I

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Report No. 38

PAPERS ON WESTERN AUSTRALIAN STRATIGRAPHY AND PALAEONTOLOGY

Complimentary

Issued under the Authority of Senator the Hon. W. H. Spooner, M.M.,
Minister for National Development
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LIST OF REPORTS

1. Preliminary Report on the Geophysical Survey of the Collie Coal Basin.—N. G. Chamberlain, 1948.
2. Observations on Stratigraphy and Palaeontology of Devonian, Western Portion of Kimberley Division, Western Australia.—Curt Teichert, 1949.
3. Preliminary Report on Geology and Coal Resources of Oaklands-Coorabin Coalfield, New South Wales.—E. K. Sturmfels, 1950.
4. Geology of the Nerrima Dome, Kimberley Division, Western Australia.—D. J. Guppy, J. O. Cuthbert and A. W. Lindner, 1950.
5. Observations of Terrestrial Magnetism at Heard, Kerguelen and Macquarie Islands, 1947-1948 (carried out in co-operation with the Australian National Antarctic Research Expedition, 1947-1948).—N. G. Chamberlain, 1952.
6. Geology of New Occidental, New Cobar and Chesney Mines, Cobar, New South Wales.—C. J. Sullivan, 1951.
7. Mount Chalmers Copper and Gold Mine, Queensland.—N. H. Fisher and H. B. Owen, 1952.
8. Geological and Geophysical Surveys, Ashford Coal Field, New South Wales.—H. B. Owen, G. M. Burton and L. W. Williams, 1954.
9. The Mineral Deposits and Mining Industry of Papua-New Guinea.—P. B. Nye and N. H. Fisher, 1954.
10. Geological Reconnaissance of South-Western Portion of Northern Territory.—G. F. Joklik, 1952.
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12. Stratigraphy and Micropalaeontology of the Marine Tertiary Rocks between Adelaide and Aldinga, South Australia.—I. Crespin, 1954.
13. The Geology of Dampier Peninsula, Western Australia.—R. O. Brunnschweiler, 1957.
14. A Provisional Isogonic Map of Australia and New Guinea, showing Predicted Values for the Epoch 1955.—F. W. Wood and I. B. Everingham, 1953.
15. Progress Report on the Stratigraphy and Structure of the Carnarvon Basin, Western Australia.—M. A. Condon, 1954.
16. Seismic Reflection Survey at Roma, Queensland.—J. C. Dooley, 1954.
17. Mount Philp Iron Deposit, Cloncurry District, Queensland.—E. K. Carter and J. H. Brooks, 1955.
18. Petrology and Petrography of Limestones from the Fitzroy Basin, Western Australia.—J. E. Glover, 1955.
19. Seismic Reflection Survey, Darriman, Gippsland, Victoria.—M. J. Garrett, 1955.
20. Micropalaeontological Investigations in the Bureau of Mineral Resources, Geology and Geophysics, 1927-52.—I. Crespin, 1956.
21. Magnetic Results from Heard Island, 1952.—L. N. Ingall, 1955.
22. Oil in Glauconitic Sandstone at Lakes Entrance, Victoria.—R. F. Thyer and L. C. Noakes, 1955.

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Minister: SENATOR THE HON. W. H. SPOONER, M.M.
Secretary: H. G. RAGGATT, C.B.E.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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CONTENTS

TUMBLAGOODA SANDSTONE TRAILS AND THEIR AGE

by

A. A. Öpik

INTRODUCTION

In October 1955, J.W. Thomas, Manager of West Australian Petroleum Pty. Ltd., shipped three specimens of a sandstone with fossil trails to the Bureau of Mineral Resources and expressed his interest "in obtaining whatever age determination can be made from them". The specimens were collected by Mr. P.E. Playford, from the Tumblagooda Sandstone of the Murchison River area, Western Australia. All the specimens show a similar kind of trail and the largest is illustrated here on Figure 2.

The present writer was entrusted with the task of studying the material and preparing a note for eventual publication of the result. The findings of the study were communicated to Mr. J.W. Thomas in letters and the opinion expressed as to the age of the fossils was in brief the same as presented in this paper. From the beginning it was obvious that the tracks were not made by a vertebrate, but by invertebrates; they suggested a similarity with Protichnites. A Cambrian to lower Ordovician age was inferred. A single fossil trail, however, has no value of an index fossil; and the geological information pertaining to the Tumblagooda Sandstone and all available material of fossils were studied also.

The writer has not visited the Tumblagooda Sandstone area, and has no first-hand knowledge of its geology and its problematical fossils; but additional material was supplied by Messrs J.M. Dickins and W.J. Perry, and is exploited in the present paper. Professor Kenneth E. Caster, Cincinnati, helped in discussions of the problem and by advice in matters of interpretation of fossil tracks, especially of arthropods.

PREVIOUS RESEARCH

Clarke and Teichert (1948) give a summary of the history of the study of the Tumblagooda Sandstone. They introduced the name Tumblagooda Sandstone for the formation studied in the area west of the Ajana ridge of Precambrian rocks. Their paper contains the description of the lithology, sections, and several illustrations. The rock is a hard, bedded and current-bedded quartzose sandstone and is interpreted as a deltaic deposit.

The authors report that "the only fossils in this sandstone are invertebrate tracks and vertical burrows". "The burrows are always vertical and generally have a diameter of one half to one inch, although diameters up to two inches have been observed." "On the bedding planes the place of a burrow is indicated by a little mound."

The invertebrate tracks are "meandering trails which are six to eight mm. wide and stand out in low relief above the bedding plane; they are characterized by a sharp furrow in the middle and may have been made by gastropods." These trails are not represented in the material available to me.

The Tumblagooda Sandstone is overlain by the "Butte" Sandstone, which is friable, almost a "running sand", and contains worm burrows and fossil wood. The "Butte" Sandstone and the marine fossiliferous sequence above it are Cretaceous, according to Teichert (1947). Teichert placed the Tumblagooda Sandstone at the base of the Cretaceous System, because of its apparently conformable relationship with the overlying strata; it does not rest on fossiliferous Jurassic rocks, as his charts show, but on basement rocks of the Ajana Area.

GEOLOGY OF THE TUMBLAGOODA SANDSTONE

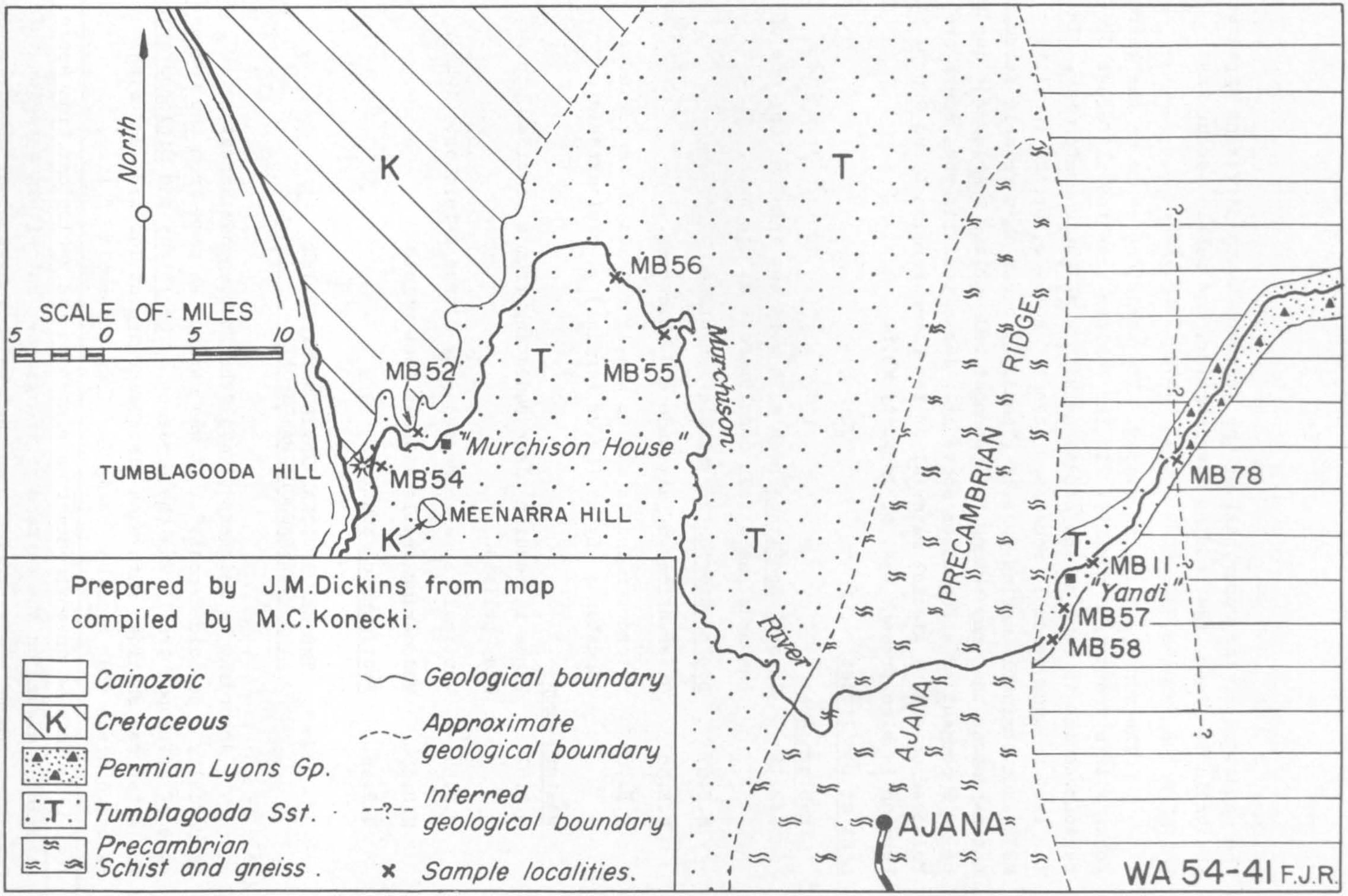
This account of the geology of the Tumblagooda Sandstone is an abridgement from data collected by geologists of the Bureau of Mineral Resources during several field seasons. Part of the information is published in Konecki, Dickins, and Quinlan (1959). The available data have been summarized by J.M. Dickins in the form of unpublished personal communications.

The locality map, Fig.1. was compiled by J.M. Dickins.

The rocks of the Tumblagooda Sandstone occur in two separate areas. The separation is effected by a meridional ridge of basement rocks, the Ajana ridge, ten to fifteen miles wide. The western area on the lower reaches of the Murchison River was originally investigated by Clarke and Teichert, and its sandstone is the Tumblagooda Sandstone proper. The sandstone east of the Ajana ridge is assumed to have been originally continuous with the western area, and later sundered by erosion.

In the western area the general dip of two to three degrees, according to Clarke & Teichert, is to the north-west. Along the western margin of the Ajana ridge the rocks dip west and the angles are steeper. Twenty degrees or even more seems to be the rule. Here a total thickness of about 4,000 feet is estimated.

In the eastern area the Sandstone dips east, and off the Ajana ridge. The angle of the dip is variable, with a maximum of more than 40°. The total thickness here is up to 10,000 feet. The lower part of this sequence is similar in the lithology to the Tumblagooda Sandstone proper


North
SCALE OF MILES
5 0 5 10
K
T
MB 56
MB 52
MB 55
Murchison River
"Murchison House"
TUMBLAGOODA HILL
MB 54
MEENARRA HILL
PRECAMBRIAN RIDGE
AJANA
MB 78
MB 11
"Yandi"
MB 57
MB 58
Prepared by J.M.Dickins from map compiled by M.C.Konecki.
Cainozoic
Cretaceous
Permian Lyons Gp.
Tumblagooda Sst.
Precambrian Schist and gneiss.
Geological boundary
Approximate geological boundary
Inferred geological boundary
Sample localities.
WA 54-41 F.J.R.

The sandstone of the upper half of the sequence has a different appearance; the grain is finer, the bedding more regular, and pebbles occur that resemble the Tumblagooda Sandstone of the western area.

The superposition is simple. The sandstone rests on the basement rocks with a great unconformity. In the western area fossiliferous Cretaceous sediments rest on the sandstone with a slight unconformity. In the eastern area Mesozoic rocks are absent. However, at the locality MB78 indeterminable marine fossils ("shells") occur in a friable ferruginous sandstone that may belong to uppermost beds of the Tumblagooda Sandstone or to a remnant of a formation above it. These fossiliferous rocks are followed upward by glacial material of the Lower Permian Lyons Group. The Permian is also present east of locality MB78.

List of Localities

Eastern Area

M.B.11	Several Scolithus beds with worm castings on top; one of the beds has a thin conglomerate at its base.
M.B.57	Diplocraterion in friable sandstone.
M.B.58	Observations of altitude and thickness.
M.B.78	Interdeterminable marine shelly fossils in ferruginous sandstone; Lyons (Lower Permian) glacial material.

Western Area

M.B.52	Pipes in bedding plane radiating from a vertical pipe. Clay pellets.
M.B.54	Vertical pipes as recorded by Clarke & Teichert (1948).
M.B.55	Meandering trails without foot prints.
M.B.56	Protichnites trails.

THE DEPOSITIONAL ENVIRONMENT OF THE TUMBLAGOODA SANDSTONE

According to Teichert (1947) "the Tumblagooda Sandstone is essentially a deltaic deposit". It was marine, as seen from the occurrence of arthropod trails and the presence of Scolithus and Diplocraterion. The water was shallow, with sand flats emerging at low tide and with extended areas that remained awash for long intervals of time.

This is an environment unrelated to the geological time scale; it existed always on the surface of the globe. But within a region this fossil environment may provide important palaeogeographical clues, especially when an upper and lower age limit of deposition are apparent.

FOSSILS FOUND IN THE AREA OF OUTCROP OF THE TUMBLAGOODA SANDSTONE

It is mentioned in the Introduction to this paper that Cretaceous fossils have been found in formations resting on the Tumblagooda Sandstone in the western area by Clarke & Teichert (1948). In the east, according to J.M. Dickins and W.J. Perry, remnants of Lower Permian Lyons Group have also been found on the surface of the sandstone. They were identified from the abundance of erratic material.

Mr.Dickins also showed a sample of a weathered, ferruginous and friable rock with fossils, that is certainly older than the Permian Lyons Group. It seems likely that this rock belonged to the topmost levels of the Tumblagooda Sandstone. Small shells can be recognized, but the preservation is vestigial. They could be brachiopods suggesting orthoids or spiriferoids, or ribbed pelecypods. One fragment may, possibly, be a pleuron of a trilobite. According to Mr.Dickins, these fossils are not "Lyons", and it seems that they are not Cambrian. Their age is doubtful. Of course, fossils resting on a sequence that is assumed to be 4,000 - 10,000 feet thick cannot indicate the age of that sequence.

DESCRIPTION OF THE PROBLEMATICA

Two different groups of problematical trails occur in the Tumblagooda Sandstone. One group consists of arthropod trails. They are trackways produced by footprints of animals moving on the ground and are discussed under Protichnites. The other group is trails of animals without footprints (appendages), an example of which is the meandering trail described below. Besides the trails, burrows occur; they are described under the heading "pipe rock". Most of these pipes were dwellings of unknown animals with a colonial mode of life.

TRAILS WITH FOOTPRINTS

PROTICHNITES Owen 1852

Walcott (1912) gives the literature and refers to the history and the interpretation of the Protichnites tracks. Walcott (1918) illustrates a number of Protichnites-like trails and refers to them as trilobite tracks. His Pl.37, figs. 1 and 2 show a trackway with a middle "drag trail". Seilacher (1955) gives additional bibliography and describes new material of Protichnites.

Tracks named by Owen Protichnites occur in the Upper Cambrian Potsdam Sandstone of Canada and U.S.A. (State of New York). Protichnites is interpreted as a trilobite track, and the tracks in the Potsdam Sandstone are attributed by Walcott to the trilobite Dikelocephalus hartti (Walcott). Dikelocephalus is characteristic of the upper third of the Upper Cambrian.

Seilacher describes two forms of Protichnites from the Cambrian of the Salt Range, Pakistan. The rock is the Magnesian Sandstone, assumed to be Lower Cambrian. However, it is most probably lower Middle Cambrian and should be correlated with a higher level of Redlichia-bearing rocks of Northern Australia (see Öpik, 1958).

Protichnites is a walking trail with a double "drag trail" between the two rows of footprints. This double drag trail was interpreted by Walcott as the trail produced by the caudal furca. It is produced indeed by the tail of the animal, and not by some other appendages, as shown by Seilacher on a specimen from the Magnesian Sandstone.

The footprints of Protichnites are trifid or bifid; they are produced by arthropods - crustacea or trilobites.

The Protichnites trails from the Potsdam Sandstone show a narrow drag trail. It is much narrower than the drag trail of the Tumblagooda trails: the Potsdam Sandstone and the Tumblagooda Sandstone contain tracks of different animals that nevertheless were in general of a similar organization and of a similar mode of life.

The direction of the motion is recorded in the oblique set of the footprints in relation to the middle line: the extensions of the footprints meet in the middle of the trail in the form of a Roman V. Seilacher shows that the point of the V indicates the rear and the start of the trail. This V-rule is applied here in orienting the Protichnites tracks of the Tumblagooda Sandstone. Seilacher, however, orients his Protichnites sp. A (Seilacher pl.16, fig.2 and p.356), which is most similar to the Tumblagooda tracks, in a reverse manner. This reversal of the V-rule appears to be necessary because Seilacher assumes that the trail starts at a "nest" (Rusophycus): it is interpreted as a trail of departure from the nest. But the signs can be read differently: following the V-rule the Rusophycus could be the end of the trail. This is, in fact, the only possible explanation, because the trail finishes at the pointed end of the Rusophycus that corresponds to the position of the tail of the animal resting in the nest.

Seilacher himself doubts his own interpretation and writes in the explanation of his Plate XVI: "at the start of the trail there is , oriented in opposite direction, a "rest-track" ("Rusophycus didymus"). Thus the author contradicts his own idea of a departure trail. At this point it should be noted that the particular Rusophycus specimen is quite distinct from the R.didymus specimens illustrated by Seilacher. But it resembles Fengtienia peculiaris Endo (1937, Pl.66, fig.14, p.326) and this resemblance may help to read the somewhat confused scene of the Protichnites A trail of the Magnesian Sandstone. Fengtienia has been described from two specimens believed to be fossilized in copula.

The Rusophycus in question seems also to consist of replicas of two similar specimens oriented in the same direction. One of them is somewhat rotated out of the bedding plane, which destroys the symmetry expected in a Rusophycus. Absent also is the annulated sculpture of a Rusophycus. But the division into tagmata (a large cephalon, thorax, and a small pygidium) is indicated. Each of the specimens shows also the prints of a pair of antennae. Of course, without a special study of the material, it is difficult to decide whether Fengtienia is only a Rusophycus, or the Rusophycus in question is the nest of two specimens in copula. Anyway it seems that the V-rule to determine the direction of motion in Protichnites trails has a general validity.

PROTICHNITES SP. T

Figures 2 - 7.

The Protichnites from the Tumblagooda Sandstone is designated here as "sp.T"., where "T" stands for Tumblagooda. It is "open" and informal nomenclature because it is difficult to apply the formal zoological nomenclature to invertebrate trails without any knowledge of the animal itself.

All the specimens available have one feature in common; they are not preserved as original surfaces, but seem to represent a reflection of the trail on a deeper surface below the original floor. This may explain why the details of the footprints are not well preserved.

The largest specimen (Fig.2.)is 67 cm. long and the trackway is 7.5 cm.wide. The median drag trail is 2.5 cm. wide. The footprints are deep and some of them show the bifid character well. The drag trail is impressed unevenly: its impression is intermittent, as is that of other described Protichnites trails. None of the described Protichnites trails has such a wide median drag trail; its width is here one third of the width of the trackway, whereas in the others it is a sixth or even less.

The specimen in Fig.4 belongs, most probably, to the same Protichnites sp.T. The trail is confused because of the very abrupt turn; inside the hairpin loop another trail is visible, not connected with the first.

Fig.5 shows two crossed trails. The longer trail shows the intermittent impression of the medium drag trail. The rock surface is worn.

The specimens discussed so far are tracks in soft sediment with the bodies dragged along almost in touch with the floor. The specimen in Fig.6 shows several trackways of footprints only, without the dragtrails. It is assumed that the animal walked on a firmer ground and did not touch the floor with its body or tail. Of course, it may have been a different animal altogether. It was still an arthropod, a crustacean, as seen from the form of the footprints. These tracks are preserved not on the original floor, but are replicas projected into a deeper lamina. In Fig.7 the filling of the tracks may represent material of the original substratum.

What animal left its tracks in the Tumblagooda Sandstone is uncertain. It was quite large, perhaps not less than seven cm.wide, and was segmented. The tracks are arranged in two even lines, indicating that the legs were of about equal length. In most trilobites the length of the legs decreases towards the rear; but an asaphid trilobite, perhaps, could produce such a regular trackway. Asaphids have an elliptical body with eight segments of the thorax that are of equal width (Walcott, 1918,pl.25). The appendages of the thorax and also the two posterior pairs of cephalic appendages were also equal in length and could have a regular trackway. In most trilobites the width of the body decreases towards the rear, the appendages decrease in length accordingly, and the footprints will not fall into line. The size of the trail, especially its width, indicates a very large arthropod or a trilobite, perhaps about 15 cm. in length. This is not uncommon in the early half of the Ordovician Period that was the time of the asaphids.

Seilacher (1955) has shown that one and the same trilobite produces different trackways and a variety of tracks depending on the mode and purpose of its motion. Almost straight trackways, however, provide too little information for a proper interpretation of the organisation of the animal. Thus, the Protichnites T trails are made by an arthropod that may or may not have been a large trilobite.

TRAILS WITHOUT FOOTPRINTS
Figures 8 and 10

Only two examples of trails without footprints are available in the collection. Fig.8 was found in the western area, and belongs to the Protichnites - assemblage. These trails are meandering channels with bordering walls of ploughed-out material. The width of channel is about 1.5 mm. only, and of the whole track 3 - 4 mm.

These trails are visible on several bedding planes in the same hand specimen and could be mistaken for burrows parallel to the bedding. However, they are made on the bedding planes, and are channels with lateral walls and not tunnels. Worms, tiny gastropods, or even pelecypods may have produced these trails on the sandy floor of the shallow sea. No age can be given to such trails.

Clarke & Teichert (see above) observed in the same area much wider trails (6 to 8 mm. wide) that seem to be of the same form as the trails here described.

It should be mentioned here that Teichert (1941) illustrates and describes two forms of invertebrate trails without footprints, from the Permian of Western Australia. None of these trails are present in the Tumblagooda material. More types of trails have been observed in the Permian (Teichert, 1951), but remain undescribed. The Tumblagooda trail cannot therefore be compared with Permian trails of the same region.

The worm castings mentioned in the description of Scolithus pipe rock (Fig.10) are also trails without footprints. They are feeding trails of unknown animals and, as such, are no markers of time.

PIPE ROCK IN THE TUMBLAGOODA SANDSTONE

Figures 9 - 13

The pipe rock described here was discovered by J.M. Dickins and W.J. Perry. Samples collected by them are used in the present description. They all occur in the eastern area only.

The most common form (Fig.9) consists of sandstone "stems" which are vertical and almost in touch with one another. The stems are fillings of vertical shafts dug into the unconsolidated sand. The beds that consist of these stems were colonies of unknown animals living in the vertical shafts.

Such pipe rocks - correctly, the stems are pipes - carry the name of Scolithus. Scolithus is widespread in Cambrian sandstones, and most common in Lower Cambrian of all continents, but it occurs also in the lower Ordovician of some regions. However, Scolithus-like shafts are built even by some recent annelids and, therefore, they have generally little stratigraphic value. Particular forms of Scolithus can, nevertheless, be exploited palaeogeographically and stratigraphically.

The stems of the Tumblagooda Scolithus are unusually thick, attaining a diameter of almost half an inch, and the longest fragments seen reach 10 - 12 inches.

Only one of the described species of Scolithus has such a diameter. This is Scolithus magnus Howell (1944). It is found in the Lower Cambrian Hardyston Formation of Pennsylvannia and New Jersey. A correlation cannot be based on this Scolithus, however, because the occurrences are too far apart and belong to separate palaeogeographical regions.

But similar Scolithus pipe rock occurs also in the Australian region. It is the "Tubicolor Sandstone" in north-western Tasmania (see Smith, 1957). It rests on the Owen Conglomerate and its age is Lower Ordovician, most probably Tremadocian. I have examined this pipe rock in the field and in samples and found that it is a Scolithus with unusually thick stems.

The surface of the Tumblagooda Scolithus pipe rock beds is exceptionally well preserved (Fig.10). It is the only case known to me of preservation of such surfaces. It is covered densely with worm castings and was, therefore, a popular feeding ground. It seems probable that the worm castings represent "dumps" of material dug out of the shafts because a single casting covers several apertures in an irregular manner. In our sample the shafts have reached a conglomerate band and no branching is visible at the base of the shaft; it remains a pipe.

Another important form of pipe rock that occurs in the same eastern area is Diplocraterion. Diplocraterion is a shaft consisting of two vertical pipes that are joined below into a single pipe by a hair-pin bend; a narrow lumen connects the pipes along the inside of the "U" structure (see Fig.12). The material is not well preserved and only one satisfactory specimen is available. Its "lumen" seems to be slightly twisted and slightly bent out of the geometrical plan of the "U". A similar structure has been mentioned in literature in only one Diplocraterion: Carophioides = Diplocraterion helmerseni Öpik (1929); otherwise D.helmerseni is distinct in having a pendulum-like shape. It is a baltic Lower Cambrian form. It is significant that the combination of Scolithus and Diplocraterion is most common in the Lower Cambrian (e.g. Westergaard, 1931), but it may occur in the Lower Ordovician.

In Australia Diplocraterion, according to my own observations, occurs in the Lower Cambrian south of Duchess (Mt.Birnie Beds), in Lower Ordovician sandstones of Central Australia, and in Tasmania in sandstones on top of the Owen Conglomerate (Tremadocian). The Tasmanian Diplocraterion (Fig.12) has its lumen curved also.

The rock sample with the Diplocraterion from the Tumblagooda Sandstone shows little of its particular structure. The shafts are 5 mm. wide, the diameters of the pipe vary between 0.4 and 1.0 cm. In Figure 11 a bed with Diplocraterion is shown. Only one basal U-bend is seen, at the left end of the tuft of gum leaves and dry grass. It protrudes from the weathered lower edge of the pipe rock bed. The joint plane cuts across the shafts and therefore no walls of the lumina are seen.

At Tumblagooda itself, in the western area, Clarke & Teichert found coarse vertical pipes, and each pipe was indicated on the surface of the bed by a little mound. In the absence of collected material this pipe rock (Fig.12) cannot be interpreted, but it seems that a type different from the Diplocraterion is there present.

The occurrence of a Diplocraterion (= Corophioides) in Permian rocks of Western Australia has been mentioned by Teichert (1951). In Europe it occurs also in the Triassic, and even in the Jurassic.

Finally, narrow pipes occur in bedding planes arising from an aperture of a vertical pipe. Only one sample is available and allows no further interpretation. It is not illustrated (for comparison see "Addendum", "shaft-and-tunnel" trails).

AGE OF THE TUMBLAGOODA SANDSTONE (GEOLOGICAL CONSIDERATIONS)

According to a personal communication by J.M. Dickins and W.J. Perry, erratic material interpreted as belonging to the glacial Lyons Group (Lower Permian) rests on the eroded surface of the Tumblagooda Sandstone east of the Ajana ridge. In the western area no covering rocks older than Cretaceous are known to exist. For simplicity, it may be assumed for a moment that the sandstone in both areas is of a similar, pre-Permian age.

The Protichnites trails, as here described, indicate a highly organized invertebrate life that cannot be interpreted as Precambrian. Thus, the Tumblagooda Sandstone is Palaeozoic: its age is Cambrian to Carboniferous.

A Carboniferous age is doubtful on geological evidence. The Tumblagooda Sandstone was, to some extent, folded and eroded before the Lower Permian, and the interval itself may be Carboniferous.

According to Mr.Dickins (personal communication), "folding in the Tumblagooda is minor; it may be also associated with the faulting. The age of the faulting we do not know except that considerable movement must have taken place during sedimentation. The main folding (drag folding) may have occurred later. Apparently however, the Tumblagooda was eroded before the Permian."

Every one of the remaining Periods (Cambrian, Ordovician, Silurian and Devonian) has been considered as the age of the Tumblagooda Sandstone: as the number of the systems is only four, somebody may hold already the correct opinion as to the age of the Tumblagooda Sandstone.

Glenister (1957) refers the Tumblagooda Sandstone tentatively to the early Silurian, though it may extend into the Ordovician. Glenister's second thought (Ordovician) is intended to meet Öpik's suggestion (unpublished) of an "older Palaeozoic age" of the Sandstone, The phrase "older Palaeozoic age" (Glenister, p.116) is seemingly an abridgement of Öpik's unpublished suggestion: "it is probable that the Tumblagooda Sandstone is Middle Cambrian to Tremadocian in age" (see also introduction). But Glenister's suggestion of a tentative Silurian age of the Tumblagooda Sandstone does not refer to the Tumblagooda area itself, but to a Sandstone in a bore on Dirk Hartog Island, almost 200 miles north of Tumblagooda. This inferred Silurian age of the sandstone in Dirk Hartog Island is extrapolated south (via sandstones met in some water bores between the Dirk Hartog Island area and the Murchison River) and given to the Tumblagooda Sandstone (proper). Similarly, the formation Tumblagooda Sandstone is assumed to extend as a lithic entity from Tumblagooda to Dirk Hartog Island. One should agree with Glenister that this interpretation is tentative and that it remains a problem for further investigation. Thus, in the Dirk Hartog bore a queried Tumblagooda? Sandstone is apparent and a queried ?Silurian age is possible for the Tumblagooda Sandstone (proper).

The discovery of Silurian rocks above the sandstone in the Dirk Hartog Island excludes a Devonian age of that sandstone. The idea of a Devonian age arose when the Dirk Hartog Limestone was lithologically compared with some Devonian Limestones of the region and its fossils were still unknown. The present writer even now is of the opinion that the upper part of the Limestone may extend into the Devonian. No other indications are available in favour of a Devonian age of the Tumblagooda Sandstone and for this reason Devonian will not be considered here further. However, there remains a slight chance that the Tumblagooda Sandstone is Devonian or Carboniferous. To sum up, the age of the Tumblagooda Sandstone proper has been narrowed considerably: Cambrian, Ordovician and lower Silurian alone remain to be considered. Of course, more than one system may be involved because of the great thickness of the Sandstone (5 -6,000 feet or even more).

THE AGE OF THE TUMBLAGOODA SANDSTONE (PALAEOGEOGRAPHIC AND PALAEONTOLOGICAL CONSIDERATIONS)

No fossils have been found as yet in the Tumblagooda Sandstone that could indicate properly the age of the formation. Trails and burrows alone are available and none of them has the power of index fossils.

Assemblages of trails and burrows, however, may have a value in determining the geological age of the rock within a region where the majority of the trail-bearing formations is known and the trail assemblages in them are described.

In Australia no systematic research has been done as yet and the published information is casual and fragmentary.

Glaessner (1957), in his pilot paper on fossil trails from Australia, has announced the preparation of the description of South Australian Cambrian and Central Australian lower Ordovician trails. The Central Australian occurrences, as I have seen them, refer to fossiliferous rocks containing trilobites and trilobite trails as well. Glaessner describes also the trail known as Tasmanadia twelvetreesi Chapman. According to Banks (1956, p.183) it is of a Middle Cambrian age. It is a trail that may fit into a pattern of a Protichnites "walking high" and not touching the floor with its tail. But the material available allows no comparison with the Tumblagooda trails. The Tasmanadia-bearing rock is shale, indicating a biotope different from the "track bearing sandstone" facies.

Two great developments of track-bearing sandstones of pre-Silurian age are known in Australia: (1) the Cambrian and Ordovician sandstones of Central Australia, and (2) Lower to Middle Cambrian sandstones in South Australia.

In Central Australia Lower Ordovician sandstones especially contain a variety of tracks, some of which are made by trilobites.

In South Australia, according to Daily (1956), two Cambrian formations contain tracks. The first is the Billy Creek formation, 3,300 feet thick, interpreted as passage beds between the Lower and the Middle Cambrian, and the second is the Lake Frome Group, 8,700 feet thick, of Middle Cambrian age.

No Cambrian seaways are evident, connecting South Australia and the coastal regions of Western Australia. It is, however, evident that the Central Australian Cambrian and Ordovician sea reached the regions of the present Indian Ocean (Öpik, 1956). Sandstone deposition and shallow marine hydrology may have prevailed not only in Central and Northern Australia, but also in the extension of these seas along the west-facing borders of the shield, in Cambrian and Ordovician time. Thus the palaeogeography, the uniformity of facies, the similarity in lithology and thickness, the shield as the common provenance of the sediments, the abundance in tracks, all taken together may suggest a rough contemporaneity of the Tumblagooda Sandstone and the Lower Palaeozoic Sandstone sequence of Central Australia. Silurian and the upper half of the Ordovician are absent in Central Australia and so the limits for the age of the Tumblagooda Sandstone may be also restricted. The similarity with the Salt Range Middle Cambrian sequence that is apparent in the discussion of the Protichnites sp.T. from Tumblagooda is also significant.

The occurrence of Scolithus"cf.magnus" in the Tumblagooda Sandstone, its similarity to the Tasmanian Scolithus of a Tremadocian age, and the prevalence of Scolithus in Cambrian and lower Ordovician, in general contribute independently to the above suggested rough correlation.

