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GEOLOGY OF THE SYDNEY BASIN—A REVIEW

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SUMMARY

The Sydney Basin extends for 380 km along the east coast of New South Wales south of latitude 32°S, and has an onshore area of about 36 000 km^2. About 4800 m of Permian and Triassic sedimentary rocks are preserved in the basin which lies between the New England and Lachlan Fold Belts.

In the west and south the Sydney Basin sequence rests unconformably on lower and middle Palaeozoic rocks of the Lachlan Fold Belt, while in the north and northeast the sequence rests on Carboniferous rocks of the New England Fold Belt, although the Sydney Basin succession is partly coeval with the sequence in the fold belt.

The sequence in the Sydney Basin has been subdivided into 14 basin-wide units, called 'intervals', each of which consists of a group of rock units laid down during approximately the same time-interval. Broadly speaking the sedimentary rocks were deposited during a fluctuating marine advance followed by a fluctuating marine regression. The oldest rocks include valley-fill conglomerate, poorly stratified clastics, and small seams of coal laid down in and around a shallow sea that flooded the area between the New England mobile zone and the older craton (Lachlan Fold Belt). The sediment derived from the craton was predominantly glacigene, while the detritus from New England was mainly derived from extensive contemporaneous lava flows and pyroclastics. During the marine advance the silts and fine sands of the Branxton Formation, Wandrawandian Siltstone, Mulbring Siltstone, and Berry Formation were laid down, while during the temporary regressions the Greta Coal Measures/Snapper Point Formation and the Muree Sandstone Member/Nowra Sandstone were deposited. The advance culminated during the Kazanian, and was followed by a major regression during which extensive coal swamps were formed in the complex marginal environment behind the retreating sea (Illawarra Coal Measures and correlatives). This retreat was interrupted by two minor transgressions during which the Kulnura Marine Tongue and the Dempsey Beds and correlatives were deposited.

Towards the close of the Permian, the coal swamps were destroyed by the Hunter-Bowen orogenic movements, which perhaps coincided with a marked change in climate. The period of delta-prograding which followed lasted till the end of recorded sedimentation in the Anisian. During this period very little coal was formed, and there were several temporary incursions of the sea. The deltaic deposits of Narrabeen and Wianamatta Groups are separated by the Hawkesbury Sandstone which was laid down in tidal channels and offshore bars.

The three main periods of igneous activity in the Sydney Basin may have been associated with the development of the Permo-Carboniferous New England Fold Belt, the development of the Mesozoic New Zealand Fold Belt, and the formation of the Tasman Rift Valley and Tasman Sea in the Cretaceous and Tertiary.

Earth movements and plutonic activity in the New England marginal mobile zone caused folding and faulting in the Hunter Valley, where there are several angular unconformities on the Lochinvar Dome. The north-northeasterly rifting which occurred later in the Mesozoic cuts obliquely through the fold belts and was the precursor to the development of the Tasman Sea by sea-floor spreading. The present steep continental slope marks the general line of this rifting. During the upper Cainozoic the Kosciusko Movement produced topographic plateaux and basins within the Sydney Basin.

Gaseous hydrocarbons have been found in small quantities in the Sydney Basin, but all the potential reservoir rocks encountered have been too impermeable to give significant production. For the same reason there are limited supplies only of groundwater. Oil shale, associated with the coal seams, has been mined as a source of petroleum.

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INTRODUCTION

The study of the Sydney Basin by the Sedimentary Basins Study Group of the Petroleum Exploration Branch of the Australian Bureau of Mineral Resources was undertaken in co-operation with the New South Wales Department of Mines, who prepared a 1:500 000 geological map (Pl. 1). The study has required constant exchange of ideas and information with petroleum exploration companies and the Department of Mines. In addition to the authors of this Bulletin the following members of the Sedimentary Basins Study Group since late 1966 have contributed to the study: D. J. Forman, M. A. Reynolds, K. G. Smith, R. Bryan, A. R. Jensen, P. J. Alcock, P. J. Hawkins, R. B. P. Pitt, S. Ozimic, J. I. Raine, K. Rixon, and B. G. West.

The study involved detailed petrological examination of cores and cuttings from 15 petroleum exploration wells and stratigraphic holes (Alcock, 1968a,b; Hawkins & Ozimic, 1967; Jensen & Bryan, 1969; Mayne, 1968, 1969; Nicholas, 1968, 1969; Ozimic, 1968, 1969, 1971; Pitt, 1968; Raine, 1969), on which the basinwide correlation of rock units (Intervals 1-14, Pls 2-4) is based, and a review of the literature (Mayne et al., 1972). Our conclusions regarding the development of the basin and its petroleum potential are presented in this Bulletin.

The geophysical compilations include a 1:500 000 map showing total magnetic intensity contours and depth to magnetic basement contours and a 1:500 000 Bouguer gravity anomaly map. Many of the seismic surveys were re-processed in the BMR playback centre, and all suitable onshore record sections were reduced photographically to a vertical scale of about 1 second to 3 cm. After conversion from depth to time using an appropriate velocity function all relevant geological boundaries, from outcrop and wells, were plotted onto the seismic sections, and traced between and beyond control points. Isochron maps were then prepared for a number of geological boundaries. The isochron maps were converted to structure contour maps using several velocity functions throughout the area.

The stratigraphy and geological history are described with reference to isopach, sand-shale ratio, and environment maps and the structure is illustrated by structure contour maps and maps showing the depth to magnetic basement and Bouguer gravity anomalies. The history of petroleum exploration and future prospects are discussed.

Definition of the Sydney Basin

The Sydney Basin (Fig. 1) is filled with a sequence of alternating marine and non-marine Permian rocks and mainly non-marine Triassic rocks with a thickness of about 4800 m, ranging up to about 5900 m in the north. It covers an area of about 36 000 km^2 onshore and about 16 000 km^2 offshore to the edge of the continental shelf.

In the west the sequence rests unconformably on rocks of the Lachlan Fold Belt, but to the northeast it is bounded by the Hunter Thrust, and to the east probably by the continental slope. It is partly coeval with the sequence in the New England Fold Belt to the northeast, and is partly separated by a basement ridge from the Permo-Jurassic rocks of the Oxley Basin to the northwest. Part of the northwestern area described in this Bulletin lies in the Oxley Basin.

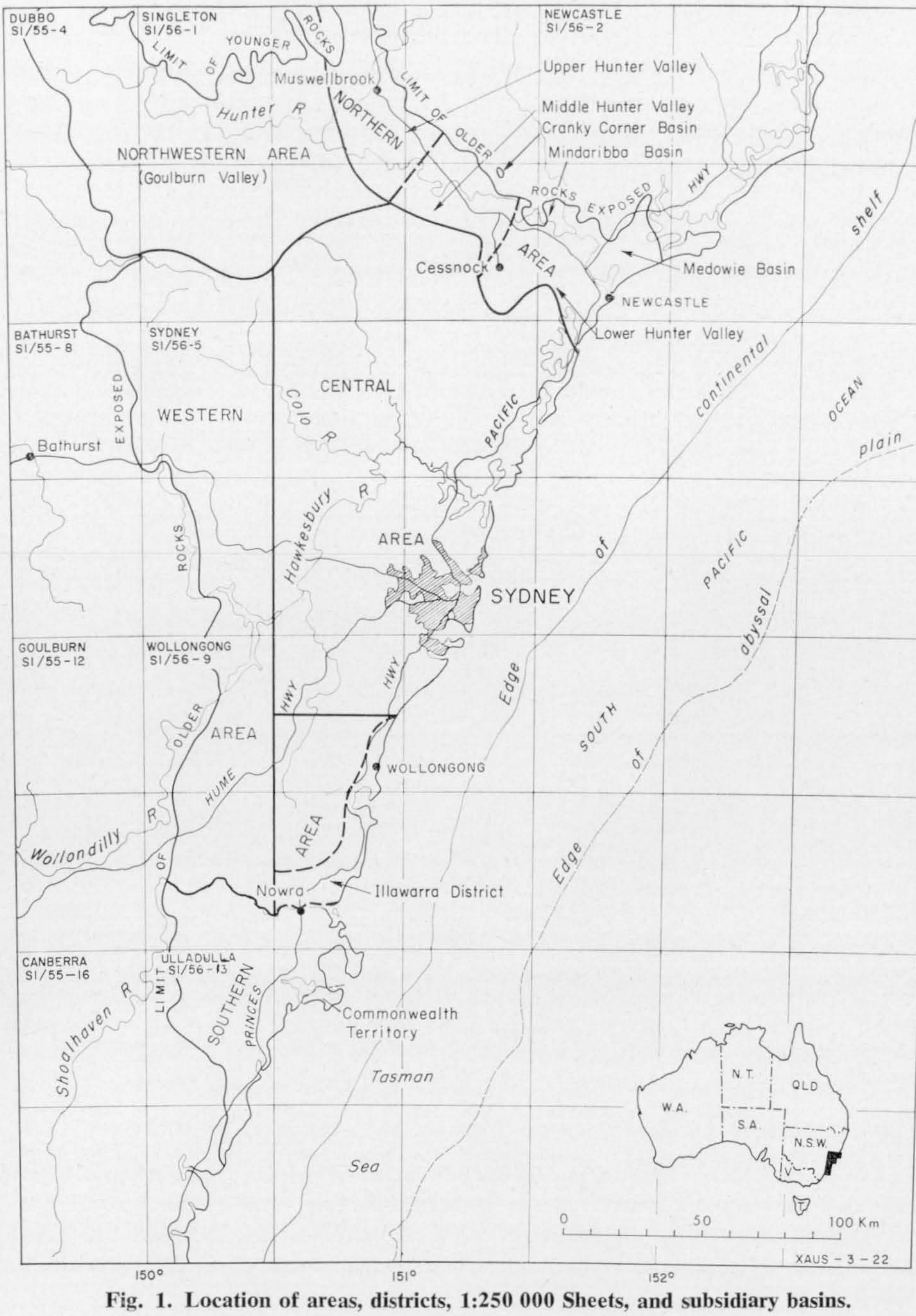

Fig. 1. Location of areas, districts, 1:250 000 Sheets, and subsidiary basins.

The Geological Survey of New South Wales (Bembrick et al., 1973) recognizes the Sydney-Bowen Structural Basin, which is divided into northern and southern parts by a structural high near Narrabri. The southern part is subdivided by the Mount Coricudgy Anticline into the Gunnedah Basin in the north and the Sydney Basin in the south, which is coextensive with the 'Sydney Basin' as defined in this Bulletin.

Location of areas, districts, 1:250 000 Sheets, and subsidiary basins

For convenience of description the Sydney Basin has been informally subdivided into five areas—southern, western, central, northwestern, and northern (Fig. 1). The northwestern and northern areas include parts of the Goulburn Valley and the Hunter Valley respectively. The Hunter Valley is subdivided into upper, middle, and lower parts. The Illawarra district is a subdivision within the southern area.

In addition there are two subsidiary basins, the Mindaribba Basin and the Medowie Basin (Packham, 1969), and an outlier named the Cranky Corner Basin (Packham, 1969) in the northern area.

Figure 1 also shows the 1:250 000 Sheet areas.

Coalfields and coal districts

The Sydney Basin contains large reserves of coal, and has been subdivided into six coalfields—the Northern, Western, Central, Southwestern, Southern, and Clyde River fields (Fig. 2); the Northern Coalfield has been subdivided into five Coal Districts. Coal has been produced from all except the Clyde Coalfield, although the Central Coalfield is no longer producing.

Correlation

The Permian rocks crop out almost all the way around the basin, and three different nomenclatures have evolved (Fig. 3). A fairly complete sequence of Permian and Triassic rocks is exposed in the west and south. In the north the Triassic rocks have been removed by erosion, but a complete sequence of the Permian rocks is exposed. Only Triassic rocks crop out in the central area, but the Upper and Lower Permian rocks have been penetrated by the deeper petroleum exploration wells. The names used for the Lower Permian stratigraphic units in the south have also been applied to the subsurface sequence in the central area (Fig. 4).

Plates 2 to 4 and Figure 3 show the rock unit correlation that forms the basis of this basin study. Correlation of the rock units (Pls 2-4) is based on lithology, lateral continuity, order of superposition, palaeontological data, and structure, including seismic evidence. The correlation chart (Fig. 3) relates the rock units to the geological time scale based on the age of the fossils. Fourteen basinwide subdivisions (called 'intervals') with an aggregate thickness of about 4800 m (Pls 2, 3) were laid down over a period of about 80 million years.

Intervals

Basinwide subdivision of the sequence is essential to produce meaningful lithofacies, thickness, and environment maps. For this reason an operational subdivision called an 'interval' has been adopted (McKee et al., 1959). It is used as

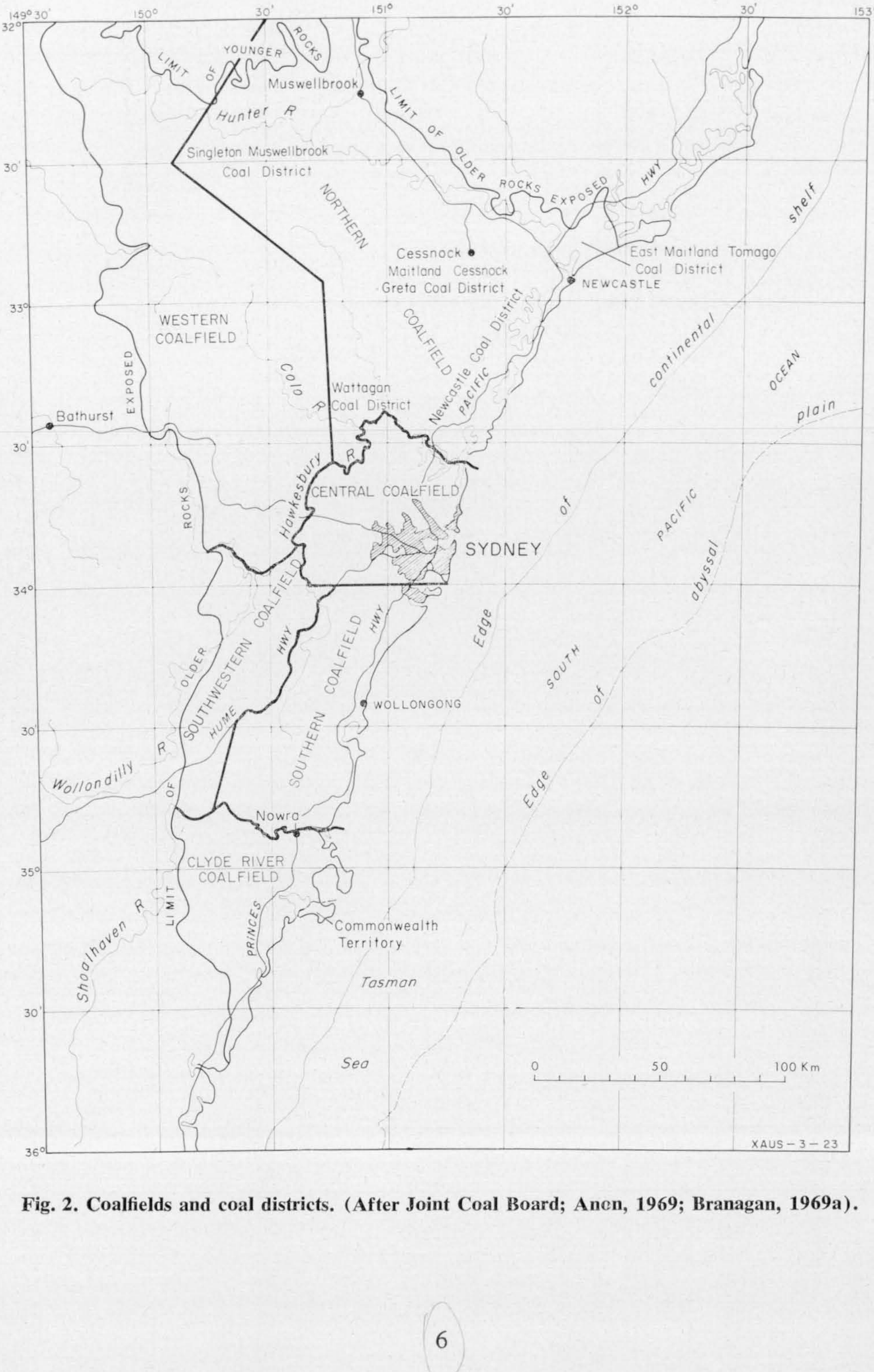

Fig. 2. Coalfields and coal districts. (After Joint Coal Board; Anon, 1969; Branagan, 1969a).

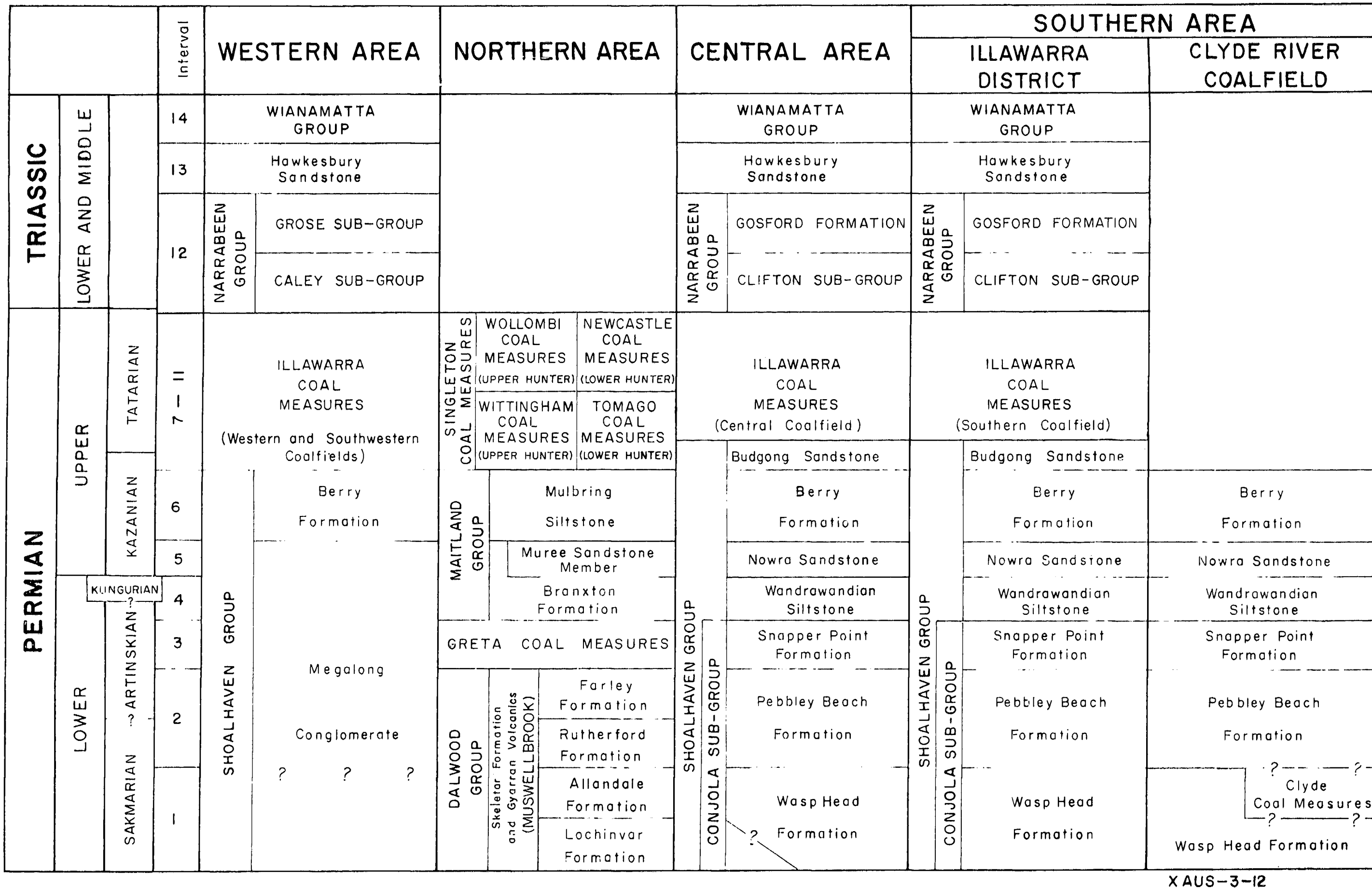

Fig. 3. Time correlation of Permo-Triassic rocks.

a purely practical and informal subdivision of the rocks into widespread units that have genetic significance appropriate to the purpose and scale of the study. The boundaries of the intervals are taken at lithological changes in the sequence, and each interval is broadly coeval. Fourteen intervals have been chosen for this study (Fig. 3): Intervals 1 to 11 are of Permian age, Interval 12 is Permo-Triassic, and Intervals 13 and 14 are Triassic.

Metric conversion

All linear measurements in the text and line drawings have been converted to the metric system. The contours on the isopach maps, which were originally plotted at 100-foot intervals, have been converted to metres. The Plates have not been changed.

Isopach maps

The interpreted original thickness of each interval is shown as far as possible beyond the margins of outcrop, but in some cases the preserved thickness is shown within the basin if beneath an unconformity in the Permo-Triassic rocks. In most cases the sediment removed by erosion beneath an unconformity has been restored.

Sand-shale ratio maps

The sand-shale ratio patterns are applied only in areas of good geological control.

The maps only show sand-shale ratios as carbonate rocks are virtually absent. Coal has been ignored in the lithofacies calculations, but is shown diagrammatically in the sections accompanying the maps. Volcanic detritus was calculated as sand or shale according to its grainsize, and the presence of significant volcanic flows is indicated by an overprint pattern. The sand-shale ratio was determined by dividing the thickness of all beds of sandstone (plus conglomerate) by the thickness of claystone, siltstone, and mudstone beds, after correction for sandy siltstone and silty sandstone. Cross-sections accompany each map to show the manner in which the sand and shale are distributed throughout the interval and to show graphically where downbuckling or upwarping was greatest. They also depict the lateral relations between various named and unnamed stratigraphic units within the interval.

Nomenclature of sedimentary rocks

The modified Wentworth-Udden scale (Lane et al., 1947) has been used for grainsize classification. The sandstone classification of Pettijohn (1957) is generally used for specific rock names, with the following modifications: (1) the term quartz greywacke is used to distinguish quartz-rich rocks (sand and gravel composed of more than 75% quartz) in which detrital matrix is prominent (15-50% total rock); (2) the term greywacke is used only where a full rock description could not be obtained in its place. Where the term greywacke is used it is not intended to imply that the rock is a turbidite.

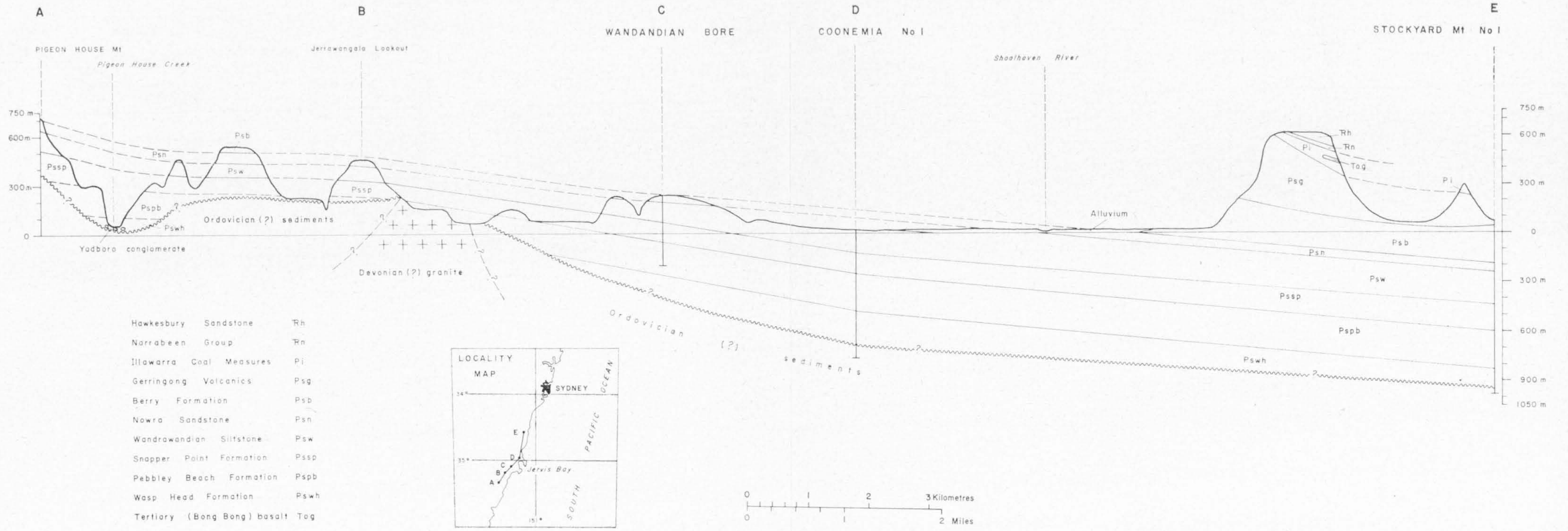

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Fig. 4. North-south section, southern area.

Palaeoenvironment maps

Maps have been constructed to show the main environments which existed during each interval. The types of environment selected are shown in Figure 5. Consideration of the changes of environment with time has led us to the conclusion, brought out in the geological history, that the environments and the sedimentary rocks deposited in them must be diachronous.

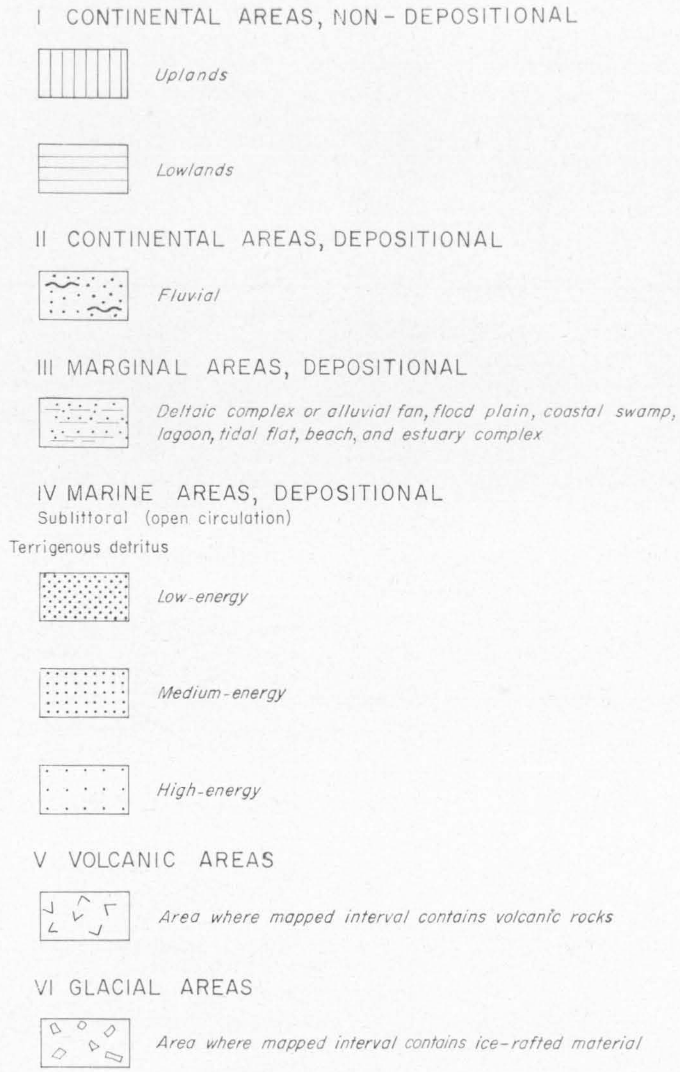

Fig. 5. Symbols used on palaeoenvironment maps.

Control points

Plate 4 shows the control used for the study, including water bores, deep exploratory holes drilled on the coalfields, petroleum exploration wells, measured sections, and seismic surveys. Each well, bore, measured section, or seismic survey is identified on the map by small and large numbers, and is briefly described and a reference given in Tables 1 and 2. The symbols used are explained in the reference on Plate 4. Petroleum exploration wells are further described in Table 4.

TABLE 1. STRATIGRAPHIC CONTROL POINTS*

Name or Location of Control Point	*Reference*
1. Ulan	Rayner (1949)
2. Martindale No. 1A	Nicholas (1969)
3. Savoy Trig. Station	Basden (1969)
4. St Heliers BMR No. 1	Reynolds (1956)
5. Jerrys Plains No. 1	Esso (1969)
6. Bayswater BMR No. 1	Bursill et al. (1952)
7. Camberwell DDH RH	Joint Coal Board (1962)
8. Glennies Creek	AOG (1966c)
9. Camberwell No. 1	AOG (1966b)
10. Loder No. 1	Nicholas (1968)
11. Sedgefield No. 1	AOG (1964b)
12. On Hunter R. 9.5 km E of Singleton	McKellar (1969)
13. Belford No. 1	Ozimic (1968)
14. In railway cutting 1.5 km W of Branxton	McKellar (1969)
15. From 0.75 km N of Greta to Branxton	McKellar (1969)
16. Cranky Corner Basin	Rattigan (1969), Osborne (1949)
17. Allandale	Osborne (1949)
18. Lochinvar	Osborne (1949)
19. Gosforth	Osborne (1949)
20. Sunwell No. 1	Rattigan (1969)
21. Farley No. 1	Anon (1960)
22. Farley	Osborne (1949)
23. East Maitland No. 1	Jensen & Bryan (1969)
24. Buttai No. 1	Dep. Min. N.S.W. (1889), David (1907)
25. Iron Bark Brush No. 2	Dep. Min. N.S.W. (1898, 1903)
26. Hexham Island bore	Dep. Min. N.S.W. (1888)
27. Dempsey Island bore	Dep. Min. N.S.W. (1884, 1885)
28. Walsh Island bore	Dep. Min. N.S.W. (1901, 1902)
29. Australian Agricultural Company's bore	David (1907)
30. Stratford-Gloucester trough	Loughnan (1954)
31. Bulahdelah-Myall Syncline	Engel (1962)
*See Plate 1	
32. Kandos	Dulhunty (1941), Branagan (1960)
33. Mellong No. 1	Mayne (1969)
34. Mt Murwin No. 1	Mayne (1968)
35. DM Doyles Creek No. 1	Stuntz (pers. comm., 1970)
36. DM Doyles Creek No. 2	Stuntz (pers. comm., 1970)
37. DM Doyles Creek No. 4	Stuntz (pers. comm., 1970)
38. DM Doyles Creek No. 5	Stuntz (pers. comm., 1970)
39. Milfield No. 1	AOG (1966c)
40. Aellalong No. 2	AOG (1966c)
41. Pokolbin to Mt View	Osborne (1949, 1950)
42. Aberdare	Jones (1939)
43. Abermain	Jones (1939)
44. Pelaw	Jones (1939)
45. Stanford Merthyr	Jones (1939)
46. Congewai	Jones (1939)
47. Barraba	Jones (1939)
48. Quarrybylong	Jones (1939)
49. Brokenback Range	McKellar (1969)
50. Mt Vincent-Quarrybylong road	McKellar (1969)
51. Heaton	Jones (1939)

TABLE 1—*Cont.*

	Name or Location of Control Point	Reference
52.	Capertee	Carne (1908, 1910)
53.	Marrangaroo No. 1	Dep. Min. N.S.W. (1884)
54.	Western State Coal Mine No. 1	Dep. Min. N.S.W. (1911)
55.	Western State Coal Mine No. 2	Dep. Min. N.S.W. (1911)
56.	Western State Coal Mine No. 4	Bryan et al. (1966)
57.	Western State Coal Mine No. 5	Bryan et al. (1966)
58.	Newnes Junction bore	Dep. Min. N.S.W. (1921)
59.	Howes Swamp No. 1	Esso (1970)
60.	Higher Macdonald No. 1	AOG (1968a)
61.	Kulnura No. 1	Ozimic (1969)
62.	Morisset No. 1	Bryan et al. (1966)
63.	Morisset No. 2	Bryan et al. (1966)
64.	Morisset No. 3	Bryan et al. (1966)
65.	Morisset No. 4	Bryan et al. (1966)
66.	Morisset No. 5	Bryan et al. (1966)
67.	Morisset No. 6	Bryan et al. (1966)
68.	Bungaree Norah bore	Dep. Min. N.S.W. (1907)
69.	Wyong (Alison No. 2) bore	Dep. Min. N.S.W. (1882, 1883)
70.	Wyee bore	Dep. Min. N.S.W. (1890, 1891)
71.	Amos No. 1	Dep. Min. N.S.W. (1882)
72.	Amos No. 2	AOG (1966c)
73.	Cams No. 4	AOG (1966c)
74.	Budgewoi No. 1	AOG (1966c)
75.	Budgewoi No. 6	Bryan et al. (1966)
76.	Budgewoi No. 4	Bryan et al. (1966)
77.	Ourimbah Creek No. 1	AOG (1966c)
78.	Terrigal Nos 1 & 1A	J. Strevens (pers. comm.)
79.	Mt Tomah	David (1902)
80.	Kurrajong Heights No. 1	Pitt (1968)
81.	Lower Portland No. 1	AOG (1968a,b)
82.	Grose River	Crook (1956)
83.	Windeyers Hawkesbury River bore	Dep. Min. N.S.W. (1910)
84.	Kedumba Creek	AOG (1960)
85.	Mulgoa No. 2	AOG (1960)
86.	Leehome No. 1	Bryan et al. (1966)
87.	Woodford No. 1	Dep. Min. N.S.W. (1888)
88.	Bedford Creek bore	Bryan et al. (1966)
89.	Berkshire Park No. 1	AOG (1968a,c)
90.	Fairfield No. 1	Bryan et al. (1966)
91.	Kenthurst No. 1	Bryan et al. (1966)
92.	Dural (East) No. 2	Bryan et al. (1966)
93.	Dural (East) No. 1	Bryan et al. (1966)
94.	Dural South No. 1	Hawkins & Ozimic (1967)
95.	Narrabeen bore	Bryan et al. (1966)
96.	Baulkham Hills No. 1	Bryan et al. (1966)
97.	Liverpool-Moorebank bore	Dep. Min. N.S.W. (1889, 1890)
98.	Balmain shafts and bore	Dep. Min. N.S.W. (1907), Bryan et al. (1966)
99.	Cremorne No. 2	Dep. Min. N.S.W. (1892, 1893)
100.	Bunnerong bore	AOG (1966c)
101.	Mt Hunter No. 1	AOG (1962d)
102.	Kirkham No. 1	Raine (1969)
103.	Badgelly No. 1	AOG (1966c)
104.	Camden No. 8	Bryan et al. (1966)
105.	Camden No. 7	Bryan et al. (1966)
106.	Camden No. 11	Bryan et al. (1966)
107.	Camden No. 3	AOG (1966c)
108.	Razorback	Lovering (1954)

TABLE 1—*Cont.*

Name or Location of Control Point	Reference
109. Woronora No. 1	Alcock (1968b)
110. Stanwell Park No. 1	Harper (1924), Joint Coal Board (1963)
111. Tylers Bargo No. 1	Harper (1924), Dep. Min. N.S.W. (1921), Joint Coal Board (1960a)
112. Yerrinbool No. 1	Harper (1924), Dep. Min. N.S.W. (1883), Joint Coal Board (1966)
113. Balmoral Hill Top bore	Harper (1924), Dep. Min. N.S.W. (1910)
114. Colo Vale No. 2A	Harper (1924), Dep. Min. N.S.W. (1884), Joint Coal Board (1960b)
115. Cataract No. 1	This Bulletin
116. National Park (State Colliery) DDH 2	Joint Coal Board (1964a)
117. Mt Kembla DDH	Joint Coal Board (1964b)
118. Mt Murray No. 1	Joint Coal Board (1951)
119. Belanglo	AOG (1966c)
120. Stockyard Mt No. 1	Alcock (1968a)
121. Broughton Head	Harper (1915)
122. Mt Cambewarra	Harper (1915)
123. Greenwell Point Nos 1 & 2	Smart (1962b)
124. BMR Wollongong No. 1	Ozimic (1971)
125. BMR Wollongong Nos 2 & 2A	Ozimic (1971)
126. Coonemia No. 1	Genoa (1969a)
127. Point Perpendicular bore	Smart (1962b)
128. Tomerong-Nerriga road	McElroy & Rose (1962)
129. 3 km from Tianjara Trig. Station	McElroy & Rose (1962)
130. Jerrawangala Lookout to point 0.75 km to NE	McElroy & Rose (1962)
131. BMR Ulladulla No. 1	Jackson (1970)
132. 2 km N of junction of Clyde River and Claydons Creek	McElroy & Rose (1962)
133. S. bank of Conjola Creek below bridge on Princes Highway	McElroy & Rose (1962)
134. 0.75 km N of Pigeon House Creek-Clyde River junction	McElroy & Rose (1962)
135. 2.5 km SE of Yadboro Creek-Clyde River junction to Pigeon House Trig. Station	McElroy & Rose (1962)
136. 3.8 km SE of Pigeon House Trig. Station	McElroy & Rose (1962)
137. Ulladulla	Dickins et al. (1969)
138. Snapper Point	Dickins et al. (1969)
139. Pebbley Beach	Dickins et al. (1969)
140. Wasp Head	Dickins et al. (1969)
141. Wandandian bore	David & Stonier (1891), Harper (1915)
142. DM Upper Colo No. 1	J. Stuntz (pers. comm.)
143. DM Howes Valley DDH 1	J. Stuntz (pers. comm.)
144. DM Cape Banks No. 1	J. Stuntz (pers. comm.)
145. DM Doyle Creek DDH 11	Britten (1972)

History of Petroleum Exploration

The Reverend W. B. Clarke, who arrived from England in 1839, is generally credited with being the first trained geologist to work in Australia. However, Berry, in 1822, was the first to record and briefly describe the strata around Batemans Bay and the newly discovered Clyde River. Clarke was the first to recognize the Sydney Basin as a geological entity, and in 1847 he predicted that the coal seams cropping out around the margins of the basin were part of a single sedimentary unit that continued at depth beneath Sydney. The occurrence of coal measures close to Sydney inspired many of the early geological investigations in the Sydney Basin, both by officers of the Geological Survey of New South Wales (established in 1855) and by individuals and mining companies. The resulting well documented observations of W. B. Clarke, F. W. Booker, J. E. Carne, T. W. E. David, L. F. Harper, L. J. Jones, H. G. Raggatt, and T. L. Willan, in particular, provided basic geological information that has been of great value in the search for petroleum. Later, the Geological Survey of New South Wales mapped various parts of the basin and compiled 1:250 000 coloured geological maps based on their own work and on information made available by mining and petroleum exploration companies and the Universities of Sydney and Newcastle. Finally, in 1969 they published a coloured 1:500 000 geological map (Pl. 1) of the whole of the Sydney Basin.

The search for coal, and its exploitation, led to the discovery, in 1885, of gas in sandstone of the Triassic Narrabeen Group in wells now known as Narrabeen No. 1 and No. 2. These and other occurrences of gas in Triassic sandstone, and emanations of gas from Permian coal measures, suggested that the Sydney Basin might contain oil or gas fields, or both, and stimulated the search for hydrocarbons. The history of this search may conveniently be divided into three periods: 1910 to 1916; 1918 to 1938; and 1953 to 1970 (Tables 3, 4). Figure 6 is a graph of petroleum drilling activity from 1910 to the end of 1970, and Figure 7 shows the location of the wells drilled in this period. Table 3 lists the geophysical surveys completed in the search for petroleum.

1910 to 1916. The first well drilled for petroleum was Richmond No. 1, which was located near Richmond and operated by a Mr Duke. It was the first of three wells drilled in the same area between 1910 and 1916. Shows of natural gas were reported in each well, but no commercial production was obtained, and details concerning the shows are not available.

1918 to 1938. A syndicate of local residents began a well at Penrith in 1918, and another syndicate began drilling at Yerrinbool in 1921. Neither well was located on geological advice, but both penetrated more than 600 m of sedimentary rock without reaching economic basement, and both encountered shows of natural gas of unknown magnitude.

Wade (1925) wrote an encouraging report on the petroleum potential of the Sydney Basin, and in the same year the Prime Minister of the Commonwealth made an offer to the New South Wales Government to subsidize drilling on a pound for pound basis provided (1) that the drilling was done in Wade's locations on the Belford Dome in the Hunter Valley, and (2) that the total cost to the Commonwealth would not exceed £22 500. Jones (*in* Andrews, 1925) stated that there was no evidence that the Permian marine sediments in the Hunter Valley contained commercial oil or gas.

The Belford Dome was tested for hydrocarbons in a series of three wells drilled by Belford Dome Ltd in 1927-28, after the dome had been accurately mapped by H. C. Millard of the Hunter River Oil Co. Belford Dome No. 1 and No. 2 were core holes, and No. 3 was drilled with a cable tool rig. Small shows of gas were

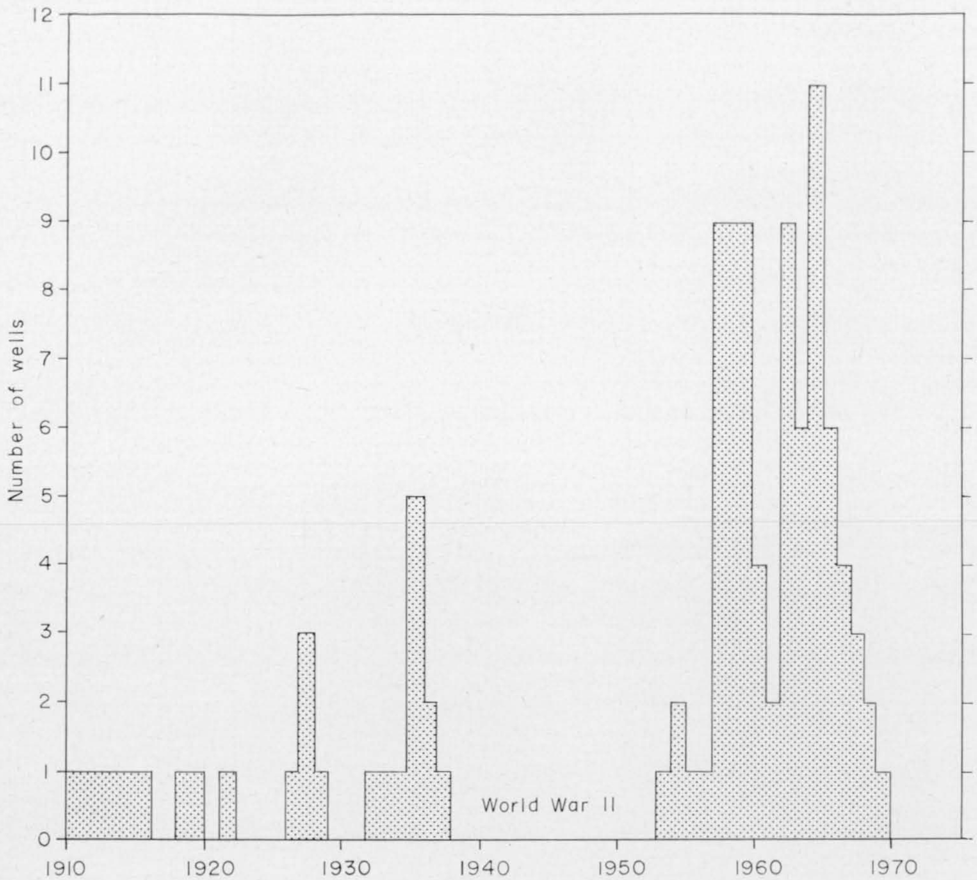

Fig. 6. Petroleum drilling, Sydney Basin, 1910-1970.

reported. The company spent about £24 000 on drilling the three holes, but does not seem to have received any subsidy from the Commonwealth Government. However, the Commonwealth paid a subsidy of £2260 to Oil and Gas Investigations Ltd, who drilled Loder Dome No. 1 to test the Loder Dome in 1926-27. This well was terminated at 729.3 m after passing from the Permian 'Upper Marine Series' into the 'Lower Marine Series' at 619.7 m. Only slight gas shows were reported.

The lack of success on these two prominent structures caused a lull in drilling for about seven years, until a Mr Tyler drilled a well a few kilometres west of Bargo. Little is known about the well, except that it was suspended at a depth of 1082.7 m in 1935 and that some gas was recorded. In the northern part of the basin, W. J. Maskell drilled Farley No. 1 to a depth of 1636 m in 1936. The well penetrated steeply dipping Permian sediments of the 'Lower Marine Series' from surface to total depth. Minor gas shows were reported, and gas was still in evidence when the well was partly cleaned out in 1959.

Three other deep wells—Kulnura No. 1, Mulgoa No. 1, and Balmain No. 1—were drilled, with financial assistance from the Commonwealth, before 1939. Gas

Fig. 7. Location of petroleum exploration wells. (To 30.6.1970).

shows were reported in all three wells, but no commercial production was obtained, although gas from Balmain No. 1 was produced for use as an emergency fuel in motor vehicles during World War II. For this purpose, a production rate of 3240 m^3 per week was attained.

1954 to 1970. When drilling resumed in 1954 greater use was made of available geological and geophysical data. The work was done mainly by soundly based Australian companies, aided in some cases by cash payments under the Commonwealth Petroleum Search Subsidy Act. This Act, introduced in 1957 and amended in 1959, provided for cash payments by the Commonwealth to defray part of the cost of drilling and geophysical surveys for approved projects. Other Commonwealth assistance was provided in the form of seismic surveys conducted by the Bureau of Mineral Resources.

Since 1954, 55 petroleum exploration wells and several scout holes have been drilled in the onshore Sydney Basin (Table 4, Fig. 7). Some of the wells began in Permian sedimentary rocks, others drilled through the Triassic sequence into Permian rocks, and some tested the Triassic section only. Several wells reached effective basement; most were drilled on surface structures, but some were sited to test seismically determined structures, and a few of the more recent wells have been drilled where sections of clean sandstone have been predicted. The wells have provided a great deal of stratigraphic information and have given a reasonable coverage of reservoir conditions within the basin. However, commercial supplies of oil and gas were not found, and all the wells except Kulnura No. 1 and Poggy No. 1 have been abandoned (Kulnura No. 1 and Poggy No. 1 are suspended).

TABLE 2. SEISMIC SURVEYS

	Name of Survey	*Date*	*Reference*
1	*Central Sydney Basin seismic survey	1957	Robertson (1958)
2	*Sydney Basin seismic survey	1961	AOG (1962a)
3	*Newcastle-Maitland seismic survey	1962	Planet (1962)
4	*Nowra-Coolah seismic survey	1962	Smart (1962a)
5	*Singleton-Camden seismic survey	1962–3	AOG (1962b)
6	*Woronora-Dural seismic survey	1962–3	AOG (1962c)
7	*Otway and Sydney Basin experimental 'Vibroseis' seismic survey	1964	Anon (1965)
	Darkes Forest seismic survey	1964	Coal Cliff Collieries (1965)
8	*Offshore Sydney Basin marine seismic survey	1964–5	Shell (1964b)
9	*Sydney-Newcastle seismic survey	1964–5	Shell (1964a)
10	*Camberwell seismic survey	1965	AOG (1965a)
11	*Richmond-Cessnock seismic survey	1965–6	Shell (1966a)
	Werombi seismic survey	1965–6	Doyle et al. (1966)
12	*Putty-Oakdale seismic survey	1965–6	AOG (1965d)
13	*M.E.L. 25 seismic survey	1966	AOG (1966b)
14	*Denman seismic survey	1966	AOG (1965c)
	Stanwell Park seismic survey	1966	Coal Cliff Collieries (1966b)
15	*Girvan seismic survey	1966	AOG (1966a)
16	*Offshore Sydney seismic survey	1967	Shell (1967)
	Port Jackson seismic survey	1967	Phipps & Emerson (1969)
	Currumbene seismic survey	1969	Genoa (1969b)
17	*Broken Bay marine seismic survey	1969	Longreach (1970)
18	*Tasman-Bass Strait marine seismic and magnetic survey	1969	Magellan (1970)
	BMR marine gravity, magnetic, seismic, and bathymetric survey	1971	
	Sealion marine seismic survey	1971	Longreach (1971)

*Surveys shown on Plate 4; number refers to identifying number on Plate 4.

TABLE 3. GRAVITY AND MAGNETIC SURVEYS

Name	*Date*	*Reference*
	Magnetic Surveys	
*Sydney Basin test magnetic	1954	AOG (no report available)
*Sydney Basin magnetic	1955	AOG (no report available)
*West Maitland magnetic	1958	P.E. Gould (no report available)
*Sydney-Nowra airborne magnetometer	1962–3	Smart (1963)
*Terrigal aeromagnetic	1964	Central Coast Oil Pty Ltd (1964)
*Sydney-Newcastle offshore magnetic	1966	Shell (1966b)
Aeromagnetic survey, Helensburgh area	1966	Coal Cliff Collieries Pty Ltd (1966a)
*Stanwell Park offshore magnetic	1967	Ringis et al. (1970)
*Broken Bay marine seismic and magnetic	1969	Longreach (1969)
BMR marine gravity, magnetic, seismic, and bathymetric survey	1971	

*Surveys shown on Plate 6.

Name	*Date*	*Reference*
	Gravity Surveys	
*Sydney Basin N.S.W. gravity	1954–6	AOG (no report available)
Sydney district gravity	1950–6	Hancock et al. (no report available)
Singleton area gravity	1955–63	AOG (no report available)
*Gravity survey PEL 59	1961	Smart (1962d)
*Helicopter gravity training survey and southern N.S.W.	1966	Lodwick & Flavelle (1968)
BMR marine gravity, magnetic, seismic, and bathymetric survey	1971	

*Surveys shown on Plate 5.

The geophysical surveys in the Sydney Basin are listed in Tables 2 and 3. The first, in 1954, was an onshore aeromagnetic survey conducted by the Australian Oil and Gas Corporation Ltd, which was later extended offshore for a distance of up to 48 km. The first seismic survey, in 1957, was carried out by the Geophysical Branch of BMR, with the support of the New South Wales Department of Mines. This survey demonstrated the usefulness of seismic work in the Sydney Basin, and a considerable amount of seismic surveying has since been done, both onshore and offshore. The marine surveys extended up to 48 km offshore, but the results were not good, probably because restricted charges were used in order to protect marine life. In the onshort part of the basin the terrain is unfavourable and large tracts are in built-up areas; a reasonable reconnaissance coverage has been achieved in the central and northern areas, but coverage in the south is sparse (Pl. 4).

The gravity coverage of the Sydney Basin is incomplete; the northern and some of the southern part have been covered by reconnaissance surveys, but there is no cover in much of the central area.

The BMR carried out a marine gravity, magnetic, seismic, and bathymetric survey in April 1971. The survey covered about 1900 line kilometres, but the quality of the seismic records was generally poor.

TABLE 4. PETROLEUM EXPLORATION WELLS
(To 30.6.1971)

Company or Operator	Name of Well	Co-ordinates	Date Drilled	Total Depth (m)	Hydrocarbons	Status	Stratigraphy† (m)
1910-16							
Mr Duke	Richmond (Dukes) Nos 1, 2, 3	At Redbank W of Richmond	1910-16	deepest 267.5	Gas traces; paraffin trace in No. 3	Abandoned	
1918-38							
	Penrith No. 1	33°48′S 150°39′E	1918-20	823.5	Gas traces	Abandoned	W: 0-15.3; H: 15.3-305; N: 305-769.5; UCM: 769.5-TD
Yerrinbool Oil Prospecting Syndicate	Yerrinbool No. 1	34°23′S 150°31′E	1921-22	682.6	Gas traces	Abandoned	H: 0-133.9; N: 133.9-269; UCM: 269-362.3; S: 362.3-TD
Oil and Gas Investigations Ltd	Loder Dome No. 1	32°38′S 151°08′E	1926-27	729.3	Gas trace	Abandoned	
Belford Dome Ltd	Belford Dome No. 1 Belford Dome No. 2 Belford Dome No. 3	32°39′S 151°17′E	1927	472.8	Gas trace	Abandoned	
Mr W. J. Maskell	Farley No. 1	32°45′S 151°31′E	1935-36	1636	486 m³ gas p/d; oil traces	Abandoned	D: O-TD
Mr Tyler	Tylers Bargo No. 1	34°18′S 151°31′E	1935	1082.8	Gas traces	Suspended	
Gas Drillers Ltd (Oil Search Ltd)	Mulgoa No. 1	33°48′S 150°38′E	1935	951.3	Gas traces	Abandoned	H: 0-58; N: 58-631.4; UCM: 631.4-TD
Natural Gas and Oil Corporation Ltd	Balmain No. 1	North Sydney	1932-37	895.8 coal shaft; 610 bore hole; TD 1505.8	3240 m³ gas p/week from 1274.6-1381.7 m	Abandoned	UCM: 895.8-1385.6
Kamilaroi Oil Co. Ltd (Oil Search Ltd)	Kulnura No. 1	33°13′S 151°12′E	1935-38	1919.4	Small traces gas	Abandoned	H: 0-94.6; N: 94.6-829; UCM: 1445.7; S: 1445.7-TD

TABLE 4—*Cont.*

Company or Operator	*Name of Well*	*Co-ordinates*	*Date Drilled*	*Total Depth* (m)	*Hydrocarbons*	*Status*	*Stratigraphy*† (m)
1954-70							
Australian Oil and Gas Corporation Ltd.	Kurrajong Heights No. 1	33°32′S 150°37′E	1954	1450.3 (later deepened by Exoil)	Gas trace at 610 m	Abandoned	H: 0-222.7; N: 222.7-889.1; UCM: 889.1-1390.8; S: 1390.8-TD
Australian Oil and Gas Corporation Ltd.	Dural (East) No. 1	33°41′S 151°03′E	1956-57	1586.9	Gas trace at 934.2 & 1073.9 m	Abandoned	H: 0-263.8; N: 263.8-841.8; UCM: 841.8-1520.7; dolerite sill: 1520.7-TD
Australian Oil and Gas Corporation Ltd.	Dural (East) No. 2	33°40′S 151°01′E	1957-58	1971.8	20 000 m³ gas p/d at 1014.1 m	Abandoned	H: 0-276.6; N: 276.6-875.4; UCM: 875.4-1674.5; dolerite sill: 1518.9-1557.6; S: 1674.5-TD
Australian Oil and Gas Corporation Ltd.	Morisset No. 1	33°10′S 151°29′E	1957	174.2	Gas trace	Abandoned	N: 0-112.5; UCM: 112.5-TD
Australian Oil and Gas Corporation Ltd.	Morisset No. 2	33°10′S 151°27′E	1957	223.9		Abandoned	N: 0-198.9; UCM: 198.9-TD
Australian Oil and Gas Corporation Ltd.	Morisset No. 3	33°08′S 151°29′E	1957	158.3	Gas trace	Abandoned	N: 0-129; UCM: 129-TD
Australian Oil and Gas Corporation Ltd.	Morisset No. 4	33°09′S 151°31′E	1957	221.4	Gas trace	Abandoned	N: 0-79.6; UCM: 79.6-TD
Australian Oil and Gas Corporation Ltd.	Morisset No. 5	33°07′S 151°30′E	1957	83	Gas trace	Abandoned	N: 0-47; UCM: 47-TD
Australian Oil and Gas Corporation Ltd.	Morisset No. 6	33°07′S 151°30′E	1958	92.4	Gas trace	Abandoned	N: 0-46.7; UCM: 46.7-TD
Australian Oil and Gas Corporation Ltd.	Camden No. 1	34°05′S 150°43′E	1957	693	Dry gas at 357.8, 368.7, & 413.3 m. 13 500 m³ p/d	Abandoned	Triassic & UCM
Australian Oil and Gas Corporation Ltd.	Camden No. 2	34°05′S 150°44′E	1958	680.2	Dry gas at 328.2 & 518.2 m	Abandoned	Triassic & UCM

TABLE 4—*Cont.*

Company or Operator	Name of Well	Co-ordinates	Date Drilled	Total Depth (m)	Hydrocarbons	Status	Stratigraphy† (m)
Australian Oil and Gas Corporation Ltd.	Camden No. 3	34°09′S 150°43′E	1958	558.2	Dry gas at 278.8 m	Abandoned	Triassic
Australian Oil and Gas Corporation Ltd.	Camden No. 4	34°05′S 150°42′E	1958	576.5	Dry gas at 355.9 & 368.7 m	Abandoned	Triassic
Australian Oil and Gas Corporation Ltd.	Camden No. 5	34°05′S 150°46′E	1958	591.4	Dry gas at 252.8, 276.9, 372.1, 382.5, & 476.4 m	Abandoned	Triassic
Australian Oil and Gas Corporation Ltd.	Camden No. 6	34°02′S 150°45′E	1959	604.2	Several gas shows below 268.4 m. 18 900 m^3 p/d at 593.8 m	Abandoned	W: 0-?; H: ?-287.9; N: 287.9-TD
Australian Oil and Gas Corporation Ltd.	Camden No. 7	33°57′S 150°47′E	1959	520	1890 m^3 p/d at 411.8 m & 2700 m^3 p/d at bottom	Abandoned	W: 0-111.3; H: 111.3-311.7; N: 311.7-TD
Australian Oil and Gas Corporation Ltd.	Camden No. 8	33°53′S 150°44′E	1959	641.1	Dry gas at 531.3 m	Abandoned	W: 0-87.2; H: 87.2-299.2; N: 299.2-TD
Australian Oil and Gas Corporation Ltd.	Camden No. 9	33°58′S 150°48′E	1959	641.7	Dry gas at 410.5, 424, & 549 m	Abandoned	W: 0-119; H: 119-323.3; N: 323.3-TD
Australian Oil and Gas Corporation Ltd.	Camden No. 10	33°56′S 150°46′E	1959	531.6	13 500 m^3 p/d at 530.7 m	Abandoned	W: 0-102.2; H: 102.2-298.9; N: 298.9-TD
Australian Oil and Gas Corporation Ltd.	Camden No. 11	33°57′S 150°45′E	1960	618.8	Dry gas at 502 & 534.7 m	Abandoned	W: 0-83.9; H: 83.9-271.5; N: 271.5-TD
Australian Oil and Gas Corporation Ltd.	Mulgoa No. 2*	33°49′S 150°38′E	1958-59	1717.2	12 gas shows below 396.5 m yielded 1080 m^3 p/d waning to 270 m^3 p/d	Abandoned	W: 0-21.4; H: 21.4-259.3; N: 259.3-761.9; UCM: 761.9-1097.1; S: 1097.1-TD

TABLE 4—*Cont.*

Company or Operator	*Name of Well*	*Co-ordinates*	*Date Drilled*	*Total Depth* (m)	*Hydrocarbons*	*Status*	*Stratigraphy*† (m)
Australian Oil and Gas Corporation Ltd.	Baulkham Hills No. 1	33°45′S 151°01′E	1960-61	1069.9	Minor gas	Abandoned	H: 0-244; N: 244-832; UCM: 832-TD
Australian Oil and Gas Corporation Ltd.	Mt Hunter No. 1	34°04′S 150°39′E	1962	1071.2	14 gas horizons yielded 1080 m³ p/d, waning	Abandoned	Base of N: 640.5; UCM: 640.5-976; S: 976-TD
Australian Oil and Gas Corporation Ltd.	Loder No. 1*	32°38′S 151°08′E	1963	2063.9	Oil & gas shows in Branxton, Farley, & Rutherford Fms	Abandoned	M: 0-689.3; GCM: 689.3-774.7; D: 774.7-TD
Australian Oil and Gas Corporation Ltd.	Mt Murwin No. 1*	32°51′S 150°55′E	1963	887.6	Minor gas shows from UCM	Abandoned	H: 0-82.4; N: 82.4-772.6; UCM: 772.6-TD
Australian Oil and Gas Corporation Ltd.	Mellong No. 1	33°00′S 150°42′E	1964	905.9	Minor gas shows	Abandoned	H: 0-112.9; N: 112.9-756.4; UCM: 756.4-TD
Australian Oil and Gas Corporation Ltd.	Woronora No. 1*	34°12′S 150°55′E	1963-64	2314	Minor gas shows	Abandoned	H: 0-164.7; N: 164.7-512.4; UCM: 512.4-1189.5; S: 1189.5-2279.9; B: 2279.9-TD
Australian Oil and Gas Corporation Ltd.	Kenthurst No. 1	33°40′S 150°59′E	1963	1066.6	310 m³ gas p/d at 436.8 m	Abandoned	H: 0-258; N: 258-855.5; UCM: 855.5-TD
Australian Oil and Gas Corporation Ltd.	Fairfield No. 1	33°52′S 150°55′E	1964	854.9	Gas at 544 & 835.7 m	Abandoned	W: 0-72.6; H: 72.6-311.4; N: 311.4-TD
Australian Oil and Gas Corporation Ltd.	Kulnura No. 1	33°13′S 151°12′E	1964	Started at 1919.4, TD at 2474.2	Gas at 2218.6 m. Outburst at 2342.4 m	Suspended	S: 1919.4-TD
Australian Oil and Gas Corporation Ltd.	Sedgefield No. 1	32°31′S 151°15′E	1964	687.5		Abandoned	N: 0-45.8; GCM: 45.8-495.6; D: 495.6-TD
Australian Oil and Gas Corporation Ltd.	Cecil Park No. 1	33°52′S 150°51′E	1964-65	697.2	5400 m³ gas p/d, waning, at 617.9-623.7 m	Abandoned	W: 0-160.7; H: 160.7-389.5; N: 389.5-TD
Australian Oil and Gas Corporation Ltd.	Cecil Park No. 2	0.8 km S of No. 1	1964	689.9	Minor gas	Abandoned	W: 0-139.7; H: 139.7-357.2; N: 357.2-TD

TABLE 4—*Cont.*

Company or Operator	*Name of Well*	*Co-ordinates*	*Date Drilled*	*Total Depth* (m)	*Hydrocarbons*	*Status*	*Stratigraphy*† (m)
Australian Oil and Gas Corporation Ltd.	Kirkham No. 1	34°02′S 150°42′E	1964	2563.8	Dry	Abandoned	W: 0-113; H: 113-310.5; N: 310.5-748.5; UCM: 748.5-1302.4; S: 1302.4-2547.7; D: 2547.7-TD
Australian Oil and Gas Corporation Ltd.	Badgelly No. 1	34°03′S 150°48′E	1964	660.6	Gas at 365.7 & 381.6 m	Abandoned	
Australian Oil and Gas Corporation Ltd.	Leehome No. 1	33°49′S 150°45′E	1965	664.6		Abandoned	W: 0-96.7; H: 96.7-304.1; N: 304.1-TD
Australian Oil and Gas Corporation Ltd.	Belford No. 1*	32°39′S 151°17′E	1964-65	1175.5	Gas shows at 13 levels	Abandoned	M: 0-393.5; GCM: 393.5-506.3; D: 506.3-TD
Australian Oil and Gas Corporation Ltd.	Camberwell No. 1*	32°32′S 151°06′E	1965	1908.1	Oil trace at about 720 m	Abandoned	M: 0-658.8; GCM: 658.8-1186.5; D: 1186.5-TD
Australian Oil and Gas Corporation Ltd.	Martindale Nos 1 and 1A*	32°30′S 150°37′E	1967	1182.2	Dry	Abandoned	UCM: 0-683.2; M: 683.2-1034; GCM: 1034-TD
Australian Oil and Gas Corporation Ltd.	Berkshire Park No. 1	33°46′S 150°47′E	1968	1091.9	Dry	Abandoned	W: 0-122; H: 122-323.3; N: 323.3-1024.8; UCM 1024.8-TD
Australian Oil and Gas Corporation Ltd.	Higher Macdonald No. 1*	33°12′S 150°55′E	1968	628.3	Dry	Abandoned	N: 24.4-589.3; UCM: 589.3-TD
Australian Oil and Gas Corporation Ltd.	Lower Portland No. 1	49 km N of Windsor	1968	890	Dry	Abandoned	H: 0-141.8; N: 141.8-825; UCM: 825-TD
Sun Oil Co.	Sunwell No. 1	32°44′S 151°30′E	1953	632.6	Minor gas show	Suspended	D
Central Coast Oil N.L. (=Alkane Exploration Terrigal N.L.)	Terrigal Nos 1 and 1A	33°26′S 151°26′E	1959-68	1885.5	Oil & gas shows	Abandoned	N: 0-582.2; NCM: 582.2-865.6; TCM: 865.6-1798.3; M: 1798.3-TD
Planet Exploration Co. Ltd.	East Maitland No. 1*	32°46′S 151°37′E	1962	3051.2	Gas show	Abandoned	UCM: 0-58.9; M: 58.9-1396.9; GCM: 1396.9-1462.8; D: 1462.8-TD

TABLE 4—*Cont.*

Company or Operator	*Name of Well*	*Co-ordinates*	*Date Drilled*	*Total Depth (m)*	*Hydrocarbons*	*Status*	*Stratigraphy*† *(m)*
L. H. Smart Oil Exploration Co. Ltd.	Greenwell Point No. 1	34°45′S 150°43′E	1962	51.9	Dry	Abandoned	S: O-TD
L. H. Smart Oil Exploration Co. Ltd.	Greenwell Point No. 2	34°45′S 150°43′E	1962	140	Dry	Abandoned	S: 7.6-TD
Exoil N.L.	Kurrajong Heights No. 1*	33°32′S 150°37′E	1962	Started at 1450.3, TD at 2785.3	Dry	Abandoned	S: 1450.3-2400.4; D: 2400.4-TD
L. H. Smart Oil Exploration Co. Ltd.	Point Perpendicular No. 1	35°00′S 150°48′E	1962	177.5	Dry	Abandoned	S: 3.1-TD
Farmout Drillers N.L.	Stockyard Mt No. 1*	34°36′S 150°47′E	1962	1072.4	Gas trace	Abandoned	S: 0-1006.5; B: 1006.5-TD
Alliance Oil Development Australia N.L.	Cataract No. 1	34°19′S 150°53′E	1964-65	1306.6	Dry	Abandoned	H: 0-?115.9; N: ?115.9-?335.5; UCM: ?335.5-?941.2; S: ?941.2-TD
A. J. Wood	Poggy No. 1	32°16′S 150°08′E	1964-67	734.1		Suspended	
Planet Exploration Co. Ltd.	Woodberry No. 1	32°47′S 151°41′E	1965-66	915.9	Dry	Abandoned	
Shell Development (Australia) Pty Ltd	Dural South No. 1*	33°43′S 151°01′E	1966	3060.7	Dry	Abandoned	W: 0-36; H: 36.6-241; N: 241-832.7; UCM: 832.7-1714.1; S: 1714.1-3051.5; D: 3051.5-TD
Esso (Exploration and Production Australia Inc.)	Jerrys Plains No. 1*	32°28′S 150°56′E	1969	1596.4	Dry	Abandoned	UCM: 0-189.1; M: 189.1-640.5; GCM: 640.5-1001.6; D: 1001.6-TD
Genoa Oil N.L.	Coonemia No. 1*	34°58′S 150°42′E	1969	797	Gas trace	Abandoned	S: 0-718; B: 718-TD
Esso (Exploration and Production Australia Inc.)	Howes Swamp No. 1*	33°07′53″S 150°41′32″E	1970	2562	Gas trace	Abandoned	H: 0-96.1; N: 96.1-750.3; UCM: 750.3-1807.1; S: 1807.1-TD

*Subsidized wells.

