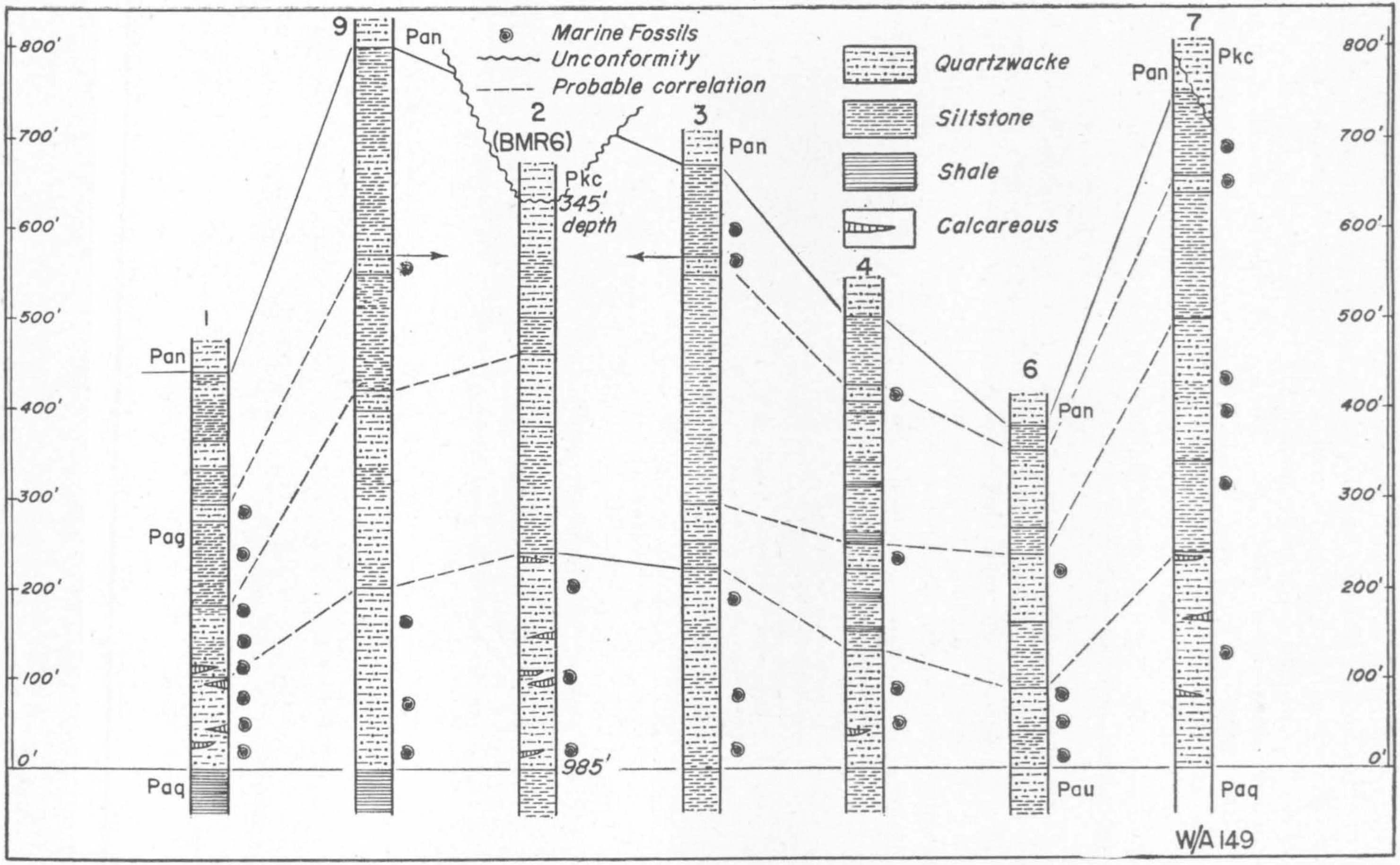


Fig. 129. Stratigraphic columns, Wandagee Formation (Pag). Location of sections shown in Fig. 121. Pan-Norton Greywacke ; Pkc-Coolkilya Greywacke ; Paq-Quinnanie Shale ; Pau-Cundlego Formation.

homestead (sand/shale about 1.0); about 630 feet 12 miles south of Merlinleigh (only bottom and top exposed but this is the northernmost outcrop where the Wandagee rests on the Cundlego); about 470 feet 10 miles west-north-west of Lyons River homestead (sand/shale about 1.5); 435 feet 8 miles west of Lyons River homestead (sand/shale = 1.2); 540 feet 14 miles south-south-west of Lyons River homestead (sand/shale = 1.1); 400 feet 10 miles north of Gascoyne Junction (sand/shale = 1.0); 380 feet 5 miles north of Gascoyne Junction, east of Walbarune Peak (sand/shale = 1.1); 750 feet 8 miles west-north-west of Gascoyne Junction (sand/shale = 1.3); about 600 feet in Salt Gully, 11 miles west of Gascoyne Junction (sand/shale ratio low) (see Fig. 129).

Fossils.—The Wandagee Formation is one of the more fossiliferous of the Permian formations, with a fauna moderately rich in species and very abundant in individuals. Although the fauna has been studied since 1910, it is still very incompletely known. Because of its wide variety of forms it is essential that the whole fauna be adequately described to help in correlations with sequences containing less diverse faunas. The faunal list at present established is as follows (only firm reliable determinations are given species names);

Foraminifera (Crespin, 1958):
- *Ammobaculites wandageensis* Crespin
- *Ammodiscus nitidus* Parr
- *A. wandageeensis* Parr
- *Hyperammina acicula* (Parr)
- *H. coleyi* Parr
- *H. elegans* (Cushman & Waters)
- *Hyperamminita rudis* (Parr)
- *Giraliarella rhomboidalis* Crespin
- *Proteonina arenosa* Crespin
- *Reophax emaciatus* Plummer
- *R. tricameratus* Parr
- *Thurammina phialaeformis* Crespin
- *Tolypammina undulata* Parr
- *Trochammina subobtusa* Parr
- *Flectospira prima* Crespin & Belford
- *Frondicularia parri* Crespin
- *Hemigordius harltoni* Cushman & Waters
- *Nodosaria raggatti* Crespin
- *Pseudohyperammina radiostoma* Crespin
- *Rectoglandulina serocoldensis* (Crespin)
- *Thuramminoides sphaeroidalis* Plummer

Corals (Hill, 1952):
- *Allotriophyllum*
- *Euryphyllum*
- *Thamnopora*
- *Veerbeekiella*

Bryozoa (Crockford, 1944a & b):
- *Fenestella*
- *Minilya*
- *Polypora*

Crinoids (Teichert, 1949):
- *Calceolispongia abundans* Teichert
- *C. elegantula* Teichert
- *C. multiformis* Teichert
- *C. rotundata* Teichert
- *C. rubra* Teichert
- *C. spectabilis* Teichert

Blastoids

Brachiopods (Coleman, 1957; Thomas, 1958; and others):

Aulosteges baracoodensis Etheridge fil.
A. ingens (Hosking)
Dictyoclostus
Hustedia
Krotovia spinulosa (J. Sowerby)
Linoproductus cancriniformis (Tschernyschew)
Marginifera gratiodentalis (Grabau)
Taeniothaerus coolkiliensis Coleman
T. miniliensis Coleman
T. teicherti Coleman
Etheridgina muirwoodae Prendergast
Strophalosia multispinifera (Prendergast)
S. (Heteralosia) etheridgei Prendergast
S. (Heteralosia) kimberleyensis Prendergast
S. (Heteralosia) tenuispina Waagen
Streptorhynchus hoskingae Thomas
Chonetes
Cleiothyridina
Phricidothyris
Neospirifer
Spiriferella
Yochelsonia thomasi Stehli
Hoskingia wandageeensis Campbell
Gilledia cf. *homevalensis* Campbell

Pelecypods (Dickins, 1963):

'Allorisma' sp.
Astartila blatchfordi (Hosking)
A. cf. *fletcheri* Dickins
Atomodesma mytiloides Beyrich
Aviculopecten sp.
Aviculopecten sp. nov.
Cypricardinia? sp.
'Deltopecten' sp. nov.
Euchondria sp. nov.
Girtypecten? sp.
Glyptoleda cf. *glomerata*
Leiopteria? sp.
'Modiolus' sp.
Palaeocosmomya teicherti Dickins
P. cf. *aplatum*
Palaeosolen? sp.
pectinid gen. et sp. nov.
Phestia basedowi (Eth. fil.)
Platyteichum johnstonei
Pseudomonotis sp. nov.
Pseudomyalina mingenewensis
Schizodus kennedyensis Dickins*
S. cf. *kennedyensis* Dickins
Schizodus sp. nov.
Streblopteria sp.
Streblopteria? sp. nov.
Stutchburia sp. nov.
Undulomya rugulata Fletcher

Gastropods (Dickins, 1963):

Bellerophon sp. nov.
Euphemites sp. nov.
Mourlonia (Mourlonia) sp. nov.
Peruvispira sp. nov.
Ptychomphalina cf. *maitlandi* Eth.
Retispira cf. *emerii*
Stachella sp. nov.
Straparolus (Euomphalus) sp.

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* In Dickins (1963, Fig. 5) *Schizodus kennedyensis* is shown as not occurring in the Wandagee Formation. However, the stated locality of Paratype B in Dickins (1956, p.31) is definitely in the Wandagee Formation.

Ammonoids:
Propinacoceras australe Teichert
Nautiloids:
Titanoceras
Conularia.

Age and Correlation.—Raggatt & Fletcher (1937) established the Permian age of the Byro Group. Teichert (1941) first correlated the Wandagee Formation with the Artinskian Stage, and this has been confirmed by later work.

Because of differences in the faunal assemblages, detailed correlation with Permian sequences in eastern Australia cannot be made, but the following formations (in whole or part) may be correlated with the Wandagee: Berriedale Limestone of Tasmania, Mulbring Subgroup of the north Sydney Basin, and Ingelara Formation of the north Bowen Basin. Firm correlation is established with the upper part of the Noonkanbah Formation of the Fitzroy Basin of Western Australia.

Economic Geology.—The Wandagee Formation includes good source beds with interbedded sands that would have favoured early migration of petroleum. The quartzwacke member may be permeable enough to form reservoirs in areas that were topographically high during deposition e.g. bore BMR 6 Muderong, and, probably, the eastern flank of the Wandagee basement ridge.