Weighing all the suggested possible ages for the Tumblagooda Sandstone, I am inclined to give most credit to the palaeontological evidence from the Salt Range and from Tasmania, and to the palaeogeography of the western half of Australia in Cambrian and in the earlier half of Ordovician time. Thus, it is probable that the Tumblagooda Sandstone is Middle Cambrian to Tremadocian in age. It is also probable that the deposition of the Tumblagooda Sandstone covered more than one epoch of the geological time scale.

SOME CONCLUSIONS

It is evident that a pre-Permian age of the Tumblagooda Sandstone is warranted by the available facts, and that it is not Precambrian but Palaeozoic. Within these limits any narrower age determinations are opinions and not unambiguous conclusions enforced by fossil evidence from within the formation itself, or from rocks below it. The strata above the Sandstone are fossiliferous.

The sandstone deposits east and west of the Ajana Ridge are regarded as a single formation, the Tumblagooda Sandstone. No indisputable evidence, however, exists that it is in reality a single rock unit. The assumed unity is not supported by the evidence provided by the problematical tracks.

Protichnites, the meandering trails, an unillustrated pipe rock, and another trail described by Clarke & Teichert, occur in the western sandstone, the Tumblagooda Sandstone proper, and are absent in the east. In the eastern area Scolithus and Diplocraterion occur, but are missing in the west. No commingling of these assemblages is seen in the available material. Consequently, no positive evidence for a correlation exists, but the diversity of the assemblages of the trails does not enforce the conclusion that the sandstones are of different ages. It is perhaps, of some interest that the eastern assemblage of Scolithus and Diplocraterion hints at a Tasmanian connexion and a Tremadocian age, whereas the western Protichnites trails may indicate a relation to the Cambrian of the Salt Range.

ADDENDUM

LOWER PALAEOZOIC INVERTEBRATE TRAILS FROM THE SNOWY MOUNTAINS AND CANBERRA

Three different invertebrate trails from southern New South Wales were briefly discussed and illustrated by Öpik in an unpublished report in 1952. The stratigraphic part of this report will be published in a paper dealing with the geology of Canberra. The trails described in 1952 are published in this "Addendum" for two reasons:

(1) The localities of the Snowy Mountains are now inaccessible because of the progress in the building of the dams; the trails were the only fossils found below the graptolite horizons and deserve to be published.

(2) The present paper represents, beside an attempt to estimate the age of the Tumblagooda Sandstone, a review of Australian Palaeozoic tracks and trails, published, or only observed, by the present writer. It is convenient to amplify the review and to have collected all available information in a single paper.

Trails from the Snowy Mountains

The fossils were collected by the geologists of the Snowy Mountains Hydro-Electric Authority and by the present writer, on the Big Tolbar Creek. The locality is one mile down-stream from the Bald Mountain Creek tunnel portal.

The rocks are referred to as the Bald Mountain Creek beds. Their age is unknown, but they are assumed to be separated from Middle Ordovician rocks by about 10,000 feet of sediments. Consequently, the age may be lowermost Ordovician or even Cambrian (Öpik, 1956).

The Bald Mountain Creek Beds consist of micaceous dark-green hard fissile shale, dark-green banded mudstone, and hard sandstone in a rhythmic order. They are several thousand feet thick.

The tracks of the Bald Mountain Creek beds cannot be readily compared with the trails of the Tumblagooda Sandstone because the sequences are deposited in very different environments. The Tumblagooda Sandstone is a sediment of tidal flats, whereas the rhythmic shale and sandstone sequence of the Bald Mountain Creek was deposited in a geosynclinal trough. Both the sequences are, however, marine, and the distribution of life in the sea is controlled by other factors than the tectonic setting. Among other physical factors the depth of water is, perhaps, the most important. No evidence is available that the Bald Mountain Creek beds are deep water deposits and no reason exists to assume that the invertebrates of the Tumblagooda Sandstone lived only in the tidal zone. On the contrary, the Tumblagooda Sandstone is conspicuous by the absence of the actual fossil and one may assume that the trails were left behind by temporary visitors of the tidal flats. These visitors lived outside the tidal zone in the shallow sea. When all such possibilities are considered a comparison of the Bald Mountain Creek trails with some of the Tumblagooda trails may be justified.

Beaded Meander Trails (Figures 14 and 15).

Figure 14 shows an invertebrate trail "without footprints" meandering on a shale bed. The meanders are very close, and are impressed at least on two laminae of the sediment. The specimen itself is the lower surface with the replica of the trail and not the top surface of the bed. The unknown animal moved along, almost touching, but not crossing, its own track and observing a distance between the loops of the trail. It is a feeding trail and by meandering a considerable surface was "grazed". Similar meandering trails occur from the lower Palaeozoic until Recent time and are produced by various invertebrates. But in this trail a particular character, not seen in other fossils, may be of some importance: some of the meanders seem to be divided into "beads". As seen below the animal took some elementary sanitary precautions.

Figure 15 is a specimen of the meandering trail with well preserved "beads". These beaded meanders, almost a string of beads, should be classified as a "worm casting", consisting of droppings left behind on the feeding trail of the same animal as Figure 15. It is more than a non-differentiated "worm casting" because the beads indicate a special organization of the digestive tract of the animal. To conclude, the "beaded meanders" differ from any other meandering trail and may have a value as markers of geological time at least within the region of their occurrence.

Shaft and Tunnel Trails (Figures 16-18)

Straight or slightly curved solid trails are seen in the shale, combined with short vertical shafts. The horizontal trails radiate from the vertical shafts, and some of the shafts are seen as pits on the exposed bedding planes. The following explanation is suggested: a mud-feeding animal built a short shaft from the surface into the mud and searched for food by crosscuts in bedding planes and within the beds of the unconsolidated sediments. Similar structures are mentioned above as occurring in the Tumblagooda Sandstone. One of these structures is shown diagrammatically in Figure 17.

Several forms consisting of a vertical shaft with various trails around the aperture are shown by Seilacher (1955) in his chart, figure 5.

They range from Cambrian into the Mesozoic and even the Tertiary. But none of them has the long straight crosscuts as seen in the specimens from Big Tolbar Creek or from Tumblagooda.

Trails from the Middle Ordovician of Canberra (Figure 19).

These trails are found in the Pittman Formation in a small abandoned quarry on Carne Creek, west of Black Mountain. The rock is a fine-grained sandstone or even silt, interlaminated with argillaceous black shale. The layer with the trails contains also conodonts, and in the shale fragments of grapholites occur. The age is about zone 6 of the British Scale, as seen from the occurrence of Trigonograptus ensiformis and Phyllograptus anna in a horizon below, which is exposed in the creek downstream from the little quarry. It is lower Darriwillian according to the Victorian scale of Ordovician stages.

The trails are channels with bordering walls of ploughed-out material, as already seen in the corresponding trails from Tumblagooda (Fig.8). The Canberra trails, however, are not meandering and are narrower.

One of the specimens from the Snowy Mountains (Fig.18) shows a wavy trail that is, perhaps, comparable with the Canberra trails. But the trail in figure 18 has no bordering walls, and may have been made not in the bedding surface, but as a tunnel in the sediment. One notes in Figure 19 that some of the trails are not channels but appear to be elevated "strings". This is the result of preservation: in some of the channels the matrix (filling) of the next bed above was not removed when the rock was split.

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Figure 2.—*Protichnites* sp. *T.*, the largest specimen, collected by Mr. P. E. Playford at the Murchison River in the Tumblagooda area " approximately six miles due east of the telephone line 200 feet below the edge of the breakaway ". Magnification about 0.35 of natural size. Direction of progress is upward in the illustration. In its upper half a " channel trail " with lateral walls crosses the *Protichnites* trail obliquely.

Figure 3.—*Protichnites* sp. *T.*, detail from lower half of Figure 2. The Y-shaped impression illustrates the " trifid or bifid " arthropod footprint. The upper, " bifid " part of the Y is made by the terminal joints, and the lower stalk may represent the next joint of the leg. The Y is resting on its right side.

Figure 4.—*Protichnites* sp. *T.*, Locality No. MB56, Tumblagooda areas. XO.3. Several trails are visible, but details are confused by the abrupt turn.

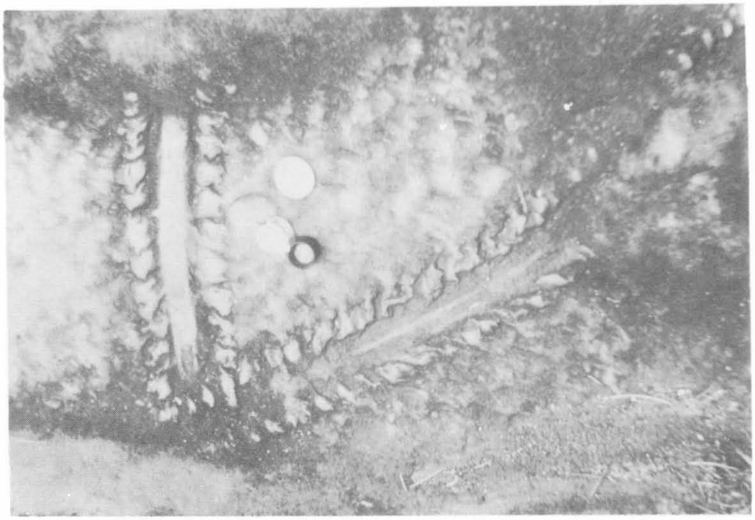


Figure 5.—*Protichnites* sp. *T*., two crossing trails. The bedding surface is worn. In the longer trail the " drag trail " is seen to be intermittent.

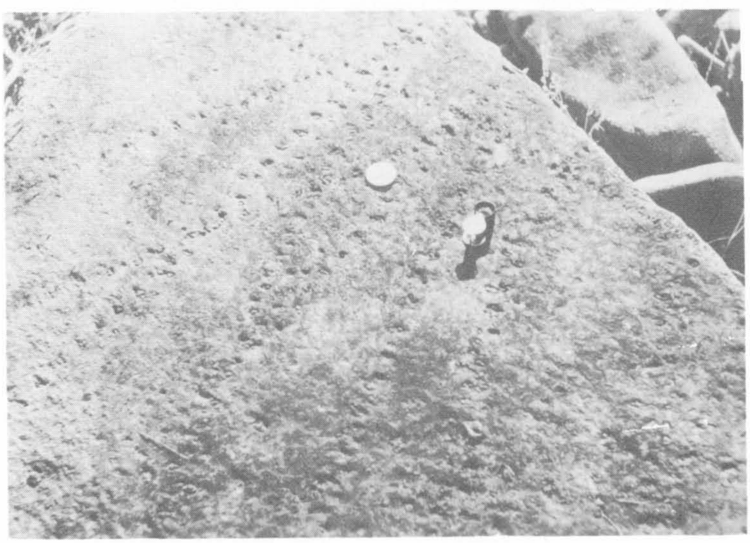


Figure 6.—Arthropod walking tracks without median " drag trails " produced, perhaps, by *Protichnites* keeping its body and tail above the ground. P. E. Playford photo.

Figure 7.—Detail of Figure 6. The filling of the imprints may belong to the worn-off bed on which the tracks were originally made. The tracks are bifid, as seen in the right lower part of the picture. P. E. Playford photo.

Figure 8.—Meandering trails without footprints, Locality No. MB55, Tumblagooda area. XO.5.

Figure 9.—*Scolithus* " stems " or pipes. Locality No. MB58.

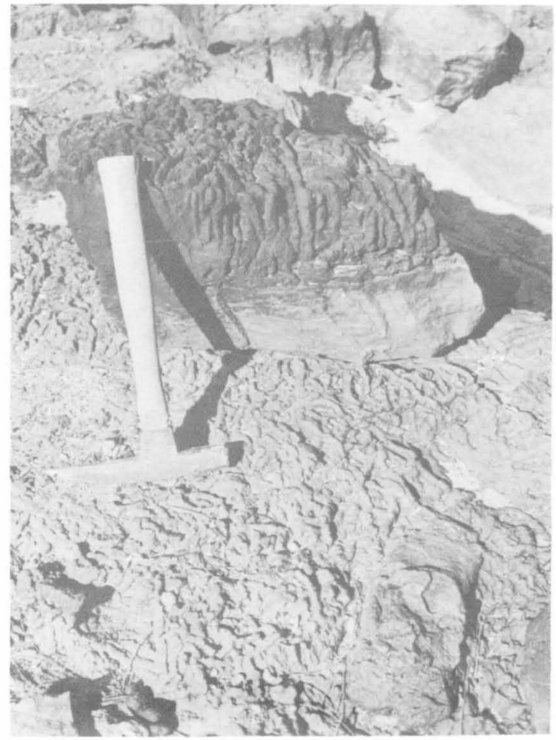


Figure 10.—Worm castings on surface of a *Scolithus* bed. Locality No. MB11. Slabin background is a worn part of another *Scolithus* bed, perhaps half destroyed by feeding worms. J. M. Dickins photo.

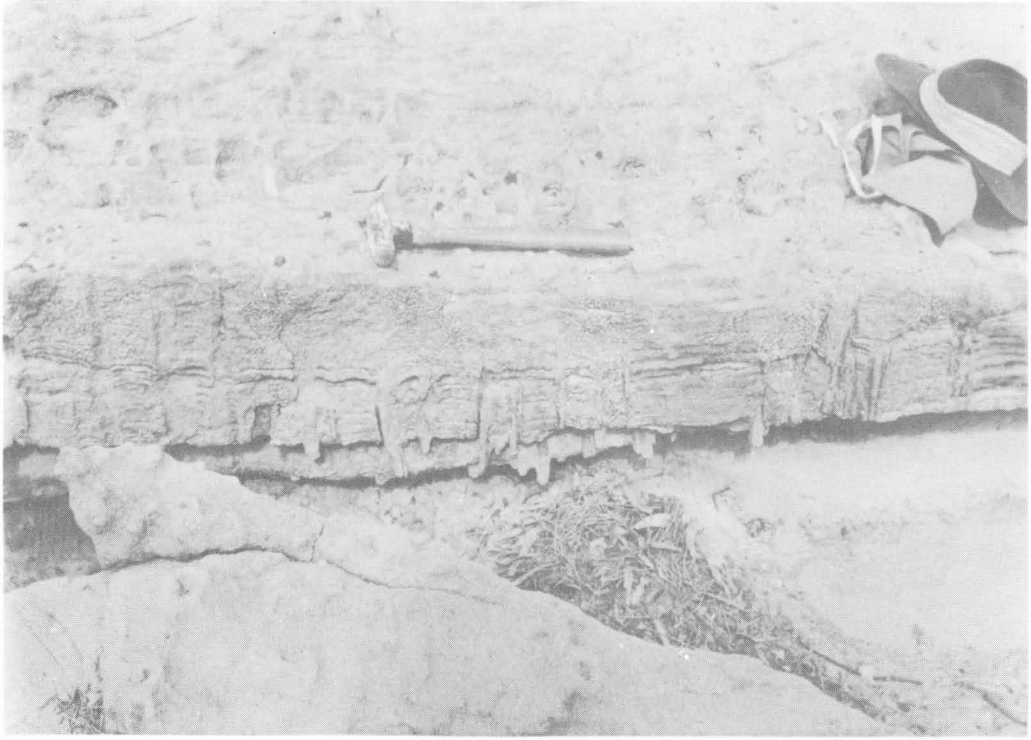


Figure 11. —A *Diplocraterion* bed, Locality No. MB57. The laminae of the sandstone are slanting down at the apertures of the shafts. Below the middle of the hammer and above the left end of the tuft of dry grass the U-shaped bottom part of a shaft protrudes out of the lower bedding plane. J. M. Dickins photo.

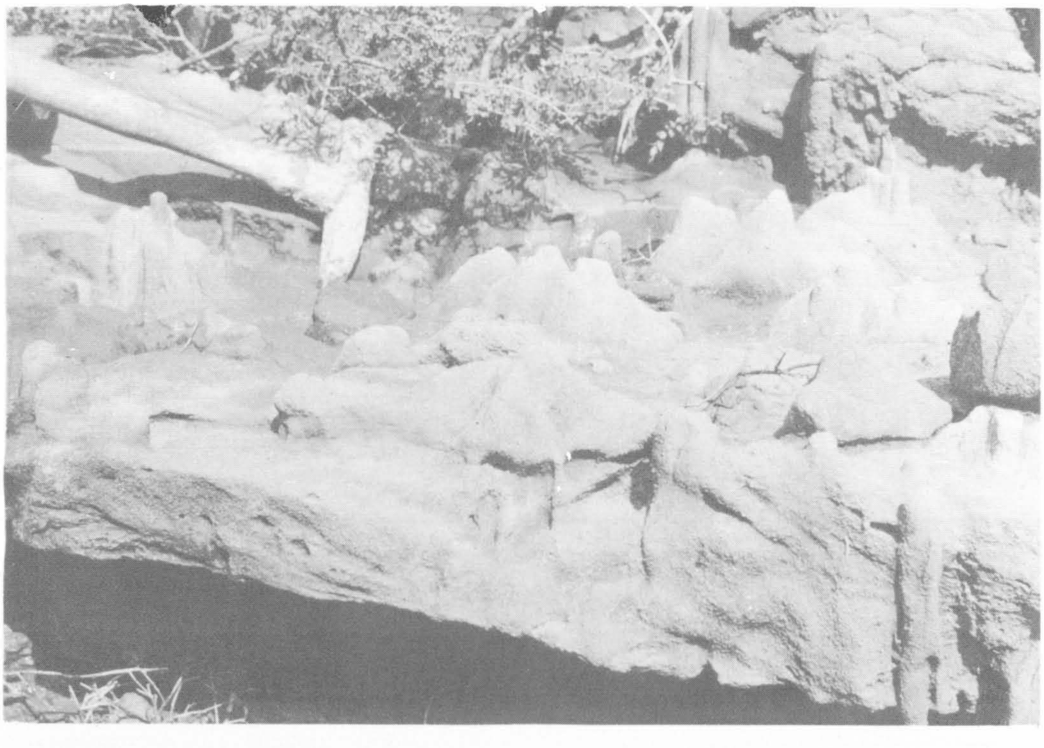
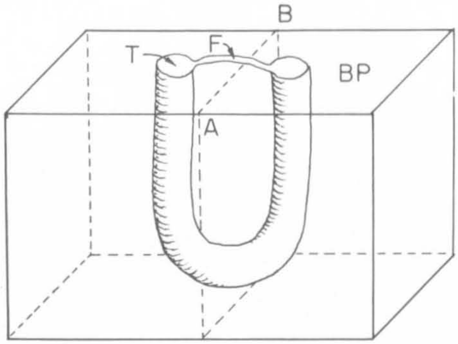
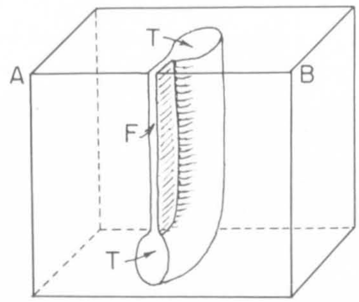


Figure 13.—Pipes in sandstone described by Clarke and Teichert (1948). Locality No. MB54, near Tumblagooda Hill. J. M. Dickins photo.

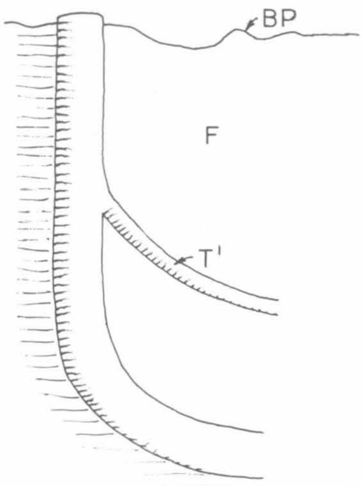
Fig. 12



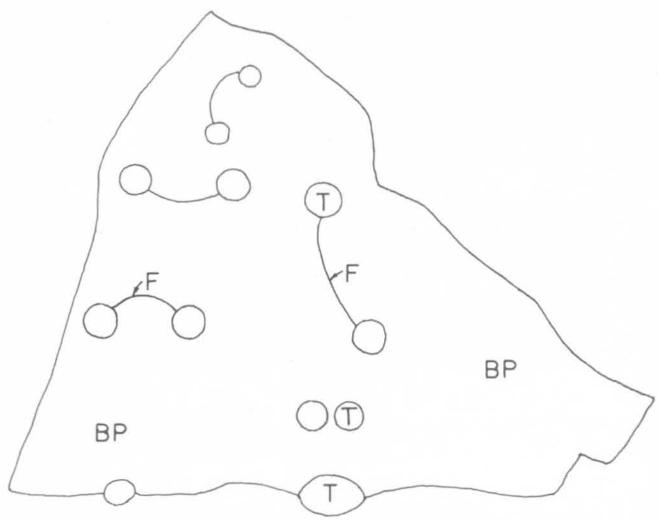
1. Position in Sandstone.



2. Section A-B of 1.



3. Section of a fragment as explained above (1 & 2).



4. Cross section of several shafts on a bedding plane.

T Vertical pipe.

T' Position of bottom of "U" shaped bend in an earlier stage.

F Connecting fissure or lumen.

BP Bedding plane.

A-B Section line.

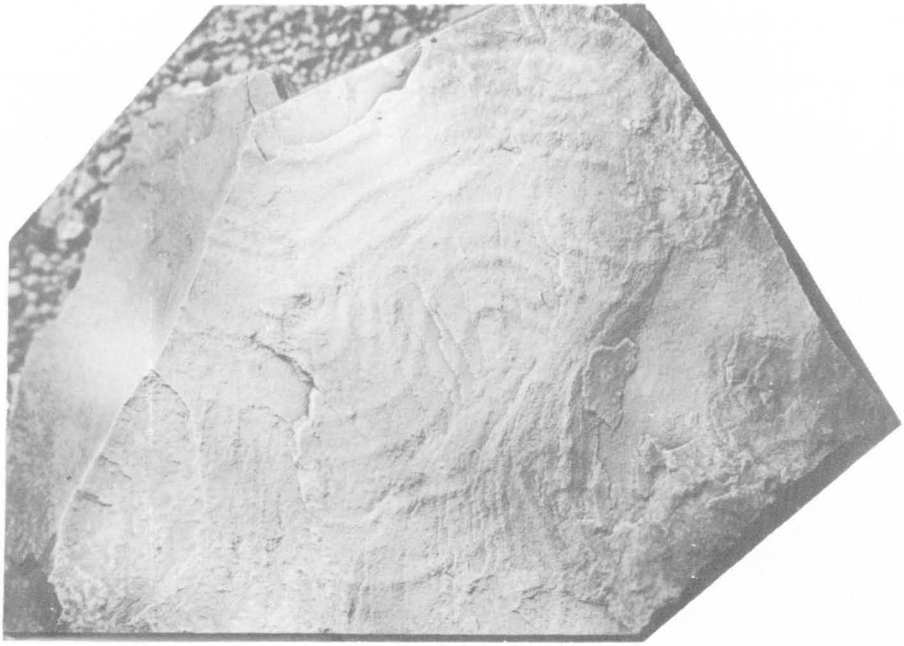


Figure 14.—Meandering trail in shale from Big Tolbar Creek, Snowy Mountains, x 1½. Parts of the trail are indistinctly " beaded ".

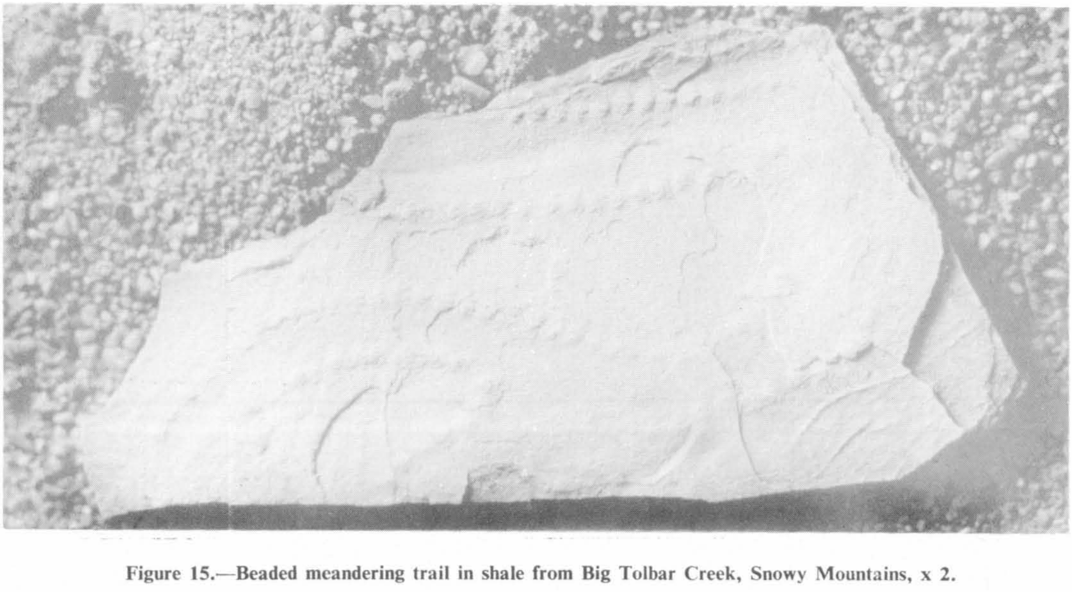


Figure 15.—Beaded meandering trail in shale from Big Tolbar Creek, Snowy Mountains, x 2.

Figure 16.—Shaft-and-tunnel trails in shale from Big Tolbar Creek, Snowy Mountains, x 2. See also Figure 17.

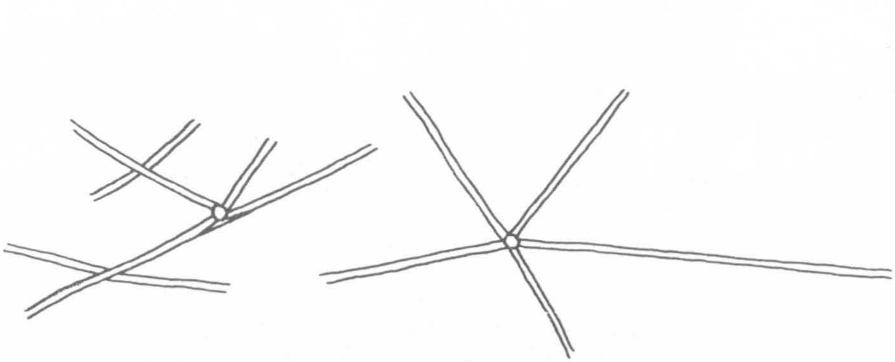


Figure 17.—Diagram drawn from the upper part of the specimen, Figure 16, x 4. Straight tracks radiate from shafts shown as circles. Some of the trails cross one another.

Figure 18.—Shaft-and-tunnel trails in shale from Big Tolbar Creek, Snowy Mountains, x 1½. Some of the horizontal trails are curved. In the left upper corner a wavy trail is seen that may be made by a different animal.

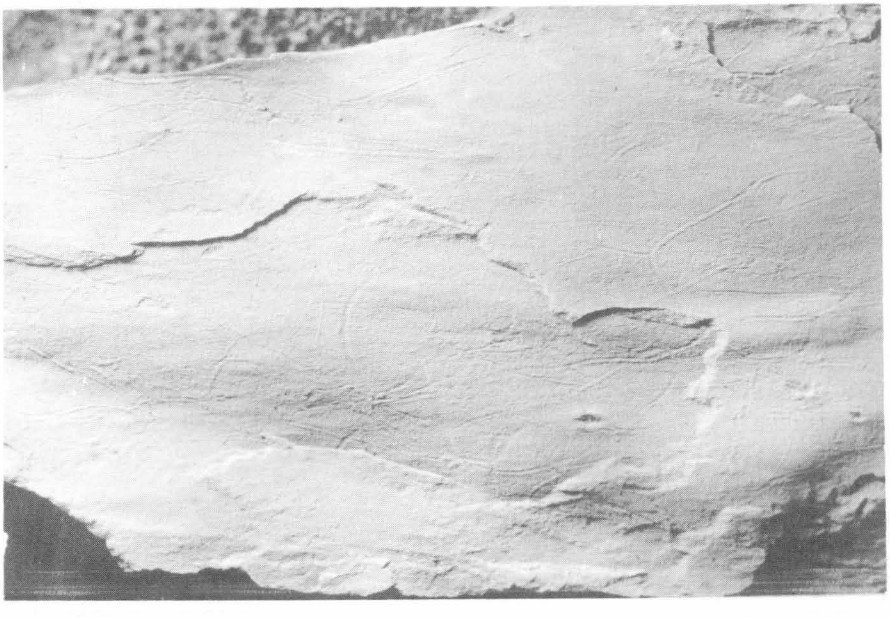


Figure 19.—Trails in fine-grained sandstone or silt, Pittman Formation, Carne Creek, west of Black Mountain, Canberra, x 1½. These trails are " channels with lateral walls ".

THE LOWER CARBONIFEROUS LAUREL FORMATION OF THE FITZROY BASIN

by

G. A. Thomas

SUMMARY

Fossiliferous marine Lower Carboniferous outcrops in the Fitzroy Basin are described. The sequence, 1,500 feet thick, consists of calcarenite and calcareous siltstone with brachiopods, sharks' teeth, rare corals, nautiloids, pelecypods, ostracods, conodonts, and ammonoids. Its age is probably Tournaisian. The sequence is probably unconformable on the Upper Devonian and is overlain unconformably by the Permian Grant Formation.

INTRODUCTION

In 1953 the author, while examining the area in company with geologists of West Australian Petroleum Pty Ltd, collected fossils from near the top of a section two miles north-west of Twelve Mile Bore, Brooking Springs Station, then thought to belong to the Upper Devonian Fairfield Beds, which are named and described by Guppy et al. (1958). When these fossils were examined they appeared to indicate a Lower Carboniferous age. Consequently the area was revisited in 1955 and an abundant fauna collected from several sections and numerous localities. This fauna confirmed the presence of a considerable extent of Lower Carboniferous sediments in the area.

Thomas (1957) published a preliminary account of the stratigraphy and fauna of the Laurel Beds.

In 1957, Messrs F. Williams and M.McKellar of West Australian Petroleum Pty Ltd mapped the Laurel Beds in greater detail and made further collections which have yielded some additional fossil species. When the results of this survey become known some changes may be required to the short account presented here, which is mainly based on field work of the writer and collections made by him in 1955 and by S.D. Henderson in 1956.

LAUREL FORMATION

The Laurel Formation is defined as the sequence of fossiliferous calcarenite and siltstone of Lower Carboniferous age between the Upper Devonian Fairfield Beds and the Permian Grant Formation, probably in unconformable relationship to both. The formation was at first named Laurel Beds in Thomas (1957).

The name is taken from Laurel Downs pastoral station, where the sequence crops out over wide areas.

The type locality is near Twelve Mile Bore, Brooking Springs Station. The two type sections of different parts of the formation are (I) 2 miles north-west of the bore at Lat.17°55'S., Long.125°14'30"E. and (II) at 3 miles south-south-east of the bore at Lat.17°58'S., Long. 125°2'E. (Figure 1).

Dips are difficult to measure accurately and thus the thicknesses in the sections recorded below are approximate, especially in section II, where a dip of 8° recorded near the top of the section has been assumed as characteristic of the complete section. If, as is possible, the dip of the lower beds is greater, the calculated thickness is too small.

The complementary sections I and II are illustrated in Text-figure 2.

Type Section I was measured in folded sediments, with the lowest bed situated about 2 miles north-west of Twelve Mile Bore. The following section is exposed, in descending order:

(b) Yellowish-brown shelly calcarenite, mostly thin-bedded, interbedded with poorly exposed thicker sequences. The calcarenite is medium grained; some beds are sandy; the poorly exposed beds are, in part at least, siltstone. Fossils are abundant in some beds; they include brachiopods, sharks' teeth, rare corals, nautiloids and pelecypods.
Thickness, about 300 feet.

(a) Pale grey to pale brown sandy calcarenite, mainly thin tough beds with several thicker sequences, interbedded with softer non-outcropping sediments. The non-calcareous sand grains are mostly quartz and are fine-grained to coarse-grained and sub-angular to rounded. Thin sandstone beds are present near the base. Fossils are generally rare.
Thickness, about 700 feet.

The upper boundary of Section I is covered by sand, and the lower by alluvium.

Type Section II, part of which may correspond to part of Section I, was measured about 3 miles south-south-west of Twelve Mile Bore. It consists of yellow-brown fossiliferous calcarenite, similar in lithology to that of Section Ib, with poorly exposed sediments interbedded. Fossils are abundant and include forms not present in section Ib; weathered-out specimens are common.

Thickness, about 470 feet.