†*Abbreviations used*

W: Wianamatta Group; H: Hawkesbury Sandstone; N: Narrabeen Group; UCM: Tomago Coal Measures, Newcastle Coal Measures, Singleton Coal Measures, Illawarra Coal Measures; M: Maitland Group; S: Shoalhaven Group; GCM: Greta Coal Measures; D: Dalwood Group; B: Basement.

Longreach Oil Ltd also conducted a marine seismic survey in April 1971, and a site for an offshore well, Sealion No. 1, has been selected to test a structure outlined by the survey.

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BASEMENT ROCKS

The basement of the Sydney Basin includes rocks of the Lachlan Fold Belt and correlatives of the New England Fold Belt. The sequence in the Sydney Basin consists of gently folded sedimentary rocks with relatively few volcanic rocks, except near the base, whereas the sequence in the New England Fold Belt comprises a thick sequence of strongly folded sedimentary and volcanic rocks, all of which have been intruded by granite.

Lachlan Fold Belt

Rocks of the Lachlan Fold Belt crop out west of, and unconformably underlie part of, the Sydney Basin. The folded sediments are interbedded with a wide range of volcanic rocks, mainly felsic lavas, and have been intruded by granitic batholiths ranging in age from Silurian to Lower Carboniferous. Granite fragments have been found in a Triassic diatreme at The Basin (Nepean River) and the Woronora No. 1 well bottomed in granite. Dulhunty (1964) and others have shown that most of the sediment laid down in the Sydney Basin during the Permian was derived from mountainous borderlands in the west, and that much of it was of glacigene origin. The Permian and Triassic sedimentary rocks contain appreciable proportions of quartz and feldspar derived from igneous rocks.

New England Fold Belt

In the area adjacent to the Sydney Basin most of the Carboniferous rocks are of continental origin. These continental rocks ('Kuttung Group') and their marine correlatives were deposited in upper Visean, Namurian, Westphalian, and Shephanian times. Much of the sequence in the New England Fold Belt consists of lavas and pyroclastics, or sediments derived from their disintegration. Although many of the rock units in the fold belt are only of local extent, the main subdivisions of the 'Kuttung Group' in the Hunter Valley region are briefly described in Table 5.

TABLE 5. THE 'KUTTUNG GROUP' IN PART OF THE HUNTER VALLEY REGION
(After Engel et al., 1969)

Formation	*Description*
Seaham Formation	Chiefly glacigene sediments derived from igneous rocks, principally penecontemporaneous lavas, interbedded, especially near top, with flows of rhyolite, felsite, and basalt. Volcanics near Gosforth, Stanhope, and Pokolbin include trachyandesite, trachyte, and basalt
Paterson Toscanite	One or several flows with associated ignimbrite and tuff
Mount Johnstone Formation	Largely tuffaceous sandstone, conglomerate (derived from lava), and tuff
Gilmore Volcanics	Wide variety of flows, ignimbrite, and tuff interbedded with coarse clastics derived from igneous rocks
Wallaringa Formation	Coarse-grained tuffaceous sandstone overlying coarse conglomerate containing clasts of igneous rocks

The New England Batholith, the southern tip of which extends into the map area at Barrington, is of Permian age. The isotopic K/Ar ages range from 269 to 221 m.y. (Evernden & Richards, 1962; Binns & Richards, 1965). It consists chiefly of adamellite, granodiorite, and granite.

EARLY SAKMARIAN ROCKS

The oldest sediments within the Sydney Basin contain volcanic rocks similar to those in the New England Fold Belt. On the Lochinvar Anticline the volcanics are interbedded with the early Sakmarian sediments of the Allandale and Lochinvar Formations, and in the Muswellbrook district the Skeletar Formation also contains volcanic rocks, while the Gyarran Volcanics consist entirely of volcanics. Volcanic rocks were also encountered in several deep wells and make up part of the ejectamenta of a Triassic diatreme (Osborne, 1920) at The Basin (Nepean River). No volcanics are present, however, in the Wasp Head Formation, a correlative in the south.

Interval 1: Lochinvar and Allandale Formations and Correlatives

The early Sakmarian rocks include the Lochinvar and Allandale Formations and their major correlative the Wasp Head Formation plus a number of formations of limited areal distribution. They are all included in Interval 1. A summary of the lithology of the rocks and their relationships, correlation, and age is given in Plates 2 and 3 and Figures 3, 8, 9, and 10. The thickness, sand-shale ratios, and palaeoenvironments are given in Figures 11 to 13.

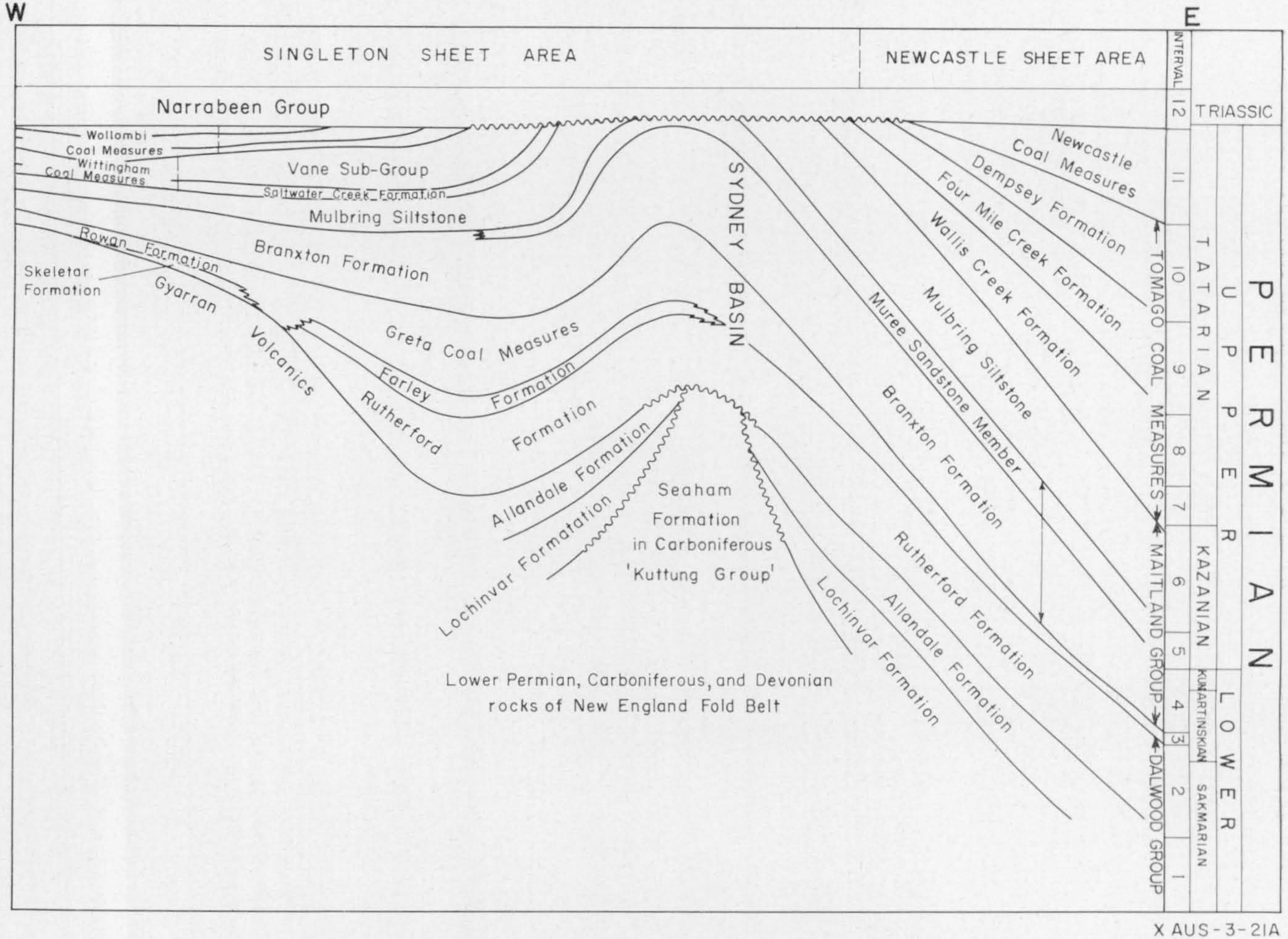

Fig. 8. Relationship of main rock units, Singleton and Newcastle 1:250 000 Sheet areas.

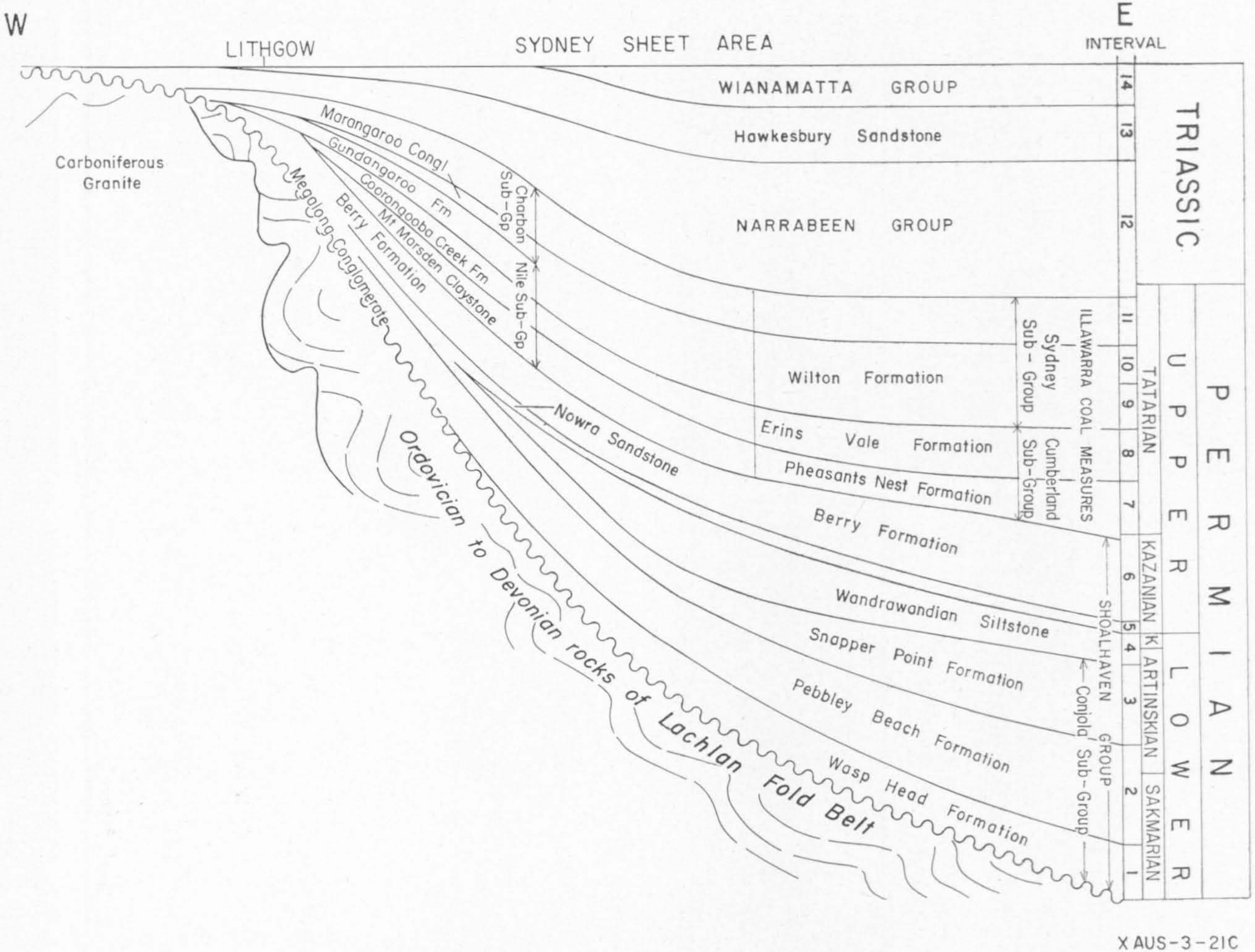

Fig. 9. Relationship of main rock units, Sydney 1:250 000 Sheet area.

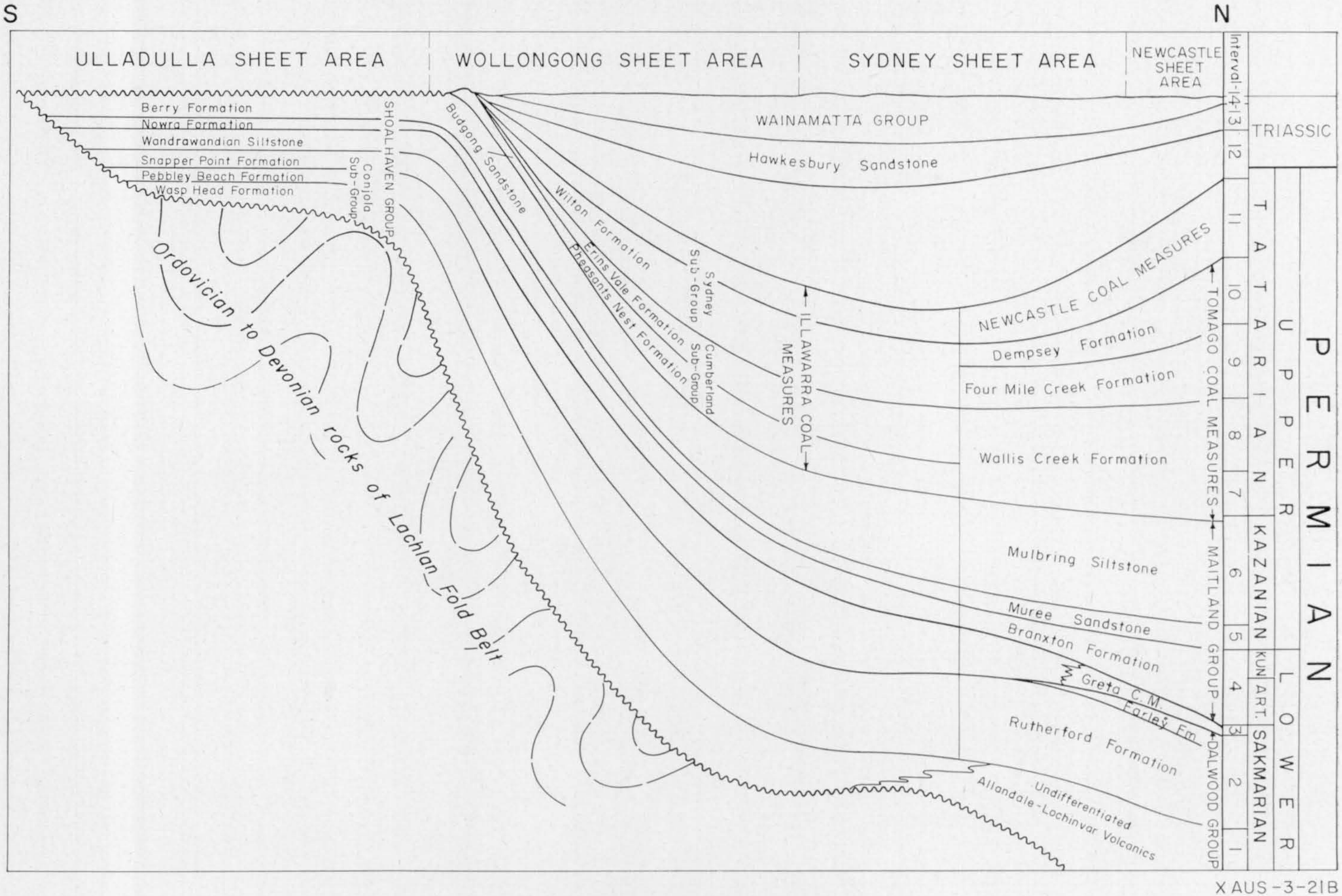

Fig. 10. Relationship of main rock units, Ulladulla, Wollongong, Sydney, and Newcastle 1:250 000 Sheet areas.

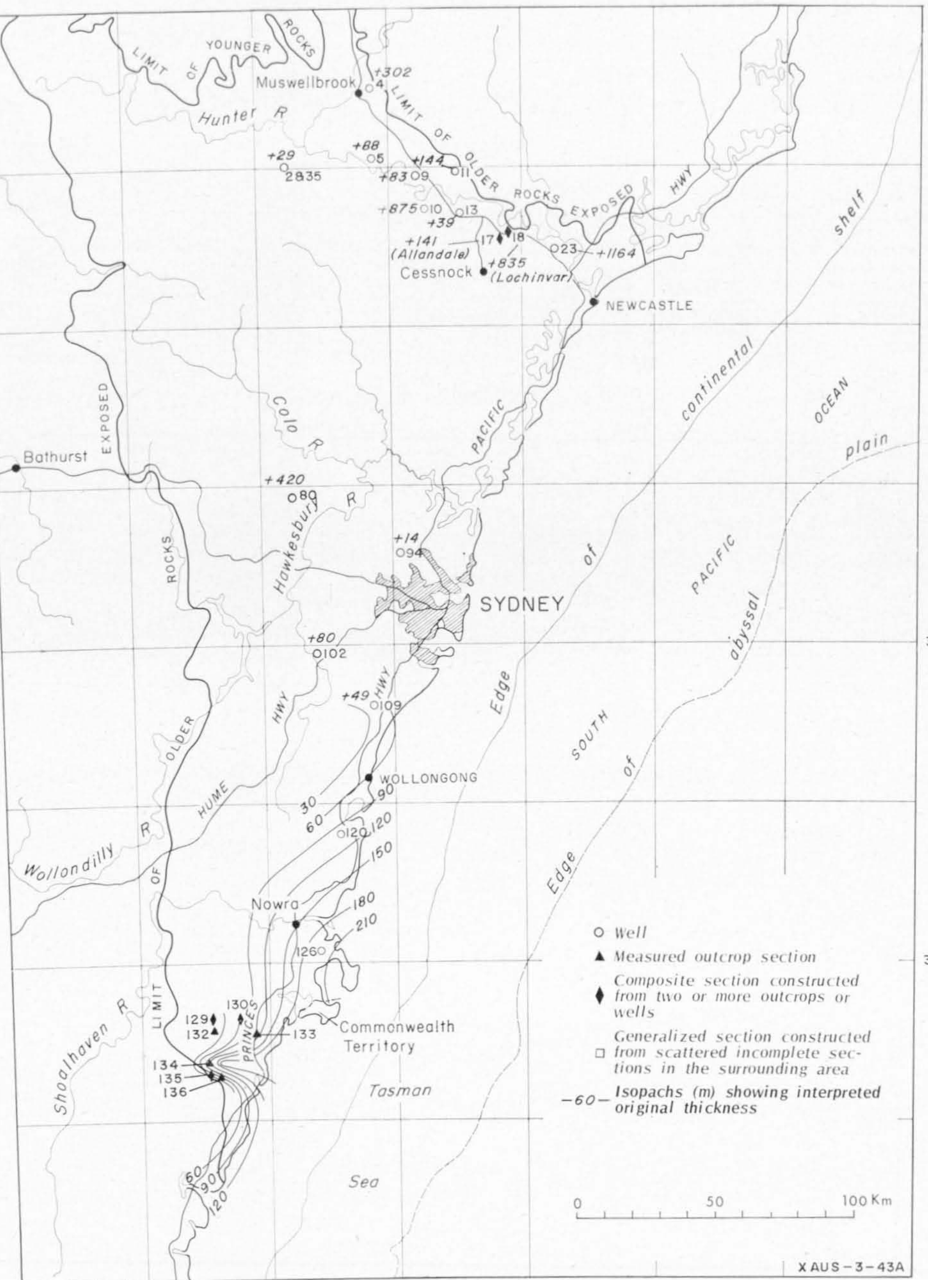

Fig. 11. Isopach map, Interval 1—Allandale and Lochinvar Formations and correlatives.

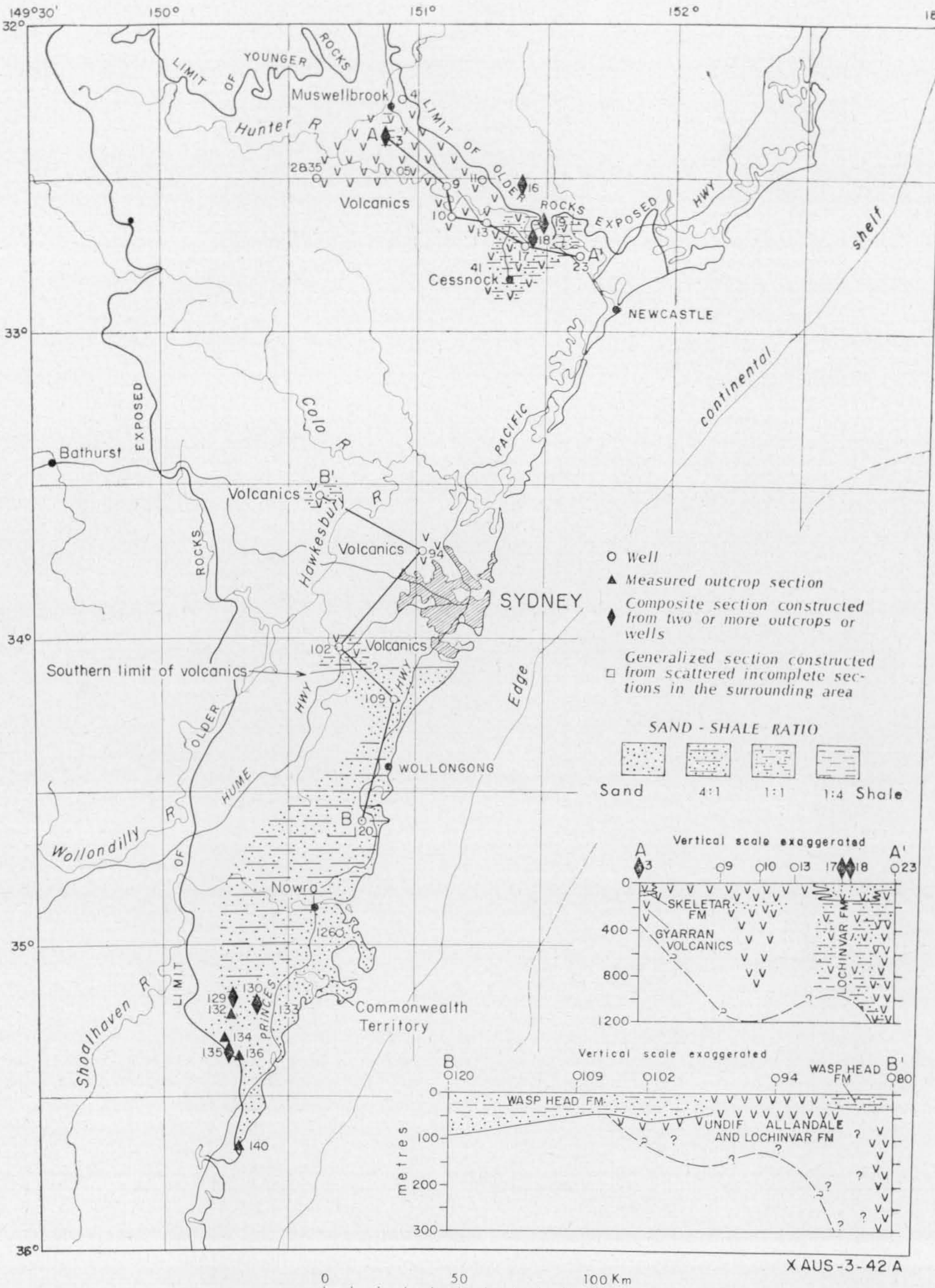

Fig. 12. Sand-shale ratios, Interval 1—Allandale and Lochinvar Formations and correlatives.

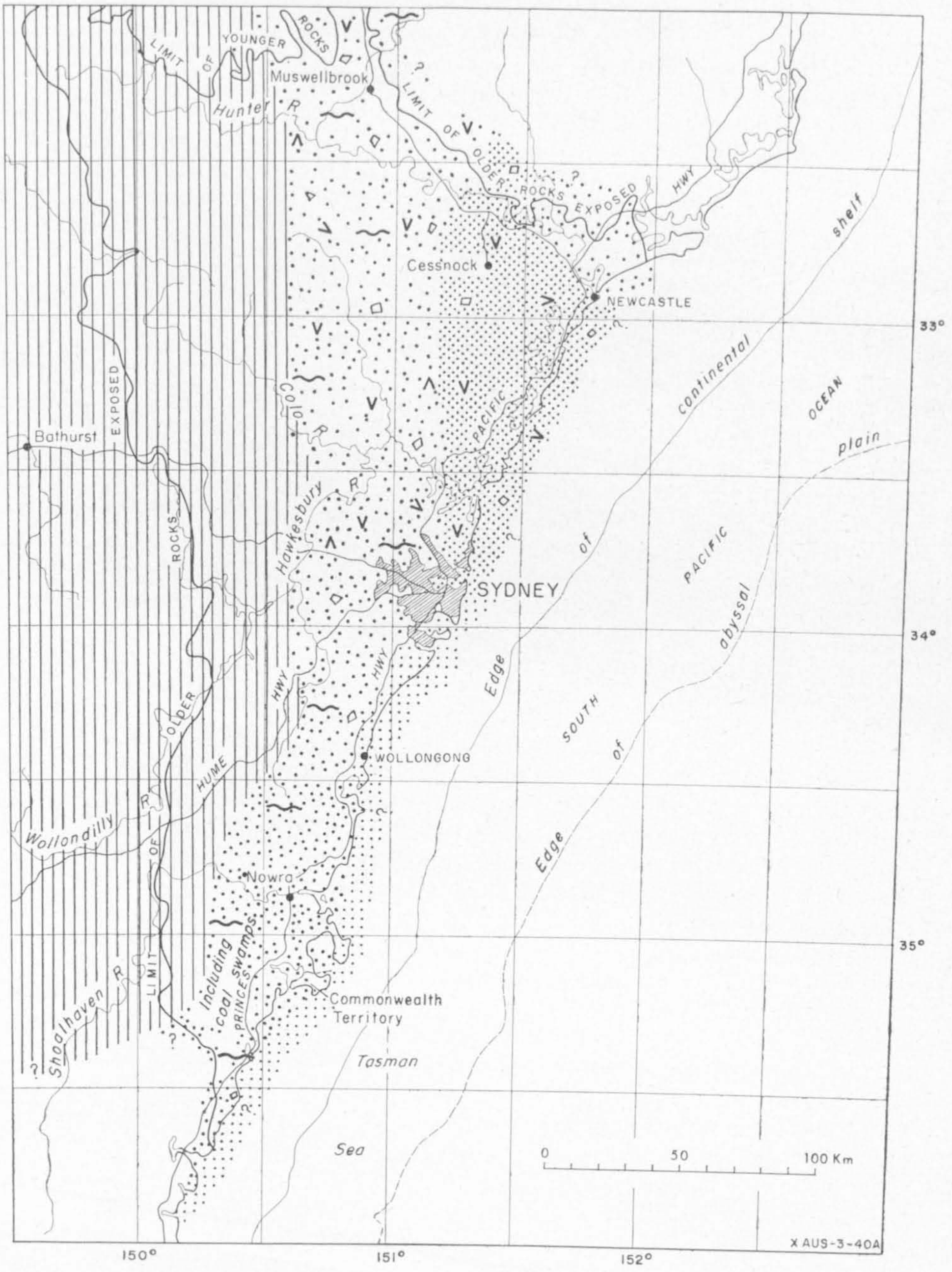

Fig. 13. Palaeoenvironments, Interval 1—early Sakmarian.

Details of lithology, correlations and age, and relations with older units are given in Appendix 1.

Conclusions

The thickness of Interval 1 is unknown over most of the northern and central areas. Geological control on the base of the interval is limited to the area of outcrop in the lower Hunter Valley. The isopach map (Fig. 11) shows the thickness of the Lochinvar and Allandale Formations in the type area and the thickness penetrated in deep wells. In the northern area, where the interval is over 900 m thick, the isopachs suggest that the sediments were deposited in a northwesterly trending trough. In the south the sequence is unconformable on lower Palaeozoic basement, and the thickness is controlled by the topography of the underlying erosional surface.

In the southern part of the basin, where volcanics are absent, the sand-shale ratios (Fig. 12) are high to moderately high. In the north the sequence in the Lochinvar Anticline consists of interbedded sedimentary and volcanic rocks. The sedimentary rocks in the Lochinvar and Allandale Formations have a higher shale content than those in the south, presumably because the source area had a lower relief, or was more distant. The composition of the phenoclasts in the intraformational conglomerates indicates that the sediment in the northern trough was derived from the New England Fold Belt to the northeast, whereas the sediment laid down on the southern shelf was derived from the Lachlan Fold Belt to the south and west. The proportion of volcanics increases to the northwest and northeast of the Lochinvar Anticline. The predominantly volcanic sequences in the deep wells in the middle and upper part of the Hunter Valley crop out in the lower Hunter Valley between Paterson and Raymond Terrace. The volcanics extend as far south as the Camden area, and were intersected in the Kurrajong Heights No. 1, Dural South No. 1, and Kirkham No. 1 wells.

The Lochinvar and Allandale Formations, where they crop out in the Lochinvar Anticline, were probably deposited in a near-shore marine environment (Fig. 13) close to active volcanoes. This interpretation is based on the presence of strong-shelled marine fossils, including *Eurydesma hobartense* and *E. cordatum,* and the abundance of interbedded basaltic and andesitic pyroclastics. Volcanism also occurred in the middle and upper Hunter Valley, but in the Muswellbrook district of the upper Hunter Valley the presence of *Gangamopteris* and *Glossopteris* in the Skeletar Formation suggests deposition in a continental fluvial environment, and at Raymond Terrace in the lower Hunter Valley the presence of *Gangamopteris* and minor coal underlying volcanics correlated with the Lochinvar-Allandale sequence suggests a similar environment. In the central area the lithic sandstone in the Kurrajong Heights No. 1 and Kirkham No. 1 wells is interpreted as fluvial because of the absence of marine fossils and the presence of carbonaceous material, including coal. The depositional environment of the Wasp Head Formation cropping out on the coast in the far south is interpreted as near-shore open marine because of the presence of marine fossils, including *Eurydesma cordatum,* sedimentary breccia, cross-bedded lithic sandstone, and the abundance of plant fragments. Elsewhere in the south the available lithological data suggest that the lithic sandstones and siltstones correlated with the Wasp Head Formation are of fluvial origin. Marine fossils are absent, and they contain carbonaceous material and local coal measures. Conglomerates fill old drainage channels (Herbert, 1972).

The Wasp Head, Lochinvar, and Allandale Formations all contain boulders and pebbles that may have been transported into the basin by ice-rafting.

SAKMARIAN TO KAZANIAN ROCKS

The rocks of Sakmarian to Kazanian age include the Rutherford and Farley Formations, the Greta Coal Measures, the Branxton Formation, the Mulbring Siltstone, and their correlatives. Their distribution is given in Plate 1. Figures 3, 8, 9, and 10 show the rock relationships and the five intervals into which the sequence has been subdivided.

In the northern part of the basin Intervals 2 to 6 consist of two dominantly marine sequences separated by a non-marine sequence containing coal measures. In the central and southern areas the whole sequence is dominantly marine. Adjacent to the western margin of the basin (Fig. 3), Intervals 2 to 5 merge into a conglomeratic shoreline sequence, in which only the youngest interval can be identified.

Interval 2 contains the Rutherford and Farley Formations and their correlative, the Pebbley Beach Formation, which range in age from Sakmarian to early Artinskian. Interval 3 comprises the Greta Coal Measures and their correlative the Snapper Point Formation. Interval 4 contains the Branxton Formation (excluding the Muree Sandstone Member) and correlative, the Wandrawandian Siltstone. Intervals 3 and 4 are of Artinskian age. Interval 5 comprises the Muree Sandstone Member of the Branxton Formation and its correlative, the Nowra Sandstone. Interval 6 contains the Mulbring Siltstone and its correlative, the Berry Formation. Intervals 5 and 6 are of Kazanian age.

Interval 2: Rutherford and Farley Formations and Correlative Pebbley Beach Formation

The Rutherford Formation, Farley Formation, and Pebbley Beach Formation are included in Interval 2. Their lithology, relationships, correlation, and age are summarized in Plates 2 and 3, and Figures 3 and 8 to 10. The thickness, sand-shale ratios, and palaeoenvironments are given in Figures 14 to 16.

The detailed lithology, correlations and age, and relations with older units are given in Appendix 2.

Conclusions

The interval is over 600 m thick (Fig. 14) in a narrow northwesterly trending depression in the northern part of the basin, and exceeds 480 m in a broader westerly trending depression beneath Sydney. From these areas and the east coast the interval thins toward an interpreted zero isopach.

The thinning of the interval over the Carboniferous basement highs in the Pokolbin district of the northern area is not indicated on the map because of lack of data. This local uplift was possibly related to a widespread movement in the New England area which is indicated by the rapid thinning to 60 m to the north-east.

The sand-shale ratio map (Fig. 15) shows areas with a low sand-shale ratio centred around Newcastle in the north and Jervis Bay in the south and a westerly

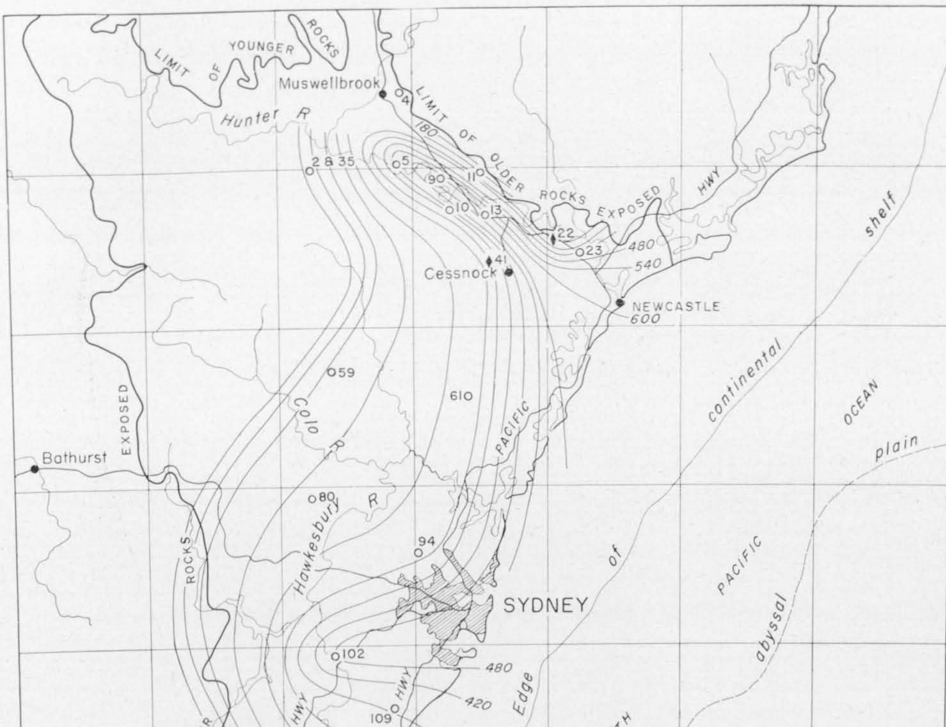

Fig. 14. Isopach map, Interval 2—Farley and Rutherford Formations and correlative Pebbley Beach Formation.

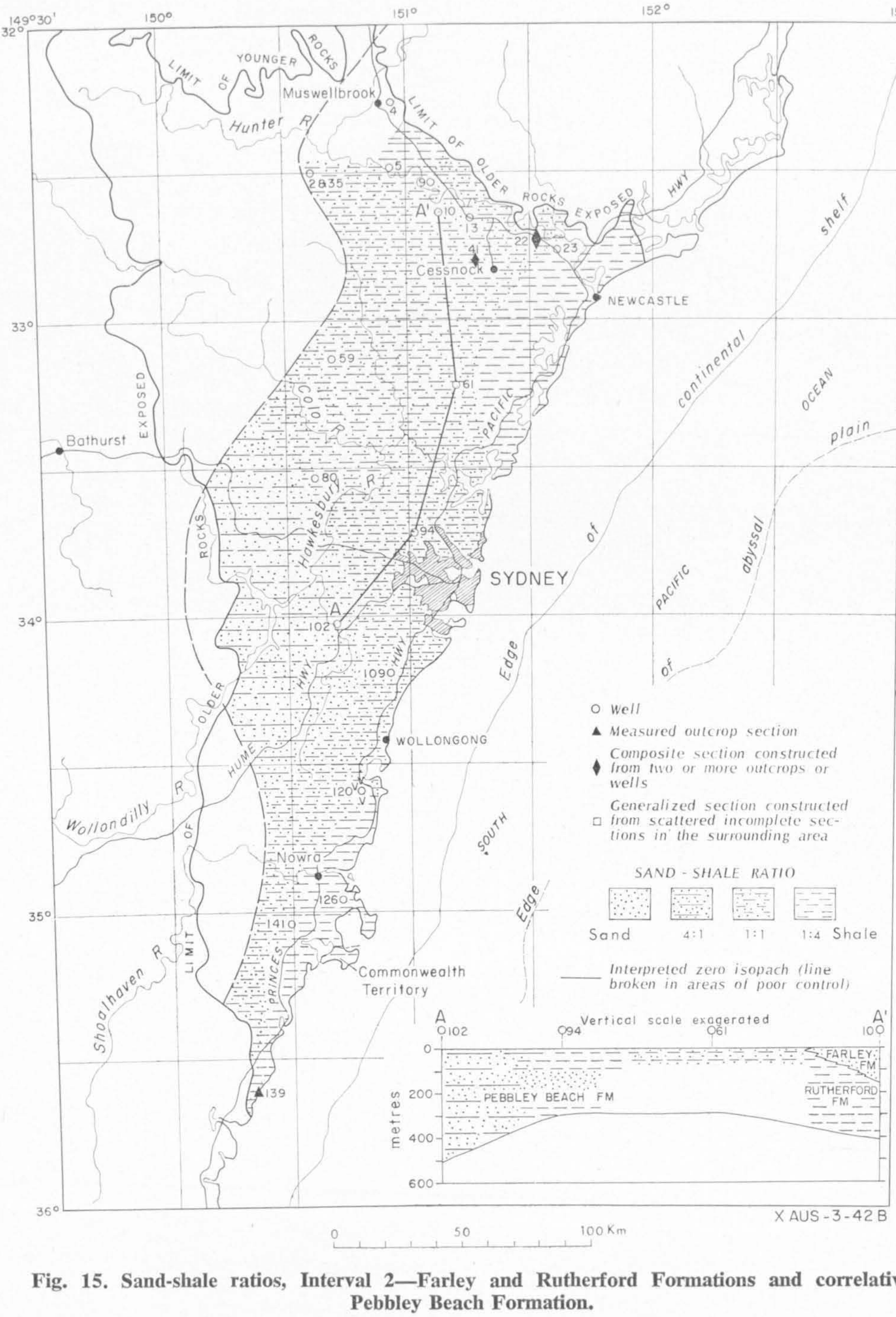

Fig. 15. Sand-shale ratios, Interval 2—Farley and Rutherford Formations and correlative Pebbley Beach Formation.

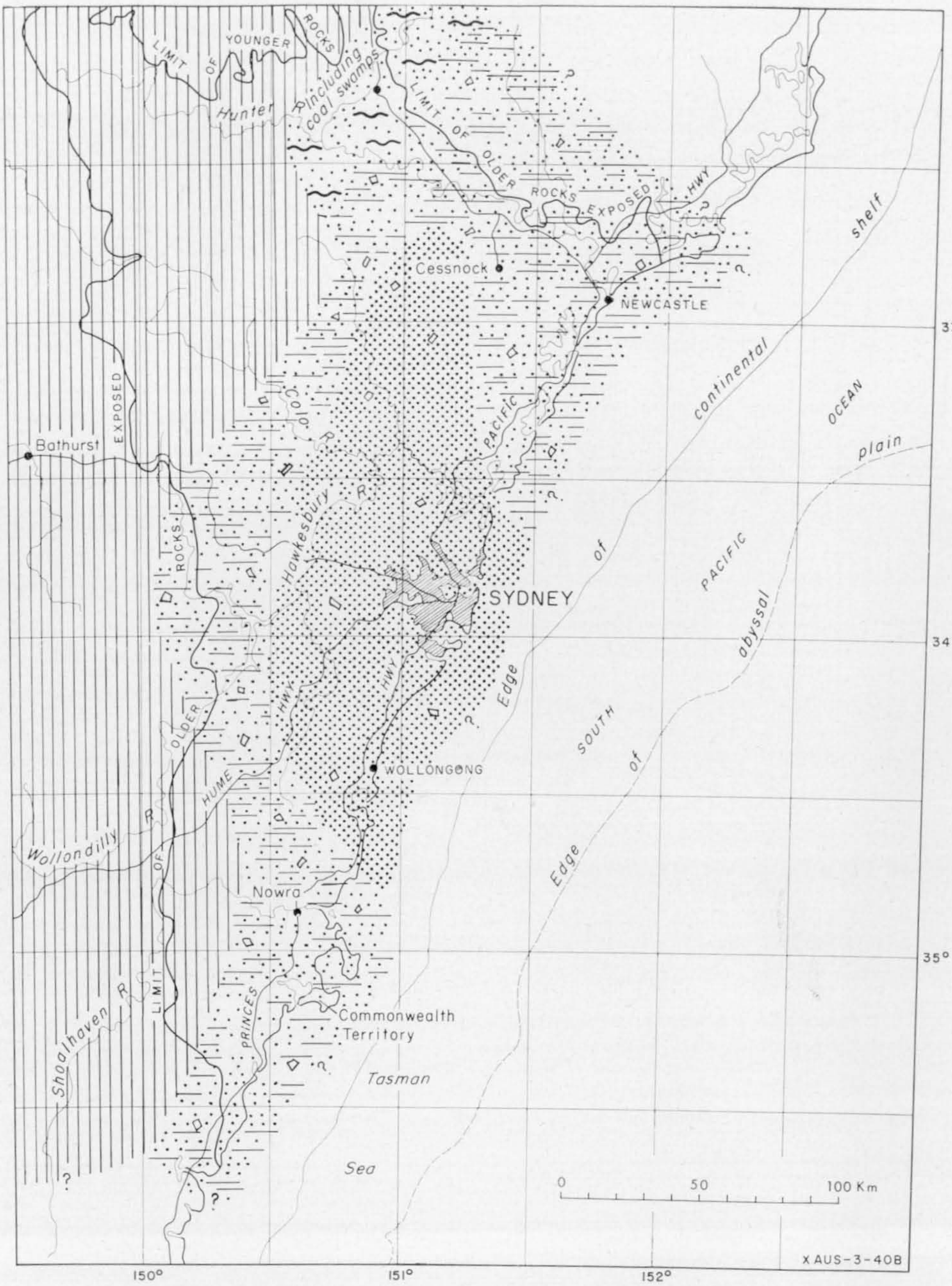

Fig. 16. Palaeoenvironments, Interval 2—Sakmarian to early Artinskian

increase in sand toward the interpreted zero isopach. The geological control on which the map is based is sparse over much of the basin, but is sufficient to indicate that the interval is predominantly composed of siltstone and poorly sorted fine-grained lithic sandstone in which volcanic rock fragments are common.

The beds were laid down during a marine transgression which began in the early Sakmarian (Interval 1). Active volcanism had ceased, but a chain of volcanic islands may have existed to the east of the Sydney Basin, shedding detritus into it and sheltering it from the full force of the open sea so that fine-grained clastic material remained within the basin.

The presence of the sea, whose western limits are poorly defined (Fig. 16), is deduced by the occurrence of thick-shelled brachiopods and pelecypods, bryozoans, and Foraminifera. The presence of thin beds of bryozoal and foraminiferal limestone on the west side of the southern end of the Lochinvar Anticline, in Dural South No. 1, in the central area, and in Stockyard Mountain No. 1 in the northern part of the southern area are indicative of a placid marine environment. Brachiopods and pelecypods occur throughout the interval, and also in the Pebbley Beach Formation on the far south coast. The occurrence of large scour channels filled with fine-grained sandstone in the upper part of the Pebbley Beach Formation suggests a mud-flat environment with tidal channels (Gostin *in* Dickins et al., 1969).

The occurrence of burrow structures throughout the interval and the presence of carbonaceous material suggest a near-shore environment. Carbonaceous material, including coal, is particularly common in the north.

Although included in Interval 3 the Greta Coal Measures of the upper Hunter Valley may be the northern time-correlative of part or all of Interval 2 in the south; in the upper Hunter Valley the coal measures conformably overlie volcanics of Interval 1. For this reason the coal swamps in the northwest (Fig. 16) are shown as contemporaneous with the transgressive sea. This correlation is supported by the presence of marine fossils in a thin sandstone within the Greta Coal Measures in Martindale No. 1.

Erratic pebbles occur in the Farley and Rutherford Formations and large erratic boulders in the Pebbley Beach Formation. The latter depress the underlying beds and appear to have been dropped from floating ice.

Interval 3: Greta Coal Measures and Correlative Snapper Point Formation

The Greta Coal Measures and the Snapper Point Formation are included in Interval 3. A summary of the lithology of the rocks and their relationships, correlation, and age is given in Plates 2 and 3, and Figures 3 and 8 to 10. The thickness, sand-shale ratios, and palaeoenvironments are shown in Figures 17 to 19.

The detailed lithology, correlations and age, and relations with older units are given in Appendix 2.

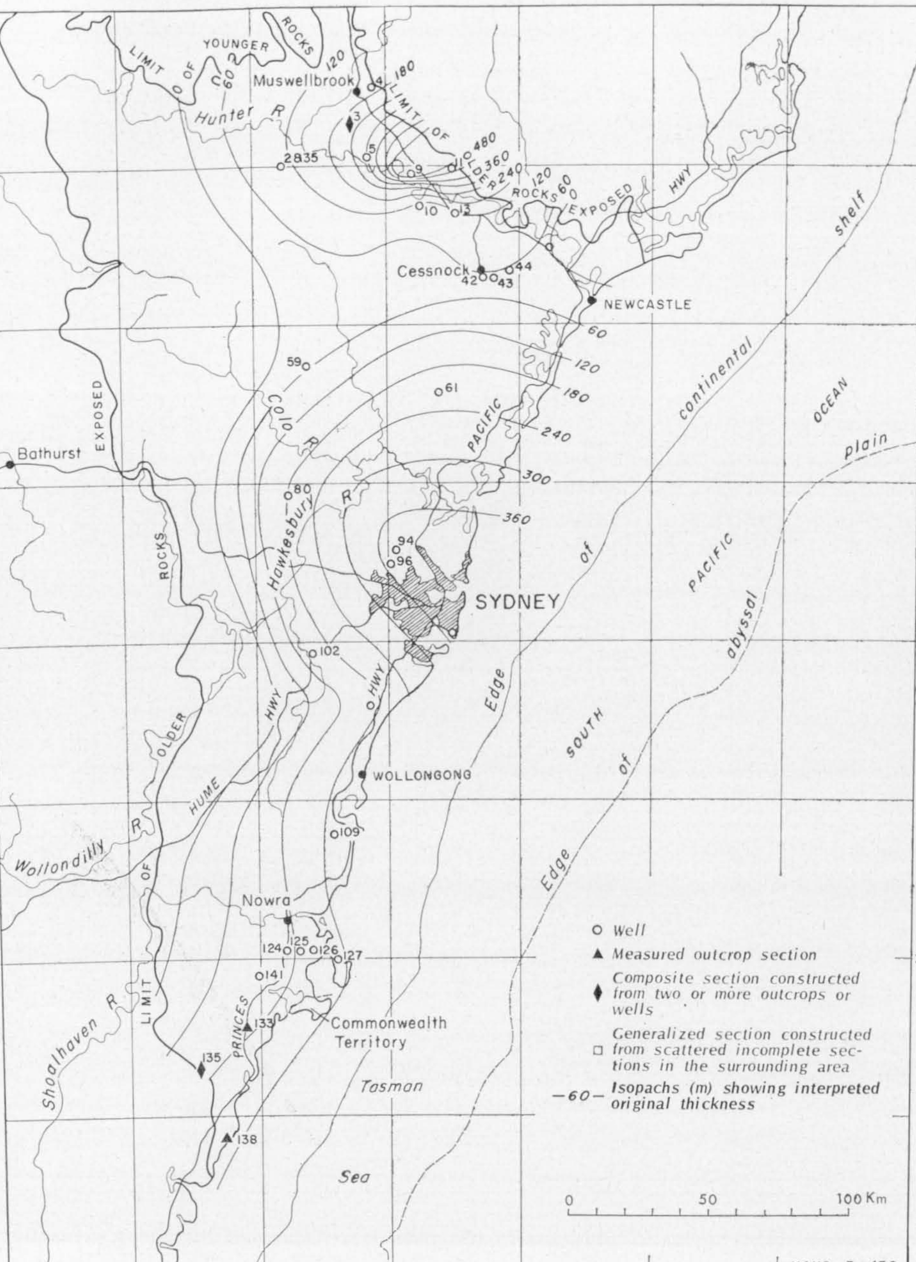

Fig. 17. Isopach map, Interval 3—Greta Coal Measures and correlative Snapper Point Formation.

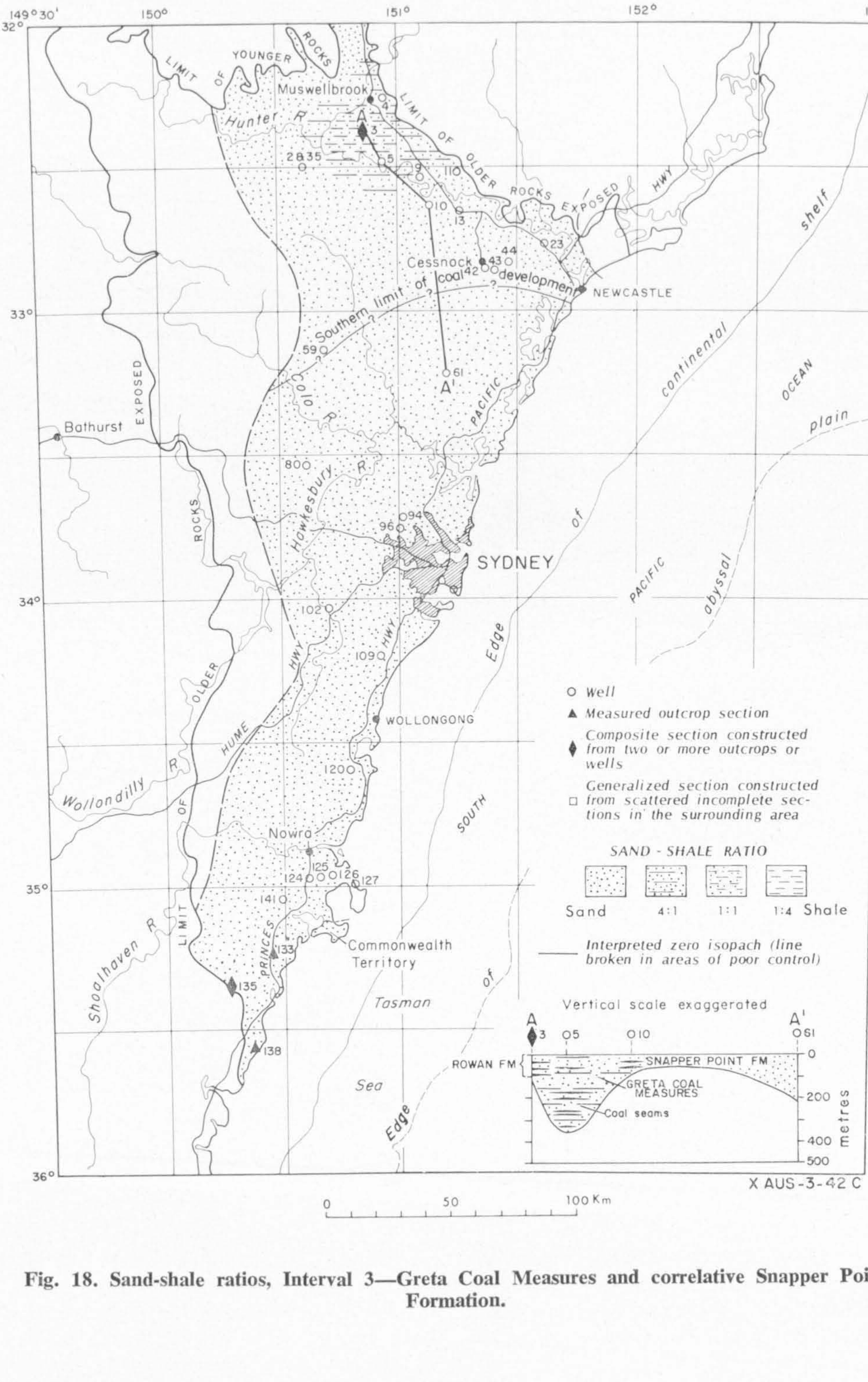

Fig. 18. Sand-shale ratios, Interval 3—Greta Coal Measures and correlative Snapper Point Formation.

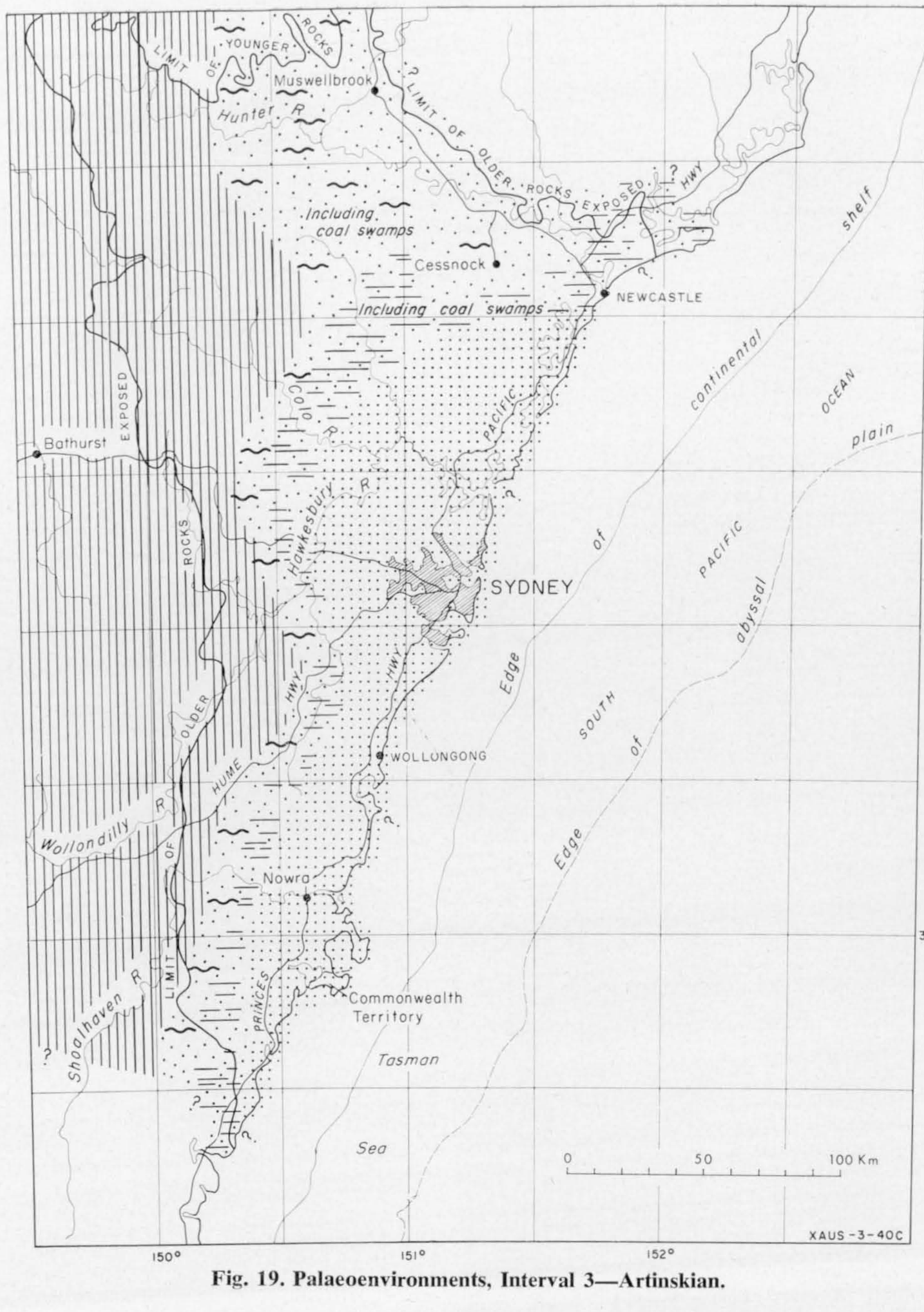

Fig. 19. Palaeoenvironments, Interval 3—Artinskian.

Conclusions

In the north the Greta Coal Measures are up to 480 m thick (Fig. 17) in an easterly trending depression that is cut off by the Hunter Thrust along the north-east margin of the basin. To the south the coal measures thin to 30 to 60 m over a westerly trending arch, and to the east and west to interpreted zero isopachs. South of the arch, the Snapper Point Formation thickens to over 390 m in a depression beneath Sydney, and to the west it thins to an interpreted zero isopach.

The sand-shale ratio (Fig. 18) is high in the southern and central areas where the Snapper Point Formation consists predominantly of fine to medium-grained pebbly protoquartzite. In the north there is a high proportion of sand in the Greta Coal Measures around the southeast margin of the trough (Fig. 17) where conglomerates are characteristic of the sequence, particularly on the Lochinvar Anticline. Most of the phenoclasts consist of volcanic rocks derived from the New England Fold Belt, and the coarsening and thickening of the conglomerates toward the northern end of the anticline suggest that the source area was nearby. The grainsize and sand-shale ratio decrease to the northwest where, at Muswellbrook in the upper Hunter Valley, siltstone and shale predominate in the sequences between the coal seams.

The beds were laid down during a marine regression from the northern area, and as the sea retreated the coal swamps which had already been formed in the upper Hunter Valley in the Sakmarian (Interval 2) extended into the lower part of the valley. The coal is generally considered to be allochthonous because of the lack of underclays. A marine influence during deposition is indicated by the high boron content (Swaine, 1962). Marine fossils, principally brachiopods and pelecypods, indicate that the Snapper Point Formation was deposited in a sublittoral marine environment. The high sand-shale ratio suggests that the basin was shallower than, or not as sheltered from the open sea, as during the deposition of Interval 2.

Interval 4: Branxton Formation (excluding Muree Sandstone Member) and Correlative Wandrawandian Siltstone

The Branxton Formation, excluding the Muree Sandstone Member, and the Wandrawandian Siltstone are included in Interval 4. Their lithology, relationships, correlation, and age are given in Plates 2 and 3, and Figures 3 and 8 to 10. The thickness, sand-shale ratios, and palaeoenvironments are shown in Figures 20 to 22.

Details of lithology, correlations and age, and relations with older units are given in Appendix 2.

Conclusions

Interval 4 attains a maximum thickness in a northerly trending depression (Fig. 20) that extends along the whole length of the basin. Some 120 m, or less, of sediment was deposited in the southern part of the depression and about 210 m in the centre of the basin. The thickness of sediment in the depression increases rapidly from the central part of the basin to over 900 m in the north adjacent to the Hunter Thrust. From the depression, the sequence thins westward to an interpreted zero isopach. The sequence also thins to the east into the offshore part of the basin. Comparison with the isopach maps for Intervals 2 and 3 indicates an apparent rotation of the depositional axis from a northwesterly to a northerly trend.

The sand-shale ratio (Fig. 21) generally decreases from the zero isopach in the west. The increase in the ratio of sand to shale in the northern part of the depression, where the sequence consists characteristically of pebbly fine-grained

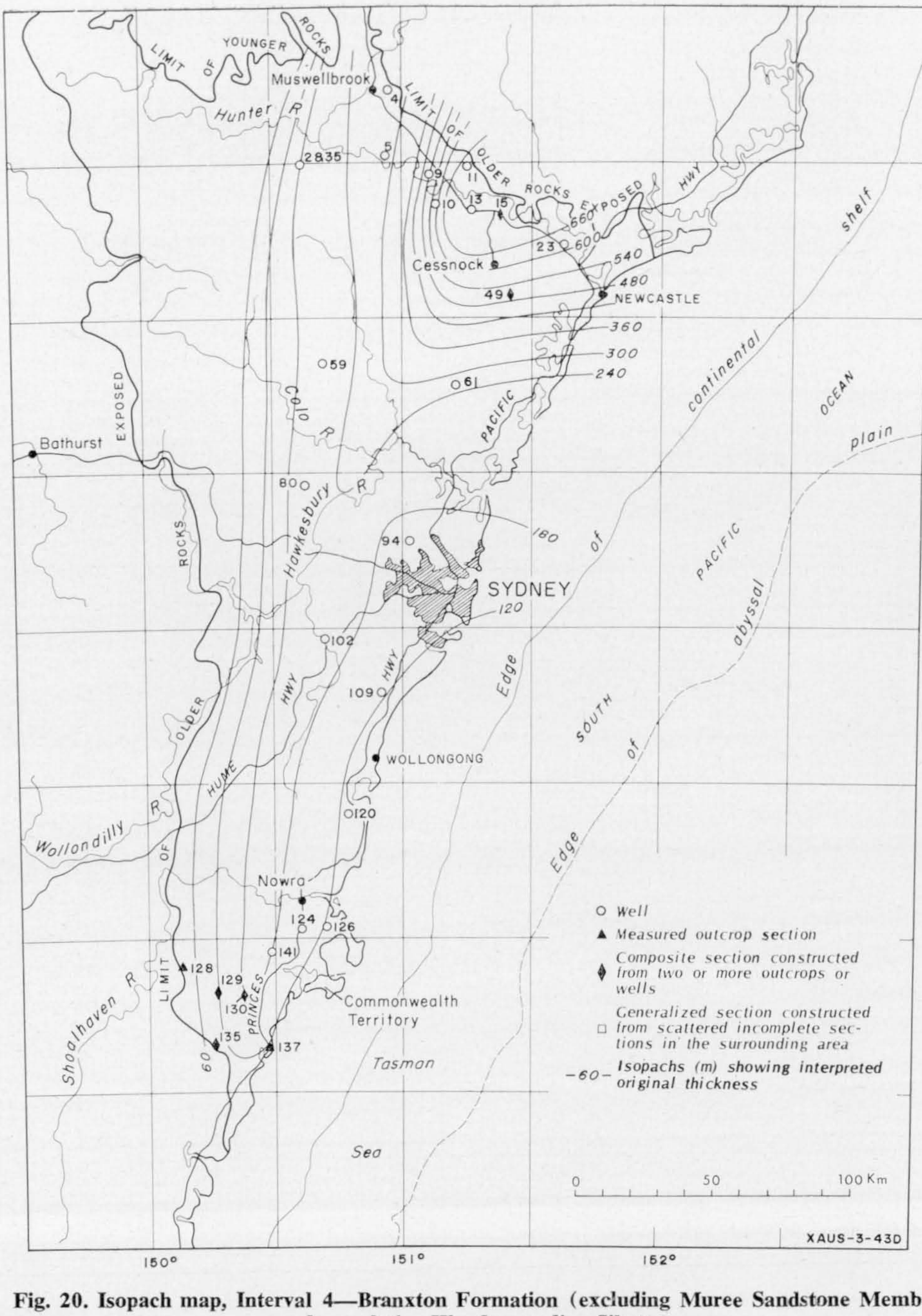

Fig. 20. Isopach map, Interval 4—Branxton Formation (excluding Muree Sandstone Member) and correlative Wandrawandian Siltstone.

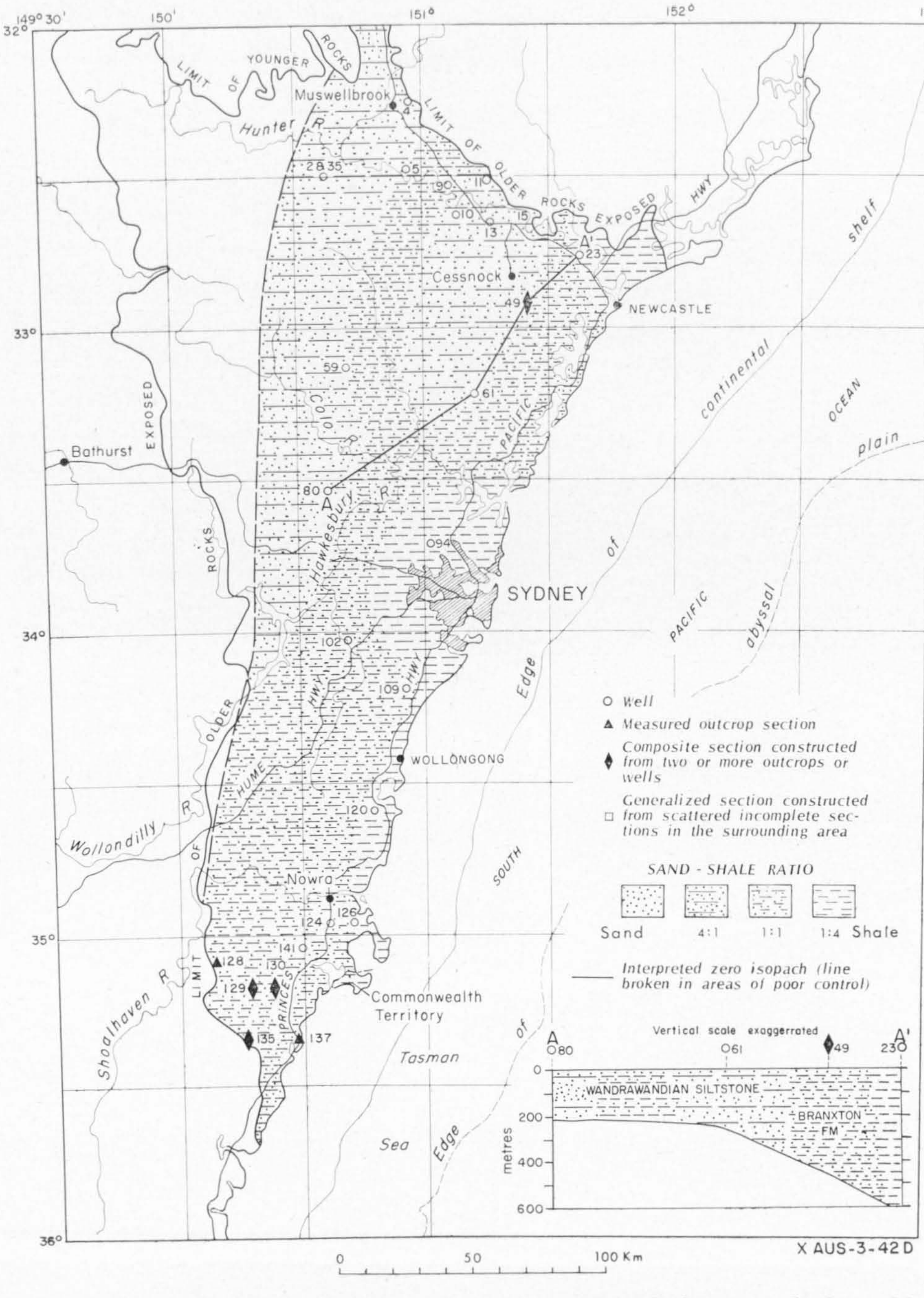

Fig. 21. Sand-shale ratios, Interval 4—Branxton Formation (excluding Muree Sandstone Member) and correlative Wandrawandian Siltstone.