Norton Greywacke

The Norton Greywacke (Condon, 1954) is the formation predominantly of medium-grained to fine-grained quartzwacke, conformably between the Wandagee Formation below and the Baker Formation above. In some places it grades laterally into the Baker Formation and is likely to grade completely into the Baker Formation, in the central area of the Merlinleigh Basin. It is overlain unconformably by the Coolkilya Greywacke at the south end of Kennedy Range.

The type locality of the Norton Greywacke (Fig. 130) is near the head of a tributary of Norton Creek. The type section (Fig. 131) was measured across the ridge 9 miles south-east of Bakers Bore, Middalya, where a fully exposed section crops out (lat. 24° 12¼′, long. 115° 02′ E). The base is fairly well exposed in the eastern scarp of the ridge and the top is well exposed in a knoll on the western side; the thickness there is 235 feet. The base is taken at the change from fine-grained sediments (siltstone and laminated very fine-grained quartzwacke) below to roughly bedded medium-grained quartzwacke above. The top is at the change from medium-grained quartzwacke to siltstone and laminated fine-grained quartzwacke above.

The Norton Greywacke is fairly uniform in lithology, varying mainly in percentage of silt matrix. Other minor variations include carbonate cement, generally in lenticular masses, and fossiliferous beds, containing mainly pelecypods. The cleaner varieties are porous and permeable enough to form useful aquifers and certainly would be adequate as petroleum reservoirs. The permeability of the formation is estimated to range from about 5 to 50 millidarcies.

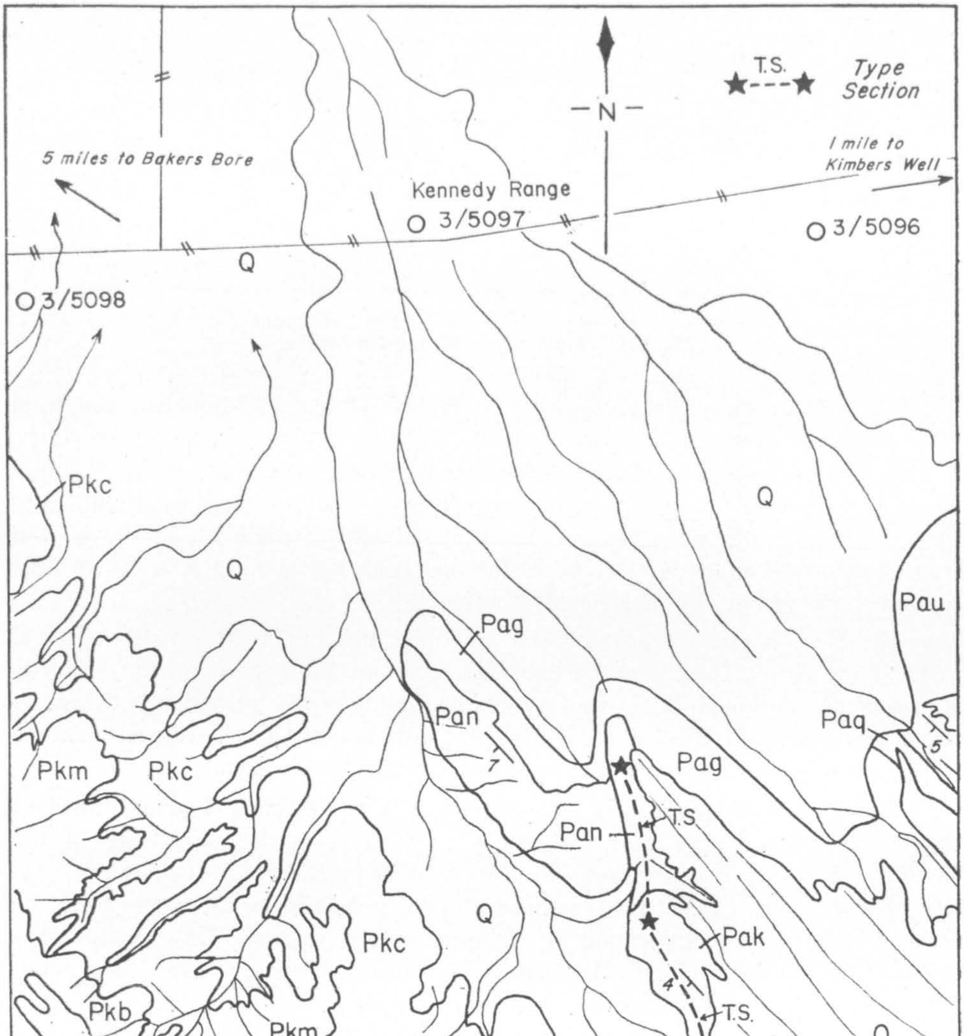
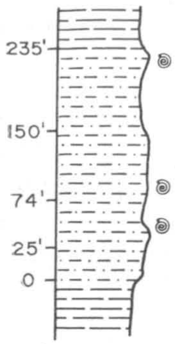


Fig. 130. Type locality, Norton Greywacke (Pan) and Baker Formation (Pak). Q-Quaternary ; Pau-Cundlego Formation ; Paq-Quinnanie Shale ; Pag-Wandagee Formation ; Pkc-Coolkilya Greywacke ; Pkm-Mungadan Sandstone ; Pkb-Binthalya Formation.



Soft dark grey laminated micaceous carbonaceous siltstone (BAKER FORMATION) conformably overlying:

85 feet friable grey laminated medium-grained micaceous quartzwacke with small ferruginous concretions;

76 feet friable to medium hard grey bedded medium-grained quartzwacke; low conical 'worm mounds' on bedding planes; scattered large ferruginous concretions; pelecypod coquinite at base;

49 feet medium hard roughly bedded medium-grained quartzwacke with conical 'worm mounds' and pelecypods;

25 feet friable thin-bedded to laminated medium-grained quartzwacke; conformably overlying soft dark grey siltstone with few thin beds of laminated fine-grained quartzwacke (WANDAGEE FORMATION).

235 feet - thickness of Norton Greywacke in type section.

Fig. 131. Type section, Norton Greywacke.

The Norton Greywacke crops out at Paddys Outcamp, Middalya, and from there eastward to south of Kimbers Well, Williambury, in a series of synclines. It crops out in the eastern scarp of Kennedy Range southward from 1¼ miles south-west of Merlinleigh, leaves the scarp 9 miles south of Merlinleigh and from there crops out intermittently as a low ridge roughly parallel to the scarp and from ½ mile to 2 miles away. At Walbarune Peak the outcrop belt swings west around the southern end of Kennedy Range.

The Norton Greywacke has been identified also in the Minilya River area, in the same stratigraphic position and with the same lithology as in the Kennedy Range area. Although there is no present continuity of the formation between the two areas the similarities of the unit in the two areas strongly suggest that the formation was continuous before erosion of the intervening area.

The Norton Greywacke is 177 feet thick in the Minilya Syncline north of the Minilya River (Fig. 133, column 1); 250 feet at the south end of the Coolkilya Syncline 2 miles north-north-west of Wandagee Hill (Column 9) (in this area Teichert (1957, p.1) mapped Coolkilya 'Sandstone', but there can be no doubt about the identification of the formations in sequence here, and there is certainly no Coolkilya Greywacke in the Coolkilya Syncline—see Fig. 134); about 200 feet 1.3 mile south-east of Wandagee Hill (upper boundary not well exposed): 250 feet at Paddys Outcamp, Middalya; 135 feet in bore BMR 6 Muderong, (335 to 470 feet), where the Coolkilya rests unconformably on it; 255 feet in BMR 7 Muderong (from 485 to 740 feet depth); 220 feet 1½ miles east of Bakers Bore, Middalya; 235 feet in the type section 9 miles south-east of that bore; 175 feet (incomplete at top) 3 miles south-east of Kimbers Well, Williambury; 176 feet 10 miles south of Merlinleigh; 180 feet 9½ miles west of Lyons River homestead; 240 feet 3 miles farther south; about 350 feet 10½ miles south-west of Lyons River homestead; about 400 feet 16 miles north of Gascoyne Junction; 220 feet 4 miles farther south; 280 feet 11 miles north of Gascoyne Junction; 200 feet 9 miles north of Gascoyne Junction (here the upper part of the Norton has changed into the Baker Formation); about 180 feet at Walbarune Peak and at Mungarra Creek; and 130 feet to the south of Kennedy Range, 9 miles west-north-west of Gascoyne Junction.

As there are very few siltstone beds in the Norton Greywacke the sand/shale ratio is not significant; however, the proportion of silty matrix varies considerably and in general the thicker sections also have the cleaner lithology, except in the Coolkilya Syncline.

Fossils.—The fossil beds in the Norton Greywacke are discontinuous but where present are consistently in a few levels of the formation: up to three pelecypod coquinites are present in the middle part of the formation and a brachiopod-pelecypod coquinite near the top. The following forms have been identified:

Crinoids:
- *Calceolispongia*

Brachiopods:
- *Chonetes*
- *Strophalosia (Heteralosia) kimberleyensis* Prendergast
- *Neospirifer*
- *Aulosteges*
- *Marginifera gratiodentalis* (Grabau)
- *Taeniothaerus teicherti* Coleman
- *Permorthotetes teicherti* Thomas

Pelecypods (Dickins, 1963):
- *'Allorisma'* sp.
- *Astartila blatchfordi* (Hosking)
- *Atomodesma mytiloides* Beyrich
- *Aviculopecten*? cf. *hardmani*
- *Chaenomya* sp.
- *Cypricardinia*? sp.
- *Euchondria* sp. nov.
- *Leiopteria*? sp.
- *Megadesmus* sp. nov.
- *'Modiolus'* sp.
- *Oriocrassatella stokesi* Eth. Jr.
- *Palaeosolen*? sp.
- *Phestia thomasi* (Dickins)
- *Plagiostoma* sp.
- *Pseudomonotis* spp. nov.
- *Schizodus kennedyensis* Dickins
- *Schizodus* sp. nov.
- *Streblopteria* sp.
- *Streblopteria*? sp. nov.
- *Stutchburia muderongensis* Dickins
- *Stutchburia* sp. nov.

Gastropods (Dickins 1963):
- *Bellerophon* cf. *pennatus*
- *Mourlonia (Mourlonia)* sp. nov.
- *Mourlonia (Platyteichum?)* sp. nov.
- *Retispira* cf. *emerii*
- *Stachella* sp.
- *Warthia* cf. *micromphala*

Bradyodont Shark:
- *Helicoprion*

Although the assemblages are different from those of the Wandagee Formation most of the species found in the Norton are found also in the Wandagee. Some of the species found in the higher Coolkilya Greywacke are not found in the Norton, although the lithology is similar. It may be concluded that the Norton is Artinskian like the Wandagee rather than Kungurian.