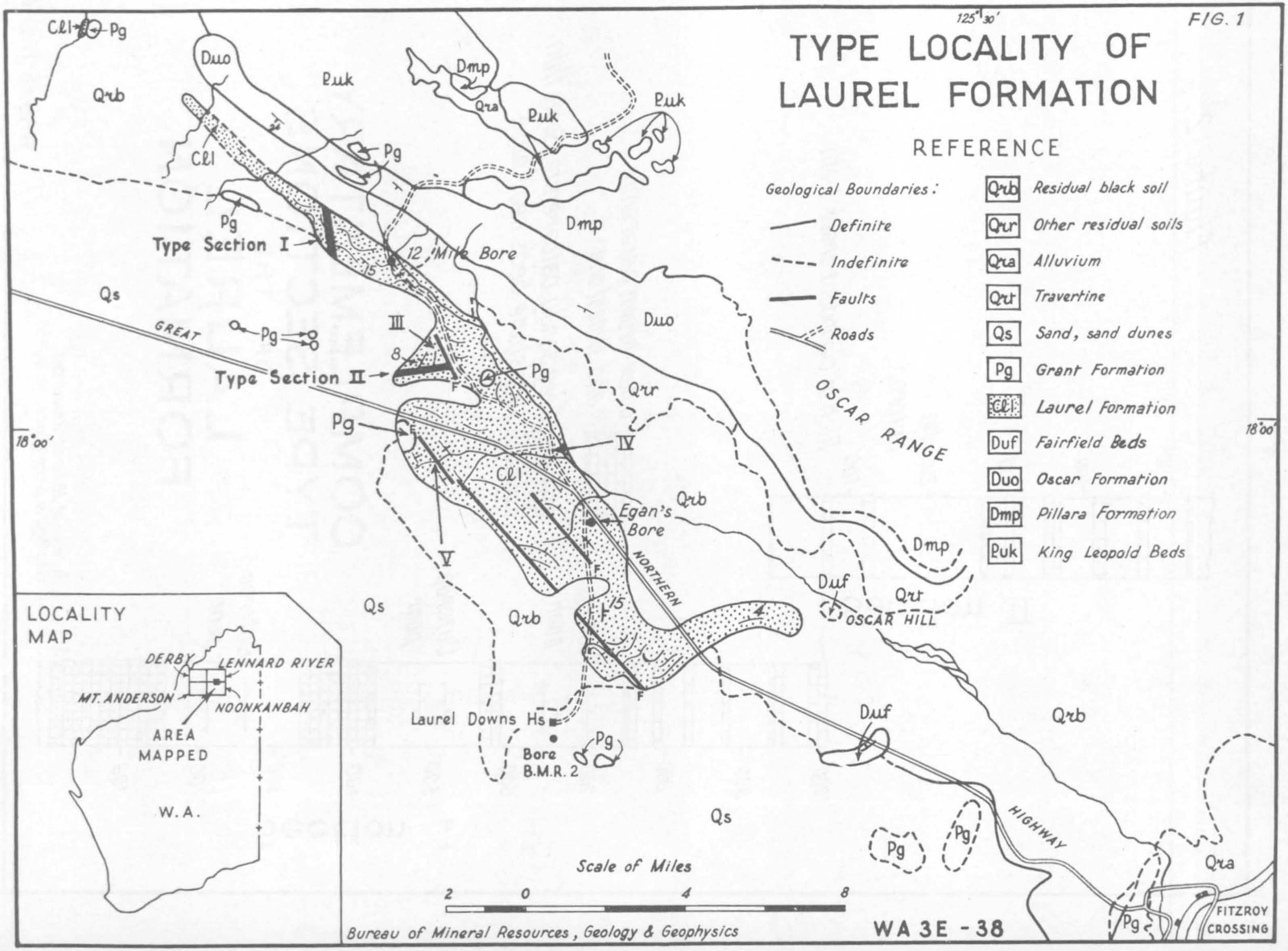


FIG. 1
TYPE LOCALITY OF
LAUREL FORMATION
REFERENCE
Geological Boundaries:
Definite
Indefinite
Faults
Roads
Qrb Residual black soil
Qrr Other residual soils
Qra Alluvium
Qrt Travertine
Qs Sand, sand dunes
Pg Grant Formation
Cll Laurel Formation
Duf Fairfield Beds
Duo Oscar Formation
Dmp Pillara Formation
Puk King Leopold Beds
125°30'
18°00'
Type Section I
Type Section II
12 Mile Bore
Egan's Bore
OSCAR RANGE
OSCAR HILL
GREAT NORTHERN HIGHWAY
Laurel Downs Hs
Bore B.M.R. 2
FITZROY CROSSING
LOCALITY MAP
DERBY
LENNARD RIVER
MT. ANDERSON
NOONKANBAH
AREA MAPPED
W.A.
Scale of Miles
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WA 3E - 38

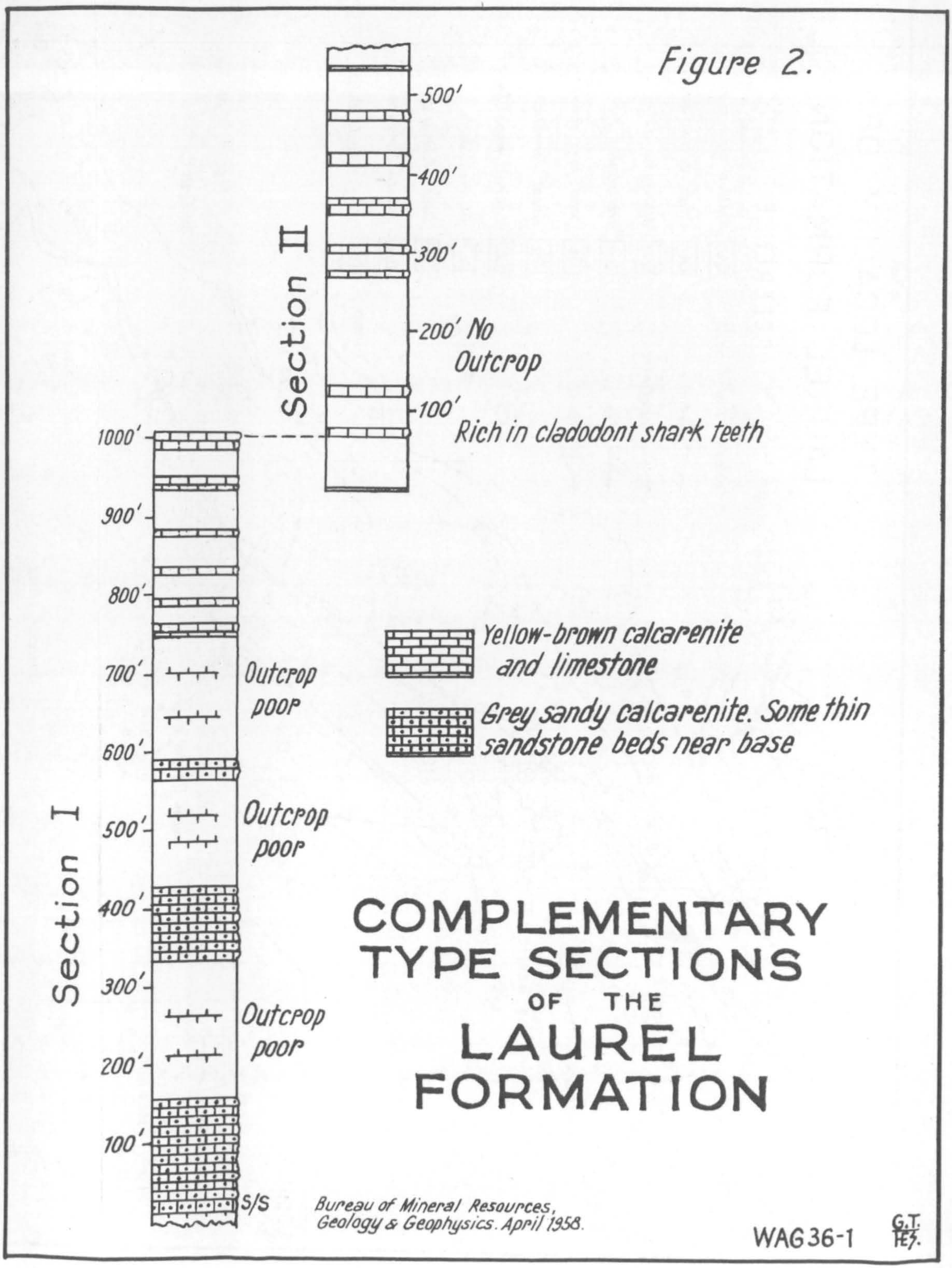


Figure 2.

COMPLEMENTARY TYPE SECTIONS OF THE LAUREL FORMATION

The lower, i.e. eastern, boundary of Section II is a probable fault plane, on the eastern side of which is yellow brown calcarenite, and farther east is grey sandy calcarenite, similar to that in Section Ia. The upper boundary is covered by sand. Section II is certainly stratigraphically higher in part than Section I and may be entirely so. A bed rich in cladodont sharks' teeth occurs at the top of Section I and low in Section II; if these are the same horizon, as appears likely, then all of Section II is stratigraphically higher than Section I, and the outcropping section totals about 1,500 feet.

DISTRIBUTION AND NATURE OF OUTCROP

Outcrops of the Laurel Formation were identified in the areas shown in Figures 1 and 3. About 6 miles north-west of Twelve Mile Bore, on Spielers Creek, the lower sandy calcarenites are not exposed; some 500 to 600 feet of yellow to grey calcarenite crop out. These beds have Lower Carboniferous brachiopods at several levels.

The widest extent of outcrop is in the region south and west of Egan's Bore. The lithologies are similar to those of Sections I and II. About 4 miles west of Egan's Bore, beds high in the formation are exposed in gullies. Here thick sequences of grey siltstone interbedded with thinner yellow-brown calcarenites are present; fossils are abundant.

About one mile south of Oscar Hill beds of grey calcarenite, with variable low dips, probably should be included in the Laurel Formation. They are not shown in the sketch map (Figure 1).

PALAEONTOLOGY

The fossils collected from the two complementary sections and from several other localities are briefly outlined below.

Section I

The lower grey sandy calcarenites are generally not rich in fossils. Near the base Syringopora sp. nov. ex group S. reticulata Goldfuss (identified by Dr. D. Hill) was collected. Some beds contain crinoid stems, Camarotoechia pleurodon var. tripla Prendergast, and fragmentary gastropods. At about 600 feet bradyodont sharks teeth were observed.

The yellow-brown calcarenites of Ib occurring from about 750 feet are much richer in fossils. In ascending order at the approximate levels occur the following species;

750 feet - bradyodont sharks' teeth, Camarotoechia sp.
800 feet - bradyodont teeth, Camarotoechia, and incomplete pelecypods.
850 feet - Composita sp. nov.
Pustula sp.
Camarotoechia pleurodon var. tripla Prend.,crinoid stems, orthoceroid nautiloid
Bothrophyllum sp. nov.(identified by Dr.D. Hill)
1010 feet - Productid gen. et sp.
Camarotoechia pleurodon var. tripla Prend.
Composita sp. nov.
Cladodont teeth (Plate I, figure a)
Bradyodont teeth (Plate I, figure b. c. d)
Bone-like plates
Pelecypoda and gastropoda indet.
Orthotetacea indet.

Section II

At 60 feet - Cladodont teeth
Camarotoechia pleurodon var. tripla Prend.
Syringopora sp.
Bellerophontid gen. et sp. indet.
120 feet - Camarotoechia pleurodon var. tripla Prendergast
300 feet - Camarotoechia pleurodon var. tripla "
350 feet - bradyodont teeth
bone fragments
Athyrid gen. et sp. indet.
415 feet to c. 435 feet - Rich fauna including:
Spirifer fluctuosus Glenister
Linoproductus sp. nov.
Rhipidomella sp.aff. R.michelini (L'eveille)
Athyris? sp.
Punctospirifer sp.
Pustula? sp.
Eomartiniopsis? sp.
Schuchertella sp.
Composita sp. nov (= C. "subtilita" Prendergast non Hall)
Camarotoechia pleurodon var. tripla Prend.
Bryozoa indet.
bellerophontid gen. et sp.
Straparollus? sp.
Murchisonia? sp.
Syringopora sp.nov. ex group S.reticulata Goldfuss

470 feet - Schizodont pelecypods indet.
and incomplete brachiopods, mainly Camarotoechia sp.

530 feet - Brachiopod fragments

From locality III, about two miles north of section II, collections made over a sequence of beds approximately equivalent to about 100 to 350 feet in section II yielded many of the species found at 415 feet, and also Cleiothyridina sp. nov.

Fossils were collected from numerous other localities in the area, mainly from beds equivalent to the higher parts of section II. Several of these localities are included in Figure I.

Locality IV

Unispirifer sp.nov.aff. U.tornacensis (de Koninck)
Camarotoechia pleurodon var. tripla Prendergast
Plicatifera ? sp. nov.
Avonia ? sp. nov.
Schuchertella sp.
Buxtonia ? sp.
cf. Michelinia sp.

P.J. Jones (personal communication) has identified the following ostracods:

Bairdia sp.
Cavellina spp. (3)
Cryptophyllus sp.
Jonesina sp.
Macropypris sp.
Paraparchites sp.

Locality V.

Spirifer fluctuosus Glenister
Punctospirifer sp.
Rhipidomella sp. aff.R.michelini (L'eveille)
Cleiothyridina sp.
Composita sp. nov.
Athyris ? sp.
Linoproductus sp.
Chonetes sp.
cf. Allorisma sp.)
cf. Murchisonia sp.) identified by J.M. Dickins
Bucanopsis sp.)
straight nautiloid
Syringopora sp.
cf. Michelinia sp.

The beds at this locality are probably equivalent to the Spirifer fluctuosus horizon in Section II.

Near Egans Bore, especially to the south, numerous specimens occur weathered free on the surface. Predominating in the collections are specimens of Composita sp.nov. (= C."subtilita" Prend. non Hall), and Camarotoechia pleurodon var. tripla Prend. Also from this area several specimens of an ammonoid were collected in 1957 by Messrs Williams and McKellar of West Australian Petroleum Pty Ltd. This has been identified by Dr. B.F. Glenister as Imitoceras rotatorium (de Koninck).

Conodonts have also been collected from outcrops of the Laurel Formation, and also from the B.M.R. No.2 Bore. B.F. Glenister (in press) has recorded the following conodonts from B.M.R. No.2 Bore at 350' to 360': Ligonodina sp., Subbryantodus sp. and Gnathodus sp. cf. G.bilineatus (Roundy). Glenister also recorded, from near 12 mile Bore, Prioniodina sp., Hindeodella sp., Gnathodus sp., Cavusgnathus sp. P.J. Jones (this volume) has recorded species of Cryptophyllus, Cavellina, Microcheilinella, Paraparchites, Bythocypris, Tetratylus?, Perprimitia, Leptoprimita?, and Jonesina from cores from 250 feet down to about 1010feet. No definite conchostracans have been observed: they were incorrectly recorded in Thomas (1957).

Age of the Faunas

The lower beds have a sparse fauna, but the brachiopods appear to be conspecific with species occurring higher. Furthermore, Dr.D. Hill has identified Syringopora sp. nov. from near the base. This species, which also occurs in the topmost beds, she considers to be a member of the group of Syringopora reticulata Goldfuss. This is a widespread Lower Carboniferous group.

The brachiopod species occurring in the higher beds of Section I and throughout Section II are undoubtedly of Lower Carboniferous (Dinantian) age. The species of Rhipidomella is closely allied to or conspecific with R.michelini (L'eveille), a species occurring in the Dinantian of Europe and the Moscow Basin, and with allied species in the Mississippian. Linoproductus sp., Punctospirifer sp., Pustula sp., Plicatifera? sp., Schuchertella sp., Cleiothyridina sp., Composita sp., are all allied to species ranging through the Dinantian. Unispirifer sp. nov. is closely allied to Unispirifer tornacensis (de Koninck) a characteristic Upper Tournaisian species from Western Europe, the Moscow Basin, and the Donetz Basin, with allies in the Early Mississippian of North America. An allied species occurs in beds of Upper Tournaisian age in New South Wales. Spirifer fluctuosus Glenister shows more primitive characters than Spirifer striatus (Martin) a characteristic European Visean species. The absence of distinctive Visean species such as Spirifer striatus (Martin), "Spirifer" bisulcatus Sowerby, Gigantoproductus spp., etc., is noteworthy. Hence the brachiopods indicate an early Dinantian age, i.e. probably late Tournaisian.

The conodonts recorded by B.F. Glenister from 12 Mile Bore come from an horizon probably near the top of Section I. Glenister (1958) considers that the affinities of this fauna indicate a Middle Mississippian age not older than the late Osagean.

The ammonoid Imitoceras rotatorium (de Kon) was found in the vicinity of Egan's Bore from an horizon probably fairly high in Section II. Glenister (1958) records that this species is known from the Upper Tournaisian Calonne Limestone at Tournai in Belgium, the late Kinderhookian Marshall Sandstone of Michigan, the late Kinderhookian Rochford Limestone of Indiana, and beds of Upper Tournaisian age in the Burindi Series of New South Wales. Jones considers that the ostracods in the B.M.R. No.2 Bore from 250 to 1010 feet show some affinity with Chester ostracods of Illinois. The Chester constitutes the uppermost series of the Mississippian. However, early Mississippian ostracods are not as well known as the later Mississippian and the affinity does not necessarily imply the same age.

The bradyodont teeth have not yet been sufficiently studied. Bradyodonts are known from Devonian, Carboniferous, Permian, and later rocks and have been collected from the Permian Noonkanbah Formation in the Fitzroy Basin. Teichert (1943) described some Carnarvon Basin Permian species. Representative Laurel specimens are shown in Figure 4b, c, and d. Numerous cladodont teeth were found at the top of Section I and low in Section II. A typical example is shown in Figure 4a. The crown is enamelled and fluted and the lateral cusps number three or four on either side. These teeth resemble some of the forms described by Davis (1883) from the Lower Carboniferous of Ireland and referred by him to species of Cladodus. They closely resemble in size and shape the teeth of Ctenacanthus costellatus Traquair from Glencarthsholme, Dumfriesshire, Scotland, in beds of Tuedan (Lower Carboniferous) age. Moy Thomas (1936), who re - described this species, states that Lower Carboniferous cladodonts are distinguished from Devonian ones by the presence of enamel. The Devonian forms seem generally to have fewer lateral cusps.

Bone-like fragments are quite common in the Laurel Formation, usually in association with the sharks teeth. They may be portions of ossified cartilage from the jaws or skull parts of sharks.

The faunas of brachiopods, conodonts, and the ammonoid thus indicate an age equivalent approximately to the late Tournaisian of Europe or to the Osagean of the Mississippian. The mollusca other than the ammonoid have been insufficiently studied to provide evidence of the age.

The small coral fauna is indicative of a general Dinantian age. The brachiopod faunas have much in common with those of the Moogooree Limestone of the Carnarvon Basin and of the Septimus Limestone of the Bonaparte Gulf. The relationships are discussed in Thomas (in press).

STRUCTURE

Outcrops of the formation are folded and faulted. The major structures are indicated on the sketch map (Figure 1). The whole sequence appears to be conformable, though in and near Section I the higher yellow-brown calcarenite dips more steeply than the lower grey sandy calcarenite; the strikes are parallel and sinuous. Generally in the area near Twelve Mile Bore and farther north-west, dips are south-west to south. In the area west and south of Egan's Bore, dips are mainly north-east to north, except about four miles south-east of the bore, where the beds are folded.

Strikes of the Laurel Formation notably differ from those of the Oscar Formation (massive Upper Devonian limestones), which dip at about 15-20^{o} south-west. A belt of alluvium, which separates outcrops of the two formations, may mask the Fairfield Beds, which crop out at Oscar Hill and on the main road some four miles south of Oscar Hill. The contact between Laurel Formation and Fairfield Beds was not observed. They are probably unconformable. Certainly, the fold and fault pattern of the Laurel Formation suggests that they have had a different structural history from that of the Oscar Formation. Possibly the Laurel beds were deposited on an eroded surface of the Devonian, and some of the dips may be initial. The age difference between the Fairfield Beds (Upper Devonian Stufe IV or V; Teichert, 1949) and the Laurel Formation (Late Tournaisian) indicates a considerable diastem.

The northern boundary of the outcrops of the Laurel Formation, north and north-west of 12 Mile Bore, may be a fault. If this northern boundary is a fault, the nearby folds in the Laurel Formation could be interpreted as drag-folds.

The southern fault at its eastern end has its upthrown side on the north. As the hade is north-easterly, this is a reverse fault.

The relationship of the faults in the Laurel Formation to the regional structural pattern is conjectural. The Laurel structures are post-Tournaisian and antedate the deposition of the Grant Formation. Major subsidence in the basin must have occurred in the Upper Carboniferous and early Permian to permit the accumulation of 5,000 - 6,000 feet of Anderson Formation and 9,000 feet of Grant Formation. Both these formations are of shallow-water origin. The Anderson Formation increases in thickness from probably nothing at the Sisters Bore to 5,000 feet at Grant Range No.1 Bore. The Grant Formation is 1,000 feet thick at the 67 Mile Bore, possibly 2,700 feet at the Sisters Bore and 9,000 feet in the Grant Range.

The structures in the Laurel Formation may be related to fault movements which accompanied the major subsidence. This subsidence may have been connected with movements along a north-westerly continuation of the Pinnacle Fault, which is known in outcrop only at the Pinnacles, near Prices Creek.

The Grant Formation (Permian) is seen to overlie the Laurel Formation unconformably in places, but generally the upper boundary of the Laurel is covered by sand or alluvium. Higher parts of the Laurel Formation or other Carboniferous rocks may be present below the sand cover in the areas west of Laurel Downs homestead.

OTHER OCCURRENCES OF CARBONIFEROUS ROCKS IN THE FITZROY BASIN

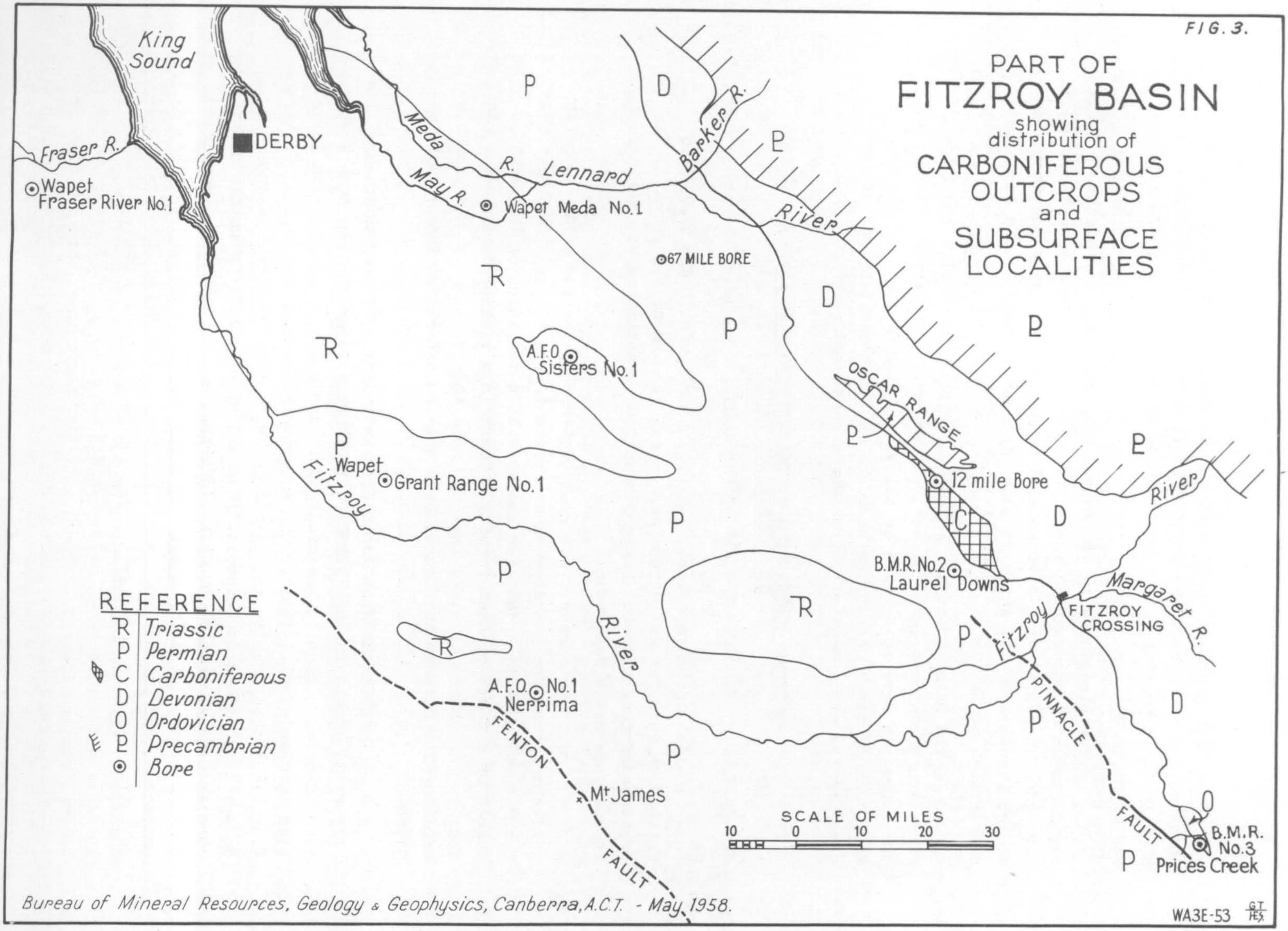
(Figure 3)

An exploratory bore, B.M.R.2, near Laurel Downs homestead, drilled in 1956 for the Bureau of Mineral Resources, has revealed the presence of fossiliferous Lower Carboniferous sediments below 178 feet of possible Grant Sandstone.

S.D. Henderson (1956, p.4) interprets the log of the bore as indicating that the Laurel Beds are present from 178 to 1,420 feet. "At 1,420 feet there is a decisive change with a variation of dip of 3°, caused by a fault or unconformity. There is a similar change at 1,885 feet." The change at 1,420 feet may mark the position of the probable unconformity between the Laurel Beds and the underlying Devonian formations.

In 1955 the West Australian Petroleum Ltd Grant Range No.1 Bore (figure 3) passed through 8,000 feet of Grant Formation and then about 5,000 feet of marine to brackish water sediments - the Anderson Formation (McWhae et al., 1958). The Anderson Formation consists of "alternating sandstones, shales and siltstones with thin beds of limestone, dolomite and anhydrite especially in the upper part". From the Grant Range bore at several levels, Dr.Öpik (in McWhae et al. 1958) has identified conchostracans including _Leaia_ (_Hemicycloleaia_) Raymond, fish remains, ostracods, and _Lingula_ sp., and J.M. Dickins has determined pelecypods ? _Naiadites_ sp.cf. _N.modiolaris_. The faunas indicate a Westphalian to possibly Stephanian age. Balme (in McWhae et al., 1958) has recorded spores from the Anderson Formation of the Grant Range bore and also from

FIG. 3.



Bureau of Mineral Resources, Geology & Geophysics, Canberra, A.C.T. - May, 1958.

WA3E-53

the Fraser River No.1 bore. The spore content of the overlying Grant Formation shows an abrupt change.

The Anderson Formation is also present at 4,852 to 10,045 feet in Fraser River No.1 Bore (McWhae et al.,1958).

Lower Carboniferous fossils, including conodonts and ostracods, have been identified from the Sisters Bore sunk by Associated Freney Oil Co. in 1957. The Lower Carboniferous fauna occurs in marine calcareous shaly rocks from about 6,000 to 7,140 feet, below a sequence of Permian deposits. Lower Carboniferous conodonts and corals are present. Devonian forms were found at greater depths. Lower Carboniferous fossils have recently been identified in the Meda No.1 Bore.

Some of the older writers on the Fitzroy Basin refer to the presence of Lower Carboniferous rocks in the basin (e.g. Wade, 1924). These are incorrect; the beds so designated are either Devonian or Permian. The suggestion in David (1950, p.306) and Neaverson (1955, p.304) that Lower Carboniferous marine fossils are present in certain old bores, e.g. the Price's Creek bores, is also incorrect. The rocks in this area are of Ordovician age.

GEOLOGICAL HISTORY

The Laurel Formation represents a period of infraneritic deposition, probably on a shelf; the sea was probably transgressive.

During the Devonian a complex succession of deposits, including coarse and fine clastics, bioherms, biostromes, and reefs, was accumulated. The last phase of Devonian deposition was a widespread thin succession of calcarenite and shelly coquinites rich in brachiopods, bryozoa, and corals - the Fairfield Beds. These are of late Fammenian age (Stufe IV to V of the German succession).

Deposition was then interrupted and the surface was probably uplifted and eroded. The Laurel deposition began in the Tournaisian with the accumulation of well sorted sandy calcarenite, in places with small <u>Syringopora</u> growths, but generally poor in fossils. Later in the Tournaisian more richly fossiliferous calcarenites and siltstones were laid down. Marine life was abundant and comprised brachiopods, molluscs, corals, ostracods, conodonts, bryozoa, and sharks.

Deposits of Tournaisian age are so far known only from the outcrop area, from Laurel Downs Bore B.M.R. No.2, and probably from the Sisters Bore. The shelf area was at least of that extent during the Tournaisian. After the Tournaisian, deposition on the shelf was interrupted presumably by uplift, and subsequently the sediments were folded and faulted.

During the Upper Carboniferous, farther out in the basin, subsidence permitted the accumulation of a great succession of shallow lacustrine to brackish-water deposits - the Anderson Formation. The erstwhile shelf area was probably land at this time. In the early Permian, subsidence continued in the central parts of the basin. Some submergence took place on the original shelf area and shallow clastics of partly marine and partly fluvio-glacial origin were deposited over Lower Carboniferous and Devonian rocks. These shallow clastics are the marginal representatives of the Grant Formation, which is about 9,000 feet thick in the central parts of the basin.

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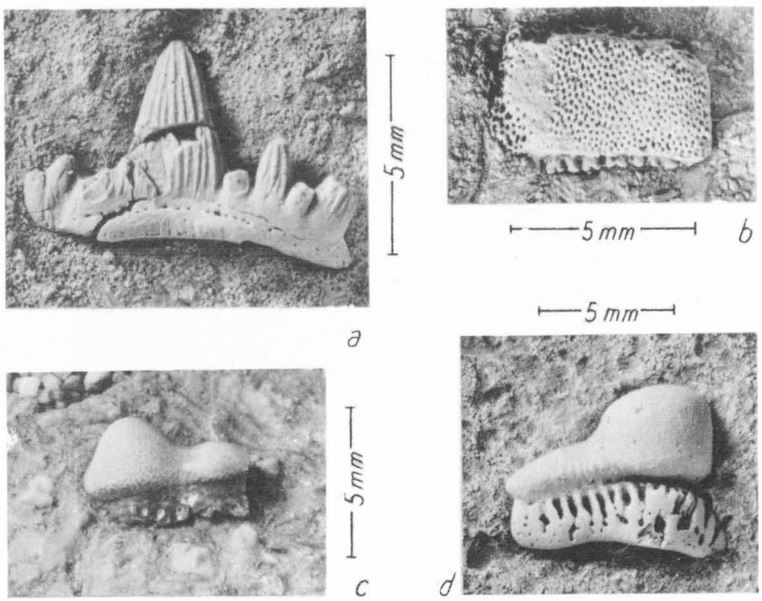
Fig. 4



Examples of sharks' teeth from the Laurel Formation

a. Cladodont tooth, showing 4 lateral cusps and fluted crown.
b. Bradyodont tooth, with flat crown.
c, d. Bradyodont teeth, in lateral view, showing crown and root.

PRELIMINARY REPORT ON OSTRACODA FROM BORE B.M.R. No.2 LAUREL DOWNS, FITZROY BASIN. WESTERN AUSTRALIA

by

P.J. Jones

INTRODUCTION

Bore B.M.R. No.2 is situated about 17 miles west-north-west of Fitzroy Crossing and 0.4 miles south of Laurel Downs Homestead, at longitude 125°19'E., latitude 18°07'S. (See Figure 1). The bore was spudded in on the 8th December 1955, and completed to the total depth of 4,000 feet on the 10th May 1956. Core samples were taken at intervals of about 100 feet, and cuttings at intervals of 5 feet.

An important feature of the bore cores is the presence of a large fauna of Lower Carboniferous and Upper Devonian ostracods, which will be figured and described at a later date. As this report represents the initial work of the author on the Upper Palaeozoic Ostracoda of Western Australia, the identifications given below must be regarded as preliminary and, for the present, open nomenclature has been used to refer to possible new species.

DETAILED EXAMINATION OF CORES AND CUTTINGS

Core 1 Depth 50-60 feet: recovery 0 feet 2 inches.
Friable medium-grained buff-coloured quartz sandstones.
No fossils found.

Core 2. Depth 150-162 feet; recovery 4 feet 3 inches.
Fine-grained ochre-coloured quartz sandstone, which grades downwards into a coarse siltstone. Ostracods common; badly preserved as internal casts in the middle part of the core, but better preserved in the more silty material.
Ostracoda: *Cavellina* sp.
Cryptophyllus sp.

Core 3 Depth 250-260 feet: recovery 8 feet 9 inches.
Grey shaly fossiliferous siltstone interbedded with a fine-grained calcareous sandstone. A rich fauna includes brachiopod remains (fragments of shell material, and "*Productus*" spines), an internal cast of an unidentified pelecypod, crinoid columnals, echinoid remains (cidaroid spines and tubercles), abundant ostracods, and fish remains (small rhomboid plates).