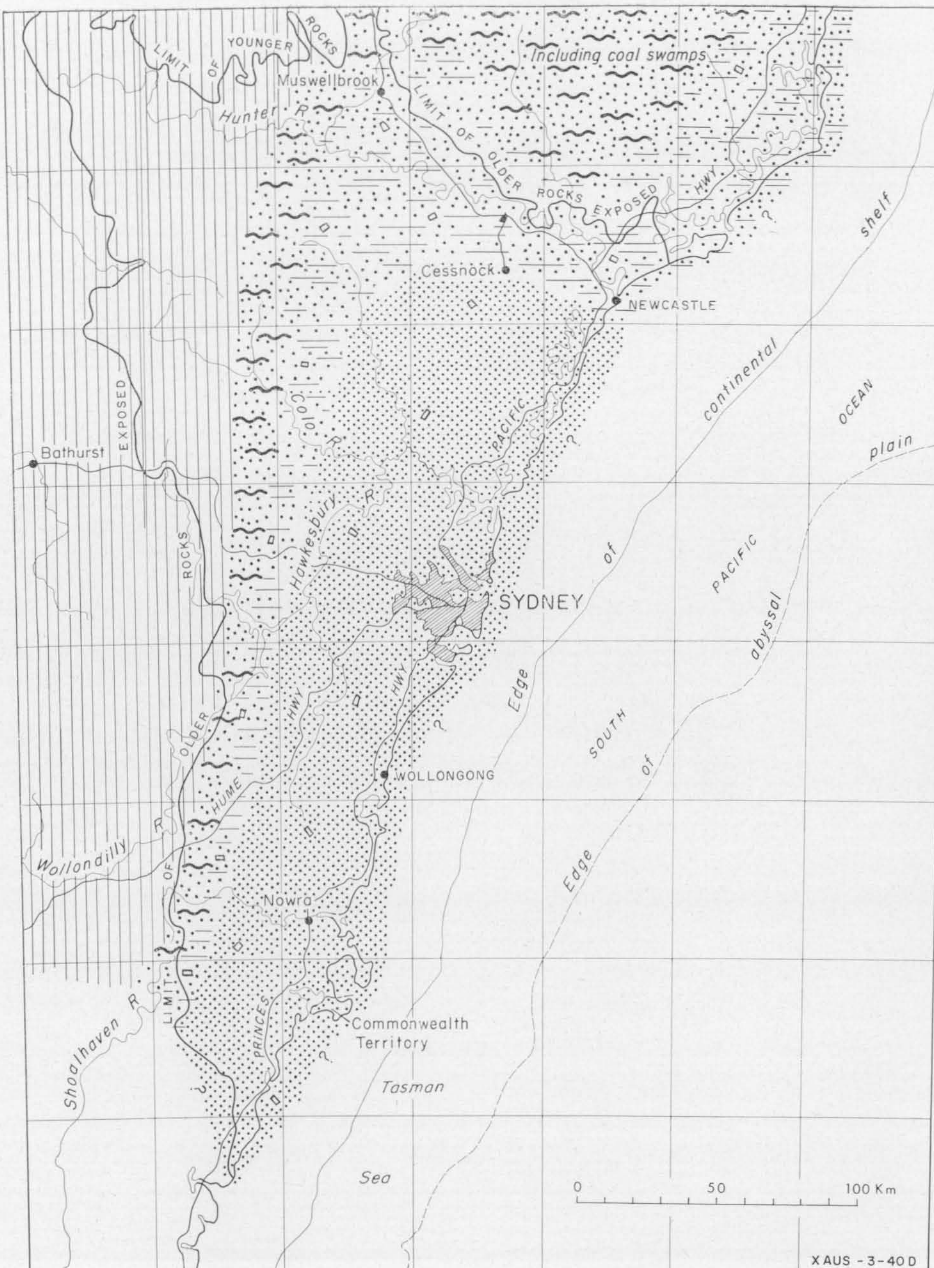

Fig. 22. Palaeoenvironments, Interval 4—late Artinskian and Kungurian.

silty sandstone and sandy siltstone with conglomeratic horizons, may indicate that some of the detritus was derived from the north along the axis of the trough.

Interval 4 was laid down during another marine transgression in the north, which also extended farther west. The marine pelecypods and brachiopods, laminated bedding, and burrow structures, indicate a placid sublittoral marine environment protected from strong tidal action. The coarser clastic material was possibly ice-rafted.

In the north the prevalence of carbonaceous material, including coal, in the Branxton Formation, and the presence of zones containing marine fossils (*Fenestella* Zone, Wollong Siltstone Member), indicates the proximity of the retreating coal swamps, and paralic sedimentation. Interpretation of seismic sections near Singleton shows that additional coal seams appear at the top of the Greta Coal Measures, which pass laterally into the Branxton Formation.

Interval 5: Muree Sandstone Member of the Branxton Formation and Correlative Nowra Sandstone

The Muree Sandstone Member of the Branxton Formation and the Nowra Sandstone are included in Interval 5. A summary of the lithology of the rocks and their relationships, correlation, and age is given in Plates 2 and 3 and Figures 3, 8, 9, and 10. The thickness and palaeoenvironments are given in Figures 23 and 24. Insufficient detail is available to provide a lithofacies map.

The detailed lithology, correlations and age, and relations with older units are given in Appendix 2.

Conclusions

Interval 5 reaches a maximum of about 90 m in the southern and central areas (Fig. 23), but to the northeast, in East Maitland No. 1, the thickness increases to 180 m. In the north it thins to the west, and beyond Singleton it can no longer be recognized as a mappable unit, or in the subsurface. It probably interfingers with the upper part of the Branxton Formation (Fig. 8). In the central area it has been tentatively identified as a thin sequence as far west as Howes Swamp No. 1 and Kurrajong Heights No. 1. In the Tallong district, at the southern end of the western area, it interfingers with the Megalong Conglomerate (McElroy & Rose, 1966).

The beds were deposited during a brief marine regression followed by transgression in the early Kazanian. A record of the event is preserved only in the area indicated on the isopach map (Fig. 23). The beds were laid down in a nearshore marine environment (Fig. 24), similar to that prevailing during the deposition of the Snapper Point Formation. The sequence consists mainly of pebbly protoquartzite with siltstone partings. The beds are conglomeratic in the north and coarse-grained in the south, but medium or fine-grained in the centre of the basin, and the sediment was probably derived both from the north and south. Cross-bedding is very common in the upper part of the Nowra Sandstone, and palaeocurrent measurements indicate a dominantly southerly source (Paix, 1968; McKelvey et al., 1971).

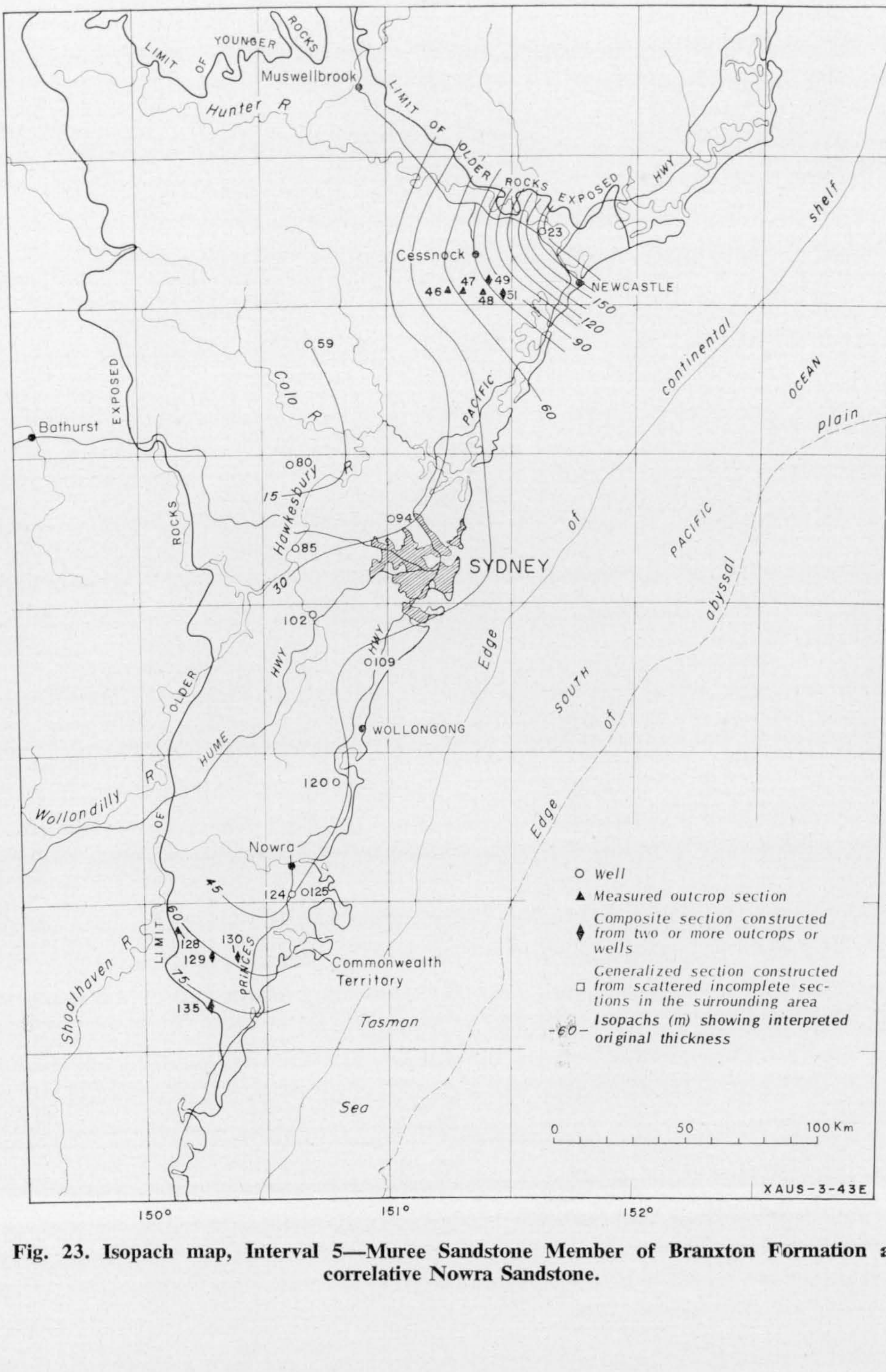

Fig. 23. Isopach map, Interval 5—Muree Sandstone Member of Branxton Formation and correlative Nowra Sandstone.

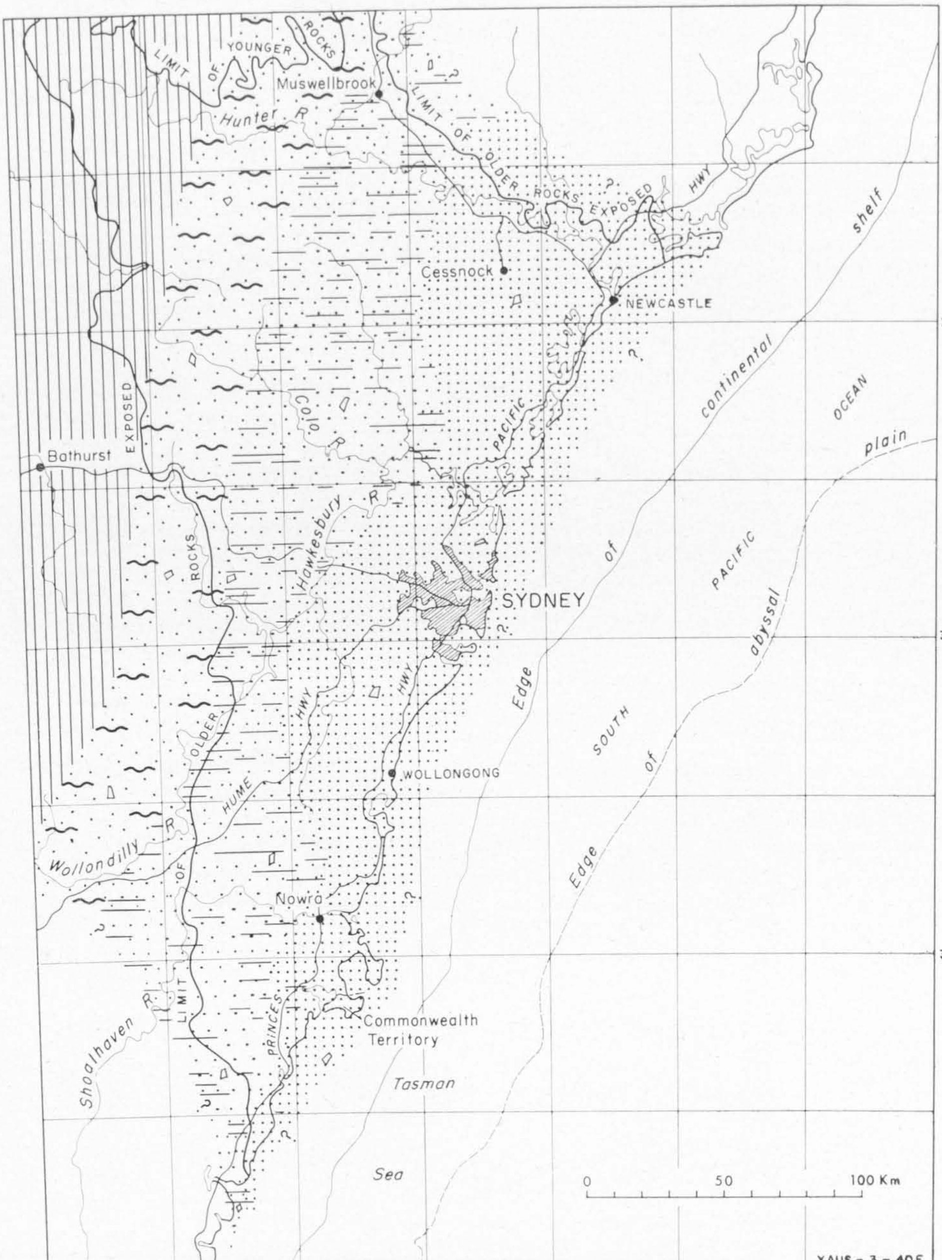

Fig. 24. Palaeoenvironments, Interval 5—lower Kazanian.

Three units have been recognized in the type section of the Muree Sandstone Member—two cliff-forming sandstone units separated by a sequence of interbedded siltstone and sandstone. Three similar units have also been distinguished in the Nowra Sandstone (Paix, 1968; Ozimic, 1971) in the Nowra/Jervis Bay area, and farther north in Stockyard Mountain No. 1. Both regressive and transgressive units may be preserved in these areas, but the subsurface extension of the Muree Sandstone Member and Nowra Sandstone in the central area is probably equivalent to the upper two units which represent only the transgressive phase.

Interval 6: Mulbring Siltstone and Correlative Berry Formation

The Mulbring Siltstone and the Berry Formation are included in Interval 6. Their lithology, relationships, correlation, and age are given in Plates 2 and 3, and Figures 3 and 8 to 10. The thickness, sand-shale ratios, and palaeoenvironments are shown in Figures 25 to 27.

Details of lithology, correlations and age, and relations with older units are given in Appendix 2.

Conclusions

The thickness of Interval 6 (Fig. 25) increases eastward to about 460 m in a trough we have called the MacDonald Depression, and farther east it is interpreted as thinning over the Kulnura Arch (about Cessnock) before it thickens again to 510 m west of Newcastle (East Maitland No. 1).

The arch and complementary depression were probably formed by gentle warping during the deposition of the Mulbring Siltstone.

The sand-shale ratio (Fig. 26) is low in the north and south and along the present coastline, but increases to the west. The sequence consists mainly of siltstone and poorly sorted fine-grained sandstone. Marine pelecypods and brachiopods are widely distributed, except on the western margin to the north of the Shoalhaven River. Foraminifera have been recorded in outcrops of the Mulbring Siltstone in the north, and in wells in the central area. The presence of marine fossils, burrow and scallop structures, and the fine grainsize indicate a sheltered sublittoral marine environment (Fig. 27) similar to those prevailing during earlier transgressions (Interval 2 and 4). The beds were laid down in deeper and quieter water during and after the marine transgression that began during the deposition of Interval 5. This is the most widespread transgression into the Sydney Basin, and faunal evidence (Dickins, 1968) suggests that the sea was connected with the Bowen Basin at this time. The connexion remained open until a regression at the end of the Kazanian destroyed the marine environment. The ice-rafted material in the sediments in the western part of the basin is the youngest record of glacial activity in the Sydney Basin.

UPPER KAZANIAN TO MIDDLE TRIASSIC ROCKS

The rocks of Tatarian and Triassic age include the Newcastle, Tomago, Singleton, and Illawarra Coal Measures, the Narrabeen Group, the Hawkesbury Sandstone, and the Wianamatta Group. Their distribution is given in Plate 1. Figures 8, 9, and 10 show the rock relationships, and the six intervals into which the sequence has been subdivided.

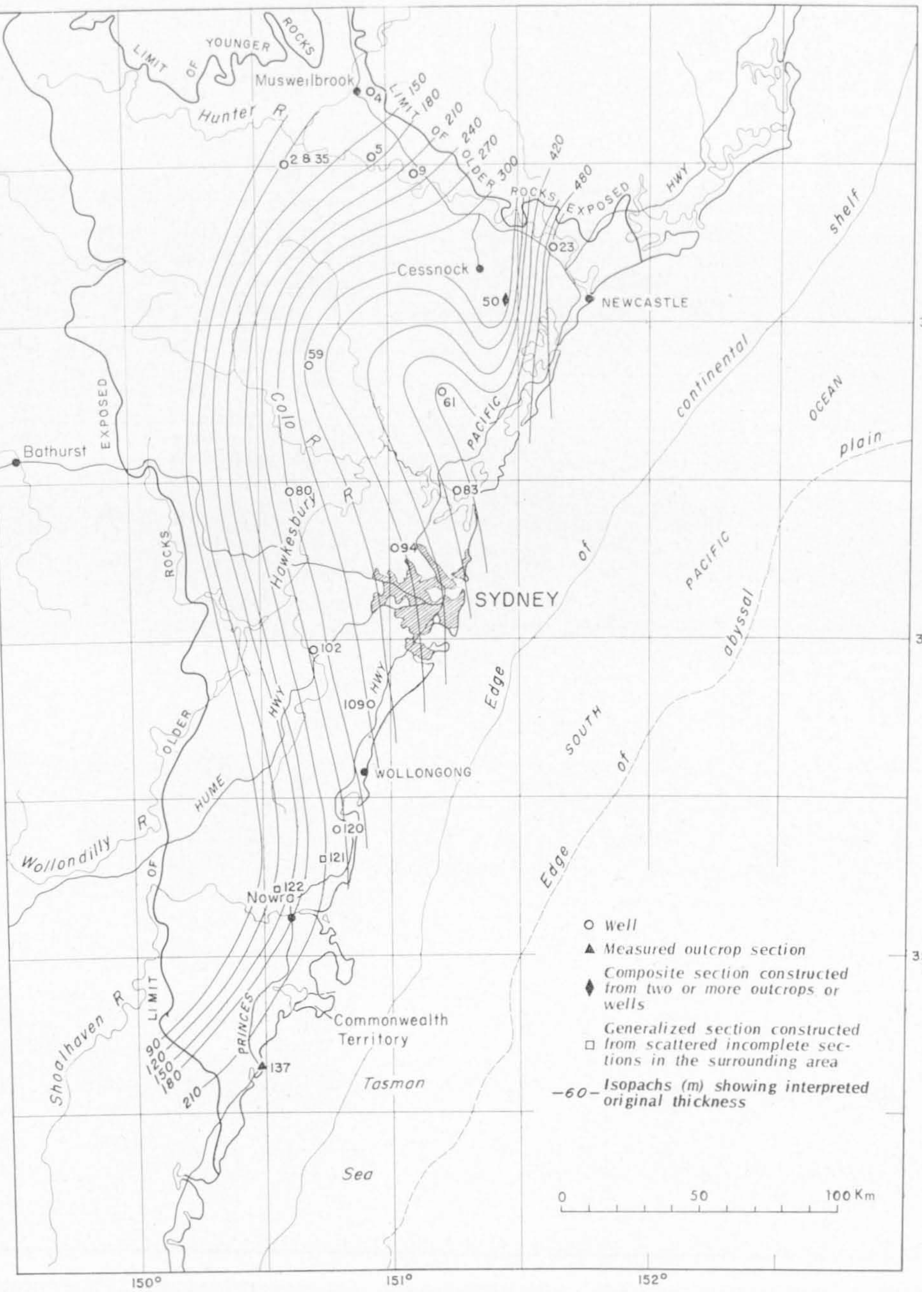

Fig. 25. Isopach map, Interval 6—Mulbring Siltstone and correlative Berry Formation.

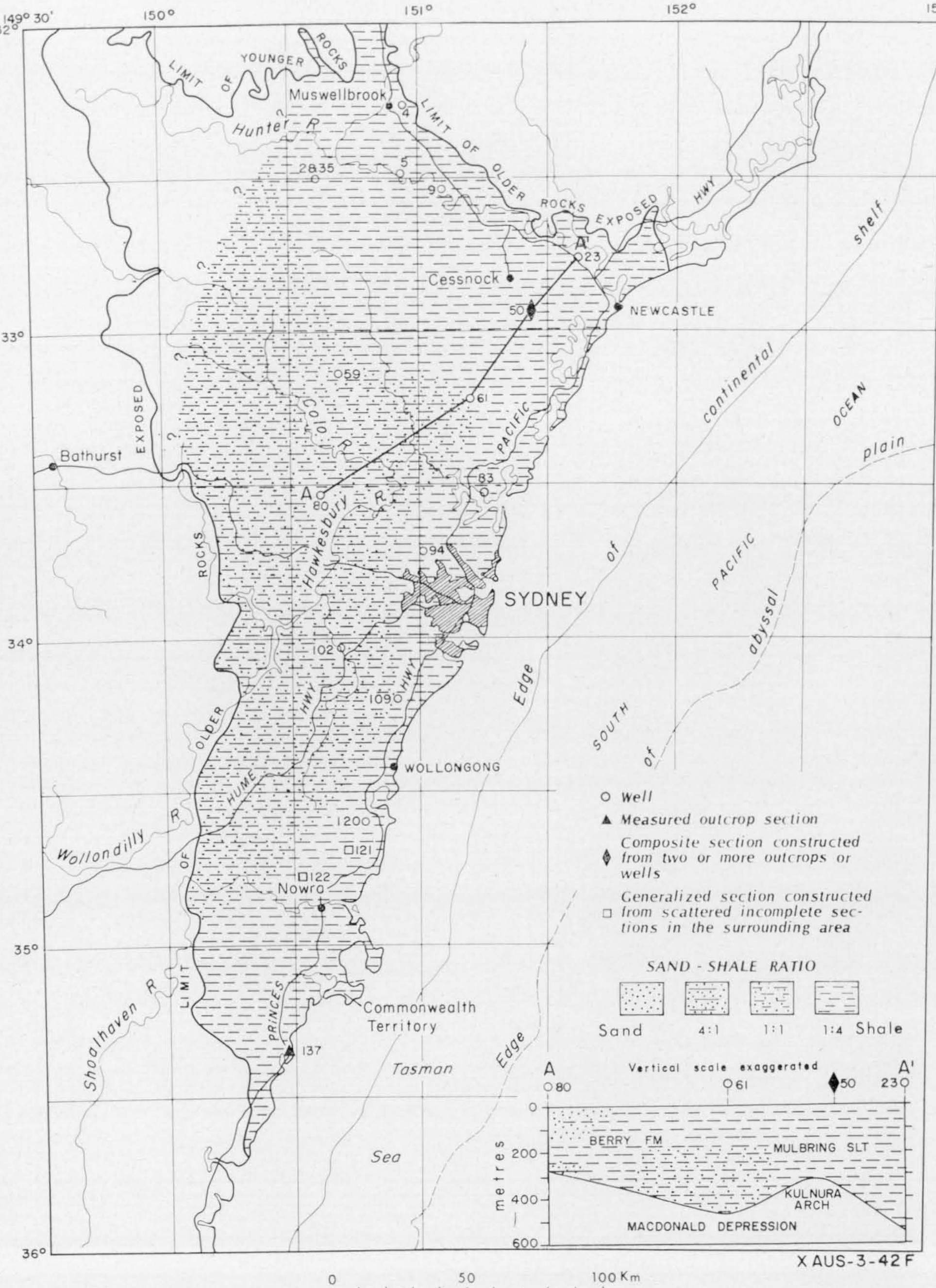

Fig. 26. Sand-shale ratios, Interval 6—Mulbring Siltstone and correlative Berry Formation.

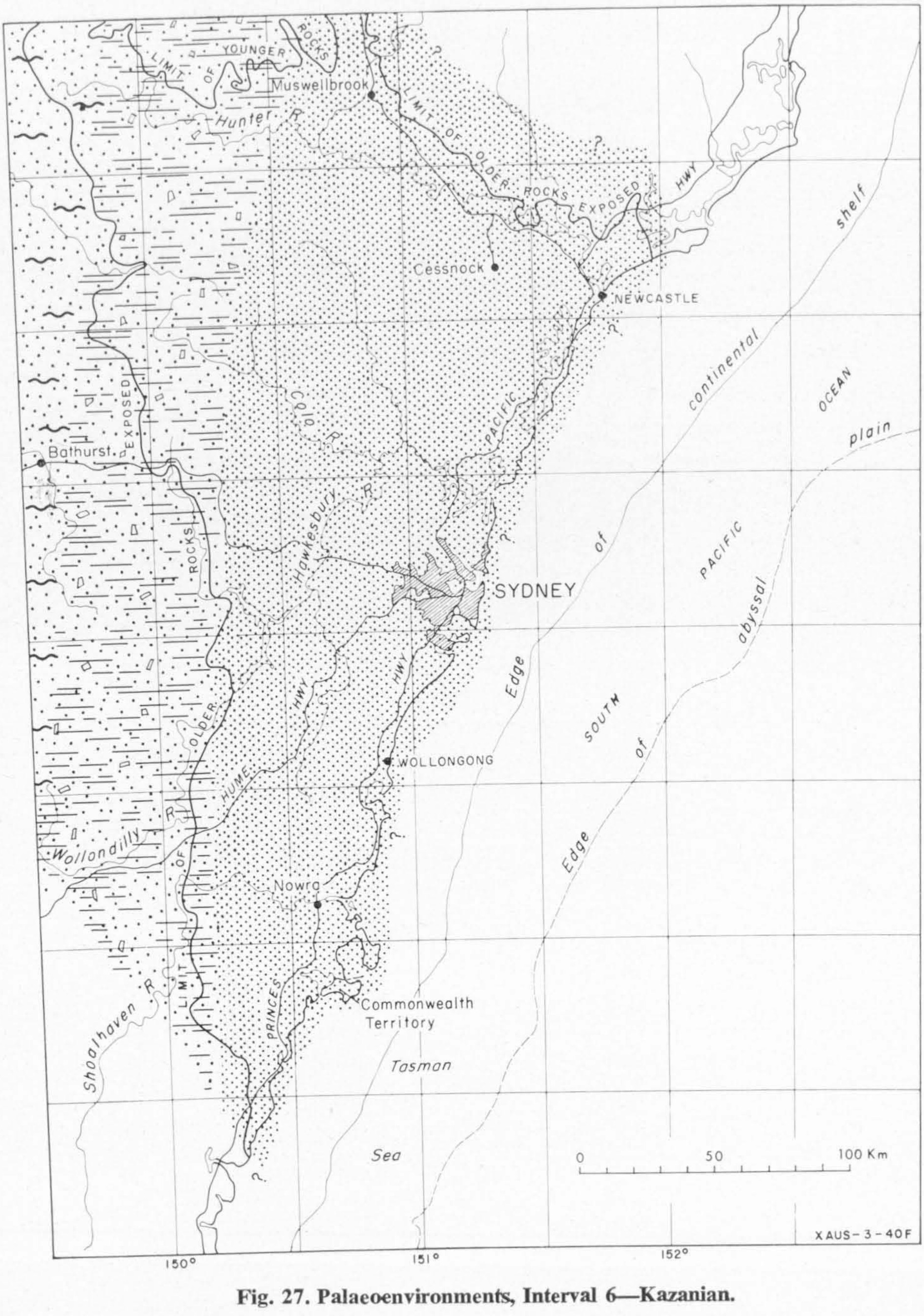

Fig. 27. Palaeoenvironments, Interval 6—Kazanian.

Interval 7 contains the lower part of the Wallis Creek Formation and its correlatives; Interval 8 comprises the upper part of the Wallis Creek Formation and correlatives; Interval 9 contains the Four Mile Creek Formation and correlatives; Interval 10 comprises the Waratah Sandstone and Dempsey Formation and correlatives; Interval 11 consists of the Newcastle Coal Measures, excluding the Waratah Sandstone, and correlatives; Interval 12 is the Narrabeen Group; Interval 13 is the Hawkesbury Sandstone, and Interval 14 is the Wianamatta Group. Intervals 7 to 11 and the lower part of Interval 12 are of Tatarian age; the upper part of Interval 12, and Interval 13, are Lower Triassic; and Interval 14 is Middle Triassic (see also Fig. 44).

The detailed lithology, correlations and age, and relations with older units are given in Appendix 3.

Interval 7: Lower Part of the Wallis Creek Formation and Correlatives

The Wallis Creek Formation of the Tomago Coal Measures is informally subdivided into two units; the subdivision is taken at the top of the Rathluba Seam in the lower Hunter Valley. The lower unit, which consists of sandstone and shale with interbedded coal seams, and its correlatives the Mount Marsden Claystone, Budgong Sandstone, Pheasants Nest Formation, the lower half of the Vane Sub-Group, and the Saltwater Creek Formation are included in Interval 7. The distribution of the Upper Permian coal measures within which Interval 7 occurs, is given in Plate 1. A summary of the lithology, and the relationships, correlation, and age of the rocks are given in Plates 2 and 3 and Figures 3, 8, 9, and 10. The thickness, sand-shale ratios, and palaeoenvironments are shown in Figures 28 to 30.

Details of lithology, correlations and age, contacts, and relations with older units are given in Appendix 3.

Conclusions

Interval 7 attains a thickness of 300 m in the Macquarie Depression, a narrow belt along the present coastline (Fig. 28), and is interpreted to thin to the west over the Kulnura Arch and thicken again in the Macdonald Depression. From this depression it thins gradually to the interpreted zero isopach near the present western margin of the basin. The two depressions and the intervening arch developed just before, or early in, the depositional cycle, and continued to influence the thickness and type of sediments laid down until the early Triassic. Sediment removed by erosion over the Lochinvar Anticline has been restored in Figure 28.

Figure 29 shows a gradual change from a high sand-shale ratio in the south to a low ratio in the north, especially in the Macdonald Depression.

A shallow sea (Fig. 30) with active volcanoes existed in the southern area, where latite lava flows of the Gerringong Volcanics are interbedded with the tuffaceous fossiliferous marine Budgong Sandstone (Bowman, 1970). A restricted sea extended into the middle of the basin where the Mount Marsden Claystone, which consists of claystone with thin interbeds of limestone and dolomite containing the rare carbonates dawsonite and nordstrandite, was laid down conformably on the Berry Formation. Along the coast a belt of emergent silt and mud of the Berry

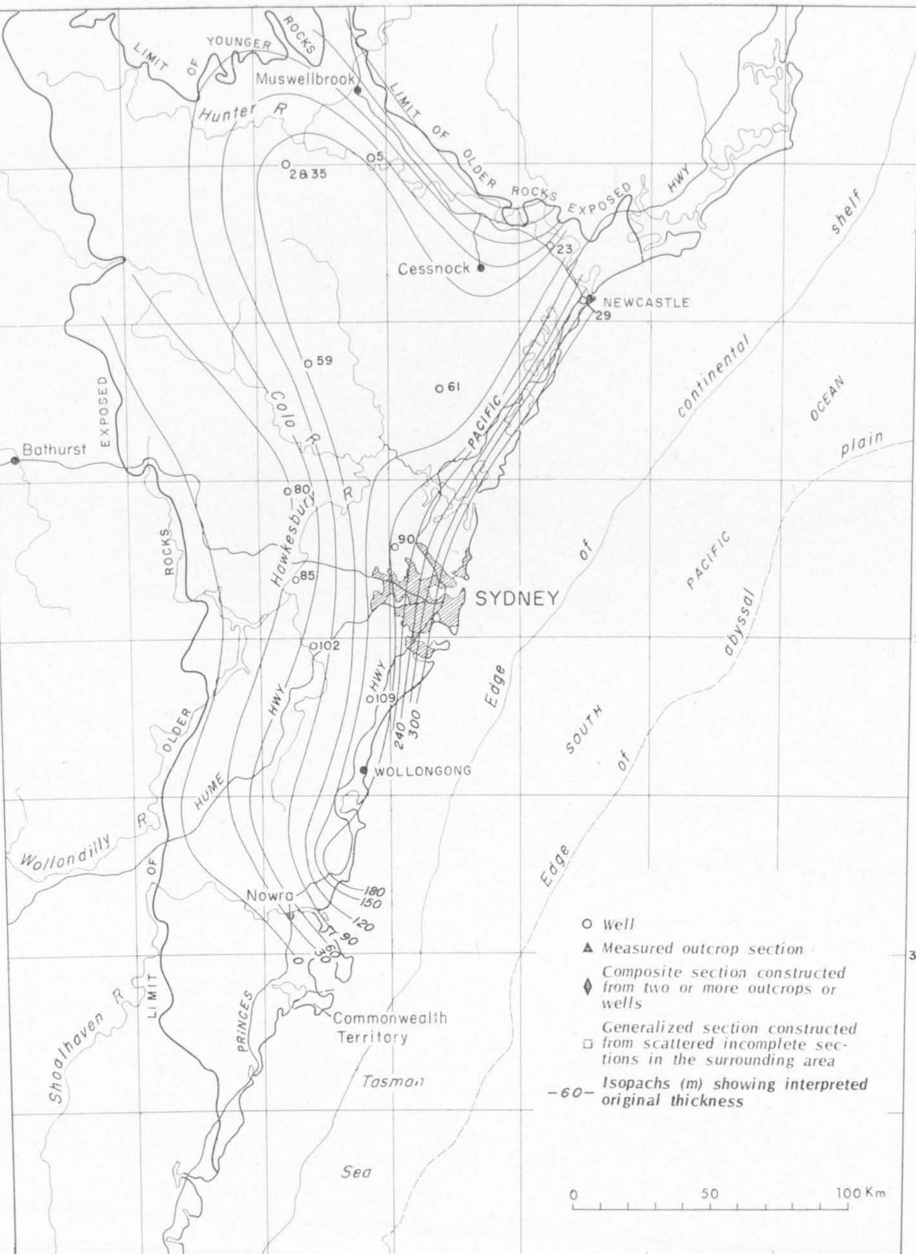

Fig. 28. Isopach map, Interval 7—lower part of Wallis Creek Formation and correlatives.

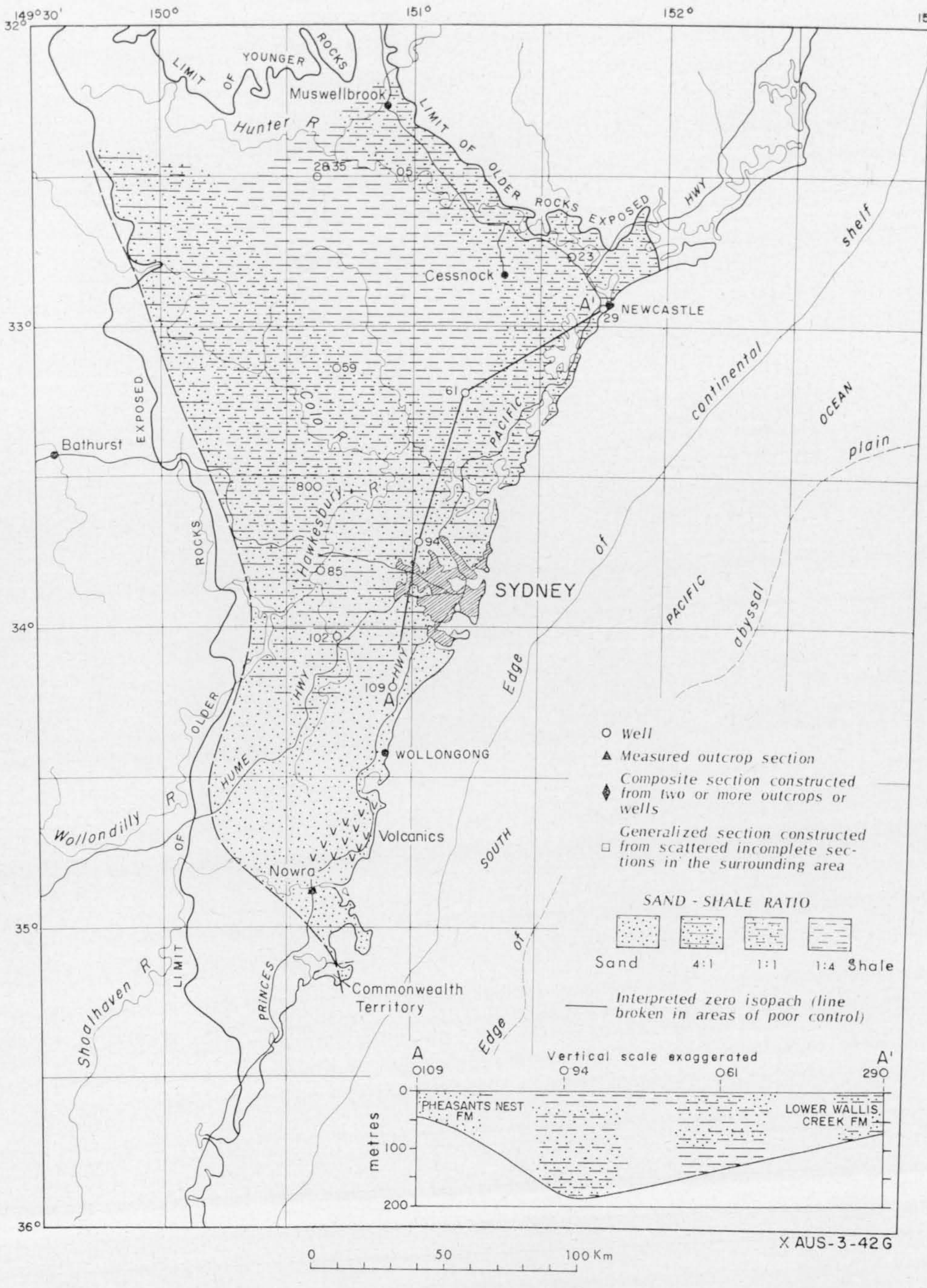

Fig. 29. Sand-shale ratios, Interval 7—lower part of Wallis Creek Formation and correlatives.

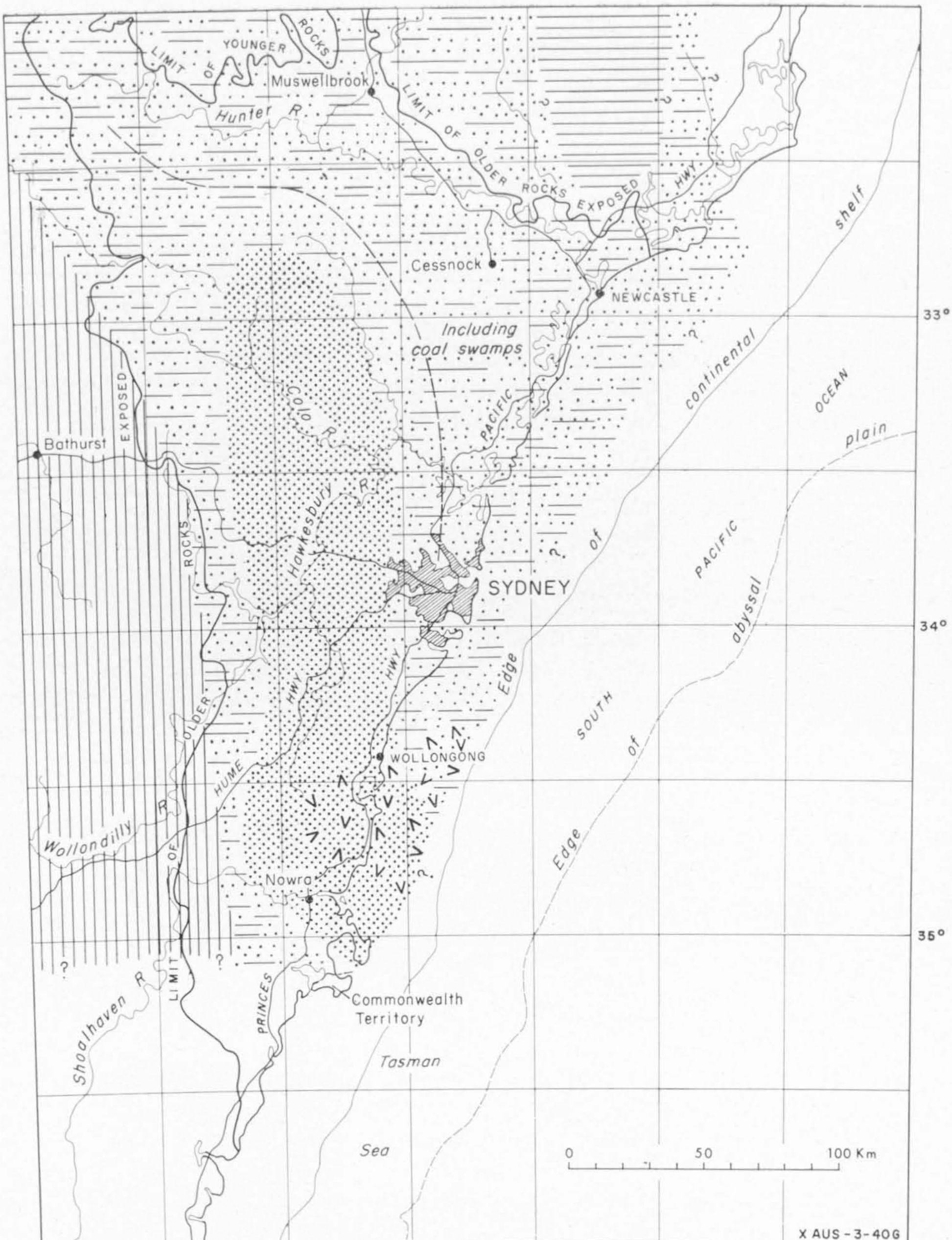

Fig. 30. Palaeoenvironments, Interval 7—upper Kazanian to lower Tatarian.

Formation and the Mulbring Siltstone was gradually covered by swamps and coal forests. The presence of dwarfed marine fossils in the lowest beds of the Wallis Creek Formation indicates the transition from sea to land conditions. Terrestrial conditions are indicated by the presence of plant impressions, carbonaceous material, and thin coal seams in the sandstones and shales of the Pheasants Nest

Formation, the Wallis Creek Formation, the Vane Sub-Group, and the Saltwater Creek Formation. There is no evidence that Interval 7 or any subsequent interval was deposited south of the area in which the Gerringong Volcanics are preserved (see Fig. 10).

Interval 8: Upper Part of the Wallis Creek Formation and Correlatives

Interval 8 comprises the upper part of the Wallis Creek Formation, which consists chiefly of sandstone, and its correlatives, the upper part of the Vane Sub-Group, the Coorongooba Creek Sandstone, and the Erins Vale Formation. The distribution of the Upper Permian coal measures, in which the interval occurs, is given in Plate 1. Their lithology, relationships, correlation, and age are given in Plates 2 and 3, and Figures 3 and 8 to 10. The thickness, sand-shale ratios, and palaeoenvironments are shown in Figures 31 to 33.

The detailed lithology, correlations and age, and relations with older units are given in Appendix 3.

Conclusions

In the north (Fig. 31) Interval 8 thickens eastwards from the interpreted zero isopach to about 180 m in the Macdonald Depression. It is interpreted to thin slightly over the Kulnura Arch and then thickens rapidly into the Macquarie Depression. Both the Macdonald Depression and the Kulnura Arch die out to the south. Sediment removed by erosion over the Lochinvar Anticline has been restored in Figure 31.

The sand-shale ratio map (Fig. 32) shows a high sand-shale ratio in the west and a much lower ratio in the Macdonald and Macquarie Depressions to the east.

Interval 8 contains a marine tongue, and at one stage a shallow sea covered the southern and middle parts of the basin (Fig. 33). In this area the Coorongooba Creek Sandstone contains a calcarenite (Goldbery, 1969) that was probably laid down after partial reworking of the underlying carbonate lenses in the Mount Marsden Claystone. Shallow marine flats covered most of the area occupied by the coal swamps during Interval 7, and the presence of the sea is recorded by the occurrence of marine fossils in the Kulnura Marine Tongue (Bowman, 1970) of the Erins Vale Formation and its correlatives in the upper part of the Wallis Creek Formation and the Vane Sub-Group. Flood-plains and minor coal swamps fringed the sea as it transgressed and then regressed.

Interval 9: Four Mile Creek Formation and Correlatives

The Four Mile Creek Formation, the Burnamwood, Mount Ogilvie, and Malabar Formations, the Gundangaroo Formation, and the lower part of the Wilton Formation are included in Interval 9. A summary of the lithology of the rocks and their relationships, correlation, and age is given in Plates 2 and 3 and Figures 3 and 8 to 10. The thickness, sand-shale ratios, and palaeoenvironments are shown in Figures 34 to 36.

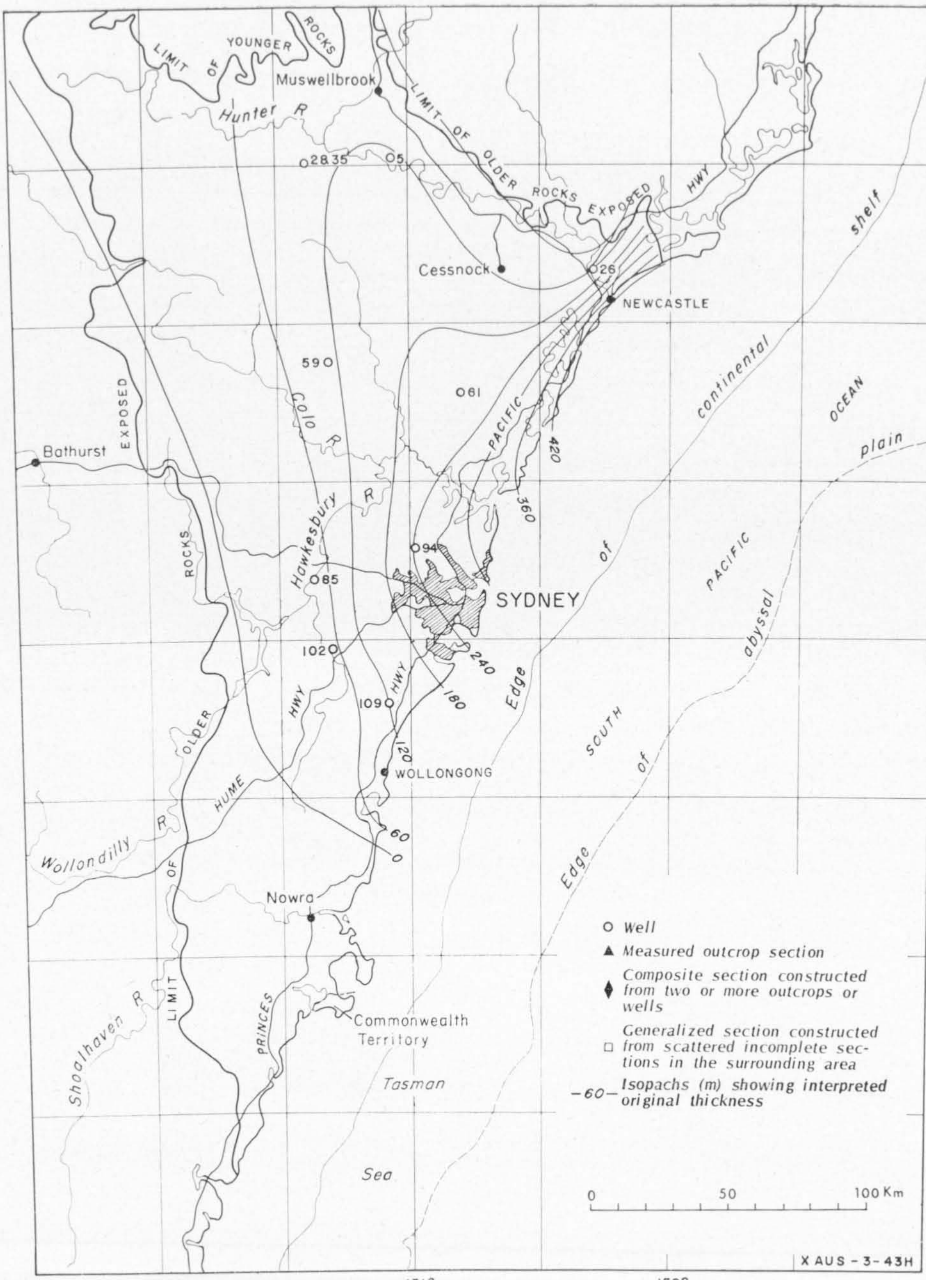

Fig. 31. Isopach map, Interval 8—upper part of Wallis Creek Formation and correlatives.

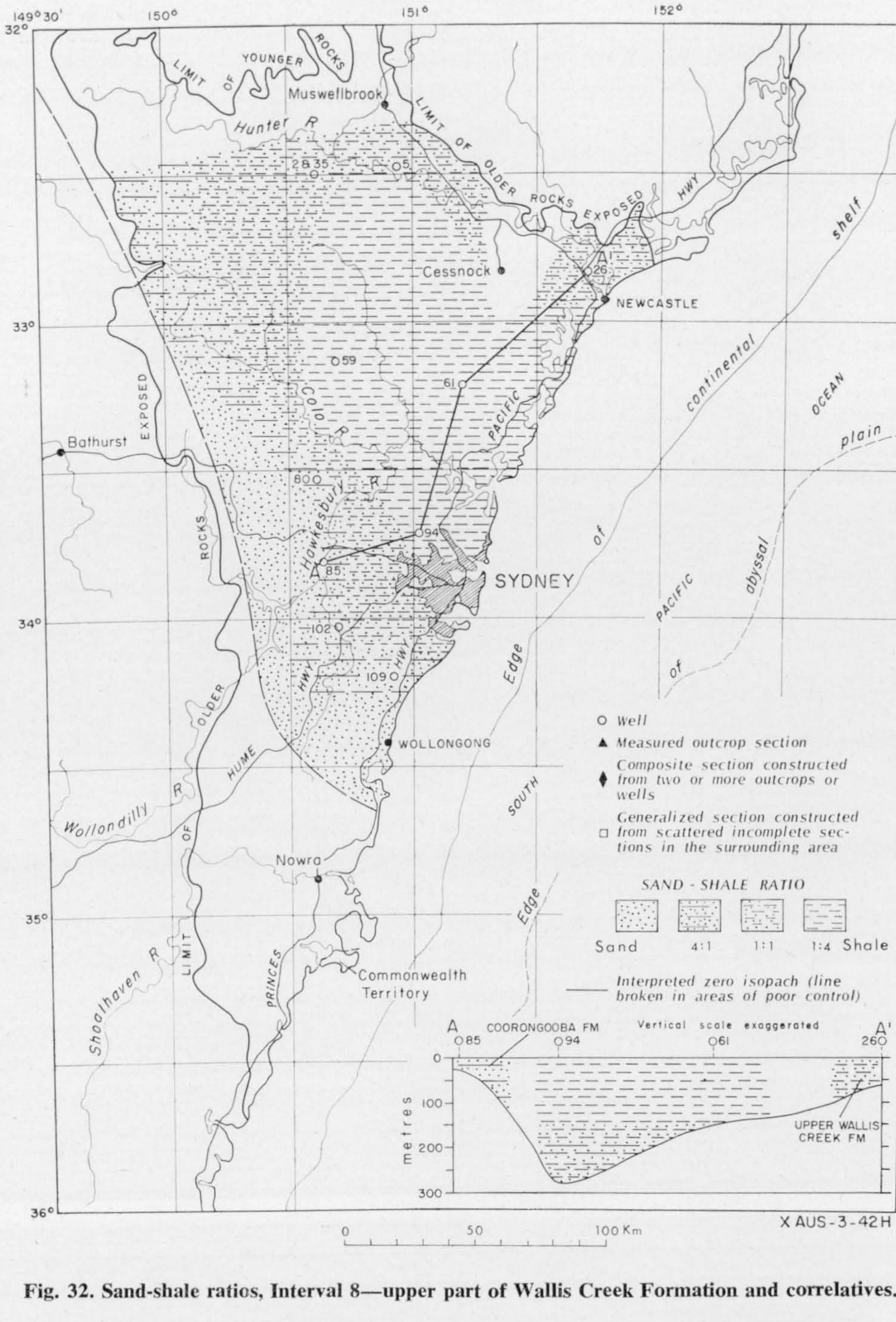

Fig. 32. Sand-shale ratios, Interval 8—upper part of Wallis Creek Formation and correlatives.

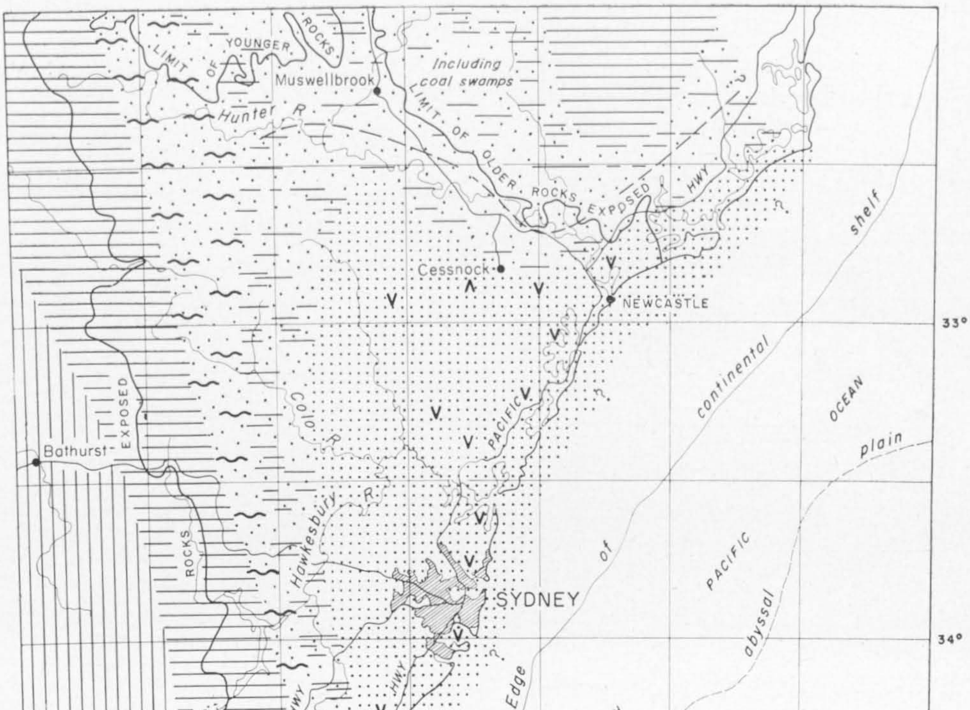

Fig. 33. Palaeoenvironments, Interval 8—lower Tatarian.

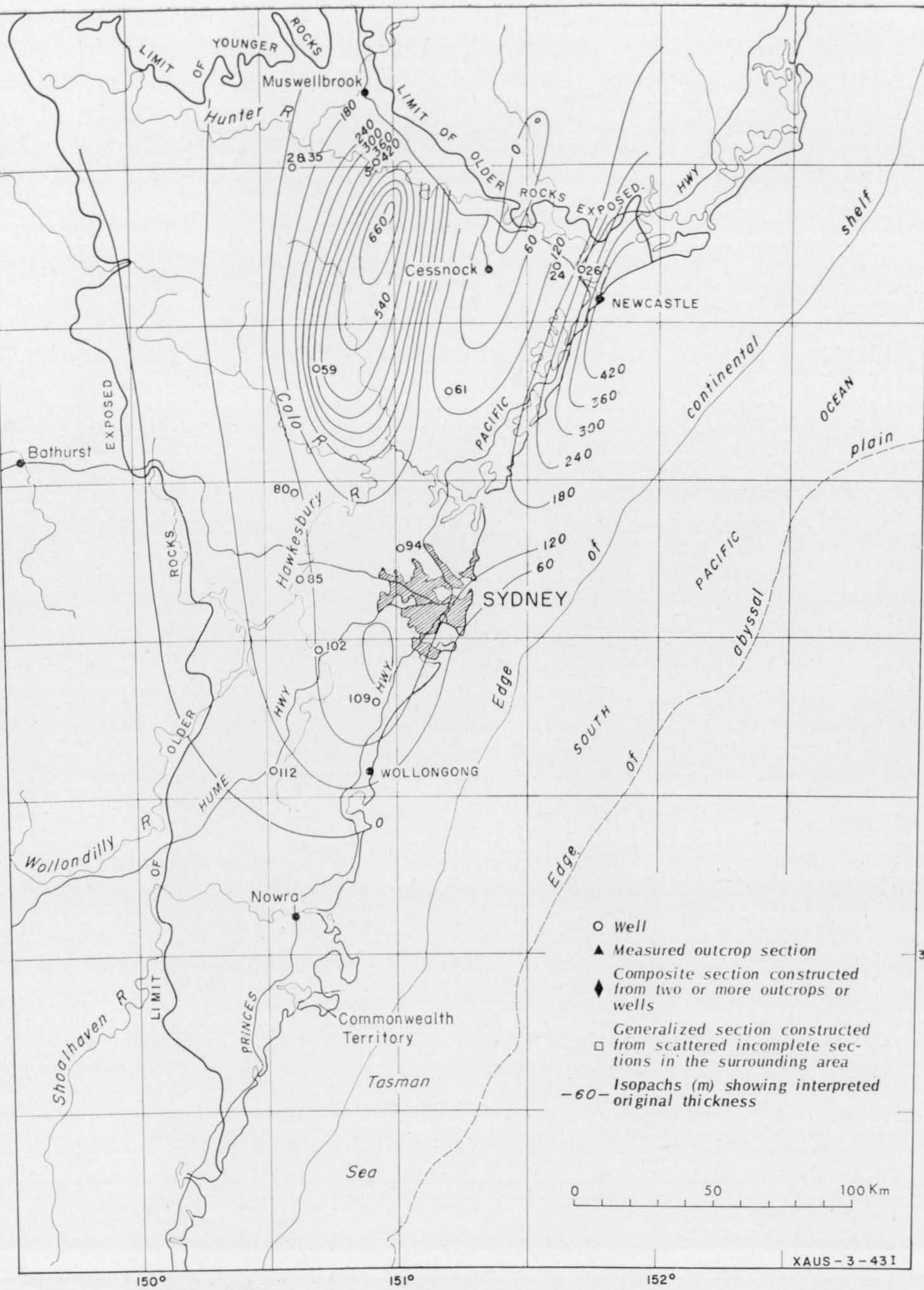

Fig. 34. Isopach map, Interval 9—Four Mile Creek Formation and correlatives.

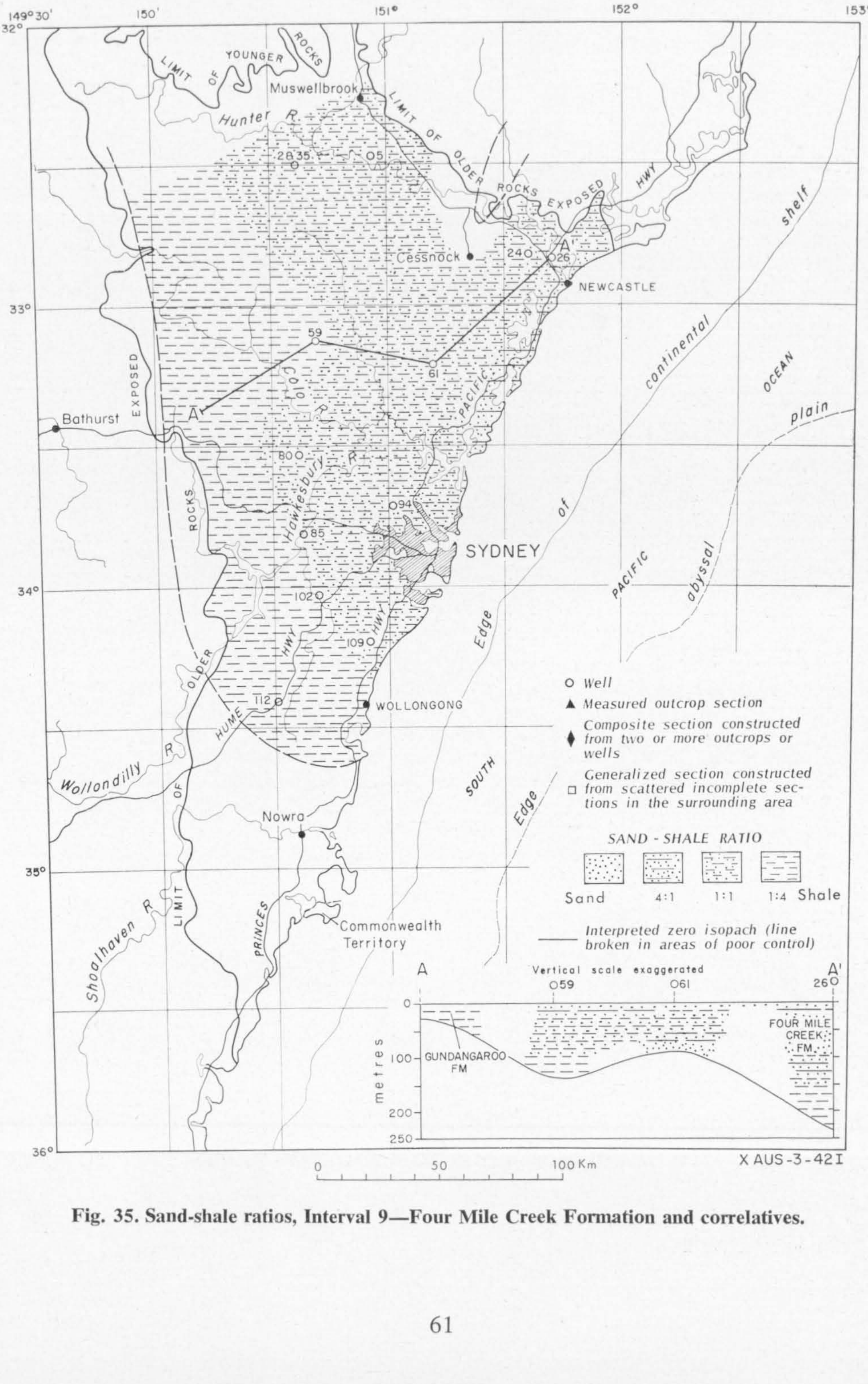

Fig. 35. Sand-shale ratios, Interval 9—Four Mile Creek Formation and correlatives.

Fig. 36. Palaeoenvironments, Interval 9—middle Tatarian.

Details of lithology, correlations and age, and relations with older units are given in Appendix 3.

Conclusions

Interval 9 is up to 450 m thick in the Macquarie Depression which extended northwards into New England; it thins over the Kulnura Arch to an interpreted zero isopach at the northern end and thickens to about 670 m in the Macdonald Depression (Fig. 34). Elsewhere it thins gradually to the west and south to the interpreted zero isopach near the present margin of the basin. Sediment removed by erosion over the Lochinvar Anticline has been restored in Figure 34.

Figure 35 shows a low sand-shale ratio in the west, and a gradual increase in the proportion of sand to the east.

The sequence is entirely fluvial or deltaic (marginal), and contains abundant plant remains and coal deposits. Coal swamps were especially prominent in the Hunter Valley region, where the Four Mile Creek, Burnamwood, Mount Ogilvie, and Malabar Formations contain large quantities of economically important coal. Elsewhere, the coal swamps were relatively poorly developed: in the Southern Coalfield there is only one lenticular seam, and in the Western Coalfield only coal laminae and fossil wood. The great coal swamps of the Northern Coalfield probably gave way to the south to a more elevated and less swampy terrain where forest trees were more prominent.

Interval 10: Waratah Sandstone and Dempsey Formation and Correlatives

The Waratah Sandstone and the Dempsey Formation, the Watts Sandstone and the Denman Formation, the Marrangaroo Conglomerate, the Higgins Creek Sandstone, and the upper part of the Wilton Formation are included in Interval 10. It consists of barren coal measures and a tongue of marine beds. The distribution of the stratigraphic units is given in Plate 1. Their lithology, relationships, correlation, and age are given in Plates 2 and 3, and Figures 3 and 8 to 10. The thickness, sand-shale ratios, and palaeoenvironments are shown in figures 37 to 39.

The detailed lithology, correlations and age, and relations with older units are given in Appendix 3.

Conclusions

Interval 10 is 500 m thick in the Macquarie Depression, which extended into New England; it thins over the Kulnura Arch to an interpreted zero isopach at the northern end and thickens to 130 m in the Macdonald Depression (Fig. 37). The position of this zero isopach is uncertain because the interval was eroded from the Lochinvar Anticline before the Newcastle Coal Measures were laid down. It thins gradually to the west and south to the interpreted zero isopach near the present margin of the basin.

The high sand-shale ratio in the west (Fig. 38) and the low ratio in the east is a reversal of the conditions prevailing during the deposition of Interval 9, and a return to those obtaining during Interval 8.