Correlation.—The Norton may be correlated with the upper part of the Noonkanbah Formation of the Fitzroy Basin, but precise correlation cannot be established with formations of Eastern Australia.

The relationship of Teichert's 'Nalbia Sandstone' (1950) to the Norton Greywacke is still somewhat doubtful, despite Teichert's efforts (1957) to describe the outcrop of his unit. The upper boundary of the 'Nalbia' shown on plate 1 of his 1957 paper is within a sequence of similar lithology (quartzwacke) and is certainly not a valid formation boundary as it must rely for its identification on fossils that are established as of sporadic occurrence.

I must reiterate that exposures are not good enough in the Wandagee area to establish the sequence from the upper Byro Group to the Kennedy Group: it was only after the sequence was established in the Kennedy Range area that the sequence in the Wandagee area could be reliably inferred. Although the Baker Formation is exposed only in the Minilya Syncline north of the Minilya River it is evident in the outcrop plain around Wandagee Hill by reason of the development of clayey soil and gilgais in the areas on the downdip side of the Norton Greywacke, e.g. west of the 'Nalbia' type locality and in the central part of the Coolkilya Syncline northward from 400 yards north of the north fence of Woolies Paddock (see Fig. 134).

Furthermore, the 'Coolkilya Sandstone' or 'Coolkilya Formation' as used by Teichert (1952 and 1957) is invalid as it includes an important disconformity, not evident of course in the Wandagee area, but well established in the Kennedy Range area. Even in the Wandagee Hill area the coarse sand beds of the Coolkilya Greywacke are probably related to the transgression that followed the post-Baker regression.

Part of the reason for the confusion of sequence in the Wandagee area has been Teichert's reliance on particular fossil occurrences which he has regarded, unjustifiably, as of significance for stratigraphic identification or correlation. The '*Fenestella* nodule beds', which he states to be confined to the lower part of this 'Coolkilya Sandstone', in fact are developed in the Wandagee Formation, in the Baker Formation, and in the Coolkilya Greywacke, in areas where there is no doubt about the identification of these formations.

Dickins (1963, pp. 146-147) discusses the relationships of the 'Nalbia', Norton, and Coolkilya. He provides good evidence that the 'Nalbia' may be correlated with the Norton Greywacke and that both are almost certainly older than the Coolkilya Greywacke. He concludes that 'the retention of the younger name, Norton, hardly seems any longer necessary'. However, the Norton Greywacke was the first properly defined lithological unit in this part of the sequence.

Structure.—The Norton Greywacke is characterized by the deranged bedding produced by sediment-eating scavengers.

Palaeogeography.—The Norton Greywacke was deposited under shallower water than was the rest of the Minilya Subgroup. It probably indicates a temporary regression heralding the larger regression that followed the deposition of the Baker Formation.

Economic Geology.—The Norton Greywacke produces shallow groundwater that is quite suitable for stock, although somewhat brackish. It is permeable enough to form a prospective petroleum reservoir and is well situated between source beds of the Wandagee and Baker Formations to have obtained petroleum from them. The Baker Formation is an adequate caprock and also provides lateral porosity-gradients that may produce stratigraphic traps. Structural traps are likely on the east flank of Wandagee Ridge and beneath depositional unconformities at the north end of Kennedy Range. Homoclinal stratigraphic traps may be present, particularly in the thick sand development south-west of Lyons River homestead.

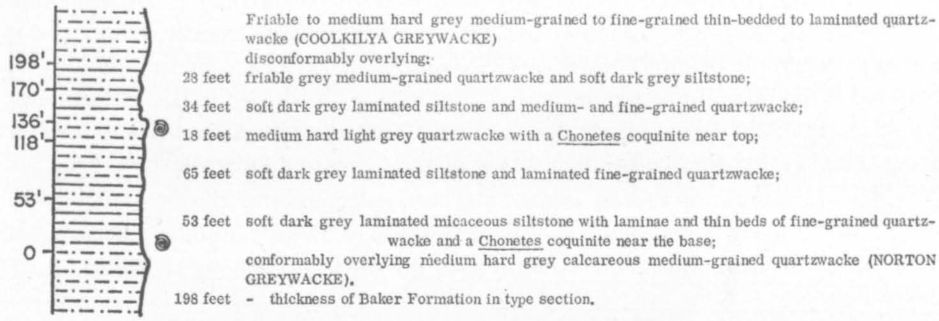


Fig. 132. Type section, Baker Formation.

Baker Formation

The Baker Formation (Condon, 1954, p.88) consists of siltstone and laminated quartzwacke and is conformable on the Norton Greywacke and is disconformably (in places unconformably) overlain by the Kennedy Group.

The type locality (Fig. 130) is at the head of Blackheart Creek, at lat. 24° 13¼'S., long 115° 02¾'E. In the type section (Fig. 132) the Baker Formation is 198 feet thick.

The base of the formation is taken at the change from quartzwacke below to siltstone above. In most places it is close to a fossiliferous hard calcareous bed near the top of the Norton Greywacke. The top of the formation is at the change from interlaminated quartzwacke and siltstone to dominant quartzwacke; although the upper part of the Baker is rarely exposed the boundary can be mapped approximately by reference to the lowermost hard calcareous quartzwacke beds of the Coolkilya.

The Baker Formation crops out in the Minilya Syncline north of the Minilya River and from near Paddys Outcamp, Middalya, to the south end of Kennedy Range. It is probably present to the east of Wandagee Hill but is not exposed.

Thickness.—In the Minilya Syncline (Section 1, Fig. 133) the Baker Formation is 153 feet thick and is sandier than elsewhere (the sand/shale ratio is 0.5). Seven miles east of Paddys Outcamp, the Baker is about 210 feet thick (sand/shale ratio 0.3) (Section 9, Fig. 133); 3½ miles south of Paddys Outcamp (Section 9) it is only 70 feet thick and the sand/shale ratio is relatively high (0.5); this outcrop is on the west flank of a syncline. The Baker Formation is absent in BMR 6, where the Coolkilya is unconformable on the Norton Greywacke. In BMR 7, only 920 feet east of BMR 6, the Baker Formation is 295 feet thick (from 190 to 485 feet depth) and the sand/shale ratio is very low (about 0.2). In the type section (Section 3) the Baker is 198 feet thick (sand/shale = 0.5); 7 miles south of the mouth of Norton Creek it is 125 feet thick; it is 121 feet 9 miles south of Merlinleigh (Section 5) at the foot of the scarp of Kennedy Range (sand/shale = 2.0); about 90 feet 21 miles south of Merlinleigh and 9½ miles west of Lyons River homestead (sand/shale low); 85 feet 13 miles north of Gascoyne Junction (sand/shale 0.2) (Section 6); and 140 feet 10 miles north-west of Gascoyne Junction at the south end of Kennedy Range (sand/shale 0.2). Thirteen miles north-west of Gascoyne Junction the Baker Formation is truncated and unconformably overlain by the Coolkilya Greywacke. The variations in lithology are believed to be related to irregularities of the surface on which the Baker Formation was deposited; the variations in thickness are related to the depositional structure accentuated by erosion before deposition of the Coolkilya Greywacke.

The Baker Formation is commonly carbonaceous and pyritic—attesting to the non-oxidizing environment of deposition. Slump folding and slump brecciation are common and confirm the presence of sloping bottoms during deposition.

Age.—The fossils are mainly foraminifera and chonetids not distinctive of precise age. The foraminifera are commonly infilled by pyrite.

Palaeogeography.—Practically no indication can be given of the regional palaeogeography during the deposition of the Baker. The central part of the Merlinleigh Basin was an area of restricted marine circulation where fine-grained sediments, probably derived mainly from a sedimentary terrain of low relief, were deposited on a floor of moderate topographic relief.

Economic Geology.—The Baker has characteristics of a good source formation for oil: non-oxidized fine-grained sediments with abundant organic debris and fine-grained sand laminae and beds to provide primary migration. The oil from the Baker may have been trapped in more sandy developments on the topographic high areas or, in areas where there was later structural movement, it may have migrated into the Kennedy Group. In some places it may have drained into the Cretaceous Birdrong Formation.

Kennedy Group

The Kennedy Group (Condit, 1935; Raggatt, 1936; Condon, 1954) consists of predominantly arenaceous sediments disconformably (in places unconformably) overlying formations of the Byro Group. It includes the Coolkilya Greywacke, Mungadan Sandstone, and Binthalya Formation.

Maitland (1919, p. 5) first referred to 'the sandstones of the Kennedy Range'. Condit (1935, p. 870) first formally named the unit Kennedy Sandstone, and Raggatt (1936, p. 141) described it as overlying the Byro Group conformably.

The type locality is the Kennedy Range—a flat-topped, steep-sided plateau about 60 miles long, 12 to 20 miles wide and 300 to 600 feet above the surrounding plains, between the Minilya and Gascoyne Rivers.