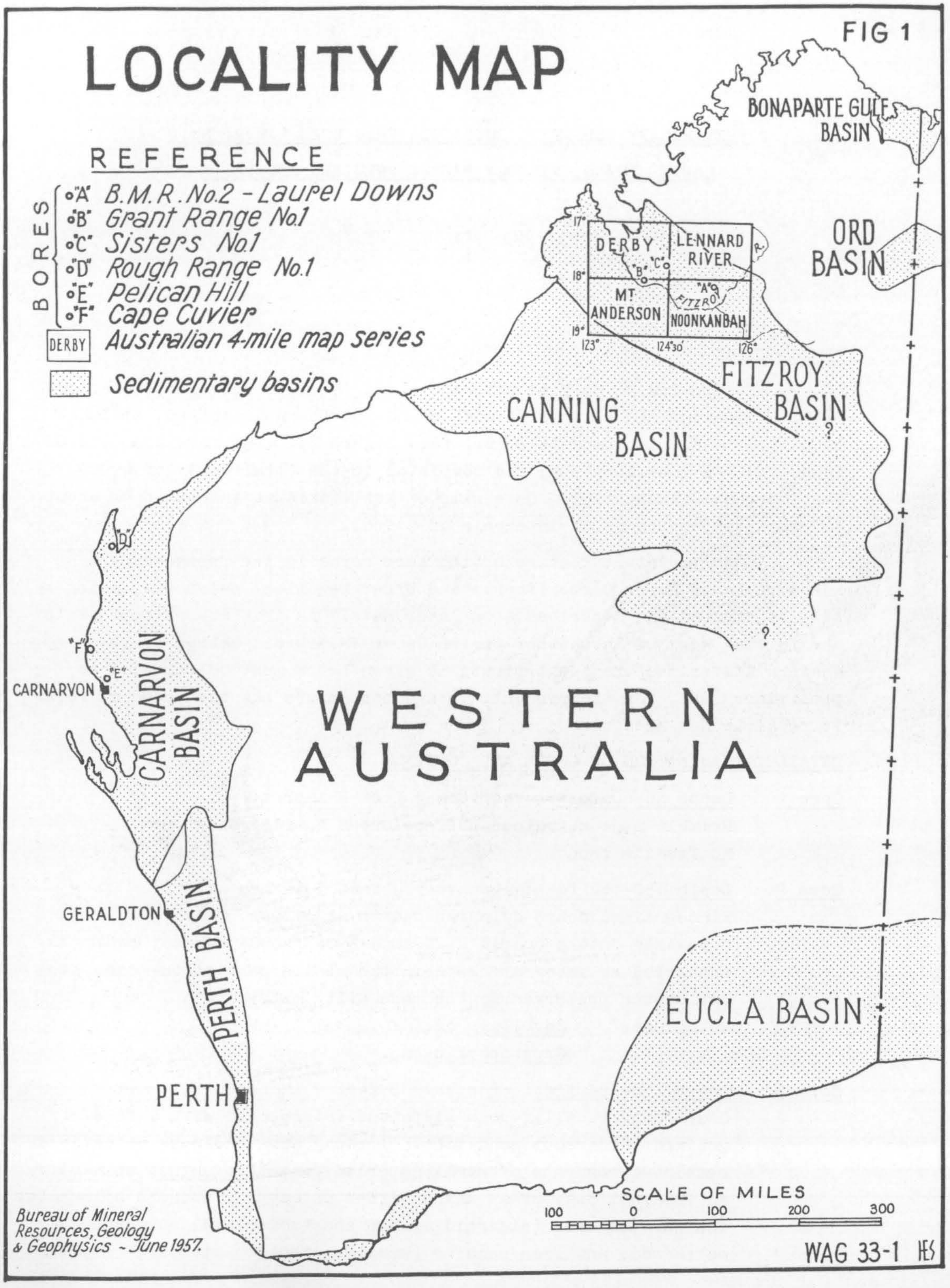


FIG 1
LOCALITY MAP
REFERENCE
BORES
"A" B.M.R. No.2 - Laurel Downs
"B" Grant Range No.1
"C" Sisters No.1
"D" Rough Range No.1
"E" Pelican Hill
"F" Cape Cuvier
DERBY Australian 4-mile map series
Sedimentary basins
BONAPARTE GULF BASIN
ORD BASIN
DERBY
LENNARD RIVER
MT ANDERSON
NOONKANBAH
FITZROY
17°
18°
19°
123°
124°30'
126°
FITZROY BASIN
CANNING BASIN
CARNARVON BASIN
CARNARVON
GERALDTON
PERTH BASIN
PERTH
WESTERN AUSTRALIA
EUCLA BASIN
SCALE OF MILES
100 0 100 200 300
Bureau of Mineral Resources, Geology & Geophysics - June 1957.
WAG 33-1 HES

Ostracoda: Cavellina cf. C.ovatiformis (Ulrich) 1891
C. cf. C.geisi (Croneis & Gale) 1938
C. cf. C.coryelli Croneis & Gale 1938
C. sp.nov. 1
Cryptophyllus sp.nov.
Jonesina sp.nov.1
J. sp.nov. 2
J. sp.nov. 3
Leptoprimitia? sp. nov.
gen.et sp. unidentified

Core 4 Depth 350-360 feet: recovery 4 feet 0 inches.
Soft grey siltstone alternating with hard bands of silty shelly limestone. Fossils numerous; a marine fauna of small brachiopods and "Productus" spines, the annelid Spirorbis, small fragments of crinoid columnals, ostracods (common), and fish remains (teeth, bones and rhombic scales).

Ostracoda: Cavellina cf. C.coryelli Croneis & Gale 1938
C. cf. C.geisi (Croneis & Gale) 1938
Cryptophyllus sp. nov.
Jonesina sp. nov.1
Microcheilinella sp.
Paraparchites nicklesi (Ulrich) 1891
P. cf.P. ovatus Cooper 1941
P. cf. P.okeni (Munster) 1830

Core 5 Depth 450-460 feet: recovery 8 feet 6 inches.
Coarse siltstone interbedded with silty limestone in which only one ostracod specimen was found.

Ostracod: Bythocypris sp.

Core 6 Depth 548-558 feet: recovery 10 feet 0 inches.
Hard grey siltstone, grading downwards into a silty limestone, in which only poorly preserved internal casts of ostracods were found; the adult carapaces were broken while the material was being crushed during preparation for microscopic examination.

Ostracoda: Cavellina sp. indet.
Jonesina sp. indet.
Microcheilinella sp.
?Tetratylus sp. indet.

Core 7 Depth 650-657: recovery 3 feet 6 inches.
Arenaceous limestone containing a few immature ostracods.

Ostracoda: Cavellina sp. indet.
Microcheilinella sp.
Perprimitia sp.

<u>Core 8</u> <u>Depth 800-814 feet</u>; recovery 5 feet 0 inches.
White fine-grained calcareous sandstone, with some siltstone in which ostracods are common, and generally well preserved.

Ostracoda: *Cavellina* sp. nov.1
Jonesina sp.nov.1
Microcheilinella sp.

<u>Core 9</u> <u>Depth 900-912 feet</u>: recovery 12 feet 0 inches.
Grey silty limestone, containing abundant well preserved ostracods.

Ostracoda: *Cavellina* sp. nov.1
Jonesina sp. nov.1

<u>Core 10</u> <u>Depth 1000-1010 feet</u>: recovery 7 feet 3 inches.
White coarse silty calcilutite resting on a grey limestone, which contains a few well preserved ostracods.

Ostracoda: *Bythocypris ovata* Cooper 1941
Microcheilinella obesa Cooper 1941
M. sp. nov.

<u>Core 11</u> <u>Depth 1090-1100 feet</u>: recovery 9 feet 6 inches.
Grey micaceous siltstone, grading downwards into a medium-grained sandstone which becomes coarse near the base.
No fossils found.

<u>Core 12</u> <u>Depth 1200-1210 feet</u>: recovery 10 feet 0 inches.
Grey calcareous siltstone interbedded with a coarse white calcareous sandstone. No fossils found.

<u>Core 13</u> <u>Depth 1300-1310 feet</u>: recovery 5 feet 6 inches.
White fine-grained calcarenite with bands of calcareous siltstone. Small fragments of brachiopods were found in the middle of the core. No ostracods were found.

<u>Core 14</u> <u>Depth 1400-1410 feet</u>: recovery 7 feet 6 inches.
Fine-grained calcarenite and thin beds of green siltstone, containing a few indeterminate ostracod fragments.

<u>Core 15</u> <u>Depth 1500-1510 feet</u>: recovery 6 feet 6 inches.
Grey dolomitic sandstone grading downwards into a fine-grained micaceous quartz sandstone. No fossils found.

<u>Core 16</u> <u>Depth 1600-1610 feet</u>: recovery 1 foot 3 inches.
Very fine-grained brown dolomite. No fossils found.

<u>Core 17</u> <u>Depth 1696-1707 feet</u>: recovery 5 feet 0 inches.
Medium-grained quartz sandstone. No fossils found.

<u>Core 18</u> <u>Depth 1775-1785 feet</u>: recovery 9 feet 6 inches.
Grey limestone, in which ostracods are common.

Ostracoda: _Cavellina_ sp.
_C_.sp.nov. 2
Glyptopleura sp.nov.aff. _G.parvacostata_ Geis 1932
Jonesina sp. nov.1

Conchostraca: _Rhabdostichus_

Core 19 Depth 1923-1929 feet: recovery 6 feet 0 inches.
Interbedded green and red mottled siltstone. No fossils found.

Core 20 Depth 1929-1935½ feet: recovery 6 feet 6 inches.
Red laminated siltstone, grading downwards into a green siltstone. No fossils found.

Core 21 Depth 2033-2041 feet: recovery nil.

Core 22 Depth 2041-2043 feet: recovery 2 feet 0 inches.
Red siltstone, with polished slickensided surfaces. No fossils found.

Core 23 Depth 2129-2139 feet: recovery 6 feet 3 inches.
Green siltstone, the lower part of which contains inclusions of clay pellets which give an appearance reminiscent of cornstones found in the Old Red Sandstone of the Welsh Borderlands. Abundant ostracods include species of _Aparchites_ or possibly immature specimens of _Phlyctiscapha_.

Core 24 Depth 2207-2217 feet: recovery 7 feet 0 inches.
Red mottled siltstone interbedded with green siltstone containint plant streaks. No fossils found.

Core 25 Depth 2294-2304 feet: recovery 7 feet 5 inches.
Green siltstone, containing a few indeterminate ostracods.
Cuttings from 2385-2390 feet yielded the following microfossils:

Ostracoda: _Cavellina_ sp. nov.2
Glyptopleura sp.nov.aff. _G.parvacostata_ Geis 1932
?Phlyctiscapha sp. (immature specimens?).
gen.nov.et sp.nov.? (in family Kloedenellidae).

Conchostraca: _Rhabdostichus_ sp.

Core 26 Depth 2391-2401 feet: recovery 3 feet 11 inches.
Green-grey siltstone. No fossils found.

Core 27 Depth 2490-2499 feet: recovery 5 feet 9 inches.
Green and mottled siltstone, passing downwards into red siltstone with a dark green finely laminated siltstone containing plant streaks at the base of core. No microfossils found.
M.E. White (1957) has identified the plant _Leptophloeum australe_ at 2498 feet in this core, 2490-2499 feet. Cuttings from 2560-2565 feet yielded the following species:-

Ostracoda: Cavellina sp.
C. sp.nov.2
?Phlyctiscapha sp. (immature specimens)
gen,nov.et sp.nov.? (as in cuttings from 2385-2390 feet).

Core 28 Depth 2580-2590 feet: recovery 8 feet 0 inches.
Finely laminated, interbedded green and red siltstone.
No fossils found.

Core 29 Depth 2700-2706 feet: recovery 2 feet 0 inches.
Red and green mottled siltstone, containing poorly preserved, indeterminate ostracods (steinkerns and broken carapaces).

Core 30 Depth 2800-2810: recovery 5 feet 9 inches.
Grey silty limestone with plant streaks. Well preserved ostracods are common, usually replaced by calcite, but specimens are difficult to extract.
Ostracoda: Cavellina sp.
C. sp.nov.2
Cryptophyllus sp.
Paraparchites nicklesi (Ulrich) 1891
Phlyctiscapha sp.

Core 31 Depth 2890-2896 feet: recovery 2 feet 7 inches.
Grey silty limestone containing very few ostracods.
Ostracoda: Cavellina sp. indet.

Core 32 Depth 2896-2902 feet: recovery 2 feet 6 inches.
Grey-green siltstone with a grey silty limestone at the base of the core, in which ostracods are common.
Ostracoda: Cavellina sp.
?Phlyctiscapha sp.

Core 33 Depth 3000-3010 feet: recovery 0 feet 2 inches.
Red siltstone with greenish inclusions. Most of the core cut between the depths of 3000 feet and 3010 feet was recovered with core 34. A core sample from 3009 feet yielded the following species:-
Ostracoda: Glyptopleura sp.nov.cf. G.parvacostata Geis 1932.
Paraparchites cf.P.okeni (Munster) 1830
?Phlyctiscapha sp.

Core 34 Depth 3010-3013 feet: recovery 10 feet 6 inches, which includes most of core 33. Dark green well bedded siltstone, overlying silty limestone containing bryozoa, the annelid Spirorbis, and abundant ostracods which are difficult to extract.

Ostracoda: Cavellina sp.
Glyptopleura sp.nov. aff.G.parvacostata Geis 1932
?Jonesina craterigera (Jones & Kirkby) 1886
Paraparchites cf.P.nicklesi (Ulrich) 1891
?Phlyctiscapha sp. (immature specimens)
Conchostraca: ?Rhabdostichus

Core 35 Depth 3100-3110 feet: recovery 1 foot 6 inches.
Purple siltstone overlying dark green fossiliferous siltstone, which contains abundant well preserved ostracods.
Ostracoda: ?Phlyctiscapha sp. (adult males)

Core 36 Depth 3160-3170 feet: recovery 5 feet 6 inches.
Green fossiliferous siltstone grading downward into an interbedded red, green, and white siltstone. Ostracods common, although mainly immature forms.
Ostracoda: Paraparchites cf. P.okeni (Munster) 1830
?Phlyctiscapha sp. (adult males)

Core 37 Depth 3255-3265 feet: recovery 6 feet 6 inches.
Green siltstone containing many ostracods and the annelid Spirorbis, capped with red shaly mottled siltstone at the top of the core.
Ostracoda: Paraparchites cf.P.okeni (Munster) 1830

Core 38 Depth 3344-3354 feet: recovery 9 feet 6 inches.
Interbedded green and red siltstone. No fossils found.

Core 39 Depth 3500-3509 feet: recovery 8 feet 0 inches.
Slickensided green siltstone passing downwards into a finely interbedded green siltstone and micaceous fine-grained light grey sandstone. Ostracods rare; only one poorly preserved, indeterminate specimen found.

Core 40 Depth 3580-3586 feet: recovery 3 feet 3 inches.
Interlaminated fine-grained light grey-brown quartz sandstone, and coarse micaceous dark grey siltstone. No fossils found.

Core 41 Depth 3715-3725 feet: recovery 8 feet 8 inches.
Fine-grained light grey-brown sandstone with silty micaceous partings. No fossils found.

Core 42 Depth 3800-3810 feet: recovery 10 feet 4 inches.
Finely interbedded light grey, fine-grained sandstone and grey siltstone. Ostracods rare; only two very poorly preserved indeterminate specimens found.

Core 43 Depth 3890-3900 feet: recovery 10 feet 0 inches.
Grey-green shaly micaceous siltstone, containing shell fragments

(Spiriferids?), and a few poorly preserved indeterminate ostracods. G.A Thomas (in Henderson, 1956) has identified Cyrtospirifer from this core, which indicates an upper Devonian age.

Ostracoda: Kloedenellid gen.

Core 44 Depth 3980-3990 feet: recovery 10 feet 0 inches. Dark green micaceous siltstone. No fossils found.

Core 45 Depth 3990-4000 feet: recovery 8 feet 2 inches. Dark green micaceous siltstone, with thin lenses of white fine-grained sandstone. No fossils found.

NOTES ON OSTRACOD ASSEMBLAGES, AND AGE RELATIONSHIPS.

The ostracod fauna has been divided into four assemblages purely for the convenience of discussing their age relationships.

Assemblage 1 - found between the depths of 150 feet and 360 feet; characterized by four species of Cavellina, C.cf.C.coryelli, C.cf.C.geisi, C.cf.C.ovatiformis, C.sp.nov.1, Cryptophyllus sp.nov., Jonesina sp.nov.1, Leptoprimitia? sp.nov., and three species of Paraparchites, P.nicklesi, P.cf P.okeni, and P. cf.P.ovatus.

Assemblage 2 - found between the depths of 548 feet and 1010 feet; characterized by the more frequent occurrence of Microcheilinella spp., together with Cavellina sp. nov.1 and Jonesina sp.nov.1. Perprimitia sp. joins this assemblage between the depths of 650 feet and 657 feet.

Assemblage 3 - found in core 18 at 1,775-1,785 feet, characterized by Cavellina sp.nov.2, Glyptopleura sp.nov., and Jonesina sp.nov.1.

Assemblage 4 - found between the depths of 2,129 feet and 3,265 feet; characterized mainly by the dominance of ?Phlyctiscapha spp., together with Cavellina sp.nov.2, Glyptopleura sp.nov., Paraparchites spp., and a possible new genus belonging to the family Kloedenellidae.

In an earlier unpublished report (Jones, 1957a), the author believed that many of the ostracod species found between the depths of 250 feet and 1,010 feet had Chesterian affinities, but no direct age relationship with the North American Chesterian Series was suggested, as few ostracod faunas of the Lower and Middle Mississippian rocks of North American have been described, compared with the great number described from the Upper Mississippian Chesterian Series. Therefore, it is possible that species apparently restricted to the Chesterian Series may eventually be found in rocks of early Mississippian age. In recent years, papers by Benson (1955), Echols & Gouty (1956) and Benson & Collinson (1958) have described ostracod faunas of formations of Lower and Middle Mississippian ages, but still much research remains to be done, and until more is known of the stratigraphical distribution of the ostracod species throughout the whole of the Mississippian rocks of North America, no definite intercontinental correlations can be made.

As present attempts to correlate ostracod species on an intercontinental scale would be uncertain, the author examined many surface samples collected from West Australian formations of Lower Carboniferous and Upper Devonian ages, which have been reliably dated by means of macrofossils. Eventually, the stratigraphical ranges of the ostracod species will be determined, in order to establish a local correlation between subsurface material and the type sections. The Fitzroy Basin samples examined to date which have yielded ostracods include those taken from the Laurel Formation (Lower Carboniferous), the Fairfield Beds and the Sadler Formation (both Upper Devonian). Thus, the present state of knowledge of the distribution of ostracods in these formations permits the author to suggest the following tentative local correlations for the ostracod assemblages found in Bore B.M.R. No.2.

Assemblage 1.

All the species referred to assemblage 1 have been found in surface samples collected from the upper part of the Laurel Formation. The uppermost surface samples have also yielded species of Bairdia and Graphiadactyllis, but their absence in the bore may indicate either environmental influence or a slight age difference. Henderson (1956) considered that the fossils found in core 2 (150-162 feet) were derived from boulders of the Laurel Formation incorporated in the overlying Grant Formation (Lower Permian), to which he referred the sandstone sequence between 30 feet and 178 feet. The beds between 178 feet and 360 feet can therefore be provisionally correlated with a part of the upper section of the Laurel Formation. Thomas (this volume, p.28) in his discussion of the fauna of the Laurel Formation, regards the absence of brachiopods of exclusive Visean affinities, and the presence in the upper beds of a species of Spirifer belonging to the S. tornacensis group, as good indications of a late Tournaisian age, which is confirmed by the discovery in the Laurel Formation of the Tournaisian ammonoid species Imitoceras rotatorium (de Koninck) by Glenister (1958).

Assemblage 2.

The beds between 548 feet and 1,010 feet may possibly be the equivalent of the lower part of the Laurel Formation, but surface samples from this lower unit have yet to be examined for ostracods. The presence of species referred to Bythocypris ovata, Microcheilinella obesa, and Perprimitia (forms suggesting Chesterian affinities) still indicates a Lower Carboniferous age.

Assemblage 3

Core 18 (1775-1785 feet) was taken from an ostracod limestone which contained Cavellina sp.nov.2. This species is present in the Fairfield Beds at Oscar Hill, and in the lower beds of this formation south of the Burramundi Range. Both of these localities are in the Avonia proteus zone of Veevers (1959). The Fairfield Beds were referred to as the "Productella limestone" by Teichert (1949), who regarded them as late Famennian. Cavellina sp.nov.2 has not been found in the Laurel Formation. Glyptopleura sp.nov. and Jonesina sp.nov.1 also occur in the Fairfield Beds at Oscar Hill. This assemblage is probably of proteus-zone age, which is consistent with the suggestion of Henderson (1956) that core 18 should be referred to the Fairfield Beds.

Assemblage 4

This assemblage is characterized by the dominance of ?Phlyctiscapha, and has not been recognised in Upper Devonian surface samples examined to date; no species of this genus have been found by the author in samples of the Fairfield Beds and the Sadler Formation (Frasnian). However, Cavellina sp.nov.2 and Glyptopleura sp.nov. are present, both of which occur in the proteus zone. The absence of Jonesina sp.nov.1 and the presence of ?Phlyctiscapha could indicate either the presence of a basin environment or an age difference . Therefore, the thick succession of red and green siltstones (1885-3503 feet) which Henderson (1956) referred on lithological grounds to the Virgin Hills Formation may be of proteus age or older.

The distribution of most of the ostracod species found in the formations penetrated by Bore B.M.R. No.2 have been plotted together with age determinations in Figure 2.

NOTES ON THE OSTRACOD GENERA AND SPECIES

Only one specimen has been identified as belonging to the genus Bythocypris: B.ovata Cooper 1941, a species which occurs in the Paint Creek Formation (lower Chesterian) of the United States.

The following forms of Cavellina were tentatively identified: C.cf.ovatiformis (Ulrich) 1891, C.cf.coryelli Croneis & Gale 1938, C.cf. geisi (Croneis & Gale) 1938; all of which occur in the Laurel Formation. C.ovatiformis occurs in the Upper Mississippian of the United States, mainly in the upper Chester formations. C.coryelli occurs in the Upper Mississippian, in the Clore (upper Chester) and Golconda (lower Chester) formations. C.geisi occurs in the Vienna and Golconda formations of Upper Mississippian (Chester) age. Cavellina sp.nov.1 is found in cores 3, 8, and 9 (between 250 feet and 912 feet), and C.sp.nov.2 is found in cores 18 and 30 (between 1775 and 2810 feet) and in cuttings from 2385-2390 feet and 2560-2565 feet.

CORE	DEPTH in feet	OSTRACODA	AGE	SUGGESTED FORMATION
1-2	50 - 162			?
3	250 - 260	Bythocypris ovata; Microcheilinella obesa; Perprimitia sp.; ?Leptoprimitia sp.nov.; Jonesina sp.nov.1; Jonesina sp.nov.3; Cryptophyllus sp.nov.; Cavellina cf ovatiformis; Cavellina cf coryelli; Cavellina cf. geisi; Cavellina sp.nov.1; Paraparchites cf. ovatus; Paraparchites cf. okeni; Paraparchites nicklesi		
4	350 - 360		LOWER	
5	450 - 460			LAUREL
6	548 - 558		CARBONIFEROUS	
7	650 - 657			FORMATION
8	800 - 814		(Tournaisian)	
9	900 - 912			
10	1000 - 1010			
11-17	1090 - 1707		?	?
18	1775 - 1785		Proteus-zone (Famennian)	FAIRFIELD FORMATION
19-22	1923 - 2043	NO FOSSILS FOUND	?	
23	2129 - 2139			
24	2207 - 2217	Glyptopleura sp.nov.; Cavellina sp. nov.2; Cryptophyllus sp.; ?Phlyctiscapha spp.; n.gen. et sp. ?		
25	2294 - 2304		UPPER	VIRGIN
26	2391 - 2401			
27	2490 - 2499			
28	2580 - 2590			
29	2700 - 2706			
30	2800 - 2810			
31	2890 - 2896		DEVONIAN	HILLS
32	2896 - 2902			
33	3000 - 3010			
34	3010 - 3013			
35	3100 - 3110		Famennian	
36	3160 - 3170		Proteus-zone and possibly	FORMATION
37	3255 - 3265		older	
38	3344 - 3355			
39	3500 - 3509			
40-42	3580 - 3810			?
43	3890 - 3900	Klondenellid		
44-45	3980 - 4000			

Cavellina sp.nov.2 has a strongly developed comb-like elevation on the dorsal edge of the right valve, a feature which may eventually justify the removal of this species to the genus Chapmanites; species belonging to this genus occur in the Middle Devonian rocks of Victoria (Krömmelbein, 1954). Like Bythocypris, the genus Cavellina includes smooth forms of ostracods which are often difficult to identify specifically, as many species have been erected on very slight differences in the outline of the carapace.

Numerous well preserved valves of a new form already identified from outcrop samples of the Laurel Formation are present in cores 2, 3, and 4 (depths 150-360 feet). This form was identified as a conchostracan by G.A. Thomas (unpublished) in his preliminary examination of the cores taken between the depths of 140 feet to 253 feet, from B.M.R. Bore No.2, Laurel Downs. It was also identified by J.M. Dickins (unpublished) as a conchostracan from the Grant Range No.1 Bore at the depths 9796-9799 feet in Upper Carboniferous (Westphalian) strata, and was previously reported from the Gneudna Formation, the Pelican Hill (Carnarvon) bore, and the Cape Cuvier bore as ?Pelecypoda Nucula? sp. Recently it has been found between the depths of 6435-7650 feet in the Sisters No.1 Bore, just above and below the boundary between the Upper Devonian and the Lower Carboniferous.

Examination of many specimens from B.M.R. Bore No.2, Laurel Downs, showed that in external and thin section, this form must be identified as the ostracod genus Cryptophyllus Levinson 1951. Dr. S.A.Levinson has examined numerous specimens collected from Core 3, and has confirmed that they belong to a new species of Cryptophyllus. The specimens are very well preserved, and this is the first occasion that the presence of a distinct internal ridge has been noted in this genus (Levinson, written communication). This ridge corresponds with the position of a sulcus on the external surface and is probably related to the adductor muscle; these forms are still being studied. In the United States, Cryptophyllus occurs in Ordovician, Silurian, and Middle and Upper Devonian strata, and in Belgium it occurs in the Upper Devonian (Frasnian). More fossiliferous surface samples of known Carboniferous and Devonian ages need to be collected from Western Australia before any conclusions on the stratigraphical range of Cryptophyllus sp.nov. can be formed.

One undescribed species of Glyptopleura, which shows marked sexual dimorphism and a slight resemblance to G.parvacostata Geis 1933, was found in core 34 (3010-3013 feet). G.parvacostata is recorded from the Salem Formation (lower Meramec) of the Middle Mississippian. Until 1952 the genus Glyptopleura was only known from Carboniferous and Lower Permian strata, but the work of Kesling and Kilgore (1952), Kesling and Weiss (1953), and Pribyl (1953) has shown that representatives of this genus occur in the Middle Devonian.

Both Jonesina sp.nov.1 and J.sp.nov.2 have been previously referred by the author to the genus Lochriella in unpublished reports (Jones, 1957, a,b), and Jonesina sp.nov.2 may possibly have to be regarded as a sexual dimorph of J.sp.nov.1. Both forms occur in the Laurel Formation. Jonesina sp.nov.3 is a small form which bears a heavy reticulate ornament, and is not unlike the German Visean species J.rugulosa Kummerow 1939.

Several specimens that have been tentatively assigned to the species Jonesina craterigera (Jones & Kirkby) 1886 were found in core 34 (3010-3013 feet). J.craterigera is recorded from the Lower Carboniferous of England and Scotland, and Cooper (1941) recognised this species in the Glen Dean and Golconda Formations of the Chesterian Series. The species belonging to a Kloedenellid genus in core 42 (3806-3810 feet) has been found by the author in samples of the Upper Devonian Fairfield Beds taken from Oscar Hill.

Specimens of a new species occurring in core 3 at 253 feet have been tentatively referred to the genus Leptoprimitia; this genus has been previously recorded only from the Middle Devonian of eastern Poland.

Only one species of the genus Microcheilinella has been recognised in this bore, namely M.obesa Cooper 1941, which occurs in core 10 (1000-1010 feet). Cooper found this species in the Kinkaid and Menard formations (upper Chester), and the Paint Creek formation (lower Chester). The only other species of Microcheilinella found in core 10 appears to be an undescribed form which shows a slight resemblance to Microcheilinella? exila Cooper 1941. As a genus, Microcheilinella ranges from the Devonian (possibly Silurian) to the Lower Permian.

Paraparchites is another smooth ostracod genus which, like Bythocypris and Cavellina, often presents difficulties in specific identification. At least three species of the genus Paraparchites, however, are present in this bore; they have been tentatively referred to P.nicklesi (Ulrich) 1891, P. cf.P.okeni (Munster) 1830, and P.cf. P.ovatus Cooper 1941. These three forms are found in the Laurel Formation (Lower Carboniferous), and P.nicklesi and P. cf. P.okeni also occur in the Upper Devonian sequence of the bore. P.nicklesi occurs mainly in the Mississippian, ranging from the Kinderhookian Series to the Lower Pennsylvanian. P.okeni occurs in the Carboniferous of Germany, U.S.S.R., and Nova Scotia, the Lower and Upper Carboniferous of the British Isles, and the Middle Devonian (Givetian) of Belgium. Cooper (1941) has found P.ovatus only in the Clore Formation (upper Chester) of the Upper Mississippian.

Well preserved specimens which appear to be very similar to the male forms of the type species of Phlyctiscapha, P.rockportensis Kesling 1953, occur abundantly in core 35 (3100-3110 feet). As no females were found, these forms are only tentatively referred to the genus Phlyctiscapha, and specimens regarded as immature instars of this genus may eventually have to be re-assigned to the genus Aparchites. Phlyctiscapha is a non-sulcate beyrichiid, characterized by marked sexual dimorphism, and has been recognized only from the Middle Devonian of North America; little is known, however, about the Upper Devonian ostracod faunas of this continent. Levinson (in Sabins, 1957) recorded the presence of forms which he referred to as "Aparchites sp. aff. Phlyctiscapha rockportensis Kesling" from the Upper Devonian Portal Formation of Arizona, but did not positively assign them to Phlyctiscapha as he did not find female forms.

The occurrence of Perprimitia sp. between the depths of 650 feet and 657 feet may be of stratigraphical value, as in the United States this genus appears to be restricted to the Upper Mississippian. Perprimitia was thought to be confined to the Chesterian Series (Cooper, 1941), but recently Crane and Kelly (1956) found representatives of the genus in the Bayport limestone of Michigan. On the basis of similar macrofossils and lithology, the Bayport limestone is thought by Ehlers and Humphrey (1944) to be the stratigraphical equivalent of the St.Louis limestone of Illinois and Indiana, which is older than Chesterian. If this correlation were correct, the earliest recorded occurrence of Perprimitia would be in the middle Meramec, of Middle Mississippian age.

One of the specimens identified in core 6 (548-558 feet) may possibly belong to the genus Tetratylus, but it does not possess the characteristic median sulcus of this genus. On the other hand, the absence of the sulcus could be explained by the bad preservation of the specimen. Cooper (1941) found the genus Tetratylus mainly confined to the Paint Creek formation (lower Chester), with the occurrence of one species in the Menard formation (upper Chester).

NOTE ON THE CONCHOSTRACAN RHABDOSTICHUS

Minute bivalved shells which show a concentric pattern of growth-lines have been found in cores 18 (1775-1785 feet) and 34 (3010-3013 feet), and in cuttings taken from 2385-2390 feet). These forms bear delicate reticulations between the growth-lines, which indicate that they are related to the Conchostraca, and they resemble the elongated forms of Rhabdostichus buchoti (Peneau). This species occurs in north-west France in beds of Devonian (or Silurian ?) age (Raymond, 1946).

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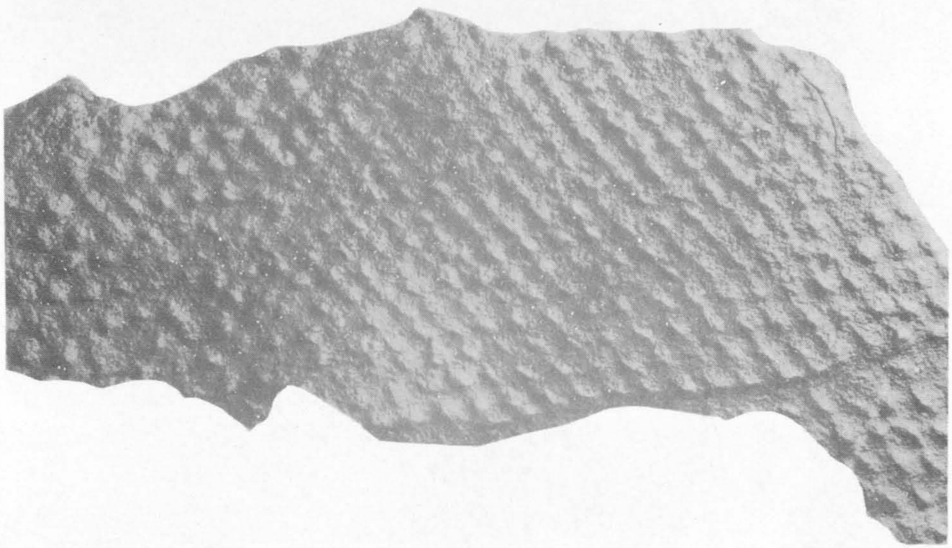
BOTANICAL REPORT ON A LEPIDODENDROID LOG FROM THE HARRIS SANDSTONE, CARNARVON BASIN, WESTERN AUSTRALIA

by

Mary E. White

A portion of a fossilized tree trunk with Lepidodendroid surface features was collected from the Harris Sandstone near Harris Well, Williambury Station, by M.A. Condon in 1953.

The specimen is in the University of Western Australia's Geological Collection, No.38163, in Perth. Rubber casts of the surface of the specimen were made on request and sent to the B.M.R. Canberra for examination. They show a pattern of roughly conical protuberances which correspond to the regularly arranged depressions on the specimen. In the base of each depression is an oval pit which represents the leaf trace (Figure 1).



This type of decorticated Lepidodendroid impression is regarded by Edwards (1952) as a form of Lycopodiopsis pedroanus Carr, which is typically Lower Permian and occurs in the Poole Range, West Kimberleys, W.A. (collected by Wade), and associated with the Glossopteris flora in South Africa and Brazil.

Lepidodendroid specimens collected near Arthur River Woolshed, Carnarvon Basin, W.A. from Basal Lyons Series rocks have been referred to this species (White, 1957).