Interval 10 contains a minor marine tongue within the predominantly terrestrial sequence. At one stage (Fig. 39) the shallow sea transgressed as far west as Mulgoa, where Foraminifera are present. The coarser-grained clastic sediments

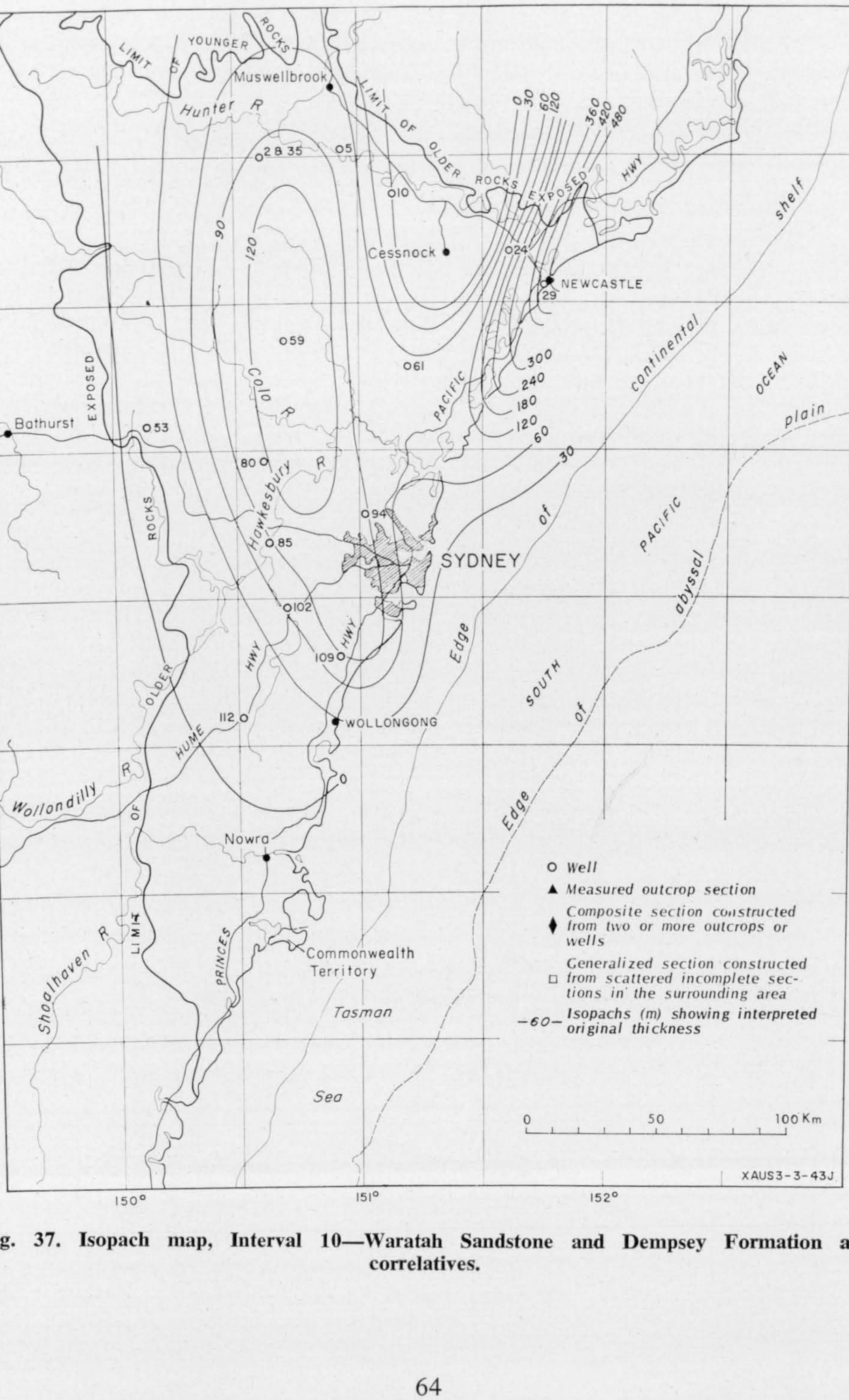

Fig. 37. Isopach map, Interval 10—Waratah Sandstone and Dempsey Formation and correlatives.

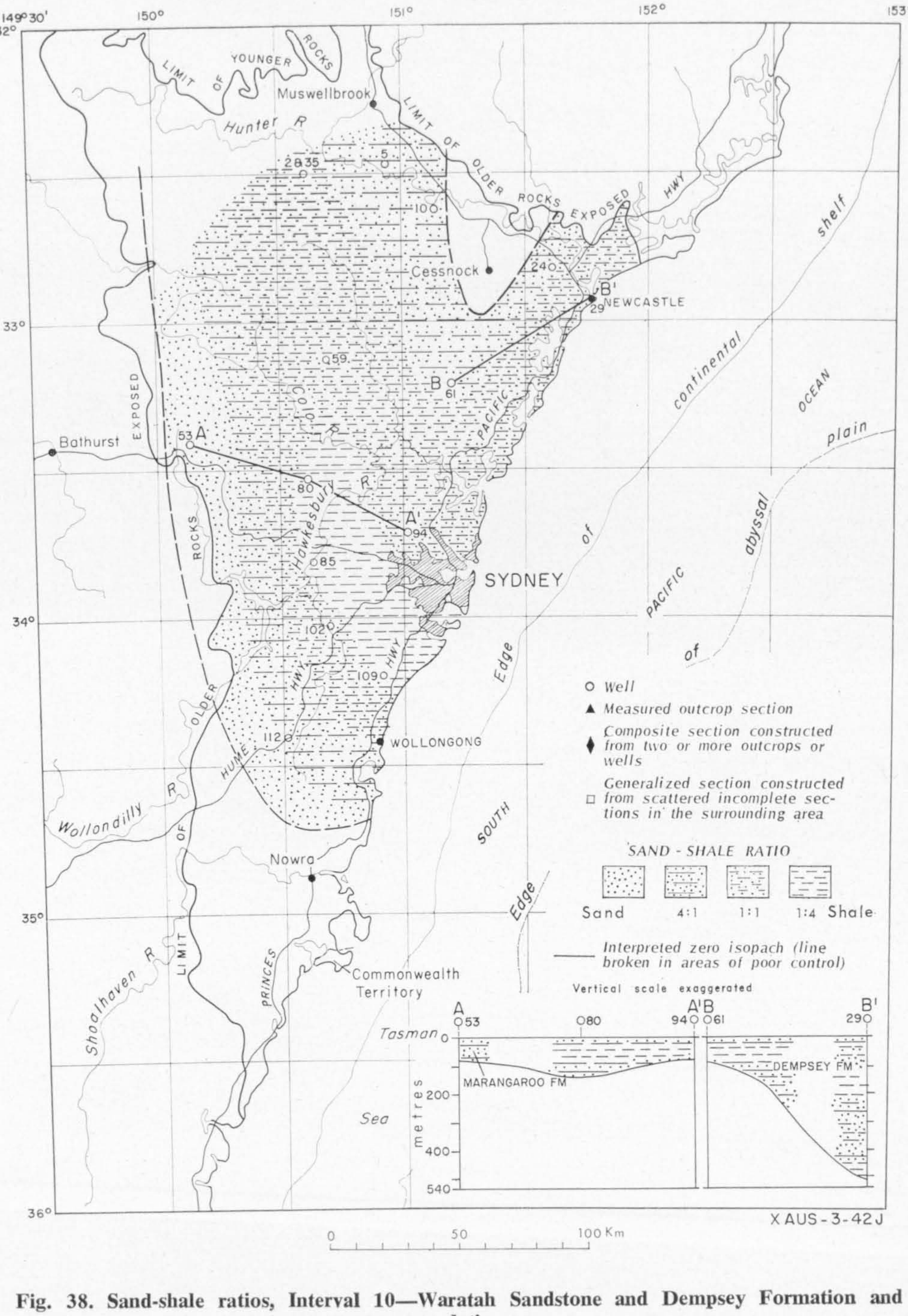

Fig. 38. Sand-shale ratios, Interval 10—Waratah Sandstone and Dempsey Formation and correlatives.

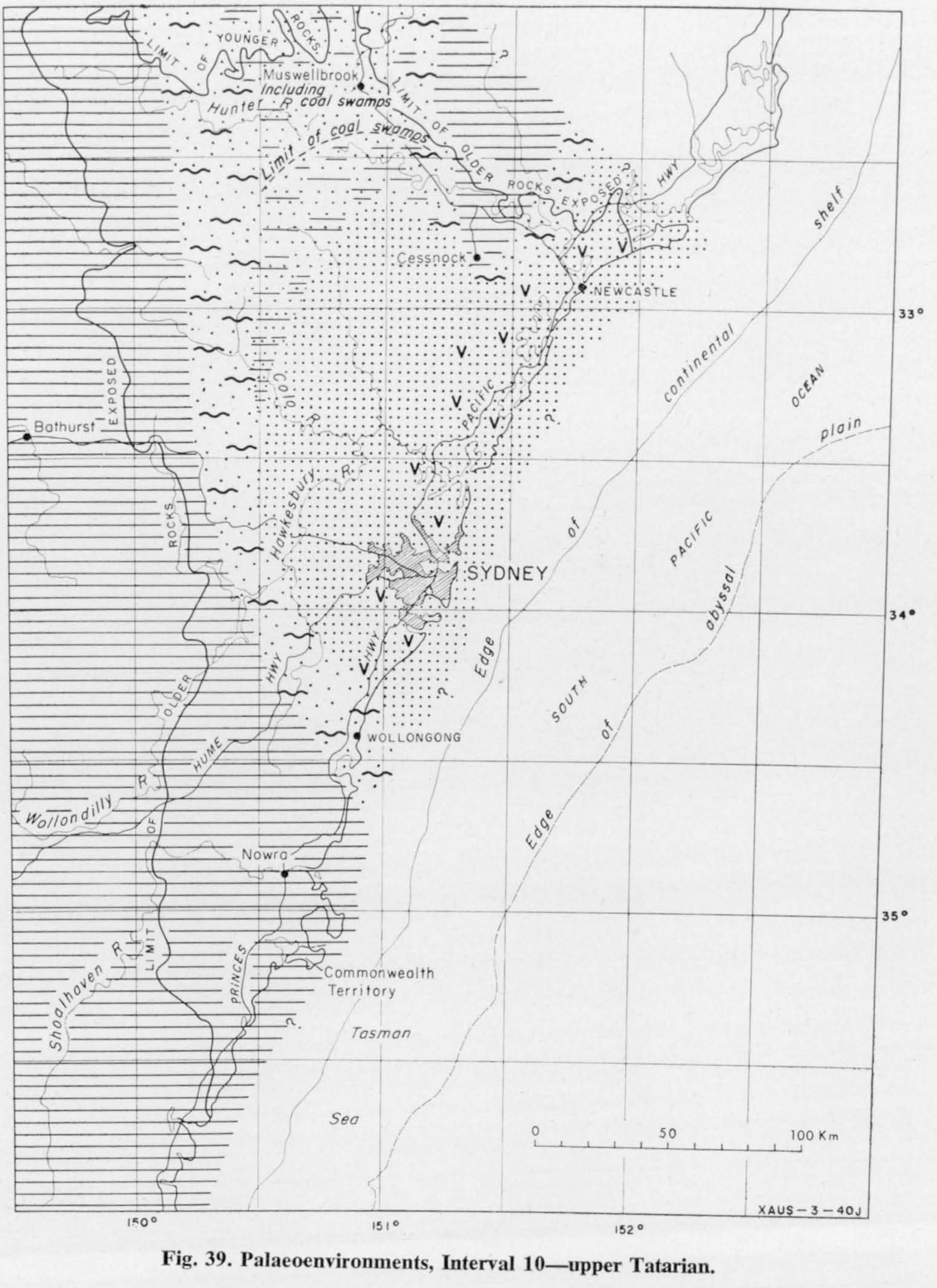

Fig. 39. Palaeoenvironments, Interval 10—upper Tatarian.

above and below the marine tongue contain plant impressions and fossil wood; they were probably laid down in sparsely vegetated marginal swamps flanked on the landward side by a fluvial environment.

Interval 11: Newcastle Coal Measures (excluding Waratah Sandstone) and Correlatives

Interval 11 comprises the Newcastle Coal Measures (excluding the Waratah Sandstone), the Wollombi Coal Measures (excluding the Watts Sandstone), the Charbon Sub-Group above the Marrangaroo Conglomerate, and the Sydney Sub-Group above the Wilton Formation.

The distribution of the Newcastle Coal Measures is given in Plate 1. Their lithology, relationships, correlation, and age are given in Plates 2 and 3, and Figures 3 and 8 to 10. The thickness, sand-shale ratios, and palaeoenvironments are shown in Figures 40 to 42.

Details of lithology, correlations and age, and relations with older units are given in Appendix 3.

Conclusions

Interval 11 is 430 m thick in the Macquarie Depression and thins to a zero isopach around the northern end of the Kulnura Arch (Fig. 40). The Macquarie Depression extended into New England, and there was a slight thinning near Dural. Figure 40 shows the preserved thickness in the Lochinvar Anticline area, where an unknown thickness was removed by erosion before the Narrabeen Group was laid down. The sequence thickens again to 430 m in the Macdonald Depression, and then thins gradually to the west and south to an interpreted zero isopach near the present margin of the basin.

Most of the rocks have a low sand-shale ratio (Fig. 41). The increase in the ratio in the middle part of the western area may possibly be due to the growth of a delta formed of sediment derived from the granitic hinterland to the west. Another area containing a comparatively high proportion of sand occurs in the lower Hunter Valley, where a considerable thickness of coarse fanglomerates, derived from the north and northeast, were laid down.

At this time the basin was almost entirely covered by coalescing deltas (Fig. 42), which in the north and northeast were fed by vigorous streams. Coal swamps were more widespread than at any other time, and many of the most important coal seams in New South Wales were laid down during this interval. Volcanism continued in the region to the east of the present coast, and extensive tracts were buried under ash falls.

Interval 12: Narrabeen Group

Although the Narrabeen Group covers much of the Sydney Basin, vertical sections are rare. Formations have been described from the mid-central area, the south-central area, and from near Katoomba in the western area. The lithology, relationships, correlations, and age are summarized in Plates 2 and 3 and Figures 3, 8, 9, 10, 43, and 44. The thickness, sand-shale ratios, and palaeoenvironments are given in Figures 45 to 47.

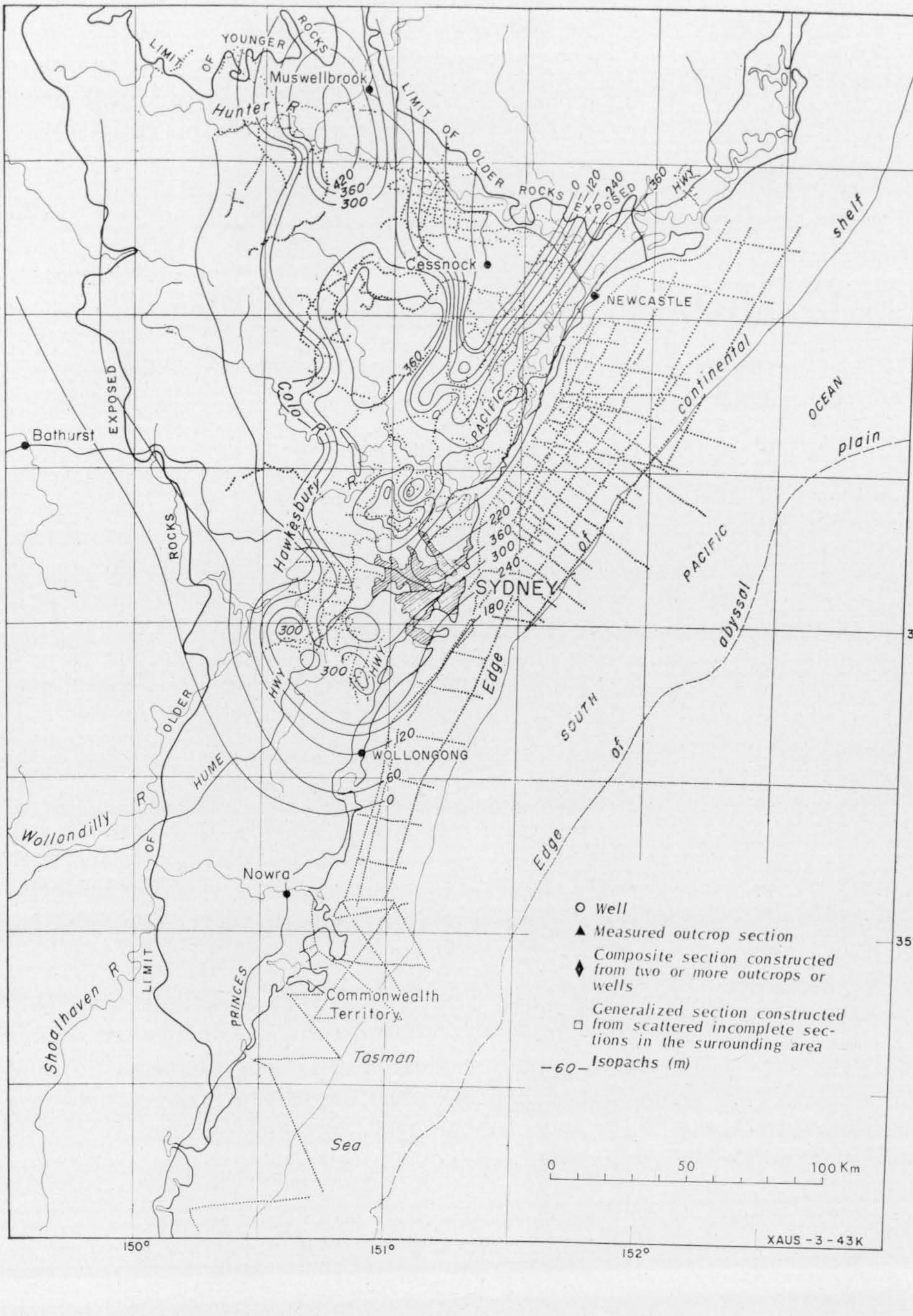

Fig. 40. Isopach map, Interval 11—Newcastle Coal Measures (excluding Waratah Sandstone) and correlatives.

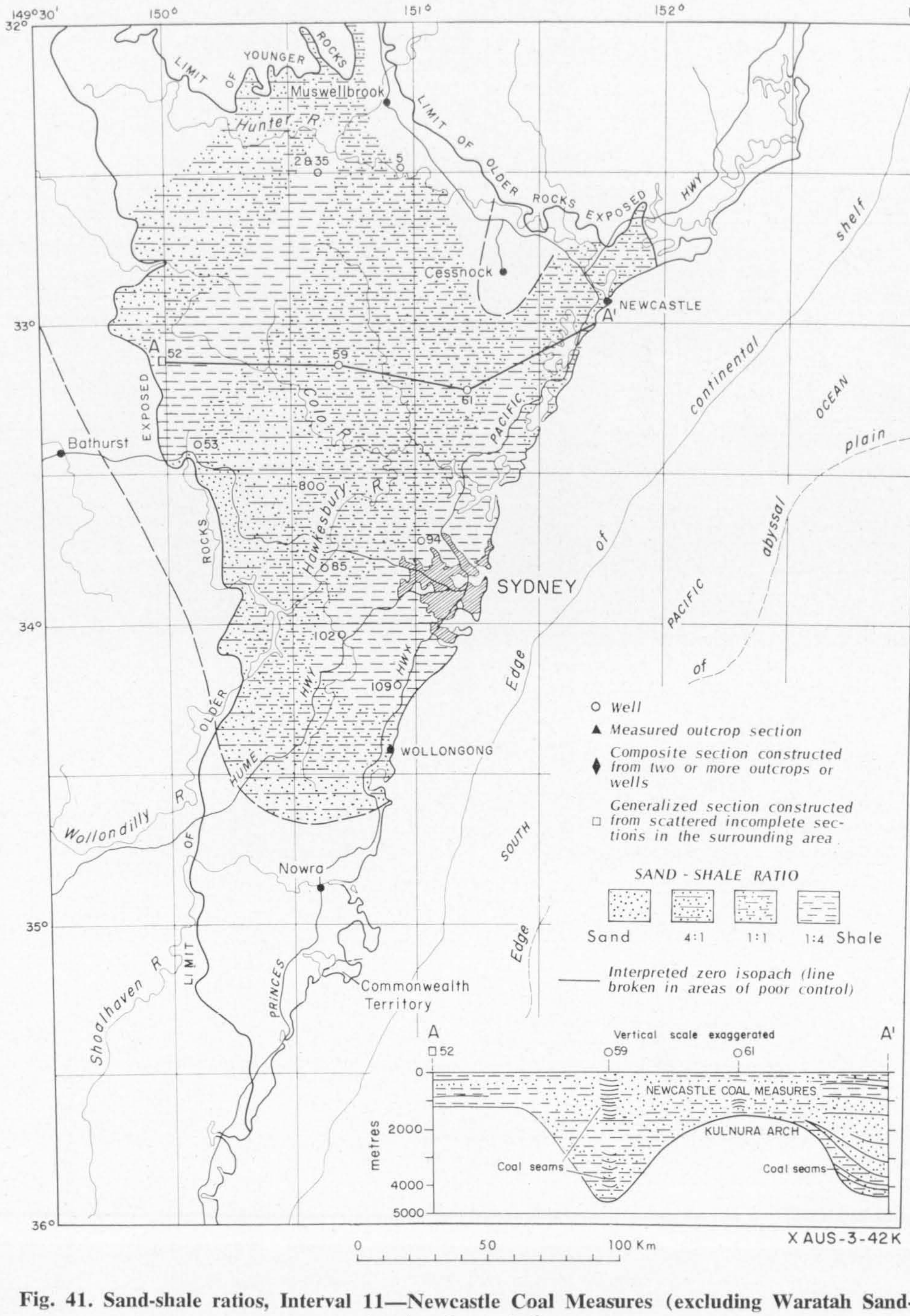

Fig. 41. Sand-shale ratios, Interval 11—Newcastle Coal Measures (excluding Waratah Sandstone) and correlatives.

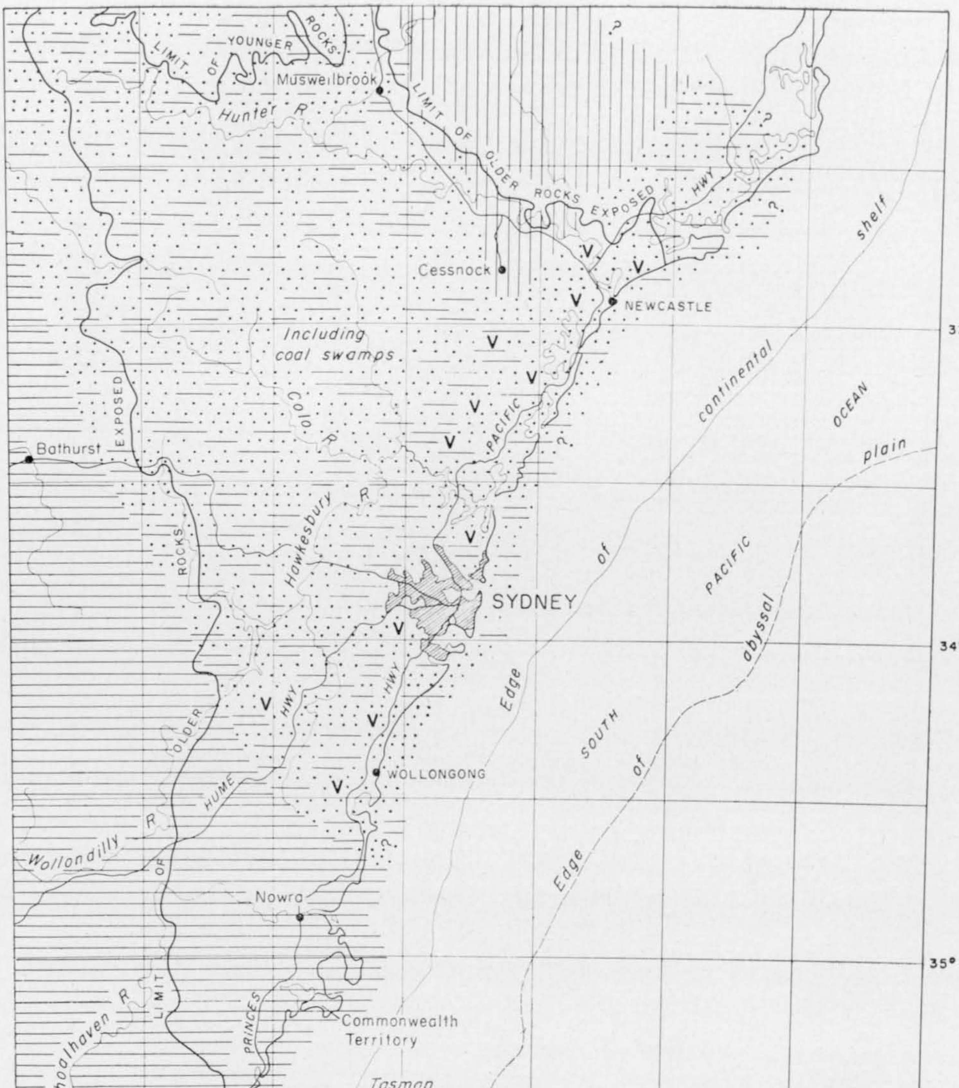

Fig. 42. Palaeoenvironments, Interval 11—upper Tatarian.

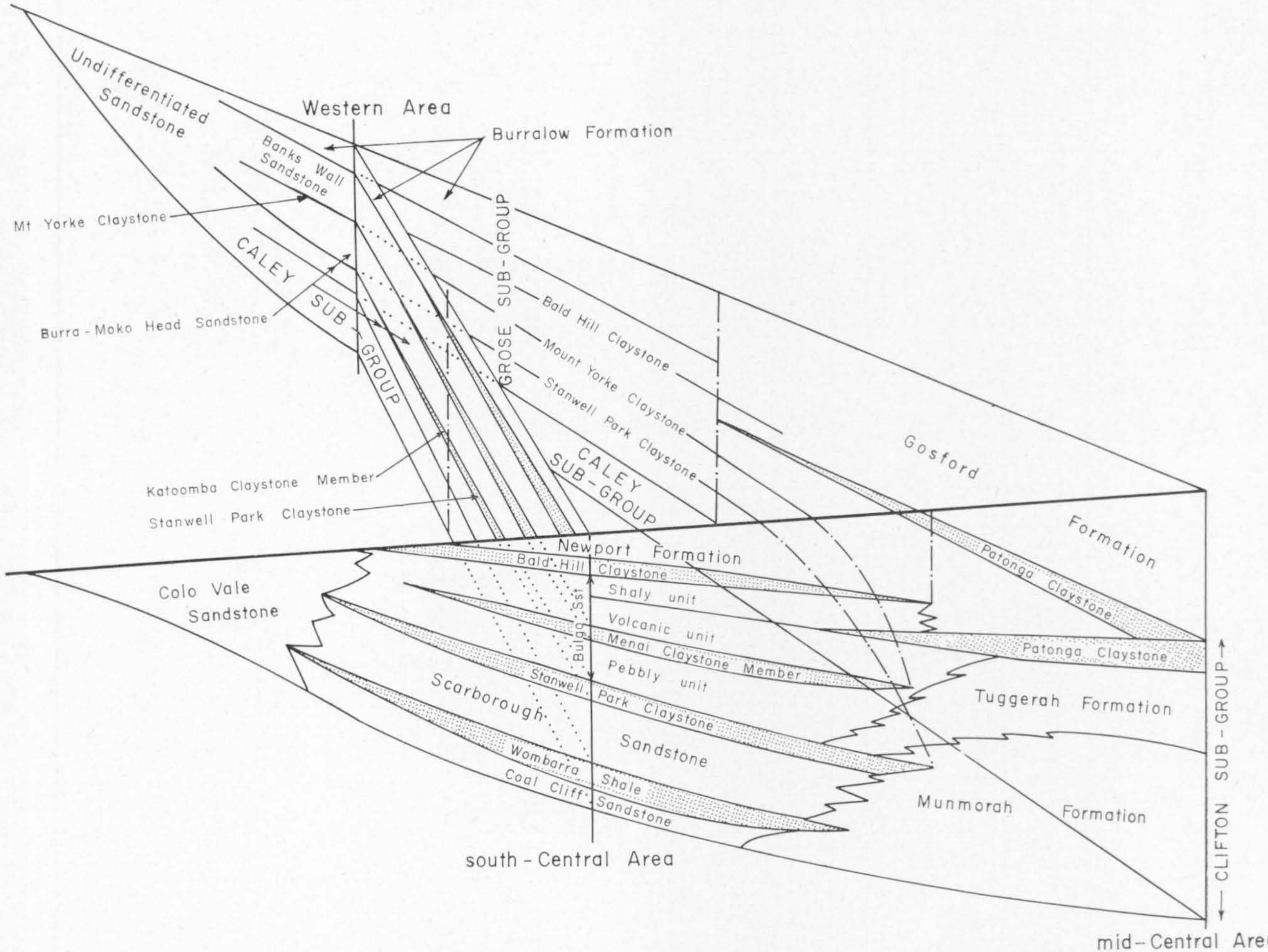

Fig. 43. Relationship of rock units in Narrabeen Group.

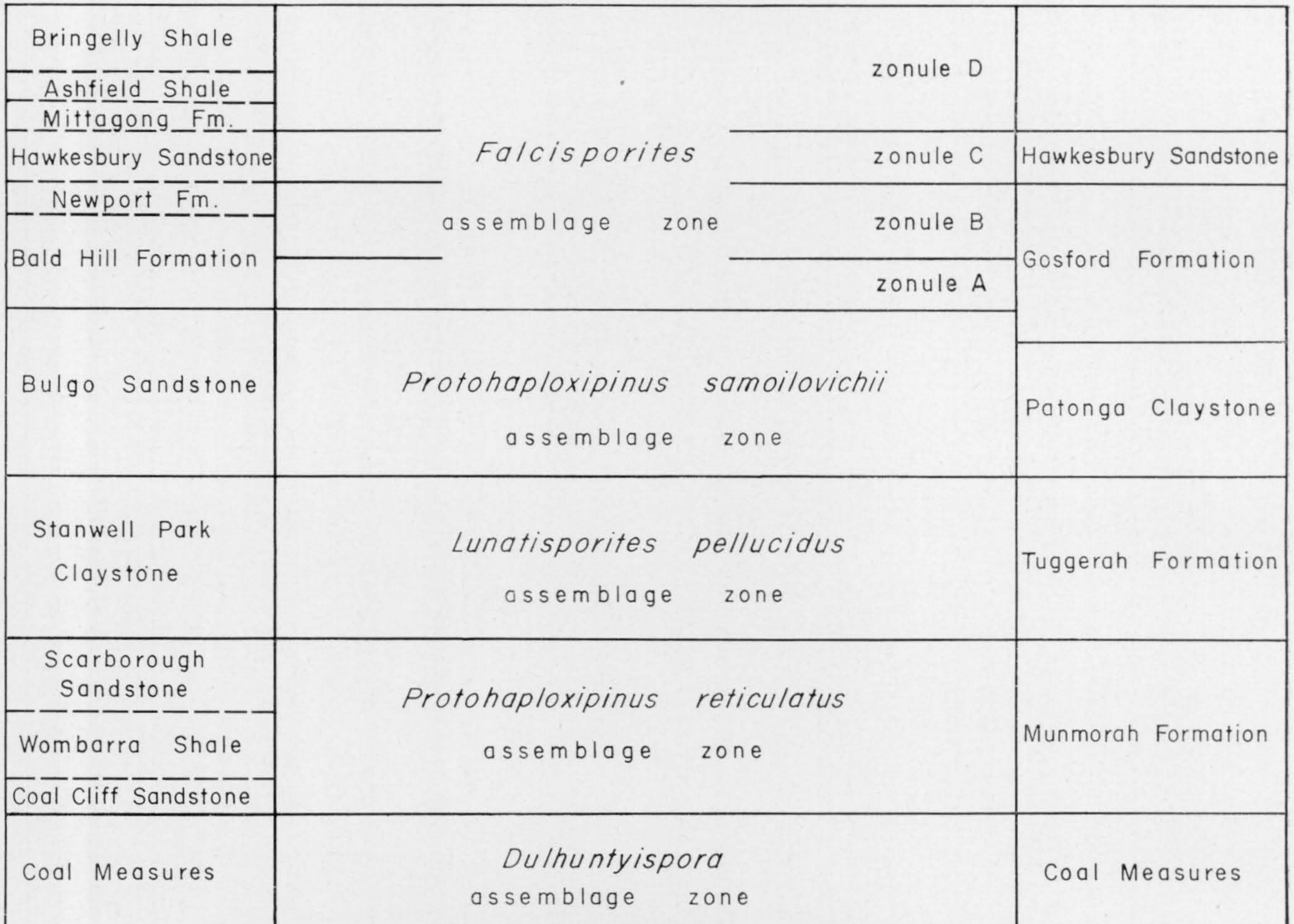

Fig. 44. Palynological zones, Intervals 11 to 14. (Based on Helby, 1970).

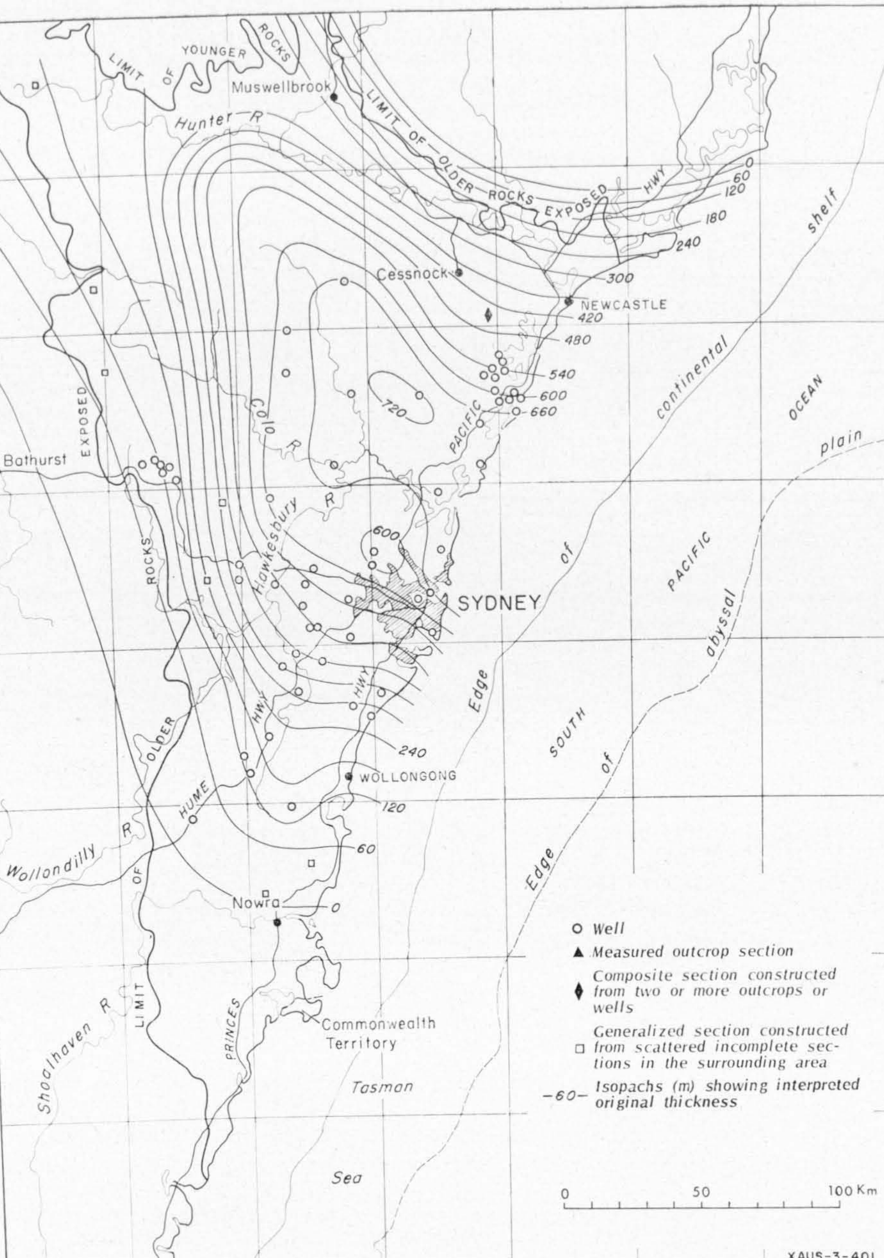

Fig. 45. Isopach map, Interval 12—Narrabeen Group.

The detailed lithology, correlations and age, and relations with older units are given in Appendix 3.

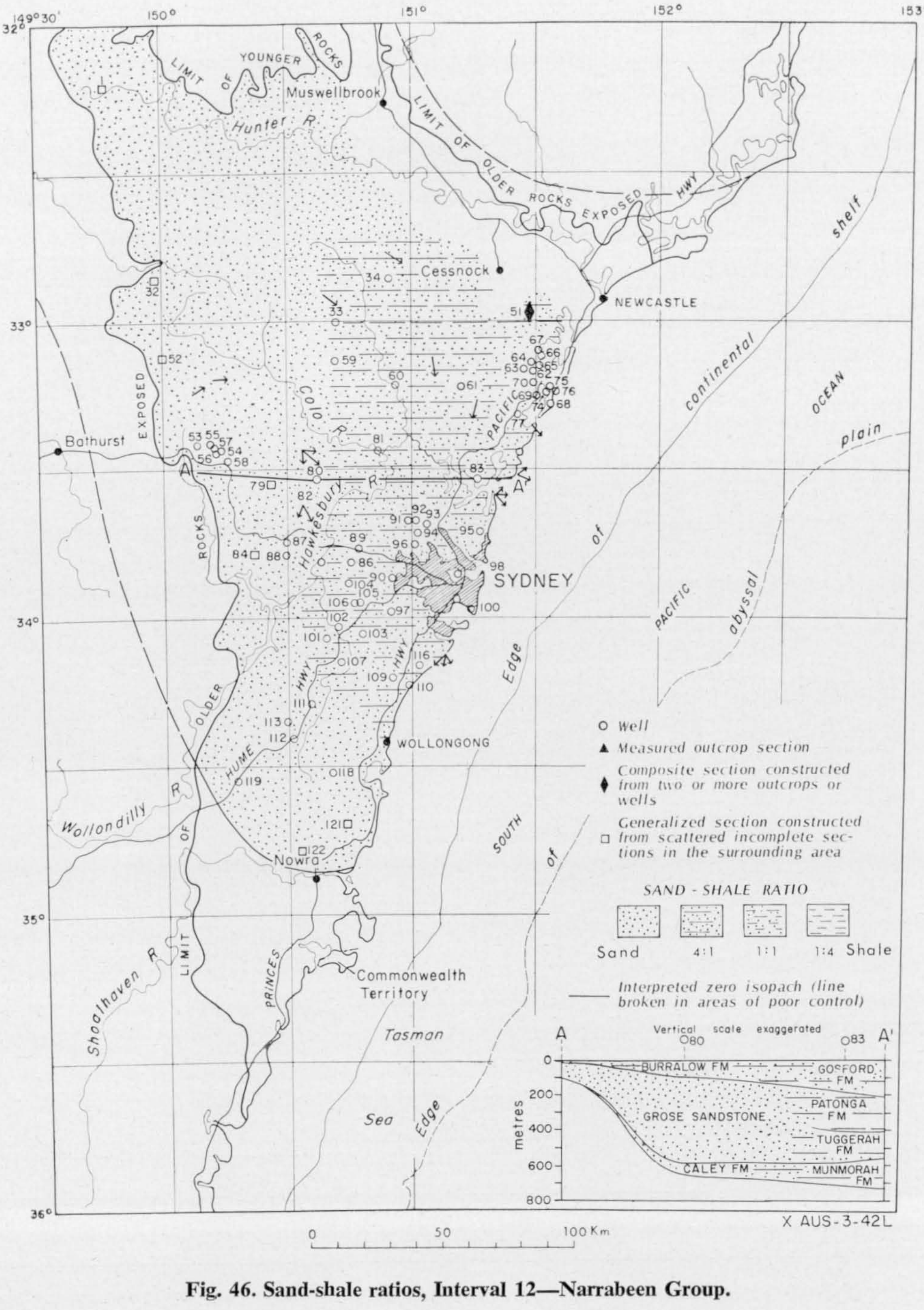

Fig. 46. Sand-shale ratios, Interval 12—Narrabeen Group.

Fig. 47. Palaeoenvironments, Interval 12—Lower Triassic.

Conclusions

The Narrabeen Group was deposited after uplift along the Hunter Thrust and in the area of the Lochinvar Anticline. The isopach map (Fig. 45) shows Interval 12 to be basin-shaped; the sediments are up to 90 m thick on the edge, 90 to 510 m on the slope, and from 510 to 720 m on the floor of the basin, which has its centre near Kulnura. In the Lochinvar Anticline area the sediments rest with angular unconformity on rocks as old as the Maitland Group (Interval 5).

The sand-shale ratio map (Fig. 46) shows a decrease in grainsize to the east owing to the prograding and coalescence of deltas over the coal measures, so that prodelta sediment predominated in the east and fluviodeltaic sediment in the west.

The rocks fall naturally into three suites according to the composition of the sediment (Ward, 1971). The quartzose sandstone suite, which is found throughout the western part of the basin and in the upper part of the sequence in the east, was derived from the Lachlan Fold Belt; the quartz-lithic suite in the north and northeast was derived from the New England Fold Belt, and the volcanic sandstone suite, which is found only in the coastal belt, was derived from a volcanic source to the east. The red or chocolate colour of the shales in the Narrabeen Group is due to weathering on the Triassic delta plains (see Appendix 3).

According to Ward (1971) there was a general decline in fluvial activity with the passage from a fluvial to a deltaic regime.

Interval 13: Hawkesbury Sandstone

The Hawkesbury Sandstone, which forms prominent cliffs around Port Jackson and Broken Bay, is the only stratigraphic unit included in Interval 13. Its distribution is shown in Plate 1, and the lithology, relationships, correlations, and age are given in Plates 2 and 3 and Figures 3, 8 to 10, and 44. The thickness and palaeoenvironments are shown in Figures 48 and 49.

Details of lithology, correlations and age, and relations with older units are given in Appendix 3.

Conclusions

The Hawkesbury Sandstone thickens gradually from a zero isopach near the western margin of the basin to over 240 m along the present coastline.

The sequence consists of a blanket sand laid down in an intertidal embayment under the influence of tides setting northwards along the coast. Braided streams entered the tidal flats from borderlands which had been reduced to base level. Transient lagoons supported populations of fish adapted to brackish conditions.

Interval 14: Wianamatta Group

The Wianamatta Group includes the youngest rocks of the Permo-Triassic sequence preserved in the Sydney Basin. The group consists chiefly of lutites, with minor interbeds of sandstone. The constituent formations are shown in Figure 50, and the distribution in Plate 1. Because the upper formations have a very much smaller distribution than the lower, due to erosion, no sand-shale ratio map is given, but details of lithology, correlations and age, and relations with older units are given in Appendix 3. The preserved thickness is shown in Figure 51 and palaeoenvironments in Figure 52.

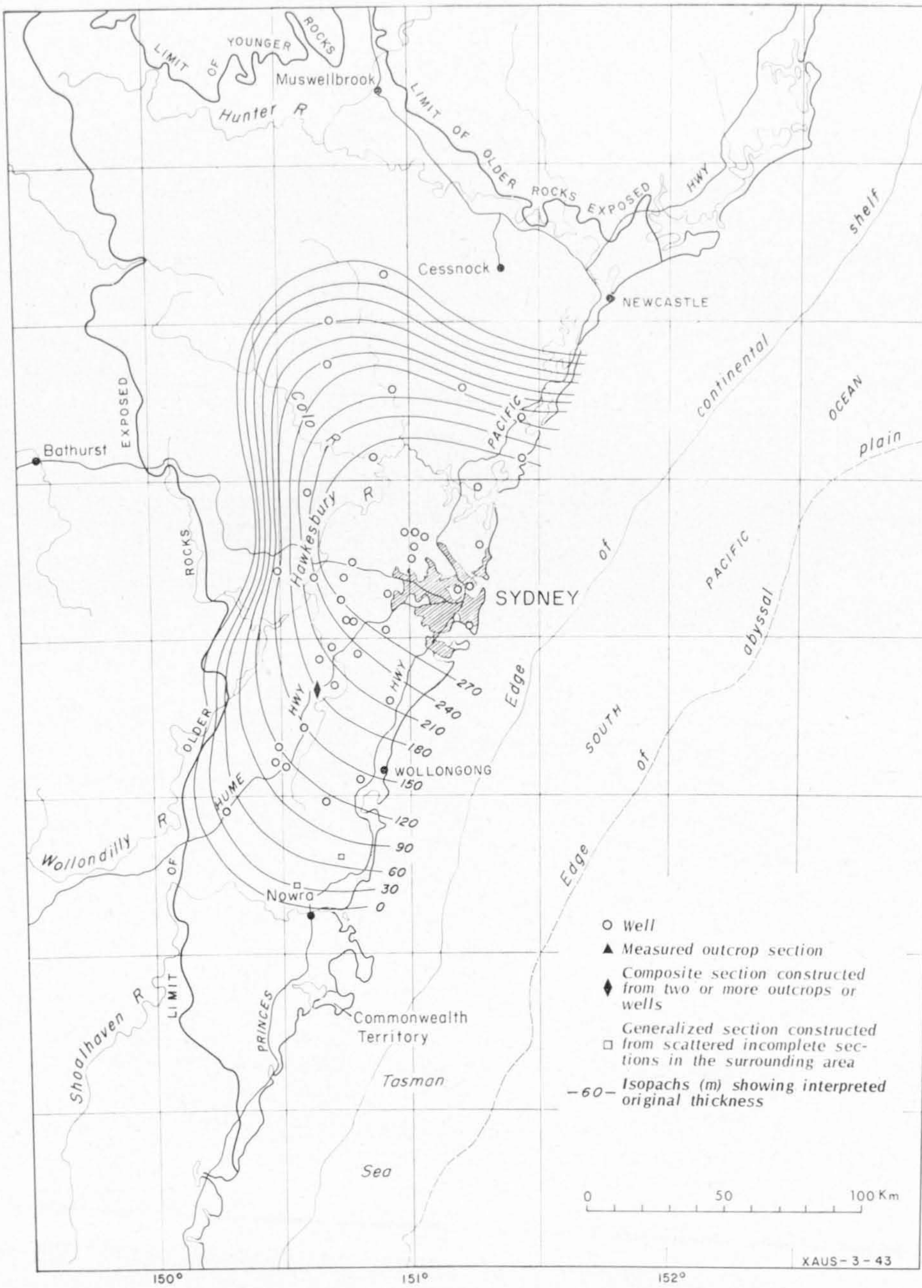

Fig. 48. Isopach map, Interval 13—Hawkesbury Sandstone.

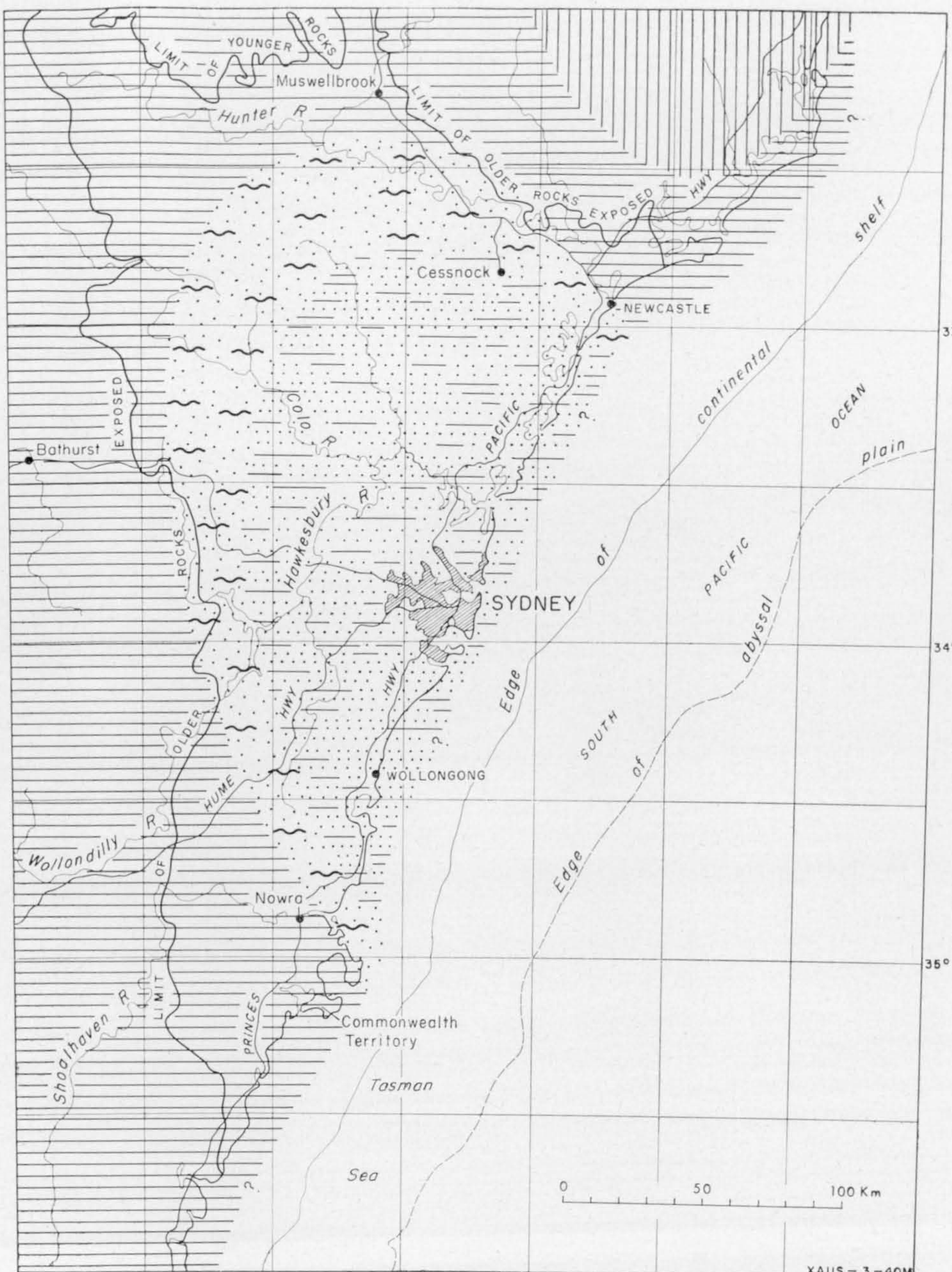

Fig. 49. Palaeoenvironments, Interval 13—Middle Triassic.

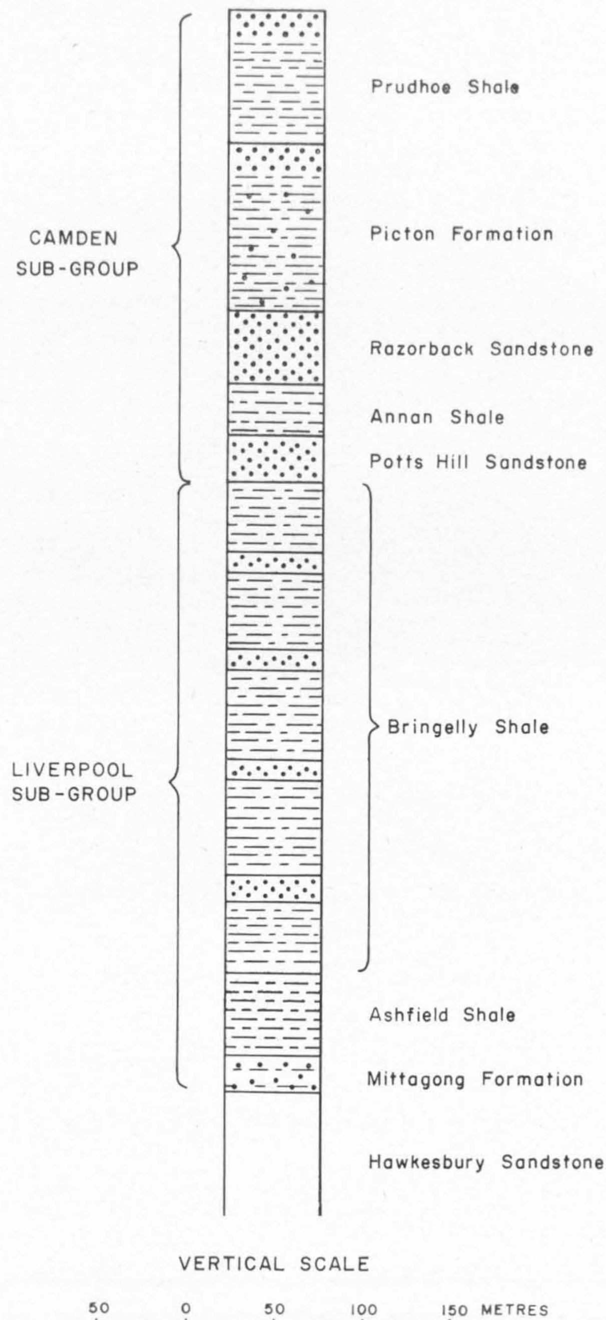

Fig. 50. Formations of Wianamatta Group. (After Herbert, 1970a).

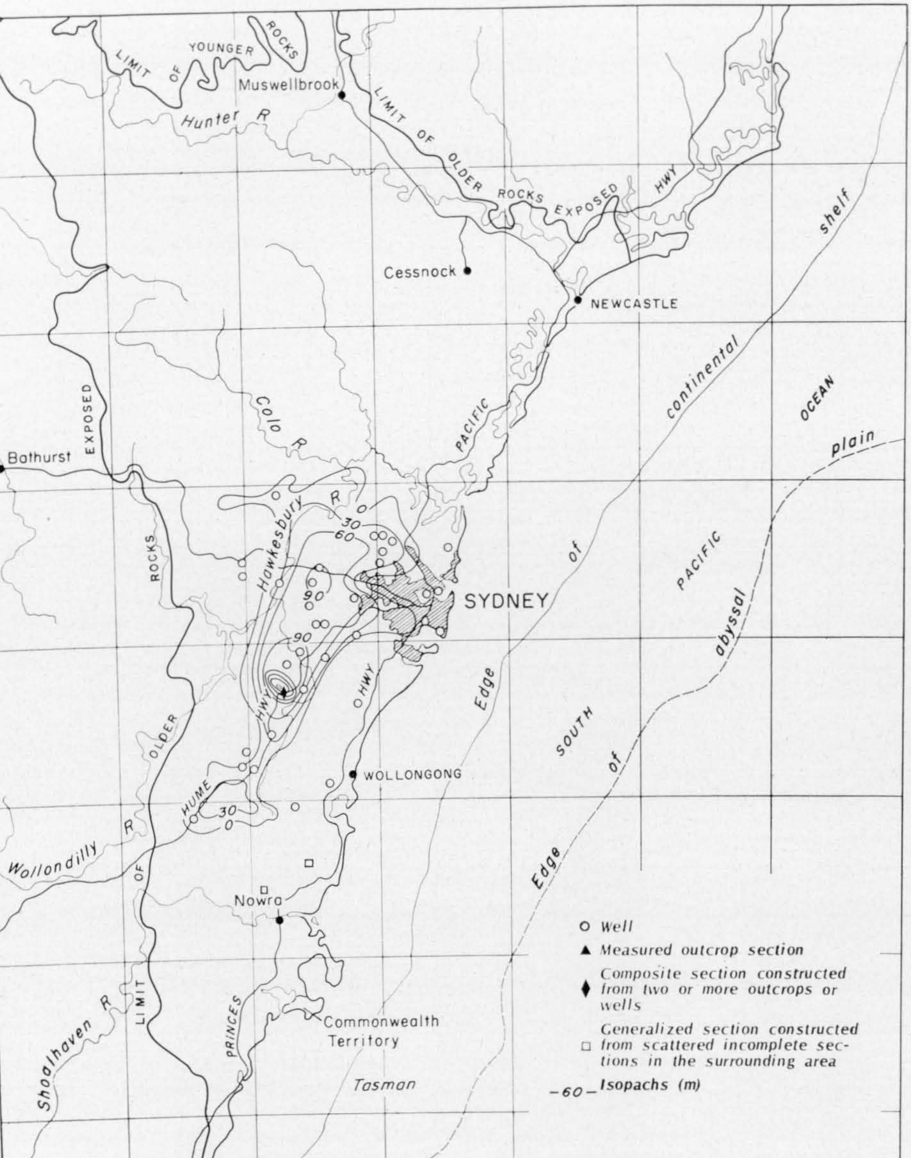

Fig. 51. Isopach map, Interval 14—Wianamatta Group.

Fig. 52. Palaeoenvironments, Interval 14—Middle Triassic.

Conclusions

The work of Lovering (1954) and Herbert (1970a) has shown that the Wianamatta Group was laid down in deltas where swampy, lagoonal, and shallow marine conditions prevailed from time to time. The large volume of lithic sand carried by the river systems was derived from nearby intermittent volcanoes.

IGNEOUS ROCKS

Permian, Triassic, Jurassic, and Cainozoic hypabyssal and volcanic rocks occur in the Sydney Basin. They are chiefly mafic in composition. Only a few of them have been isotopically dated, but the age of most of them can generally be inferred from their stratigraphic and structural relationships and their chemical affinities with dated rocks. Many of them have been described by Joplin (1964).

Permian Igneous Rocks

The Permian igneous rocks (Table 6) include laccoliths, sills, plugs, flows, and tuffs. The intrusions and flows were derived from shoshonitic magmas (Joplin, 1964), but some of the tuffs are felsic in composition (Leitch, 1969). Tuffs and bentonitic clays are widely distributed especially in the Newcastle Coal Measures.

Mesozoic Igneous Rocks

Most of the numerous igneous intrusions in the Permian sequence are believed to be Jurassic.

Triassic

The Triassic igneous rocks include basalt flows and plugs, breccia pipes, and abundant tuff and ash, which occur in beds or as contaminants in the sediments (Table 7).

Jurassic

In the Sydney Basin, which is presumed to have been stable in the Jurassic, there are many alkaline sills, flows, dykes, plugs, and laccoliths ranging from teschenitic dolerite to alkaline trachytes and syenites (Table 8). They are assigned to the Jurassic although only three of them have been isotopically dated (Table 8).

Cretaceous

The potassium-rich stocks, plugs, lavas, and sills in the Southern Coalfield have been assigned to the Cretaceous on the basis of their resemblance to dated occurrences, one within the basin and others along the eastern seaboard of Australia (Table 9).

Undifferentiated

Card (*in* Harper, 1915) recognized three types of dykes and sills in the Triassic rocks of the Sydney Basin—nepheline syenites and tinguaites, basalts, and monchiquites—the last being the most common. Dykes are particularly common in a band 16 km wide along the present coast. Hills (1955) indicated at least 200 dykes between Nowra and Port Hacking, at least 103 around Sydney, and 48 in the Newcastle district. Nashar & Catlin (1960) have described a swarm of 60 dykes around Port Stephens, some of which are aligned roughly north-south, others roughly east-west. They are up to 5 m wide. Taylor & Mawson (1903) noted that

TABLE 6. PERMIAN IGNEOUS ROCKS

Name or Locality	*Rock Type*	*Reference*	*Relationships*	*Age*	*Remarks*
Gerringong Volcanics	Latite (see Appendix 3)	Raam (1969)	Extruded in shallow seas and over coal swamps; intruded into unconsolidated sediments	252 m.y. (K/Ar: feldspar from Berkely Latite; Evernden & Richards, 1962). 240 m.y. (K/Ar: feldspar from Bombo Latite; Evernden & Richards, 1962). Associated sandstone has Fauna IV fossils	Berkely Latite occurs near top of sequence; Bombo Latite near bottom
Milton Laccolith	Porphyritic monzonite	Harper (1915), Brown (1925), McElroy & Rose (1962)	Irregular intrusion in sediments of Conjola Sub-Gp	240 m.y. (K/Ar; J. R. Richards, pers. comm., 1971)	
Currambene Dolerite	Potassic porphyritic trachybasalt	Gellatly (*in* Ozimic, 1971)	Intruded into unconsolidated sediments of Wandrawandian Sltst and Nowra Sst	234 ± 6 m.y. (K/Ar; Webb *in* Ozimic, 1971)	Laccolith?
Stockyard Mountain No. 1	Porphyritic basalt	Alcock (1968a)	Intruded between Wandrawandian Sltst and Nowra Sst	Permian?	
Nobbys Tuff	Tuff altered to claystone	McKenzie (1962)	In Lambton Sub-Gp near base of Newcastle Coal Measures (see Appendix 3)	Tatarian	Most persistent of numerous tuff layers; forms marker horizon
Fern Valley Tuff	Tuff altered to claystone		In Adamstown Sub-Gp of Newcastle Coal Measures (see Appendix 3)		Very persistent; maximum thickness 29 m
Awaba Tuff	Tuff altered to claystone		In Moon Island Beach Sub-Gp of Newcastle Coal Measures (see Appendix 3)		Up to 24 m thick
Wongawilli Seam	Tuff altered to claystone	Hanlon (1953), Loughnan (1966), Duff (1967)	In middle of Wongawilli Seam	Tatarian	

TABLE 6—*Cont.*

Name or Locality	*Rock Type*	*Reference*	*Relationships*	*Age*	*Remarks*
Burragorang Claystone	Tuff altered to claystone	Morris (1926), Whiting & Relph (1969)	Interbedded in coal measures of Southwestern and Western Coalfields (see Appendix 3)	Tatarian	
Martindale No. 1A	Basalt and pale claystone	Nicholas (1969)	Interbeds in Wittingham Coal Measures. No evidence as to whether flows or sills	Tatarian	One claystone layer 6 m thick and at least 6 thin layers of altered basalt
Eastern part of Sydney Basin	Tuff altered to claystone, and volcanic fragments in terrigenous rock		Interbeds and contaminants in coal measures	Tatarian	
Bayswater BMR No. 1	Crystal tuff and ignimbrite	Booker et al. (1954)	Intercalated in Tomago Coal Measures	Tatarian	
Kulnura No. 1	Tuff altered to claystone	Ozimic (1969)	Interbedded in Newcastle Coal Measures	Tatarian	Up to 15 m thick
	Tuff altered to claystone	Ozimic (1969)	Interbedded in Tomago Coal Measures	Tatarian	
	Amygdaloidal basalt	Ozimic (1969)	Interbedded in Tomago Coal Measures	Kazanian?	
Dural South No. 1	Tuff altered to claystone	Hawkins & Ozimic (1967)	Interbedded in Newcastle Coal Measures	Tatarian	

TABLE 7. TRIASSIC IGNEOUS ROCKS

Name or Locality	*Rock Type*	*Reference*	*Relationships*	*Age*	*Remarks*
Moss Vale/ Mittagong area	Tholeiitic basalt	O'Reilly (1971)	Surface flows	194 m.y. (K/Ar) (Triassic-Jurassic boundary)	
Central area, particularly near Sydney e.g. The Basin, Hornsby, Dundas, Erskine Park, Minchinbury, Plumpton, Peats Ridge	Basalt and breccia	Adamson (1969), Herbert (1970a)	Diatremes in Wianamatta Gp. Volcanic necks and plugs	Microfloras in coal fragments as young as Ashfield Sh (Triassic)	Some volcanoes active during formation of Bringelly Fm. Adamson lists about 10 volcanic necks in Sydney region. Basalt dykes radiate from plug at South Colah
Moss Vale/ Mittagong area	'Gabbroic, dioritic and syenitic bodies'	O'Reilly (1971)	Intrusive into Hawkesbury Sst	Older than 194 m.y., younger than Hawkesbury Sst (mid-Triassic)	
Eastern part of Sydney Basin	'Chocolate shales'	Loughnan (1963)	Interbeds in Narrabeen Gp	L. and M. Triassic	Detritus of volcanogenic origin is widespread contaminant in Narrabeen Gp
Dural South No. 1	Tuff altered to claystone	Hawkins & Ozimic (1967)	Interbeds in Narrabeen Gp	L. and M. Triassic	

TABLE 8. JURASSIC IGNEOUS ROCKS

Name or Locality	*Rock Type*	*Reference*	*Relationships*	*Age*	*Remarks*
Prospect Hill Lopolith	Teschenitic dolerite	Wilshire (1967)	Intrusive into Ashfield Sh of Wianamatta Gp	168 m.y. (K/Ar on biotite. Evernden & Richards, 1962)	
Mount Gibraltar, Mittagong	Microsyenite	Boesen et al. (1961)		178 m.y. (K/Ar on hornblende. Evernden & Richards, 1962)	
Umbiella Creek near Kandos	Nephelinite	McDougal (pers. comm., 1971)	Plug in Triassic rocks	About 179 m.y. (K/Ar on whole rock)	
Tillynambulan Mountain (Gingenbullen)	Dolerite	Browne (1933), Boesen et al. (1961)	Possibly denuded sill; on Liverpool Sub-Gp	Probably younger than M. Triassic	100 m thick; contains augite, pigeonite, olivine, and rarely quartz
Mount Jellore	Trachyte and essexite	Taylor & Mawson (1903)	Intrusive into Hawkesbury Sst	Jurassic?	
Mount Flora	Essexite, dolerite, teschenite, syenite	Whitbread (1947)	Multiple sills and small dykes		Essexite intruded by teschenite and both by syenite. Much hydrothermal metamorphism
Nattai Dome	Solvsbergite	Whiting & Relph (1969)	Intrusion near top of Illawarra Coal Measures	Jurassic?	Has caused anthracitization of Bend Creek Seam
Cordeaux Dolerite near Wollongong	Dolerite	Harper (1915), Sussmilch (1923)	Surrounded by Hawkesbury Sst and Narrabeen Gp. Considered a flow by Harper, and a denuded teschenite sill by Sussmilch	Jurassic?	Aphanitic to gabbroidal texture
Nebo, near Wollongong	Teschenite-picrite	Edwards (1953)	In basal part of Narrabeen Gp. Probably a sill.	Jurassic?	Encountered in boreholes, 79 m thick. Thought by Edwards to be same body as that at Cordeaux
Mount Murray near Wollongong	Teschenite	Edwards (1953)	In Narrabeen Gp and topmost Illawarra Coal Measures. Probably a sill	Jurassic?	
Rixons Pass and Undola	Olivine-analcite basalt (basanite) and monchiquite	Harper (1915), Hanlon et al. (1954), Vallance (1969)	Sill emplaced under light cover of part of Narrabeen Gp	Jurassic?	

TABLE 8—*Cont.*

Name or Locality	*Rock Type*	*Reference*	*Relationships*	*Age*	*Remarks*
Western Coalfield; Tonbong Mountain, Growee near Rylstone, Bocable and Mount Dangar near Bylong	Teschenitic dolerite	Vallance (1969)	Sills in Triassic and U. Permian	Jurassic?	
Far northwest Sydney Basin: Barigan Cr. phonolites, The Porcupine, Mount Stormy, Davids Mountain, Bald Mountain, The Pinnacle	Phonolite and tinguaite	Card (*in* Carne, 1903), Sussmilch (1933), Day (1961)	Laccoliths and sills in Triassic rocks	Jurassic?	Thought by Sussmilch to lie along an E-W line of monoclines and faults. Undersaturated
Murrumbo and Wollar	Microsyenite	Day (1961)	Sills	Jurassic?	Undersaturated
Middle and Upper Hunter Valley; Martindale No. 1	Syenite?	Nicholas (1969)	Sill between Intervals 7 and 8 in Wittingham Coal Measures	Jurassic?	33.6 m thick; contains potash feldspar, pyroxene biotite, and chlorite
Martindale No. 1A	?	Nicholas (1969)	Sill within Wollombi Coal Measures	Jurassic?	48.8 m thick. Fine-grained, mafic; contains hornblende and abundant chlorite, with minor pyroxene and biotite
Savoy Sill	Teschenite with syenite intrusions	Raggatt & Whitworth (1932)	Sill in western part of Muswellbrook Anticline; in Greta Coal Measures	Jurassic?	90 m thick. Teschenite consists of labradorite augite, and little olivine. Syenite contains soda feldspar and arfvedsonite
Plashett Sill	Dolerite and aplite	Raggatt & Whitworth (1930)	Sill in trough of small syncline	Jurassic?	
Howick Sill	Pink trachyte and dolerite	Veevers (1960)	Sill in Wittingham Coal Measures	Jurassic?	8 m thick, 1.5 km long
Fordwick Sill at Broke	Dolerite	Raggatt & Whitworth (1930)	Sill in Wollombi Coal Measures	Jurassic?	