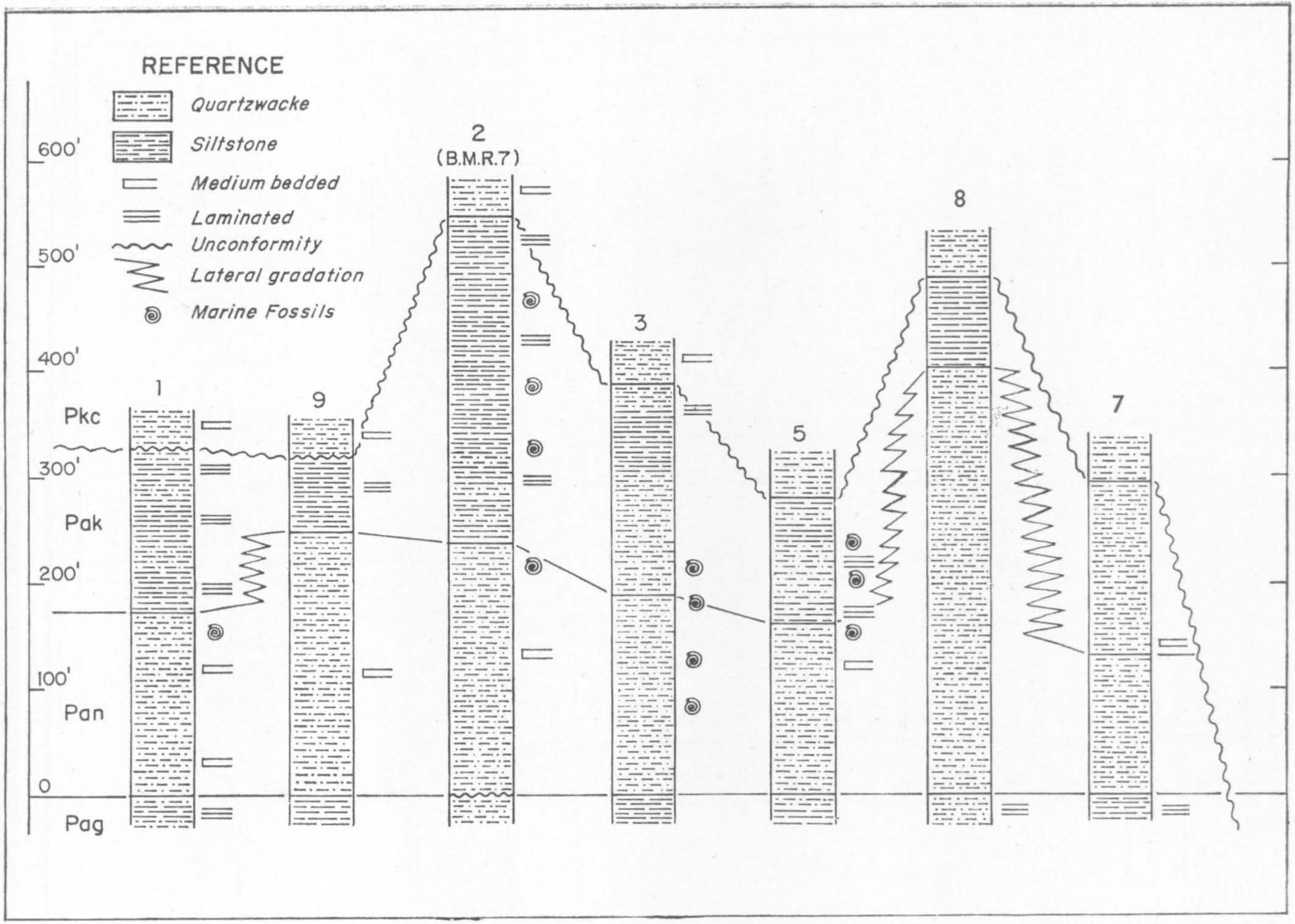


Fig 133. Stratigraphic columns, Norton Greywacke (Pan) and Baker Formation (Pak). Pkc-Coolkilya Greywacke ; Pag-Wandagee Formation. Location of columns shown in Fig. 121.

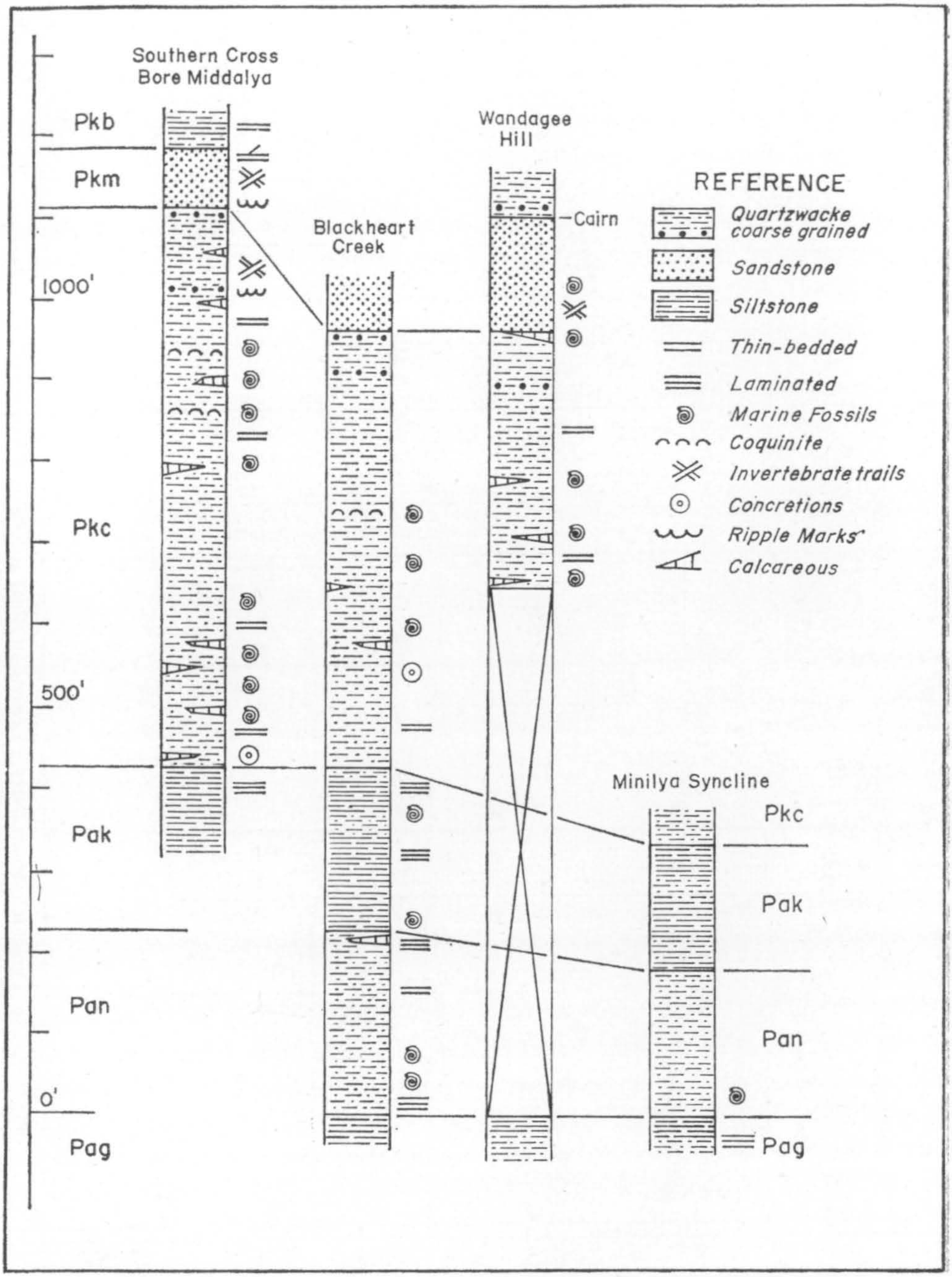


Fig. 134. Stratigraphic columns, Kennedy Range and Wandagee areas, showing identification of lithological units in the two areas. Pkb-Binthalya Formation ; Pkm-Mungadan Sandstone ; Pkc-Coolkilya Greywacke ; Pak-Baker Formation ; Pan-Norton Greywacke ; Pag-Wandagee Formation.

The base of the Group is at the change from siltstone, shale and quartzwacke below to predominant quartzwacke with minor siltstone above. This boundary is generally concordant, but at the southern end of Kennedy Range, near Calvary Well, there is a well-developed unconformity where the Kennedy Group rests on a truncated surface of the Byro Group, eroded into the Wandagee Formation.

The Kennedy Group is the uppermost remaining part of the Permian sequence in the Carnarvon Basin and is known only in the structurally lower parts of the Merlinleigh Basin (Fig. 135). In the broad sense, therefore, it represents the closing regressive stages of Permian sedimentation. Within this general regression there were two or more minor fluctuations of sea level.

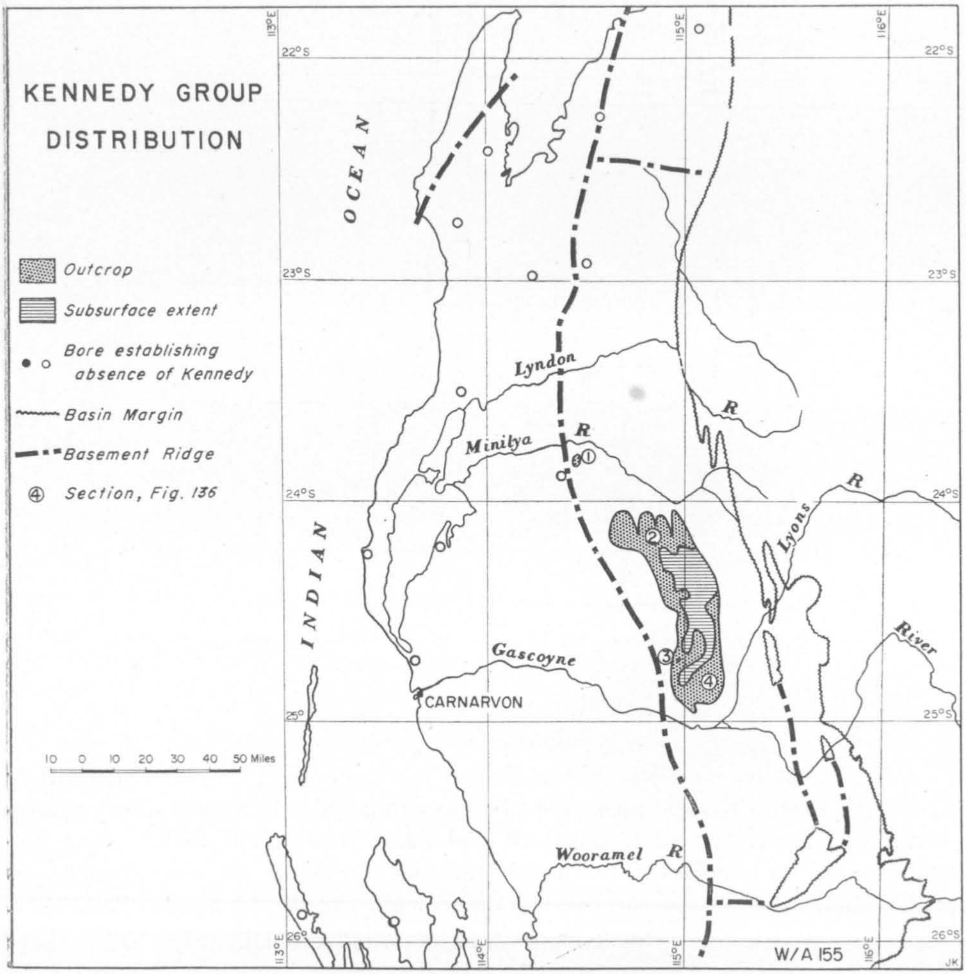


Fig. 135. Distribution of Kennedy Group.