Although an identification based on one decorticated specimen only cannot be completely satisfactory, there is little doubt in this case that the specimen is referable to Lycopodiopsis pedroanus Carr and that it indicates a Lower Permian age for the fossil horizon in the Harris Sandstone.

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A SPECIES OF LEPIDODENDRON FROM THE BASAL LYONS GROUP CARNARVON BASIN, WESTERN AUSTRALIA.

by

Mary E. White and M.A. Condon

SUMMARY

Several impressions and petrifactions from near the base of the Lyons Group in the Carnarvon Basin of Western Australia are all referred to a single species of *Lepidodendron*, distinct from any previously recorded from Australia and not so far referred to any extra Australian species. The age of these specimens may be Carboniferous or Permian.

INTRODUCTION

In this paper, Mary E. White examined, described and determined the relationships of the plant fossils; M.A. Condon provided the notes on the field occurrence of the fossils.

FIELD OCCURRENCE

Lepidodendroid plant remains were first discovered in the Carnarvon Basin by C.E. Prichard in 1949, about 115 miles east-north-east of Carnarvon, 1½ miles north of Moogooree Homestead, in material then tentatively regarded as Harris Sandstone. Since then other Bureau geologists have made collections from this same locality (which is considered to be in the lowermost part of the Lyons Group) and in the lowermost Lyons Group one mile south and 1½ miles west of south of Williambury Homestead and 4 miles south-west of Arthur River Woolshed, and from the Harris Sandstone 2½ miles west of Williambury Homestead. (See Locality Map, Figure 1).

The material described here was all collected by M.A. Condon and G.A. Thomas in 1955 from the lowermost Lyons Group south of Williambury and north of Moogooree.

The sequence at the locality one mile south of Williambury Homestead, measured by M.A. Condon, is shown in Figure 2. The base of the Lyons Group is not well exposed here, although the Yindagindy Formation crops out nearby. In the type locality of the Harris Sandstone and Lyons Group, 2½ miles west of Williambury Homestead, the lowermost boulder bed of the Lyons Group is 90 feet above the base of the Lyons Group, and 370 feet above the base of the Harris Sandstone; lepidodendroid fossils are

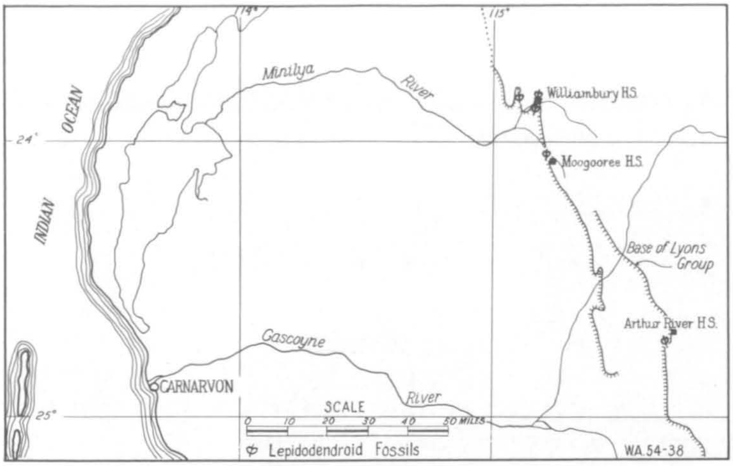


Fig. 1. Locality map, showing Lepidodendroid localities.

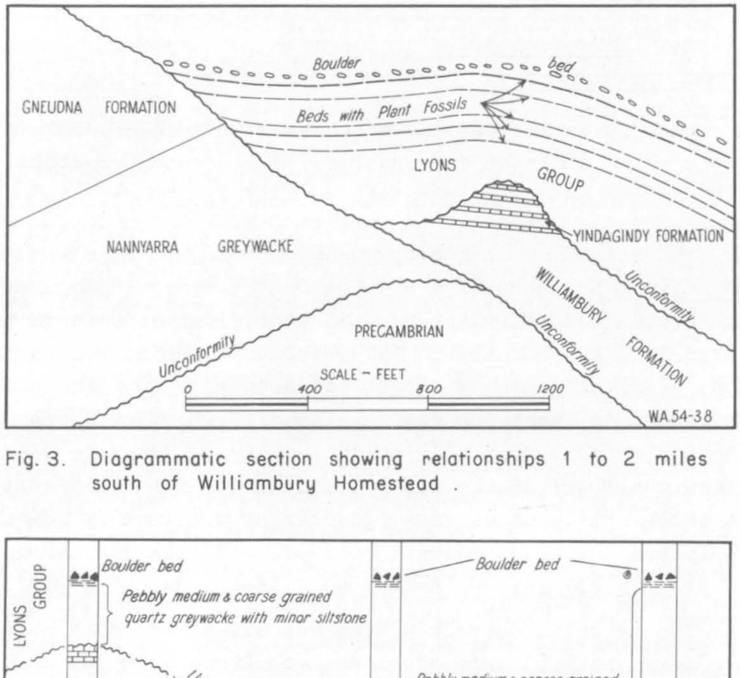


Fig. 3. Diagrammatic section showing relationships 1 to 2 miles south of Williambury Homestead.

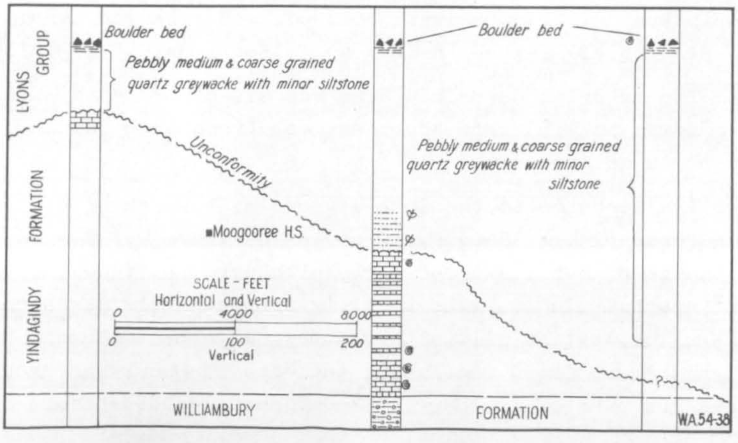
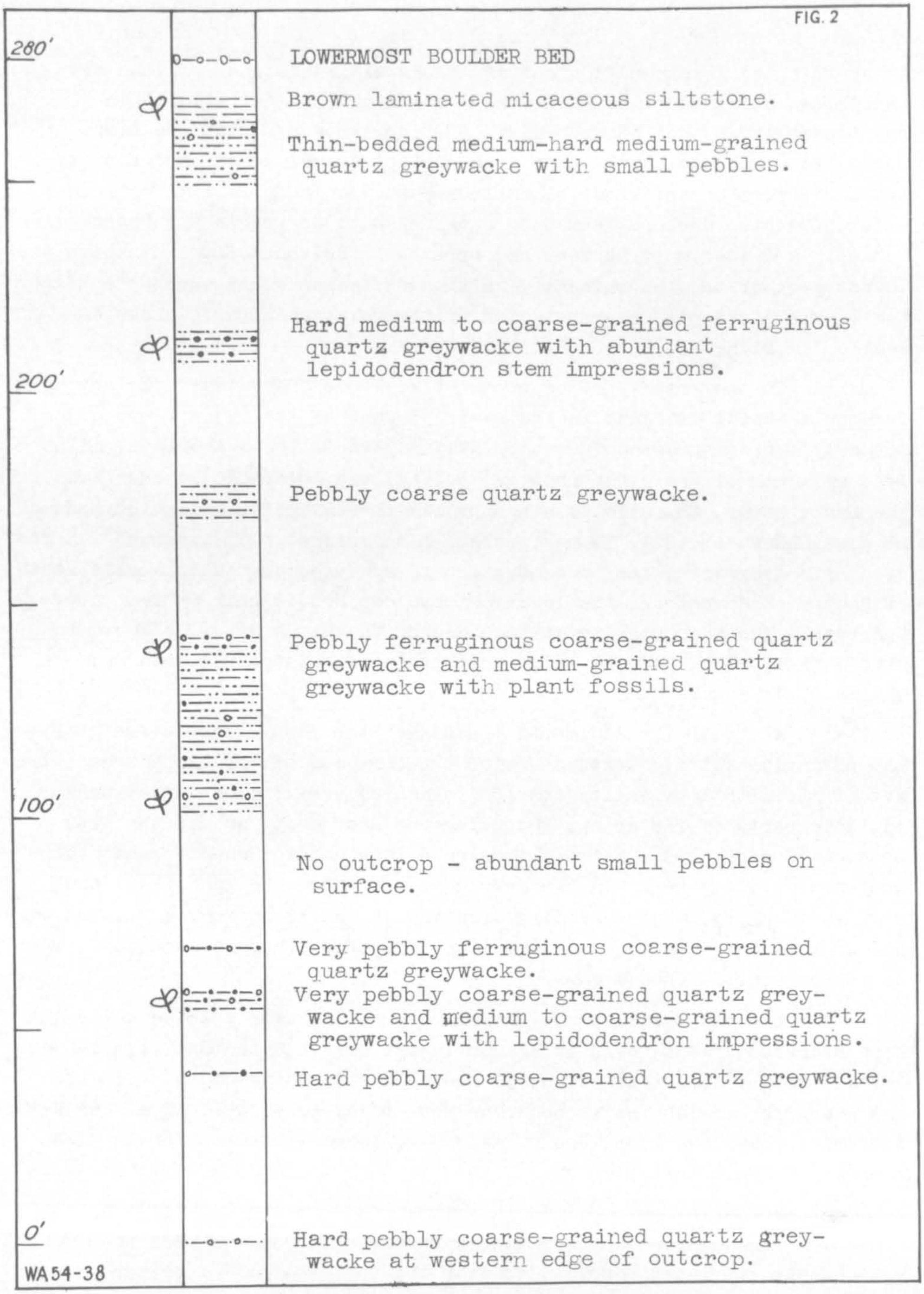


Fig. 4. Relationships at base of Lyons Group, Moogooree Area.

FIG. 2


280'
LOWERMOST BOULDER BED
Brown laminated micaceous siltstone.
Thin-bedded medium-hard medium-grained quartz greywacke with small pebbles.
Hard medium to coarse-grained ferruginous quartz greywacke with abundant lepidodendron stem impressions.
200'
Pebbly coarse quartz greywacke.
Pebbly ferruginous coarse-grained quartz greywacke and medium-grained quartz greywacke with plant fossils.
100'
No outcrop - abundant small pebbles on surface.
Very pebbly ferruginous coarse-grained quartz greywacke.
Very pebbly coarse-grained quartz greywacke and medium to coarse-grained quartz greywacke with lepidodendron impressions.
Hard pebbly coarse-grained quartz greywacke.
0'
Hard pebbly coarse-grained quartz greywacke at western edge of outcrop.
WA54-38

present in the lowermost 36 feet of the Harris Sandstone. In the area one to two miles south of Williambury Homestead, the stratigraphic relationships are not clear because of poor exposures, but the Lyons Group sediments apparently rest on a dissected surface of unconformity cutting Lower Carboniferous Yindagindy Formation and Williambury Formation, Devonian Gneudna Formation and Nannyarra Greywacke and Precambrian schist. The lowermost boulder bed appears to be about 500 feet above the lowest part of this unconformity, although it also abuts against a higher part. M.A. Condon's interpretation of the relationships is shown in section in Figure 3.

In the area $1\frac{1}{2}$ miles north of Moogooree Homestead, the Lepidodendron material is found in the basal 35 feet of the Lyons Group unconformably overlying Carboniferous Yindagindy Formation. About 1.7 miles west of north of the plant fossil locality, the lowermost boulder bed of the Lyons Group, there containing bryozoa, brachiopods, and pelecypods of Permian character (G.A. Thomas, personal communication), overlies 275 feet of quartz greywacke, the base of which is not exposed. Half a mile south of Moogooree Homestead, the lowermost boulder bed is only 55 feet above the base. The unconformity at the base of the Lyons Group is known to have marked relief and the relationships in this Moogooree area are indicated in Figure 4.

Although the sediments containing the plant fossils are not of the strongly tillitic texture of the boulder beds of the Lyons Group, they are of the lithology (silty quartz greywacke) very common in the non-tillitic parts of the group, including the lowermost part of the type section (Condon, 1954) between the top of the Harris Sandstone and the lowermost boulder bed. In the area north of Moogooree Homestead, the plant-bearing sediments, resting directly on the Yindagindy Formation, are not of the clean quartz sandstone lithology of the Harris Sandstone, which is not present in that area.

Lycopod fossils, not necessarily of the same species as that here described, were found by M.A.C. in the Harris Sandstone $2\frac{1}{2}$ miles west of Williambury Homestead (about 30 feet above the base of the formation) and near the base of the Lyons Group four miles south west of Arthur River Woolshed, where the Lyons Group rests unconformably on a strongly dissected surface of Precambrian schist. They have been tentatively determined as Lycopodiopsis pedroanus Carr (this volume, p.53).

The marine fossils of the Lyons Group, found in beds from near the base (above the plant fossils) to near the top, indicate a Sakmarian age (Thomas and Dickins, 1954). The Yindagindy Formation, now regarded as of Lower Carboniferous age (G.A. Thomas, personal communication), is unconformably below the plant bearing beds.

PALAEOBOTANY

An examination of the large number of specimens collected shows Lepidodendroid plant remains only. The fossils are mostly impressions of stems of different sizes, with rare examples of petrifactions of portions of stems. As is usual in Lepidodendroid fossils, the varying degrees of decortication and decay of the stems before they were fossilized and the different methods of preservation have resulted in a wide range of forms.

Nearly all the specimens can be assigned with little doubt to the genus *Lepidodendron*, but many show no characters of positive value in specific identification. More than one species may be represented, but such specimens as show specific characters appear to be all referable to one species only: this species appeara to be distinct from any described species recorded from Australia or any extra-Australian species. Many of its forms resemble forms of several known species of *Lepidodendron*. A complete revision of Lepidodendroid plants collected in Australia is required before it can be decided whether the range of forms in the basal Lyons Group *Lepidodendron* merits the formation of a new species.

The described species which most closely resembles that under discussion is *Lepidodendron scutatum Lx.* which occurs in the "Meso-Carboniferous" Coal Measures in Missouri. The species is also similar to some forms which have been attributed to *Lepidodendron Veltheimianum* Stbg. (Lower Carboniferous), but does not in any specimen show the features regarded as diagnostic in European examples. It also resembles a specimen referred to *L. pedroanum* from the Ecca Series in South Africa, and an undetermined species figured by Jack and Etheridge from the Drummond range in Queensland. Specific names such as *Lepidodendron Veltheimianum* have been loosely used to include any impression of the same general type.

Forms of the species are compared with similar forms of other described species in Figure 15.

A representative selection of specimens, showing the range of forms in the species, is described and illustrated below.

DESCRIPTION OF PLANT REMAINS

A. Impressions and Casts.

Figure 5 shows a surface impression of a mature stem (Specimen F21581, from near the base of the Lyons Group, 1.4 miles west of north of Moogooree Homestead (Lat. 24°03'45" S., Long. 115°12'10"E.) The leaf cushions decrease in size upwards on the stem, from 7mm near the base of the specimen to 4mm at the top, over a distance of five inches. This rapid tapering suggests that the stem was a lateral rather than a main axis. The leaf cushions have a rounded top and taper steeply to a point at the bottom. Each cushion has a median linear depression and resembles an inverted bract or scale leaf with midrib.

Specimen F21582 (Figure 6) is from near the base of the Lyons Group, 1.1 miles south-south-west of Williamsbury Homestead (Lat.23°52½'S., Long. 115°08'20"E.) It shows a layered series of bark impressions with surface and near-surface ("Aspidiaria") views of leaf cushions. The mature cushions are 14mm long and have a maximum width of 3mm (at 2mm from the top of each cushion). The "Aspidiaria" casts are internal casts of pieces of bark which had been shed from the parent trunk and embedded separately, and there is no indication of the size of the parent trunk.

Specimen F21583 (Figure 7) is from near the base of the Lyons Group 1.4 miles west of north of Moogooree Homestead (Lat. 24°03'45"S., Long.115°12' 10"E). It shows an "Aspidiaria"-type cast. The leaf cushions of the trunk from which the bark came were larger and more separated than in Figure 6.

Specimen F21584 (Figure 8) is from near the base of the Lyons Group (Locality as for F21583). It shows an impression of a slightly decorticated stem with leaf trace scars near the apices of the cushions.

Specimen F21585 (Figure 9) is from near the base of the Lyons Group at 0.8 miles south of Williamsbury (Lat.23°52'16"S., Long.115°08'55"E). It shows an impression of a young stem which had been decorticated to a deep level so that the leaf cushions were obliterated and the leaf trace bundles are represented by vertical slits. This is a "Bergeria" condition.

Specimen F21586 (Figure 10) is from about 50 feet above the base of the Lyons Group at 1.4 miles west of north of Moogooree Homestead (Lat.24°03' 55"S., Long.115°12'05"E.). It is a slightly compressed cylindrical cast of a deeply decorticated stem. No internal structure has been preserved in this cast or in any of the others of which this is a representative example.

Specimen F21587 (Figure 11) is from near the base of the Lyons Group at the same locality as F21586. It shows a cast of a branching stem in "Knorria" condition.

Specimen F21588 (Figure 12) is from about 50 feet above the base of the Lyons Group, 1.4 miles west of north of Moogooree Homestead (Lat.24°03'55"S., Long.115°12'05"E). It shows a cast of a laterally compressed young stem in "Knorria" state of decortication. No internal structure is preserved.

Other specimens (F21590 to F21601) not figured show intermediate degrees of decortication. There are also casts with vertically ribbed surfaces which look more like casts of a Calamites than a Lepidodendron but which are almost certainly medullary casts of Lepidodendroid stems.

B. Petrifactions.

Small stem:

Specimen F21589 is from about 50 feet above the base of the Lyons Group at the same locality as F21588.

This somewhat compressed stem less than an inch long with diameter varying from a half to a third of an inch, and a "Knorria" condition of decortication, was sectioned at four levels. Many internal tissues are preserved. A semi-diagrammatic radial transverse section was compiled from portions of the sections where tissue preservation was best.

Details of tissues from the leaf cushions to the inner primary cortex are illustrated in Figure 13. Figure 14 is a continuation of the radial section and shows the tissues from the inner cortex to the central medulla.

Explanation of Radial Transverse Sections:

The leaf cushions are composed of unspecialized (parenchyma) cells. The primary cortex is the region of the stem immediately outside the central conducting strand, and contains three zones. The inner and outer primary cortex were composed of large thin-walled cells unsuited to preservation and are largely disorganized and replaced by mineral matter. The middle primary cortex is a"secretory zone" of small, irregularly shaped and sized parenchyma cells. Small secretory zones are tangentially arranged in the inner and outer primary cortex, but, unlike the large secretory zone of the middle cortex, these are not continuous.

The vascular (conducting) cylinder in the centre has a medulla of large thin-walled cells, largely disorganized. The xylem (wood) elements are elements external (an exarch protoxylem arrangement). Groups of small xylem elements in a ring beyond the protoxylem are the vascular strands to supply the leaf cushions. A secretory zone beyond the ring of leaf traces completes the stelar region of the stem.

The stem is young and there is no secondary xylem. There is, however, a phelloderm of secondary cortical tissue. The cells of this region are radially arranged and similar to cork cells in present day plants.

Fragments of petrified wood showing "annual rings" to the naked eye were sectioned and found to have bands of tissue of radially arranged elements alternating with denser zones in which the cells are less regularly arranged. The denser zones may be secretory zones such as occur in the outer tissues of old Lepidodendroid stems. Other fragments of wood showed radially arranged xylem vessels of secondary xylem tissue.

CONCLUSIONS

A species of Lepidodendron is present in rocks of the lowermost part of the Lyons Group, but this species does not determine the precise age of that part of the group.

The genus Lepidodendron is to a great extent a form genus and does not lend itself to precise definition. The species under discussion is referred to the genus on grounds of its internal anatomy as well as on superficial resemblances. It is not referable to the related genera Leptophloeum or Lycopodiopsis. The range of the genus Lepidodendron is from Devonian to Permian. Edwards (1952) is of the opinion that the only lepidophytes occurring in Permian horizons in the southern hemisphere are referable to Lycopodiopsis, but this has yet to be proved conclusively. The internal structure of a stem of the species under discussion shows a medullated stele, and for this reason as well as on the grounds of the dissimilarity of the species from known Devonian species, an age younger than Devonian is probable.

The age of the lowermost part of the Lyons Group based on the presence of the species of Lepidodendron alone could be Carboniferous or Permian. As the material occurs above an unconformity developed on marine Lower Carboniferous rocks, and unconformably below marine Permian (Sakmarian) beds, its age is most probably Sakmarian although it is possible that it is uppermost Carboniferous.

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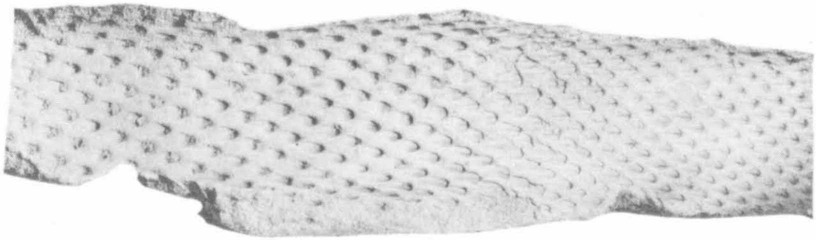
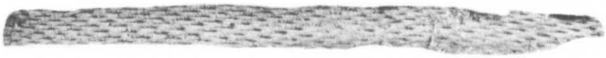


Figure 5.

Figure 6.

All Figures to ¾ Scale.

Figure 7.



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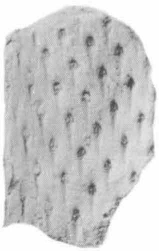


Figure 8.

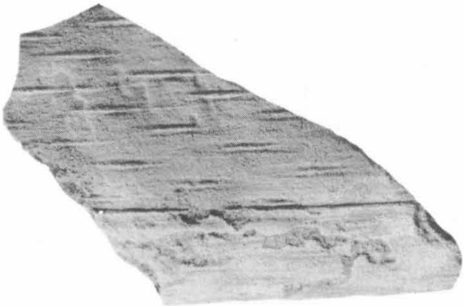


Figure 10.

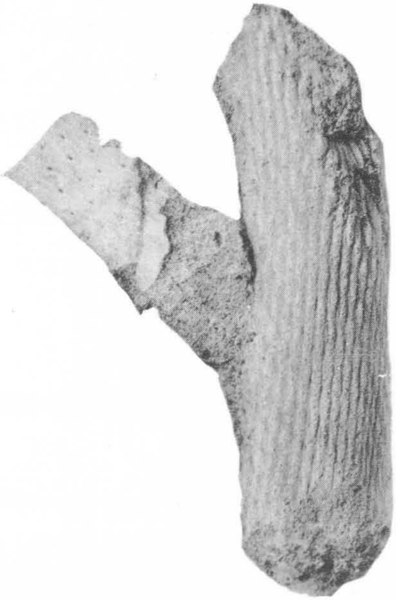


Figure 11.

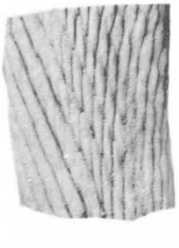
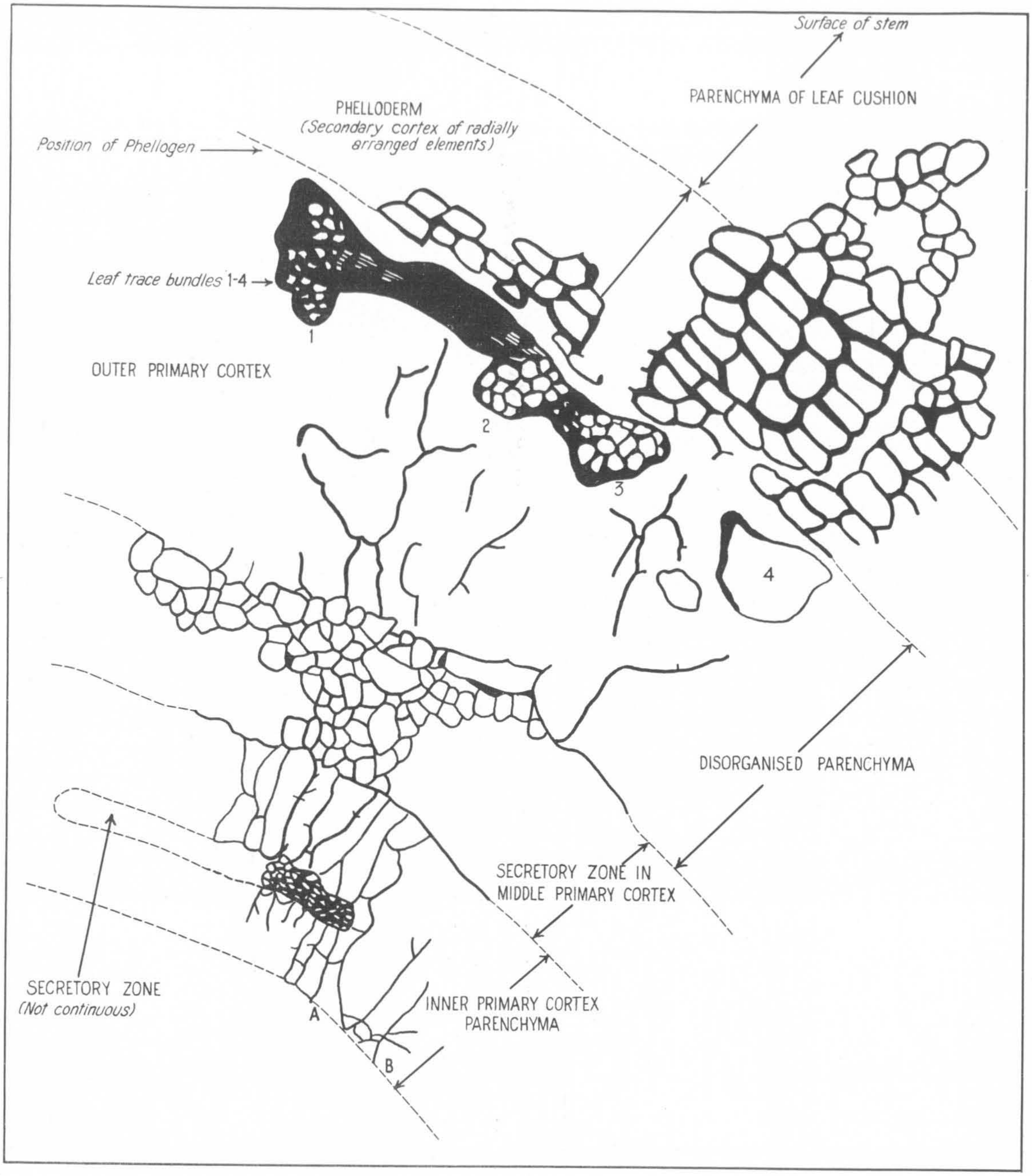


Figure 12.

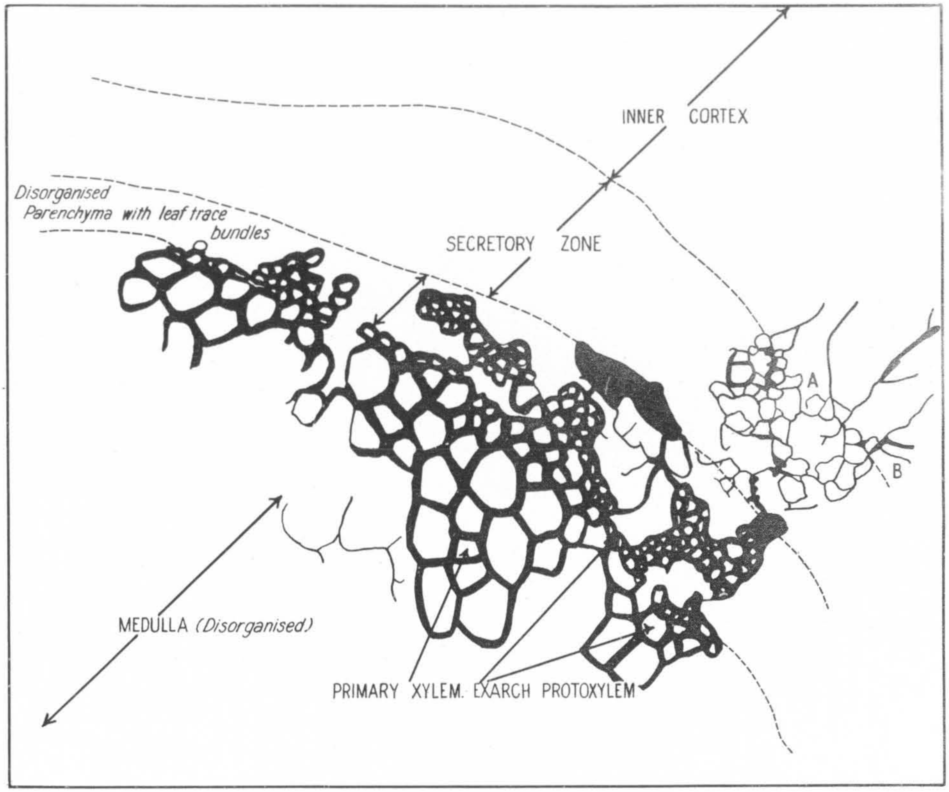
All Figures to ¼ Scale.

Figure 13.



Surface of stem
PARENCHYMA OF LEAF CUSHION
PHELLODERM
(Secondary cortex of radially arranged elements)
Position of Phellogen
Leaf trace bundles 1-4
1
2
3
4
OUTER PRIMARY CORTEX
DISORGANISED PARENCHYMA
SECRETORY ZONE IN MIDDLE PRIMARY CORTEX
SECRETORY ZONE
(Not continuous)
INNER PRIMARY CORTEX PARENCHYMA
A
B

Figure 14.



INNER CORTEX
Disorganised Parenchyma with leaf trace bundles
SECRETORY ZONE
A
B
MEDULLA (Disorganised)
PRIMARY XYLEM. EXARCH PROTOXYLEM

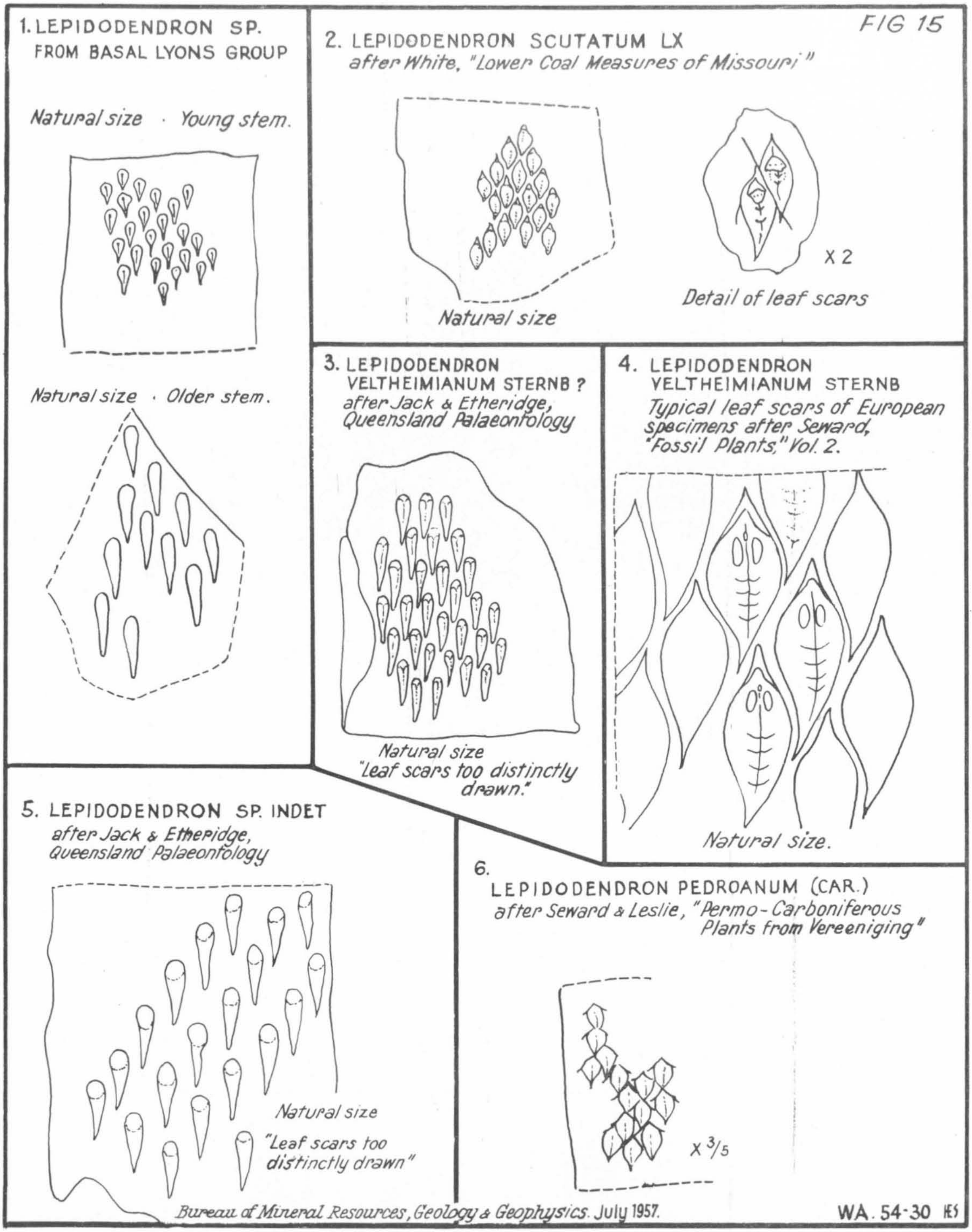


FIG 15
1. LEPIDODENDRON SP.
FROM BASAL LYONS GROUP
Natural size · Young stem.
Natural size · Older stem.
2. LEPIDODENDRON SCUTATUM LX
after White, "Lower Coal Measures of Missouri"
Natural size
X 2
Detail of leaf scars
3. LEPIDODENDRON
VELTHEIMIANUM STERNB ?
after Jack & Etheridge,
Queensland Palaeontology
Natural size
"Leaf scars too distinctly drawn."
4. LEPIDODENDRON
VELTHEIMIANUM STERNB
Typical leaf scars of European specimens after Seward,
"Fossil Plants," Vol. 2.
Natural size.
5. LEPIDODENDRON SP. INDET
after Jack & Etheridge,
Queensland Palaeontology
Natural size
"Leaf scars too distinctly drawn"
6.
LEPIDODENDRON PEDROANUM (CAR.)
after Seward & Leslie, "Permo-Carboniferous Plants from Vereeniging"
X 3/5
Bureau of Mineral Resources, Geology & Geophysics. July 1957.
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THE MARINE FAUNA OF THE LYONS GROUP [*] AND THE CARRANDIBBY FORMATION OF THE CARNARVON BASIN, WESTERN AUSTRALIA.

by

J.M. Dickins and G.A. Thomas

SUMMARY

The fauna of the Lyons Group is rather distinct from the later Permian faunas in Western Australia. The Lyons Group is mainly unfossiliferous, and the fossils occur sporadically both vertically and horizontally; molluscs predominate over brachiopods, and both are represented by relatively few species, although many individuals occur. Of the Permian faunas of Western Australia, that of the Lyons is closest to those of Eastern Australia. The Lyons fauna appears to be more closely related to that of the lower part of the marine sequence of New South Wales than to the upper part. Outside Australia the fauna of the Umaria beds is considered to be closely related to that of the Lyons Group; elsewhere in India the Lyons fauna is most closely related to those of the Speckled Sandstone and the Agglomeratic Slate of Kashmir and probably the new fauna from Sikkim and Subansiri recently recorded by Sahni and Srivastava (1956). The "*Eurydesma*-fauna" of South Africa and the "*Eurydesma*-fauna" of Argentina are also probably of a similar age. The Lyons Group is considered to be mainly if not entirely of Lower Permian (Sakmarian) age. The lower part of the Lyons Group may be of Carboniferous age, although the present evidence does not suggest this. In eastern Australia it is concluded that the earlier more cosmopolitan "*Eurydesma* - fauna" persisted longer than in Western Australia and India and that an indigenous development took place there.