TABLE 8—*Cont.*

Name or Locality	*Rock Type*	*Reference*	*Relationships*	*Age*	*Remarks*
Marulla Sill at Wingen	Dolerite with basalt plug and dyke	Raggatt (1938)	Sill in Wittingham Coal Measures	Jurassic?	75 m thick, 13 km long
Carrington Sill	Diorite with syenite veins	Veevers (1960)	Sill in Wittingham Coal Measures	Jurassic?	60 m thick, 2 km long
Dural	Dolerite	Hawkins & Ozimic (1967)	Sill in Interval 8 in Illawarra Coal Measures. Low-grade metamorphism above and beneath (Shell, 1966c)	Jurassic?	45 m thick in Dural South No. 1 well. Fine to medium-grained; contains andesine, augite, biotite, but no quartz. Recorded also in Dural Nos 1 and 2
Warrawolong in Myall Range	Dolerite and theralite	Boesen & Ritchie (1971)	Plug intrusive into Narrabeen Gp	Jurassic?	Alkali basalt magma
Bulli Colliery Sill	Analcite basalt	Harper (1915)	Sill in upper part of Illawarra Coal Measures	Jurassic?	
Botany Bay	Syenite	Stuntz (pers. comm., 1970)	Near top of Illawarra Coal Measures, probably a laccolith	Jurassic?	Encountered in DM Cape Banks No. 1 bore between 726.9 and 760.5 m

TABLE 9. CRETACEOUS IGNEOUS ROCKS

Name or Locality	*Rock Type*	*Reference*	*Relationships*	*Age*	*Remarks*
Mount Dromedary Complex at Tilba Tilba	Monzonite, andesite, and latite	Boesen (1964)	Stock and lavas associated with older Palaeozoic strata	93 m.y. (K/Ar on biotite; Evernden & Richards, 1962)	Just south of present boundary of Sydney Basin. Composition similar to that of occurrences within basin
Good Dog Mountain Complex in Southern Coalfield	Porphyritic quartz dolerite, hornblende and mica lamprophyre, and porphyrite	Card (*in* Harper, 1915), Browne (1933)	Plug, sills, and veins penetrating Hawkesbury Sst	Cretaceous?	A potassium-rich suite resembling that at Mount Dromedary
O'Hara Head, Bawley Point	Coarse-grained essexite	Vallance (1969)	Intrusive into Conjola Sub-Gp	Cretaceous?	Similar to monzonite at Mount Dromedary
Budderoo Lamprophyre at Wallaya in Southern Coalfield	Mica lamprophyre	Harper (1915), Hanlon et al. (1953)	Intrusive into Hawkesbury Sst	Cretaceous?	Resembles Good Dog Mountain Complex. Originally called monzonite

the Mittagong district is 'permeated' with trachytic dykes, and Raggatt (1938) states that basaltic dykes and sills are 'too numerous to list or show on a map' of the upper Hunter Valley.

The dykes in the Southern Coalfield may be divided into three groups according to their average strike, viz. 100°, 355°, and 50° (Wilson et al., 1958). The persistent dykes of the first group are up to 5 km long and 15 m wide; the second group consists of swarms of small impersistent dykes; while the third group includes occasional small dykes which generally trend parallel to the associated faults.

The post-Triassic dykes and sills have damaged the coal seams. The dykes commonly branch into sills or a series of sills that may entirely replace the coal seams. The coal has been altered for a few centimetres to several metres. In places the coal is cindered, and partly replaced by calcite, pyrite, and stringers of igneous rock. In a few places the coal has not been cindered, but has been upgraded in rank by the loss of volatiles. In the Bulli Pass Colliery a natural coke was formed, and in the Mount Alexander Colliery at Mittagong one of the sub-bituminous coals has been upgraded to anthracite. At the contact with the coal some of the dykes have been converted into a white puggy clay. David (1907) states that the dykes in the Newcastle district have been less destructive than those in the Southern Coalfield. The Maitland and Singleton districts are free from dykes.

Gold has been recorded in one of the diorite dykes near Moss Vale.

Cainozoic Igneous Rocks

Wellman (1971) has distinguished several Cainozoic igneous provinces in New South Wales, four of which occur in or partly in the Sydney Basin (Table 10). The Nerriga, Mittagong, and Airlie provinces contain remnants of basaltic flows of middle Eocene to middle Oligocene age; Miocene basalts occur in the Katoomba part of the Abercrombie province. The rocks were dated by the K/Ar method.

TABLE 10. CAINOZOIC IGNEOUS ROCKS

Name or Locality	*Rock Type*	*Reference*	*Remarks*
Mittagong Province			
Robertson	Analcite basanite	Harper (1915), O'Reilly (1971)	Many flow remnants, largest up to 60 m thick and up to 3 km^2 in area
Mittagong/ Moss Vale	Alkali basalt, including hawaiite and mugearite	Craft (1931), O'Reilly (1971)	
Wingello	Basalt	Harper (1915), Craft (1931)	Occupy valleys eroded in Tertiary sediments
Nerriga Province			
Endrick River	Basalt	Craft (1931)	Largest outcrop extends about 21 km along Tertiary river valley. Several flows, with total thickness of 12 m, separated by fluvial sediments.
Sassafras	Olivine basalt	Craft (1931), Vallance (1969)	Largest flow about 10 km long and up to 3 km wide

Name or Locality	Rock Type	Reference	Remarks
Airlie Province			
Dairy Mountain near Rylstone	Olivine and aegirine-augite phonolite	Day, (1961), Wellman (1971)	Diamonds in stream gravels
Nullo Mountain, east of Rylstone	Basalt/monchiquite	Browne (1933), Day (1961), Wellman (1971)	
Jimmy Jimmy	Olivine trachyte	Day (1961)	
Ulan	Olivine nephelinite	Browne (1925)	
Katoomba part of Abercrombie Province			
The Peak, Yerranderie	Olivine nephelinite	Vallance (1969)	
Mount Muruin	Olivine nephelinite	Card (*in* Carne, 1903)	
Kurrajong-Bilpin	Alkali olivine basalt	Crook (1957)	Flows, dykes, and necks. Merroo neck shows reversed polarity
Mount Molong, Western Coalfield	Trachytic basalt	Carne (1908)	
Mounts Caley, Banks, Tomah, Irvine, Wilson, and Tootie	Basalt	Carne (1908), Crook (1957), Adamson (1969)	

STRUCTURE

Introductory Review

The structural features in the Sydney Basin are shown on the 1:500 000 geological map (Pl. 1), the 1:500 000 tectonic map (Pl. 5), and the structure contour maps (Pls 6, 7, 8).

Three main periods of diastrophism have been recognized: (1) Upper Permian movements which are commonly but loosely called the Hunter-Bowen Orogeny, (2) possible Upper Triassic movements, and (3) late Tertiary epeirogenic movements during the Kosciusko Epoch. We review the structure first and the structural history second.

The strongest deformation in the Sydney Basin occurs adjacent to its northeastern margin where the Hunter Thrust and a series of northerly trending folds with associated normal faults are developed. The structure of this area has been described by many authors including David (1911), Raggatt (1929b, 1938), Osborne (1950), Voisey (1959 a,b), and Booker (1960). Raggatt and Booker described the structures in the Hunter Valley in some detail.

The northwesterly trending Hunter Thrust consists of a zone of reverse faults which has brought middle Carboniferous rocks in the north against Upper Permian rocks in the south, and forms the northeastern boundary of the Sydney Basin. The Permian strata are also displaced by a group of smaller thrust faults running parallel or subparallel to the major thrust.

The Lochinvar Anticline, which is the dominant structure in the lower Hunter Valley, is flanked on the west by a group of smaller structures in the Singleton area, including the Belford and Loder Domes and the Sedgefield Anticline. A broad synclinal area separates these structures from the Muswellbrook Anticline.

The axial traces of the anticlines tend to be sigmoidal. The steepest dips occur on the east flanks, but in the Lochinvar Anticline dips up to 60°W also occur on the west flank near the Elderslie and Mathews Gap Faults. These normal faults, and a seismically indicated fault zone on the east flank, have displacements of up to 300 m.

In the north the Lochinvar Anticline has been eroded down to the Carboniferous rocks. Its northern end is truncated by the Hunter Fault Zone and further modified by the Radforslee and Greta overthrusts. The continuation of the anticline has been mapped southwards in gently dipping Triassic rocks, where it is named the Kulnura Anticline, and still farther south the Dural Dome.

The Muswellbrook Anticline is the largest structure in the enclave between the Lochinvar Anticline and the Hunter Fault Zone. The east limb is intersected in the north by normal faults running parallel or subparallel to the axis, and by thrust faults subsidiary to the main Hunter Fault Zone. The faults have been described in detail by Raggatt (1938) and Booker (1960). Several laccoliths occur along the trend of the Muswellbrook Anticline.

In the central area the Triassic rocks have been folded into a number of gentle northerly trending anticlines and synclines. Of these, the Kulnura Anticline and Dural Dome, an apparent continuation of the Lochinvar Anticline, have been mapped in some detail (Raggatt, 1938). Raggatt also defined the Yarramalong and Macquarie Synclines to the east of the Kulnura Anticline and the Wollombi Syncline to the west. He mapped an anticlinal axis in the Triassic rocks south of the Loder Dome in continuity with the axis of the dome.

The most prominent feature to the west is the Lapstone Monocline (David, 1896, 1902; Standard, 1964; Galloway, 1967; Branagan, 1969b). On Plate 1 it is shown as extending from Bargo to Upper Colo, but Galloway (1967) has since shown that it continues northwards to Mount Kindarun. The monocline passes into the Nepean Fault at its southern end south of Wallacia. Branagan (1969b) has also described the faulting on the monocline farther north near the Hawkesbury Lookout, a series of small step faults in the Mulgoa region, and monoclinal flexures associated with faulting at Picton.

The Kurrajong Fault extends from the Colo River to Glenbrook Creek, roughly parallel to, and to the west of, the Lapstone Monocline. The fault is downthrown to the west. It becomes a westerly downwarped monocline at its southern end (Branagan, 1969b). The Oakdale Fault runs parallel to, and west of, the southern end of the Nepean Fault. A group of curved monoclinal structures, convex to the southwest, have been mapped farther south (Wilson et al., 1958).

In the Nowra/Jervis Bay area there is a series of folds which intersect the coast roughly at right angles. Faulting parallel with the coast occurs on the southern side of Jervis Bay. Some of the structures on Plate 5 are based on the work of Paix (1968), Bowman (in prep.), and Bembrick & Holmes (in prep.), which were not available when the 1:500 000 map (Pl. 1) was compiled.

Mapping in the Mount Coricudgy area (Stuntz, 1969) has demonstrated a reversal in regional dip on the base of the Triassic which is thought to reflect a basement high running from near Bogee through Mount Coricudgy toward Muswellbrook. Stuntz believes that this feature forms a convenient boundary between the Sydney and Oxley Basins.

Diastrophism Recorded by Angular Unconformity on Lower and Middle Palaeozoic Basement Rocks

In the west and south the Sydney Basin sequence rests unconformably on lower and middle Palaeozoic rocks of the Lachlan Fold Belt. The folded rocks were deformed during several orogenies which culminated in the Kanimblan Orogeny about the middle of the Carboniferous. During the Devonian-Carboniferous, sedimentation took place only in the New England marginal mobile zone. There is an unconformity between the Middle Carboniferous granodiorite and Upper Carboniferous volcanics beneath the Sydney Basin.

Diastrophism Recorded by Angular Unconformity in Permo-Triassic Rocks

The Permo-Triassic rocks in and beneath the Sydney Basin were deposited without major interruption in the arc-rear belt to the west of the New England marginal mobile zone. Unconformities which developed at the beginning and the end of the Permian, are exposed in the Lochinvar Anticline.

Lower Sakmarian unconformities

One local angular unconformity, which has been mapped beneath the Allandale Formation on the Lochinvar Anticline (David, 1907), has been extended beneath the Lochinvar Formation by seismic interpretation, and another local angular unconformity has been tentatively interpreted on seismic records (this study) beneath the Rutherford Formation of Interval 2. On the Lochinvar Anticline the Allandale Formation rests unconformably on the 'Kuttung Group' near Pokolbin and Mount Bright. Osborne (1949) suggests this relationship is due to onlap of the Permian marine beds onto islands of Carboniferous rocks. Seismic interpretation (this study) suggests that the Allandale Formation overlaps the Lochinvar Formation and that the unconformity then traces beneath the Lochinvar Formation at the base of Interval 1. The unconformity developed in the late Carboniferous or early Permian is shown on the tectonograms of Figure 53.

The other angular unconformity, which occurs beneath the Rutherford Formation, has been tentatively interpreted on seismic records over the Lochinvar Anticline, and has also been interpreted with very low reliability near the Loder Dome and Camberwell Anticline, which suggests that it may extend into the northwestern part of the basin. The folding indicated by this unconformity is shown in Figure 53.

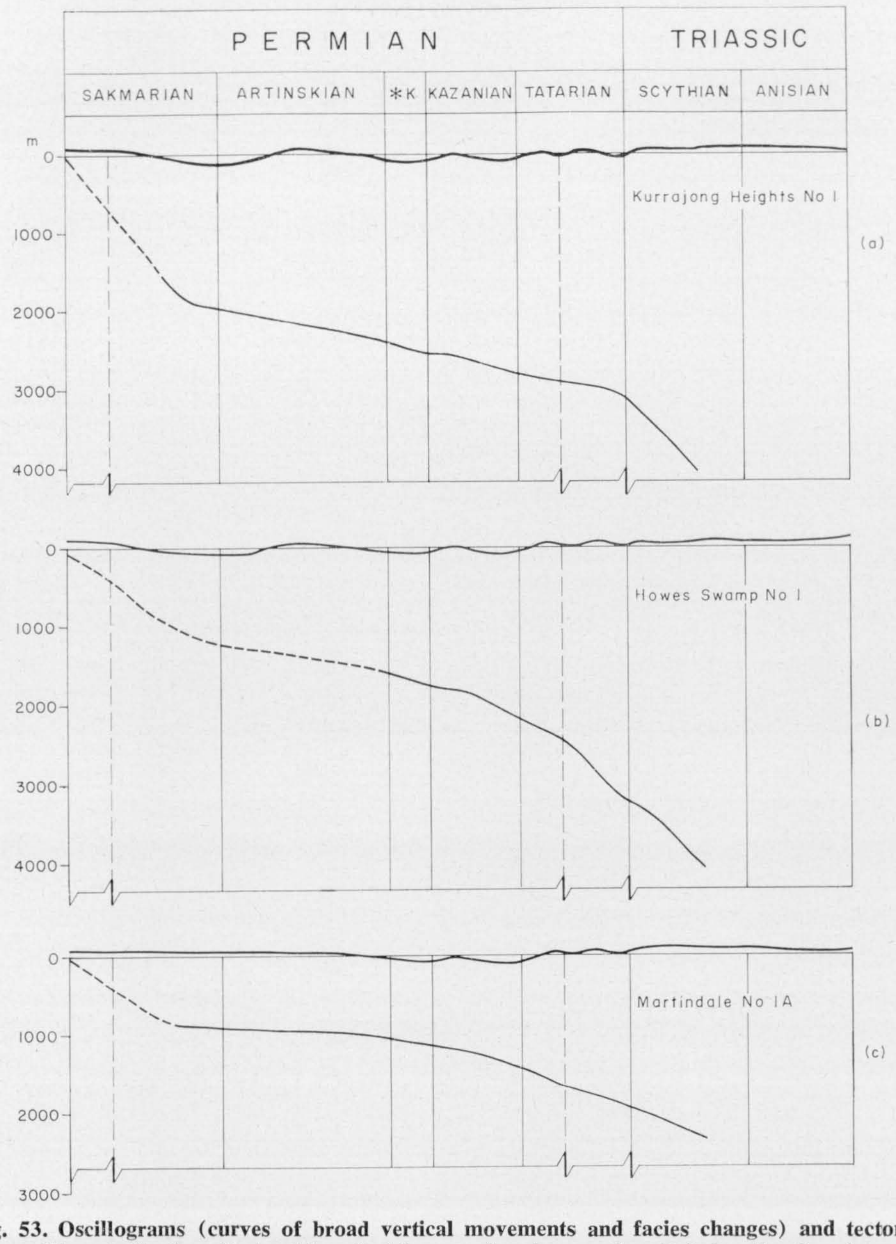

Fig. 53. Oscillograms (curves of broad vertical movements and facies changes) and tectonograms (lines indicating diastrophism that has produced unconformity) for the Permian and Lower Triassic rocks in the Sydney Basin. Upper line represents position of surface of deposition relative to sea level; lower line represents base of Sydney Basin sediments.

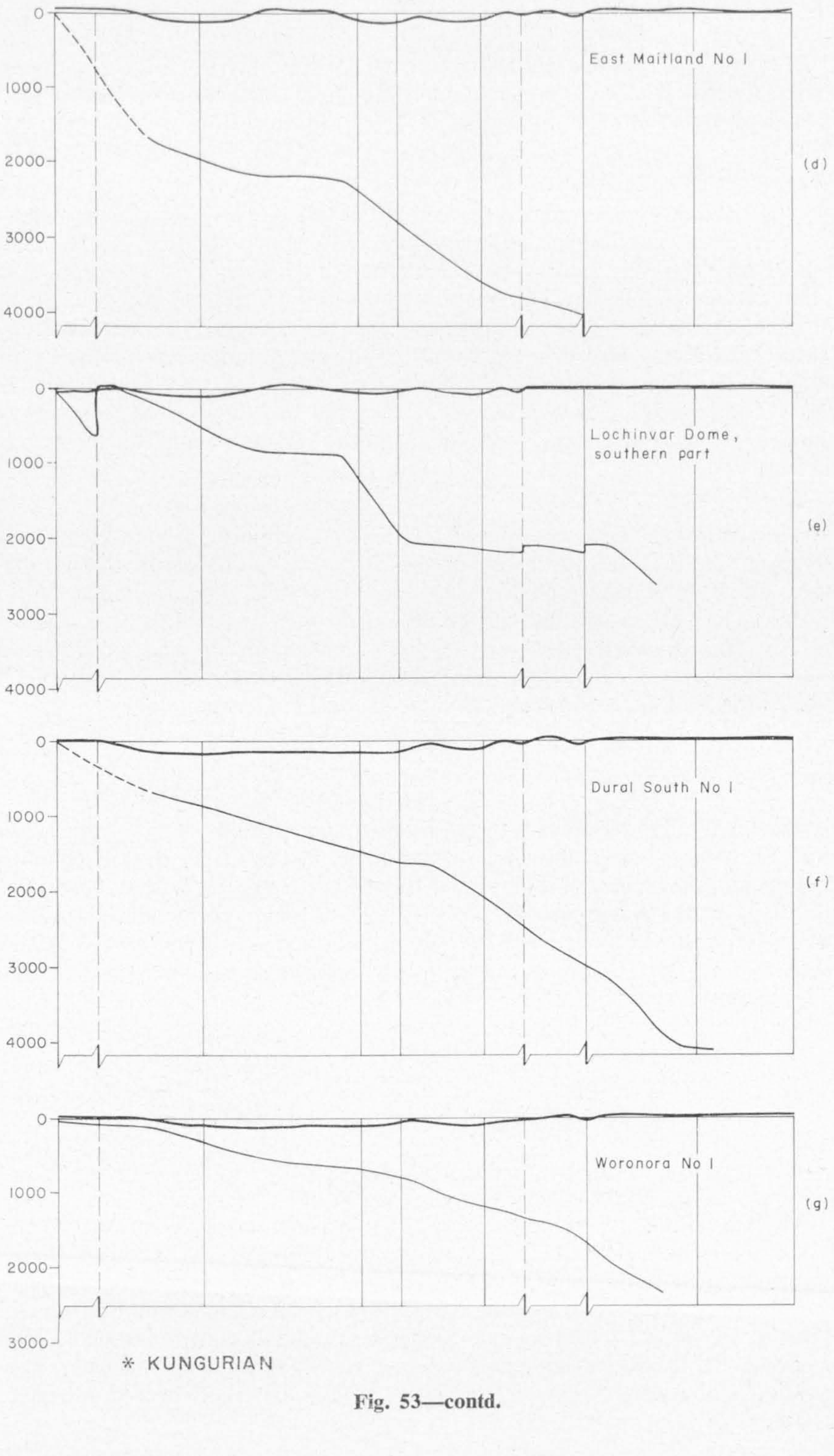
0
1000
2000
3000
4000
East Maitland No 1
(d)
0
1000
2000
3000
4000
Lochinvar Dome, southern part
(e)
0
1000
2000
3000
4000
Dural South No 1
(f)
0
1000
2000
3000
Woronora No 1
(g)
* KUNGURIAN

Fig. 53—contd.

Tatarian unconformities

Two angular unconformities have been mapped in the Tatarian sedimentary rocks exposed in the Lochinvar Anticline: one beneath the Newcastle Coal Measures and the other beneath the Narrabeen Group. Both events are shown on Figure 53.

Unconformity beneath Newcastle Coal Measures. The Newcastle Coal Measures unconformably overlie the Muree Sandstone Member of the Branxton Formation on the west flank of the Lochinvar Anticline, and the Mulbring Siltstone on the southeast flank. The Tomago Coal Measures are absent, except in the northeast near Maitland. These relationships can be explained if the Tomago Coal Measures, Mulbring Siltstone, and Muree Sandstone Member were eroded from the Lochinvar Anticline before the Newcastle Coal Measures were laid down (Jones, 1939). The anticline was then buried beneath the Newcastle Coal Measures which onlapped progressively over both the Mulbring Siltstone and Muree Sandstone Member.

Unconformity beneath Narrabeen Group. Higher in the sequence the Narrabeen Group is unconformable on the Newcastle Coal Measures, Mulbring Siltstone, and Muree Sandstone Member (Jones, 1939). The Lochinvar Anticline appears to have been uplifted and eroded again after deposition of the Newcastle Coal Measures while the basal part of the Narrabeen Group was laid down on the flanks. Eventually the anticline was partly buried beneath the Narrabeen Group which overlapped unconformably on to the Muree Sandstone Member.

Upper Triassic unconformity(?)

Regional considerations suggest folding and erosion in the Upper Triassic before the deposition of the Jurassic sediments in the Oxley Basin. The Jurassic sequence on the southern margin of the Oxley Basin rests disconformably on equivalents of the Narrabeen Group (Pl. 1) and overlaps the Permian sequence and rocks of the Lachlan Fold Belt to the northwest. This relationship and the presence of an Upper Triassic unconformity between the Bowen and Surat Basins in Queensland are presumptive evidence of a period of minor folding and erosion in the Sydney Basin area during the Upper Triassic.

Diastrophism Without Unconformity

Permo-Triassic movements

Oscillograms (von Bubnoff, 1963), summarizing the broad vertical movements of the crust in the Sydney Basin region, are given in Figure 53. They show (1) the initial Sakmarian transgression, (2) the middle Artinskian regression in the north, where the Greta Coal Measures were deposited, (3) the Kungurian transgression in the north, (4) a late Kazanian increase in the rate of downwarping of the floor of the basin, (5) the Kazanian regression and transgression, (6) the early Tatarian regression and transgression, and (7) the middle Tatarian regression and transgression.

Structural History

The folds and faults and the age and stratigraphic position of unconformities have already been described. We presume that the folding and faulting, which are now recorded as angular unconformities, were the result of local movements that occupied a relatively short period of time, whereas the broad vertical movements of the crust took place over much longer periods of time and are recorded in the sedimentary rocks as disconformities, onlap, offlap, facies changes, and variations in the rate of sedimentation. The broad vertical movements are summarized by the oscillograms, and the folding and faulting by the tectonograms in Figure 53.

The tectonograms do not identify the structures developed during each pulse of folding and faulting. For example, the sedimentary rocks over the Lochinvar Anticline were folded and eroded twice in the lower Sakmarian and twice in the Tatarian, and were folded again after the Triassic sediments were deposited; the anticline has also been faulted. It is therefore difficult to unravel the complex tectonic history even if less well documented events such as the two Sakmarian unconformities are ignored. Most of the folding and faulting of the Lochinvar Anticline and other structures in the Hunter Valley developed during the two Tatarian movements which are loosely referred to as the Hunter-Bowen Orogeny. However the isopach maps of the Narrabeen Group show a depression to the south of the Lochinvar Anticline which suggests that the Kulnura Anticline and Dural Dome were formed at a later stage. The Kulnura Anticline and Dural Dome, and similar structures in the central area, were formed either in the Upper Triassic or in the Tertiary. We believe they developed in the Tertiary because of physiographic evidence of their youth.

In eastern New South Wales a peneplain had developed by the Miocene (Browne, 1969). The peneplain was uplifted, faulted, and warped into gentle folds during a period of epeirogenic uplift called the Kosciusko Period by Andrews (1910) and the Kosciusko Epoch by David (1932). The deformation and uplift reached a maximum in the late Miocene and early Pliocene. The peneplain was uplifted to form the Southern Highlands and the highlands of New England; in the Sydney Basin the western borderland was uplifted to form the Blue Mountains, and elsewhere there was minor buckling and warping to form the Woronora and Hornsby Plateaux, the Cumberland Basin, and many of the folds and faults to be seen in the rocks south of the Hunter Valley. The gorges of the lower Shoalhaven, Wollondilly, Cox, and Grose Rivers bear witness to the rejuvenation of the river systems and the deep dissection of the uplifted peneplain. One example of the effects of this new erosional cycle is seen in the abrupt right-angled bend taken by the Shoalhaven River at Tallong, where rapidly eroding easterly flowing streams captured the waters of the northerly flowing Shoalhaven River and severed its connexion with the Wollondilly River.

The absence of marine deposits of Tertiary and Pleistocene age from lowlying areas around Sydney and Newcastle is thought to imply that the coastal area was depressed after the Pleistocene high sea levels. The Lapstone Monocline and the Nepean and Kurrajong Faults were formed, or at least underwent further movement, at this time (Jaeger & Browne, 1958; Brown et al., 1968).

Summary of Crustal Structure

The present day crustal structure in the Sydney Basin region is shown in Figure 54 (based on Doyle et al., 1966).

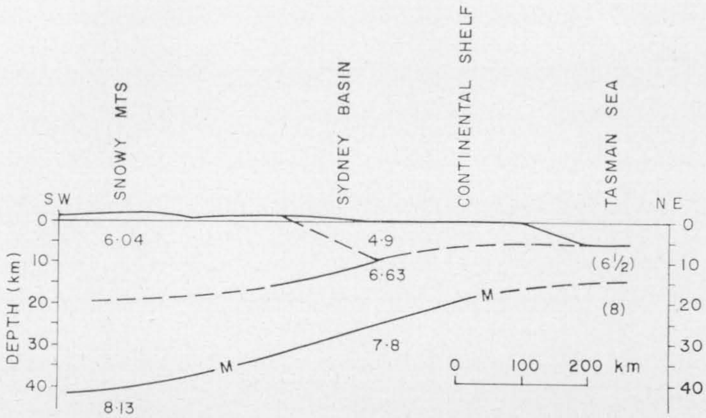

Fig. 54. Northeast-southwest cross-section of crust across the Sydney Basin. M is the Mohorovicic discontinuity; the numbers are velocities in km/s. (From Doyle et al., 1966).

The following features have also been observed (Phipps, 1967; Conolly, 1969):

1. The continental slope is unusually steep—up to 20°.
2. There is no continental rise.
3. The slope abuts on the Tasman abyssal plain, the deepest part of which is at the foot of the slope.
4. The continental shelf is covered at least in part by a wedge of sediment.
5. Several drowned and warped terraces interpreted as Pleistocene to Holocene strandlines exist on the shelf.

Conolly (1969) sees a connexion between the Holocene downwarping of the continental slope and the fact that the abyssal plain is deepest at the foot of the slope.

GEOPHYSICS

Seismic

All land seismic record sections available to the end of 1971 (Table 1) were reinterpreted and four horizons were traced over the basin. The four horizons were first mapped in two-way travel time and then converted into structure contour maps using appropriate velocity functions. Three structure contour maps have been prepared: (1) at the base of the Narrabeen Group (Pl. 6); (2) at the top of the Greta Coal Measures and correlative the Snapper Point Formation (Pl. 7); and (3) at the base of the Rutherford Formation and Pebbley Beach Formation (Pl. 8). An isopach map of the Newcastle Coal Measures and correlatives was also prepared (Fig. 40).

The marine seismic surveys were not reinterpreted. The time contours from the company's interpretation of one horizon were converted to depth below sea level contours and are included in Plate 8.

Data gathering and data quality

The data used included the final reports on the seismic surveys listed in Table 1 and the original seismic records obtained from the companies. The data quality of many of the records was improved by reprocessing in the BMR playback centre. The seismic records (excepting some from the Sydney Basin seismic survey) were reduced to a vertical scale of about 1 second to 3 cm and spliced together into long sections. Although reduction was advantageous in reducing the volume of paper to be handled during interpretation it obscured the character and amplitude of the seismic events and increased errors in reading the travel time. Original records from the Sydney Basin seismic survey in the area to the south of the Great Western Highway to Camden were available, but only time sections from this area were reduced and interpreted. The seismic surveys are located on Plate 4 at 1:500 000 scale.

The study of sonic logs confirms that the main velocity contrast occurs between coal seams and the neighbouring sediments. The best reflections are therefore obtained from within the coal measures. Fair quality reflection from the upper coal measures can be traced throughout the basin at shallow depth (Pl. 6), and in the Singleton-Camberwell area continuous and strong reflections originate from coal seams within the Greta Coal Measures (Pl. 7), but the quality of reflection from the equivalent Snapper Point Formation in the south is poor.

Reflections originating from the base of the Rutherford Formation (Pl. 8) are observed in some places in the northern part of the basin. At Loder No. 1 the interval velocity changes from about 13 000 ft/sec. in the Rutherford Formation to 15 000 ft/sec. in the Allandale Formation and at East Maitland No. 1 the velocity change at the interface is from about 15 000 ft/sec. to about 16 000 ft/sec. In the centre and the south, there is no evidence of reflection from the base of the Pebbley Beach Formation.

Velocity study

A velocity study was made to determine vertical and lateral velocity variations. Seismic velocity is a function of the thickness of overburden and the age of the rocks (Faust, 1951) and may be expressed in the form $V_i = V_o + a\,Z$ (where V_i is instantaneous velocity at depth in ft/ sec., V_o is velocity at zero depth in ft/sec., a is a constant indicating the velocity increment, and Z is depth in feet below sea level).

Continuous velocity measurements in nine wells, one well velocity shoot (Table 11), and two expanded-spreads were available for analysis. A velocity function was estimated for each well using Miller's method (Dix, 1952) whereby a sufficiently accurate velocity function is obtained by choosing values of V_o and a and feeding these into the equation $V_i = V_o + a\,Z$ until the time-depth curve of the equation approximates the time-depth curve obtained from the survey.

TABLE 11. VELOCITY SURVEYS

Name of Well or Locality	*Type of Velocity Measurement*	*Company/Operator*
Martindale No. 1	sonic	Australian Oil and Gas Corporation Ltd
Jerrys Plains No. 1	sonic	Esso (Exploration and Production Aust. Inc.)
Camberwell No. 1	sonic	Australian Oil and Gas Corporation Ltd
Loder No. 1	sonic	Australian Oil and Gas Corporation Ltd
Belford No. 1	sonic	Australian Oil and Gas Corporation Ltd
East Maitland No. 1	sonic	Planet Exploration Co. Pty Ltd
Kurrajong Heights No. 1	well shoot	Exoil N.L.
Dural South No. 1	sonic	Shell Development (Australia) Pty Ltd
Kirkham No. 1	sonic	Australian Oil and Gas Corporation Ltd
Woronora No. 1	sonic	Australian Oil and Gas Corporation Ltd
Shot point 073, traverse C2 (Richmond-Cessnock seismic survey)	expanded spread	Shell Development (Australia) Pty Ltd
Shot point 18, traverse 2 (Sydney basin seismic survey)	expanded spread	Australian Oil and Gas Corporation Ltd

Five velocity functions were determined, each representative of one or more wells or localities (see index maps Pls 6-8):

A. $V_i = 10\,700 + 0.55Z$, for Dural South No. 1 and the expanded spread at shot-point 073 traverse C2
B. $V_i = 11\,300 + 0.52Z$, for Kurrajong Heights No. 1
C. $V_i = 11\,900 + 0.50Z$, for Martindale No. 1A, Kirkham No. 1, and Jerrys Plains No. 1
D. $V_i = 12\,300 + 0.48Z$, for Belford No. 1 and Camberwell No. 1
E. $V_i = 12\,700 + 0.45Z$, for Loder No. 1, East Maitland No. 1, and Woronora No. 1.

Loder No. 1, East Maitland No. 1, and Woronora No. 1, where the present sedimentary cover is thinnest, have the highest velocities, whereas the velocities for Dural South No. 1, in the central part of the basin, are the lowest.

It seems reasonable to deduce that seismic velocity varies laterally with the depth of the sedimentary rocks in the basin and this principle was followed in drawing the rather arbitrary contours (index maps, Pls 6-8) that separate the areas in which the velocity functions are to be applied. The position and shape of these contours is different on each index map, and reflects the variation in thickness of the sedimentary rocks. The time contours from the interpretation of the marine surveys (Longreach, 1969) were converted into the depth contours using a water bottom velocity function of $V_i = 10\,700$ ft/sec. $+ 0.55Z$.

Interpretation

Petroleum exploration wells and deep holes on or close to a seismic traverse (Pl. 4) were plotted. The geological boundaries intersected in these holes were converted to time, plotted onto the seismic sections, and then traced, in closed loops wherever possible, to the next geological control point, phantoming where necessary. In addition geological boundaries and structure from the geological map were added to the section. In this way all geological control was added to the sections and traced throughout. As much of this tracing proved to be unreliable, only four horizons that could be traced throughout the basin were chosen for mapping.

Base of the Narrabeen Group. This horizon can be identified with fair to good reliability in most parts of the basin, and has been confirmed by correlation between several wells. The reflection originates from the topmost coal seam of the 'Upper Coal Measures'. At Windeyers Hawkesbury River Bore, the depth to the base of the Narrabeen Group is 700 m, whereas the horizon traced from Dural South No. 1 occurs at a depth of about 840 m. This difference suggests that an additional coal seam (or seams) occurs in the Windeyers Hawkesbury River Bore. Data along the western margin of the basin and to the south and west of Helensburgh were obtained directly from shallow boreholes and topographic information.

Base of the Newcastle Coal Measures and correlatives. The continuous reflections from coal seams at the base of the Newcastle Coal Measures (excluding the Waratah Sandstone) and correlatives persist throughout the basin, and enable this horizon to be reliably traced. In areas where the quality of the data is poor, interpretation consists of phantom tracing between wells and geological outcrops.

Top of the Greta Coal Measures and correlatives. The reflections from the Greta Coal Measures are strong and continuous. This type of reflection is recorded only in the Singleton-Camberwell area to the east of the Mount Thorley Fault and roughly to the north of latitude 32°45'S. The disappearance of the strong and continuous reflections to the west of the fault suggests that the Greta Coal Measures interfinger with the Snapper Point Formation.

An additional strong and continuous reflection, above the main reflecting horizon, was observed from shot-point 11 along traverse AF to the north, and another was observed on traverse W from shot-point 14 westward. These are interpreted as additional coal seams, that increase the thickness of the Greta Coal Measures to the north and to the west and explain the difference of 435 m in the thickness of the Greta Coal Measures between Camberwell No. 1 and Loder No. 1.

Over, and to the east of, the Lochinvar Anticline, the correlation of this horizon is invariably fair.

Outside the Singleton-Camberwell area the interpretation of this horizon depends heavily on geological control and phantom tracing.

Base of the Rutherford and Pebbley Beach Formations. Reflections originating from the base of the Rutherford Formation can be recognized in some areas near Singleton and the Lochinvar Anticline. An unconformity between the Rutherford and Allandale Formations was interpreted on the east side of the anticline.

No reflections can be detected from the base of the Pebbley Beach Formation and there is no evidence of a velocity contrast between the Pebbley Beach and Wasp Head Formations. Horizon B of the marine seismic survey may correlate with the base of the Rutherford and Pebbley Beach Formations.

Gravity

Bouguer anomaly contours (Pl. 5), covering the whole onshore area of the basin, except between latitudes 33°S and 33°30′S, have been compiled from the results of the gravity surveys listed in Table 3 and from unpublished data supplied by BMR. Rock densities assumed for the Bouguer correction (Pl. 5) vary from survey to survey.

Prior to this work the only gravimetric information came from two gravity traverses, one from the west along the railway to Sydney and the other from the south through Sydney to Newcastle and Muswellbrook (Marshall & Narain, 1954).

Gravity features in the south

Bouguer gravity anomalies generally increase in value from the western boundary of the basin to the east coast (Fig. 55). The eastward shallowing is reflected by two major northerly trending gradient zones—one called the Coastal Gradient Zone and the other the Wollondilly-Blue Mountains Gradient Zone (Pl. 5) (Day, 1969). Across the Coastal Gradient Zone the Bouguer anomalies increase eastward from +10 mgals to +50 mgals, at the rate of about 1.8 mgal/km.

West of Sydney the two gradient zones are separated by an undulating gravity platform with a high near Kingswood and a low to the east centred 10 km northwest of Hornsby.

Gravity features in the north

The steep gradient east of Mount Coricudgy, which dies out farther north, appears to be an extension of the Wollondilly-Blue Mountains Gradient Zone. The gradient is flanked to the east by a Bouguer anomaly high, which is interpreted to be the southerly continuation of the Meandarra Gravity Ridge (Lodwick & Bigg-Wither, 1962; Darby, 1969). The high is flanked to the east by a Bouguer gravity low which is interpreted as a southerly extension of the Gwydir Gravity Low (Darby, 1969). From the extended Gwydir Gravity Low the Bouguer anomaly values increase toward the coast over the Coastal Gradient Zone.

Correlation of northern and southern gravity features

It is likely that the Meandarra Gravity Ridge and its southerly extension are a continuation of the gravity high east of the Wollondilly-Blue Mountains Gradient Zone in the south. Similarly, the Gwydir Gravity Low and its southerly continuation may extend from the north into the southern area to the east of the Bouguer gravity high.

The Sydney Basin is therefore characterized by: (1) the Wollondilly-Blue Mountains Gradient Zone in the west; (2) a parallel flanking zone of Bouguer gravity high (Meandarra Gravity Ridge); (3) a parallel zone of Bouguer gravity low (Gwydir Gravity Low) farther east; and (4) the Coastal Gradient Zone which obliquely intersects the southern end of the other three zones.

Interpretation

Marshall & Narain (1954) have suggested that the general increase in value of Bouguer gravity anomalies from the western boundary of the basin to the east coast is due to shallowing of the lower (basaltic) crust. Doyle et al. (1966) have confirmed this shallowing. Their studies of seismic velocities between points offshore from the central coast of New South Wales (where explosions were detonated) and the Snowy Mountains suggest that the basaltic crust rises eastwards from a depth of about 20 km below the Snowy Mountains to an estimated 5 km below the continental shelf (Fig. 54).

The theory of isostasy predicts that areas of thick crust (and Bouguer gravity lows) are elevated and that areas of thinner crust (and Bouguer gravity highs) are depressed. Present topographic elevations agree generally with this prediction (Fig. 55). Furthermore there is a close reverse correlation (Fig. 55) between the structure of the basin sediments (Pls 6-8) and the Bouguer anomaly map, particularly to the west of Sydney. The area in which the sediments deepen along the western margin coincides with the Wollondilly-Blue Mountains Gradient Zone and the Lapstone Monocline and Kurrajong and Nepean Faults. The deep syncline to the east coincides with the southern extension of the Meandarra Gravity Ridge, and the anticline farther east coincides in the south with the southern extension of the Gwydir Gravity Low.

There are two possibilities: the Bouguer anomaly pattern developed after sedimentation ceased in the onshore basin, or before or during sedimentation and has been modified by more recent diastrophism. A simple answer to this question is not possible with the data available. Isopach maps of Intervals 1 to 5 suggest a fairly simple easterly thickening wedge of sediments, but the isopachs of Intervals 6 to 12 show a persistent depositional trough (the Macdonald Trough), which coincides approximately with the extension of the Meandarra Gravity Ridge. This trough is flanked to the east by a depositional arch (the Kulnura Arch), but the arch is not coincident with the Gwydir Gravity Low extension. However, the isopach maps are highly interpretative in this area and many of them show the preserved thickness of sediments rather than the original thickness.

Darby (1969) has shown that the Mooki-Hunter Thrust is parallel to and just east of the axis of the Gwydir Gravity Low for several hundred kilometres in New England. If the Gwydir Gravity Low has been correctly extended by us into the Sydney Basin, then by analogy the thrust should continue in the same position relative to the gravity low. In this case the thrust or some other lateral development of the feature should continue along the west flank of the Lochinvar Anticline and disappear southward beneath the younger Triassic cover.

Magnetic Anomalies

Magnetic intensity contours and interpreted depth to magnetic basement contours from all aeromagnetic and shipborne magnetic surveys carried out in the Sydney Basin to the end of 1971 (Table 3) are compiled on Plate 6 at 1:500 000.

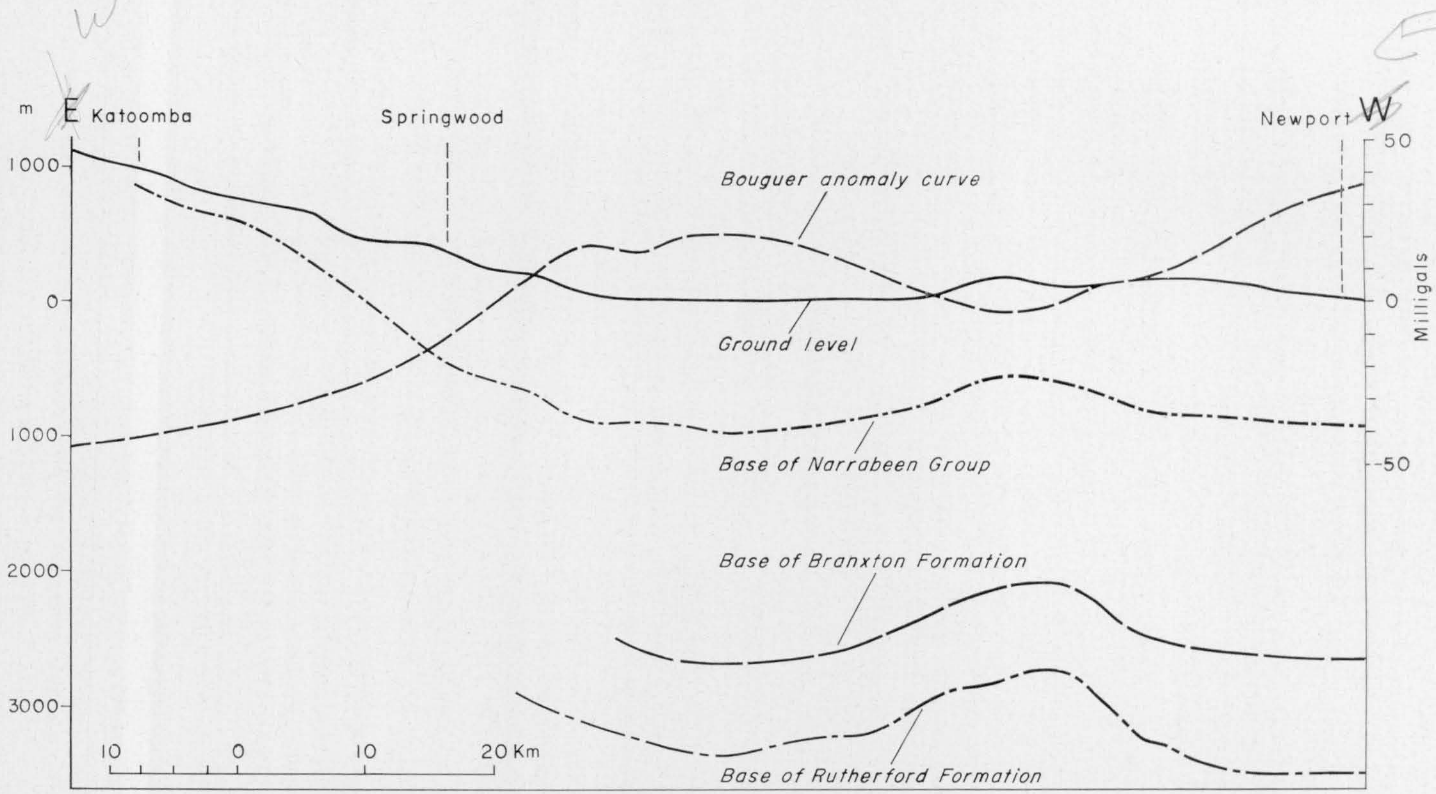

Fig. 55. Cross-section from Katoomba to Newport showing relationship between topography, structure, and Bouguer anomalies.

Interpretation of the depth to magnetic basement by the contractors was hampered by the wide spacing of the flight lines and, in the north, by the excessive height at which the lines were flown.

Magnetic basement

In general the results of this study confirm that magnetic basement and economic basement are coincident with the top of the Allandale volcanics in the north and with the unconformity between the Lachlan Fold Belt and the Permian sediments in the south. Magnetic basement therefore is the same as the base of the Sydney Basin as defined in this Bulletin. However, local intrusive and extrusive igneous rocks within the overlying Sydney Basin succession (Tables 6-10, Pl. 5) also give rise to anomalies that increase the uncertainty in the identification of magnetic basement. These anomalies are located on Plate 6. The effect of the Tertiary volcanics and intrusions cropping out in the north is uncertain as the report on the survey for Australian Oil and Gas Corp. Ltd in 1955 could not be obtained, and only the map accompanying this report was available to us.

The high-frequency magnetic intensity contours in the southern part of the basin are due to the presence of the Gerringong Volcanics at shallow depth, and the estimated depth to magnetic basement in this area is the depth to the Gerringong Volcanics. Offshore, a well defined area containing high-frequency magnetic intensity contours (Pl. 6) is interpreted as a sequence of sediments, 2000 to 4000 m thick, which contains shallow intrusive plugs or shallow volcanics, or both, at a depth of a few hundred metres below the sea floor. A depth estimate of 150 m was made on the east side of a closed anomaly 5 km southeast of Botany Bay.

Interpretation

The western margin of the basin, which has a northerly trend is clearly defined by high-frequency contours. The magnetic basement deepens from the western margin toward a deep trough with a maximum depth exceeding 4000 m. Farther east, a northerly trending basement high is separated from the trough by an interpreted fault. The basement high coincides with the trends of the Lochinvar Anticline, Kulnura Anticline, and Dural Dome.

The fault appears to have been interpreted because of the large difference in depth estimates made on two circular anomalies: one in the west giving a depth of 3000 m and the other in the east giving a depth of 1800 m. The presence of this fault is questionable. The anomalies could be due to the presence of igneous intrusions, but it is more probable that the depth estimates are inaccurate as the Kulnura No. 1 well penetrated about 160 m below the depth to magnetic basement shown on the map, without reaching basement.

Farther east another basement high is separated from the Lochinvar-Kulnura-Dural trend by a deep trough which extends southward from south of Lake Macquarie to Broken Bay and then offshore almost parallel to the coast.

Near Newcastle magnetic basement deepens rapidly eastward to a maximum depth of about 4800 m.

A slight basement high between Mount Coricudgy and Muswellbrook, which Stuntz (1969) suggests as the boundary between the Sydney Basin and the Oxley Basin, appears as a saddle.

The general form of the magnetic basement agrees with the structure contours from seismic interpretation (Pl. 8).

GEOLOGICAL HISTORY

The history of deposition in the Sydney Basin is summarized in Figure 56.

The sea first entered the basin in the early Sakmarian. In the marginal mobile zone a thick sequence of basic, intermediate, and acid volcanics, interbedded with fluvial or marine sediments, was laid down about the same time as the fluviatile, paludal, and marine sediments of Interval 1 were being deposited on the craton. Coal swamps developed along the southern margin of the basin (Clyde Coal Measures) and to a lesser extent (Garretts Seam) on the northeast margin. Volcanism ceased in the Sakmarian and from then onwards the Permo-Triassic history is one of alternating marginal and shallow marine environments.

The first marine encroachment reached its maximum in middle Sakmarian time (Interval 2) when direct links with the Bowen Basin were probably established. The rapid thinning of the sediments to the north indicates continuing uplift of the mobile zone in the New England area.

Late in the Sakmarian and through the Artinskian the sea retreated and an area of marginal deposition including coal swamps spread southward over the northern half of the basin (Interval 3).

During the Kungurian the sea advanced again over the basin and the coal swamps shrank northwards as marine conditions were re-established (Interval 4).

A marine regression and subsequent transgression in the late Kungurian and early Kazanian is recorded in the Muree Sandstone Member and Nowra Sandstone (Interval 5). The transgression reached its maximum in the middle Kazanian when a connexion between the Sydney and Bowen Basins was established. The connexion remained open until marine regression in the upper Kazanian brought dominance of marine sedimentation in the Sydney Basin to an end; henceforth marginal conditions were more in evidence.

During the upper Kazanian regression the coal swamps spread southward again, but the southern part of the basin was still covered by a shallow sea. Lava from vents to the east of the present coast flowed over the sea floor and adjacent swamplands (Interval 7). Volcanism was renewed in middle Kazanian time with outbursts of volcanic ash, and minor igneous activity continued into the Cainozoic, probably as a result of tensional fracturing of the Gondwanaland lithospheric plate.

In the early Tatarian a brief marine transgression obliterated the coal swamps, except in the north and northwest (Interval 8).

The mid-Tatarian was marked by a major marine regression and the extensive development of coal swamps. The chief coal seams of the Tomago Coal Measures were laid down at this time (Interval 9).

The pattern of marine transgression (Interval 10) followed by regression and the accumulation of coal (Interval 11) was repeated in the upper Tatarian. The Newcastle Coal Measures marked the culmination of coal development. Explosive volcanicity continued on a large scale to the east of the present coastline: volcanogenic material is common in the epiclastics of the adjacent coal measures and the sequence includes several layers of tuff. Alluvial cones and fans were built in the lower Hunter Valley by rivers draining uprising land to the north and east.

Towards the end of the Tatarian the swampy lowlands of the Sydney Basin were destroyed and the environment became less favourable for the accumulation of coal. It is not known whether this was due to a climatic change or to the development of alluvial plains over the old coal swamps, or both (Interval 12). There

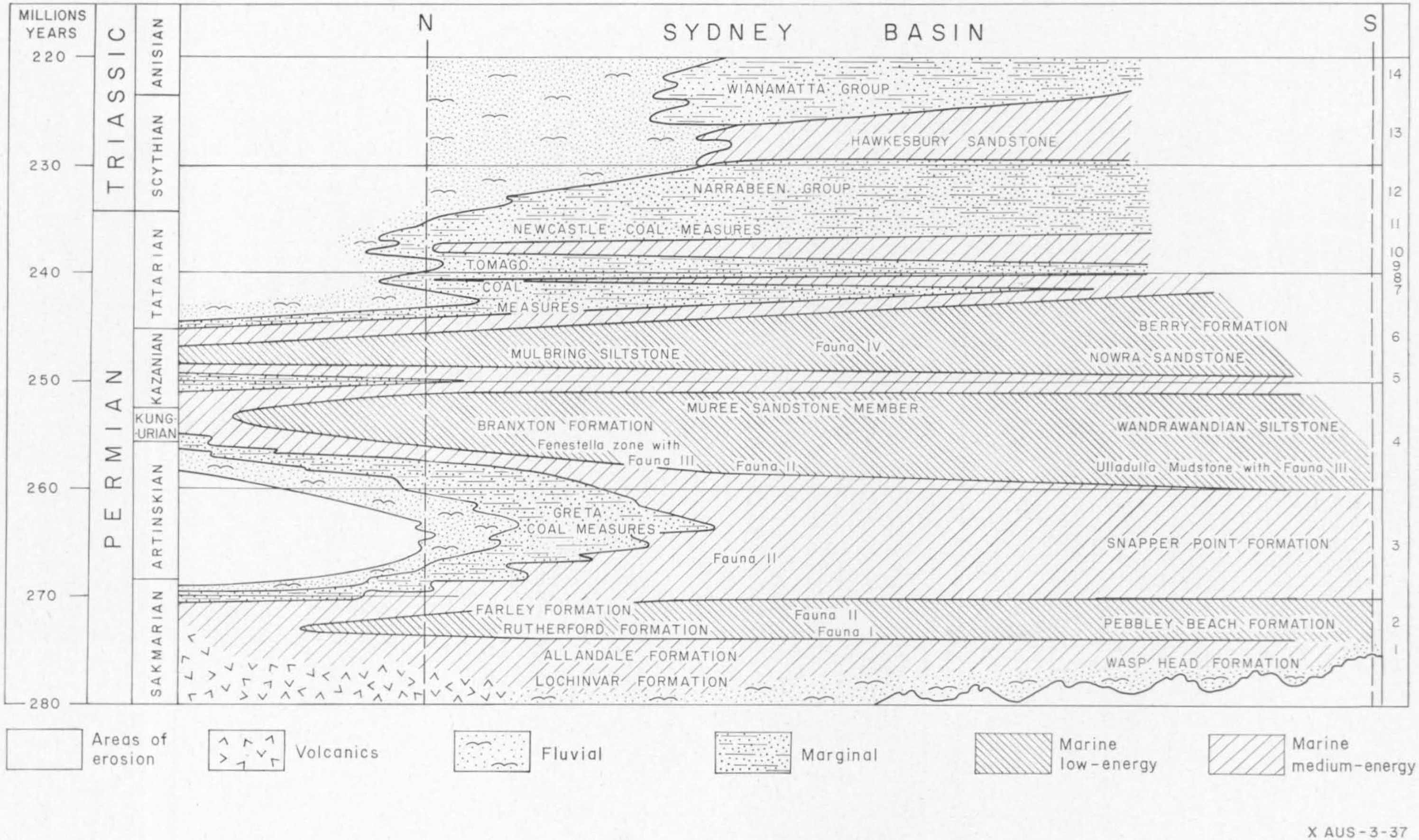

Fig. 56. Diagram relating environments of deposition, intervals, and time.

were minor changes of sea level which resulted in the advance and retreat of delta-fronts in the complex system of Narrabeen deltas.

By the end of the Lower Triassic it is probable that the western borderlands of the Sydney Basin had been reduced to a low-level peneplain, and that braided streams spread over the Narrabeen delta-plain which by now was reduced almost to sea level. This great flat was probably subject only to the influence of spring tides rather than the daily tides. A modern example of such a situation is the Rann of Cutch in India. The sediment left by the winnowing action of the tides now constitutes the Hawkesbury Sandstone (Interval 13). It is assumed that the rifting, which was later to produce the Tasman Sea, had developed to a Red Sea-like stage which allowed the tides to sweep northwards along it and impress a general northeasterly dip on the current-bedded sands in the Sydney Basin area.

By the Middle Triassic conditions had reverted to those of an alluvial plain with deltas prograding into a shallow sea (Interval 14). Small volcanoes erupted explosively in the central and eastern parts of the plain. The Wianamatta Group is the youngest part of the sequence preserved in the Sydney Basin, except for riverine gravels. The group has been eroded to its basal formation, except in the Razorback Range.

There is some evidence, however, of Jurassic sedimentation in the Sydney Basin:

1. Jurassic beds crop out on the northwestern margin of the basin.

2. The rank of the coal laminae in the Wianamatta Group indicates that they may have been buried beneath a thousand metres of sediment.

3. The type of Cretaceous sedimentation in the Great Artesian Basin indicates that much of the clastic detritus was derived from a southeasterly source; this could not have been the older Palaeozoic rocks, and the Wianamatta Group was too small.

4. The Jurassic beds in the Clarence Basin are over 2000 m thick.

5. The zeolites in the coal measures have been attributed to diagenesis, but they could have been formed as a result of burial metamorphism beneath a thick sequence of sediment that has since been eroded.

6. The plant spores in the Permo-Triassic rocks are commonly carbonized, and some of the fossil leaves have been replaced by graphite.

7. In New Zealand, Jurassic sediments of the New Zealand Geosyncline have been derived from a 'Tasmantis' to the west.

Sedimentation was influenced by the waxing and waning of continental glaciers. According to Crowell & Frakes (1971) the continental ice sheets spread rapidly to the north and east at the end of the Carboniferous, and the glaciation reached a maximum in late Sakmarian or early Artinskian time. The advance of the ice sheet corresponded with a shift of palaeolatitude (Irving, 1966; Irving & Robertson, 1968; McElhinny, 1969). The ice cap grew on the Carboniferous highlands bordering the palaeo-Pacific. The Permian marine sedimentary rocks contain evidence of ice-rafting.

Meyerhoff (1970) does not consider that it is necessary to invoke polar wandering to explain the glaciation. He suggests that it occurred in a period of glacial maxima related to episodic changes in average world temperature, which resulted in the alternation of periods of glacial maxima with periods of evaporite maxima.

If the history of the Sydney Basin is interpreted in the context of the current theories of global tectonics (Griffiths, 1971; Packham & Falvey, 1971) the following assumptions may be made as a framework (Fig. 57).

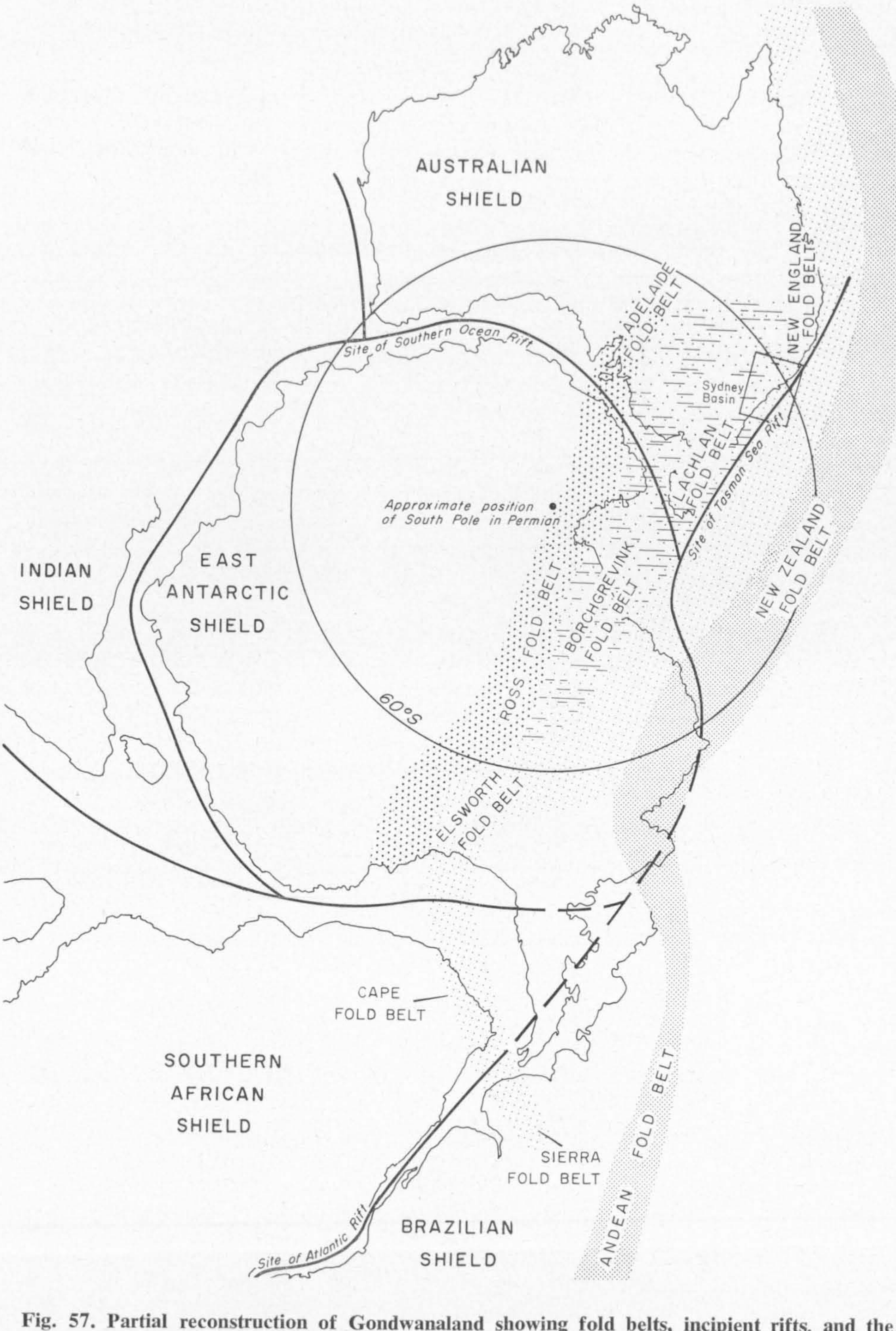

Fig. 57. Partial reconstruction of Gondwanaland showing fold belts, incipient rifts, and the position of the South Pole in Permian time. (After Antarctic Map Folio Series, 12, xxiii, *Amer. geogr. Soc.*).

1. Australia was a part of the protocontinent of Gondwanaland during the upper Palaeozoic, with the South Pole somewhat to the west of the present Bass Strait.

2. Sea-floor spreading from the Darwin Rise in Permo-Carboniferous time resulted in a lithospheric plate descending along a subduction zone off the east coast of Gondwanaland. An island arc complex was formed which became accreted to the craton: the Sydney Basin is a part of the sediment trap which lay between the arc and the mainland of older rocks.

3. By the middle Mesozoic crustal fracturing in 'eastern' Gondwanaland had developed into a system of rift valleys, including the Otway Rift Valley, by which the protocontinent was eventually to be dismembered by sea-floor spreading. In addition to the rifting which separated the Australian and Antarctic segments a splinter rift valley opened out to the north, cutting obliquely through the stabilized Permo-Carboniferous orogenic belt with its Mesozoic accretion (The New Zealand Fold Belt). Sea-floor spreading carried this eastern sliver of the continent away as the Lord Howe Rise and New Zealand; the part that was originally adjacent to the Sydney Basin is the section north of the Bellona Gap in the Lord Howe Rise. The transcurrent faults of coastal New England may be related to this sea-floor spreading which resulted in the formation of the Tasman Sea. A great volume of magma was injected in the Sydney Basin as dykes and sills, mostly during the Jurassic, and possibly at the same time as the Great Dolerite Sill of Tasmania.

The present-day situation in Malaya-Sumatra and the Mentawai subduction zone is rather like that in the Sydney Basin at the end of the Palaeozoic, with the Straits of Malacca and the densely vegetated fringing lowlands as the equivalent of the Permo-Triassic sediment trap.

Permo-Triassic sedimentation in the Sydney Basin was accompanied by orogenic and volcanic activity in a north-northwesterly trending island arc which ran through the New England area (Voisey, 1959a,b). Uplift began during the Carboniferous and continued through the Permian. Erosion of the mountains provided a major source of sediment for the Sydney Basin. The poor sorting and rounding of the sediment in the Permian marine sedimentary rocks indicate deposition in sheltered waters. The island arc formed a barrier behind which sediment was trapped.

ECONOMIC GEOLOGY

Coal, oil shale, heavy mineral sands, construction and ceramic materials, and natural gas have been exploited in the Sydney Basin. Traces of phosphate and oil have also been found.

Petroleum

The history of petroleum exploration in the Sydney Basin has already been described on pages 12 to 24. Natural gas shows were encountered in both the Permian and Triassic sedimentary rocks. The most significant discovery was an initial flow of 35 245 m^3 per day from the base of the Narrabeen Group in Camden No. 7. During World War II, methane gas (4229 m^3 per week) from the Balmain Colliery was used as a substitute for petrol. Traces of oil were recorded in Farley No. 1, Loder No. 1 (Branxton, Farley, and Rutherford Formations), Camberwell No. 1 (Mulbring Siltstone), and Terrigal No. 1.

The Permian and Triassic sedimentary rocks are prospective for petroleum. Economic basement in the south and west is the rocks of the Lachlan Fold Belt, and to the north the Allandale Formation. The prospective section in the Sydney Basin is generally about 800 m thick in the south, 2300 m in the central area, and 1600 m in the north, and reaches a maximum in the Macquarie Syncline near Newcastle of about 5900 m (from seismic interpretation).

Source, reservoir, and cap rocks

Many of the fine-grained marine sedimentary rocks are a potential source of petroleum. They include the Farley, Rutherford, Pebbley Beach, and Branxton Formations, the Wandrawandian and Mulbring Siltstones, and the Berry Formation. Brooks (1970) considers that some of the Permian and Triassic plants may have been the progenitor of both coal and petroleum. Under the right conditions, plants in a forest growing near the sea shore would decay on land first to form peat, and then brown coal. However, waterborne and windborne plant material, consisting of the smaller fragments (particularly of leaves) containing a higher proportion of lipids than the main plant, could reach the lakes or the ocean and decay under quite different conditions to produce carbonaceous lacustrine or marine muds—that is, the type of sediment that is frequently the source of petroleum. The Greta Coal Measures and the Upper Permian coal measures have therefore also been included as potential source rocks. The oil shale deposits in the upper Permian coal measures are known source rocks.

There are no known reservoir rocks in the Sydney Basin. Studies of porosity and permeability (Table 12) demonstrate that although porosity reaches 36 percent of the bulk volume in the Upper Permian coal measures in Woronora No. 1 it is generally only about 9 percent. The highest permeability measured is 1330 millidarcies (horizontal) in the Narrabeen Group in Woronora No. 1; for the Permian the average is 0.14 millidarcies (vertical) and 0.212 millidarcies (horizontal); and for the Triassic 26.216 millidarcies (vertical) and 39.083 millidarcies (horizontal).

TABLE 12. POROSITY, PERMEABILITY, AND FLUID SATURATION DETERMINATIONS

Name of Well	Depth (m)	*Average Effective Porosity from 2 Plugs* (% bulk vol.)	*Absolute Permeability* (Millidarcy)		*Fluid Saturation* (% of pore space)	
			Vertical	*Horizontal*	*Water*	*Oil*
Interval 1						
Loder No. 1	1200.9	5	nil	nil	69	nil
	1371.6	19	nil	nil	93	nil
Jerrys Plains No. 1	1545.1	6.3	nil	nil	18	nil
Martindale No. 1A	1181.1	14	nil	nil	n.d.	n.d.
Woronora No. 1	2245.8	2	nil	nil	34	nil
Dural South No. 1	3050.4	8	nil	nil	n.d.	n.d.
Kirkham No. 1	2501.6	4	nil	nil	—	—
	2561.9	3	nil	nil	—	—
Kurrajong Heights No. 1	2377.1	16	nil	nil	n.d.	n.d.
	2434.4	15	nil	nil	n.d.	n.d.