The Kennedy Group has a marine fauna, concentrated in relatively few beds, consisting of pelecypods and brachiopods with minor foraminifera, bryozoa and crinoids. The lower part of the group is certainly Kungurian, the upper part may be Tatarian.

Although it includes beds of good reservoir characteristics it is unlikely to be prospective for oil in its outcrop area, where the structure is mainly synclinal, and no subsurface occurrence of the Group or its equivalents has been found within the Carnarvon Basin.

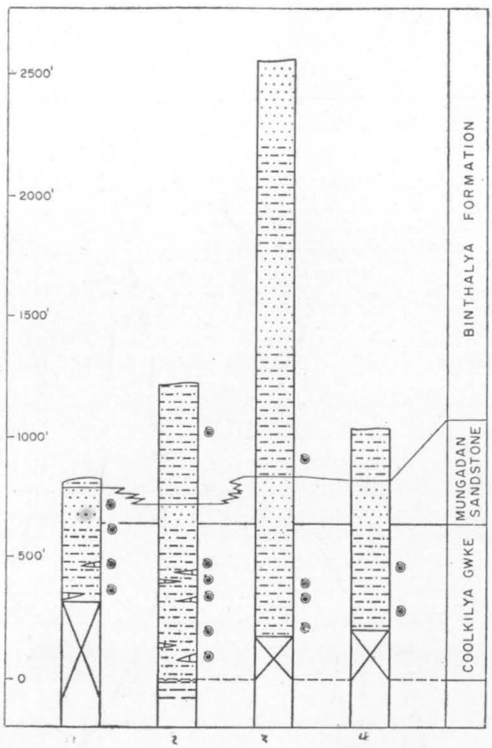


Fig. 136. Stratigraphic columns, Kennedy Group. Location of sections shown on Fig. 135.

Coolkilya Greywacke

The Coolkilya Greywacke was named by Teichert (1950) and defined by Condon (1954). It is the formation of friable thin-bedded and laminated quartz-wacke with lenticular calcareous beds and many fossiliferous beds resting disconformably on the Baker Formation (or unconformably on older formations of the Minilya Subgroup) and overlain conformably by the Mungadan Sandstone.

The type locality is the eastern slope of Wandagee Hill (Fig. 137), where the type section (Fig. 138) is exposed. The base of the formation is not exposed in this area. It crops out 2 miles north of Wandagee Hill, but exposure is poor.

Because no complete section is available in the type locality Condon (1954) proposed an amended type section at the north-western end of Kennedy Range. Although there is no doubt about the identity of the formation, this section cannot replace the original type section as such. It is, however, a useful reference section, where the full sequence of the formation is exposed and the relationships to adjoining formations can be seen. This reference section (Fig. 140) is located north and south of Southern Cross Bore, Middalya (Fig. 139).

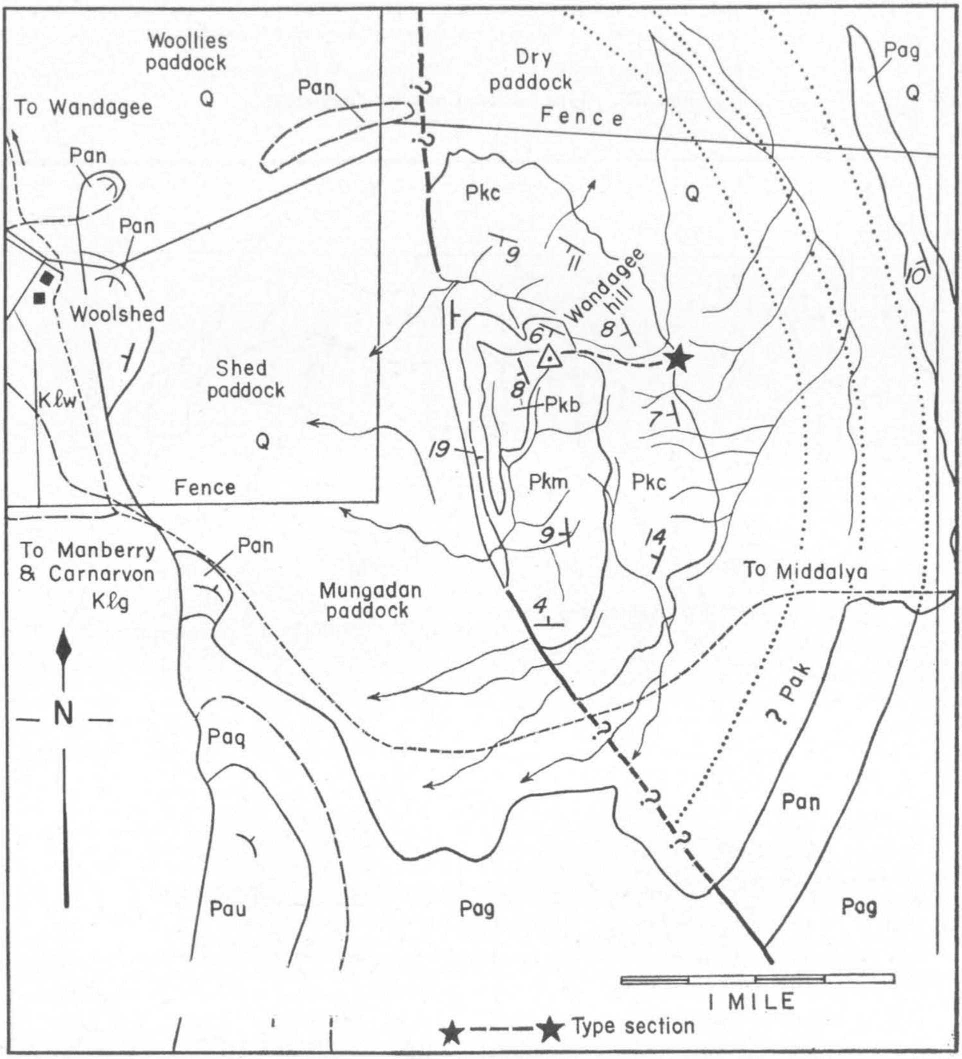
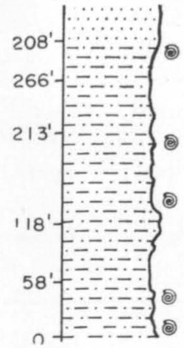


Fig. 137. Type locality, Coolkilya Greywacke (Pkc) and Mungadan Sandstone (Pkm). Q-Quaternary deposits ; Klg-Gearle Siltstone ; Klw-Windalia Radiolarite ; Pkb-Binthalya Formation ; Pak-Baker Formation ; Pan-Norton Greywacke ; Pag-Wandagee Formation ; Paq-Quinnanie Shale ; Pau-Cundlego Formation.



Thin-bedded medium hard medium-grained silty quartz sandstone (MUNGADAN SANDSTONE) conformably overlying:

42 feet thin-bedded friable grey medium-grained quartzwacke with a bed of hard ferruginous coarse-grained quartzwacke with fossils at top.

53 feet thin-bedded friable grey medium- to coarse-grained quartzwacke. few thin hard calcareous beds;

95 feet thin-bedded friable grey medium-grained quartzwacke with few beds of hard grey calcareous quartzwacke with fossils.

60 feet thin-bedded to laminated friable grey fine-grained to coarse-grained quartzwacke with few thin beds of hard grey coarse-grained calcareous quartzwacke;

58 feet laminated grey fine-grained quartzwacke with thin beds of hard calcareous quartzwacke with scattered grains of coarse quartz sand; molluscs, brachiopods and bryozoa;

Bottom of exposed section.

308 feet thickness of exposed part of Coolkilya Greywacke in type section.

Fig. 138. Type section, Coolkilya Greywacke.

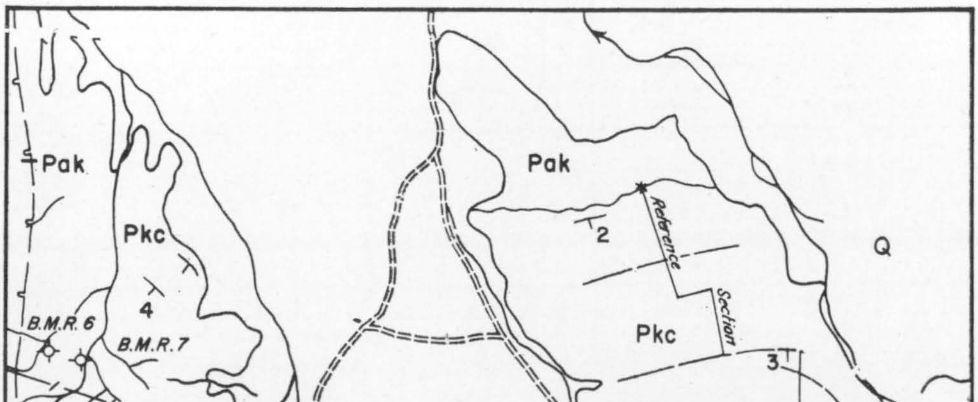


Fig. 139. Reference section locality, Coolkilya Greywacke (Pkc). Q-Quaternary deposits ; Pak-Baker Formation ; Pkm-Mungadan Sandstone ; Pkb-Binthalya Formation.