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[*] The authors would place in the Lyons Group, the Carrandibby Formation (Konecki, Dickins and Quinlan, 1959) of the Wooramel River area and what is considered to be the Carrandibby equivalent in the Jimba Jimba (Gascoyne) area, because of common lithological and lithogenetical features. Condon, however, places the Carrandibby Formation, which occurs below the Callytharra Formation and is transitional with it, outside the Lyons Group. In order to avoid the possibility of confusion, the fauna of the Carrandibby Formation and the Carrandibby equivalent are listed separately from the rest of the fauna, but in the text the term Lyons Group includes the Carrandibby Formation unless otherwise specifically stated. Faunistically, the authors do not consider it possible to distinguish the Carrandibby Formation from the rest of the Lyons Group and common elements distinguish both from the overlying Callytharra Formation.

INTRODUCTION

The occurrence of sediments of glacial origin of Permian and Carboniferous age in South Africa, India, Australia, and South America has been of interest to geologists for many years and has been the basis of much conjecture.

The glacial character of deposits in what is now known as the Lyons Group was first recognised in 1909 by Gibb Maitland. He deduced a glacial origin for striated and faceted boulders in a clayey matrix, of which he gives excellent illustrations (Maitland, 1909, p.12-13). His observations have been confirmed by later workers. Sediments of glacial origin have been described by Clapp (1925), Condit, Raggatt & Rudd (1936), Raggatt (1936), Teichert (1941, 1946, and 1952) and Condon(1954). Raggatt (p.120) and Condon (p.42) record the presence of varve-like sediments.

In Western Australia glacial deposits of similar age have also been described from the Irwin River area (see Clarke et al., 1951) and from the Fitzroy River area of the West Kimberleys (Blatchford and Talbot, 1924), and later workers; (see Guppy et al., 1958) and from the south-western edge of the Canning Basin, west of Port Hedland (Traves, Casey, and Wells 1957). The age of all these rocks has generally been held to be Upper Carboniferous or Permian. The faunas of the Carnarvon Basin, including the Lyons Group, were reviewed by Raggatt and Fletcher (1937), and arguments put forward for regarding the Lyons and higher beds as Permian. Similarly Teichert (1941, 1950a) has suggested that the base of the Lyons Group corresponds approximately to the base of the Permian. Until recently, however, only a single species has been described from the Lyons Group - the brachiopod *Linoproductus* (*Cancrinella*) *cancriniformis* var. *lyoni* (Prendergast) (1943 p.24, pl.3, fig. 1:2), redescribed by Coleman (1957) as *Linoproductus lyoni* Prendergast. *Linoproductus* (*Cancrinella*) *lyoni* is evidently allied to forms from the Umaria beds of peninsular India, although this was not recognised by Prendergast. Recently molluscs have been described by Dickins (1956, 1957) and brachiopods by Thomas (1958). Conjectures about the age of the Lyons Group were based on its upper transitional relationship with the Callytharra Formation and its correlation with other glacial deposits in Western Australia, especially the Holmwood Shale of the Irwin River area, which contains ammonoids and has been correlated with the upper part of the Lyons Group. Etheridge (1907), Miller (1932), Teichert (1942), and Teichert & Glenister (1952) have described ammonoids from the Holmwood Shale.

In recent years (1948-1955) important collections have been made from the Lyons Group, including specimens of *Eurydesma* in great numbers, by geologists of the Bureau. (These faunas are described in part in Dickins (1957), Thomas (1958), and work in progress). The affinities of the fauna have important implications for the correlation and palaeogeography of the Upper Carboniferous and Lower Permian deposits of the southern "Gondwana" areas.

DISTRIBUTION AND MODE OF OCCURRENCE OF THE FAUNA

The Lyons Group crops out in a belt running from the Lyndon River to the Murchison River as indicated in Text figure 1.

The stratigraphy of the Lyons Group has recently been described by Condon (1954) and the Lyons Group and the Carrandibby Shale by Konecki et al.(1959). Condon measured a section of 4,600 feet of Lyons Group in the Williambury-Moogooree area, but the Group is much thinner in the Wooramel River area, where Condon measured a section of 2,640 feet at Coordewandy.

In the Irwin River area the Nangetty Glacial Formation and the Holmwood Shale are equivalents of the Lyons Group.

Most of the sequence is non-fossiliferous and the marine faunas occur sporadically both vertically and horizontally. The fossiliferous beds are mainly sandy sediments and commonly are calcareous. The fauna comprises molluscs, brachiopods, bryozoans, and crinoids. Corals have been recorded by Raggatt & Fletcher (1937), and Teichert (1941), although none occur in the present collections. Crespin (1958) has recently discovered foraminifera in the sediments of the Lyons Group. Molluscs are more abundant than brachiopods and the brachiopods are rather restricted in type as compared with their rich development in later Permian deposits in Western Australia. It is considered that this difference is an expression of the difference in environments. In this paper 20 species of pelecypods and gastropods and 11 species of brachiopods are listed. The Spiriferacea, though represented in the Lyons Group by three genera, are few as compared with the very rich development later of Spiriferacea, Rostrospiracea, and Punctospiracea. Other groups are similarly poorly represented. Thus there is only one species of Productacea, compared with the extremely abundant development of genera such as Dictyoclostus, Strophalosia, Aulosteges, Taeniothaerus, Krotovia, in the later Permian deposits. Crinoids, especially a calceolispongid species, and bryozoa are locally abundant, but nowhere are there more than a few species. The dominance of the molluscs, together with the occurrence of the faunas in comparatively coarse sediments, is thought to indicate that the outcropping marine horizons of the Lyons Group were deposited in shallow water.

The molluscan fauna also displays some interesting distinctions from later faunas, especially those from formations above the Callytharra.

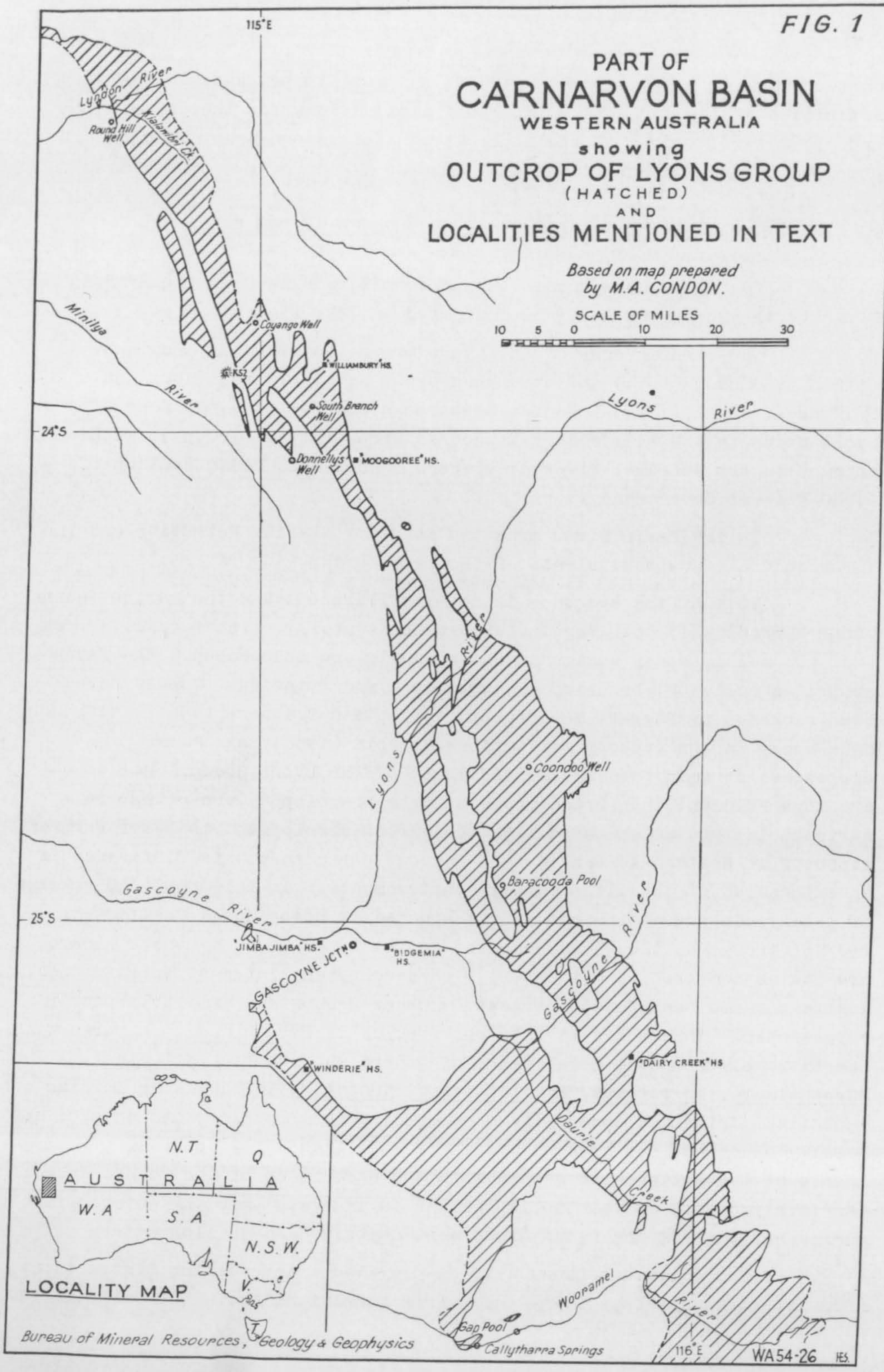
FIG. 1
PART OF
CARNARVON BASIN
WESTERN AUSTRALIA
showing
OUTCROP OF LYONS GROUP
(HATCHED)
AND
LOCALITIES MENTIONED IN TEXT
Based on map prepared
by M.A. CONDON.
SCALE OF MILES
10 5 0 10 20 30
115°E
116°E
24°S
25°S
Lyndon River
Round Hill Well
Coyango Well
WILLIAMBURY HS.
South Branch Well
Donnelly's Well
"MOOGOOREE" HS.
Minilya River
Lyons River
Coondoo Well
Baracooda Pool
Gascoyne River
"JIMBA JIMBA" HS.
GASCOYNE JCT.
"BIDGEMIA" HS.
"WINDERIE" HS.
"DAIRY CREEK" HS
Daurie Creek
Wooramel River
Gap Pool
Callytharra Springs
N.T
Q
AUSTRALIA
W.A
S.A
N.S.W.
V.
T
LOCALITY MAP
Bureau of Mineral Resources, Geology & Geophysics
WA54-26

Eurydesma and Keeneia are not known above the Lyons Group, and Deltopecten is only very poorly represented in formations above the Callytharra Formation, whereas Atomodesma, Oriocrassatella, Pseudomyalina, Heteropecten, and bellerophontids, which are often very abundant in the higher formations, are lacking in collections from the Lyons Group. These differences are also considered to be in part the result of environmental differences.

Although generally at a single locality only a few genera and species are represented, individuals can be very numerous. For example in the Lyndon River area some of the outcrops are covered with hundreds and even thousands of Deltopecten shell fragments.

IDENTIFICATION OF THE FAUNAS

Outcrops of the Lyons Group are usually poor, and dips are difficult to measure. Consequently it is difficult to measure accurate sections and to divide the Group into distinct formational units. The fossil localities are grouped together in broad areal and stratigraphical divisions, and as far as possible are in order from top to bottom.

Ia CARRANDIBBY FORMATION IN WOORAMEL RIVER AREA.

Localities: WB2, WB4, WB6, WB21, WB52, GW77, GW81, GW141, GW142, GW143 and GW144.

Brachiopoda:

Martiniopsid gen.nov.et sp.nov.

Mollusca:

Nuculana darwini (de Koninck) 1877
Stutchburia variabilis Dickins 1957
Astartila condoni Dickins 1957
Astartila? obscura Dickins 1957
Cleobis sp.[1]
Pachymyonia occidentalis Dickins 1957
Chaenomya sp.nov.
Praeundulomya elongata Dickins 1957
Leiopteria? carrandibbiensis Dickins 1957
Eurydesma playfordi Dickins 1957

---

(1) In Dickins (1957) this species is doubtfully referred to Pachydomus. After that paper went to press Newell (1956) named Cleobis grandis Dana 1847 as the type species of Cleobis and the Western Australian species should now be referred to this genus.

Deltopecten lyonsensis Dickins 1957
Aviculopecten tenuicollis (Dana) 1847
Peruvispira umariensis (Reed) 1928 (2)

Crinoidea:

Calceolispongidae sp.nov. (This species should probably be referred to a new genus).
Undetermined cup and stem ossicles.

Bryozoa:

Fenestellidae
Batostomellidae

Foraminifera:

Miss Crespin (pers.comm.) records three fragments of Hyperammina sp.ind.

Wood fragments.

Ib. CARRANDIBBY EQUIVALENT IN JIMBA JIMBA (GASCOYNE) AREA.

Locality: GW105.

Brachiopoda:

Trigonotreta sp.nov.

Mollusca:

Eurydesma playfordi Dickins 1957
Keeneia carnarvonensis Dickins 1957

Wood Fragments.

II TOP OF LYONS GROUP IN MINILYA RIVER/WILLIAMBURY AREA

Localities: F17,238, MG136 and MG161.

Brachiopoda:

Pseudosyrinx sp.nov.
Neospirifer sp.nov.
Streptorhynchus sp.nov.

Mollusca:

Stutchburia variabilis Dickins 1957
Deltopecten lyonsensis Dickins 1957

Indeterminate crinoids and fenestellids

(2) In Dickins (1957) this species has been referred to Ptychomphalina; it is apparently referable, however, to the new genus Peruvispira Chronic 1949 (in Newell et al., 1953). The type species, Peruvispira delicata, from Peru occurs in beds which are considered to of Wolfcampian (=Sakmarian) age. In Western and Eastern Australia forms of this type also occur in deposits of Artinskian age.

IIb **TOP OF LYONS GROUP IN LYNDON RIVER AREA**

Locality: ML90.

Mollusca:

Stutchburia variabilis Dickins 1957
Deltopecten lyonsensis Dickins 1957

Bryozoa:

Batostomellidae
Fenestellidae

IIIa **UPPER PART OF LYONS GROUP IN GASCOYNE RIVER AREA**

Localities: GW10, GW34 and 1/4 mile east of Winderie Homestead.

Brachiopoda:

Trigonotreta sp.nov.
Linoproductus (Cancrinella) lyoni (Prendergast)1943
Permorthotetes crespinae Thomas 1958

Mollusca:

Eurydesma playfordi Dickins 1957
Deltopecten lyonsensis Dickins 1957

Bryozoa:

Fenestellidae

Foraminifera (Crespin, 1958):

Calcitornella stephensi (Howchin) 1894
Reophax tricameratus Parr 1942

IIIb **UPPER PART OF LYONS GROUP IN MINILYA/WILLIAMBURY AREA**

MG160 - 570 feet below top of Lyons Group.

Linoproductus (Cancrinella) lyoni (Prendergast)1943
Permorthotetes sp.
Batostomellidae
Crinoid stems

MG159 - 800 feet below top of Group.

Neospirifer sp.
Deltopecten lyonsensis Dickins 1957
Platyschisma? sp.
Kenneia carnarvonensis Dickins 1957

MG158 - 900 feet below top of Group.

Neospirifer sp. ind.
Pseudosyrinx sp. nov.
Deltopecten lyonsensis Dickins 1957
Cidaroid spines

IIIc **UPPER PART OF LYONS GROUP IN LYNDON RIVER AREA**
(exact stratigraphical position not known)

ML105, ML106, ML107, ML108, ML109, ML110, T23, T24, T25,T26, T27.

Brachiopoda:

Trigonotreta sp.nov.
Linoproductus (*Cancrinella*) *lyoni*(Prendergast)1943
Neospirifer sp.nov.
Pseudosyrinx sp.nov.

Mollusca:

Stutchburia variabilis Dickins 1957
Astartila condoni Dickins 1957
Cleobis sp.
Eurydesma sp.ind.
Schizodus crespinae Dickins 1957
Deltopecten lyonsensis Dickins 1957
Aviculopecten sp.ind.
Peruvispira umariensis (Reed) 1928
Mourlonia? lyndonensis Dickins 1957
Keeneia carnarvonensis Dickins 1957

Crinoidea:

Calceolispongidae sp.nov.
Stem and cup ossicles

Bryozoa:

Fenestellidae
Batostomellidae

Conulariidae:

Conularia sp.

Foraminifera (Crespin,1958) :

Calcitornella stephensi (Howchin) 1894

IV **MIDDLE PART OF LYONS GROUP IN MINILYA RIVER/WILLIAMBURY AREA**

MG156 - 1850 feet below top of Group (lowest fossiliferous horizon in Condon's section, 1954, p.36-40).

Deltopecten lyonsensis Dickins 1957
Fenestellidae

CC125 - 1750 feet below top of Group; 1-4/5 miles north-west of Coyango Well, Williambury Station.

Pseudosyrinx sp.nov.
Neospirifer sp.nov.
Streptorhynchus sp.nov.
Martiniopsid gen.nov.et sp.nov.
Deltopecten lyonsensis Dickins 1957
Fenestellidae
Worm trails

F17203 - 1250 feet below top of Group, 3 miles west of Moogooree Homestead.

Spiriferacea gen.et sp. ind.
Nuculana lyonsensis Dickins 1956
Astartila condoni Dickins 1957
Cleobis sp.
Parallelodon? sp.ind.
Aviculopecten tenuicollis (Dana) 1847
Scaphopoda
Wood fragments

LOWER PART OF LYONS GROUP

GW62 - probably in lower third of Lyons Group; $3\frac{1}{2}$ miles on a bearing of 65° from Coondoo Well, Arthur River Station.

Kiangsiella sp.nov.
Aviculopecten cf.A.tenuicollis (Dana) 1847
Fenestellidae

ML6 This is the lowest known marine horizon, $3\frac{1}{2}$ miles west of north of Moogooree Homestead. Stratigraphically below this bed are lepidodendroid plant-bearing sandstones. *

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* These beds, consisting of pebbly quartz greywacke and sandstone, were originally mapped in 1949 by G.A. Thomas and C.E. Prichard, supervised by M.A. Condon. They were named the "Red Hill Sandstone" by Teichert (1950b), who considered them to be of Carboniferous age.

Condon (1954, p.31) proposed the name Harris Sandstone to replace "Red Hill Sandstone" and included these beds. The type section of the Harris Sandstone is about five miles north-west of Williambury Homestead. Condon (1954, p.32) states that the Lyons Group conformably overlies the Harris Sandstone in the type area. Recently Condon (in White and Condon, this volume p.58) has placed some of the beds, originally included in the Harris Sandstone, in the Lyons Group. The present authors consider that all these plant-bearing beds form a distinguishable stratigraphical unit because of their lithology, field occurrence and stratigraphical position. They are distinguishable from the Lyons Group proper in that they are not tillitic in texture. Although they are overlain by the boulder-containing beds of the Lyons Group, in most places the contact is obscured by a cover of talus or alluvium.

Mary White (in White and Condon, this volume) has identified Lepidodendron sp. from a locality about three-quarter miles south of Williambury Homestead. She considers this "most closely resembles Lepidodendron acutatum Lx. which occurs in "Meso-Carboniferous" Coal Measures in Missouri". However, in the conclusion she states that "the age based on the species of Lepidodendron alone could be Carboniferous or Permian". Mary White (this volume) has also tentatively identified Lycopodiopsis pedroanus (Carruthers) from a rubber mould of a decorticated log from the Harris Sandstone.

Trigonotreta? sp.ind.
Neospirifer sp.ind.
Linoproductus (Cancrinella) lyoni Prendergast 1943
Rhynchonellacea gen.ind.
Rostrospiracea? gen.ind.
Deltopecten lyonsensis Dickins 1957

REVIEW OF THE LYONS GROUP FAUNAS

A. Brachiopoda

The brachiopods comprise eleven species in all. None of the families is strongly represented as compared with the faunas of higher formations, e.g. the Callytharra Formation. Individuals may be locally numerous. The forms present are discussed below. Detailed descriptions of the unnamed species are being prepared by one of the authors (G.A.T.)

TRIGONOTRETA sp.nov. is present at several horizons and localities. The specimens are rather small, not exceeding 1¼ inches in width. The Lyons species has evidently close affinities to Trigonotreta stokesi Koenig (see Brown,1953). The ventral ribbing is very similar, with six or seven lateral and partly bifurcating costae. The dorsal valve is also similar, with four primary costae in the fold. The internal structures are also similar, notably the receding dental plates. The shells are mostly oval but some display an anterior median curvature corresponding to the fold. This species is distinguished from T.stokesi in being much smaller and thinner shelled, and in its proportions. Another species with probably even closer affinities is Trigonotreta narsarhensis (Reed) from the Umaria beds of India. It differs in being thinner shelled and smaller.

Trigonotreta has not so far been observed in beds younger than the Lyons Group in Western Australia.

LINOPRODUCTUS (CANCRINELLA) LYONI(Prendergast)has lately been redescribed by Coleman (1957). This species has a wide hinge-line and relatively flattened pedicle valve. It closely resembles Linoproductus (Cancrinella) umariensis (Reed),which is similar in form but is thinner shelled, a little finer ribbed, and less spinose. A variety L. (Cancrinella) umariensis var. spinosa (Reed) appears to be even closer to the Lyons species.

L.lyoni is distributed throughout the Lyons Group and is known also in the Callytharra Formation.

MARTINIOPSID gen.nov.et sp.nov. A small to medium sized martiniopsid species is present at several levels. This form shows the general characters of a group of species common in the Permian of Eastern Australia.

The features include long, nearly parallel dental plates in the ventral valve, a prominent umbo, fold and sulcus, and lateral plications on each side of both valves. The plications vary in intensity from specimen to specimen. The surface ornament is distinctive and consists of fine short offset linear radiating grooves. The largest specimen measures 4.1 mm. wide and 3.4 mm. long. The species has some features in common with Notospirifer darwini (Morris), an East Australian Permian species which, however, has a low umbo and divergent dental plates and subcircular pits on the surface (vide Mr.K. Campbell, University of New England, personal communication 2/7/1957).

The Lyons species thus belongs to a new genus which is distinguished from another allied genus, Martiniopsis Waagen, which has neither plications, fold or sulcus. The internal structures appear to be similar. Martiniopsis Waagen, Notospirifer Harrington, and the new genus are probably all related genera.

The new genus appears to be abundantly represented in the Permian of Eastern Australia. The Queensland examples have been studied by Mr.K. Campbell.

The new Lyons species is present also in the Callytharra Formation. Other species are known also from higher beds in the Carnarvon Basin and also from the Fitzroy Basin of Western Australia.

Waagen (1891) described as Martiniopsis darwini a small dorsal valve from the Speckled Sandstone of the Salt Range, and Reed described three small dorsal valves under the same specific name, referring it to the genus Brachythyris. The affinity of all these specimens is in doubt, but they may be allied to Notospirifer darwini (Morris) or possibly to the new genus recorded here.

Harrington (1955) erected the genus Notospirifer for Spirifer darwini and described an Argentinian species under the same name: but the Argentinian form may not be conspecific with Morris' species. Some specimens show a high umbo and the ornament may differ. Possibly more than one species is present in the Argentine material.

Sahni and Srivastava (1956) have described a new genus and species, Ambikella fructiformis, from probably early Permian deposits in the Eastern Himalayas of Sikkim. This form is known from a single internal mould. It is possibly a distorted martiniopsid, perhaps referable to Notospirifer, or is possibly a representative of the new genus outlined here. Better material will be required to solve this problem.

One of the Umarian brachiopod species - "Reticularia" barakarensis Reed - appears to be of uncertain affinities. Some of Reed's figures, and material collected by Professor S.W. Carey in 1953, suggest that a martiniopsid may be represented. Some of Reed's illustrations (e.g. Reed, 1928, plate 34, figure 7) show a surface ornamentation very reminiscent of the ornament of the martiniopsids.

NEOSPIRIFER spp. At least two species of this genus are present in the Lyons Group. They appear to be closely allied to or identical with species in the Callytharra Formation. In the Callytharra and higher formations Neospirifer is richly developed.

PSEUDOSYRINX sp.nov. This species is present at several horizons in the Lyons Group and another species occurs very abundantly in the Callytharra Formation. The Callytharra forms have been in the past referred to Syringothyris? exsuperans (de Koninck) by Etheridge (1897) Foord (1890), and others. The genus is represented in Western Australia also in the lower part of the Byro Group.

The type species of Pseudosyrinx, P.gigas Weller, is of Mississippian age. The genus is reported from other early Permian beds, e.g. the Kolyma area in Russia (Licharew, 1934). The Lyons and Callytharra species are provisionally referred to Pseudosyrinx as they lack a syrinx and septum and have the general form of P.gigas and other Mississippian species.

Campbell (1953) has recognized the genus in the Ingelara beds of Queensland. "Spirifer" nagmargensis Bion (1828) from the Agglomeratic Slate of Kashmir is probably a Pseudosyrinx and somewhat similar in form to the Lyons species . P.nagmargensis has a lower area than the Callytharra species and the fold is distinctly divided. The Lyons species likewise has a median groove on the fold. P.nagmargensis (Bion) was referred to Syringothyris by Reed (1932) but as pointed out by Licharew (1934, p.24) Reed's illustrations do not confirm the presence of a syrinx.

The West Australian forms appear to be impunctate as do the North American species, according to Cooper (1954, p.332). The new genus Subansiria Sahni and Srivastaca 1956 from the Eastern Himalayas seems to be closely allied, and is stated to lack punctae and thus may be a synonym of Pseudosyrinx.

DIELASMA sp. A small species of this genus is present in the Lyons Group. Its affinities are uncertain. Somewhat similarly shaped species are present also in the Agglomeratic Slate of Kashmir and the Speckled Sandstone.

Terebratuloids are much more abundant in later Permian formations in the Carnarvon Basin.

STREPTORHYNCHUS is sparsely represented in the Lyons Group by a rather large finely costellated but inadequately known species (Thomas, 1958). Its affinities are uncertain. Streptorhynchus is extremely abundant in the higher Permian deposits in Western Australia.

PERMORTHOTETES CRESPINAE Thomas 1958 is a large septate orthotetacean with a secondary spondylium. The genus is very well developed in higher Permian deposits in Western Australia but is not known with certainty elsewhere.

KIANGSIELLA sp. nov. Thomas 1958. A small inadequately known representative of this genus is present at the locality in the Lyons Group. In the higher Permian deposits other species showing marked affinities with Salt Range Productus Limestone species are abundant.

RHYNCHONELLACEAN gen. et sp. indet. This form is known only from the base of the Lyons Group. It has a gentle sulcus and 18 costae. Its affinities are unknown and it does not appear to be related to any species or genera occurring in higher beds.

ROSTROSPIRACEAN? gen. et sp. indet. A single specimen of a spinose athyrid? is present near the base of the Lyons Group. The specimen is inadequate for determination.

B. Mollusca

The molluscs, which are the dominant group, are often very numerous. The species are discussed below:

NUCULANA LYONSENSIS Dickins 1956 is an elongated form with the umbo turned towards the back. It is most closely related to N.thompsoni Reed 1932, from the Agglomeratic Slate of Kashmir.

NUCULANA DARWINI (de Kon.) 1887 is a moderately elongated species as compared with N.lyonsensis and the umbo is more upright. In Eastern Australia Fletcher (1945, p.306) considers that N.darwini has only been authentically recorded from the Branxton Sub-group of the Maitland Group (= Upper Marine Series, see Hanlon in Hill, 1955, p.94) of New South Wales.

STUTCHBURIA VARIABILIS Dickins 1957, is a costate form related to S.costata (Morris) 1845, the type species from the Permian of New South Wales. It is the only costate form of the genus known to occur in the Western Australian sequence. This species also occurs in the Callytharra Formation.

CLEOBIS sp. is closely related to Cleobis globosus (Sowerby)1838 from the Dalwood Group (= Lower Marine Series, see Hanlon, loc.cit.) of New South Wales.

PACHYMYONIA OCCIDENTALIS Dickins 1957, although distinct from the two New South Wales species, is the first species of this genus recognised in Western Australia.

EURYDESMA PLAYFORDI Dickins 1957. The specimens of this characteristic genus of the Lyons Group belong to a new species which shows closest relationship to Eurydesma mytiloides Reed from the Agglomeratic Slate of Kashmir and the Speckled Sandstone of the Salt Range. Specimens described by Harrington (1955) from Argentina are also related, as is the specimen figured by Etheridge and Dun (1910, pl.18, figure 2) as E.hobartense (Johnston) 1887.

DELTOPECTEN LYONSENSIS Dickins 1957 is closely related to D.illawarrensis (Morris) 1845, the type species; the structure of the hinge of the Western Australian species, however, is simpler. Morris considered that the specimens on which he based his description of D.illawarrensis were collected from Illawarra, which is in the Gerringong Volcanics ("Upper Marine") of New South Wales. This species, however, has apparently not since been collected from the Upper Marine and appears to be confined to the "Lower Marine beds" of New South Wales (Etheridge and Dun 1906, p.12).

D. MITCHELLI (Etheridge and Dun 1906), which is closely related to D.illawarrensis or perhaps even conspecific with it, occurs in the lower part of the Dalwood Group and Branxton Subgroup according to Fletcher (Raggatt and Fletcher, 1937, p.155). Reed (1932) has also described a similar form from the Agglomeratic Slate of Kashmir as D.illawarrensis.

AVICULOPECTEN TENUICOLLIS (Dana) 1847. This is a small aviculopectinid with comparatively simple ribbing and was originally described from the Dalwood Group ("Lower Marine Series") of New South Wales.

KEENEIA CARNARVONENSIS Dickins 1957 is distinguished by its rounded whorl cross section and is most closely related to an undescribed species from the Allandale Formation of the Dalwood Group of New South Wales. This is the first species of this genus known outside Eastern Australia.

PERUVISPIRA UMARIENSIS (Reed) 1928. This species was previously described from the Umaria beds of peninsular India. It is related to, but specifically distinct from, P.morrisiana (McCoy) 1847 from the Permian of Eastern Australia.

C. Calceolispongid Crinoids

CALCEOLISPONGIDAE gen. et sp. nov. Although related to Calceolispongia Etheridge, 1915, it is considered that this form should be referred to another genus. Included in the material are basal, radial and brachial plates. The Western Australian form, which has not been found in the Callytharra Formation, is closely related to specimens from Umaria, India, described by Reed (1928) as "dermal tubercles of a fish", and may even be conspecific.

D. Foraminifera

Two species - Calcitornella stephensi (Howchin) 1894 and Reophax tricameratus Parr 1942 - are recorded by Crespin (1958) from the Lyons Group. Both species occur also in the overlying beds.

RELATIONSHIP OF THE FAUNAS OF THE CARRANDIBBY FORMATION AND THE LYONS GROUP.

In the present study seventeen forms are specifically identified from the Carrandibby Formation and the Carrandibby equivalent in the Jimba Jimba (Gascoyne) area. Of these, eight are known elsewhere only from the Lyons Group:-

Trigonotreta sp. nov.
Astartila condoni Dickins 1957
Cleobis sp.
Eurydesma playfordi Dickins 1957
Deltopecten lyonsensis Dickins 1957
Peruvispira umariensis (Reed) 1928
Keeneia carnarvonensis Dickins 1957
Calceolispongidae sp. nov.