TABLE 12.—*Cont.*

Name of Well	Depth (m)	Average Effective Porosity from 2 Plugs (% bulk vol.)	Absolute Permeability (Millidarcy) Vertical	Absolute Permeability (Millidarcy) Horizontal	Fluid Saturation (% of pore space) Water	Fluid Saturation (% of pore space) Oil
	2487.8	0	nil	nil	n.d.	n.d.
	2521.0	10	nil	nil	n.d.	n.d.
	2607.9	4	nil	nil	n.d.	n.d.
Stockyard Mountain No. 1	922.0	4	nil	nil	n.d.	n.d.
	999.4	5	nil	nil	n.d.	n.d.
	1041.2	4	nil	nil	nil	nil
	1070.4	4	nil	nil	n.d.	n.d.
Coonemia No. 1	626.9	1.9	n.d.	0.39	22	nil
	794.8	1.6	n.d.	nil	36	nil
Interval 2						
Loder No. 1	815.0	7	nil	nil	n.d.	n.d.
	906.2	7	nil	nil	n.d.	n.d.
	950.9	13	nil	nil	n.d.	n.d.
	1079.0	10	nil	nil	n.d.	n.d.
	1163.4	9	nil	nil	n.d.	n.d.
Camberwell No. 1	1246.7	13	nil	nil	nil	n.d.
	1723.0	11	nil	nil	n.d.	n.d.
Jerrys Plains No. 1	1004.3	9.4	nil	nil	30	nil
	1006.9	7.6	nil	nil	31	nil
	1009.5	6.7	nil	nil	24	nil
Woronora No. 1	1942.2	4	nil	nil	n.d.	n.d.
	2034.2	3	nil	nil	n.d.	n.d.
	2138.5	2	nil	nil	91	nil
Dural South No. 1	2758.7	3	nil	nil	n.d.	n.d.
	2920.2	4	nil	nil	n.d.	n.d.
Kirkham No. 1	2072.7	6	nil	nil	—	—
	2183.7	6	nil	nil	—	—
	2305.6	8	nil	nil	—	—
	2400.7	6	nil	nil	—	—
Kurrajong Heights No. 1	2144.9	4	nil	nil	n.d.	n.d.
	2247.9	4	nil	nil	n.d.	n.d.
	2328.7	9	nil	nil	n.d.	n.d.
Stockyard Mountain No. 1	762.9	4	nil	nil	n.d.	n.d.
	825.1	7	nil	nil	n.d.	n.d.
Coonemia No. 1	365.1	5.6	n.d.	nil	7.8	nil
	508.6	1.9	n.d.	nil	24	nil
Wollongong No. 1	305.1	5.9	0.1	0.1	15	nil
Wollongong No. 2A	303.7	5.7	0.1	0.1	27	nil
Interval 3						
Loder No. 1	718.4	5	nil	1 (fracture)	29	nil
Camberwell No. 1	744.6	8	nil	nil	nil	nil
	751.4	13	nil	nil	nil	nil
	957.9	7	nil	nil	5	nil
	1074.4	7	nil	2	3	nil
Jerrys Plains No. 1	715.8	9.1	nil	nil	12	nil
	719.0	8.2	nil	nil	31	nil
	721.3	9.1	nil	nil	18	nil
	725.4	8.5	nil	nil	14	nil
	729.6	6.3	nil	nil	16	nil
	859.6	6.3	nil	nil	26	nil
	863.4	6.2	nil	nil	21	nil
	1001.8	8.8	nil	nil	30	nil
Martindale No. 1A	1051.4	9	nil	nil	24	tr
Woronora No. 1	1761.7	5	nil	nil	n.d.	n.d.
	1854.1	7	nil	nil	8	nil
Dural South No. 1	2444.8	3	nil	nil	n.d.	n.d.
	2615.9	6	nil	nil	n.d.	n.d.
Kirkham No. 1	1844.1	3	nil	nil	—	—
	1963.3	6	nil	nil	—	—

TABLE 12.—*Cont.*

Name of Well	Depth (m)	Average Effective Porosity from 2 Plugs (% bulk vol.)	Absolute Permeability (Millidarcy) Vertical	Horizontal	Fluid Saturation (% of pore space) Water	Oil
Kurrajong Heights No. 1	1953.8	5	nil	nil	n.d.	n.d.
	2053.1	6	nil	nil	n.d.	n.d.
Stockyard Mountain No. 1	495.9	8	nil	nil	nil	nil
	583.1	16	11	6	nil	nil
	673.9	8	nil	nil	n.d.	n.d.
BMR Wollongong No. 1	212.9	48	0.1	0.1	2.2	nil
	239.1	9.3	0.14	0.14	2.9	nil
	240.5	11	0.25	0.23	2.3	nil
	276.2	3.5	0.1	0.1	22	nil
	288.6	9.4	0.10	0.12	4.0	nil
BMR Wollongong No. 2A	190.2	10	0.19	0.10	6.7	nil
	202.2	11	0.12	0.14	8.3	nil
	257.9	8.9	0.13	0.14	6.2	nil
	274.8	12	0.13	0.13	5.0	nil
Interval 4						
Loder No. 1	166.4	7	nil	nil	n.d.	n.d.
	258.2	9	nil	nil	n.d.	n.d.
	338.6	10	nil	nil	9	nil
	426.4	12	nil	nil	n.d.	n.d.
	566.9	12	nil	nil	13	nil
Camberwell No. 1	629.7	10	nil	nil	n.d.	n.d.
Jerrys Plains No. 1	582.4	7	nil	nil	31	nil
Woronora No. 1	1654.1	5	nil	nil	n.d.	n.d.
Dural South No. 1	2292.2	5	nil	nil	n.d.	n.d.
Kirkham No. 1	1731.4	4	nil	nil	—	—
Kurrajong Heights No. 1	1687.4	6	nil	nil	n.d.	n.d.
	1780.9	6	nil	nil	n.d.	n.d.
	1865.4	5	nil	nil	n.d.	n.d.
Stockyard Mountain No. 1	316.1	2	nil	nil	n.d.	n.d.
	416.9	9	nil	nil	n.d.	n.d.
Coonemia No. 1	143.8	1.3	n.d.	0.36	63	nil
BMR Wollongong No. 1	45.7	4	0.1	0.1	34	nil
	70.7	3.1	0.1	0.1	13	nil
	86.9	2.5	0.1	0.1	36	nil
	133.1	3.2	0.1	0.1	60	nil
Interval 5						
Woronora No. 1	1560.6	7	nil	nil	6	nil
Mulgoa No. 2	1522.2	9.4	nil	nil	—	—
	1522.5	10.5	nil	nil	—	—
	1523.4	8.6	nil	nil	—	—
	1523.7	9.8	5	nil	—	—
	1524.0	10.3	nil	nil	—	—
Kirkham No. 1	1586.0	9	nil	nil	—	—
Stockyard Mountain No. 1	266.1	6	nil	nil	n.d.	n.d.
Cataract No. 1	1229.7	6	nil	nil	—	—
	1230.4	5	nil	nil	—	—
	1238.2	6	nil	nil	—	—
	1246.6	4	nil	nil	—	—
BMR Wollongong No. 1	18.6	4.7	0.1	0.1	54	nil
	23.0	7.4	0.1	0.1	14	nil
	27.0	9.9	0.16	0.15	7.9	nil
Interval 6						
Woronora No. 1	1189.3	10	nil	nil	10	nil
	1366.1	8	nil	nil	30	nil
	1482.5	1	nil	nil	100	nil
Dural South No. 1	1943.3	10	nil	nil	n.d.	n.d.
	2146.0	4	nil	nil	n.d.	n.d.
Kirkham No. 1	1409.5	8	nil	nil	—	—
	1503.1	5	nil	nil	—	—

TABLE 12.—*Cont.*

Name of Well	Depth (m)	Average Effective Porosity from 2 Plugs (% bulk vol.)	Absolute Permeability (Millidarcy) Vertical	Horizontal	Fluid Saturation (% of pore space) Water	Oil
Kurrajong Heights No. 1	1419.1	11	nil	1 (fracture)	n.d.	n.d.
	1448.1	9	nil	nil	n.d.	n.d.
	1542.3	7	nil	nil	n.d.	n.d.
	1627.8	6	nil	nil	n.d.	n.d.
Stockyard Mountain No. 1	93.6	3	nil	nil	n.d.	n.d.
	191.1	5	nil	nil	n.d.	n.d.
Cataract No. 1	940.6	9	nil	nil	—	—
	942.6	5	nil	nil	—	—
	1050.3	7	nil	nil	—	—
	1153.8	5	nil	nil	—	—
	1155.6	4	nil	nil	—	—
	1192.1	4	nil	nil	—	—
	1194.2	3	nil	nil	—	—
	1225.5	5	nil	nil	—	—
BMR Wollongong No. 2	30.1	4.7	0.1	0.1	35	nil
Intervals 7-11						
Martindale No. 1A	98.8	3	nil	nil	n.d.	n.d.
Mount Murwin No. 1	815.3	11	n.d.	n.d.	n.d.	n.d.
Woronora No. 1	587.4	32	n.d.	n.d.	n.d.	n.d.
	588.0	36	n.d.	n.d.	n.d.	n.d.
	588.1	n.d.	n.d.	n.d.	22	0.9
	915.6	15	nil	nil	60	nil
	1056.7	2	nil	nil	88	nil
	1123.8	8	nil	nil	19	nil
Mulgoa No. 2	1160.4	6	nil	nil	—	—
Dural South No. 1	1679.6	7	nil	nil	n.d.	n.d.
Berkshire Park No. 1	1090.1	14	n.d.	n.d.	30	nil
	1090.5	8	n.d.	n.d.	72	nil
Higher Macdonald No. 1	622.9	14.6	nil	7	20	nil
	623.0	13.7	nil	2	40	nil
	625.8	14.6	nil	1	39	nil
Kirkham No. 1	750.8	10	nil	nil	—	—
	752.6	12	nil	nil	—	—
	753.9	13	nil	nil	—	—
	755.7	8	nil	nil	—	—
	916.6	10	n.d.	n.d.	—	—
	918.5	11	nil	nil	—	—
	1004.4	6	nil	nil	—	—
	1005.0	8	nil	nil	—	—
	1005.6	9	nil	nil	—	—
	1006.2	10	nil	nil	—	—
	1006.8	9	nil	nil	—	—
	1124.2	8	nil	n.d.	—	—
	1124.8	13	nil	nil	—	—
	1125.4	12	nil	nil	—	—
	1205.6	10	nil	nil	—	—
	1206.2	12	nil	nil	—	—
	1206.8	11	nil	nil	—	—
	1207.4	12	nil	nil	—	—
	1208.0	12	nil	nil	—	—
	1283.3	7	nil	nil	—	—
	1285.1	6	nil	nil	—	—
Kurrajong Heights No. 1	890.9	12	nil	nil	n.d.	n.d.
	890.9	13	nil	1	11	nil
	936.9- 941.5	10	nil	nil	n.d.	n.d.
	936.9- 941.5	12	nil	nil	n.d.	n.d.
	936.9- 941.5	10	nil	nil	18	nil
	1275.5-1279.8	13	2	5	nil	nil
	1275.5-1279.8	13	2	3	n.d.	n.d.

TABLE 12.—*Cont.*

Name of Well	Depth (m)	Average Effective Porosity from 2 Plugs (% bulk vol.)	Absolute Permeability (Millidarcy) Vertical	Horizontal	Fluid Saturation (% of pore space) Water	Oil
	1275.5-1279.8	12	3	6	n.d.	n.d.
	1275.5-1279.8	12	nil	1	5	nil
Lower Portland No. 1	888.3	9	nil	nil	51	nil
Cataract No. 1	199.4	13	nil	nil	—	—
	372.0	19	nil	nil	—	—
	718.3	18	nil	nil	—	—
Interval 12						
Mount Murwin No. 1	192.0	13	n.d.	3	n.d.	n.d.
	531.3	15	n.d.	n.d.	n.d.	n.d.
	592.2	14	n.d.	8	n.d.	n.d.
	669.9	9	n.d.	n.d.	n.d.	n.d.
	704.7	8	n.d.	nil	n.d.	n.d.
Woronora No. 1	455.3	31	n.d.	1330	5	nil
	487.3	27	n.d.	n.d.	n.d.	n.d.
	487.6	26	n.d.	n.d.	21	nil
Mulgoa No. 2	450.2	16	nil	nil	—	—
	450.8	17.6	nil	nil	—	—
	451.1	17.5	3	nil	—	—
	451.7	16.8	1	nil	—	—
Berkshire Park No. 1	330.4	17	nil	nil	39	nil
	331.4	19	nil	1.4	23	nil
	332.7	21	3	7	23	nil
	740.8	14	nil	nil	51	nil
	742.5	14	0.63	2	22	nil
Higher Macdonald No. 1	352.5	16.7	6	n.d.	14	nil
Kirkham No. 1	429.6	18	nil	nil	—	—
	522.8	10	nil	nil	—	—
	522.8	9	n.d.	nil	—	—
	523.4	12	nil	nil	—	—
	622.2	10	nil	nil	—	—
	622.8	16	nil	nil	—	—
	702.9	10	nil	nil	—	—
	704.2	13	nil	nil	—	—
	734.9	6	nil	nil	—	—
	739.2	8	nil	nil	—	—
	740.5	33	nil	nil	—	—
	744.1	5	nil	nil	—	—
Kurrajong Heights No. 1	217.3- 223.4	18	nil	nil	n.d.	n.d.
	217.3- 223.4	14	9	7	n.d.	n.d.
	217.3- 223.4	13	n.d.	1	n.d.	n.d.
	217.3- 223.4	19	nil	nil	3	nil
	276.4	9	n.d.	n.d.	n.d.	n.d.
	321.9	14	nil	nil	5	nil
	327.4	22	862	437	n.d.	n.d.
	327.4	21	93	312	nil	nil
	515.1	19	65	138	nil	nil
	515.1	17	2	12	n.d.	n.d.
	629.7- 635.8	7	nil	nil	n.d.	n.d.
	629.7- 635.8	10	nil	nil	n.d.	n.d.
	629.7- 635.8	17	10	16	n.d.	n.d.
	629.7- 635.8	15	2	2	5	nil
	629.7- 635.8	12	nil	nil	n.d.	n.d.
	840.3- 845.8	17	7	15	n.d.	n.d.
	840.3- 845.8	16	1	8	n.d.	n.d.
	840.3- 845.8	15	2	8	13	nil
	840.3- 845.8	16	6	6	n.d.	n.d.
Lower Portland No. 1	307.9	17	nil	0.49	11	nil
	309.2	19	51	592	51	nil
	309.6	20	214	246	27	nil

Name of Well	Depth (m)	Average Effective Porosity from 2 Plugs (% bulk vol.)	Absolute Permeability (Millidarcy) Vertical	Horizontal	Fluid Saturation (% of pore space) Water	Oil
Interval 13						
Kirkham No. 1	298.5	15	nil	nil	—	—
	300.9	16	nil	nil	—	—
Kurrajong Heights No. 1	213.0- 216.1	18	nil	nil	3	nil
Lower Portland No. 1	128.0	8	nil	nil	21	nil

n.d. — not detected

The two most widespread marine sandstones, the Muree Sandstone Member and its correlatives and the Snapper Point Formation, are impermeable in areas drilled to date. The low permeability in the basin is due in part to the lack of sorting which resulted in sediments with two modes of grainsize, the presence of large amounts of cement (a result of diagenesis), compaction of the sediments, and in some formations the presence of clay matrix.

We have considered the possibility that permeability was lost largely as a result of diagenesis and that petroleum could have accumulated before the loss of permeability. Under these hypothetical circumstances the presence of oil instead of water in the pore spaces would retard diagenesis (Orlova, 1958; Chepikov et al., 1959, 1960, 1967; Fuchtbauer, 1961; Millot, 1964; Klubova, 1965; Perozio, 1965; Prozorovich, 1967; and others) and production of petroleum would still be a possibility. For example, Yurkova (1970) studied one of the productive horizons (17th) of north Sakhalin. The sandstones and siltstones in the productive reservoir beds consist of quartzofeldspathic greywacke with polyminerallic clay (chlorite, kaolinite, hydromica, and montmorillonite) and carbonate cement. The mineral composition of both the detrital and the secondary components shows a regular variation down the section. There is a gradual disappearance and replacement of unstable clastic minerals (sphene, ilmenite, garnet, epidote, and feldspar) and an increase in the proportion of complex authigenic minerals. This gradual change is abruptly disturbed at the oil-water interface. The disappearance of unstable components and the formation of authigenic minerals is retarded in the oil accumulation compared with the adjacent water-saturated areas. This retardation is especially manifest in the deep productive horizons where some of the unstable components (sphene and epidote) disappear almost completely outside the oil accumulations.

However, our petrological studies of the cuttings and cores from petroleum exploration wells, which provide a fairly good coverage of the onshore basin, suggest that the loss of porosity and permeability is due to the presence of large amounts of cement in places and to the high proportion of silt-size detrital material. The loss of permeability probably took place shortly after deposition, and probably before any petroleum could accumulate to retard the diagenetic process. It is however difficult to assess the relative loss of permeability due to compaction, pressure solution, and authigenesis.

Cap rocks are abundant in the Permian sequence.

Hydrocarbons have not been found in large amounts in the onshore basin. Some gas was found in the Camden area, but although some of the initial flows were large, the rate of flow fell rapidly owing to the lack of permeability.

Structural traps

A number of structural traps have been drilled for hydrocarbons (see Pl. 5). The structures drilled are the Muswellbrook Anticline (Jerrys Plains No. 1), Camberwell Anticline (Camberwell No. 1), Loder Dome (Loder No. 1), Sedgefield Anticline (Sedgefield No. 1), Belford Dome (Belford No. 1), Kulnura Anticline (Kulnura No. 1, Dural South No. 1), a small closed structure near Maitland (East Maitland No. 1), Martindale Anticline (Martindale No. 1A), Murwin Anticline (Mount Murwin No. 1), Lapstone Monocline (Kurrajong Heights No. 1), Woronora Anticline (Woronora No. 1), a small structural high south of Lake Illawarra (Stockyard Mountain No. 1), and the Bherwherre Anticline (Coonemia No. 1).

Stratigraphic traps

Interpretation of seismic sections shows stratigraphic thinning over, and abutment unconformity against, the Lochinvar Anticline. Two seismic sections cross the Lochinvar Anticline V(1-42), C11(36-50), C10(44-50), H(1-26) and U48(15-1, 16-24), C14(78-97), C16(9-50).

Interpretation of both sections suggests that the Lochinvar Formation abuts against the anticline and that the Allandale Formation thins and onlaps over the Lochinvar Formation. The Farley and Rutherford Formations (Interval 2) show slight thinning on the anticline, but the Greta Coal Measures and the Branxton Formation (including the Muree Sandstone Member) maintain their uniform thickness. The Mulbring Siltstone pinches out on the sides of the anticline, and the Singleton Coal Measures thin rapidly and rest unconformably on the Muree Sandstone Member in the centre of the anticline.

There are two local unconformities (Fig. 53)—one at the base of the Allandale Formation and another at the base of the Singleton Coal Measures.

This evidence suggests two possibilities. (1) The Lochinvar Formation may have been laid down against a ridge and was then onlapped by the Allandale Formation; the Farley and Rutherford Formations were subsequently deposited over the ridge. (2) Alternatively, it is possible that the ridge was developing continuously during the deposition of the sequence. The upward movement was fairly rapid at first, so that the Lochinvar Formation was deposited only on the flanks, followed by slower movement during the deposition of the Allandale, Farley, and Rutherford Formations.

Regional subsidence with local fluctuations continued throughout the deposition of the Greta Coal Measures and Branxton Formation. When the area was again uplifted during the deposition of the Mulbring Siltstone and Singleton Coal Measures unconformities developed on the Lochinvar Anticline. These movements apparently ceased before the Triassic, as the Narrabeen Group does not thin in the area.

These unconformities do not seem likely to be favourable sites for the accumulation of hydrocarbons as the lower unconformity probably involves volcanics and the higher one does not have good cap rock. In any case no closure can be demonstrated without further seismic surveying.

Generation and migration of petroleum

According to Brooks (1970) petroleum will not form in sediments containing land plant material, which is a probable source for oil, unless the increasing temperature accompanying deeper burial has been sufficient to alter brown coals to high-volatile bituminous coals with carbon contents near 80 percent. If diagenesis proceeds further, petroleum hydrocarbons largely disappear when the carbon content of the associated coals reaches about 85 percent. In these circumstances natural gas hydrocarbons in sediments are associated with high-rank bituminous coals with 88 to 89 percent carbon.

The carbon content of the coal in the Sydney Basin (McLeod, 1965) ranges from 75.4 to 89.0 percent (average 82%) in the Upper Permian measures and is about 83.0 percent in the Greta Coal Measures; therefore any hydrocarbons present should consist of the lighter oil fractions and gas.

We have already discussed the importance, from the point of view of petroleum migration and accumulation, of knowing the cause and timing of the loss of permeability, and it was concluded that the loss of permeability in the Sydney Basin is mainly due to the unsorted state of the sediment (an original feature), the presence of large amounts of cement (probably before compaction), and to compaction. Most of the permeability was probably lost by the time compaction began.

Primary migration of petroleum probably takes place after compaction of the sediment. This involves movement of the petroleum entrained in the connate water in the source rocks to the reservoir rocks. In the reservoir rocks the oil tends to remain in the larger pore spaces whilst the water moves towards lower fluid potential gradients. This results in the petroleum accumulating in small patches. Under special conditions petroleum pools may form at this stage.

Secondary migration moves the petroleum from a disseminated state in the reservoir rock to form a pool in the trap. This utilizes the artesian flow of meteoric waters through the basin.

In the Sydney Basin, it seems likely that secondary migration did not take place because (1) the permeability loss was probably completed during compaction, and (2) no artesian water has been found in the basin.

Only relatively small amounts of petroleum have been found in the Sydney Basin. This may be due to (1) the small size of the accumulations, or (2) the lack of permeability which inhibits the flow into the well, or both.

Conclusions

Only very small amounts of oil and slightly larger amounts of gas have been found in the Sydney Basin.

The loss of permeability at an early stage was the main factor which limited the accumulation of petroleum in the sediments. A sufficient number of wells has been drilled in the basin to indicate the general conditions obtaining, and it is probable that permeability is low over the entire basin.

All the major structural traps have been tested and found to be barren. In the lower Hunter Valley there are unconformities on the Lochinvar Anticline: the lower ones involve volcanics and are unlikely to be prospective; the higher ones involve unconformities beneath the Singleton Coal Measures or the Narrabeen Group, neither of which are good cap rocks for petroleum. The oil prospects of the basin are therefore rated as low.

Oil Shale

Between 20 and 30 deposits of oil shale (Fig. 58) are known in the Upper Permian coal measures in the western part of the basin and these have been utilized to produce kerosene for lighting (1865-1924), and as a source of motor fuel during World War II and for about seven years afterwards (Fig. 59). Some of the oil shale seams are very rich; Turner (1965) has compiled the following yields:

Deposit	*Yield* (l per ton)
Glen Davis	200-450
Mount Coolaway	1000
Baerami	250-400
Hartley Vale	700
Marrangaroo	1100

The deposits at Glen Davis and Hartley Vale were worked for more than 25 years in the last century and have been almost exhausted. The remaining reserves at Glen Davis are about 2 000 000 tonnes, of which about half is recoverable. The highest annual production of motor spirit was slightly more than 20 000 000 l, achieved at Glen Davis in 1947. The high cost of mining this type of irregular deposit was the main reason why the industry in the west was closed down in 1952.

In the southern part of the basin oil shale has been mined from the Upper Permian coal measures at America Creek, west of Port Kembla, and in the north oil shale has been worked in the Greta Coal Measures at Greta. Other occurrences are known in the same sequence in some of the coal mines near Muswellbrook and Cessnock.

Coal

Black coal occurs in the Greta, Singleton, Newcastle, Tomago, Illawarra, and Clyde Coal Measures. Coal has been mined from the Greta, Singleton, Newcastle, Tomago, and Illawarra Coal Measures. The coal districts are shown in Figure 2. Table 13 shows the productive horizons in each coal district, together with the estimated reserves (after Mead & de Ferranti, 1971). Figure 60 (after Mead & de Ferranti, 1971) shows the areas in which these reserves are located.

TABLE 13. PRINCIPAL PRODUCING COAL SEAMS

Coalfield	*Name of Coal Measures*	*Names of Principal Producing Seams and Approximate Depth below Top of Coal Measures*	*Reserves** (after Mead & Ferranti, 1971) (tonnes)
Northern and Northwestern	Greta Coal Measures	Main Greta Seam 6.1-42.7 m Homeville Seam 70.1 m Muswellbrook Seam 21.3 m St Heliers Seam 33.5 m Lewis Seam 51.8 m	
	Singleton Coal Measures	Bayswater Seam 670.6 m Pikes Gully Seam 822.9 m Liddell Seam 883.9 m	
	Newcastle Coal Measures	Wallarah Seam 0 m Great Northern Seam 30.5 m Fassifern Seam 60.9 m Australasian Seam 152.4 m Montrose Seam 228.6 m Victoria Tunnel Seam 320.0 m Borehole Seam 396.2 m	2 814 000 000
	Tomago Coal Measures	Donaldson Seam 76.2 m Big Ben Seam 103.6 m Rathluba Seam 213.4 m	
Western	Illawarra Coal Measures	Katoomba Seam 0 m Lithgow Seam 76.2 m	1 227 000 000
Southern and Southwestern	Illawarra Coal Measures	Bulli Seam 0 m Wongawilli Seam 39.6 m Tongarra Seam 67.0 m	3 076 000 000

* The estimated reserves include only coal for which sufficient reliable data were available.

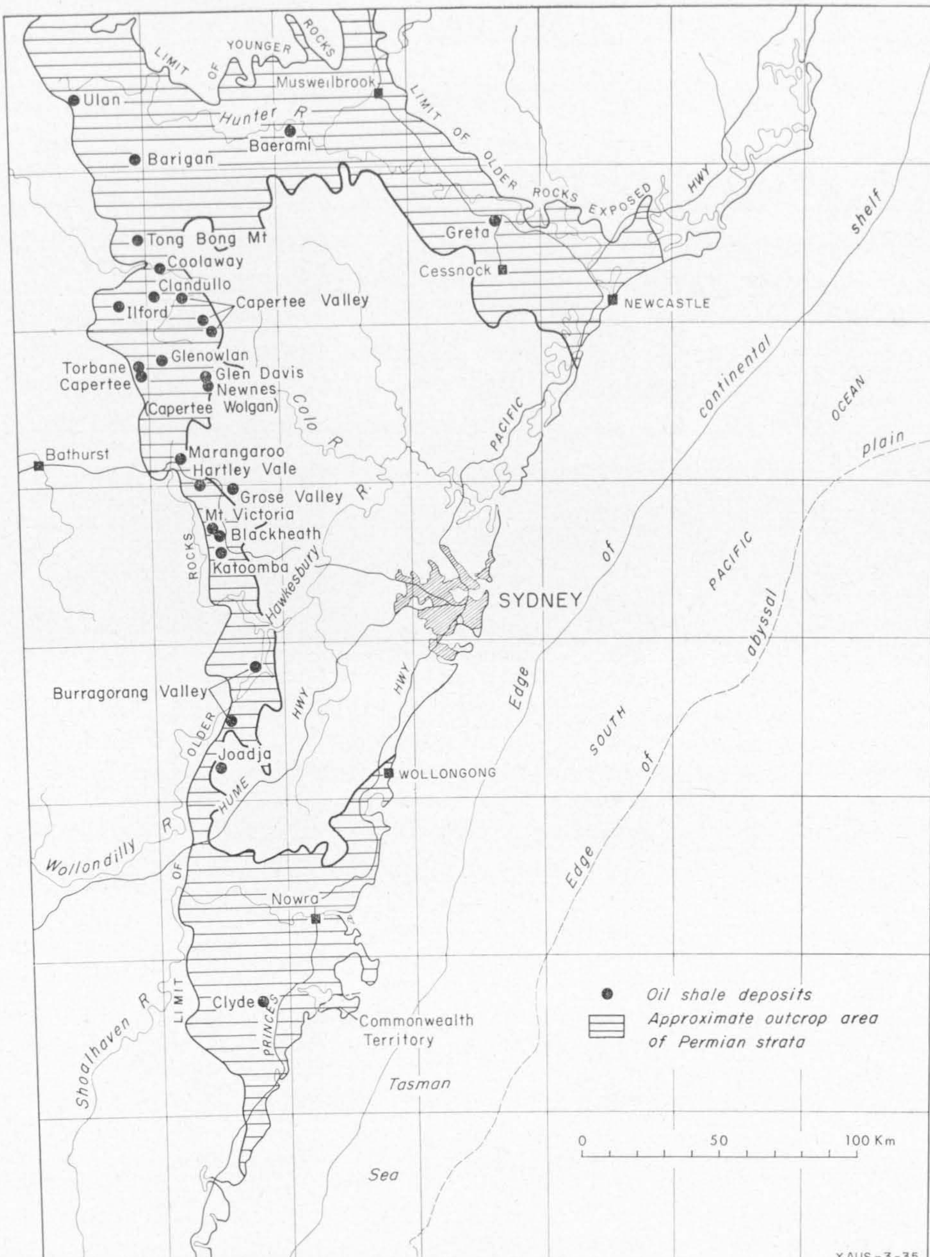

Fig. 58. Oil shale deposits.

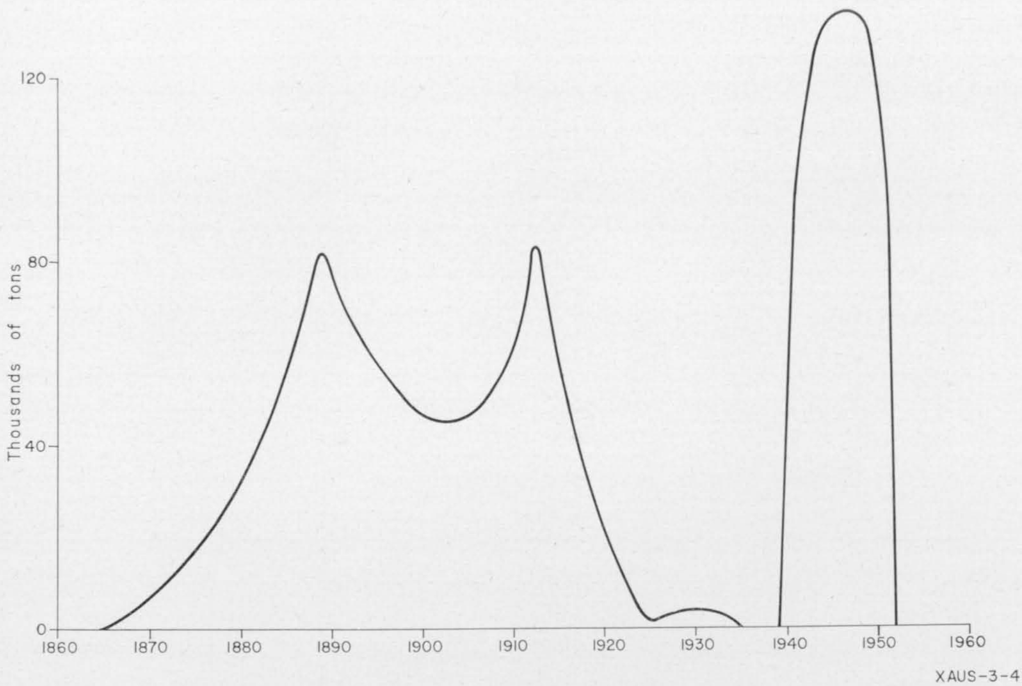

Fig. 59. Production of oil shale.

The structure contour maps (Pls 6, 7), which show the depths below sea level to the top of the Newcastle Coal Measures and correlatives and the Greta Coal Measures and correlatives, may serve as a guide to further prospecting for coal. Mead & de Ferranti (1971) state that the minimum thickness of seams mined is rarely less than 1.5 m, and that economically attractive coal generally occurs with an overburden of less than 600 m. In theory therefore areas in which the coal measures may be intersected at less than 600 m below surface are worth prospecting.

Figure 61 indicates approximately the depth of overburden over the top of the Newcastle Coal Measures and its correlatives. It has been derived from generalized topographic contours and the structure contour map.

Phosphate

Small amounts of phosphatic rock have been found in the Illawarra Coal Measures and in the Narrabeen Group.

Illawarra Coal Measures. Bowman (1970) records slightly phosphatic silty sandstone near the base of the Erins Vale Formation.

Narrabeen Group. Phosphate has been recorded in the Bulgo Sandstone and its correlatives (Fig. 43). It occurs in the Bulgo Sandstone south of Sydney, the base of the Gosford Formation at Mona Vale, and in the Tuggerah Formation in the north.

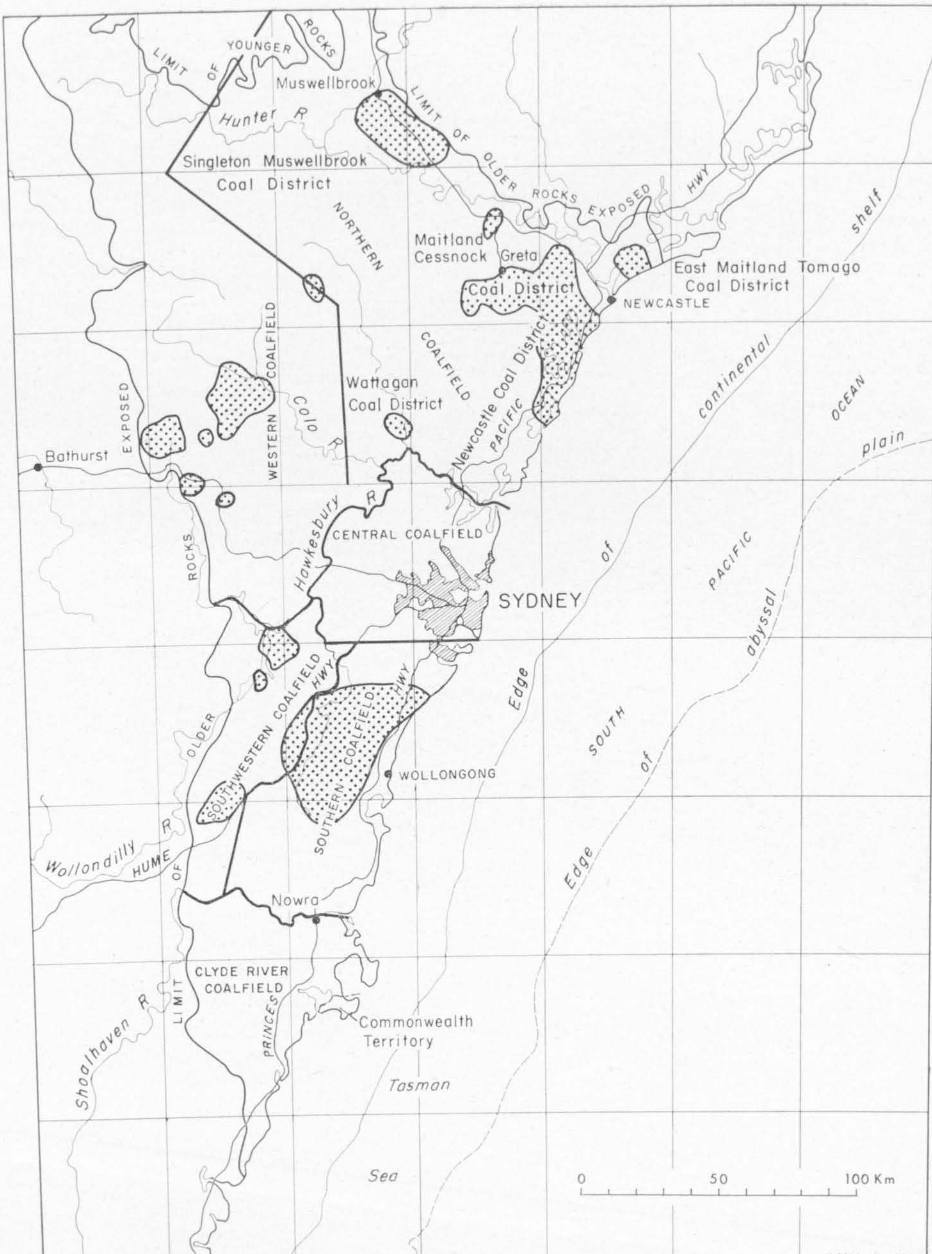

Fig. 60. Location of coal reserves. (After Mead & de Ferranti, 1971).

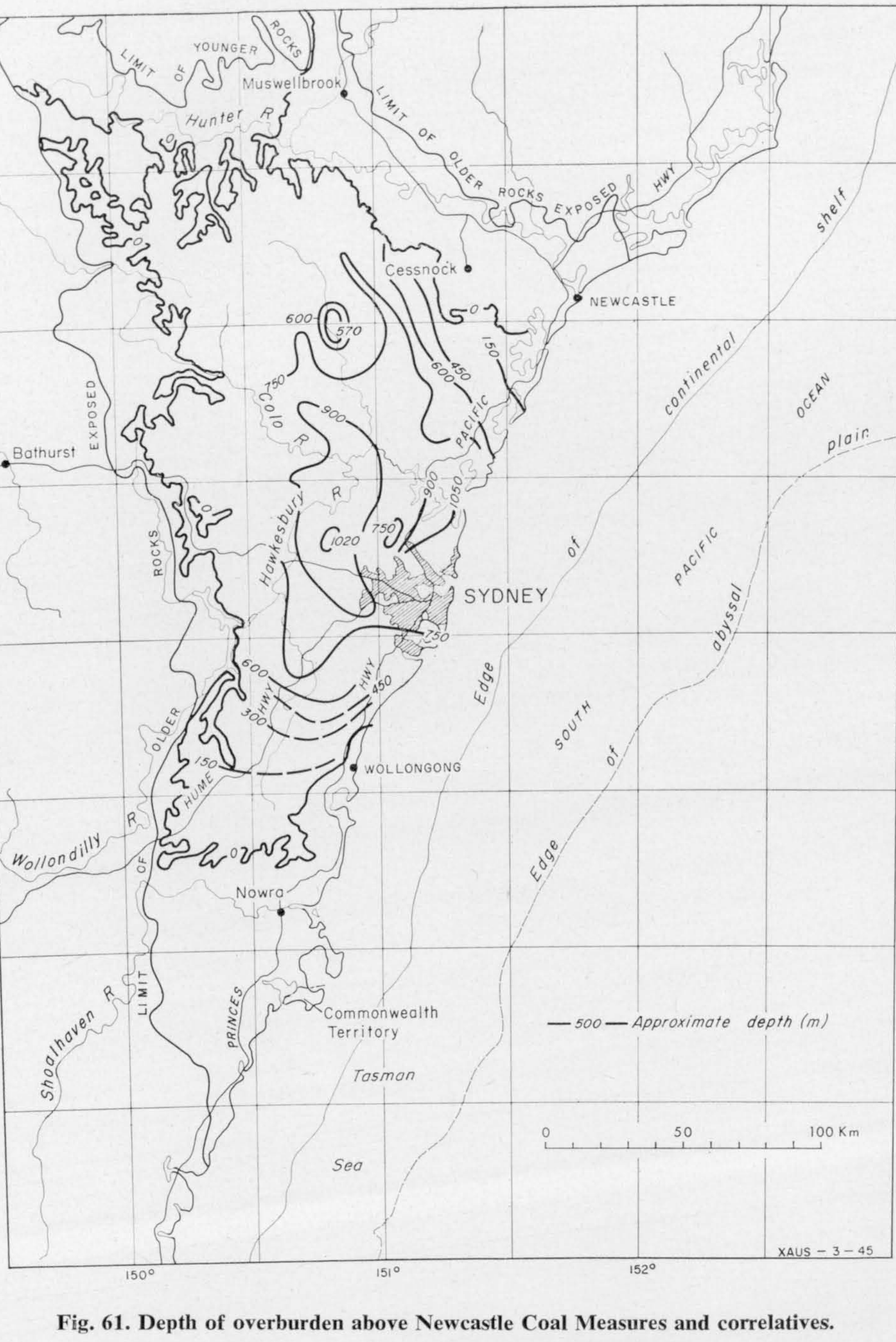

Fig. 61. Depth of overburden above Newcastle Coal Measures and correlatives.

Lassak & Golding (1966) have suggested that phosphatic lenticles, beds, nodules, and concretions may be widespread within the upper part of the Narrabeen Group for over 80 km along the coast in the vicinity of Sydney. Most, if not all, of the samples examined were derived from pre-existing phosphatic sediments, but the larger pebbles and nodules have not been transported far from their source, and the age of the original sediments may not differ substantially from the observed derivatives. Following the initial fixation of the phosphorus by plants, the source beds may have been formed in estuaries by replacement of calcareous mud.

Because of the apparent lenticular nature of the deposits, Taylor (1967) considers that the phosphate was laid down in lakes and deltas. The phosphate occurs as nodular beds and lenses, pellet rock, and patchy phosphate. The nodular material is the most abundant source of phosphate in the Narrabeen Group, and although it averages 20 percent P_2O_5, it is too scattered to be of economic significance.

Dawsonite

The rare mineral dawsonite [$NaAlCO_3(OH)_2$] which is regarded as a potential source of aluminium in the U.S.A. (Smith & Milton, 1966; Smith & Young, 1969) was detected in eight wells in the central and northern part of the basin (Nicholas & Ozimic, 1970). It occurs in both the marine beds and coal measures, and in one well (Kurrajong Heights No. 1) in the lower part of the Narrabeen Group. Loughnan & See (1967) have described dawsonite in the Greta Coal Measures at Muswellbrook and Loughnan (1967) and Loughnan & Goldbery (1972) have described it in the Berry Formation in the western part of the basin and in the Singleton Coal Measures.

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APPENDIX 1. EARLY SAKMARIAN ROCKS

INTERVAL 1: LOCHINVAR AND ALLANDALE FORMATIONS AND CORRELATIVES

Lochinvar Formation

The Lochinvar Formation crops out in the Lochinvar Anticline in the lower Hunter Valley; it also occurs in the Mindaribba Basin, a north-trending trough to the northeast in the Paterson-Maitland area. The type area is between Lochinvar and Allandale.

The name is synonymous with the Lochinvar Stage of the Lower Marine Series (David, 1950; Osborne, 1949). The Lochinvar Formation (Booker, 1953) is the basal unit in the Dalwood Group (Lower Marine Series).

Osborne (1949) measured a composite section near Lochinvar which he regarded as fairly complete.

	Thickness (m)
Shale, pebbly	15.2
Tuff, spheroidal	30.5
Clay shale and ferruginous grit with some erratics at top	91.4
Basalt and basalt tuff (fourth horizon)	30.5
Shale with scattered erratics	24.4
Sandy shale, tuffaceous; with erratics	61.0
Basalt (third horizon)	67.1
(Hiatus in section, probably due to shale)	61.0
Mudstone, shaly	61.0
'Ptychomphalina' Bed No. 2 (*Peruvispira*)	0.3
Sandy shale	5.5
'Ptychomphalina' Bed No. 1 (*Peruvispira*)	0.3
Sandstone, shaly, fossiliferous	45.7
Basalt (second horizon)	91.4
Sandy shale	3.1
Tuff with sporangia	3.1
Tuff, hard	3.1
Mafic tuff	15.2
Basalt, amygdaloidal (first horizon)	45.7
Sandstone	61.0
Conglomerate	91.4
Tuff, pebbly	15.2
Total	823.1

The erratics consist of quartzite, porphyry, and slate up to 0.7 m in diameter.

In the Gosforth district the base of the Lochinvar Formation is a shaly sequence containing *Eurydesma hobartense* (Brown & Dun, 1924), which was named the Gosforth Shales (Osborne, 1949). A summary of the section, which is considered to represent the lower part of the formation, is given by Osborne (1949).

	Thickness (m)
Basalt and mafic tuff with interbedded mudstone	51.8
Sandstone and tuffaceous sandstone	45.7
Limestone	3.1
Shale with calcareous shale at top	61.0
Basalt	182.9
Sandstone and tuff with fossil plants and marine fossils	24.4
Gosforth Shales with *Eurydesma hobartense*	2.7
Total	371.6

Osborne (1949) measured a composite section of the Lochinvar Formation in the Mindaribba Basin.

Eelah-Comerfords Section

	Thickness (m)
Basalt and tuff	122.0
Tuff and tuffaceous mudstone	91.4
Mudstone and tuff, interbedded	85.3
Basalt	3.1
Tuff, coarse-grained	15.2
Tuff or chert (No. 2) with sporangia	18.3
Mudstone	15.2
Sandstone, pebbly	18.3
Chert (No. 1) with sporangia	18.3
Sandstone and tuff	30.5
Mudstone with plant remains	7.6
Total	425.2

Engel (1966) and Rattigan (1969) have described the lithology of the Lochinvar Formation in the type area. The basalts are commonly amygdaloidal, but most of the olivine basalts are massive. Volcanic breccia and lapilli tuff are the predominant pyroclastic rocks. The sandstones are poorly sorted and contain numerous lithic and feldspathic fragments. Pebbles of possible glacial origin occur throughout the sedimentary rocks. Rattigan considers that the 'tuffs' not directly associated with basalts are volcanolithic sandstones and that the 'cherts' are silicified sandstone and siltstone.

Allandale Formation

The Allandale Formation (Booker, 1953) crops out on the Lochinvar Anticline in the lower Hunter Valley and also in the Mindaribba Basin. The formation, together with the underlying Lochinvar Formation, forms the lower part of the Dalwood Group. The name Allandale Formation is synonymous with the Allandale Stage of the Lower Marine Series of David (1950) and Osborne (1949). The type area is near Allandale.

A section of the Allandale Formation was compiled from a number of exposures near Allandale (Osborne, 1949).

	Thickness (m)
Mudstone, pebbly	3.1
Tuff with *Pecten*	0.9
Tuff, blackish green	15.2
Conglomerate (andesite boulders)	24.4
Shale, soft, brown; with numerous erratics	6.1
Sandstone, tuffaceous (Harpers Hill type)	15.2
Conglomerate with tuff band (4.5 m) and *Eurydesma cordatum* horizon (0.6 m)	45.7
Tuff, greenish black	6.1
Conglomerate	24.4
Total	141.1

The lithology in the type area has been described by Engel (1966) and Rattigan (1969). The conglomerates are coarse and unsorted, and consist of well rounded, mainly basaltic, boulders set in a dark green lithic matrix. They are interbedded with dark green and grey lithic tuff and arenite.

In the Pokolbin district on the west flank of the Lochinvar Anticline the Allandale Formation consists of tuffaceous conglomerate, tuff, and basalt. The sequence contains *Eurydesma* and onlaps inliers of Carboniferous rocks.

In the Mindaribba Basin, Osborne (1949) measured about 6 m of poorly sorted conglomerate, lithic sandstone, and tuff with abundant *Eurydesma, Spirifer, Fenestella,* and *Deltopecten* overlying basalt also of the Lochinvar Formation.

Gyarran Volcanics and Skeletar Formation

The Gyarran Volcanics (Raggatt, 1929a) and Skeletar Formation (Booker, 1960) are a conformable sequence of predominantly volcanic rocks below the Greta Coal Measures in the Muswellbrook district. The sequence was subdivided by Raggatt into the Gyarran Volcanics, containing 182.9 m+ of amygdaloidal basalt overlain by 35 m of rhyolite and rhyolite breccia, and the younger Skeletar beds containing 83.8 m of rhyolite, rhyolite breccia, and white tuffaceous shale with *Glossopteris* and *Gangamopteris.* In the latest interpretation of the sequence (Anon, 1969), the 35 m of rhyolite and rhyolite breccia included by Raggatt in the Gyarran Volcanics are placed in the Skeletar Formation. Booker (1960) and Robinson (1963) included the Skeletar Formation in the Greta Coal Measures but Leitch (1969) considers that it should be included in the Gyarran Volcanics because of its lithological affinity.

Wasp Head Formation (Gostin & Herbert, 1973)

The type area of the Wasp Head Formation is at South Durras on the south coast between Myrtle Beach and Wasp Head (Gostin, 1968; Gostin & Herbert, 1973; Dickins et al., 1969). The name was introduced by Gostin (1968) for the lower sandy unit of the Conjola Formation which was upgraded to the Conjola Sub-Group of the Shoalhaven Group.

The formation is about 100 m thick in the type area (Dickins et al., 1969). The lowermost 15 m includes four lobate units of sedimentary breccia interbedded with, and overlain by, cross-bedded lithic sandstone. The sandstone contains thin layers of pebble conglomerate with phenoclasts of chert.

The upper part consists mainly of fine-grained fossiliferous sandstone with thin layers of conglomerate and many large boulders. The fossils are concentrated in pockets or horizons. Silty worm burrows are common in the fine sand, and plant fragments occur throughout.

Pigeon House Creek Siltstone

The type section of the Pigeon House Creek Siltstone lies near the junction of Pigeon House Creek and the Clyde River where the formation attains its maximum thickness of 49 m (McElroy & Rose, 1962). It contains alternating buff to olive-green siltstones, shaly in part, and soft clayey feldspathic quartz sandstone in beds 0.6 to 6 m thick.

Yadboro Conglomerate

The type section of the Yadboro Conglomerate is in Landslide Creek in the Parish of Yadboro, where it is 179.8 m thick (McElroy & Rose, 1962). Most of the sequence consists of cobble conglomerate, but in places the rock is composed of pebbles averaging about 1 cm across, and elsewhere boulders up to 37 cm in diameter are common. The phenoclasts (in approximate order of abundance) include quartzite, quartz, black chert, phyllitic siltstone, and lava (mostly rhyolite), slate, shale, and mudstone.

Clyde Coal Measures

The Clyde Coal Measures (David & Stonier, 1891; Cook & Read, 1968) consist of a sequence of lenticular coal seams, sandstone, and shale up to 41 m thick, which crops out sporadically in the Clyde River Valley. They also occur at Pigeon House Mountain, Budawang Creek, Bunnair Creek, Little Forest Creek, Wandandian Creek, and Yalwal Creek (McElroy & Rose, 1962), Yarunga Creek (Gray, 1968), and in the Wandandian Bore (David & Stonier, 1891; Harper, 1915).

Interval 1 in the Deep Wells

All the deep wells in the Hunter Valley bottomed in Interval 1. The greatest thicknesses were penetrated in East Maitland No. 1 and Loder No. 1, to the east and west of the Lochinvar Anticline respectively. The sequence in both wells consists predominantly of pyroclastics, but marine sedimentary rocks are interbedded in the topmost 300 m in the East Maitland well. No marine sedimentary rocks were identified in Loder No. 1. Differentiation into Lochinvar Formation and Allandale Formation was not possible in either well.

Loder No. 1
(Nicholas, 1968)

	Thickness (m)
Altered basalt with zeolite and pyrite	51.2
Andesite agglomerate composed predominantly of altered andesite with large vugs ..	164.6
Conglomerate with pebbles of altered andesite, basalt, and chert. Silicified matrix composed of fine-grained material of both volcanic and sedimentary origin	45.7
Lapilli tuff composed of trachytic-textured andesite with some fragments of very fine-grained sedimentary rock. Vugs filled with chlorite and chalcedony common	48.8
Conglomerate with interbeds of lapilli tuff	26.0

Tuff	70.1
Altered andesite. Fine-grained matrix devitrified; feldspar phenocrysts altered to carbonate; pyroxene altered to epidote	44.2
Tuff or agglomerate	38.1
Basalt	6.1
Volcanic rock with large altered plagioclase phenocrysts	68.6
Altered tuff with chlorite and hematite	311.5
Total	874.9

East Maitland No. 1
(Jensen & Bryan, 1969)

	Thickness (m)
Lithic sandstone, conglomeratic at base; clasts mainly of crystal and lithic tuff; abundant carbonate cement	68.9
Pyroclastic rocks, including lapilli tuff, interbedded with minor pebble conglomerate and greywacke. Sandy siltstone, interbedded with mudstone (with brachiopods and corals); interbedded pyroclastics towards base	173.4
Pyroclastic rocks, very altered, mafic; mainly lapilli tuffs, with rare thin beds of siltstone and silty sandstone. Laumontite identified by X-ray analysis (G. Berryman, pers. comm.)	813.0
Total	1068.3

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Subgreywacke, medium-grained, grading into arkose; carbonaceous pyritic mudstone grading into siltstone; at least one very thin coal seam	35.1
Andesite agglomerate, breccia, and vesicular amygdaloidal lava rich in calcite, chlorite, and iron oxide	88.4
Basalt	24.4
Rhyolite and rhyolite welded tuff with xenoliths of felsic to mafic volcanic rocks	115.8
Basaltic volcanic rock, massive	156.1
Total	419.8

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Tuff, very altered, grey-white: contains siderite crystals, thin beds of spheroids and shards of devitrified glass, and abundant montmorillonite	13.7

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Subgreywacke, slightly pebbly, medium to coarse-grained, with interbeds of sandy siltstone and laminae of coal. Petromict conglomerate at base. Sediments faulted during sedimentation; presence of scour and fill structures suggests erosion and reworking	63.4
Andesite agglomerate	15.8
Total	79.2

Woronora No. 1
(Alcock, 1968b)

Protoquartzite and feldspathic sandstone with pebbly horizons and siltstone beds. Rare brachiopod spines and Foraminifera?	48.8

Stockyard Mountain No. 1
(Alcock, 1968a)

	Thickness (m)
Subgreywacke, commonly carbonaceous	24.4
Shale, carbonaceous; minor coal	39.6
Subgreywacke, commonly carbonaceous	25.9
Conglomerate, petromictic	13.7
Total	103.6

Coonemia No. 1
(Genoa, 1969a)

	Thickness (m)
Shale (25%): moderately tough, dark grey to dark brown, carbonaceous; quartz sandstone (15%): tough, medium-grained, siliceous cement; siltstone (45%): moderately tough, dark grey, micaceous and carbonaceous; coal (15%): hard, black, lustrous, bituminous, some shaly, beds 0.3-1.5 m thick	67.7
Pebble conglomerate, very hard, dark grey-green: composed of rounded to sub-angular (few angular) pebbles of quartzite, quartz, silicified sandstone, phyllite, and plutonic and volcanic igneous rocks set in matrix of poorly sorted fine to coarse siliceous sandstone	138.7
Total	206.4

Wandandian Bore
(David & Stonier, 1891; Harper, 1915)

Coal measures correlated with the Clyde Coal Measures were encountered in the Wandandian bore. The sequence consists of 3.9 m of inferior coal, interbedded with sandstone and shale, underlain by 20.4 m of sandstone, shale, and conglomerate ....

Relations with Older Units

The Lochinvar and Allandale Formations are conformable in the type area, the only location where their relationships are exposed. The interval is generally conformable with the underlying Carboniferous Seaham Formation except locally in the Pokolbin district where the Allandale Formation onlaps inliers of Carboniferous rocks (Osborne, 1949; Rattigan, 1969). A. L. Bigg-Wither (pers. comm., 1971) has interpreted local unconformities south of the type area, from the seismic sections.

The Wasp Head Formation is unconformable on lower Palaeozoic basement. The Pigeon House Creek Siltstone rests with marked angular unconformity on Ordovician phyllitic siltstone and forms steep slopes at the base of the overlying cliffs of Yadboro Conglomerate. The Yadboro Conglomerate rests with slight angular discordance on the Pigeon House Creek Siltstone where it is present, and elsewhere unconformably on lower Palaeozoic basement (McElroy & Rose, 1962). The Clyde Coal Measures are unconformable on lower Palaeozoic basement.

Interval 1 was interpreted by three deep wells in the southern area. In Woronora No. 1 (AOG, 1964a; Alcock, 1968b) the Wasp Head Formation is unconformable on sheared coarse-grained Carboniferous(?) granodiorite. In Stockyard Mountain No. 1 (Farmout, 1963; Alcock, 1968a) the Wasp Head Formation rests unconformably on flat-bedded partly reddish sandstone, shale, and siltstone of

Devonian(?) age. In Coonemia No. 1 (Genoa, 1969a) the Wasp Head Formation is unconformable on strongly jointed and slickensided metamorphosed silicified sandstone and phyllite with quartz veins containing galena, pyrite, and chalcopyrite(?). The company gives a lower Palaeozoic(?) age for the basement rocks, pointing out the lithological similarity to lower Palaeozoic rocks on the western border of the basin.

Correlations and Age

The Lochinvar and Allandale Formations in the north and the Wasp Head Formation in the south are correlated through the wells as shown in Plate 2 on their stratigraphic position below the marine sedimentary sequence of Interval 2, and on faunal evidence.

The Allandale and Wasp Head Formations are correlated on faunal evidence (Dickins et al., 1969). The fauna includes *Megadesmus globosus, Pyramus laevis, Australomya hillae, Eurydesma cordatum, Neoschizodus australis, Ambikella konincki,* and *Keenia ocula.* The fauna of the Lochinvar Formation is less well known, but appears to be slightly older. It contains *Eurydesma cordatum* which ranges into the overlying Allandale Formation. The fauna of the Lochinvar and Allandale Formations is of early Sakmarian age, and regarded as older than the earliest marine fauna, that is, Fauna I, in the Bowen Basin (Dickins et al., 1964; Dickins, 1968). It was named the Allandale Fauna (Runnegar, 1969). On the basis of the faunal evidence all or part of the Reids Dome Beds (the 'Undivided Freshwater Beds' of Dickins, 1968) of the Springsure area, and all or part of the Lizzie Creek Volcanics ('Lower Bowen Volcanics' of Dickins, 1968), minus the upper part which contains Fauna I, may be the age equivalent of the Lochinvar, Allandale, and Wasp Head Formations.

Gangamopteris occurs in the first *Ptychomphalina* bed in the Lochinvar Formation, about 400 m above its base and according to Osborne (1949) this is the lowest horizon in New South Wales in which it has been recorded.

Glossopteris and *Gangamopteris* occur in the tuffaceous shales of the Skeletar Formation (Raggatt, 1929a) and also in the Clyde Coal Measures (David & Stonier, 1891) where *Neoggerathiopsis* sp. has also been collected (McElroy, 1969a).

Evans (1967b) has recorded a microfloral assemblage containing *Parasaccites* spp., *Verrucosisporites pseudoreticulatus, Protohaploxypinus goraiensis,* and *Granulatisporites trisinus* from the Allandale Formation or upper Lochinvar Formation in the Sunwell No. 1 Bore (Pl. 4, Table 1). He assigns the assemblage to the base of his Lower Permian palynological Stage 3 (Evans, 1967a) and considers that most of the Lochinvar Formation could fall into the Lower Permian Stage 2 with the possibility of the oldest beds being as old as the Upper Carboniferous Stage 1.

A belt of basaltic volcanic rocks correlated with those of the Dalwood Group (Engel, 1966) extends from the Mindaribba Basin, near Paterson, to Raymond Terrace and northwards on the flanks of the Medowie Basin, in the northeastern part of the Sydney Basin. The sequence is poorly exposed, but marine rocks are not known in the Medowie Basin, and in the Raymond Terrace district the volcanics are underlain by tuffaceous sedimentary rocks with coal (Garretts Seam) and *Gangamopteris* (David, 1907).

Correlatives of the Lochinvar and Allandale Formations occur in the Cranky Corner Basin, a Permian outlier north of the Hunter Thrust (Booker, 1949; Osborne, 1949). Booker gives the following section:

	Thickness (m)
Mudstone, sandstone, and conglomerate	91.4
Sandstone, coarse, tuffaceous; numerous marine fossils (*Eurydesma* horizon)	36.6
Mudstone, shaly, bluish; numerous marine fossils, chiefly Fenestellidae	91.4
Sandstone, coarse; plant remains	30.5
Total	249.9

He suggests correlation of the *Eurydesma* horizon and the associated tuffaceous sandstone with the *Eurydesma* horizon in the Allandale Formation, and the basal plant-bearing sandstone with that at the base of the Lochinvar Formation.

McElroy & Rose (1962) placed the Clyde Coal Measures at the base of the Permian because they considered them to be older than the Pigeon House Creek Siltstone. Recent work (Helby & Herbert, 1971; Herbert, 1972), however, suggests that the Clyde Coal Measures are younger than the Pigeon House Creek Siltstone, and probably younger than the Yadboro Conglomerate. The suggestion is based largely on palynological evidence and on a reinterpretation of the published sections of McElroy & Rose (1962).

Microfloral assemblages from the Clyde Coal Measures (Helby, 1968, 1971; Helby & Herbert, 1971) are characterized by several species of *Parasaccites,* a *Striatites* suite, *Marsupipollenites triradiatus,* and *Verrucosisporites pseudoreticulatus*. Overall the assemblages compare closely with Stage 3 of Evans. One sample from the top of the Clyde Coal Measures in the Clyde Gorge contains microspores characteristic of Stage 4. The microfloras compare fairly closely with those of the Greta Coal Measures.

The only assemblage from the Pigeon House Creek Siltstone examined (Helby & Herbert, 1971) contains several species of *Parasaccites* and *Potonieisporites*. The authors consider that the virtual absence of *Striatites* and the absence of *Marsupipollenites* and *Verrucosisporites* indicate an older age than the Clyde Coal Measures, even as old as Evans' Stage 1. The microflora from the Yadboro Conglomerate was not examined. Helby & Herbert (1971) have suggested that the Pigeon House Creek Siltstone and Yadboro Conglomerate were laid down in a valley (glacial?) during the late Carboniferous or early Permian.

The Carboniferous-Permian Boundary

The Carboniferous-Permian boundary in Australia has been discussed by Evans (1967a, 1969), Helby (1969), and Runnegar (1969). The boundary is defined both by the change from the *Rhacopteris* to the *Glossopteris* flora (Walkom, 1944), and by the incoming of the *Eurydesma* fauna (Browne *in* Osborne, 1949).

In the Sydney Basin, the boundary is exposed in the Lochinvar Anticline between Lochinvar and Gosforth, and this has been the classical area for the study of the boundary in eastern Australia. The Gosforth Shale, containing *Eurydesma,* is accepted both as the base of the Lochinvar Formation and of the Permian (Browne & Dun, 1924; Osborne, 1949) in the area.

Palynological studies have also demonstrated a distinct change in microfloras with the incoming of spermatophyte pollen, which Balme (1962, 1964) equated with the incoming of the *Glossopteris* flora and regarded as the palynological expression of the base of the Permian. He defined the *Nuskoisporites* assemblage as the basal microfloral assemblage in the Permian. In later work (Wapet, 1967) he divided the assemblage into three, placing the lower subdivision in the Carboniferous. Evans (1964, 1969) subdivided the assemblage into four informal palynological units, the lower two of which occur in the upper part of the range of the *Rhacopteris* flora, and were therefore placed in the Upper Carboniferous. Helby (1968), who described the palynological sequence in the 'Kuttung Group' in the lower Hunter Valley, defined a major change in the microfloral assemblage in the basal part of the Seaham Formation with the incoming of the *Potonieisporites* microflora. Helby equated the microflora with the basal part of Balme's *Nuskoisporites* assemblage, and Evans' lowest unit (Stage 1). He suggested that the base of the *Potonieisporites* microflora might be the closest approximation to the top of the Carboniferous System in Australia (Helby, 1969).

APPENDIX 2. SAKMARIAN TO KAZANIAN ROCKS

INTERVAL 2: RUTHERFORD AND FARLEY FORMATIONS AND CORRELATIVE PEBBLEY BEACH FORMATION

Rutherford Formation

The type area for the Rutherford Formation is the Lochinvar Anticline in the lower Hunter Valley (Osborne, 1949). Together with the overlying Farley Formation it forms the upper part of the Dalwood Group (Booker, 1953).

The Rutherford Formation is poorly exposed around the flanks and southern plunge of the Lochinvar Anticline. Osborne (1949) measured the following composite section in the Pokolbin district:

	Thickness (m)
Sandy mudstone with abundant *Martiniopsis* and *'Ptychomphalina'* (*Peruvispira*)	152.4
Sandy shale	30.5
Sandstone, ferruginous, with *Martiniopsis*	3.1
Sandstone	3.1
Sandy limestone with *Fenestella*	3.1
Shaly sandstone	30.5
Sandy limestone	3.1
Basalt	45.7
Sandy shale with erratics	61.0
Sandstone, fine, and tuff	10.7
Limestone, foraminiferal	6.1
'Bishops Hill Bryozoal Tuff'	7.6
Total	356.9

Engel (1966) describes the 'Bishops Hill Bryozoal Tuff' as a poorly sorted conglomeratic lithic sandstone. The overlying sequence consists mainly of micaceous sandy siltstone, mudstone, shale, silty sandstone, and sandstone. Small erratic pebbles are common and the rocks are generally poorly sorted. The calcareous shale and foraminiferal and bryozoal limestone, which occur on the west side of the Lochinvar Anticline near Pokolbin, are not present on the east flank.

Farley Formation

The type area for the Farley Formation is the Lochinvar Anticline in the lower Hunter Valley (Osborne, 1949). The formation is well exposed and has a distinctive stratigraphic marker, the Ravensfield Sandstone Member, at its base. Osborne (1949) measured the following composite section near Farley:

	Thickness (m)
Mudstone and brown sandstone	61.0
Shale crowded with *Martiniopsis*	3.7
Grit, tuffaceous	6.1
Mudstone, bluish	4.0
Sandy shale, bluish	6.1
Sandstone with *Martiniopsis* and *'Ptychomphalina'* (*Peruvispira*)	30.5
Tuff, plant-bearing	4.6

Grit, tuffaceous, bluish grey	67.1
Sandstone	47.2
Shale rock with *'Ptychomphalina'* (*Peruvispira*)	3.1
Sandstone, bluish	30.5
Sandstone, buff, fine	9.1
Sandstone, pebbly	21.3
Ravensfield Sandstone	6.1
Total	300.4

The Ravensfield Sandstone Member (Engel, 1966) is a massive cross-laminated even-textured sandstone; the fresh rock is blue-grey but weathers brown.

Pebbley Beach Formation (Gostin & Herbert, 1973)

The type area for the Pebbley Beach Formation is on the south coast (Gostin, 1968; Gostin & Herbert, 1973; Dickins et al., 1969) at Durras North, Pebbley Beach, and Wasp Island. The name Pebbley Beach Formation was proposed by Gostin (1968) for the middle silty unit of the Conjola Formation which has been upgraded to sub-group status within the Shoalhaven Group.

In the type area, the Pebbley Beach Formation consists of about 153 m of dark grey siltstone and fine-grained sandstone, which is commonly thinly stratified and contains small ripple marks. Thin layers of pebbles and beds of diamictite (commonly pebbly silty medium-grained sandstone) are common in the lower two-thirds of the sequence. They contain large boulders that appear to have been ice-rafted. The upper third of the formation contains large scour channels filled with siltstone and very fine-grained sandstone with thin coaly stringers. Wood stems, burrow structures, concretions of calcite and siderite, and scattered marine fossils occur throughout the formation.

Interval 2 in the Deep Wells

The deep wells in the Hunter Valley, with the exception of Martindale No. 1A, all penetrated units correlated on lithology with the Rutherford and Farley Formations. Reliable correlation by fossils is not possible as the marine fossils recovered are poorly preserved.