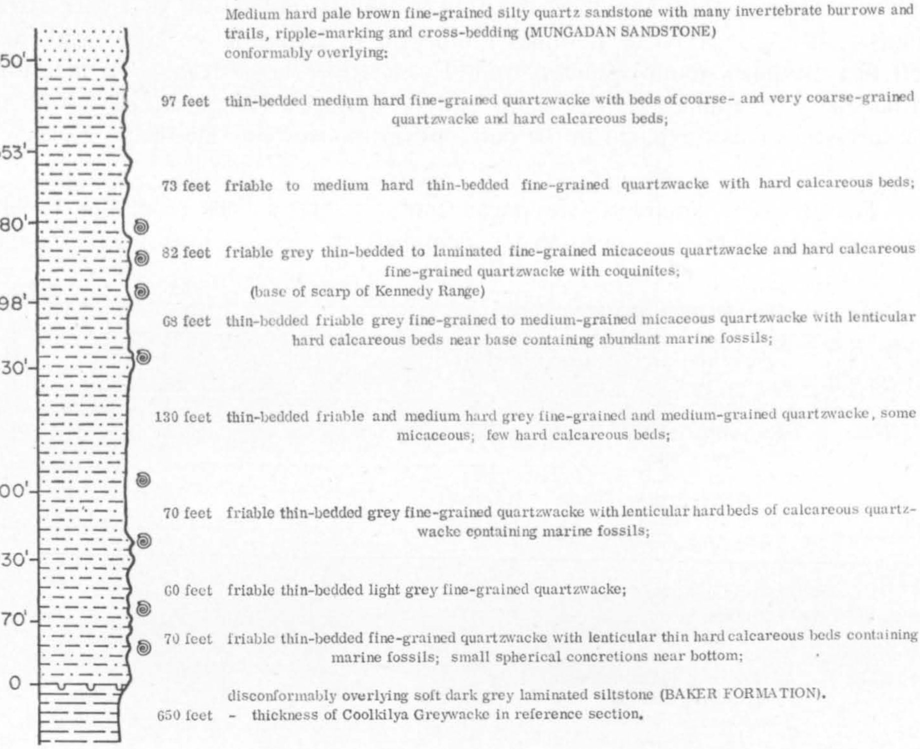


Fig. 140. Reference section, Coolkilya Greywacke.

The base of the Coolkilya Greywacke is at a sharp change in lithology from siltstone and/or laminated fine-grained quartzwacke below to medium-grained (or coarse-grained) quartzwacke above. Only the sharp change in grainsize suggests the disconformity, which is established by the variation in thickness of the Baker Formation and in the lithology of its upper part and confirmed by the unconformity at the south end of Kennedy Range, where the Coolkilya rests on a truncated surface of the Minilya Subgroup. The upper boundary of the Coolkilya Greywacke is at the change in lithology from predominant quartzwacke, fine-grained to coarse-grained, to quartz sandstone. The upper beds of the Coolkilya are commonly calcareous or ferruginous.

The Coolkilya Greywacke crops out in a small area in the Minilya Syncline north of Minilya River, 2 miles north of Wandagee Hill immediately east of a prominent fault, over the greater part of Wandagee Hill, and in and near the scarps of Kennedy Range on all sides except the far north-eastern.

Thickness (*Fig. 136*).—The exposed upper part of the Coolkilya is 308 feet thick at Wandagee Hill and the exposed lower part in the area 2 miles north is about 400 feet thick. The reference section at Southern Cross Bore, Middalya, is 650 feet thick. The Coolkilya Greywacke is 500 feet thick near Bakers Bore, Middalya; 565 feet 10 miles to the south-east at the head of Blackheart Creek;

450 feet 14 miles south of Merlinleigh; 425 feet 10 miles west of Lyons River homestead; about 400 feet 12 miles south-west of Lyons River homestead; and 450 feet 14 miles south-westward from Lyons River homestead. No measurements have been made at the south end of Kennedy Range and the base of the formation is not exposed in the outcrops on the western side of the range.

Fossils.—The Coolkilya Greywacke contains several beds of marine fossils, dominantly pelecypods. Forms so far identified are:

Foraminifera:
- *Hyperammina acicula* (Parr)

Crinoids:
- *Calceolispongia robusta* (Teichert)

Bryozoa:

Brachiopods:
- *Linoproductus cancriniformus* (Tchernyschew)
- *Aulosteges* sp.
- *Krotovia spinulosa* (J. Sowerby)
- *Marginifera gratiodentalis* (Grabau)
- *Streptorhynchus johnstonei* Thomas
- *Permorthotetes teicherti* Thomas
- *Derbyia* sp.

Mollusca (Dickins, 1963):

Gastropods:
- *Euphemites* sp. nov.
- *Mourlonia* (*Mourlonia*) sp.
- *Mourlonia* (*Platyteichum?*) sp.
- *Ptychomphalina* sp.
- *Straparolus*? sp.
- *Warthia* cf. *micromphala*

Pelecypods:
- *Streblopteria* sp.
- *Stutchburia muderongensis* Dickins
- *Schizodus kennedyensis* Dickins
- *Oriocrassetella stokesi* (Etheridge Jnr)
- *Pseudomonotis* sp. nov.
- *Atomodesma exaratum* (Beyrich)
- *Undulomya pleiopleura* (Fletcher)
- *Phestia thomasi* (Dickins)
- *Pseudomyalina obliqua* Dickins
- *Middalya johnstonei* Dickins
- *Parallelodon subtilistriatus* (Wanner)
- *Astartila fletcheri* Dickins

Goniatites

Age.—Because Teichert's 'Coolkilya Sandstone' included beds (and fossils) below and above a disconformity the resulting mixed assemblage caused confusion as to the age of the sequence. With the separation of the Norton Greywacke, Baker Formation, and Coolkilya Greywacke and the recognition of a regional disconformity at the base of the Coolkilya Greywacke the faunas have been properly separated, so that the Artinskian ammonite (Teichert, 1950) *Paragastrioceras wandageense* and shark *Helicoprion davisii* (Teichert, 1943) of the Norton and Baker can be separated from the Coolkilya pelecypods of Kungurian affinities (Thomas & Dickins, 1954). As there is no younger element in the assemblage, it is reasonably certain that the Coolkilya Greywacke is of Kungurian age.

Correlation.—Good correlation is established between the Coolkilya Greywacke and the Lightjack Member of the Liveringa Formation (Guppy et al., 1958) of the Fitzroy Basin. No definite Kungurian sediments have been found in the Perth Basin. The faunas of Eastern Australia have so far yielded little of value for correlation with the Kungurian.

Palaeogeography.—The Coolkilya Greywacke was deposited in a shallow sea with an abundant supply of sand and mud and an abundant invertebrate fauna. The lithology suggests derivation, in part at least, from pre-existing sediments, and it seems possible that the provenance included uplifted Palaeozoic sediments to the west. The topographic form of the marine basin was probably similar to the present structural shape of the Coolkilya, although there must have been an outlet to the ocean, most probably to the north.

Economic Geology.—The Coolkilya Greywacke is not permeable enough to act as an aquifer or as a petroleum reservoir. The abundant evidence of scavenging invertebrates reduces the possibility of generation of petroleum in this formation, although in the central part of the basin conditions may have been suitable for the formation and preservation of petroleum. Primary migration would have been easy and some petroleum may have moved into the Mungadan Sandstone.

Problems.—The fauna is still inadequately described. The correlation with formations in Eastern Australia has yet to be established. More work on sedimentary structures may establish the shape of the floor of deposition and detailed petrology may establish the provenance of the sediment.

Very little structural detail has been mapped, mainly because of difficulties of access in the strongly dissected Kennedy Range.

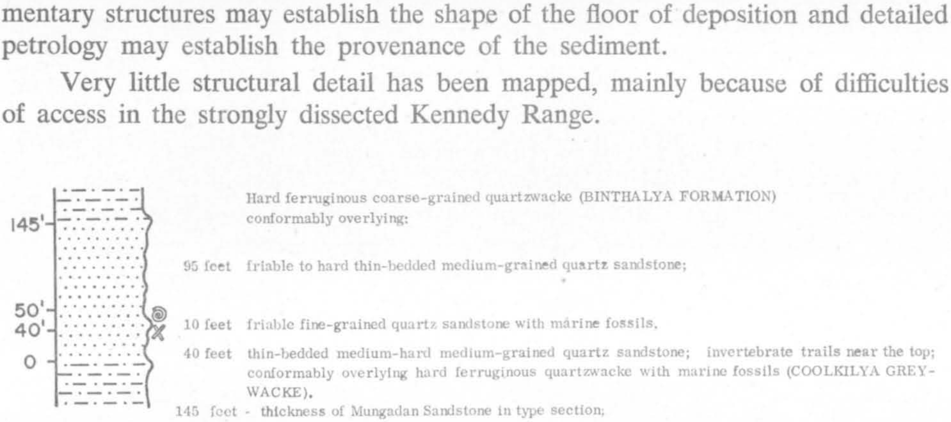


Fig. 141. Type section, Mungadan Sandstone.

Mungadan Sandstone

The Mungadan Sandstone (Teichert, 1950; amended Condon, 1954) is the formation, predominantly of quartz sandstone, conformable between the Coolkilya Greywacke below and the Binthalya Formation above.

The type locality (Fig. 137) is on the east side of Wandagee Hill from the survey cairn eastward. This is in the Mungadan Paddock, Wandagee station. The type section (Fig. 141) is 145 feet thick; the base is taken at the change from quartzwacke below to silty quartz sandstone above. The top bed of the Coolkilya is commonly calcareous and fossiliferous, and ferruginous at outcrop. The top of the formation is at the change from quartz sandstone below to coarse-grained quartzwacke above.

The Mungadan Sandstone crops out in the western part of Wandagee Hill, in a synclinal outlier. The main development is in Kennedy Range, where it crops out mainly near the top of the scarp or near the edge of the plateau of the Range. There is no outcrop in the north-eastern part of the Range between the head of Blackheart Creek and the east scarp of the Range south of Merlinleigh homestead.

Thickness (Fig. 136).—The Mungadan Sandstone is 145 feet thick at Wandagee Hill; 70 feet in the scarp south of Southern Cross Bore, Middalya; 145 feet 2 miles south of Baker's Bore, Middalya; 155 feet at the head of Blackheart Creek, 8 miles south-east of Bakers Bore; 70 feet 15 miles south-west of Lyons River homestead; 172 feet 2½ miles west of trig K38 and 18 miles south-west of Lyons River homestead; 186 feet 14 miles north-west of Gascoyne Junction (at the south end of Kennedy Range); 184 feet 2 miles north of Calvary Well and 12 miles west-north-west of Gascoyne Junction; about 200 feet in the syncline 2½ miles east-south-east of Mooka.

Very rare pelecypods and *Serpulites* have been found in the Mungadan at Wandagee Hill and a very few pelecypods in the Kennedy Range outcrop. Because of its lithogenetic relationship to the underlying Coolkilya Greywacke, the Mungadan is probably, also, of Kungurian age, and must be included with it in any broad correlation.

The Mungadan Sandstone was laid down during a regressive phase, ending a smaller sedimentary cycle. It appears from the sparse data on thickness that the Mungadan may have filled a shallow basin that had its deepest part in the area along the western side of the Kennedy Range. There is no indication of any present extension of this formation beyond the Kennedy Range and Wandagee Hill areas, although it is possible that it is preserved under Exmouth Gulf. Structurally the Mungadan Sandstone forms part of the large syncline of the Kennedy Range and of the smaller Wandagee Hill syncline.