Three species are known from the Lyons Group and the Callytharra Formation:-

Martiniopsid gen.nov. et sp.nov.
Stutchburia variabilis Dickins 1957
Aviculopecten tenuicollis (Dana) 1847

Eleven of the seventeen species specifically identified in the Carrandibby Formation thus occur elsewhere also in the Lyons Group. Of the six remaining species five are known only from the Carrandibby Formation:-

Astartila obscura Dickins 1957
Pachymyonia occidentalis Dickins 1957
Chaenomya sp. nov.
Praeundulomya elongata Dickins 1957
Leiopteria? carrandibbiensis Dickins 1957

Two of these, Astartila? obscura and Leiopteria? carrandibbiensis, are related to forms elsewhere which are long ranging, and some of the above forms may have been found only in the Carrandibby Formation because conditions were favourable for the growth and preservation of pelecypods when the upper part of the formation was deposited.

The remaining species, Nuculana darwini (de Koninck) 1877, is also known from the Nura Nura Member of the Poole Sandstone of the Fitzroy Basin, which is regarded as correlable with the Callytharra Formation (see Thomas and Dickins, 1954).

Of the remaining macro-fauna from the Lyons Group, at least four species occur in the Callytharra Formation but not in the Carrandibby Formation:-

Linoproductus (Cancrinella) lyoni (Prendergast) 1943
Neospirifer spp.
Nuculana lyonsensis Dickins 1956

Seven species are known only from the Lyons Group:-

Pseudosyrinx sp. nov.
Permorthotetes crespinae Thomas 1958
Streptorhynchus sp. nov.
Kiangsiella sp. nov.
Schizodus crespinae Dickins 1957
Mourlonia? lyndonensis Dickins 1957
Platyschisma? sp.

The faunas of the Carrandibby Formation and the Lyons Group are closely related, and common elements distinguish both from the overlying Callytharra Formation. Similarly the faunas of both resemble that of the Speckled Sandstone of India, whereas both are distinctly different from that of the overlying Lower Productus Limestone, the fauna of which more closely resembles that of the Callytharra Formation. The relationships to the Indian faunas are discussed more fully later.

AFFINITIES OF THE LYONS GROUP FAUNAS

Eastern Australia

The Lyons brachiopod faunas are not for the most part closely related to the eastern Australian on the specific level; but they show a closer general relationship than has been earlier suspected. The eastern Australian faunas are characterized by the rich development of "Martiniopsis", present throughout the marine Permian of New South Wales, and in Queensland and Tasmania. These forms are present also throughout the sequences in Western Australia, but as a very subordinate element. The species are always small. Trigonotreta sp. nov. is not identical with Tasmanian species, but is evidently allied. Trigonotreta stokesi (Koenig) is an abundant form in the Berriedale Limestone and its equivalents and also lower formations in Tasmania. It is probably present in New South Wales, but no recent studies of New South Wales Permian brachiopods are yet available.

The genus Pseudosyrinx is reported by Campbell (1953) from the Ingelara Beds of Queensland, which he regards as of late Artinskian age. This is a younger occurrence than any known for this genus in Western Australia, but suggests seaways between the two areas. Neospirifer, a cosmopolitan genus, is present in Queensland and evidently also in New South Wales, but appears to be a minor element in the faunas. It is reported also from Tasmania. Neospirifer is a dominant element in the Artinskian and later faunas in Western Australia, with many species.

The pelecypods display rather closer relationships with those of the Lyons Group.

Nuculana darwini (de Kon.) is recorded in Eastern Australia only from the Branxton Subgroup of New South Wales. Stutchburia variabilis Dickins is closely related to S.costata, again known only in the "Upper Marine". Cleobis sp. is related to P.globosus from the Allandale Formation of Harpers Hill. Deltopecten lyonsensis Dickins is related to unspecialised Deltopectinids possibly confined to the "Lower Marine" and the lower part of the "Upper Marine" of New South Wales. Aviculopecten tenuicollis Dana is described only from the "Lower Marine", and Keeneia carnarvonensis Dickins is related to an Allandale species. Eurydesma, which occurs in the "Lower" and "Upper Marine" of New South Wales, seems to be more characteristic of the "Lower Marine" and appears to be restricted to the lower part of the Permian in Queensland (Hill, 1955). The Lyons Group apparently lacks the more specialized Deltopectinid forms which are characteristic of the "Upper Marine beds".

As a whole the molluscan fauna of the Lyons Group seems to show closer relationship with that of the "Lower Marine" than with the "Upper Marine beds".

Indian faunas

(1) The Umaria Beds of Peninsular India

The Umaria beds are a marine sequence about ten feet thick at the base of the Barakar coal measures and conformably overlying the Talchir boulder beds. F.Ahmad (1954) considers that the marine bed actually forms the top of the Talchir Series. The fauna, described by F.R.C. Reed (1928), contains the following species: Productus umariensis Reed, P.umariensis var. spinifera Reed, P.rewahensis Reed and P.rewahensis var. coroides Reed, Spirifer narsarhensis Reed and Spirifer narsarhensis var. subplicata Reed, two other inadequately known brachiopods, a small lamellibranch and some nondescript ostracods, Pleurotomaria umariensis Reed, and "the dermal tubercles of a fish". The writers have been able to examine a useful collection made at Umaria by Professor

SUGGESTED CORRELATIONS OF PERMIAN FORMATIONS OF INDIA AND AUSTRALIA

		KASHMIR	SALT RANGE	PENINSULAR INDIA	CARNARVON BASIN	IRWIN RIVER BASIN	QUEENSLAND (Springsure)	N. S. W. (Hunter Valley)
LOWER PERMIAN	KUNGURIAN	AGGLOMERATIC SLATE			COOLKILYA GREYWACKE		MANTUAN CATHERINE	MULBRING
	ARTINSKIAN		LOWER PRODUCTUS LIMESTONES	BARAKAR BEDS	CALLYTHARRA FORMATION	FOSSIL CLIFF FORMATION	INGELARA ALDEBARAN	MUREE BRANXTON GRETA C.M. FARLEY
				?——?			?——?	?——?
	SAKMARIAN		SPECKLED SANDSTONE TALCHIR BOULDER BEDS	UMARIA BEDS TALCHIR BOULDER BEDS	LYONS GROUP	HOLMWOOD SHALE NANGETTY GLACIALS	CATTLE CREEK STAIRCASE DILLY	RUTHERFORD ALLANDALE LOCHINVAR

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S.W. Carey of the University of Tasmania and Dr.F.Ahmad of the Geological Survey of India in 1953. A number of Reed's species were identified and some others recognised. These are listed below with revised generic names:

Linoproductus (Cancrinella) umariensis (Reed), L. (Cancrinella) umariensis var. spinifera (Reed), L.(Cancrinella) rewahensis?(Reed), "Reticularia" barakarensis Reed, Trigonotreta narsarhensis (Reed), Peruvispira umariensis (Reed), Eurydesma cf. mytiloides Reed. The "dermal tubercles of a fish" are the basal plates of a calceolispongid species which should probably be referred to a new genus. Also present are the second brachials and other plates. The crinoid affinities of the basal plates were recognised by Gerth (1936) and they are also discussed by Teichert (1949a). This species is very close to or identical with the Lyons calceolispongid.

The species listed above, with the exception of "Reticularia" barakarensis, are either identical or closely allied to species from the Lyons Group, more especially the upper beds of the Group. They are therefore probably of about the same age, namely Sakmarian. Recently Sahni (1956) has recorded Eurydesma from a new locality of the Umaria fauna at Marendargash, Central India, east of Umaria.

The close relationship of the Umaria fauna with the Lyons fauna is striking, and indicates free communication between the two areas in Sakmarian time.

(2) Agglomeratic Slate of Kashmir

The faunas of this very interesting sequence have been described by Bion (1928) and Reed (1932). They probably range in age from late Carboniferous, i.e. pre-Sakmarian, to early Artinskian. The Lyons fauna shows closest affinity with the fauna from the Nagmarg beds (Bion, 1928) and the approximately contemporary lower beds at Bren Spur (Reed, 1930).

The lower beds of the Agglomeratic Slate contain an older fauna. Bion (1928) records, from the lower Agglomeratic Slate of the Marbal Valley, Syringothyris lydekkeri (Diener), Derbyia, a productid, and bryozoa. This lower fauna appears to be related to that of the Fenestella Shale (Diener, 1915) which is possibly of Upper Carboniferous age but needs restudy.

The fauna of the Nagmarg beds and the lower beds at Bren Spur has some similarities to Lyons faunas. The Nagmarg fauna was described by Bion and the Bren Spur fauna by Reed. Reed revised some of Bion's determinations, and in turn a number of Reed's identifications may be questioned in the light of more recent knowledge.

The principal brachiopods from Nagmarg and/or Bren Spur seem to be Pseudosyrinx? nagmargensis (Bion), "Martiniopsis" darwini (Morris), Streptorhynchus bioni Reed, Taeniothaerus permixtus Reed. In addition there is a group of spiriferids, including "Spirifer" kimsari Bion, which are probably representative of Neospirifer.

Reed (1930) described in addition a number of species about which insufficient is known. These include Dielasma cf. lidarense Diener, a number of fragmentary spiriferids which possibly represent a species of Neospirifer, Strophalosia, Buxtonia kashmiricus Reed (this form may be referable to Taeniothaerus), a very doubtful Schellwienella, Streptorhynchus cf. hallianus Derby (this is possibly referable to Kiangsiella but is inadequate for determination), Reticularia kashmirica Reed (possibly a martiniopsid) and several others.

The brachiopods which are sufficiently well known appear to be related to the Lyons species. Pseudosyrinx? nagmargensis (Bion), "Martiniopsis" darwini (Morris) and perhaps Streptorhynchus bioni, and Dielasma cf. lidarense, can be compared with species from the Lyons Group.

Taeniothaerus, which becomes the dominant and almost exclusive brachiopod in the highest beds at Bren Spur, is not represented in the Lyons faunas, but is a common form in the formations above the Lyons Group. Reed (1930) has pointed out the general correlation of the Bren Spur faunas with the Speckled Sandstone fossils. The presence of Taeniothaerus in the upper beds suggests a correlation in part with the Lower Productus Limestones, which are of Artinskian age.

Among the pelecypods Deltopecten occurs in the Nagmarg Beds and the lower beds at Bren Spur. Similar forms are known only from the Lyons Group and the Callytharra Formation in the Carnarvon Basin. The lower beds at Bren Spur are characterized by the presence of Eurydesma, which in Western Australia has not so far been found above the Lyons Group, and the higher beds are characterized by Oriocrassatella (and "Procrassatella"), which in Western Australia has not been found below the Byro Group.

A comparison with the Australian faunas thus suggests that the Nagmarg Beds and the beds at Bren Spur of the Agglomeratic Slate may range in age from Sakmarian to Artinskian.

(3) Speckled Sandstone of the Salt Range

The Speckled Sandstone group of beds contains a well known fauna first described in detail by Waagen (1891) and later by Reed (1936). The Speckled Sandstone include at the base the Talchir boulder beds and are conformably followed by the Lower Productus Limestone - Amb Beds, which contain Artinskian fusulines. e.g. Parafusulina kattaensis (Schwager).

The brachiopods are few and include the following listed by Waagen. Chonetes cracowensis Etheridge, "Martiniopsis darwini" (Morris) "Spirifer vespertilio Sowerby", Discina sp., Discinisca warthi Waagen. Reed listed Dielasma dadanense Reed and Discinisca warthi Waagen.

The brachiopods in common with the Lyons are possibly "Martiniopsis darwini" (Morris) and perhaps Dielasma dadanense Reed.

The resemblance of the pelecypods of the Speckled Sandstone to Australian forms has already been pointed out by Waagen and Reed, and amongst the Western Australian faunas that of the Lyons Group is the most closely related.

(4) Eastern Himalayan Faunas

Sahni and Srivastava (1956) have described interesting new faunas from Sikkim and Subansiri, which resemble the Agglomeratic Slate fauna. They include species of Eurydesma, new Spiriferacea including the new genus Subansiria - which may be allied to Pseudosyrinx - and Pseudosyrinx cf. nagmargensis (Bion), Chonetes, Linoproductus, Ambikella fructiformis, and Conularia. Comparative material is needed to ascertain the relationships with Western Australian faunas.

South African Faunas

Eurydesma has been recorded from South Africa by Range (1912), Du Toit (1954), and others.

The South African species is found in the Dwyka Glacial deposits with a "Glossopteris - Gangamopteris" flora and so presumably is of similar age to similar faunas occurring elsewhere.

South American Faunas

Bonete fauna of Argentina (Harrington 1955).

As a whole, this fauna is not as close to the Lyons as are those of India, but some resemblance can be seen. Among the pelecypods Eurydesma mytiloides Reed and Leiopteria bonaerensis Harrington show the closest relationship. "Notospirifer darwini" (Morris) is described among the faunas: the Argentine form is evidently allied to some of the Australian martiniopsids.

Brazilian and other South American faunas.

The relationship of the pelecypod fauna of the Arenito de Taio in Brazil, described by Reed (1930) and Kegel & da Costa (1951), to the "*Eurydesma* fauna" is not clear. None of the late Palaeozoic brachiopod faunas of Brazil appear to be closely related to the Lyons fauna. In Peru, the plicated streptorhynchid *Kiangsiella* is known in beds of Sakmarian (Wolfcampian) age. This genus is now seen to be more ubiquitous than earlier was believed; although best developed in India and China, it has a fairly wide distribution including Peru, Western Australia, Russia, and perhaps the Carnic Alps in Italy.

AGE OF THE MARINE FAUNAS OF THE LYONS GROUP

The close relationship of the fauna of the Lyons Group with that of the Agglomeratic Slate of Kashmir, the Speckled Sandstone of the Salt Range, and, especially, the lower part of the marine sequence of New South Wales, and probably also with that of the Bonete beds of Argentina and the Dwyka of South Africa, strongly suggests that these faunas are of similar age. Consequently the age of the marine faunas of the Lyons Group has an important bearing on the age of all these deposits.

The lowermost bed with marine fossils contains two inadequately known species which apparently do not occur in higher beds. The other species range throughout the Group. On the other hand, although the Lyons fauna is distinctive it grades transitionally into that of the Callytharra Formation, and no sharp faunal break is discernible. The Callytharra Formation on the basis of its fauna can be correlated with the Fossil Cliff Formation of the Irwin River Basin, and the Nura Nura member of the Poole Sandstone of the Fitzroy Basin. The evidence for the early Artinskian age of these three formations has been summarized by Thomas and Dickins (1954). These conclusions were based especially on the ammonoid faunas but also on the evidence afforded by the other groups of fossils.

In consequence, because of its relationship with the Callytharra Formation and its correlation with the ammonoid-bearing Holmwood Shale of the Irwin River Valley on the basis of lithology and stratigraphical position, the Lyons Group is regarded as of Sakmarian (Lower Permian) age in large part at least. The similarity of the faunas throughout suggests that the marine beds of the Lyons Group are in the main, if not entirely, of Sakmarian age. The lowermost marine beds could be slightly older. The more recent evidence thus confirms the suggestion made by Teichert (1941; 1949b).

Underlying the marine beds of the Lyons Group in the Williambury-

Moogooree area is the lepidodendroid-bearing pebbly sandstone mentioned previously.

In summary, the relationships of the Lyons Group, especially with deposits containing ammonoids, strongly suggest that the "Eurydesma-fauna" is mainly, if not entirely, Permian in age.

EVIDENCE FOR THE AGE OF THE EASTERN AUSTRALIA DEPOSITS

Two ammonoids have been recorded in the New South Wales Permian deposits. Teichert and Fletcher (1943) described Adrianites (Neocrimites) meridionalis from near the base of the Branxton Subgroup ("Upper Marine Series"). These authors considered that the ammonoid indicated an Artinskian or Kungurian age for the beds and favoured the Artinskian because the species was more closely related to earlier than to later species of the genus.

The other ammonoid is Pseudogastrioceras pokolbinense Teichert (1954), which was recorded from the Farley Formation of the Dalwood Group. Teichert considers that this species is of a type not occurring earlier than the Artinskian.

Confirmatory evidence for post-Sakmarian deposition in Eastern Australia is the occurrence of Glyptoleda Fletcher in the Ingelara Beds of Queensland (Campbell, 1953). Fully developed species of Glyptoleda are not known lower than the Cundlego Formation in the Carnarvon Basin. The Cundlego is considered to be later Artinskian (Thomas and Dickins, 1954). Hill (1955), basing her views on her own work and that of Campbell (1953), Campbell in Hill (1955), and Maxwell (1954) on brachiopod and other faunas, considers that the Queensland Permian sedimentation ranges from Sakmarian to Kungurian in age.

In New South Wales, the simpler ribbed Deltopectinids similar to the Lyons species Deltopecten lyonsensis are characteristic of the "Lower Marine beds". In Western Australia this group is poorly represented or absent from formations above the Callytharra Formation and its equivalents, whereas in New South Wales a number of more specialized forms develop. These forms all possess the "Deltopecten" hinge, but the ribbing is diversified. Examples are "Deltopecten" squamuliferous Morris, "Deltopecten" multicostatus (Fletcher), "Deltopecten" media (Laseron) and "Deltopecten" limaeformis (Morris).

The eastern Australian marine Permian deposition may therefore be considered to range in age from Sakmarian to Kungurian.

The correlations adopted in this paper are outlined in the accompanying chart. It has been general practice to correlate the boundary of the Sakmarian and Artinskian stages of the Ural Section with the Lyons Group/Callytharra boundary. This however, should be taken as approximate only and in fact this boundary may be a little higher or a little lower than shown, although in the opinion of the writers not very much lower or higher.

PALAEOGEOGRAPHIC IMPLICATIONS

The affinities of some of the Salt Range Permian faunas with those of New South Wales and Western Australia have been recognized by many workers since Waagen. The Lyons fauna provides valuable new evidence in discussing the affinities and temporal relationship of the faunas of these areas and enables some deductions to be made concerning their faunal development and differentiation.

Schuchert (1935) distinguished seven world faunal realms in the Permian. Of interest here are the following of his realms and provinces:

- I — The faunal realm of the vast mediterranean Tethys which extended into the Salt Range, Kashmir and the Himalayas;
- Ia — The Timoran province, a branch of the above;
- Ib — The Western Australian province, also a branch of I;
- II — The cold water Eastern Australian realm, which included Tasmania, and a branch into Himalayan India.

These faunal provinces can be distinguished in later Permian time, but in early Permian times the faunas seem to be much more closely inter-related.

The evidence of the Lyons faunas suggests that in early Permian (Sakmarian) times, the marine faunas of Western Australia, peninsular India, Himalayan India, Eastern Australia and Argentina belonged to a common faunal province. Glacial deposits are associated with these faunas. Shallow marine seaways may have provided access between all these areas at that time.

In post-Sakmarian Permian times the West Australian seas remained in fairly free communication with those of Himalayan India and Timor, as evidenced by the faunal relationships (see Thomas and Dickins 1954, for summary), and new faunas largely replace the originally common elements of the widespread Sakmarian fauna. Marine deposition ceased after the Sakmarian in peninsular India and perhaps in Argentina.

The easterr Australian province, however, appears to have been relatively isolated after the Sakmarian. Many of the new faunal elements seem to be absent, especially in New South Wales, and there is apparently an indigenous development of the earlier fauna. A most striking feature in New South Wales is the persistence and diversification of Deltopecten and the Martiniopsids. The Queensland and Tasmanian Permian faunas show some signs of intermittent communication with Western Australia but their faunas on the whole appear most closely allied to those of New South Wales.

The present work thus bears out the suggestion of some previous workers including Schuchert (1935, p.21) and Teichert (1950a, p.207) that in eastern Australia the earlier fauna, which has usually been regarded as a cold water one, persisted longer than in other parts of the world such as in India and Western Australia. The causes of the isolation of the Eastern Australian province are unknown but may be in part of climatic origin: glacial phenomona persist until high in the marine Permian in New South Wales and Tasmania.

In conclusion, the marine faunas of India, Australia and probably Argentina evidently had much in common in Sakmarian times. This relationship, though consistent with the reconstructions postulated by the theory of continental drift, does not necessitate proximity of the seas of the various regions at that time. The faunal distribution can be as readily explained in other ways. The regions could have occupied approximately their present position with shallow sea connections between them. Alternately spread of planktonic larval forms may provide sufficient or partial explanation - Dunbar (1952, p.154) cites larval migration as the explanation of the present distribution of shallow marine molluscs in the Pacific.

LIST OF LOCALITIES

(in order of appearance in text)

WB2	Approximately one mile west of Callytharra Springs.
WB4	Approximately one mile west of Callytharra Springs.
WB6	1-4/5 miles slightly south of west of Callytharra Springs.
WB21	Approximately one mile north of Gap Pool.
WB52	Approximately one mile west of Callytharra Springs.
GW77	Approximately one mile west of Callytharra Springs.
GW81	Approximately one mile west of Callytharra Springs.
GW105	Approximately 10½ miles west of Jimba Jimba Homestead.
GW141	Approximately one mile west of Callytharra Springs.
GW142	Approximately one mile west of Callytharra Springs.

GW143	Approximately one mile west of Callytharra Springs, 45-55 feet below base of Callytharra Formation.
GW144	Approximately one mile west of Callytharra Springs, 70-80 feet below base of Callytharra Formation.
F17238	$2\frac{1}{2}$ miles slightly south of south-east of South Branch Well. $9\frac{1}{2}$ miles south-south-east of Williambury Homestead.
MG136	2.3 miles east south-east of K52.
MG161	3,000 feet west of rabbit proof fence. 3.7 miles west of south of Coyango Well.
ML90	Approximately 2 miles north-north-east of Round Hill Well, Winning Station.
GW10	$16\frac{1}{2}$ miles south of west of Dairy Creek Homestead, $2\frac{1}{2}$ miles south of the main road crossing of Daurie Creek, Dairy Creek Station.
GW34	4-3/10 miles east of south-east of Baracooda Pool, Arthur River.
-	Quarter mile east of Winderie Homestead.
MG160	1,800 feet west of rabbit proof fence, 3.7 miles west of south of Coyango Well.
MG159	On rabbit proof fence, 3.4 miles south of Coyango Well.
MG158	360 feet west of MG159.
ML105	Approximately $3\frac{3}{4}$ miles north-east of Round Hill Well, 700 feet west of Kialawibri Creek road crossing, Winning Station.
ML106	Approximately 3 miles north-east of Round Hill Well, one mile west of Kialawibri Creek road crossing, Winning Station.
ML107	As for ML106, 100 feet west of ML106.
ML108	As for ML106, 140 feet west of ML106.
ML109	As for ML106, 410 feet west of ML106.
ML110	Approximately 3 miles north-east of Round Hill Well, one mile west of Kialawibri Creek road crossing, Winning Station.
T23-26	Not clear but apparently stratigraphically not below ML105 and not above ML109.
T27	As for ML109.
MG156	1,200 feet west of corner of rabbit proof fence, west of Coyango Well.
CC125	1-4/5 miles north-west of Coyango Well, Williambury Station.
F17203	3 miles west of Moogooree Homestead.
GW62	$3\frac{1}{2}$ miles on a bearing of 65° from Coondoo Well, Arthur River Station.
ML6	$3\frac{1}{2}$ miles west of north of Moogooree Homestead.

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PROBABLE SALT DOME AT WOOLNOUGH HILLS, CANNING BASIN, WESTERN AUSTRALIA

by

J.J. Veevers and A.T. Wells.

SUMMARY

A dome of Cretaceous and probable Permian sediments, about 2 miles across, is exposed in the southern part of the Canning Basin, at the north-western corner of the Warri 4-mile Sheet area. Two arcs of Cretaceous cuestas lie concentrically round an inner ring of hills 50 feet high, of probable Permian age, and with a mound of brecciated dolomite at the centre. Sheared gypsum crops out 250 yards south-east of the dolomite. Only one theory of origin appears to explain all the observed features: this is that the sediments were arched up by an intrusive plug of rock salt to form a salt dome with a central area of cap rock. The economic implications of this theory - that rock salt, and possibly petroleum and sulphur, occur in the dome - can be tested by drilling only.

INTRODUCTION

Location of area

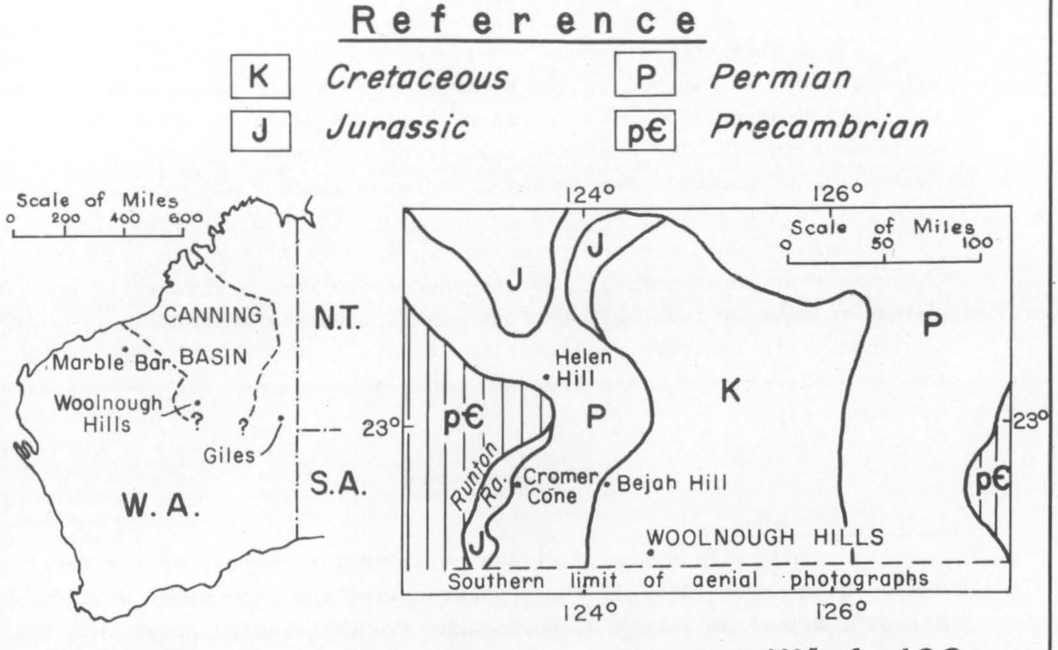
The hills situated at the north-western corner of the Warri 4-mile Sheet area (G51/4), Western Australia, are here named Woolnough Hills,* after the late W.G. Woolnough, who contributed greatly to the advancement of the geology of Western Australia. The geographical co-ordinates are 24°06'S, 124°32'E (Figure 1) and the air photographs covering the area are Morris (F51/16) Run 16/5045, 5046. Woolnough Hills lie immediately north of the southern limit of air-photograph cover of the Canning Basin. The area is situated within the Gibson Desert, 370 miles south-east of Marble Bar, and 250 miles west-north-west of Giles Meteorological Station; the nearest point of settlement is Jiggalong Mission, 240 miles to the west.

Previous work

A preliminary interpretation by J.N. Casey of the air photographs of Woolnough Hills, intended solely as a guide for future fieldwork, showed a dome of Precambrian rocks overlain by Permian rocks to the north and east. B.H. Stinear and A.T. Wells (geologists), and S. Waterlander (geophysicist) visited the structure in June 1956, as part

* This proposed name has been submitted to the Lands and Surveys Department, Western Australia, for approval.

LOCALITY MAP AND REGIONAL GEOLOGY *Fig1*
OF WOOLNOUGH HILLS



Bureau of Mineral Resources, Geology & Geophysics. Nov., 1958. **WA 4-160** F.J.R.

of a reconnaissance of the southern part of the Canning Basin. The structure was considered to be a Permian and Cretaceous dome with a core of Upper Proterozoic dolomite. One measurement of gravity was made within the dome. In October,1958, J.J. Veevers examined the air photographs of the Woolnough Hills as part of a general investigation of the Precambrian rocks at the edge of the Basin, and suspected that the structure was a salt dome. The further study of all available information is given below.

REGIONAL GEOLOGY

A broad belt of thin horizontal Cretaceous rocks lies in the southern part of the Canning Basin. It is more than 100 miles wide and 150 miles from its northern edge to the limit of air-photograph cover (Figure 1). Woolnough Hills lie about 40 miles east of the south-western corner of this belt.

The thickest measured section of Cretaceous rocks in the region (as seen at a single outcrop) is 45 feet at Bejah Hill, 30 miles north-west of Woolnough Hills. The peak of Bejah Hill is about 250 feet above the nearest Permian outcrops, and since the strata here are horizontal, this is the best estimate of thickness of the Cretaceous rocks. As Woolnough Hills lie along the southern limit of air-photograph cover, the geology immediately to the south is unknown.

Relief within the region underlain by Cretaceous rocks is low; rises of pisolitic rubbly ironstone and clay, and rare outcrops of rocks, are lightly incised by dry radial streams, along which mulga bush is concentrated; the streams pass into broad flat sandy valleys covered with spinifex. Maximum relief is 45 feet. Breakaways (scarp-retreats) are uncommon, and where formed are generally cut into ironstone caps; consequently fresh outcropping rock is also uncommon. On 4-mile air-photograph mosaics, the sand-covered valleys in the Cretaceous region form a minutely dendritic pattern, best seen on the Morris 4-mile Sheet. The most notable single feature of the Cretaceous terrain is the almost complete absence of sand dunes, which are ubiquitous in the Permian and Jurassic terrains.

The Cretaceous rocks consist of partly silicified white massive claystone (porcellanite), which at many places encloses a thin bed of medium-grained purplish porous sandstone containing numerous worm tracks. The nearest good rock exposure visited, 18 miles north of Woolnough Hills, has this lithology.

The evidence for the Cretaceous age of these rocks is presented by Traves et al. (1956, pp.28-30).

The nearest known outcrops of Permian rocks are near Bejah Hill. They are identified by lithology and photo-pattern; not until Helen Hill, 60 miles farther north-west, can Permian rocks be dated by fossils. The Permian outcrops consist of horizontal medium to coarse-grained pebbly quartz sandstone, interbedded with fine conglomerate and, in some places, thin siltstone. They crop out as isolated rises, commonly capped by pisolitic ironstone, in fields of seif dunes, and have a smooth dark photo-pattern. Fluvioglacial rocks like those of the Permian Paterson Formation crop out 50 miles west of Bejah Hill at Cromer Cone. Beds of sand and clay with erratics up to three feet across are interbedded with laminated and massive sandstone.

A plant-bearing Jurassic sequence of coarse sandstone, fine conglomerate, and current-bedded sandstone occupies the eastern margin of Runton Range (Figure 1) and transgresses Permian rocks to rest directly on Lower Proterozoic metamorphic rocks. Farther east, Jurassic rocks are absent, and the Cretaceous directly overlies the Permian.

STRATIGRAPHY OF WOOLNOUGH HILLS

Two units of clastic sedimentary rocks may be recognized at Woolnough Hills (Figure 2): a poorly outcropping sheet of fine-grained rocks, mainly claystone (porcellanite) and fine siltstone, which by lithology, photo-pattern, and continuity to the north with fossiliferous rocks, are identified as Cretaceous, underlain, probably disconformably, by an inlier of interbedded quartz siltstone, sandstone, and sedimentary breccia, at least 1,000 feet thick. The inlier (see Figure 4 for thickest measured section) is lithologically distinct from the Cretaceous rocks of the region, and is therefore almost certainly older. In lithology the inlier agrees well with the Permian rocks west of Bejah Hill, with which, therefore, it is identified.

The nearest outcrops of Jurassic rocks, at Runton Range, are coarser grained, more friable, and contain fragments of schist and granite.

At least two other rock units occur at Woolnough Hills, a dolomite, and a gypsum rock.