The Farley Formation was laid down only in the north, where it overlies the Rutherford Formation. In the central and southern areas the interval consists of one lithological unit. The following sequences were encountered in the deep wells:

East Maitland No. 1
(Jensen & Bryan, 1969)

	Thickness (m)
Undifferentiated Rutherford and Farley Formations.	
Sandstone, fine-grained, and sandy siltstone. Sequence pyritic throughout and very carbonaceous at base. Sparse brachiopod fragments; siderite cement common	424.9

Loder No. 1
(Nicholas, 1968)

	Thickness (m)
Farley Formation correlative	
Protoquartzite, fine-grained; contains coal fragments and carbonaceous material. Pebbles of quartz, chert, and rare fragments of volcanic rock abundant at base, but decrease upwards. Calcite, siderite, and minor dawsonite cement with only silica and siderite towards top. Burrow structures	128.0

Feldspathic sandstone, fine-grained, interbedded in part with coarse siltstone. Sandstone contains coal and plant fragments, and has siderite and dolomite cement. Siltstone is pyritic and carbonaceous. Youngest horizon in well in which clasts of volcanic rock are common. Bivalves; burrow structures	14.6
Rutherford Formation correlative	
Siltstone, pyritic, carbonaceous, shaly in part; contains clasts of volcanic rock and scattered pebbles of quartz and chert. Grainsize increases upwards with fine sandstone at number of levels. Calcite and siderite cement. Poorly preserved bivalves; burrow structures	251.2
Total	393.8

Camberwell No. 1
(AOG, 1965b)

	Thickness (m)
Farley Formation correlative	
Sandstone, fine to very fine-grained, silty, slightly calcareous, well consolidated	136.6
Rutherford Formation correlative	
Siltstone, dark grey, finely carbonaceous, slightly pebbly, with thin bands of sandstone and thick interbeds of dark grey to black shale	501.4
Total	638.0

Jerrys Plains No. 1
(Esso, 1969)

	Thickness (m)
Farley Formation correlative	
Sandstone (—30%), fine to coarse-grained, conglomeratic in part, unconsolidated, slightly calcareous, grading into sandy siltstone (+70%). Burrow structures; traces of Foraminifera and Bryozoa. Sandstone massive at top of sequence, with cyclic gradational bedding—possibly a non-marine facies	103.3
Rutherford Formation correlative	
Siltstone (75%), medium to dark grey, carbonaceous and argillaceous, occasionally sandy, grading into silty shale	38.7
Shale (90%), dark grey to black, pyritic; occasional fossils (Bryozoa and indeterminant); minor interbedded siltstone	326.1
Dolomite (40%) interbedded with shale	12.2
Shale (±85%), dark grey, carbonaceous, grading into sandy siltstone	50.0
Total	530.3

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Subgreywacke, fine to coarse, massive, interbedded with protoquartzite and siltstone (20%), interlaminated argillaceous sediment and fine subgreywacke (50%), and fine and coarse subgreywacke (30%), with pebbly coarse quartzose sandstone at base. Argillaceous sediments carbonaceous and pyritic. Shell fragments; evidence of organic reworking	187.5
Mudstone, highly carbonaceous and pyritic, with laminae of sideritic fine-grained subgreywacke. Glendonites; pelecypods (*Glyptoleda* and *Nuculopsis*)	47.2
Total	234.7

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Mudstone, siltstone, and claystone, with minor protoquartzite and bryozoal limestone	288.0

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Protoquartzite, fine to very fine-grained, with interbedded sandy carbonaceous shale. Shell fragments near base	82.3
Protoquartzite, fine to coarse-grained, pebbly; brachiopods and pelecypods; burrow structures	21.9
Sandstone, very fine to medium-grained, variably silty, with minor sandy siltstone and some coal laminae. Brachiopods, Bryozoa, and Foraminifera; evidence of organic reworking	400.2
Total	504.4

Woronora No. 1
(Alcock, 1968b)

	Thickness (m)
Protoquartzite with interbedded fine-grained subgreywacke, arkose, and siltstone	77.7
Protoquartzite, pebbly, with minor carbonaceous siltstone	39.6
Sandy siltstone, carbonaceous and pyritic; brachiopods common	35.1
Sandstone, quartz-rich, and quartz greywacke interbedded with sandy siltstone. Brachiopods, Bryozoa, and rare plant fossils; minor coal	74.7
Sandy siltstone with minor sandstone; burrow structures; rare shell fragments	76.2
Sandstone, fine-grained; rare Bryozoa	41.1
Total	344.4

Stockyard Mountain No. 1
(Alcock, 1968a)

	Thickness (m)
Shale, siltstone, and sandy siltstone with interbedded protoquartzite and thin limestone bed containing spines, Bryozoa, and shelly debris; plant fossils in shale	88.4
Protoquartzite and dolomitic tuff; one bed of carbonaceous shale	137.2
Total	225.6

Wollongong (BMR) No. 1
(Ozimic, 1971)

	Thickness (m)
Siltstone, grey, carbonaceous, with thin beds of grey sandstone and pebble conglomerate. Rare brachiopods and pelecypods	9.5

Wollongong (BMR) Nos 2 & 2A
(Ozimic, 1971)

	Thickness (m)
Siltstone, dark grey, carbonaceous, grading into very fine to very coarse sandstone. Rare brachiopods and pelecypods	21.9

Coonemia No. 1
(Genoa, 1969a)

	Thickness (m)
Sandy siltstone, dark grey, micaceous, pyritic, carbonaceous; scattered pebbles of quartzite, quartz, and igneous rock. Brachiopods; glauconite	66.1
Sandstone and siltstone with scattered rounded to angular pebbles of quartzite, quartz, and igneous rock; siliceous and calcareous cement; pyrite, glauconite, and carbonaceous streaks	100.0

Siltstone, dark grey, micaceous, carbonaceous, pyritic, with minor sandstone and carbonaceous shale. Brachiopods common	74.1
Total	240.2

Relationship with Older Units

The Rutherford Formation is generally conformable on the Allandale Formation, although seismic evidence (A. L. Bigg-Wither, pers. comm., 1971) indicates that locally the Rutherford Formation lies unconformably on Carboniferous rocks and on eroded strata of Interval I to the south of the type area. The Farley Formation is conformable on the Rutherford Formation. The Pebbley Beach Formation is conformable on the Wasp Head Formation where present. The sparse geological information and seismic evidence indicate that the Pebbley Beach Formation onlaps the higher parts of the lower Palaeozoic basement.

Correlations and Age

The Rutherford and Farley Formations in the north and the Pebbley Beach Formation in the south have been correlated through the wells as shown in Plate 2. The correlation is based on lithology, stratigraphic position, and faunal evidence.

The fauna of the Pebbley Beach Formation (Dickins et al., 1969) is characterized by *Megadesmus nobilissimus, Aviculopecten* sp. ind., *Ambikella* sp. ind., *Gilledia* cf. *ulladullensis* Campbell, 1965, and *G. culburrensis* Campbell, 1965. These species are not found in the underlying Wasp Head Formation but range up into the overlying Snapper Point Formation. Dickins et al. consider that the presence of *Megadesmus nobilissimus* in the Pebbly Beach Formation 'suggests correlation with the Farley Formation of the Hunter Valley, but equivalence with the slightly older Rutherford Formation cannot be precluded'. The fauna is considered similar to Fauna II of the Bowen Basin (Dickins et al., 1964; Dickins, 1968).

INTERVAL 3: GRETA COAL MEASURES AND CORRELATIVE SNAPPER POINT FORMATION

Greta Coal Measures

The Greta Coal Measures (David, 1888) crop out around the Lochinvar Anticline and along the west side of the Mindaribba Basin in the lower Hunter Valley. They also crop out on the Muswellbrook Anticline in the upper Hunter Valley, and in the Scone-Wingen district about 25 km north of Muswellbrook. Originally David (1888) applied the name to the sequence that crops out near the village of Greta on the northwest side of the Lochinvar Anticline. The sequence consists of conglomerate, sandstone, and carbonaceous shale with thin beds of clay-ironstone and several seams of coal; in places the coal has an aggregate thickness of 7.6 m. The name was later (David, 1889, 1907) applied to all these coal measures in the Hunter Valley.

The Greta Coal Measures have been studied by Raggatt (1938), Jones (1939), Booker (1953, 1960), Robinson (1956, 1963), Kemezys (1962), and Reinhold (1963) and were recently reviewed by Basden (1969).

In the Cessnock-Maitland-Greta area there are two main coal seams—the upper, Greta, and the lower, Homeville, both of which are commonly split. The splitting is more pronounced on the west limb of the Lochinvar Anticline (Booker, 1953, 1960). The coal has been mined extensively in the South Maitland Coalfield on the southern and eastern flanks of the Lochinvar Anticline. The detailed stratigraphy of the Greta Coal Measures in this area is discussed in Reinhold (1963). The type sections are described below. The repository for the type sections is the Joint Coal Board Core Store, Cardiff, New South Wales.

Neath Sandstone

The type section, which is incomplete (Reinhold, 1963), is the BHP Elrington DDH 2. The sequence consists mainly of fine to medium-grained white massive freshwater sandstone containing a few beds of fine-grained conglomerate and shale. The thickness is about 12 m. The formation crops out on the southern and eastern flanks of the Lochinvar Anticline and so far as is known underlies all the South Maitland Coalfield. However, natural outcrop is poor, and there are few exposures in open cuts or quarries. No complete drill core is available.

Kurri Kurri Conglomerate

The type section (Reinhold, 1963) is in Richmond Main Colliery Surface DDH 3. The sequence consists mainly of fine to medium-grained conglomerate with minor sandstone and shale near the base. Green jasper pebbles are characteristic of the conglomerate. The formation contains the upper and lower Homeville Coal Members. The thickness is about 36 m. The formation is well exposed around the southern and eastern flanks of the Lochinvar Anticline.

Lower Homeville Coal Member

The type section (Reinhold, 1953) is in BHP Elrington DDH 3. The member consists of coal and coaly shale with shale and minor sandstone and siltstone. The thickness is about 10 cm.

Upper Homeville Coal Member

The type section (Reinhold, 1963) is the BHP Elrington DDH 3. The member consists of coal and coaly shale with shale and minor siltstone and sandstone. The thickness is 1.5 m. This is the most variable coal horizon in the coalfield, and commonly contains two or more splits.

Kitchener Formation

The type section (Reinhold, 1963) is in Hebburn No. 2 Colliery DDH 'K'. The sequence consists of coal with minor carbonaceous shale, shale, siltstone, and sandstone. There are beds of kerosene shale and cannel coal in places. A pyritic zone is commonly present near the top of the coal. The thickness is about 9 m. The formation crops out around the southern and eastern flanks of the Lochinvar Anticline. Subsurface it extends across the entire coalfield, and apparently continues beyond the field to the south and east. The formation contains the Greta Seam and Kearsley Lens. The Greta Seam is a major source of gas coal in Australia. The Kearsley Lens is a stratum of mudstone, shale, and sandstone within the Greta Seam.

Paxton Formation

The type section (Reinhold, 1963) is in Pelton DDH 7. It consists of fine-grained conglomerate and micaceous quartz sandstone with prominent shale horizons. The thickness is 15.6 m. The formation contains the Pelton Coal Member near the top, and crops out only on the southern closure of the Lochinvar Anticline.

Pelton Coal Member

The type section (Reinhold, 1963) is in Pelton DDH 7. The member consists of coal and coaly shale with minor shale and siltstone. The thickness is about 1 m.

At Muswellbrook two formations, the Rowan Formation (Robinson, 1963) and the underlying Skeletar Formation (Raggatt, 1929a), constitute the Greta Coal Measures (Robinson, 1963). In this Bulletin the Skeletar Formation is included in Interval 1 (see Appendix 1).

Rowan Formation

The type section (Anon, 1969) is in Balmoral DDH 7 bore. The sequence consists of sandstone, shale, and mudstone with intercalated coal seams and subordinate conglomerate. The thickness is about 110 m. The formation crops out on the crest of the Muswellbrook Anticline, and can be traced from a few kilometres north of Muswellbrook township to the Savoy Trig. Station, a distance of about 19 km.

The Loder, Lewis, St Heliers, Muswellbrook, Hallett, and Fleming Seams occur in the Muswellbrook area (Andrews, 1925; Booker, 1953) and the Balmoral, Puxtrees, Grasstrees, Brougham, and Hilltop in the vicinity of the Savoy Trig. Station (Robinson, 1956). The Muswellbrook, Lewis, and St Heliers Seams are producers, the latter being the most important. In the Savoy Trig. Station area all the seams, with the exception of the Hilltop, are of economic value. Tentative seam correlations in the area are given by Basden (1969).

Snapper Point Formation (Gostin & Herbert, 1973)

The type area for the Snapper Point Formation is on the south coast (Gostin, 1968; Gostin & Herbert, 1973; Dickins et al., 1969), where it is exposed from Clear Point to Snapper Point, and from Willinga Point to Crampton Island. The name Snapper Point Formation was proposed by Gostin (1968) for the upper sandy unit of the Conjola Formation, which has been upgraded to sub-group status within the Shoalhaven Group.

In the type area the Snapper Point Formation is about 170 m thick and generally consists of well bedded quartz-rich fine-grained sandstone with thin layers of coarse pebbly sandstone and conglomerate. Marine fossils and silty worm burrows are abundant, and concretions of calcite, pyrite, and siderite also occur. The cross-bedding and ripple marks indicate that the currents flowed northwest.

Interval 3 in the Deep Wells

Martindale No. 1A
(Nicholas, 1969)

	Thickness (m)
Sandy petromict conglomerate at base, overlain by 6 thin coal seams with partings of sandy carbonaceous siltstone, followed by medium-grained subgreywacke, containing silty carbonaceous laminae, which becomes very fine-grained toward top. Sequence contains fragments of volcanic and sedimentary rocks, and pyritic carbonaceous material. Siderite, dawsonite, and calcite cement	73.2
Protoquartzite, fine-grained; contains fragments of sedimentary rock, minor carbonaceous material, and lenses of sideritic sandstone. Calcite and silica cement. Rare Bryozoa	12.2
Sandy conglomerate at base and top separated by medium-grained subgreywacke and minor pyritic black shale	33.5
Total	118.9

The sequence in Martindale No. 1A is lithologically similar to the Greta Coal Measures in the type area, but differs from the sequence at Muswellbrook.

Jerrys Plains No. 1
(Esso, 1969)

	Thickness (m)
Sandstone, very fine-grained to conglomeratic, carbonaceous, clay-choked, with interbedded sandy siltstone and minor shale	137.2
Sandstone, fine to coarse-grained, conglomeratic in part, clay-choked, carbonaceous and pyritic, with interbedded coal and minor interbeds of argillaceous siltstone and carbonaceous silty shale	223.7
Total	360.9

Camberwell No. 1
(AOG, 1965b)

	Thickness (m)
Sandstone, fine-grained, coarse-grained and conglomeratic in part, with clay matrix, red, green, and white chert fragments, and interbeds of shale and coal	388.6
Sandstone, fine to medium-grained, and conglomerate with interbedded coal and shale. Green and grey chert common in conglomerate and sandstone. Pebbles of conglomerate closely packed in clay matrix	138.7
Total	527.3

Sedgefield No. 1
(AOG, 1964b)

	Thickness (m)
Sandstone, fine to medium-grained, interbedded with conglomeratic sandstone, conglomerate, minor shale, siltstone, and coal. Green and grey chert pebbles common in conglomerate	451.1

Loder No. 1
(Nicholas, 1968)

	Thickness (m)
Protoquartzite, fine-grained, with fragments of coal and volcanic rock and abundant chert fragments	15.2
Coal seam	3.1

Petromict conglomerate with pebbles of quartz, chert, quartz sandstone, and volcanic rock grading into pyritic carbonaceous subgreywacke; cemented with siderite	21.3
Coal seam	1.5
Protoquartzite, coarse-grained, pebbly, pyritic and carbonaceous; cemented with siderite and dawsonite	19.8
Coal seams with partings of carbonaceous pyritic protoquartzite and siltstone containing numerous chert clasts	24.4
Total	85.3

Belford No. 1
(Ozimic, 1968)

	Thickness (m)
Lithic sandstone, fine-grained, with quartz and chert pebbles and volcanic rock fragments, interbedded with sandy siltstone and coal seams	112.8

East Maitland No. 1
(Jensen & Bryan, 1969)

	Thickness (m)
Petromict conglomerate composed of pebbles of sedimentary and volcanic rocks set in matrix of medium-grained quartz-rich sandstone	22.3
Coal seam	4.3
Lithic greywacke, fine to coarse-grained, interbedded with siltstone; pebbly in places	36.3
Total	62.9

Coal is mainly absent in the wells in the central and southern areas where a lithologically distinct sandstone unit is found. The following wells are representative of this sequence:

Kulnura No. 1
(Ozimic, 1969)

	Thickness (m)
Subgreywacke, fine to medium-grained, with pebbles of quartz and chert and minor interbedded siltstone. Pyrite, calcite, silica, and dawsonite cement. Brachiopods and Foraminifera	225.5

Howes Swamp No. 1
(Esso, 1970)

	Thickness (m)
Coal, black to dark brown, blocky, vitreous to dull, slickensided surfaces	3.0?
Lithic sandstone, very fine to medium-grained, conglomeratic in places, carbonaceous, clay matrix and silica cement, interbedded with medium to dark grey siltstone and carbonaceous shale	48.8
Total	51.8

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Protoquartzite, medium-grained, interbedded with medium-grained subarkose and minor siltstone. Quartz and chert pebbles. Calcite and silica cement. Brachiopods and Foraminifera (*Hyperammina* sp. in siltstone). Churned bedding	403.9

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Protoquartzite to subarkose, fine-grained, with minor siltstone interbeds. Pebbles of quartz and sedimentary, volcanic, and metamorphic rocks. Silica and calcite cement, with siderite and pyrite in siltstone. Brachiopods, pelecypods, and Foraminifera. Churned bedding and burrow structures in core	160.6

Stockyard Mountain No. 1
(Alcock, 1968a)

	Thickness (m)
Protoquartzite, medium to coarse-grained, with minor shale beds most abundant at top and bottom. Pebbles of quartz, and sedimentary, volcanic, and metamorphic rocks. Silica cement at top and bottom of sequence. Brachiopods and Bryozoa. Burrow structures	185.9

BMR Wollongong No. 1
(Ozimic, 1971)

	Thickness (m)
Sandstone, light grey, very fine to very coarse-grained, with thin interbeds of pebble conglomerate and sandy siltstone. Rare brachiopods and pelecypods	109.7

BMR Wollongong Nos 2 & 2A
(Ozimic, 1971)

	Thickness (m)
Sandstone, very fine to very coarse-grained, with quartz and chert pebbles and thin interbeds of pebble conglomerate and sandy siltstone. Rare brachiopods and pelecypods	95.1

Relations with Older Units

The Greta Coal Measures are generally considered to be conformable on the Farley Formation in the type area, although Reinhold (1963) describes a diastem between the Neath Sandstone and the underlying marine Dalwood Group where the contact is exposed at two localities in the South Maitland Coalfield. At Muswellbrook the Rowan Formation is conformable on the Skeletar Formation, and in Martindale No. 1A the Greta Coal Measures overlie volcanic rocks correlated with the Lochinvar and Allandale Formations. The Snapper Point Formation is conformable on the Pebbley Beach Formation.

Correlations and Age

The Greta Coal Measures in the north and the Snapper Point Formation in the south have been correlated through the wells in the manner shown in Plate 2. The correlation is based on a comparison of the lithology of the Snapper Point Formation with that of the underlying and overlying formations, which indicates a shallowing of the sea consistent with marine regression from the north. Geological evidence is sparse in the area where it is postulated that the Greta Coal Measures interfinger with the marine Snapper Point Formation, but the correlation is supported by seismic evidence.

The association of *Megadesmus nobilissimus, Vacunella* sp. nov. A, *Eurydesma hobartense,* and *Ambikella* cf. *ovata* indicates that the fauna of the Snapper Point Formation (Dickins et al., 1969) is equivalent to Fauna II of the Bowen Basin sequence (Dickins et al., 1964), and also suggests correlation with the

Farley Formation. The presence of *A*. cf. *undulosa* and *A*. cf. *isbelli* in the top part of the Snapper Point Formation indicates correlation with the lower part of the Branxton Formation below the *Fenestella* Zone, and suggests that this part of the unit may be equivalent in age to the oldest part of the sequence in the Bowen Basin containing Fauna III. Since the underlying Pebbley Beach Formation also contains Fauna II equivalent (see Interval 2) the faunal evidence indicates that the Pebbley Beach Formation and the Snapper Point Formation are equivalent in age to the Farley Formation, the Greta Coal Measures, and the lower part of the Branxton Formation below the *Fenestella* Zone. The fauna of the Rutherford Formation (see Interval 2) is not well known, but is considered to be possibly equivalent to Fauna I in the Bowen Basin (Dickins, 1964).

Stratigraphic evidence from the Muswellbrook area and Martindale No. 1A indicates that the Greta Coal Measures become a diachronic unit in the upper Hunter Valley.

The Cranky Corner Permian outlier north of the Hunter Thrust contains a coal measure sequence correlated with the Greta Coal Measures (Booker, 1953). The sequence consists of 9.7 m of coal in three seams associated with thick coarse-grained sandstone. The thickness of the measures ranges from 91 to 396 m.

INTERVAL 4: BRANXTON FORMATION (EXCLUDING MUREE SANDSTONE MEMBER) AND CORRELATIVE WANDRAWANDIAN SILTSTONE

Branxton Formation (excluding Muree Sandstone Member)

The type area of the Branxton Formation (Engel, 1966; McKellar, 1969) is the lower Hunter Valley. The name is synonymous with the Branxton Stage of David (1907, 1950) and the Branxton Sub-Group of Hanlon & Booker (*in* Hill, 1955) and Booker (1960).

The Branxton Formation is a marine sequence of pebbly sandstone and siltstone some 900 m thick. McKellar (1969) gives a composite type section: the upper half, which is 509 m thick, crops out from the Brokenback Range, 8 km south of Cessnock, to Bow Wow Gorge, 5 km southwest of Mulbring; the lower part, which is about 548 m thick, crops out from a point 0.8 km north of Greta to Branxton. He recognized the Wollong Siltstone Member, the *Fenestella* Zone, and the Cessnock Sandstone Member, beneath the Muree Sandstone Member, as units within it, although not all can be distinguished in every area.

The Cessnock Sandstone Member (Jones, 1939; Booker, 1960) consists of massive hard sandstone, 12 to 15 m thick, cropping out on the east side of the Lochinvar Anticline at the base of the Branxton Formation.

The Fenestella Zone (named *Fenestella* Shale by Jones, 1939) occurs between 472 and 502 m below the top of the formation. The type section near Branxton contains 50 m of interbedded siltstone and sandstone characterized by several species of fenestellids, including *Fenestella* and *Polypora*. The zone also forms a well defined lithological unit.

The Wollong Siltstone Member (David, 1905) is confined to the Mulbring/ Bow Wow Gorge area. It contains 18.6 m of medium-grey siltstone interbedded with fine-grained silty sandstone, some of which is conglomeratic. It is located about 244 m below the top of the formation and contains an abundance of *Thamnopora wilkinsoni*.

Muree Sandstone Member (see Interval 5).

Wandrawandian Siltstone

The Wandrawandian Siltstone (Joplin et al., 1952) is a sequence of fine-grained lithic sandstone and siltstone, with scattered pebbles, mainly of quartz. It is exposed around Jervis Bay and in the valleys draining the western margin of the basin. McElroy et al. (1969) state that although true siltstone is probably quite rare, the name has been used because the rocks are relatively silty compared with the underlying Snapper Point Formation. David & Stonier (1891) refer to it as the 'Wandrawandian pebbly sandstone' in the type area near Nowra. The sedimentary structures described as 'mud swirls' consist of nearly flat irregular lensing beds of clayey siltstone, or cross-cutting wavy swirls which look like worm or reed casts.

Interval 4 in the Deep Wells

With the exception of Loder No. 1 and Belford No. 1, which began in the Branxton Formation, all the wells quoted penetrated the full sequence.

East Maitland No. 1
(Jensen & Bryan, 1969)

	Thickness (m)
Quartz greywacke, greywacke, and sandy siltstone, very poorly sorted, rare siliceous pebbles in lower part. Much of 'matrix' consists of altered clasts of volcanic rock and tuffaceous material. Feldspar (especially potash feldspar) throughout, and very common in places	390.1
Greywacke, quartz greywacke, and sandy siltstone, commonly carbonaceous, essentially fine-grained, but containing some coarser intervals. Clasts of chert, shale, and low-grade metamorphic rocks. Calcite and siderite cement; pyrite common in places. Marine fossils, mainly brachiopods and Bryozoa, throughout, but more abundant towards top	237.7
Total	627.8

Belford No. 1
(Ozimic, 1968)

	Thickness (m)
Quartz greywacke and lithic sandstone with pebbles of quartz and chert, clasts of volcanic rock, and fresh and altered feldspar. Sodic plagioclase partly or wholly replaced by calcite. Siderite and calcite cement throughout. Bryozoa concentrated in zone near top of unit. Laminae; burrow structures. Well began in this interval	390.1

Loder No. 1
(Nicholas, 1968)

	Thickness (m)
Subgreywacke and protoquartzite, very fine to medium-grained, with minor interbeds of siltstone. Pebbles of quartz and red and green chert common. Carbonaceous material, including minor coal seam, in lower part. Brachiopod shells and spines and fenestellid Bryozoa common in upper part. Calcite, siderite, and silica cement; pyrite common in places. Churned bedding	478.5
Subgreywacke, fine-grained, grading in places into medium-grained protoquartzite; contains siltstone partings. Base of unit rich in pebbles of quartz, chert, and sandstone. Pyrite and carbonaceous material throughout. Dawsonite and silica cement common	73.2
Protoquartzite, fine-grained; contains pyrite and carbonaceous material. Quartz and chert pebbles throughout. Calcite, siderite, dawsonite, and silica cement. Churned bedding	137.2
Total	688.9

Camberwell No. 1
(AOG, 1965b)

	Thickness (m)
Siltstone, micaceous, sandy and pebbly in places; contains thin beds of sandstone and shale. Shelly fossils and Bryozoa	419.7

Jerrys Plains No. 1
(Esso, 1969)

	Thickness (m)
Sequence of interbedded sandstone, siltstone, and shale which becomes sandier in upper half. Sandstone poorly sorted, fine to medium-grained, and conglomeratic in places. Brachiopods and rare burrow structures in core	289.6

Martindale No. 1A
(Nicholas, 1969)

	Thickness (m)
Subgreywacke and protoquartzite, grading in places into siltstone and claystone. Concentration of quartz and chert pebbles at base; scattered pebbles, volcanic rock fragments, and pyrite throughout. Sedimentary rock fragments in bottom 60 m. Calcite, siderite, and dawsonite cement; rare glauconite	211.8

Howes Swamp No. 1
(Esso, 1970)

	Thickness (m)
Sandstone, buff, very fine to medium-grained, interbedded with carbonaceous micaceous calcareous siltstone	227.1

Kulnura No. 1
(Ozimic, 1969)

	Thickness (m)
Sandstone, fine-grained, pebbly; fragments of volcanic and sedimentary rocks, volcanic glass; carbonaceous material. Pebbles consist of milky quartz and chert. Dawsonite and calcite cement, abundant Foraminifera, brachiopods, and Bryozoa. Foraminifera identified by Crespin (1938) include *Ammodiscus multicinctus, Frondicularia parri, Hyperammina sp., Trochammina pulvilla,* and *Reophax* sp.	248.4

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Siltstone, massive, pyritic, sandy, and poorly sorted quartz greywacke. Scattered quartz and chert pebbles. Brachiopods, corals, and Foraminifera (mainly *Hyperammina* spp.). Laminae; burrow structures	172.2

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Siltstone, carbonaceous, interbedded with medium to coarse-grained slightly pebbly subgreywacke with carbonate cement. Mainly siderite cement, with some calcite, silica, dolomite, anhydrite, and pyrite. Worm tubes, Foraminifera, and brachiopods. Cross-lamination; scallop structures	73.2
Subgreywacke, fine to coarse-grained, thinly interbedded with minor siltstone. All carbonaceous and micaceous, with scattered pebbles and rare cobbles. Calcite and siderite cement; pyrite. Cross-lamination; scallop structures	146.3
Total	219.5

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Siltstone, sandy, pebbly, carbonaceous, grading into fine-grained sandstone; minor mudstone and claystone. Calcite and siderite cement; pyrite. Brachiopods and pelecypods	178.9
Protoquartzite, fine to very fine-grained, and sandy siltstone. Sandstone contains up to 5% allochthonous glauconite. Calcite and siderite cement; pyrite	15.8
Siltstone, coarse-grained, slightly pebbly, sandy, grading into silty fine-grained sandstone. Calcite and siderite cement; pyrite and glauconite	21.6
Total	216.3

Woronora No. 1
(Alcock, 1968b)

	Thickness (m)
Siltstone and sandy siltstone interbedded with fine-grained quartz greywacke; minor beds of quartz sandstone and shale. Pebbly in places. Churned bedding. Brachiopods	128.0

Stockyard Mountain No. 1
(Alcock, 1968a)

	Thickness (m)
Basalt, dark olive-black, porphyritic	85.3
Sandy mudstone interbedded with shale and fine to medium-grained dolomitic protoquartzite. Scattered pebbles. Carbonaceous, pyritic; sandy at top. Lamination; scallop structures. Marine(?) shell fragments; churned bedding and burrow structures	109.7
Total	195.0

Coonemia No. 1
(Genoa, 1969a)

	Thickness (m)
Siltstone, medium-tough, micaceous, carbonaceous; scattered sand grains	115.8

BMR Wollongong No. 1
(Ozimic, 1971)

	Thickness (m)
Siltstone, calcareous, carbonaceous, and pyritic, grading into fine to very coarse sandstone. Brachiopods, pelecypods, and Bryozoa common	153.9

Wandandian Bore
(David & Stonier, 1891)

	Thickness (m)
Mudstone, dark grey, pebbly; some small boulders. Abundant marine shells	167.6

Relations with Older Units

The Branxton Formation is conformable on the Greta Coal Measures except in the Raymond Terrace district of the lower Hunter Valley where it is conformable on the Dalwood Group.

The Wandrawandian Siltstone is conformable on the Snapper Point Formation.

Correlations and Age

The Branxton Formation in the northern part of the basin is correlated through the deep wells with the Wandrawandian Siltstone in the south as shown in Plate 2. The correlation is based mainly on its stratigraphic position between the Greta Coal Measures and Snapper Point Formation below and the Mulbring Siltstone and Berry Formation above. The Wandrawandian Siltstone is the sequence between the Snapper Point Sandstone and Nowra Sandstone as designated by Mayne et al. (1970).*

Dickins (1968) relates the fauna of the Branxton Formation below the *Fenestella* Zone to Fauna II of the Bowen Basin (Dickins et al., 1964). It contains *Deltopecten, Terrakea* sp., *Strophalosia valida* (closely related to *S. brittoni*), and a *Notospirifer* similar to *N. extensus*. Dickins (1968) relates the fauna of the upper part of the Branxton Formation to Fauna III in the middle part of the 'Middle Bowen Beds' (= Gebbie Sub-Group of Back Creek Group). Fauna III is poorly represented in the Hunter Valley and elsewhere in New South Wales. The *Fenestella* Zone contains *Strophalosia* cf. *jukesi* or *preovalis, Ambikella* related to *A. plica* and *A. plana, Notospirifer* sp., and *Myonia* sp. Dickins has subdivided Fauna III in the Bowen Basin into Faunas IIIa, IIIb, and IIIc. He considers that the fauna of the *Fenestella* Zone is related to Fauna IIIa Runnegar (1967) states that the interval in the Sydney Basin which corresponds to Fauna III in the Bowen Basin contains a mixture of species that are restricted to Faunas II and IV in Queensland, the mixture constituting the *Eurydesma-Myonia corrugata* fauna, which was later called the Ulladulla fauna (Runnegar, 1969). The following species are found in the Branxton Formation: *Eurydesma hobartense, Myonia corrugata, Neocrimites meridionalis, Ambikella* cf. *angulata, A.* cf. *ovata, Gilledia culburrensis, Fletcherithyris amygdala, and F. parkesi.*

Runnegar does not state the location of this fauna within the Branxton Formation. Dickins (1968) gives a probable Kungurian age for the top part of the Branxton Formation and an Artinskian age for the lower part.

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* This correlation supersedes the correlation shown in the company well completion reports (see Mayne et al., 1970).

Runnegar (1967) lists the following species from the Wandrawandian Siltstone as part of the *Eurydesma-Myonia corrugata* fauna: *Eurydesma hobartense, Deltopecten multicostatus, Myonia corrugata, Megousia* sp. nov., *Ambikella* cf. *ovata, Gilledia culburrensis, G. ulladullensis,* and *Fletcherithyris amygdala.*

The Ulladulla Mudstones of Harper (1915) and Brown (1925) were considered by McElroy & Rose (1962) to be an upper silty phase of the Conjola Formation, but Dickins et al. (1969) consider that they should be correlated with the lower part of the Wandrawandian Siltstone. The fauna is a mixture of Faunas II and IV of the Bowen Basin. It contains *Eurydesma hobartense, Deltopecten limaeformis, D. multicostatus, Myonia corrugata, Megousia* sp. nov., *Ambikella ingelarensis, A.* cf. *undulosa, Gilledia culburrensis, Strophalosia* cf. *preovalis,* and *Terrakea* sp. nov. The fauna of the upper part of the Wandrawandian Siltstone has not been described.

INTERVAL 5: MUREE SANDSTONE MEMBER OF BRANXTON FORMATION AND CORRELATIVE NOWRA SANDSTONE

Muree Sandstone Member

The Muree Sandstone Member (Engel, 1966; McKellar, 1969) of the Branxton Formation is exposed in the Lochinvar Anticline and between Paterson and Raymond Terrace in the lower Hunter Valley. The name is taken from the Muree Quarry in Raymond Terrace (Clarke, 1878). The Muree Sandstone Member is synonymous with the Muree Stage of David (1907) and the Muree Formation of Booker & Hanlon (*in* Hill, 1955) and Booker (1960).

The type section is located in Bow Wow Gorge 5.5 km southwest of Mulbring. It is described by McKellar (1969):

	Thickness (m)
Cliff-forming sandstone, commonly conglomeratic or tillitic	39.6
Siltstone interbedded with bench-forming units of sandstone from 0.3-0.6 m thick	22.9
Cliff-forming sandstone, commonly conglomeratic or tillitic	16.8
Total	79.3

The member loses its distinctive threefold character away from the type area, and is difficult to identify, so that there has been some doubt as to its correlation and distribution (Jones, 1939; Booker, 1960). Engel (1966) considers it to be largely restricted to the Lochinvar Anticline and areas immediately to the east. Raggatt (1938) identified it also in the Loder and Belford Domes and Sedgefield Anticline in the Singleton area, and in the Muswellbrook area. Plate 1, and the N.S.W. Department of Mines Geological Series 1:250 000 (1966) Sheet for the Singleton area, show it cropping out in the domes in the Singleton area, but not at Muswellbrook.

Nowra Sandstone

The Nowra Sandstone (Joplin et al., 1952) is a prominent cliff-forming unit in the southern area. There is no defined type section. Complete sections, exceeding 90 m in thickness, occur north of Burrier to the north of the Shoalhaven River.

According to McElroy & Rose (1962) it consists typically of quartz sandstone similar to the Hawkesbury Sandstone in composition, grainsize, and texture. The well defined cross-bedding, mode of outcrop, topography, and vegetation, are also similar. White quartz pebbles are possibly more common in the Nowra Sandstone than in the Hawkesbury Sandstone, and small fragments and large blocks of phyllitic siltstone and quartzite are widely distributed, particularly in the western part of the area.

Paix (1968) has described the following subdivisions seen in outcrop in the Nowra district:

	Thickness (m)
Cross-bedded quartz sandstone	9.0
Cliff-forming quartz sandstone with evidence of graded bedding	9-15.0
Siltstone or silty sandstone	0-6.0
Massive quartz sandstone	4.6

Fossils are particularly common towards the base and in the siltstone, which Paix has called the Currumbene Siltstone Member. The member is 9 m thick in the north bank of Currumbene Creek, about 0.8 km below the falls at Falls Creek.

To the north and east the Nowra Sandstone lenses into siltstone and is difficult to distinguish from the underlying Wandrawandian Siltstone. Paix considers that a fossiliferous interval near the base of the Nowra Sandstone at Pointer Gap in the Milton district may be on the same stratigraphic horizon as the Currumbene Siltstone Member.

West of Milton there are well known residuals of the cliff-forming sandstone at Pigeon House, The Castle, Talaterang, Corang, and Quiltys Mountain. The sandstone has a prominent joint pattern. The trend of the joints varies from place to place, but they commonly dip at 60°.

Current-bedding measurements on the cross-bedded sandstone (Paix, 1968; McKelvey et al., 1971) indicate a current from the south.

Ozimic (1971) subdivided the Nowra Sandstone on the basis of the gamma-ray patterns and the lithology in the BMR Wollongong Nos 1, 2, and 2A wells, the Stockyard Mountain No. 1 well (Alcock, 1968a), and on field observations in the Nowra district. He distinguished an upper unit composed of cross-bedded and thick-bedded sandstone, a middle unit of interbedded sandstone and shale, and a lower unit of massive sandstone.

Interval 5 in the Deep Wells

The Loder No. 1 and Belford No. 1 wells in the lower Hunter Valley began below the Muree Sandstone Member and the unit could not be identified in the deep wells in the middle and upper sections of the Hunter Valley.

The following sequences were encountered in the deep wells from north to south through the basin.

East Maitland No. 1
(Jensen & Bryan, 1969)

	Thickness (m)
Protoquartzite, fine to medium-grained, pebbly in places. Quartz grains commonly have interlocking fabric; rare microperthite grains and fragments of fine-grained mafic volcanic rock. Silica, siderite, calcite, and dawsonite cement. Thin interbeds of siltstone and mudstone in lower half. Abundant brachiopods, bryozoans, and corals at certain levels	181.7

Kulnura No. 1
(Ozimic, 1969)

	Thickness (m)
Subgreywacke, coarse-grained, pebbly. Calcite, silica, and dawsonite cement; pyrite. Foraminifera, brachiopods, and bryozoans	25.9

Howes Swamp No. 1
(Esso, 1970)

	Thickness (m)
Lithic sandstone, buff, conglomeratic	15.2

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Protoquartzite, medium-grained, pebbly. Quartz grains commonly have interlocking fabric. Thin siltstone interbeds. Calcite, siderite, and silica cement	29.0

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Subgreywacke, fine-grained, pebbly. Siderite, calcite, and silica cement; pyrite	9.1

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Protoquartzite, fine to medium-grained, slightly pebbly, and minor siltstone. Pebbles of quartz, sandstone, siltstone, and igneous rocks. Calcite, siderite, silica, and dawsonite cement; pyrite. Graded bedding (waxing and waning current types); wavy bedding; burrows	36.6

Woronora No. 1
(Alcock, 1968b)

	Thickness (m)
Protoquartzite, medium-grained, silicified; pebbles of quartz, metaquartzite, and mudstone. Brachiopods	15.0
Protoquartzite, fine-grained, interbedded with fine-grained subgreywacke and siltstone. Minor shale and mudstone	33.5
Total	48.5

Stockyard Mountain No. 1
(Alcock, 1968a)

	Thickness (m)
Protoquartzite, medium-grained, silicified, calcareous, pyritic, with interbedded sandy mudstone in middle of sequence. Quartz and chert pebbles. Poorly sorted and bedded. Brachiopods common	39.6

BMR Wollongong No. 1
(Ozimic, 1971)

	Thickness (m)
Sandstone, coarse-grained, poorly sorted, pebbly in places. Calcite, siderite, and silica cement. Sandy siltstone in middle of sequence contains fossil fragments. Began in Interval 5	31.5

BMR Wollongong Nos 2 & 2A
(Ozimic, 1971)

	Thickness (m)
Sandstone, coarse-grained, poorly sorted, pebbly; calcite, siderite, and silica cement; thinly bedded sandy siltstone in middle of sequence contains abundant brachiopods, pelecypods, gastropods, and rare fragments of bryozoans	46.3

Relations with Older Units

The Muree Sandstone Member is conformable on the Branxton Formation in the type area near Mulbring on the Lochinvar Anticline, and on the domes in the Singleton area.

The Nowra Sandstone is conformable on the Wandrawandian Siltstone, although McKelvey et al. (1971) have indicated the possibility of a disconformity at or near the base.

Correlations and Age

The correlation of the Muree Sandstone in the north with the Nowra Sandstone in the south is based on lithology, faunal evidence, and stratigraphic position. The Nowra Sandstone has been traced from outcrop, via shallow wells, into the deep wells to correlate with the Muree Sandstone Member (Pl. 2). David & Stonier (1891) referred to the Nowra Sandstone as the Nowra Grit and stated that 'the formation much resembles the Muree Rock of the upper marine series near Maitland in lithological character and contained fossils.'

The Muree Sandstone Member contains an abundant marine fauna correlated with Fauna IV of the Bowen Basin, which occurs in the upper part of the 'Middle Bowen Beds'* (Dickins, 1964, 1968). The correlation is indicated by the presence of species closely related to, or conspecific with, *Terrakea solida, Strophalosia ovalis,* and *Neospirifer* sp. B. Fauna IV is of Kazanian age.

Dickins et al. (1969) have described the fauna from Pointer Gap in the Milton district. The fauna was collected from a lower siltstone unit and an overlying sandstone. The siltstone was originally considered to be the upper part of the Wandrawandian Siltstone, but is now regarded (Dickins, *in* Olgers & Flood, 1970) as part of the Nowra Sandstone. This interpretation agrees with Paix's hypothesis (Paix, 1968). The fauna from the siltstone unit contains *Neospirifer* sp., *Terrakea* sp., and *Strophalosia* cf. *clarkei,* which suggest relationships with Fauna IV of the Bowen Basin. The fauna from the upper sandstone unit contains *Pyramus* cf. *myiformis, Terrakea* cf. *solida, Strophalosia* cf. *clarkei, S.* cf. *ovalis, Neospirifer* sp., and *Notospirifer* sp. nov., which are related to species in the Muree Sandstone Member and Fauna IV in the Bowen Basin. It also contains *Astartila* cf. *compressa, Myonia corrugata,* and *Ambikella* cf. *isbelli,* which persist from the Ulladulla Mudstone and Snapper Point Formation.

* = Blenheim Sub-Group of Back Creek Group (Dickins & Malone, 1973).

INTERVAL 6: MULBRING SILTSTONE AND CORRELATIVE BERRY FORMATION

The Mulbring Siltstone occurs in the Muswellbrook and Singleton areas, on the flanks of the Lochinvar Anticline, and in the Medowie Syncline running northeast from Raymond Terrace. It is synonymous with the Mulbring or Crinoidal Stage of the Upper Marine Series (David, 1950) and the Mulbring Sub-Group of the Maitland Group (Booker & Hanlon, *in* Hill, 1955). It has since been redefined as a formation of the Maitland Group (Engel, 1966; McKellar, 1969); two members, the Glendon Siltstone and Dochra Siltstone, have been recognized between Singleton and Greta.

The Mulbring Siltstone consists of siltstone and minor claystone. McKellar (1969) measured a thickness of 330.1 m on the southeast flank of the Lochinvar Anticline, which he considered to be close to the true thickness. The type section (McKellar, 1969) of the Glendon Siltstone Member is 9.6 km east of Singleton, where it is about 1.5 m thick and approximately 76 m above the base of the formation. It is characterized by the presence of many large calcareous globular concretions. The Dochra Siltstone Member is a prominent bench-forming micaceous siltstone in the Singleton area. The type section (McKellar, 1969) is 4 km southwest of Singleton on the left bank of the river, where it is 19.8 m thick and 21.3 m below the top of the Mulbring Siltstone.

The Berry Formation (Bryan et al., 1966) has been mapped along the western margin of the basin from Mount Talaterang in the far south to the Capertee area (McElroy, 1962), and also in the Cambewarra Range in the south (Rose, 1962). A number of nearly complete sections have been measured in the Cambewarra Range area, and the maximum estimated thickness is 143 m. The formation consists mainly of micaceous siltstone, shaly in part, with laminae of silty sandstone. North of Tallong the sequence is pebbly, particularly towards the base.

Interval 6 in the Deep Wells

The following sequences were encountered in the deep wells from north to south through the basin:

East Maitland No. 1
(Jensen & Bryan, 1969)

	Thickness (m)
Siltstone, highly carbonaceous, pyritic, grading in places into silty sandstone, overlain by thin calcareous subgreywacke	219.5
Siltstone, carbonaceous, pyritic, sandy, with mudstone and very fine-grained sandstone. Calcite cement throughout. Marine fossils and burrow structures. Scallop structures (Jensen, 1968) common at certain levels	185.9
Siltstone, carbonaceous, micaceous, pyritic, sandy, with silty sandstone and some mudstone. Brachiopods, Bryozoa, and corals. Scallop structures. Distinguished from sediments above by presence of sparse small siliceous pebbles	123.1
Total	528.5

The cylindrical scallop structures are composed of a number of concentric cylinders outlined by grey laminae rich in carbonaceous material. The structures appear as a series of scalloped swirls elongated parallel to the bedding. Similar structures have been described in the Dochra Siltstone Member (McKellar, 1969). J. Gilbert-Tomlinson (pers. comm.) has examined similar material collected by A. R. Jensen from the Mount Steel Formation, near Gyandra homestead in the Bowen Basin, and has detected a resemblance to the North American Pennsylvanian ichnogenus *Olivellites* which Fenton & Fenton (1937) considered to be a gastropod burrow.

Camberwell No. 1
(AOG, 1965b)

	Thickness (m)
Siltstone, light grey, finely micaceous, sandy in part, slightly carbonaceous. Rare fossil fragments. Well began in this unit. Upper part probably base of Singleton Coal Measures	238.7

Jerrys Plains No. 1
(Esso, 1969)

	Thickness (m)
Shale, medium to dark grey, slightly carbonaceous, grading into argillaceous siltstone; minor interbeds of sandstone. Siltstone fossiliferous in places (brachiopods?); pyritic	167.6

Martindale No. 1A
(Nicholas, 1969)

	Thickness (m)
Protoquartzite, fine-grained, carbonaceous, grading into siltstone. Siderite and dawsonite cement	12.2
Siltstone, carbonaceous, sideritic, pyritic, interbedded with claystone	9.1
Siltstone, carbonaceous. Pyrite, dawsonite, and siderite cement	24.4
Siltstone grading in places into very fine-grained protoquartzite. Small amounts of carbonaceous material, pyrite, quartz and chert pebbles, and volcanic rock fragments throughout. Dawsonite, calcite, and siderite cement. Bryozoa near top	139.0
Total	184.7

Kulnura No. 1
(Ozimic, 1969)

	Thickness (m)
Siltstone, sandy, carbonaceous, with thin beds of claystone and laminae of coal. Abundant Foraminifera and ostracods	201.2
Siltstone, as above, but with higher proportion of sand. Distinguished by large proportion of pyritic matter. Abundant Foraminifera	259.1
Total	460.3

Foraminifera identified by Crespin (1938) include *Ammodiscus iincertus, A. milletianus, A.* cf. *semiconstrictus, A.* sp., *Agathammina* sp., *Hyperamminoides* cf. *proteus, H.* cf. *rugosus, Textularia* sp., *Nodosinella* sp., *Trochamminoides anceps, Trochammina* sp., cf. *Haplophragmoides, Ammobaculites* sp., *Climacammina* sp., *Nodosaria* sp., *Frondicularia woodwardi, F.* cf. *woodwardi, F.* sp. nov., cf. *Geinitzina,* and cf. *Globivalvulina.* The ostracods present are *Macrocypris* sp., *Bairdia* sp., *Bythocypris* sp., *Cytherella* sp., *Healdia* sp., and cf. *Cavellina.*

Howes Swamp No. 1
(Esso, 1970)

	Thickness (m)
Siltstone, light to dark grey, carbonaceous, calcareous, pyritic, interbedded with medium to dark grey silty shale and minor fine to coarse silty sandstone. Brachiopods and crinoids in lower part	361.2

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Siltstone, micaceous, pyritic, carbonaceous, interlaminated with muddy very fine-grained subgreywacke. Rare quartz pebbles throughout. Mainly calcite and dolomite cement; some siderite and anhydrite. Plant fragments, worm tubes, and Foraminifera	94.5
Siltstone, as above, but with more subgreywacke	259.1
Total	353.6

Crespin (1955) identified the following Foraminifera: *Digitina recurvata* Crespin & Parr, *Reophax* cf. *aspersus* (Cushman & Waters), *R.* sp., *Hyperamminoides* sp., *Ammodiscus multicinctus* Crespin & Parr, and *Trochammina pulvilla* (Crespin & Parr).

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Siltstone, sandy, carbonaceous, with minor subgreywacke; arenaceous Foraminifera (mainly *Hyperammina* spp.)	76.2
Sandy siltstone, massive, pyritic, carbonaceous, with interbeds of claystone and rare quartz greywacke	362.7
Total	438.9

Woronora No. 1
(Alcock, 1968b)

	Thickness (m)
Sandy siltstone, micaceous, interbedded with protoquartzite and shale. Fragments of volcanic rock in sandstone	73.2
Sandy siltstone with minor sandstone. Fragments of volcanic rock in sandstone	33.5
Subgreywacke, fine-grained; abundant fragments of volcanic rock and plagioclase	15.2
Sandy siltstone with minor sandstone and shale	128.0
Siltstone with interbedded subgreywacke, shale, and mudstone. Subgreywacke contains numerous grains of volcanic rock and plagioclase, and minor chlorite, dolomite, pyrite, and silt. Scallop structures in mudstone	76.2
Total	326.1

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Mudstone, brownish black, and slightly sandy siltstone grading down into slightly pebbly sandy siltstone to fine sandstone. Carbonaceous; siderite and calcite cement; pyrite. Lamination; cross-bedding; burrows and bioturbation; brachiopods	266.1

Stockyard Mountain No. 1
(Alcock, 1968a)

	Thickness (m)
Shale grading into siltstone. Quartz sand and pyrite scattered throughout. Lamination; microcross-bedding; scallop structures. Brachiopods, Bryozoa, rare Foraminifera, and plant fragments near top	242.3

BMR Wollongong No. 2 & 2A
(Ozimic, 1971)

	Thickness (m)
Sandstone, very fine-grained, and siltstone; some shale laminae. Foraminiferal casts and broken shell fragments	26.5

Relations with Older Units

The Mulbring Siltstone is conformable on the Muree Sandstone Member where present, and on the Branxton Formation elsewhere.

The Berry Formation is conformable on the Nowra Sandstone in the south and on the Megalong Conglomerate on the western margin of the basin.

Correlations and Age

The Mulbring Siltstone in the north and the Berry Formation in the south have been correlated through the wells on the basis of lithology and stratigraphic position (Pl. 2).

The fauna of the Mulbring Siltstone is correlated with Fauna IV of the Bowen Basin (Dickins et al., 1964; Dickins, 1968), which occurs in the upper part of the 'Middle Bowen Beds' (= Blenheim Sub-Group). The correlation is indicated by the presence of *Myonia carinata* and *Chaenomya* sp. The Berry Formation also contains a fauna equivalent to Fauna IV (Runnegar, 1967; Dickins et al., 1969).

Megalong Conglomerate

The Megalong Conglomerate and the overlying Berry Formation constitute the Shoalhaven Group of McElroy (1962), which crops out on the western margin of the basin from Tallong in the south to Wollar in the north (McElroy et al., 1969). In many places the two formations have not been mapped separately.

The Megalong Conglomerate ranges from a massive cobble conglomerate, up to 15 m thick, to pebbly sandstone and interbedded siltstone and conglomerate up to 120 m thick. In the type area in the Megalong Valley, the formation consists of a sequence of cobble conglomerate about 60 m thick.

In many localities, including the Megalong area, there is a breccia-like conglomerate at the base containing large boulders of quartzite and other rocks up to 3.5 m across. McElroy et al. (1969) state that in many places the basal breccias consist of a few or numerous angular blocks and rounded boulders, cobbles, and pebbles set in a poorly sorted matrix of rock fragments, quartz, and feldspar.

In the Kandos area the Megalong Conglomerate has been interpreted as fluvioglacial (Sussmilch, 1933) or as a shoreline deposit (Lavers, 1960).

Relations with Older Units. The Megalong Conglomerate rests unconformably on Silurian and Devonian sedimentary rocks.

Correlations and Age. McElroy & Rose (1966) consider that the Megalong Conglomerate in the Tallong area, where the Wandrawandian Siltstone has lensed out, represents the western coalescence of the Conjola Sub-Group and the Nowra Sandstone.

The conglomerate in the Tallong area has been studied more recently by Herbert (1972) who has renamed it the Tallong Conglomerate. He considers that it may be a correlative of the conglomerate at the base of the Permian sequence in the Coonemia No. 1 well (Bembrick & Holmes, 1971).

Brachiopods, pelecypods, bryozoans, and gastropods have been recorded from a number of localities (McElroy et al., 1969), but the fauna has not been related in terms of age to those in other parts of the basin.

APPENDIX 3: UPPER KAZANIAN TO MIDDLE TRIASSIC ROCKS

INTERVAL 7: LOWER PART OF WALLIS CREEK FORMATION AND CORRELATIVES

Lower part of Wallis Creek Formation

The type section of the lower part of the Wallis Creek Formation (Anon, 1969) is in the lower Hunter Valley between the outcrop of the *Chaenomya* Beds, at the top of the Mulbring Formation, and the Rathluba Seam. The lower part consists of sandstone, shale, mudstone, and thin named coal seams, which amalgamate in one area, to form an economic seam, the Rathluba Seam.

Saltwater Creek Formation

The type section of the Saltwater Creek Formation (Robinson, 1969; Britten, 1972) is in DM Warkworth DDH 1 from 479.7 to 495.3 m. The formation consists mainly of sandstone with rare shaly partings and laminae. There are a few thin coaly and tuffaceous layers.

Lower part of the Vane Sub-Group

The type section of the Vane Sub-Group (Britten, 1972) is in DM Warkworth DDH 1 from 253.4 to 479.6 m. The sub-group consists of shale, siltstone, sandstone, conglomerate, and coal, and is subdivided into the Foybrook, Bulga, and Archerfield Formations, which have been described in detail by Britten. Only the lower half of the sub-group, from the Hebden Seam to the Pikes Gully Seam of the Foybrook Formation, is included in Interval 7.

Mount Marsden Claystone

The Mount Marsden Claystone (Goldbery, 1969) consists predominantly of claystone with interbeds of limestone, dolomite, siltstone, and sandstone. The type section is in the Glen Davis Post Office section, from 36.6 to 55.5 m. The rocks contain dawsonite and nordstrandite as cement. Plant remains are abundant in places.

Budgong Sandstone

The name Budgong Sandstone was first mentioned in the reference column of the Wollongong 1:250 000 geological Sheet (Geol. Surv. N.S.W., 1966).

The type section of the Budgong Sandstone (Bowman, 1970) is at Yallah-Avondale near Wollongong. The sandstone at the base is dark grey and fine-grained. The clasts consist mainly of feldspar and andesite, with some metamorphic, granitic, and sedimentary rocks. There are lenses of shale and siltstone, and abundant marine fossils, particularly towards the base. Towards the top of the formation the sandstone is light grey to yellow-brown in colour and becomes coarser-grained, cleaner, and more quartzose. It is generally flat-bedded, and the thickness of the beds increases to about 1 m at the top of the unit. Towards the top marine fossils become rare and plant fragments appear.

Between Wollongong and the Shoalhaven River red, yellow, and brown sandstone is interbedded with latite flows. Bowman (1970) suggested the informal term 'Gerringong volcanic facies' for this sequence, and the name Broughton Sandstone for the red sandstone where there are no interbedded latites. Hanlon et al. (1953) named the lavas the Gerringong Volcanics. The component members, which are often mentioned in the literature, are listed in Table A. Bowman (1970) called the highest lava in the 'Gerringong volcanic facies' the Dapto Latite. He and Raam reject the opinion of earlier writers that the basaltic detritus in the adjacent sandstone represents volcanic ejecta, and consider that it was formed by penecontemporaneous erosion of the lava flows. The presence of pillow structures in the lavas strongly suggests that they were erupted in shallow water (Raam, 1969).

TABLE A. MEMBERS OF THE GERRINGONG VOLCANICS

(After Hanlon et al., 1953)

	Cambewarra Latite Member Saddleback Latite Member
Broughton Sandstone Member (where Bumbo Latite and Blowhole Latite are missing)	Jamberoo Sandstone Member Bumbo Latite Member Kiama Sandstone Member Blowhole Latite Member Westley Park Sandstone Member

Note—The latites contain plagioclase and potash feldspar, with or without quartz (Joplin, 1964).

The Westley Park Sandstone Member is richly fossiliferous and contains glendonites and ice-rafted erratics (Booker, 1960). The Kiama Sandstone Member contains pebble horizons and a more sparse marine fauna, whilst the Jamberoo Sandstone Member contains some plant fossils.

Pheasants Nest Formation

The type section of the Pheasants Nest Formation (Wood & Bunny, *in* Wass et al., 1969) is in the DM Wollongong 35 bore, where it is 76 m thick. Bowman (1970) described the formation as follows: 'coarse-grained, poorly-sorted, thinly bedded sandstones composed of basaltic detritus, feldspar, quartz, and some lithic fragments of sedimentary, granitic, and metamorphic origin, and thin interbedded shales and minor coals. Abundant channels with overbank depositional slopes up to about 10°, thin lenticular coals, and prostrate tree-trunks, some of which appear to be close to their growing positions, characterize the Pheasants Nest Formation particularly towards the base'. The most extensive coals, the Unanderra and Figtree Coal Members, which consist of up to 15 and 5 feet (4.6 and 1.5 m) respectively of interbedded carbonaceous claystone, tuff, and coal, are developed in the finer upper section of the sequence to the south of Wollongong.

Measurement of current directions in sandstones of the Pheasants Nest Formation by the author and M. R. Bunny indicate a northeasterly current flow.[1]

Interval 7 in the Deep Wells

Cataract No. 1
(E. Nicholas, pers. comm.)

	Thickness (m)
Arkose and subgreywacke, fine to medium-grained, greyish; numerous clasts of volcanic rock; chlorite and siderite cement; accessory pyrite and carbonaceous material	222.6

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Claystone, illitic	3.0
Siltstone, sandy	21.3
Arkose, silty, greyish; chlorite cement and clay matrix	24.4
Claystone, illitic	1.5
Arkose interbedded with sandy siltstone	15.2
Claystone, illitic	1.5
Total	66.9

Woronora No. 1
(Alcock, 1968b)

	Thickness (m)
Protoquartzite with interbeds of shale and carbonaceous siltstone	45.7

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Siltstone, thinly bedded, somewhat carbonaceous, and claystone derived from a probable mafic volcanic rock	24.4
Siltstone, grey to carbonaceous, with thin layers of coal. Clay, chloritic; calcite crystals	21.3
Subgreywacke with some interbeds of siltstone and trace of coal	30.5
Siltstone, thinly bedded, with several thin coal seams	21.3
Subgreywacke, green and brown, with abundant clasts of volcanic rock, and thin interbeds of siltstone. Chlorite and calcite cement, no quartz	91.5
Total	189.0

Kulnura No. 1
(Ozimic, 1969)

	Thickness (m)
Arkose, rich in potash feldspar and plagioclase; clasts of plutonic rock common. Calcite cement exceeds 25% of total rock. Some carbonaceous siltstone with coal laminae	31.4
Tuff, fine, partly altered to clay	4.6
Siltstone, calcareous, carbonaceous	57.9
Tuff, fine, partly altered to clay	3.0
Siltstone, calcareous, carbonaceous	22.8
Tuff, fine, partly altered to clay	10.6
Arkose, as above	9.2
Total	139.5

East Maitland No. 1
(Jensen & Bryan, 1969)

	Thickness (m)
Protoquartzite, light grey, moderately well sorted; contains small coaly clasts and laminae	12.2
Siltstone and silty claystone, very carbonaceous; contains coaly laminae and plant fragments	9.2
Protoquartzite, as above	6.1
Claystone, silty, buff, soft; carbonaceous laminae common	18.3
Subgreywacke, calcareous; contains carbonaceous laminae	6.1
Total	51.9

Jerrys Plains No. 1
(Esso, 1969)

	Thickness (m)
Shale, grey, with occasional interbeds of silty sand; 2 or 3 coal seams	26.8
Shale, grey, and fine-grained poorly cemented sandstone. Shale dominant in upper part, sandstone in lower part	15.8
Shale, bituminous, and grey shale	15.2
Coal, vitreous, and poorly sorted grey lithic sandstone with clay cement	18.3
Sandstone, light grey, lithic, feldspathic, quartzose, poorly sorted, carbonaceous, with thin interbeds of grey carbonaceous siltstone	18.3
Shale, grey, laminated, carbonaceous, silty in places	24.4
Shale, grey, with carbonaceous specks; 2 coal seams	51.8
Total	170.6

Martindale No. 1A
(Nicholas, 1969)

	Thickness (m)
Sandstone with clasts of volcanic rock interbedded with carbonaceous siltstone and carbonaceous sideritic claystone; up to 10 coal seams; coal laminae	115.9
Protoquartzite, sideritic, grading down into sideritic siltstone and claystone and then into carbonaceous siltstone	21.3
Siltstone, carbonaceous	24.4
Total	161.6

Howes Swamp No. 1
(Esso, 1970)

	Thickness (m)
Siltstone, grey and partly carbonaceous, interbedded with buff fine-grained partly carbonaceous sandstone; some thin coal seams	79.3
Shale interbedded with grey carbonaceous siltstone; few thin laminae of lithic sandstone	36.6
Siltstone, grey, carbonaceous, interbedded with pale tuffaceous claystone and lithic sandstone	16.7
Total	132.6

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Siltstone, carbonaceous, interlaminated with subgreywacke and coal	9.2
Subgreywacke interbedded with micaceous and somewhat carbonaceous siltstone. Carbonate cement consists chiefly of calcite; clasts of quartz, claystone, altered volcanics, plagioclase, and chert	33.6
Total	42.8

Mulgoa No. 2
(AOG, 1960)

	Thickness (m)
Shale, dark grey, interbedded with fine to medium-grained sandstone and thin layers of limestone	15.2
Sandstone interbedded with shale, siltstone, and coal laminae	45.6
Total	60.8

Relations with Older Units

In the lower Hunter Valley the base of the Wallis Creek Formation is conformable on the *Chaenomya* Bed at the top of the Mulbring Siltstone.

In the Singleton area (middle Hunter Valley) the Saltwater Creek Formation is conformable on the fossiliferous Dochra Mudstone, and in the Bayswater-Howick area (upper Hunter Valley) it begins where Foraminifera-bearing siltstone gives way to non-fossiliferous quartz sandstone (Veevers, 1960). From Martindale through Jerrys Plains to Broke the base of the formation lies immediately above a sandstone that was probably laid down in a sublittoral environment during the final regressive stage of the Mulbring Siltstone.

In the western area the Mount Marsden Formation rests conformably on massive grey micaceous siltstone of the Berry Formation.

The Budgong Sandstone also lies conformably on siltstone of the Berry Formation. The reddish sandstone ('Red Tuffs' of Harper, 1905) of the Gerringong Volcanics provides a precise lower boundary for the formation.

The Pheasants Nest Formation has a gradational contact with the Berry Formation and the base is taken at the top of the last marine sandstone in the Berry Formation.

In the absence of a precise boundary between the formations of Interval 7 and the underlying Berry Formation and Mulbring Siltstone the boundary is taken where there is an increase in carbonaceous and volcanic material and the disappearance of marine fossils.

Correlations and Age

The various units of Interval 7 rest conformably on siltstone of the Mulbring Siltstone or Berry Formation; some were laid down in a shallow marine, some in an estuarine, and some in a coal-swamp environment.

Fossils are uncommon in Interval 7, except in the tuffaceous sandstones associated with the Gerringong Volcanics. Raam (1969) lists the following forms:

Coelenterata: *Conularia inornata.*

Brachiopoda: *Strophalosia* cf. *clarkei, Terrakea solida, Spirifer duodecimcostatus, S. convolutus, S. vespertilio, S. tasmaniensis, Gilledia ulladullensis alta, Fletcherithyris amygdala, F. parkesi,* and *Ingelarella subradiata.*

Bryozoa: *Stenopora crinita, S. gracilis, S. frondescens, Protoretepora ampla,* and *Fenestella* sp.

Pelecypoda: *Stutchburia costata, Aviculopecten subquinquelineatus, A. leniusculus, Merismopteria macroptera, Myonia carinata, M. valida, M. elongata, Atomodesma* sp., *Megadesmus grandis, Astartila intrepida, Vacunella curvata, V. etheridgei, Streblochondria engelhardti,* and *Pyramus myiformis.*

Hyolithida: *Hyolithes lanceolatus.*

Gastropoda: *Mourlonopsis strzeleckiana, Mourlonia (Walnichollisa) subcancellata, Warthia micromphala, Platyschisma* sp., *Peruvispira morrisiana,* and *Ptychomphalina* sp.

Crinoidea: *Tribrachiocrinus corrugatus, T. granulatus, T. clarkei,* and *Philalocrinus konincki.*

These fossils belong to Fauna IV of Dickins (1964, 1966), which is the youngest fauna in the Permian rocks of eastern Australia and is of Kazanian to Tatarian age.

A few underdeveloped specimens of *Stutchburia* and *Clarkeia* have been found in the Wallis Creek Formation. Glossopterid plant fragments are present in the carbonaceous beds in many of the formations. The following plants have been recovered from shales in and below the Unanderra Seam in the Illawarra coalfield (Wilson, 1969): *Glossopteris browniana, G. indica, G. ampla, G. verticillata, G. linearis, G. cordata; Gangamopteris obovata,* and *G. mosesi.*

K/Ar ages of 250 m.y. (i.e. Middle Permian, Evernden & Richards, 1962) have been obtained on the Berkeley and Bumbo Latites. The worldwide Permian magnetic reversal called the Kiaman Magnetic Interval (Irving & Parry, 1963) was first detected (Mercanton, 1926) in the Gerringong lavas from near Kiama.

INTERVAL 8: UPPER PART OF WALLIS CREEK FORMATION AND CORRELATIVES

Upper part of Wallis Creek Formation

In the type section in the Buchanan Maitland DDH 1 in the lower Hunter Valley the upper part of the Wallis Creek Formation (Robinson, 1969) consists chiefly of sandstone, with very minor shale, mudstone, and coal laminae. The formation includes the 'Buttai Beds' of David (1907).

Upper part of the Vane Sub-Group

The type section of the Vane Sub-Group (Britten, 1972) is in DM Warkworth DDH 1, from 220.7 to 479.4 m. The part included in Interval 8 comprises the upper part of the Foybrook Formation above the Pikes Gully Seam, plus the Bulga and Archerfield Formations. The Foybrook beds contain carbonaceous shale and coal seams; the Bulga Formation consists of siltstone and the Archerfield Formation of sandstone. Britten considers that the beds are partly marine.

Coorongooba Creek Sandstone

The type section of the Coorongooba Creek Sandstone (Goldbery, 1969) is in the Glen Davis Post Office section, from 17.7 to 36.6 m.

The formation consists of medium-grained subgreywacke and protoquartzite with a calcareous cement and thin interbeds of shale and siltstone. Plant remains occur in places.

Erins Vale Formation

The type section of the Erins Vale Formation is in the DM Wollongong 35 bore. It consists of fine-grained polymict sandstone with numerous lenses of siltstone. The sandstone, the upper portion of which is conglomeratic in part, contains clasts of quartz, feldspar, volcanic rock, quartzite, and chert. The formation is generally from 6 to 36 m thick (Bowman, 1970). It consists of flat-bedded poorly sorted feldspathic sandstone overlain by well sorted cross-bedded quartzofeldspathic sandstone, and is generally medium-grained throughout. Worm burrows occur throughout the section, but are particularly common at the base. The sequence is phosphatic, especially at the base. The Kulnura Marine Tongue (Bowman, 1970), which contains a few marine fossils, is a siltstone member within the Erins Vale Formation.