The Mungadan is a good aquifer and is the source of the water issuing in many of the springs on the western side of Kennedy Range.

Binthalya Formation

The Binthalya Formation (Condon, 1954, amended Condon, 1962a) is the formation of quartzwacke and quartz sandstone with minor siltstone conformably overlying the Mungadan Sandstone. The type locality (Fig. 142) is east of Venny Peak (lat. 24° 47¾′ S., long. 114° 57′ E.) on the west side of Kennedy Range. The type section (Fig. 143) was measured by D. Johnstone eastward from Venny Peak.

The base of the formation is placed at the change from medium-grained quartz sandstone below to quartzwacke in places coarse-grained above. The uppermost beds known are dominantly fine-grained quartz sandstone cropping out at the surface in synclinal areas. As the maximum development of the Binthalya is restricted to a small area near Venny Peak its thickness was measured only in the type locality.

The only fossils found in the Binthalya are invertebrate trails and burrows and sparse large *Neospirifer* and large pelecypods. These indicate a Permian age but have not been critically examined. It is likely that there is a minor hiatus between the Mungadan and the Binthalya, but no disconformity is evident, and no large faunal change.

It is possible that the Binthalya is Tatarian in age, but better fossil material would be needed to provide information on its age.

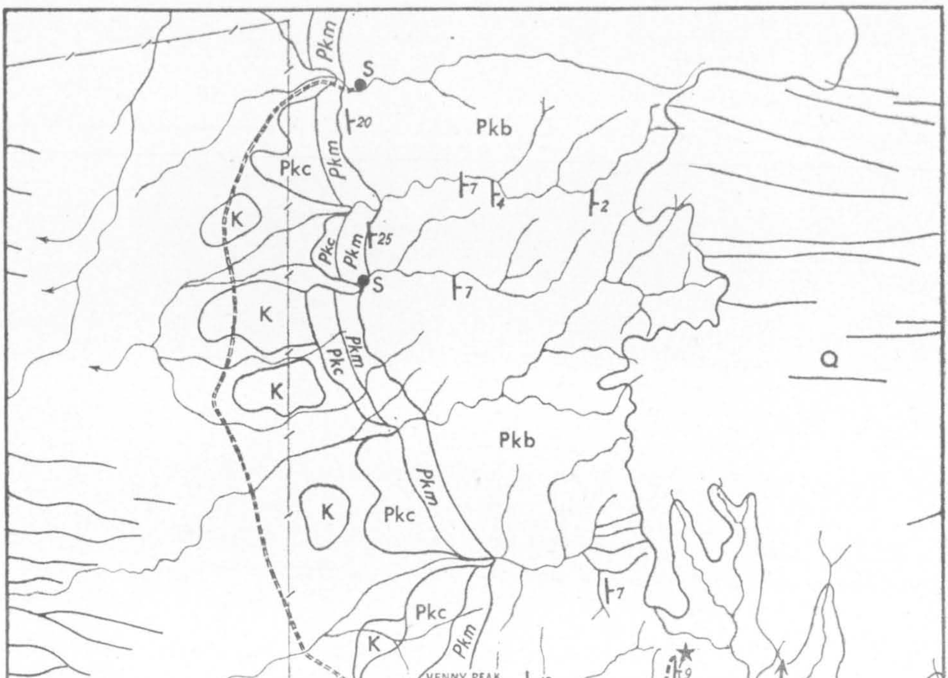
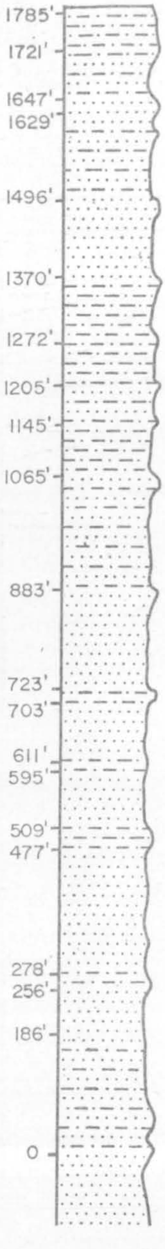


Fig. 142. Type locality, Binthalya Formation (Pkb). Q-Quaternary deposits ; K-Cretaceous ; Pkm-Mungadan Sandstone ; Pkc-Coolkilya Greywacke.

The Binthalya crops out in the central part of the Kennedy Range synclines and in a small area of the Wandagee Hill syncline. It is not known to occur outside those areas; on regional grounds it may be preserved, beneath the Mesozoic, under Exmouth Gulf.

The Binthalya should contain useful aquifers, but no bores, wells, or springs are developed in it.



Erosion surfrace (7500 feet east-north-east of Venny Peak)

64 feet bedded and laminated fine-grained quartzwacke with coarse grains (weathered);

74 feet bedded white quartzwacke and cross-laminated quartz sandstone;

18 feet cross-bedded medium-grained silty quartz sandstone; sets 1 foot thick;

133 feet friable and medium hard bedded fine-grained quartz sandstone and quartzwacke;

126 feet friable and medium-hard fine-grained quartz sandstone with medium-grained and coarse-grained beds;

98 feet medium hard to friable fine-grained quartzwacke; minor quartz sandstone;

67 feet medium-hard laminated fine-grained quartzwacke; minor quartz sandstone;

60 feet bedded and cross-laminated medium-grained and fine-grained quartz sandstone and thin-bedded and laminated fine-grained micaceous quartzwacke;

80 feet thin-bedded and laminated fine-grained micaceous quartzwacke;

182 feet thin-bedded and laminated fine-grained micaceous quartzwacke and bedded to thin-bedded fine-grained and medium-grained quartz sandstone;

160 feet firm to friable fine-grained quartz sandstone, cross-bedded in sets to 18 inches thick;

20 feet thin-bedded fine-grained micaceous quartzwacke;

92 feet friable bedded and thin-bedded fine-grained and medium-grained quartz sandstone with thin beds and laminae of micaceous quartzwacke;

16 feet laminated and thin-bedded fine-grained quartzwacke;

86 feet cross-bedded friable fine-grained to medium-grained quartz sandstone with coarse grains;

32 feet laminated fine-grained quartzwacke with siltstone fragments;

199 feet friable and hard fine-grained and medium-grained quartz sandstone; some cross-bedding;

22 feet thin-bedded very fine-grained micaceous quartzwacke;

70 feet bedded fine-grained quartz sandstone with coarse grains;

186 feet medium-hard bedded fine-grained and medium-grained quartz sandstone and friable thin-bedded and laminated micaceous fine-grained quartzwacke;

conformably overlying friable medium-grained quartz sandstone with coarse and very coarse grains (MUNGADAN SANDSTONE).

1785 feet - thickness of Binthalya Formation in type section.

Fig. 143. Type section, Binthalya Formation.