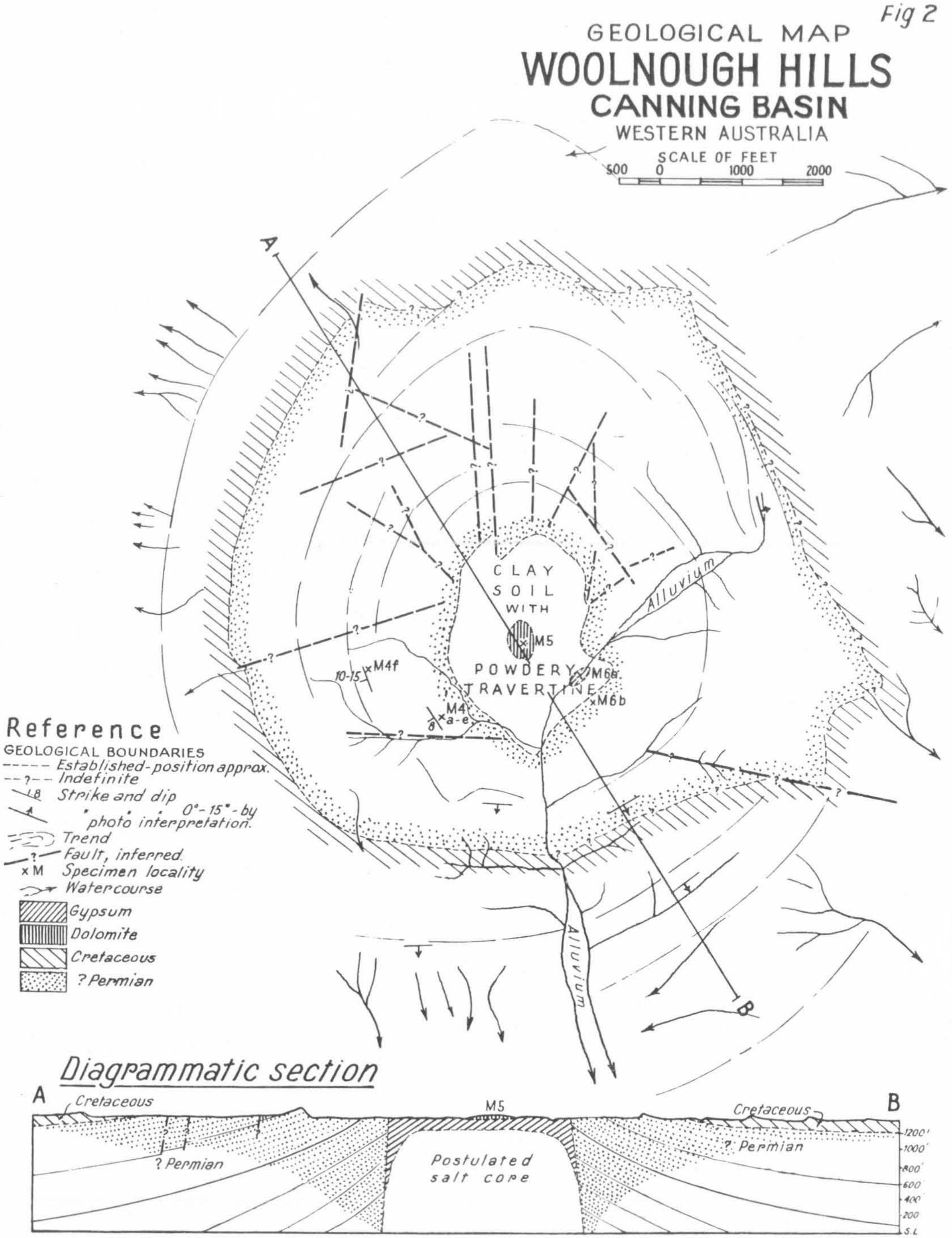


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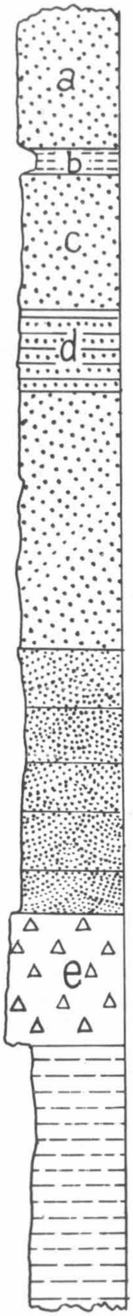
Figure 3.—Vertical air-photograph of Woolnough Hills. (*By courtesy of R.A.A.F.*)

FIGURE 4

STRATIGRAPHICAL SECTION THROUGH PROBABLE PERMIAN SEDIMENTS(M4a-e)



SANDSTONE, hard, massive in beds 2' thick, white, well sorted, medium grained, with occasional quartz pebbles 3mm.across, siliceous cement.

SILTSTONE, well bedded, poorly sorted, hard, white.

SANDSTONE, massive, poorly sorted, with quartz and quartzite fragments up to 4mm.across.

SANDSTONE, finer grained than c, well bedded (beds 3" thick), well sorted, occasional grains 1mm.across, but rest finer.

SANDSTONE, similar to d, but more massive.

SANDSTONE, beds 1' - 2' thick, current bedded, moderately well sorted, white and pink, partly silicified, coarse, quartz grains up to 3mm.across.

BRECCIA, angular fragments of grey and yellow siltstone, dark quartz, and sandstone, up to 1" across.

SILTSTONE, beds massive to finely laminated, fine, light-brown to grey, hard, partly silicified.

Exposed base.

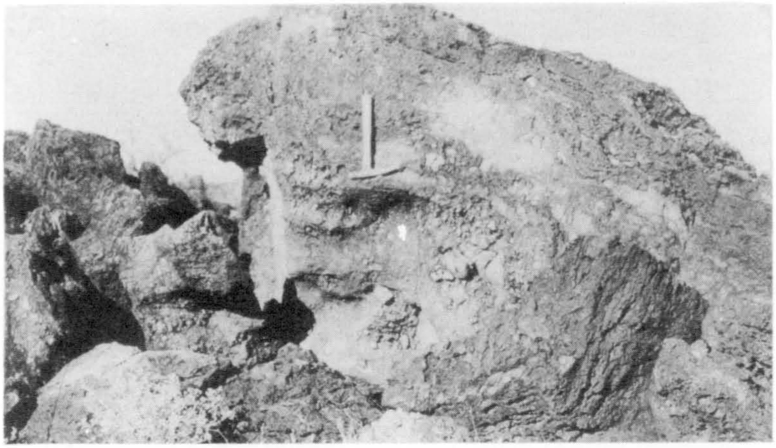


Figure 5.—Folded and brecciated dolomite (M5) in central mound at Woolnough Hills.

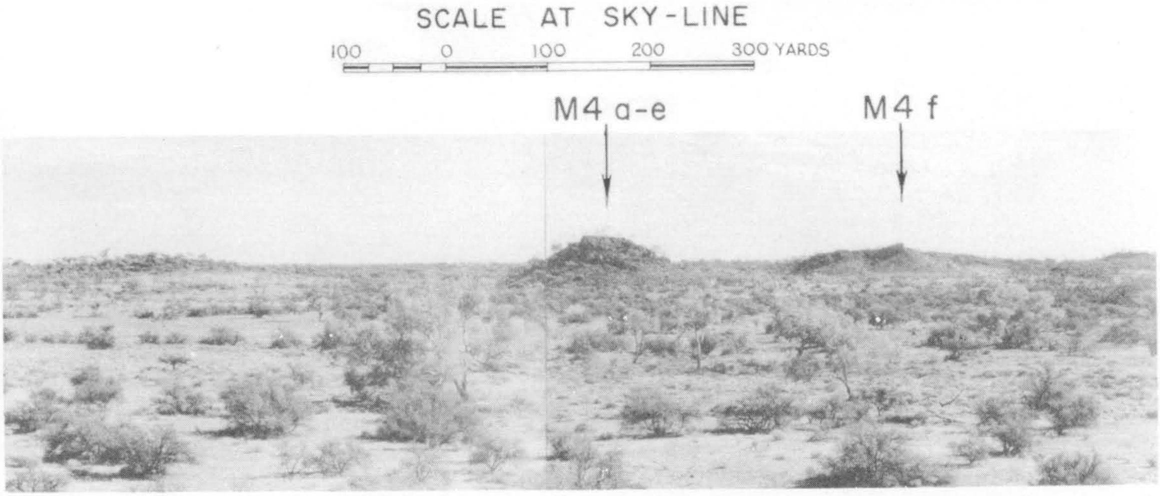


Figure 6.—Panoramic view from centre of dome of south-western quadrant of Woolnough Hills.

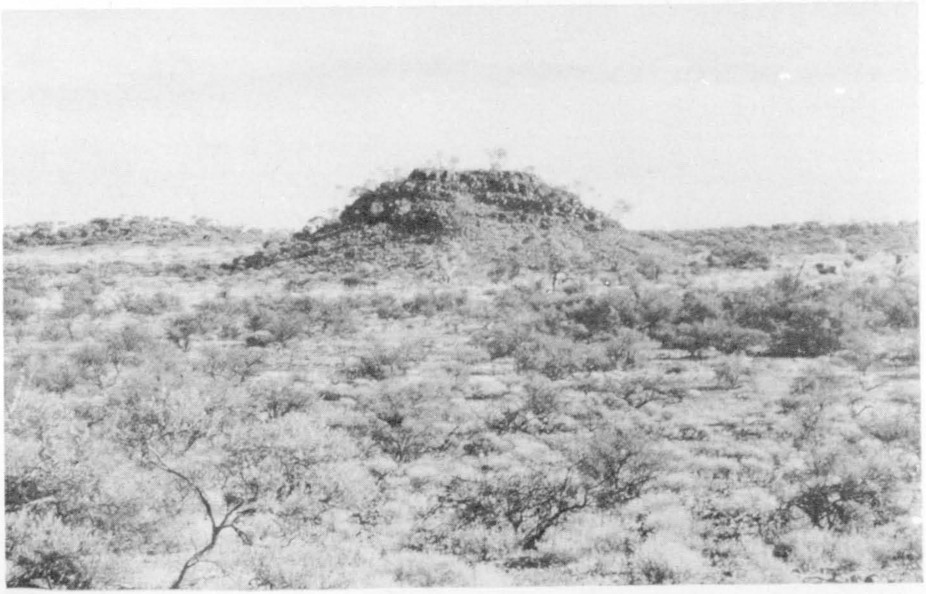
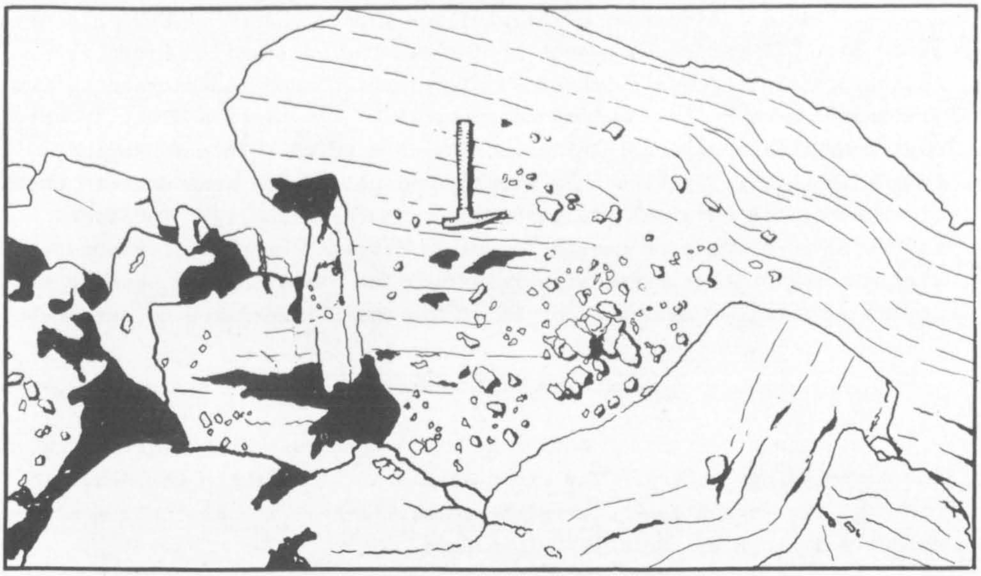


Figure 7.—View looking south at conical hill (M4a-e) of probable Permian sediments.

Figure 8.—Line drawing of Figure 5.



Dolomite is exposed in a hillock 15 feet high within the central mound of the structure (M5, figure 2). The hillock consists of several blocks, the largest of which is 5 feet high and 6 feet across (figure 5). Recent or sub-Recent weathering has introduced vein-fillings of siliceous ironstone, but the well-banded, strongly brecciated structure of the dolomite is still preserved. In the right-hand side of the larger block shown in figure 5, the banding is crenulated along incipient shears. The banding in the rest of the block is not folded. There is nothing to indicate whether the banding is original bedding or subsequent shearing. Brecciation is intense, and the breccia fragments range in size from 3 feet across (the angular block seen in the lower right-hand corner of figure 5) to half an inch. The banding of this block lies at right-angles to that of the main block.

A deeply weathered specimen consists of

41.7% $MgCO_3$
38.4% $CaCO_3$
14.1% insoluble in 1 N HCl

Polished surfaces of the dolomite are blue-grey. The rock has a granoblastic texture of dolomite anhedra. Grain diameters range from 0.005 to 0.03mm., with average diameter 0.015mm. In places, thin veins of calcite and fine-grained quartz, lined with an unidentified botryoidal mineral (possibly gypsum) with R.I. less than that of balsam, cross the dolomite.

An isolated area of crystalline gypsum occurs at M6a in a dry creek bed, 250 yards south-east of the central, dolomitic outcrop. Polished surfaces show a schistose structure. Under the microscope the grains are seen to be 2 to 5mm. long, and 1 to 4 times as long as broad. Grains are aligned parallel in finer-grained areas. Interfingering, optically parallel grains show strain extinction, and some contain bubbles of unidentified material elongated along the schistosity. Accessory minerals, consisting of quartz, possible detrital chlorite, an unidentified mineral of high refractive index and low birefringence, and argillaceous material, form less than 1% of the rock. There are no carbonates.

STRUCTURE OF WOOLNOUGH HILLS

The structure of Woolnough Hills contrasts sharply with that of the surrounding country. The steepest dip in the Permian and Mesozoic rocks of the region is 2°, without visible trend: the steepest measured dip at Woolnough Hills is 15°, in a dome.

As the section shows (figure 2), the structure is a dissected dome of Cretaceous and probable Permian rocks with a postulated core of rock salt capped by outcropping dolomite and gypsum. In other words, the postulated structure is a salt dome. Topographically, the dome is expressed as an inner discontinuous ring of low hills (figures 3 and 6), composed of probable Permian rocks, up to 50 feet high and 4,500 feet in diameter, enclosing a saucer-shaped depression, covered with rubble, clay soil, and powdery travertine, dotted with low rises, and with a mound at the centre. In the southern part, two outer arcs of low-dipping Cretaceous cuestas are separated from each other, and from the ring of inner hills, by dry streams which follow the strike. Drainage is lightly impressed except at the southern part of the structure where shallow watercourses of the inner basin unite into a trunk which cuts radially across the ring of hills and the two arcs of cuestas. All other watercourses arise at the periphery of the inner ring of hills and flow radially outwards over Cretaceous rocks. The elevation (1,375 feet) of the central mound is the same as that of the country surrounding the structure.

Two measurements of dip were observed in the field: 10° - 15° at M4f (figure 2) and 8° at M4a-e. The other dips shown on figure 2 were interpreted from air photographs. All rocks dip outwards, except the dolomite and gypsum, which have no consistent dips. The ring of Permian hills is almost perfectly circular, but the group of Cretaceous cuestas has an oval outline, with long axis north-south. This oval area of disturbed strata is 2.2 miles long and 1.8 miles wide. Outside this oval, the Cretaceous rocks are horizontal.

Numerous small faults, denoted by short displacements of strike, have been interpreted from the air photographs; most of them are marked by watercourses and lines of trees and shrubs, and most are radial. All but two of the fault traces are confined to the area of probable Permian rocks, and most are concentrated in the northern half of the dome. The traces of faults were not examined in the field.

The single Bouguer gravity measurement at the dome does not differ appreciably from measurements made at 5-mile intervals in the area to the north.

ORIGIN OF THE DOME

Two lines of argument indicate that the dome was formed by an intrusion of salt.

(a) The structure, size and topography of the dome agree with descriptions of American Gulf Coast salt domes, among which the Butler or West Point Salt Dome of Texas, recognised as 'one of the most symmetrical and best defined, both geologically and topographically, of the North American salt domes' (DeGolyer, 1919, p.647), is the closest. According to DeGolyer (p.651), the West Point Dome 'topographically ....consists essentially of an almost circular mound surrounded by a ring-shaped valley, and this in turn is bounded on its outer margin by high hills having steep faces toward the valley and long dip slopes away from it. This topography is so expressive that one would be justified in classifying this as a salt dome on the basis of topographic evidence alone'. Powers (1920) estimates the central salt core of the dome to be circular in plan and 6,000 feet in diameter, the diameter of the area of disturbed strata surrounding the core about 2½ miles, and the minimum amount of uplift at the centre of the dome 1,200 feet. Comparative estimates of the postulated Woolnough Hills salt dome are:

diameter of core	2,200 feet
diameter of area of disturbed strata	2 miles
minimum amount of uplift at centre of dome	1,000 feet

The main differences between the West Point Salt Dome and the Woolnough Hills structure are:

much wider core in West Point Dome;
steeper dips around periphery of West Point Dome (25°-80°).

These differences are well shown by a comparison of hypothetical sections of the two domes (figure 2 of this paper and figure 2 of Powers, 1920, p.130). In the West Point Dome, the salt is a few hundred feet beneath the centre, and is covered by a thin discontinuous cap of limestone. 'The salt core and cap rock are probably overlain by sand and clay to which no age can be assigned'.

(b) The occurrence of dolomite and gypsum within the central mound of the dome supports the postulate of a salt dome. The dolomite and gypsum may be:

(1) Superficial depcsits of Recent or sub-Recent age. The brecciation of the dclomite, and the flowage of the gypsum rule out this theory.

(2) The lowest exposed parts of a conformable sedimentary succession. Gypsum occurs in the Noonkanbah Formation, anhydrite and dolomite in the Anderson Formation, and dclomite in the Devonian and Ordovician successions of the Fitzroy Basin. Dolomite occurs in the Upper Proterozoic rocks along the margin of the Canning Basin. This theory also fails to account for the localized brecciation and shearing in the dolomite and gypsum.

(3) The surface of an inlying hill of pre-Permian rocks. (See p.111, for a consideration of the theory that the Woolnough Hills dome developed over a buried hill).

(4) Remnants of deep-seated beds rafted upwards by an intrusive salt plug. In possible support of this (as opposed to 5 below) is the fine lamination (laminae less than 1mm.thick) of one of the dolomite samples,and the coarser banding seen at the outcrop (figure 5), both of which may represent normal sedimentary bedding.

(5) The insoluble residue of the upper, dissolved part of a salt plug. Gypsum, as the hydration product of anhydrite, is a characteristic constituent of cap rock of practically all salt domes. Its form in cap rocks is described by Taylor (1938, p.76): 'Immediately after the completion of hydration, the gypsum consists of many small interlocking crystals that retain the outlines of the replaced anhydrite grains....... These small crystals gradually coalesce to form large irregularly interlocking crystals, with relatively large areas of the same optical orientation where shear planes are closely adjacent'. This fits the description of the gypsum from Woolnough Hills (figure 9a and b).

Figure 9(a).

Sample M6a X nicols, x20

Interfingering elongated grains of gypsum.

Figure 9(b).

Sample M6a X nicols, x20

Small cross-shear in schistose gypsum.

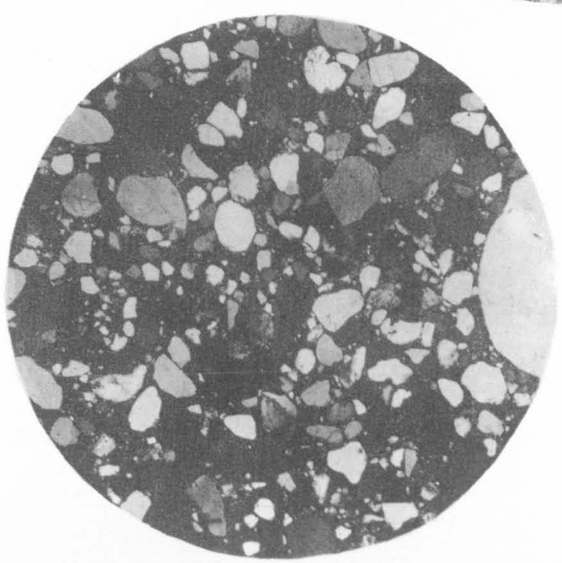


Figure 10.

Sample M4f X nicols, x20

Subrounded grains in probable Permian argillaceous quartz sandstone.

Calcite is the main carbonate in cap rock, but, as Taylor (1938, p.92) has noted, 'the less common minerals of the residues, particularly the dolomite and quartz, are locally concentrated along some of the narrow bands that show the effect of shearing'. This fits the description of the dolomite from Woolnough Hills. According to this theory, the banding in the dolomite is caused by shearing. If the unidentified botryoidal mineral found lining quartz veins in the dolomite is gypsum, as its few observable characters suggest, this would support the residue theory. To quote once again from Taylor (1938, p.59): 'Cap rock is a very heterogenous mass, particularly in its upper portion, that has been subjected to intensive faulting and brecciation. High-angle shearing, and the incorporation of breccia fragments from the surrounding sediments and from the overlying parts of the cap rock, characterize the calcite cap rock in particular'.

ALTERNATIVE THEORIES

IGNEOUS THEORY

Laccolith or stock intrusion.

Domes produced by the intrusion of laccoliths or stocks have been well known since Gilbert's description of the Henry Mountains of Utah. These and other examples are readily identified as laccolithic domes because they have been sufficiently dissected to expose the central core of igneous rock. Such a structure which has not been sufficiently dissected to reveal the igneous core might resemble the Woolnough Hills dome in size and shape, but the absence of any signs of metamorphism, and failure to account for the occurrence of dolomite and gypsum, must rule out this theory.

Cryptovolcanic Structure.

A cryptovolcanic structure is thought to be produced by the sudden release of volcanic gases at depth. Characteristic features, as summarized by Thornbury (1954, p.212), are: 'a nearly circular outline, a central uplifted portion which is usually marked by pronounced faulting; shattering and brecciation; and an absence of exposure of igneous rocks. A typical cryptovolcanic dome is two to three miles in diameter'. This theory also fails to explain the occurrence of dolomite and gypsum at Woolnough Hills.

No structures comparable with the Woolnough Hills dome, even on a smaller scale, are associated with intrusions of Fitzroy Lamproite (Guppy et al., 1958, p.71) in the Permian areas of the Fitzroy Basin.

Buried Hill Theory.

A postulated hill over which the dome sediments were draped would have the following features:

(a) shape and size: obtuse, conical, with relief of at least 1,000 feet;

(b) composition: brecciated sedimentary rocks, including gypsum rock and dolomite, at least at top of hill;

(c) in view of the dips as high as 15° in the flanking sediments, the exhumed hill of resistant rock should stand high above present plain level;

(d) dolomite fragments should be present in the flanking sediments;

(e) slump structures in flanking sediments.

None of these features is found at Woolnough Hills: no dolomite is found in the 'flanking' sediments, which are not slumped; the core of the dome is topographically lower than the 'flanking' sediments; and a conical hill 1,000 feet high is not likely to form by the erosion of sedimentary rocks including brecciated dolomite and gypsum.

Lateral Crustal Deformation.

Lateral crustal deformation fails to explain the isolated occurrence of the dome within a region of horizontal, undisturbed strata.

AGE OF THE DOME

The age of the dome cannot be estimated exactly. The youngest rocks involved in the domal folding are Cretaceous, probably Lower Cretaceous. The Permian and Cretaceous rocks are probably disconformable and it is inferred that all significant folding and subsequent erosion of the dome took place after the Cretaceous. The upper age limit of the folding must be inferred from an estimate of the time required to form the dome and reduce it by erosion to its present topography. On these grounds, an estimate of late Tertiary could be made.

AGE OF POSTULATED SALT BED

The age of the postulated 'mother' salt bed must be Permian or older. The only known evaporites in the Palaeozoic succession of the Canning Basin occur in the Anderson Formation (Carboniferous) penetrated in Wapet Grant Range Bore No.1 (McWhae et al., 1958, p.50). Incrustations of salt on relatively fresh faces of Permian outcrops are common in the north-eastern part of the Basin. In the Basin, salt is concentrated in salt lakes, and numerous bores and wells produce salty water. All these surface occurrences may be attributed to salt occluded in normal marine sediments.

CONCLUSIONS

Of the several possible theories of origin of the Woolnough Hills dome, only one accounts for all the observed features. This is the theory that a plug of rock salt rose from a deep-seated source of bedded rock salt to form a salt dome. Three economic deposits are associated with salt domes: petroleum, sulphur, and rock salt. None of these deposits would be expected to appear at the surface and only by drilling could they be detected. Only a minority of the known, tested salt domes have yielded either sulphur or petroleum, and fewer still have yielded both.

ACKNOWLEDGMENTS

Photographs of features in the Woolnough Hills area were taken by B.H. Stinear. The air photograph is reproduced by courtesy of the R.A.A.F.

Petrographical information of the samples was supplied by W.B. Dallwitz.

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CORALS FROM THE MERLINLEIGH SANDSTONE OF THE CARNARVON BASIN, WESTERN AUSTRALIA.

by

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This paper contains the description of a small collection of corals made by geologists of the Bureau of Mineral Resources during 1952. The Merlinleigh Sandstone (Teichert 1950, Condon 1954) consists of 50 feet or less of quartz sandstone unconformably overlying Permian and Cretaceous rocks in the Carnarvon Basin of Western Australia.

Teichert referred the formation to the Miocene on the basis of the presence of Aturia clarkei Teichert. However, in South Australia, this species occurs in the Tortachilla Limestone, which conformably underlies the Upper Eocene Blanche Point Marl (Glaessner, 1955). Moreover, Brunnschweiler and Dickins regard the age of the shelly fauna of the Merlinleigh Sandstone as late Middle Eocene (personal communication from Dr.Brunnschweiler). Although the corals have little stratigraphic value, they appear to be younger than this. Cyphastrea occurs widely throughout the Tertiary of the East Indies, but nowhere earlier than the Lower Miocene (e_5), while Duncanopsammia axifuga is known only from living reefs of northern Australia.

I am indebted to Professor J.W. Wells and Dr.Dorothy Hill for their advice on all aspects concerning this work. The specimens are from the Commonwealth Palaeontological Collection.

SYSTEMATIC DESCRIPTIONS

Class	HYDROZOA	
Family	MILLEPORIDAE	
Genus	MILLEPORA	Linn 1758

MILLEPORA sp.
(Plate 1, Figure 7)

A single specimen, C.P.C. 2280, from a locality 0.5 ml. north-east of Merlinleigh Homestead, 0.3 ml. south of an old anandoned well, belongs to this genus, which is found in Tertiary rocks elsewhere.

Class	ANTHOZOA	
Family	FAVIIDAE	
Subfamily	MONTASTREINAE	Vaughan & Wells 1943
Genus	CYPHASTREA	Edwards & Haime 1848

CYPHASTREA MINIMA sp. nov.

(Plate 1, Figures 1-4)

Holotype: C.P.C. 2281 from the Merlinleigh Sandstone of the Carnarvon Basin, Western Australia, 0.5 ml. north east of Merlinleigh Homestead, 0.3 ml. south of an old abandoned well.

Paratypes: C.P.C. 2282, 2283, 2284, and 2285 from the same locality.

Diagnosis: Cyphastrea with corallites 1 mm. in diameter and with two unequal cycles of septa.

Description: The corallum is nodular, with the corallites evenly distributed over the surface. They are approximately circular in cross-section, with a diameter of 1 mm. and thin walls (0.1 mm. or less). The distance between corallites is rarely more than 0.75 mm. and they may touch one another, here and there enough to cause flattenings of their walls.

There are only two cycles of septa (6/6). Those of the first reach almost to the axis, but the second cycle septa are rarely more than a third of the radius in length. Slightly downward-turned trabecular spines project from their sides and inner edges. In contrast to other species of the genus, those of the first cycle septa are not continued to form a parietal columella. The costae, which are all about the same length, project mostly 0.1 or 0.2 mm. beyond the walls. They are not continuous with those of neighbouring corallites. The endotheca consists of tabular dissepiments extending right across the corallites.

The exotheca is similar to that in other species of Cyphastrea, and consists of tabular and blister-like dissepiments from the surfaces of which rise long tapering spines. The tabular dissepiments are the more numerous.

Remarks: Although the corallites rarely touch one another in the holotype, in other specimens, notably C.P.C. 2282, many of them are in close contact, but always remain within the limits described above. The nature of the calices is unknown, since in no specimen is the original upper surface preserved.

Discussion: Until now, the earliest record of Cyphastrea was from the early Miocene (e_5) of Java in which five species are known (Osberger, 1954, 1955). Gerth (1923, 1925, 1933), Umbgrove (1939), and Wells (1954), have recorded some of these and two others from Miocene rocks elsewhere in the East Indies. Only one of these species (C.microphthalma) is definitely known in the Pliocene, during which two more appeared (Felix, 1920; Gerth 1923, 1925; and Umbgrove 1942, 1946a and b). These three are included in the several species found in present day reefs of the

Indo-Pacific region (Matthai 1914, 1924; Vaughan, 1918; Faustino, 1927; and Yabe, Sugiyama & Eguchi 1936).

Most of the species, e.g. C.monticulifera, C.chalcidicum, C.rembangensis, have small corallites, 1.5 - 2.5 mm. in diameter, with three cycles of septa, those of the first and second reaching the columella. The third cycle in some of these species is incomplete, when usually ten septa persist to the axis. However, some of the Miocene forms have large corallites with higher septal development; for example, those of C.tubifera, which are 4-6 mms. in diameter, sometimes possess an incomplete fourth cycle and as many as 14 septa reaching the columella. Moreover, the septal development in different coralla varies according to the size of the mature corallites - so much so that Gerth (1923) placed the larger ones in another species.

C. minima, the smallest known Cyphastrea, may represent the opposite end of this series. The absence of a columella is probably a consequence of the withdrawal of even the primary septa. Although this does not give any real indication of the place of C.minima in the phylogeny of the genus, especially since nothing is known of other hexacoral faunas of Western Australia, these characters are interesting in the light of the apparent age of the species.

Family DENDROPHYLLIIDAE Gray 1847
Genus DUNCANOPSAMMIA Wells 1936

DUNCANOPSAMMIA AXIFUGA (Edwards & Haime 1848)
(Plate 1, Figure 5)

D.axifuga is represented by two weathered fragments, C.P.C.2286 and 2287, from the same locality as the specimens described above. They appear to be free branches of a pedunculate flat-topped colony like that figured by Wells (1936, pl.VIII, figs. 1 and 2). The corallites are very similar to Recent specimens of D.axifuga identified by the originator of the genus. The species was previously known only from the deeper parts of present-day reefs of Northern Australia.

?DUNCANOPSAMMIA sp. nov.
(Plate 1, Figures 6a, 6b)

Included in the collection is a crateriform corallum, C.P.C. 2288, from a mesa one mile east of Merlinleigh Homestead. It is about 6 cm. broad, with irregularly distributed clumps of projecting corallites 4-5 mm. in diameter. The form of the corallum and the echinate perithecal structure is typical of Turbinaria. However, the septa are arranged according to the Pourtales plan, which is found only in young calices of species of that genus. This combination in a dendrophylliid of Pourtales septal arrangement and a pedunculate corallum with peritheca consisting of rows of crispate granulations is known only in Duncanopsammia. The collection of more material will probably establish the validity of this suggested relation.

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EXPLANATION OF PLATE

Fig. 1 *Cyphastrea minima* sp. nov. Holotype, CPC. 2281; 2/3 nat. size.

Fig. 2 *Cyphastrea minima* Holotype, CPC.2281: transverse section X 5.

Fig. 3 *Cyphastrea minima* CPC.2285; vertical section X 5.

Fig. 4 *Cyphastrea Minima* CPC.2282; nat. size.

Fig. 5 *Duncanopsammia axifuga* (Edwards & Haime 1848). Nos. 2286 and 2287; nat. size.

Fig. 6 ?*Duncanopsammia* sp. nov., CPC. 2288 (a) lateral view; (b) vertical view; both nat.size.

Fig. 7 *Millepora* sp., CPC. 2280; transverse section X 10.

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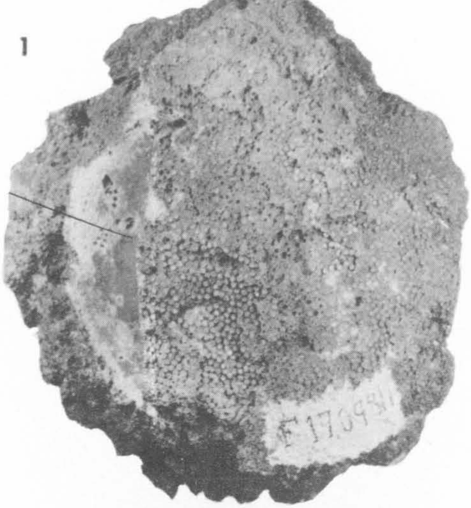

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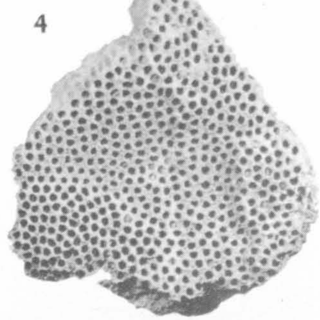

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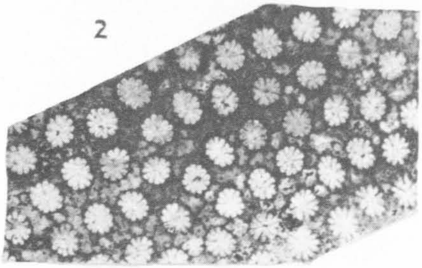

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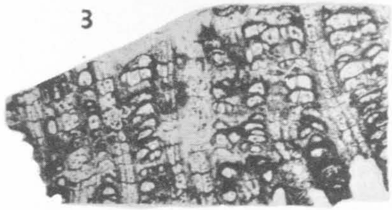

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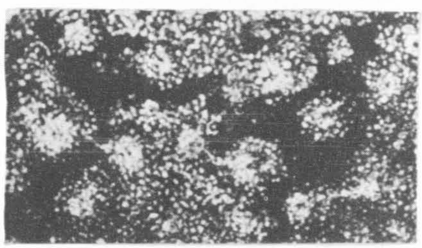

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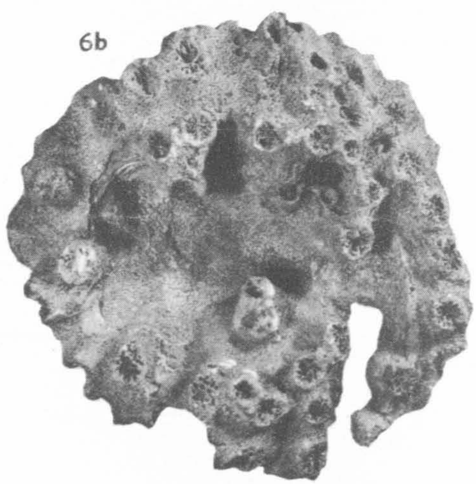

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