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PERMIAN ROCK UNITS

Group	Formation (Symbol)	Age	Author	Lithology	Maximum Thickness (Feet)	Fossils	Relationships	Outcrop	Subsurface	Correlation	Economic Geology
KENNEDY GROUP (Condit, 1935; Raggatt, 1936; Condon, 1954)	Binthalya Formation (Pkb)	?Tatarian	Condon, 1954	Quartzwacke, quartz sandstone, minor siltstone	1725	Neospirifer, pelecypods, trails and burrows	? Conformable on Mungadan	Kennedy Ra.; Wandagee Hill	Kennedy Ra.		
	Mungadan Sandstone (Pkm)	?Kungurian	Teichert, 1950; Condon, 1954	Quartz Sandstone	200	Pelecypods, *Serpulites*	Conformable beneath Binthalya and on Coolkilya	do. do.	do. do.		Water
	Coolkilya Greywacke (Pkc)	Kungurian	Teichert, 1950; Condon, 1954	Quartzwacke, minor siltstone; Calcareous beds	650	Pelecypods, brachiopods, forams, crinoids, bryozoa	Conformable beneath Mungadan. Disconformable on Baker; unconformable on Minilya Subgroup	do. do.	do. do.	Lightjack member, Liveringa	
BYRO GROUP Minilya Subgroup (Condon, 1962a)	Baker Formation (Pak)	Artinskian	Condon, 1954	Siltstone, quartzwacke	310	Forams, chonetids	Conformable on Norton; disconformable beneath Coolkilya	North and east scarps Kennedy Ra.	Merlinleigh Basin		? Oil source; ? Brick shale
	Norton Greywacke (Pan)	Artinskian	Condon, 1954	Quartzwacke	400	*Calceolispongia*, brachiopods, pelecypods, *Helicoprion*	Conformable on Wandagee, beneath Baker; ? lateral into Baker	do. do.	do. do.	Upper part of Noonkanbah	? Oil reservoir; Stock water
	Nalbia Greywacke	Artinskian	Teichert, 1950	Quartzwacke	?	Pelecypods, brachiopods	Uncertain	North of Wandagee Hill	?	Possibly with Norton	
	Wandagee Formation (Pag)	Artinskian	Condit, 1935; Condon, 1954	Siltstone, quartzwacke; minor limestone	750	Forams, bryozoa, *Calceolispongia*, corals, blastoids, brachiopods, pelecypods, gastropods, goniatites, *Conularia*	Conformable on Quinnanie or Cundlego, beneath Norton	Minilya R. to Mungadan Ck.; Paddys Outcamp to Norton Ck.; E. and S. of Kennedy Range	Merlinleigh Basin; ? N. Gascoyne Basin	Noonkanbah	? Oil source; ? Brick shale
	Quinnanie Shale (Paq)	Artinskian	Teichert, 1950; Condon, 1954	Carbonaceous shale. Minor siltstone and quartzwacke, gypsum	390	Foraminifera, *Calceolispongia*, corals, brachiopods, molluscs	Conformable on and varies laterally into Cundlego. Conformable beneath Wandagee	Minilya River to north scarp of Kennedy Range	Merlinleigh Basin; ? N. Gascoyne Basin	Noonkanbah	? Oil source; ? Brick shale; ? Salts
	Cundlego Formation (Pau)	Artinskian	Teichert, 1950; Condon, 1954	Quartzwacke, calcareous lenses, siltstone	1350	Foraminifera, bryozoa, crinoids, brachiopods, molluscs	Disconformable on Bulgadoo; conformable beneath and grades laterally into Quinnanie	Minilya River to Gascoyne River	do. do.	do. do.	? Oil source
BYRO GROUP	Bulgadoo Shale (Pab)	Artinskian	Teichert, 1941; Condon, 1954	Shale, siltstone, minor quartzwacke and calcilutite, gypsum	?2100	Foraminifera, bryozoa, corals, crinoids, brachiopods, molluscs, goniatites	Conformable on Mallens; disconformable beneath Cundlego	do. do.	Merlinleigh Basin; ? N. Gascoyne Basin and Exmouth Basin		? Oil source; ? Brick shale; ? Salts
Newman Subgroup (Condon, 1962a)	Mallens Greywacke (Pam)	Artinskian	Teichert, 1950; Condon, 1954	Quartzwacke; minor siltstone	600	*Calceolispongia*, brachiopods, molluscs	Conformable on Coyrie, beneath Bulgadoo	do. do.	do. do.		Stock water; ? Oil reservoir
	Coyrie Formation (Paj)	Artinskian	Condon, 1954; 1962a	Siltstone, quartzwacke	1300	Forams, plants, brachiopods, molluscs, trilobite	Conformable on Billidee; beneath Mallens	do. do.	do. do.	Madeline and probably Bogadi and Warrawarringa	? Oil source
	Warra Warringa Formation (Pa)	Artinskian	Konecki, Condon, et al., 1958	Siltstone, shale, quartzwacke	160	Forams, bryozoa, molluscs	Conformable on Bogadi	Byro Plain do. do.	Byro Basin	Probably Coyrie	
	Bogadi Greywacke (Paf)	Artinskian	Konecki, Condon, et al., 1958	Quartzwacke	350	Crinoids, brachiopods, molluscs	Conformable on Madeline, beneath Warra Warringa	Byro Basin; Daurie Ck.; Curbur	do. do.	do. do.	
	Madeline Formation (Pal)	Artinskian	Konecki, Condon, et al., 1958	Siltstone, shale, quartzwacke, gypsum	1050	Forams, brachiopods, molluscs, crinoids, plants	Conformable on Keogh, beneath Bogadi; grades laterally into Keogh and One Gum. Unconformable on Callytharra, Lyons and Precambrian	Byro Plain; Daurie Ck., Curbur	do. do.	Coyrie	? Oil source
WOORAMEL GROUP (Condit, 1935; amended here)	Keogh Formation (Pa)	Artinskian	Konecki, Condon, et al., 1958	Quartzwacke, siltstone	240	Bryozoa, brachiopods, molluscs, plants	Conformable on One Gum, beneath Madeline; varies laterally into Madeline	Byro Plain	Byro Basin	Upper part of Billidee	? Oil reservoir
	One Gum Formation (Pao)	Artinskian	Konecki, Condon, et al., 1958	Quartzwacke, quartz sandstone, siltstone	285	Plants, bryozoa, brachiopods, pelecypods	Conformable on Nunnery, beneath Keogh; grades laterally into Madeline and Monument	do. do.	do. do.	Lower part of Billidee	? Oil reservoir
	Nunnery Sandstone (Pay)	Artinskian	Konecki, Condon, et al., 1958	Quartz sandstone	580		Unconformable on Callytharra, conformable beneath One Gum; grades laterally into Monument	Around S. E. side of Carrandibby Range	do. do.	Moogooloo	Water; ? Oil reservoir
	Billidee Formation (Pae)	Artinskian	Condon, 1962a	Quartzwacke, siltstone, minor conglomerate	500	Fossil wood, crinoids, brachiopods, molluscs	Conformable on Moogooloo or Jimba Jimba, beneath Coyrie	Lyndon R. to Gascoyne R.	Merlinleigh Basin; North Gascoyne Basin	Keogh, One Gum, Monument	? Oil reservoir
	Jimba Jimba Calcarenite (Pai)	Artinskian	Condon, 1965b	Calcarenite, minor calcilutite	200	Brachiopods, crinoids, bryozoa, molluscs	Conformable on Moogooloo, beneath Billidee	Gascoyne R.; ? E. of Carrandibby Range	S. Merlinleigh; E. Byro Basin	One Gum	? Oil source

Group	Formation	Age	Author	Lithology	Maximum Thickness (Feet)	Fossils	Relationships	Outcrop	Subsurface	Correlation	Economic Geology
WOORAMEL GROUP (*cont.*)	Moogooloo Sandstone (Paw)	Artinskian	Craig, 1950	Quartz sandstone, minor siltstone	250	Bryozoa, brachiopods, fossil wood	Unconformable on Callytharra; conformable under Billidee or Jimba Jimba; conformable on Cordalia	Lyndon R. to Pells Range	Merlinleigh and Bidgemia Basins; ? N. Gascoyne B.	Nunnery Sandstone	Water; ? Oil reservoir
	Cordalia Greywacke (Pad)	Artinskian	Condon, 1954	Quartzwacke, calcareous lenses	453		Unconformable on Callytharra; conformable under Moogooloo	Lyndon R. to Minilya R.	Merlinleigh and N. Gascoyne Basins		
	Monument Formation (Pat)	Artinskian	Konecki et al., 1958	Quartzwacke and quartz sandstone, minor siltstone	600	Plant stems	Unconformable on Callytharra; conformable below Keogh	Byro Basin	Byro Basin; ? N. Gascoyne	Nunnery plus One Gum; Moogooloo and Billidee; part to Congo and Curbur	Stock water
	Congo Formation (Paz)	Artinskian	Konecki et al., 1958	Quartzwacke, conglomerate, siltstone	200	Brachiopods, bryozoa, molluscs, fossil wood	Unconformable on Callytharra, Lyons, Precambrian; conformable beneath Madeline	N.E. Byro Basin	E. Byro Basin	Part of Monument; Curbur; ? Nunnery	
	Curbur Formation (Pax)	Artinskian	Konecki et al., 1958	Quartzwacke, siltstone, conglomerate	....		Unconformable on Callytharra, Lyons, Precambrian; Conformable beneath Madeline	Byro and Curbur stations	S.E. Byro Basin	Congo, Wooramel Group (part)	
	Callytharra Formation (Pac)	Artinskian	Condit, 1935; Condit, Raggatt, & Rudd, 1936; Condon, 1954; 1962a	Sandy and silty calcarenite, calcilutite	800	Forams, bryozoa, corals, crinoids, brachiopods, molluscs	? Disconformable on Carrandibby; unconformable on Lyons, Precambrian. Unconformable beneath Wooramel	Lyndon R. to Wooramel R.	Merlinleigh, Byro, and Bidgemia Basins	Fossil Cliff, Nura Nura Member; ? Farley Fm. (N.S.W.); ? Ingelara Shale (Q)	? Oil source; ? Portland cement. Aggregate
	Carrandibby Formation (Ps/a)	Artinskian or Sakmarian	Konecki, Condon, et al., 1958	Shale, calcilutite, sandstone	225	Forams, bryozoa, crinoids, brachiopods, molluscs	Unconformable on Lyons; ? Disconformable beneath Callytharra	Wooramel R. area	Byro Basin	? Holmwood Shale (upper part)	
LYONS GROUP (Maitland, 1912; Condon, 1962a & b)	Weedarra Shale (Psw)	Sakmarian	Condon, 1962a	Tillitic shale and siltstone, lenticular sandstone and calcarenite members	1360	Bryozoa, brachiopods, pelecypods, crinoids	Unconformable beneath Carrandibby and Callytharra. Conformable on Thambrong	Lyndon R. to Carey Downs	Merlinleigh, Bidgemia, and Byro Basins	? Holmwood Shale	? Oil source; ? Oil reservoir; ? Brick shale
	Thambrong Formation (Pst)	Sakmarian	Condon, 1962a	Alternating quartzwacke and siltstone	1300	Forams, bryozoa, crinoids, brachiopods, molluscs, *Conularia*	Unconformable beneath Callytharra, Conformable beneath Weedarra. Conformable on Mundarie	Lyndon R. to Wooramel R.	Merlinleigh, Bidgemia, and Byro Basins; ? N. Gascoyne B.	? Part of Grant, Paterson. Lochinvar (N. S.W.), Cattle (Q)	Stock water; ? Oil source and reservoir; ? Brick shale
	Mundarie Siltstone (Psm)	Sakmarian	Condon, 1962a	Tillitic siltstone, minor greywacke and boulder beds	1200	Bryozoa, crinoids, brachiopods, molluscs, forams	Conformable on Koomberan. Conformable beneath Thambrong. Unconformable beneath Callytharra	do. do.	do. do.	do. do.	? Oil source
	Koomberan Greywacke (Psk)	Sakmarian	Condon, 1962a	Greywacke, quartz-boulder beds, minor siltstone	1440	Few bryozoa, corals, crinoids, brachiopods, molluscs	Conformable on Dumbardo, beneath Mundarie. Unconformable beneath Callytharra	do. do.	do. do.	do. do.	Stock water; ? Oil reservoir
	Dumbardo Siltstone (Psd)	Sakmarian	Condon, 1962a	Tillitic siltstone, minor quartzwacke and boulder beds	2000	Brachiopods, molluscs, bryozoa, crinoids	Conformable on Coyango and beneath Koomberan. Unconformable on Devonian and Precambrian, and beneath Callytharra and Wooramel	do. do.	do. do.	do. do.	? Brick shale; ? Oil source
	Coyango Greywacke (Psc)	Sakmarian	Condon, 1962a	Quartzwacke, boulder beds, minor siltstone	2920	Bryozoa, brachiopods, molluscs, plant fossils	Conformable on Austin and and beneath Dumbardo. Unconformable on Carboniferous, Devonian, and Precambrian	Williambury to Earilier Hill (Byro)	do. do.	do. do.	Stock water; ? Oil reservoir
	Austin Formation (Psa)	Sakmarian	Condon, 1962a	Quartzwacke and sandy siltstone, boulder beds	1500	Bryozoa, brachiopods, pelecypods	Unconformable on Lower Carboniferous, Devonian, and Precambrian. Conformable on and laterally varying into Harris. Conformable beneath Coyango	Williambury Stn to Earilier Hill (Byro)	Merlinleigh, Bidgemia, and Byro Basins; N. Gascoyne B.	? Lower part of Grant Formation; Harris Sandstone	Stock water; ? Oil source and reservoir
	Harris Sandstone	?Sakmarian	Condon, 1954	Quartz sandstone	280	*Lepidodendron*	Unconformable on Yindagindy. Conformable beneath and varies laterally into Austin	Williambury Station	Not known	Austin Formation; ? lower part of Grant Formation	Water; ? Oil reservoir