Interval 8 in the Deep Wells

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Sandstone, labile, very fine-grained, with some sandy siltstone and illitic claystone. Sandstone is partly volcanogenic and contains variable proportions of quartz. Fossil burrows in a core from 1206.3-1208.3 m indicate deposition in tranquil marine environment	33.5

Woronora No. 1
(Alcock, 1968b)

	Thickness (m)
Shale, carbonaceous, interbedded with grey siltstone which is sandy in part; coal laminae	12.2
Subgreywacke, volcanolithic, dolomitic, with minor shale and siltstone	27.6
Subgreywacke interbedded with shale and siltstone	15.2
Subgreywacke, volcanolithic, abundant feldspar and 10% quartz, partly dolomitic, with minor interbeds of siltstone, carbonaceous shale, and coal laminae	30.5
Subgreywacke	15.2
Total	100.7

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Siltstone, dark grey; abundant illitic and chloritic clay; dispersed carbonaceous matter	50.3
Subgreywacke, volcanolithic, fine-grained, rare quartz; chlorite cement and minor calcite; dispersed carbonaceous matter	61.0
Claystone, dark grey; dispersed carbonaceous matter	30.5
Subgreywacke, volcanolithic, brown, fine-grained; grains subangular	27.4
Dolerite	39.6
Subgreywacke, volcanolithic, grey-brown, thinly bedded, 25% oligoclase but no quartz, interbedded with thinly bedded siltstone	85.4
Total	294.2

Between 1265 and 1359.4 m a sparse microfauna, dominated by arenaceous Foraminifera, occurs fairly regularly.

Kulnura No. 1
(Ozimic, 1969)

	Thickness (m)
Sandy siltstone, calcareous, carbonaceous, pyritic, and 6 m of altered amygdaloidal basalt	204.9

Numerous Foraminifera and ostracods have been found between 1152.3 and 1302.9 m; this interval is called the Kulnura Marine Tongue (Bowman, 1970).

Jerrys Plains No. 1
(Esso, 1969)

	Thickness (m)
Shale, light grey to yellow, slightly carbonaceous, interbedded with grey to yellow siltstone and white to grey fine well sorted quartz sandstone	18.3

Martindale No. 1A
(Nicholas, 1969)

	Thickness (m)
Subgreywacke, volcanolithic, pebbly in places, with intervals of carbonaceous claystone and siltstone	39.6
Altered igneous rock. Lower less altered half (syenite?) composed of potash feldspar, pyroxene, biotite, and chlorite	33.5
Total	73.1

Howes Swamp No. 1
(Esso, 1970)

	Thickness (m)
Siltstone, buff to white, with few thin interbeds of shale and light grey lithic sandstone	39.6
Shale, medium to dark grey	33.5
Shale interbedded with siltstone and fine sandstone	12.2
Siltstone with trace of carbonaceous material; clay and calcite cement; volcanogenic clasts	21.3
Silty shale with thin interbeds of sandstone	21.3
Siltstone, brown to grey, with interbeds of grey fine-grained moderately well sorted sandstone; clay and calcite cement	18.3
Total	146.2

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Sandstone, sideritic, very fine to medium-grained, with interbedded siltstone. Some thin coal in lower half and polymict pebble conglomerate near base	54.9

Mulgoa No. 2
(AOG, 1960)

	Thickness (m)
Sandstone, massive. siliceous, coarse-grained, grey; minor siltstone near base and top	27.5

Relations with Older Units

The upper part of the Wallis Creek Formation is a conformable sequence between the Rathluba Seam below and the Tomago Seam above. The upper part of the Vane Formation consists of a conformable sequence between the Pikes Gully Seam below and the Bayswater Seam above. The Coorongooba Sandstone rests conformably on the carbonate-bearing beds of the Mount Marsden Claystone, and the Erins Vale Formation lies conformably on the Fig Tree Seam or equivalent carbonaceous shale of the Pheasants Nest Formation.

Correlations and Age

The formations in Interval 8, except for the Mount Marsden Claystone, rest conformably on coal or carbonaceous shale of Interval 7; they all consist largely of sandstone, with coal absent or scarce, and some of them contain a siltstone member containing marine fossils.

Fossils have been found in only five localities:

1. In the Kulnura No. 1 well, throughout 151.9 m of the 204.9 m of Interval 8 (Crespin, 1938).

Foraminifera: *Nodosaria serocoldensis, Nodosinella* spp., *Frondicularia woodwardi, F. parri, Geinitzina* sp., *Ammodiscus milletianus, A. incertus, A. multicinctus, Hyperamminoides acicule, H.* spp., *Ammobaculites* sp., *Trochamminoides anceps,* and *Agathammina* sp.

Ostracoda: *Canellina kulmensis, Macrocypris* sp., *Bythocypris* sp., *Bairdia* sp., *Cavellina aequivalis,* and *Healdia* sp.

Crespin (1938) referred to the siltstone containing this microfauna as the Kulnura Stage. Its correlative in the Erins Vale Formation is now known as the Kulnura Marine Tongue (Bowman, 1970).

2. In the Dural South No. 1 well 94.5 m of the 294.3 m of Interval 8 form the Kulnura Marine Tongue. It contains *Frondicularia parri* and indeterminate fragments of arenaceous Foraminifera (Shell, 1966c). This species also occurs at the same horizon in the Dural East No. 1 and No. 2 wells (Crespin, 1957).

3. In Balmain No. 1 the following fossils were found (Raggatt & Crespin, 1941) in the interval from 1447.8 m to total depth at 1504.2 m:

Foraminifera: *Hyperamminoides* sp. and *Trochammina* sp.

Ostracoda: *Healdia* sp. and *Bairdia* sp.

Productid spines.

4. The brachiopod *Martiniopsis subradiata* mentioned by David (1907) from the Kulnura Marine Tongue occurs in the old Ironbark Brush bore in the lower Hunter Valley, between the Rathluba and Scotch Derry Seams.

5. In a marine band in the Erins Vale Formation *Strophalosia ovalis* has been identified (Bunny & Wood *in* Wass et al., 1969).

Crespin (1938) stated that the Kulnura ostracod fauna was typical of a horizon which occurs about the middle of the Permian in Western Australia. She considered the Foraminifera to resemble typical lower 'Upper Marine' faunas. Otherwise the fossils only indicate an Upper Permian age.

INTERVAL 9: FOUR MILE CREEK FORMATION AND CORRELATIVES

Four Mile Creek Formation

The type section of the Four Mile Creek Formation ('Four Mile Creek Beds' of David, 1907) is in the Electricity Commission's Wallis Creek DDH 10. It consists of interbedded shale, sandstone, mudstone, coal seams, and claystone. The coals include the Big Ben Seams, the Donaldsons Seam, and the Buttai Seams. The Tomago Coal Measures (David, 1950) conformably overlie the Mulbring Siltstone and are overlain conformably by the Newcastle Coal Measures.

Malabar Formation

The type section of the Malabar Formation (Britten, 1972) is in DM Doyles Creek DDH 11 from 370.8 to 602.9 m. It consists of interbedded sandstone and shale with several coal members which are split. Conglomerate wedges are present in the southwestern part of the Hunter Valley. The Althorpe Claystone Member is a useful marker bed of tuff. There are numerous intrusions in the lower part of the formation.

Mount Ogilvie Formation

The type section of the Mount Ogilvie Formation (Britten, 1972) is in DM Doyles Creek DDH 11 from 602.9 to 706.2 m. It consists of interbedded sandstone and shale with several consistent named coal members. A tuff bed forms a useful marker.

Burnamwood Formation

The type section of the Burnamwood Formation (Britten, 1972) is in DM Doyles Creek DDH 11 from 706.2 to 1064.7 m. It consists of interbedded sandstone and shale, with numerous coal seams. The prominent Mount Arthur Coal Member at the top of the formation is distinguished by the presence of a thick white chert-like claystone known as the Fairford Claystone Bed, which is rich in illite and contains traces of rootlets in places. The base of the formation is the distinctive dull Bayswater Seam.

Gundangaroo Formation

The Gundangaroo Formation (Goldbery, 1969) has its type section at Glen Alice. It consists of grey shale, carbonaceous shale with several thin coal seams, and fossil wood horizons.

Lower part of Wilton Formation

The type section of the Wilton Formation (Anon, 1969) is in the DM Wollongong 35 bore. The lower part consists of about 1.2 m of conglomeratic and festoon cross-bedded sandstone, overlain by the Woonona Coal Member, which consists of 3 m of coal, shale, and tuff (Bowman, 1970). The upper part consists of dark grey shale with sandstone lenses.

Interval 9 in the Deep Wells

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Lithic sandstone, which becomes volcanolithic downwards, with thin coal layers	27.5
Subgreywacke, volcanolithic, interbedded with carbonaceous siltstone and a little coaly mudstone, coal laminae, and seams which are thicker below 1113 m	57.9
Subgreywacke, volcanolithic, rare quartz, interbedded with carbonaceous siltstone. Perhaps as many as 9 coal seams. Minor illitic claystone	57.9
Total	143.3

Woronora No. 1
(Alock, 1968b)

	Thickness (m)
Shale, carbonaceous, interbedded with minor volcanolithic subgreywacke containing grey siltstone clasts. Coal plies common	61.0
Siltstone, grey, with minor interbeds of subgreywacke and carbonaceous shale. Several prominent coal seams. White clay, formed from weathered volcanic ash, from 930.2 to 933.3 m	61.0
Shale, carbonaceous	27.5
Shale, carbonaceous, interbedded with subgreywacke and minor siltstone. Several prominent coal seams	39.6
Total	189.1

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Two coal seams at top interbedded with grey siltstone, followed downwards by thickly bedded siltstone interbedded with thin subgreywacke	61.0
Siltstone, grading into claystone in places, with thin interbeds of very fine-grained sandstone. Abundant clasts of volcanic rock; carbonaceous matter. Chlorite, siderite, and calcite cement	50.3
Subgreywacke, grey-brown, thickly bedded, medium-grained; pebble horizons, rare quartz, abundant volcanic clasts; abundant siderite, calcite, and carbonaceous matter. 2 coal seams near 1205 m	51.8
Total	163.1

Kulnura No. 1
(Ozimic, 1969)

	Thickness (m)
Siltstone, micaceous, sandy and carbonaceous, interbedded with volcanolithic sandstone. Numerous coal laminae and probably 3 coal seams	36.6

Martindale No. 1
(Nicholas, 1969)

	Thickness (m)
Subgreywacke with sideritic and carbonaceous claystone and siltstone. 4 coal seams	57.9
Subgreywacke, volcanolithic; intermediate to mafic volcanic rocks at 4 horizons between 384.3 and 405.7 m and 2 more near base. 2 coal seams at base, with carbonaceous shale	76.2
Total	134.1

Howes Swamp No. 1
(Esso, 1970)

	Thickness (m)
Coal	12.2
Shale, dark grey, interbedded with dark grey siltstone and light grey lithic pebbly sandstone with clay cement	27.4
Coal, dull black, with minor interbeds of shale and siltstone	18.3
Shale, dark grey, interbedded with carbonaceous siltstone and light grey sandstone; minor thin coal seams	54.9
Coal, bright and dull, interbedded with carbonaceous shale and a little conglomeratic lithic sandstone	21.3
Shale, grey, interbedded with grey to carbonaceous siltstone and lithic sandstone	51.9
Coal interbedded with grey and carbonaceous shale and lithic sandstone	21.3
Shale interlaminated with carbonaceous siltstone and light grey to buff lithic sandstone	45.7
Sandstone, lithic, buff, interbedded with carbonaceous silty shale and minor coal seams	27.4
Sandstone, conglomeratic, probably unconsolidated, poorly sorted, with carbonaceous silty shale	30.5
Shale, carbonaceous, interbedded with carbonaceous siltstone; minor light grey sandstone; lignitic coal seams between 1387 and 1393 m	137.2
Coal, black and shiny, or dull and woody, interbedded with shale and siltstone	30.5
Total	478.6

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Subgreywacke and arkose, sideritic and clayey, interbedded with calcareous and carbonaceous mudstone and sandy siltstone. About 10 well spaced coal seams, and several conglomerate layers near base	103.7

Mulgoa No. 2
(AOG, 1960)

	Thickness (m)
Shale with minor siltstone and thin coal seam at top	76.0
Siltstone and sandstone with minor shale and thin coal seam at bottom	33.6
Total	109.6

Relations with Older Units

All the stratigraphic units in Interval 9 are conformable on the units of Interval 8 beneath them.

Correlations and Age

The units of Interval 9 contain abundant coal and carbonaceous shale, and rest on units of Interval 8 which are, in contrast, characteristically arenaceous and poor in carbonaceous matter.

The presence of *Glossopteris* and *Vertebraria* in the Tomago Coal Measures indicates that they are of Upper Permian age; the *Dulhuntyispora* Assemblage indicates a Tatarian age.

INTERVAL 10: WARATAH SANDSTONE AND DEMPSEY FORMATION AND CORRELATIVES

Waratah Sandstone

The type section of the Waratah Sandstone (David, 1907) is in BHP Eleebana No. 1 bore in Kahibah, a suburb of Newcastle, where it consists of 18 m of massive sandstone. The sandstone is the basal unit of the Newcastle Coal Measures (see Interval 11).

Dempsey Formation

The type section for the Dempsey Formation ('Dempsey Island Measures' of David, 1907) is in the Buttai Syndicate's Buttai bore in the Thornton-Maitland area. It consists of interbedded shale and sandstone, with a few thin coal seams and some claystone. The lower half of the formation consists chiefly of shale, while sandstone predominates in the upper half. Britten (1972) considers that part of the formation is marine.

Watts Sandstone

The type section of the Watts Sandstone (Britten, 1972) is in DM Doyles Creek DDH 11, southwest of Singleton. It consists of about 25 m of massive sandstone with traces of coal.

Denman Formation

The type section of the Denman Formation (Britten, 1972) is in DM Doyles Creek DDH 11 from 342.3 to 370.8 m. It consists of dark grey striped laminite shale, sometimes referred to as the 'zebra shale'. The sequence contains abundant worm burrows throughout, and is considered by Britten to be marine.

Marrangaroo Conglomerate

The type area of the Marrangaroo Conglomerate (Stephens, 1883) is at Marrangaroo. It consists of coarse quartz conglomerate and coarse labile sandstone. The clasts consist of fine-grained unweathered material from the Lower

Permian marine strata (see Appendix 2), feldspar, quartz, and granite. Fossil leaves and wood are abundant. The sequence is conglomeratic toward the edge of the basin, but in the middle it passes into massive sandstone.

Higgins Creek Conglomerate

The type area of the Higgins Creek Conglomerate (McElroy & Relph, 1961) is near the junction of the Nattai and Wollondilly Rivers. The formation consists of coarse sandstone, with conglomerate lenses near the base. The pebbles consist of quartz, quartzite, porphyry, and rarely slate; they are commonly 5 to 7.5 cm across, but range up to 25 cm.

Upper part of the Wilton Formation

The type section of the Wilton Formation (Anon, 1969) is in the DM Wollongong 35 bore. The upper part consists of 30 m of grey claystone and siltstone laminite with interbeds of light grey fine-grained sandstone.

Interval 10 in the Deep Wells

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Subgreywacke, pebbly, and oligomict conglomerate with some sandy siltstone and coaly mudstone	16.7
Lithic to sandy siltstone with a little coal	44.2
Total	60.9

Woronora No. 1
(Alcock, 1969b)

	Thickness (m)
Siltstone, laminated, grading down into grey shale with interbeds of mudstone and quartz greywacke	61.0
Sandy siltstone, grading into very fine greywacke containing abundant plagioclase and fragment of volcanic rock, with thin interbeds of quartz greywacke and friable protoquartzite	30.5
Mudstone, shale, siltstone, sandy siltstone, and interbedded subgreywacke, in part calcareous; abundant clasts of plagioclase and volcanic rock	30.5
Total	122.0

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Subgreywacke, brownish grey, fine-grained, moderately well sorted; grains subangular to subrounded. Clasts of volcanic glass and pockets of fibrous zeolite. Carbonaceous in part, with coaly laminae	33.5
Claystone, light grey to white, illitic; contains cryptocrystalline silica	1.5
Sandy siltstone, grey, with thin layers of subgreywacke near base	41.2
Total	76.2

Kulnura No. 1
(Ozimic, 1969)

	Thickness (m)
Subgreywacke interbedded with minor carbonaceous siltstone	30.5
Siltstone interbedded with minor subgreywacke	15.2
Subgreywacke, poorly sorted, micaceous, carbonaceous, with numerous clasts of volcanic rock, interbedded with minor sandy siltstone	39.5
Total	85.2

Martindale No. 1A
(Nicholas, 1969)

	Thickness (m)
Siltstone, carbonaceous, grading into fine-grained sandstone	19.8
Claystone, grey and white, with thin layers of volcanic rock	7.6
Shale, carbonaceous, with siltstone and thin layers of coal	12.2
Subgreywacke, volcanogenic, with a few thin interbeds of carbonaceous pyritic siltstone	33.6
Siltstone, carbonaceous, grading in places into sandstone and pyritic carbonaceous shale	24.4
Total	97.6

Howes Swamp No. 1
(Esso, 1970)

	Thickness (m)
Lithic sandstone, buff to grey, very fine to medium-grained, poorly sorted, interbedded with light to dark grey siltstone, speckled with carbonaceous material, and dark grey to light brown partly carbonaceous shale	33.5
Siltstone interbedded with shale	24.4
Sandstone interbedded with silty shale and 2 thin coal seams, overlying conglomeratic sandstone with thin interbeds of silty shale	48.8
Shale interbedded with siltstone, grading into very fine-grained sandstone, and lithic sandstone	39.6
Total	146.3

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Mudstone, carbonaceous, thinly interbedded with siltstone and fine-grained subgreywacke. In bottom 60 m subgreywacke predominant. Some thin claystone layers of tuffaceous origin. Carbonized plant fragments. Green mineral in middle of sequence may be glauconite	137.5

Mulgoa No. 2
(AOG, 1960)

	Thickness (m)
Sandstone grading down into siltstone and shale*	15.2
Shale with few thin layers of siltstone in middle	61.0
Siltstone grading down into shale	30.5
Total	106.7

* Correlative of this interval in nearby Mulgoa No. 1 contains numerous Foraminifera (Crespin, 1936).

Relations with Older Units

The Dempsey Formation conformably overlies the Upper Buttai Seam at the top of the Four Mile Creek Formation. The Denman Formation rests conformably on the Whybrow Coal Member of the Wittingham Coal Measures Group.

The Marrangaroo Conglomerate rests disconformably on the marine Shoalhaven Group or unconformably on middle Palaeozoic rocks of the Lachlan Fold Belt.

The Higgins Creek Conglomerate rests conformably on coaly sediments of the Gundangaroo Formation of Interval 9 or disconformably on marine silty sandstone of the Berry Formation of Interval 6.

Correlations and Age

Interval 10 is a characteristically barren sequence of siltstone and sandstone lying conformably on the coal-rich Interval 9.

In the Mulgoa No. 1 well Interval 10 contains the following Foraminifera (Crespin, 1937): *Haplophragmoides* spp., *Trochammina* sp., *Trochamminoides* sp., *Reophax* sp., *Hyperamminoides* sp., cf. *Ammodiscus,* cf. *Ammobaculites,* and *Ruditaxis* sp.

This microfauna does not fix the age of Interval 10, but it does show that the sea extended for a time as far west as Mulgoa. Thus Interval 10 contains an unnamed marine tongue similar to the Kulnura Marine Tongue of Interval 8.

INTERVAL 11: NEWCASTLE COAL MEASURES (EXCLUDING WARATAH SANDSTONE) AND CORRELATIVES

Newcastle Coal Measures (excluding Waratah Sandstone)

The type area of the Newcastle Coal Measures (Hector, 1880) is the lower Hunter Valley, centred on the city of Newcastle. The group consists of sandstone, conglomerate, siltstone, shale, carbonaceous shale, coal, and tuff. The basal formation (Waratah Sandstone) is included in Interval 10.

The irregular lenticular sheets of conglomerate are up to 200 km^2 in area, and there are commonly several lenses on the one stratigraphic horizon. The sheets appear to be alluvial fans, and are up to 85 m thick. Most of the pebbles consist of chert and quartzite, but they also include igneous and pyroclastic rocks, sandstone, and coal. They are commonly rounded and less than 3 cm across, but range up to 15 cm.

The sandstone beds are more continuous than the conglomerates, and sheets of limited extent, apparently of fluvial origin, have been delineated.

The most uniform of the clastic rocks are the tuff beds, which can be traced over considerable distances. The tuffs have been largely altered to clay.

The coal seams are identifiable over most of the Newcastle coal district, but splitting and coalescing are common, and many of the seams contain interbeds of shale and tuff.

The following units have been defined in the lower Hunter Valley (from top to bottom):

Moon Island Beach Sub-Group
(McKenzie, 1962)

	Thickness (m)
Coal interbedded with tuff and shale (Wallarah Seam; David, 1907)	17
Conglomerate and minor shale	19
Tuff (including Awaba Tuff Member, 15 m) interbedded with coal (Great Northern Seam; McKenzie, 1962)	20
Conglomerate with minor shale and tuff (Eleebana Formation; McKenzie, 1962)	17
Coal with shale (Fassifern Seam; David, 1907)	8
Total	81

Boolaroo Sub-Group
(McKenzie, 1962)

	Thickness (m)
Conglomerate (Belmont Conglomerate Member) with minor sandstone and shale (Croudace Bay Formation; McKenzie, 1962)	26
Sandstone, tuffaceous, and coal (Upper Pilot Seam; David, 1907)	8
Sandstone with minor tuff (Reids Mistake Formation; McKenzie, 1962)	12
Coal interbedded with tuffaceous shale (Lower Pilot Seam; David, 1907)	9
Siltstone, sandy (Warners Bay Formation; McKenzie, 1962)	6
Coal and tuff (Hartley Hill Seam; Jones, 1939)	5
Sandstone, silty, with shale at base (Mount Hutton Formation; McKenzie, 1962)	27
Total	93

Adamstown Sub-Group
(McKenzie, 1962)

	Thickness (m)
Tuff, coal, and shale (Australasian Seam; David, 1907)	11
Conglomerate (Charlestown Conglomerate Member) with minor sandstone (Tickhole Formation; McKenzie, 1962)	44
Tuff and coal (Montrose Seam; Jones, 1939)	8
Shale, conglomerate, and sandstone (Kahibah Formation; McKenzie, 1962)	9
Tuff, conglomerate, sandstone, coal, and shale (Fern Valley Seam; Jones, 1939)	26
Conglomerate (Merewether Conglomerate Member), sandstone, shale, and tuff (Kotara Formation; McKenzie, 1962)	17
Total	115

Lambton Sub-Group
(McKenzie, 1962)

	Thickness (m)
Coal with minor shale and tuff (Victoria Tunnel Seam; McKenzie, 1962)	11
Shale interbedded with sandstone (Shepherds Hill Formation, McKenzie, 1962)	8
Tuff (Nobbys Tuff Member) with minor coal (Nobbys Seam; McKenzie, 1962)	6
Conglomerate, sandstone, and shale (Bar Beach Formation, McKenzie, 1962)	8
Shale, coal, and minor sandstone (Dudley Seam; Jones, 1939)	6

Conglomerate, sandstone, and minor shale (Bogey Hole Formation; McKenzie, 1962)	9
Shale with coal (Yard Seam; McKenzie, 1962)	9
Conglomerate and sandstone (Tighes Hill Formation; McKenzie, 1962)	6
Coal and sandstone (Borehole Seam; McKenzie, 1962)	6
Total	69

Wollombi Coal Measures (excluding Watts Sandstone)

The type section of the Wollombi Coal Measures (Britten, 1972) is in Doyles Creek DDH 11 from 69.8 to 316.9 m. The main subdivisions of the coal measures are correlated with those in the Newcastle Coal Measures. The basal formation (the Watts Sandstone) is included in Interval 10. The following units have been defined in the middle Hunter Valley (from top to bottom):

Glengallic Sub-Group
(Britten, 1972)

	Thickness (m)
Coal and mudstone (Greigs Creek Seam; Booker, 1953)	1
Conglomerate and sandstone (Redmanvale Creek Formation; Britten, 1972)	21
Coal with minor bands of siltstone (Hillsdale Seam; Britten, 1972)	3
Tuff with minor shale (Nalleen tuff; Britten, 1972)	5
Coal, tuff, and siltstone (Hobden Gully Seam; Britten, 1972)	23
Total	53

Doyles Creek Sub-Group
(Britten, 1972)

	Thickness (m)
Shale and tuff (Waterfall Gully Formation; Britten, 1972)	14
Tuff, sandstone, shale, siltstone, and minor coal (Pinegrove Formation; Britten, 1972)	45
Total	59

Horseshoe Creek Sub-Group
(Britten, 1972)

	Thickness (m)
Coal and shale with minor tuffaceous sandstone and siltstone (Lucernia Seam; Britten, 1972)	18
Shale and interbedded sandstone with minor tuffaceous claystone (Strathmore Formation; Britten, 1972)	20
Coal with minor siltstone and sandstone (Alcheringa Seam; Britten, 1972)	24
Sandstone with subordinate shale and minor tuff and coal (Clifford Formation; Britten, 1972)	61
Total	123

Apple Tree Flat Sub-Group
(Britten, 1972)

	Thickness (m)
Shale, carbonaceous, and coal (Stafford Seam; Britten, 1972)	3
Tuff (Monkey Place Creek Tuff Member) with sandstone and shale (Charlton Formation; Britten, 1972)	17
Shale, carbonaceous, and coal (Abbey Green Seam; Britten, 1972)	8
Total	28

These four sub-groups have been correlated (Britten, 1972) with the four sub-groups of the lower Hunter Valley.

Charbon Sub-Group (excluding the Marrangaroo Conglomerate)

The type section of the Charbon Sub-Group (Goldbery, 1969) is at Wolgan Gap, northeast of Wallerawang in the Western Coalfield. It consists of interbedded sandstone, shale, conglomerate, and coal seams. This sub-group is the Lithgow Coal Measures of David & Stonier (1891), that is, it comprises those units between the base of the Marrangaroo Conglomerate and the base of the Narrabeen Group. The Marrangaroo Conglomerate is included in Interval 10. The following units have been described (Branagan, 1969a; Anon., 1969) in the Western Coalfield:

	Thickness (m) min. max.
Coal (Katoomba Seam; Carne, 1903)	0.3– 2.4
Shale, 'chert', and sandstone	7.6– 12.2
Coal and shale (Woodford Seam; McElroy, 1957)	0.3– 1.2
Claystone or 'chert' (Burragorang Claystone)	0.0– 6.0
Shale, 'chert', and sandstone	6.0– 9.0
Carbonaceous shale, coal, 'chert', and oilshale (Middle River or Dirty Seam; Bryan et al., 1966)	2.0– 13.0
Shale, carbonaceous shale, 'chert', sandstone, and ironstone	2.0– 92.0
Sandstone, massive, quartzose (Ivanhoe or 'Vertebraria' Sandstone; Rayner, 1955)	0.3– 2.0
Coal and carbonaceous shale (Irondale Seam; Branagan, 1969a)	0.6– 3.0
Shale	0.3– 1.5
Sandstone, micaceous, silty, flaggy (Bunnyong Sandstone; Rayner, 1955)	1.0– 3.5
Shale, siltstone, shaly sandstone, and ironstone	12.0– 31.0
Coal (Lidsdale Seam; Branagan, 1969a)	0.5– 2.0
Conglomerate and coarse quartz sandstone (Blackmans Flat Conglomerate; Rayner, 1954)	0.5– 22.0
Coal and carbonaceous shale (Lithgow Seam; Carne, 1903)	0.5– 4.0
Sand and shale laminite	0.0– 1.0
Total	33.9–205.8

The following units have been described (Whiting & Relph, 1969; Anon., 1969) in the Southwestern Coalfield:

	Thickness (m) min. max.
Coal (Nattai Seam; McElroy & Relph, 1961)	0.5– 3.0
Lithic sandstone, feldspathic, and minor shale	0.0– 15.0
Carbonaceous shale and coal (Gillans Creek Seam; McElroy & Relph, 1961)	0.0– 1.0
Claystone, cherty, in places sandy and sideritic (Burragorang Claystone; McElroy & Relph, 1961)	3.0– 12.0

Shale, sandstone, and 'chert'	0.0– 22.0
Coal, shale, siltstone, sandstone, and tuff (Bend Creek Seam; Whiting & Relph, 1969)	6.0– 19.0
Sandstone with medium-sized grains of chert and quartzite and numerous thin layers of shale (Colemans Creek Formation; McElroy & Relph, 1961)	3.0– 16.0
Shale, carbonaceous, with minor coal (Bimlow Seam; Whiting & Relph, 1969)	0.0– 2.0
Shale and sandstone	15.0– 30.0
Sandstone, fine, labile, in places slightly conglomeratic (Lacys Creek Sandstone; McElroy & Relph, 1961). 3 m of carbonaceous shale, coal, and shaly sandstone in middle	1.0– 9.0
Shale, carbonaceous, with siltstone and coal (Brimstone Seam; Whiting & Relph, 1969)	0.0– 2.5
Shale and sandstone	9.0– 30.0
Coal and carbonaceous shale (Kooloo Seam; Whiting & Relph, 1969)	0.0– 2.5
Total	37.5–164.0

Illawarra Coal Measures above the Wilton Formation

The type area of the Illawarra Coal Measures (Clarke, 1866) is the Illawarra escarpment west of Wollongong. The sequence consists of sandstone, conglomerate, siltstone, shale, coal, and tuff, which rests conformably on the Berry Formation and is overlain by the Narrabeen Group. The beds included in Interval 11 are as follows, from top to bottom:

	Thickness (m) min. max.
Coal with minor shale (Bulli Seam; Wilkinson, 1872)	1.0– 5.0
Sandstone, light grey, medium-grained, massive, overlain by 3 m of dark grey shale	4.5– 9.5
Coal (Balgownie Seam; Hanlon, 1956)	0.2– 2.4
Sandstone, medium, massive, overlain by shale (Lawrence Sandstone; Hanlon, 1956)	3.0– 14.0
Shale, carbonaceous, and minor coal (Cape Horn Seam; Hanlon, 1956)	0.0– 1.2
Shale, dark grey, and sandstone	1.0– 3.0
Shale, carbonaceous, and minor coal (Hargrave Seam; Hanlon, 1956)	0.0– 0.5
Sandstone and shale	0.0– 6.0
Shale, carbonaceous, and minor coal and sandstone (Woronora Seam; Anon., 1969)	10.0– 12.0
Sandstone, fine to medium-grained, quartzose, and minor conglomerate (Novice Sandstone; Anon., 1969: Novice Sandstone up to Balgownie Seam inclusive constitutes the Eckersley Formation)	0.0– 37.0
Coal, carbonaceous shale, and tuffaceous shale; cream-coloured tuff, known as 'the Sandstone Band' in middle (Wongawilli Seam; Hanlon, 1956)	8.0– 12.0
Sandstone, pale grey, medium-grained, labile, with minor conglomerate, shale, siltstone, and coal lenticles near base (Kembla Sandstone; Hanlon, 1956)	12.0– 24.0
Shale, carbonaceous, coal, and oil shale (America Creek Seam; Hanlon, 1956)	2.0– 4.0
Sandstone, quartzose, with siltstone interbeds; minor carbonaceous shale, coal, and oil shale (Allans Creek Formation; Anon., 1969)	6.0– 45.0
Sandstone, grey, fine-grained, labile, with carbonaceous specks (Darkes Forest Sandstone; Bowman, 1970)	9.0– 24.0
Shale, dark grey, and minor siltstone (Bargo Claystone; Bowman, 1970)	14.0– 28.0
Sandstone, grey, fine, labile; weathers to white clay (Austinmer Sandstone; Bowman, 1970)	1.0– 6.0
Coal, shale, and sandstone (Tongarra Seam; Harper, 1915)	1.0– 6.0
Total	72.7–239.6

Interval 11 in the Deep Wells

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Coal, bituminous, overlying carbonaceous mudstone with thin interbeds of sideritic subgreywacke	26.2
Subgreywacke, fine-grained, with numerous coal seams, some over a metre thick, and carbonaceous mudstone	97.6
Siltstone	36.6
Conglomerate, sandy siltstone, subgreywacke, carbonaceous mudstone, and bituminous coal	10.6
Siltstone, slightly sandy, montmorillonitic, black, with some silty sandstone, carbonaceous mudstone, and coal at base	62.5
Total	233.5

Woronora No. 1
(Alcock, 1968b)

	Thickness (m)
Shale, carbonaceous, and coal seams overlying interbedded shale and siltstone with a few beds of lithic sandstone	30.5
Shale, in part carbonaceous, interbedded with pale and dark grey siltstone and subgreywacke containing clasts of sedimentary and volcanic rocks	61.0
Shale, in part carbonaceous, with interbeds of siltstone and fine-grained protoquartzite. Several thin coal seams. Thin andesitic layers at 656 and 695 m	122.0
Total	213.5

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Subgreywacke, grey-brown, medium to coarse-grained, moderately well sorted; grains subangular to subrounded; contains volcanogenic clasts. Very thin beds of carbonaceous siltstone and 4 or 5 coal seams	51.8
Subgreywacke	33.5
Siltstone, carbonaceous, sandy, with thin beds of subgreywacke and 4 or 5 coal seams	33.5
Siltstone, grey, sandy, alternating with thin-bedded sandstone. 3 coal seams interbedded with illitic claystone at base	39.6
Total	158.4

Kulnura No. 1
(Ozimic, 1969)

	Thickness (m)
Sandstone, labile, moderately well sorted, calcite-cemented, with clasts of volcanic rock, quartz, and chert, interbedded with sandy micaceous siltstone and 4 coal seams	39.6
Subgreywacke, carbonaceous, with siliceous claystone near base	42.7
Sandstone, as above, interbedded with subsidiary siltstone and probably 6 coal seams. Basal coal seam overlain by siliceous claystone (illite 45%, silica 40%) 45 m thick	70.1
Total	152.4

Martindale No. 1A
(Nicholas, 1969)

	Thickness (m)
Shale, dark grey, interbedded with labile sandstone; volcanogenic subgreywacke; carbonaceous streaks; carbonate cement throughout	30.5
Mafic igneous rock with abundant chlorite, some hornblende, biotite, and altered olivine	51.8
Subgreywacke, volcanogenic	18.3
Shale, dark grey, carbonaceous	39.6
Coal and grey carbonaceous shale overlying sandy conglomerate containing black, green, and grey chert	11.0
Siltstone, carbonaceous, sideritic, and coal laminae	9.0
Claystone, pale grey and white	9.0
Shale, carbonaceous, with very thin layers of protoquartzite and probably 6 coal seams	33.5
Total	200.7

Howes Swamp No. 1
(Esso, 1970)

	Thickness (m)
Coal, black, slightly fluorescent with strong odour, interbedded with grey medium-grained sandstone	9.1
Sandstone, quartzose, lithic, very fine to medium-grained, unconsolidated, poorly sorted; green, grey, and orange clasts	27.4
Siltstone, light brown, and sub-bituminous coal with calcite veins	14.6
Sandstone, labile, grey, unconsolidated, very fine to medium-grained, poorly sorted, grains angular to subrounded, green, yellow, and orange clasts, with grey siltstone and several sub-bituminous coal seams	46.3
Sandstone, lithic, buff, fine to medium-grained, mainly unconsolidated, moderately well sorted, with several seams of black and brown coal and very minor shale and siltstone	54.9
Total	152.3

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Sandstone, labile, fine to medium-grained, sideritic, interbedded with carbonaceous mudstone, siltstone, tuff, and coal	65.5
Similar to above, but with a higher proportion of mudstone, siltstone, tuff, and coal	97.5
Total	163.0

Mulgoa No. 2
(AOG, 1960)

	Thickness (m)
Sandstone, siltstone, and coal	24.4
Sandstone grading down into siltstone and shale	61.0
Coal and shale	21.3
Total	106.7

Relations with Older Units

Interval 11 is conformable on Interval 10. In the Pokolbin district on the Lochinvar Anticline a thin sequence of the Newcastle Coal Measures rests unconformably on the Mulbring Siltstone. The unconformity can be related to uplift of the anticline in Tomago Coal Measure time.

Correlations and Age

The coal measures in Interval 11 are correlated because they all lie conformably on the barren measures of Interval II and are overlain by the Narrabeen Group.

Many plant fossils have been found in Interval 11. Wilson (1969) lists the following plants: *Glossopteris browniana, G. indica, G. ampla, G. communis, G. verticillata, G. angustifolia* var. *taeniopteroides, G. conspicua, G. tortuosa, G. spathulato cordata, G. jonesii, G. stipanicicci, G. linearis, G. intermittens,* and *Gangamopteris obovata.* Interval 11 also contains *Phyllotheca australis, Annularia, Vertebraria, Sphenopteris,* and *Dadoxylon.* Stumps of *Dadoxylon* in position of growth are common in the Newcastle area.

The Belmont Chert, about 20 m below the Fassifern Seam, contains abundant fossil insects. They belong mainly to the order *Mecoptera* and include several sub-orders of primitive insects. They are invariably associated with *Leaia* and *Estheria.* Fish scales are abundant, and there is one specimen of *Limulus.*

The microflora belongs to unit P4 of the *Dulhuntyispora* Assemblage Zone (Evans, 1967a,b) of Tatarian age.

INTERVAL 12: NARRABEEN GROUP

The Narrabeen Group (Hanlon et al., 1953) consists of claystone, shale, tuffaceous shale, sandstone, and conglomerate. The sequence is conformable on the Bulli Seam and its correlatives, and is overlain by the Hawkesbury Sandstone. The lower beds (see Fig. 44) are of Permian age, but the bulk of the group is Triassic.

The Narrabeen Group includes a number of formations, and a separate nomenclature has been applied to these in each of three areas—the mid-central, south-central, and western areas (Fig. 43).

MID-CENTRAL AREA

Clifton Sub-Group

Hanlon et al. (1953) divided the Narrabeen Group into the Clifton Sub-Group (the 'Lower' and 'Middle Stages' of earlier writers) and the Gosford Formation (the 'Upper Stage' of earlier writers). The Clifton Sub-Group consists of the Munmorah and Tuggerah Formations and the Patonga Claystone.

Munmorah Formation

The type section of the Munmorah Formation (Hanlon et al., 1953) is the Wyong bore (Dep. Min., 1882) from 83.5 to 240 m. The section consists of conglomerate interbedded with varicoloured shale and sandstone.

	Thickness (m)
Conglomerate with jasper pebbles	2.3
Shale, blue and red, with thin beds of conglomerate	5.0
Conglomerate, brown and grey, fine-grained	4.1
Shale, green and grey, with *Phyllotheca*	3.9
Conglomerate, containing jasper pebbles, with some green and blue shale and sandstone	21.0
Conglomerate, containing jasper pebbles, with 3 beds of greenish shale and minor sandstone	24.9
Shale, green	3.6
Conglomerate and green shale	16.7
Shale, green, and sandstone	6.4
Conglomerate, coarse-grained	2.6
Sandstone, greenish, green and red shale, and fine and coarse-grained conglomerate with jasper pebbles	10.2
Shale, red, green, and blue	9.4
Conglomerate with jasper pebbles	14.9
Shale, green, red, and brown	11.8
Conglomerate, fine and coarse-grained, with beds of dark shale	12.2
Sandstone and shale	8.2
Total	157.2

Tuggerah Formation

The type section of the Tuggerah Formation (Hanlon et al., 1953) is in Windeyers Hawkesbury River bore from 373.2 to 471.9 m. It consists chiefly of interbedded shale and sandstone.

	Thickness (m)
Sandstone	6.6
Sandstone and conglomerate	16.9
Sandstone, conglomerate, and grey shale	4.3
Sandstone	6.2
Sandstone and shale	2.2
Shale, chocolate	1.5
Sandstone, shaly	3.2
Sandstone	2.3
Shale, chocolate and grey	6.1
Shale, chocolate	1.2
Shale, grey	1.8
Sandstone	3.4
Sandstone, shale, and conglomerate	2.1
Sandstone and conglomerate	0.9
Shale, chocolate	4.1
Sandstone, shaly	0.2
Sandstone	2.1
Sandstone, shaly	0.3
Conglomerate, fine-grained	11.7
Shale, grey, and sandstone	1.8
Shale, chocolate	1.1
Shale, chocolate and grey	0.4
Sandstone, shaly	0.9
Sandstone	1.8
Conglomerate, fine-grained	2.0
Shale, chocolate and grey	11.7
Shale, grey	0.7

Shale, chocolate	0.6
Shale, grey	0.5
Total	98.6

Patonga Claystone

The type section of the Patonga Claystone (Stuntz *in* McElroy, 1969b) is the Windeyers Hawkesbury River bore (Culey, 1910) from 236.7 to 373.2 m. The name replaced Collaroy Claystone by which it was formerly known (Hanlon et al., 1952) when it was found that the section was not a correlative of the claystone at Collaroy.

	Thickness (m)
Shale, chocolate and grey	7.9
Shale, chocolate	3.8
Shale, grey	0.6
Shale and sandstone	1.7
Sandstone	1.5
Shale, chocolate	17.7
Shale, chocolate, and sandstone	0.9
Shale, chocolate	2.1
Shale, grey, and sandstone	3.0
Sandstone	3.8
Shale, soft, grey	0.5
Shale, chocolate	4.0
Shale, chocolate, and sandstone	2.2
Shale, chocolate	15.2
Shale, grey	0.3
Shale, chocolate	4.0
Sandstone, fine	0.6
Shale, chocolate	7.1
Sandstone	5.6
Shale, chocolate	3.8
Shale, chocolate and grey	2.7
Shale, grey, and sandstone	1.4
Sandstone	3.1
Shale, chocolate and grey	10.8
Shale, chocolate	0.3
Shale, grey	1.1
Sandstone	3.1
Shale, chocolate and grey	4.3
Sandstone	0.5
Shale, grey	3.0
Sandstone	4.5
Shale, chocolate	1.4
Shale, grey, and sandstone	4.6
Sandstone	3.1
Shale and sandstone	0.9
Sandstone	2.9
Shale, chocolate and grey, and sandstone	3.1
Total	137.1

Gosford Formation

The type section of the Gosford Formation (Hanlon et al., 1953) is the Windeyers Hawkesbury River bore from 65.4 to 236.5 m. It consists of interbedded grey shale and quartz sandstone. Raggatt (1938) named the Wyong Sandstone, Ourimbah Sandstone, and Mangrove Sandstone Members at Wyong, but at Terrigal McDonnell (1969) described eight major sand units, from 12 to 45 m thick, separated by silty units averaging 12 m thick. The lithology varies greatly within each unit, but fine to medium-grained quartz and lithic sandstone predominate in the sand units, together with thin conglomerates and coarse-grained quartz sandstones, whilst the silty units consist of laminated siltstone, claystone, silicified siltstone, and carbonaceous shale. Many of the silicified siltstones are packed with worm burrows. Root zones are also present. Numerous bodies of massive cross-bedded lenticular sand cut into the flat-bedded siltstones. The base of each sandstone bed is irregular owing to the presence of scour-and-fill structures. Ripple marks, trough cross-bedding, concretions, and slump structures are well developed, and near Kilcare a conglomerate-sand-silt-sand point-bar sequence is repeated three times in a vertical section of 8 m.

The following is the type section:

	Thickness (m)
Sandstone, shaly	0.8
Shale	0.9
Sandstone, shaly	5.2
Sandstone, shaly, broken	4.0
Sandstone and shale	4.3
Sandstone	3.5
Sandstone, shaly	1.1
Shale	0.7
Sandstone, shaly	0.7
Sandstone	3.1
Sandstone, shaly	0.2
Shale, chocolate	5.4
Sandstone, shaly	1.8
Shale	1.1
Shale and sandstone	1.7
Sandstone	1.1
Sandstone, shaly	0.7
Chert	0.2
Sandstone, shaly	0.2
Shale	0.2
Sandstone, shaly	0.4
Shale, chocolate	1.5
Sandstone and shale	3.7
Sandstone (Mangrove Sandstone Member)	6.7
Sandstone, shale and conglomerate	3.7
Sandstone and conglomerate	3.7
Sandstone, shaly	3.7
Shale, chocolate	1.7
Sandstone, shaly	6.6
Sandstone and shale	7.6
Sandstone	3.9
Sandstone, shaly	4.0
Sandstone	5.1
Sandstone, shaly, with sandstone layers	3.1
Shale	0.2
Sandstone, shaly, with sandstone layers	4.8
Sandstone	1.2
Shale, grey	3.2
Sandstone, fine, grey (Ourimbah Sandstone Member)	12.1
Shale and sandstone	0.5
Sandstone	6.9

Sandstone, shaly	0.9
Shale	1.4
Shale and sandstone	10.1
Sandstone, grey (Wyong Sandstone Member)	1.8
Sandstone (Wyong Sandstone Member)	2.6
Conglomerate (Wyong Sandstone Member)	0.3
Sandstone (Wyong Sandstone Member)	9.3
Shale, sandstone, and conglomerate	1.3
Conglomerate	0.2
Sandstone, shaly, hard	3.4
Sandstone, shaly, with sandstone layers	3.7
Sandstone	3.8
Sandstone, shaly, with sandstone layers	3.8
Shale, grey	1.9
Shale and sandstone	3.1
Sandstone	2.2
Total	171.0

Interval 12 in the Deep Wells

Kulnura No. 1
(Ozimic, 1969)

Gosford Formation

	Thickness (m)
Siltstone, sideritic	12.2
Sandstone, fine-grained, labile	9.6
Siltstone, sideritic	27.5
Sandstone (75%), fine-grained, labile, interbedded with sideritic siltstone (25%)	57.2
Sandstone, medium-grained, labile, poorly cemented; scattered quartz and chert pebbles	91.5
Total	198.0

Patonga Claystone

	Thickness (m)
Sandy siltstone, brick red to green, clayey, micaceous	97.6

Tuggerah Formation

	Thickness (m)
Sandstone, fine-grained, labile, moderately well sorted; calcite cement and silt matrix. Minor partings of siltstone. Following Foraminifera recorded: *Verneuilina, Ammobaculites, Haplophragmium,* and cf. *Trochammina*	79.3
Sandy siltstone, micaceous. Following Foraminifera recorded: cf. *Haplophragmoides* and cf. *Trochammina*	42.7
Total	122.0

Munmorah Formation

	Thickness (m)
Sandstone, medium-grained, labile, poorly sorted; coloured chert pebbles; sideritic, clayey. Minor layers of siltstone	243.4
Total thickness of Narrabeen Group	661.0

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Protoquartzite (60%) interbedded with dark brown silty slightly carbonaceous sideritic mudstone	64.0
Claystone, reddish brown and green	44.2
Subgreywacke (80%), brown, sideritic, interbedded with grey-brown protoquartzite (20%)	56.4
Subgreywacke and protoquartzite (80%) interbedded with grey-brown mudstone and siltstone (20%) and minor red-brown claystone. Sideritic	324.8
Siltstone, grey-brown, green, grey, and reddish brown claystone (50%) interbedded with subgreywacke (50%)	102.1
Total	591.5

SOUTHERN CENTRAL AREA

Coal Cliff Sandstone

The type area of the Coal Cliff Sandstone (Hanlon et al., 1953) is the coast between Coal Cliff and Clifton. The sandstone is medium to coarse-grained with pebbly layers, but the basal part, about 12 m thick, consists chiefly of fine lithic sandstone with angular to rounded fragments of chert, quartz, and siltstone set in a matrix of clay, quartz, and siderite. A basal conglomerate occurs in places.

The following is the type section near Coal Cliff:

	Thickness (m)
Sandstone, light grey, medium to fine-grained	0.9
Shale, silty, light grey; indurated layers	2.0
Sandstone, medium to coarse-grained; pebbly layers and ironstone concretions in places	6.7
Sandstone, very fine-grained, argillaceous, indurated, dark grey near underlying coal seam	0.4
Total	10.0

Wombarra Shale

The type section of the Wombarra Shale (Hanlon et al., 1953) is on the coast between Coal Cliff and Clifton. It consists of shale, claystone, and siltstone with intercalated beds of sandstone, one of which is named the Otford Sandstone Member (Hanlon et al., 1953), and thin beds of conglomerate. Loughnan (1963) records almost twice as much lutite 6 km north of the type section.

	Thickness (m)
Shale, light grey	1.0
Sandstone, greenish grey	0.6
Shale, grey, starchy fracture	4.0
Sandstone, fine-grained to conglomeratic (Otford Sandstone Member)	6.8
Shale, grey, reddish brown in places, starchy fracture	13.4
Sandstone, argillaceous	0.9
Shale, grey, starchy fracture, with a few sandstone layers	3.6
Shale, grey, with numerous sandstone layers	5.7
Total	36.0

Scarborough Sandstone

The type section of the Scarborough Sandstone (Hanlon et al., 1953) is on the coast between Coal Cliff and Clifton. It consists (Loughnan, 1963) of 26 m of coarse-grained lithic sandstone grading into conglomerate, and is finer-grained towards the top. The rock fragments consist of quartz and chert.

Stanwell Park Claystone

The type section of the Stanwell Park Claystone (Hanlon et al., 1953), on the coast between Coal Cliff and Clifton, consists of interbedded claystone and sandstone.

	Thickness (m)
Claystone, reddish brown, green, and grey	5.5
Sandstone, greenish	.9
Claystone, green and grey	10.1
Sandstone, green and grey	0.9
Claystone, reddish brown	1.8
Sandstone, greenish grey	2.1
Claystone, green and reddish brown	1.8
Sandstone, greenish grey	0.8
Claystone, reddish grey	1.2
Sandstone, greenish	0.3
Claystone, grey, green, and reddish brown	1.8
Sandstone, fine-grained, grey and reddish brown, speckled	1.8
Sandstone, fine-grained, speckled	0.5
Claystone, reddish brown and grey, with sandstone layers	5.0
Sandstone, argillaceous, grey with reddish brown speckling on weathered surface	2.1
Total	36.6

Loughnan (1963) recognized two units within the Stanwell Park Claystone in the Metropolitan Colliery bore. The upper 22 m consists of red-brown claystone and clay breccia, containing very little quartz, in which residual volcanic textures are discernible, while the lower 25 m consists of green-grey fine-grained lutite with subordinate greenish lithic sandstone and conglomerate containing abundant quartz. Some of the pebbles have a fluidal or trachytic texture.

In the older literature the Stanwell Park Claystone was known as the Cupriferous Tuffs, Lower Chocolate Shales, and Lower Red Beds.

Bulgo Sandstone

The Bulgo Sandstone (Hanlon et al., 1953) consists of sandstone with a few interbeds of claystone. It has a banded appearance owing to the weathering of soft layers. The type section near Bulgo and Clifton is incomplete.

	Thickness (m)
Sandstone, fine to medium-grained, light grey to pale reddish brown	2.5
Breccia, medium-grained	0.4
Sandstone, fine to medium-grained, light grey to pale reddish brown	0.7
Shale, reddish brown	0.1
Sandstone, fine to medium-grained, light grey to pale reddish brown	0.1

Claystone, reddish brown		0.3
Sandstone, fine-grained, greenish grey		0.5
Shale, reddish brown		0.1
Sandstone, thin-bedded, greenish grey		0.8
Shale, reddish brown		0.1
Sandstone, fine to medium-grained, light grey to pale reddish brown		2.7
Shale, reddish brown		2.1
Sandstone, fine to medium-grained, light grey to pale reddish brown		0.8
Claystone, reddish brown, some greyish bands		1.4
Sandstone, fine-grained, light greenish grey		1.8
Sandstone, rhythmically interbedded reddish brown and greenish grey		0.3
Sandstone, fine to medium-grained, greenish grey		2.4
Sandstone, fine-grained, rhythmically interbedded reddish brown and greenish grey		1.2
Sandstone, fine-grained, light grey		1.8
Shale, reddish brown with some greenish beds		0.9
Sandstone, fine-grained, light grey, soft and shaly at base		3.2
Sandstone, fine to medium-grained, with irregular breccia bed near base		2.1
Sandstone, reddish brown and greenish grey		0.3
Silty claystone, grey, and some sandstone beds		2.4
Sandstone, medium-grained		0.6
Silty claystone, greenish grey		0.6
Sandstone, medium-grained		6.1
Lenticular beds generally similar to the overlying beds (Hanlon et al., 1954)	(approx.)	91.5
Total	(approx.)	127.8

Ward (1971) proposed as type section the complete sequence of the Bulgo Sandstone as recorded in the log of Coal Cliff DDH 17 at Garranwarra Farm west of Era. He recognized three distinctive facies:

	Thickness (m)
Upper or shaly facies: light grey-brown sandstone with layers of red shale	45.1
Middle or volcanic facies: 217.9 m of sandstone containing numerous fragments of intermediate to mafic volcanic rock. Claystone layer at base called Menai Claystone Member	50.3
Lower or pebbly facies: contains numerous pebbles of green, red, black, and grey chert	66.0
Total	161.4

Bald Hill Claystone

The Bald Hill Claystone (Hanlon et al., 1953) consists of reddish brown claystone with some mottled claystone and reddish brown sandstone layers, some of which are probably tuffaceous. The type section at Bald Hill, north of Stanwell Park, consists of:

	Thickness (m)
Claystone, reddish brown, with numerous small solution cavities	1.1
Claystone, reddish brown and occasionally greyish, with a few cavities	1.8
Claystone, reddish brown and light grey	0.8
Claystone, reddish brown, slightly mottled	1.8
Claystone, fine-grained, reddish-brown with grey mottling and sudden lateral colour changes	1.2

Claystone, reddish brown	3.7
Claystone, light reddish brown, mottled	0.3
Claystone and siltstone, reddish brown	3.6
Total	14.3

The Bald Hill Claystone has previously been referred to as the Chocolate Shales, Upper Chocolate Shales, Upper Red Beds, and Collaroy Claystone. The type section established in the Windeyers Hawkesbury River bore (Hanlon et al., 1954) for the Collaroy Claystone, is now the type section of the Patonga Claystone (q.v.).

Ward (1971) identified the Bald Hill Claystone over a large part of the basin and has shown that it thins to the east.

Garie Member of the Bald Hill Claystone. The Garie Member (Loughnan, 1969) consists of massive well crystallized kaolinite with a little siderite and anatase. It is light to dark grey and generally indurated, and commonly has a micro-oolitic texture. There is virtually no quartz.

The type area is near Bulgo Headland on top of the Bald Hill Claystone. It was given formation status by Bunny & Herbert (1972), but relegated again to a member by Ward (1971). Hanlon et al. (1954) describe the topmost unit of the Bald Hill Claystone as a grey and cream breccia, the lower part of which is indurated along joints. The Garie Member has previously been referred to as the Narrabeen Clay Conglomerate, Narrabeen Breccia, Pelletal Claystone, and the Tonstein-like Rock.

Newport Formation

The Newport Formation (Bradley, 1964) consists mainly of siltstone. The type section, as measured by Hanlon (1956) about 3 km north of Garie Beach, is as follows:

Sandstone, fine-grained, labile; some slumping	0.6
Shale, blackish, finely laminated in places; abundant plant remains	2.4
Claystone, grey	2.3
Siltstone, light grey, indurated	0.2
Claystone, grey	0.8
Siltstone, rhythmically bedded	2.4
Sandstone, fine-grained, labile, indurated; honey-comb weathering	0.3
Shale, dark grey, rhythmically interbedded with fine-grained labile sandstone. Abundant reed casts	2.0
Siltstone, grey to reddish brown, with 2 thin pebbly bands of quartz and chert	1.7
Sandstone, fine-grained, labile, rhythmically interbedded with shale	0.9
Siltstone, grey	2.7
Sandstone, grey, coarse-grained, labile	0.5
Claystone, grey, indurated, sideritic	1.5
Total	18.3

Interval 12 in the Deep Wells

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Siltstone, brownish, carbonaceous, micaceous, sideritic, interbedded with light grey labile silty protoquartzite	21.7
Claystone, chocolate, kaolinitic, pelletal, interbedded with minor subgreywacke	21.7
Protoquartzite, labile, pebbly, carbonaceous, slightly sandy. 3 or 4 fining-upwards cycles	35.1
Protoquartzite and subgreywacke, very fine to coarse, with abundant clasts of coloured chert, interbedded with greenish sandy siltstone and mudstone. About 17 fining-upwards cycles. Typical sequence consists of 10 m of pebbly coarse sandstone grading through medium and fine-grained slightly pebbly sandstone to very fine-grained sandstone, sandy siltstone, and mudstone	259.2
Five fining-upwards cycles of pebbly subgreywacke, with abundant coloured chert clasts, sandy siltstone, and greenish illitic claystone. 6 m of conglomerate at base of middle cycle	72.6
Siltstone, brownish, slightly carbonaceous, interbedded with minor medium-grained very fine to fine-grained subgreywacke. Cross-bedding; burrows; and rootlets	27.8
Total	438.1

Woronora No. 1
(Alcock, 1968b)

	Thickness (m)
Sandstone, labile, very fine-grained, and very fine-grained protoquartzite	9.1
Shale interlaminated with siltstone; a little carbonaceous material	18.3
Claystone, red-brown, upper part oolitic, with a few layers of hard white claystone and grey shale	30.5
Orthoquartzite with a few interbeds of sandy siltstone. Chert clasts abundant	73.2
Sandstone, labile, grey to red-brown; contains clasts of red and green chert and claystone; iron oxide and siderite	21.3
Orthoquartzite with a few interbeds of lutite; siderite and iron oxide	73.2
Protoquartzite, with numerous clasts of sedimentary rock, interbedded with grey and red-brown shale and minor siltstone	48.8
Orthoquartzite and protoquartzite with numerous pebbles of red and green chert. Porosity moderate to high	30.5
Subgreywacke, with numerous clasts of sedimentary rock, interbedded with shale and siltstone; calcareous cement	36.6
Subgreywacke, with numerous clasts of sedimentary rock, interbedded with shale and siltstone; calcareous cement; coarser-grained than overlying unit	15.2
Total	356.7

Western Area

Caley Sub-Group

The Caley Formation (Crook, 1956) was subdivided by Goldbery (1966) into five members which were later upgraded to formations of the Caley Sub-group (Goldbery, pers. comm., *in* Herbert, 1970b).

Beauchamp Falls Shale

The Beauchamp Falls Shale (Goldbery, 1966), at the base of the Narrabeen Group, consists of interbedded carbonaceous shale, siltstone, claystone, and fine-grained sandstone. The type section is at Beauchamp Falls.

	Thickness (m)
Shale with grey and brown micaceous siltstone	4.8
Sandstone, white to grey-brown, mostly fine-grained	3.8
Total	8.6

Clwydd Sandstone

The type section of the Clwydd Sandstone (Goldbery, 1966) is at Beauchamp Falls.

	Thickness (m)
Sandstone, white to brown, fine to coarse-grained; beds 0.3–3.3 m thick; irregularly spaced layers of coloured jasper pebbles, up to 2 cm across, which constitute up to 15% of rock. Ironstone concretions; traces of cross-bedding	8.5
Shale, grey, micaceous; lenses up to 0.3 m thick	0.6
Total	9.1

Victoria Pass Claystone

The type section of the Victoria Pass Claystone (Goldbery, 1966) is at Victoria Pass, where it consists of 2 m of greyish white to dark grey hard dense claystone with thin black cross-bedded silty layers. The formation thins gradually to the west.

Govetts Leap Sandstone

The type section of the Govetts Leap Sandstone (Goldbery, 1966) is at Burra-Moko Head, where the formation consists of 10.8 m of white to yellow fine to coarse sandstone, in beds from 0.6 to 3.3 m thick. It contains layers, up to 15 cm thick, of quartz and jasper pebbles about 6 mm across.

Hartley Vale Claystone

The type section of the Hartley Vale Claystone (Goldbery, 1966) is at Victoria Pass, where it consists of 3.3 m of grey argillaceous rock (67%) with plant remains, interbedded with white fine-grained sandstone (33%) with shaly partings. This sandy facies gradually becomes dominant to the west. In the gorges of the Blue Mountains the Hartley Vale Claystone usually forms a notch beneath the overlying Grose Sandstone.

Grose Sub-Group, formerly Grose Sandstone (Crook, 1956)

The Grose Sandstone was subdivided by Goldbery (1966) into three members, which were upgraded (Goldbery, pers. comm., *in* Herbert, 1970b) to formations of the Grose Sub-Group.

Burra-Moko Head Sandstone

The Burra-Moko Head Sandstone (Goldbery, 1966) is the oldest formation of the Grose Sub-Group. It consists of massive sandstone beds with lenses of shale and claystone. The Katoomba Claystone Member (Goodwin, 1970) in the middle of the formation is a useful marker. The type section in Bennett Gully consists of 75.6 m of yellow medium to coarse sandstone with quartzose pebbly layers interbedded with 2.7 m of grey shale in layers from 0.3 to 2.1 m thick.

Mount York Claystone

The Mount York Claystone (Goldbery, 1966; Goodwin, 1970) consists of a single bed of claystone or two beds separated by a thin bed of sandstone. The claystone is commonly reddish brown, but ranges from mottled brown to light grey or white. It lies between 102 m and 122 m above the base of the Grose Sub-Group, whereas the Katoomba Claystone Member is 39.6 to 48.8 m above the base.

The type section is in Bennett Gully, Mount York, 3 km north of Victoria Pass, where it consists of:

	Thickness (m)
Ironstone	0.1
Claystone, grey and red-brown	2.5
Sandstone, white and yellow, fine to medium-grained	3.6
Claystone, red-brown; deeply weathered to form prominent undercut ledge	5.7
Total	11.9

Banks Wall Sandstone

The Banks Wall Sandstone (Goldbery, 1966) is the youngest formation in the Grose Sub-Group. The type section at Mount Hay consists of 108.8 m of yellow medium to coarse-grained sandstone with lenses, up to 1.8 m thick, of pebbles up to 1.3 cm across. The interbedded shales, with a total thickness of 3.9 m, are grey in the upper part of the sequence and red-brown in the lower.

Burralow Formation

The Burralow Formation (Crook, 1956) consists of interbedded sandstone, shale, and claystone, all of which are micaceous. The type area is along the valley of the Burralow Creek, where Crook measured the following section:

		Thickness (m)
Shale, grey, with sandstone interbeds		17.3
Sandstone, fine-grained, soft, quartz-rich		1.2
Shale, grey, fissile, with sandstone interbeds		24.7
Tabarag Sandstone Member	Sandstone, massive, medium-grained, quartz-rich, flaggy towards top	5.4
	Claystone, red-brown	5.1
	Sandstone, massive, medium-grained, quartz-rich, coarse-grained at base	13.7
Claystone, grey		3.0
Claystone, red-brown		5.1
Shale, grey, fissile, silty, with interbedded sandstone		4.2
Sandstone, fine-grained, silty at top		1.2
Shale, grey		1.2

Conglomerate, fine-grained	0.6
Shale interbedded with sandstone towards top	16.4
Sandstone, flaggy, with shale clasts	1.8
Shale, grey, with fine-grained sandstone	4.8
Claystone, red-brown	0.9
Total	106.6

The formation is entirely arenaceous at the western edge of the outcrop.

Interval 12 in the Deep Wells

Mount Murwin No. 1
(Mayne, 1968)

	Thickness (m)
Quartz greywacke (75%), very fine-grained, slightly carbonaceous, sideritic, interlaminated with medium-grained protoquartzite (25%)	125
Protoquartzite (85%) interbedded with quartz greywacke (15%)	143.3
Protoquartzite (97%) with very thin lenses of reddish brown mudstone (3%)	240.9
Quartz greywacke (70%), very fine-grained, slightly carbonaceous, interlaminated with protoquartzite (30%)	164.7
Total	673.9

Mellong No. 1
(Mayne, 1969)

	Thickness (m)
Siltstone (70%) interbedded with protoquartzite (30%)	63.0
Orthoquartzite. Correlated with Tabarag Sandstone Member of Burralow Formation	33.5
Siltstone interlaminated with protoquartzite	42.7
Protoquartzite grading into orthoquartzite; contains up to 30% multicoloured chert clasts and a few siltstone laminae	308.0
Protoquartzite (85%) interbedded with grey-brown siltstone (15%); a few coaly partings	140.3
Siltstone (60%), grey, commonly carbonaceous, interbedded with protoquartzite (40%)	54.1
Total	641.6

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Siltstone with interbeds of protoquartzite and orthoquartzite, including the Tabarag Sandstone Member. Correlated with Burralow Formation	85.4
Orthoquartzite and protoquartzite, massive, cross-bedded, with thin siltstone partings. More pebbly in lower half. Correlated with Banks Wall Sandstone	317.2
Claystone, green and red, sandy, chloritic, sideritic. Correlated with Mount York Claystone	6.1
Protoquartzite, medium to coarse-grained, cross-bedded, with sparse laminae of siltstone. Correlated with Burra-Moko Head Sandstone	154.0
Protoquartzite, medium-grained, with interbeds of siltstone. Contains numerous clasts of coloured chert; dawsonite, dolomite, and calcite. Correlated with Caley Sub-Group	91.5
Total	654.2

Howes Swamp No. 1
(Esso, 1970)

	Thickness (m)
Burralow Formation	
Siltstone interbedded with shale, carbonaceous in part	10.6
Lithic sandstone, very fine to fine-grained, buff to grey. Glauconitic at 11.9 m	27.4
Sandstone, white, coarse to very coarse; coloured clasts. Minor rust-red claystone and grey to buff siltstone	54.9
Siltstone, grey, slightly carbonaceous, and some reddish claystone interbedded with minor white fine-grained quartzose sandstone	57.1
Grose Sandstone	
Sandstone, buff, medium to coarse; grains subangular to angular; coloured clasts; poorly cemented with silica. Very small amount of siltstone	338.5
Caley Formation	
Sandstone with very minor hard grey carbonaceous claystone and siltstone	45.7
Sandstone	30.5
Shale and siltstone, grey	21.3
Lithic sandstone, arkosic, interbedded with light grey shale	21.3
Sandstone with very minor grey carbonaceous siltstone	45.7
Total	653.0

NORTHWESTERN AREA

Pogson & Rose (1969) have recognized three units in the Narrabeen Group in the far northwestern part of the Sydney Basin. A coarse polymictic conglomerate at the base is overlain by a labile sandstone, and this in turn by a sequence of quartz sandstone and shale. The clasts become smaller towards the top of the section. The distribution and variation in thickness of the units suggest that the older beds of larger pebbles, which consist mainly of volcanic rocks, were derived from the New England district in the northeast, while the quartz came from the west; with the passage of time the westerly source became more and more important.

Pogson & Rose (1969) describe a section 3 km northeast of Wollar.

	Thickness (m)
Lithofacies C	
Sandstone, conglomeratic, and conglomerate. Pebbles up to 1.5 cm across common. Most of the grains and pebbles consist of quartz. White clay matrix	44
Sandstone, conglomeratic. Numerous pebbles up to 1.5 cm across. Most of the grains and pebbles consist of quartz. Some red grains	18
Lithofacies B	
Sandstone, chiefly coarse to very coarse-grained. Pebble beds throughout; pebbles up to 1.5 cm across, but generally less. Green and red grains abundant. Marked increase in quartz grains and pebbles from underlying section. White clay matrix	14
Sandstone, chiefly coarse and generally containing conglomeratic lenses. Red, green, and white pebbles of volcanic rock and quartz. Some ferruginous beds. White clayey matrix	8
Lithofacies A	
Conglomerate with pebbles up to 2.5 cm across. Pebbles consist of white volcanic rock, red and green aphanitic rock, quartz, quartzite, and siltstone	24
Conglomeratic with pebbles from 0.5 cm to less. Pebbles composed of white volcanic rock, red and green aphanitic rock, quartz, quartzite, and siltstone. Matrix of white clay	8
Total	116

Pogson & Rose (1969) give detailed sections from another 12 localities in the region between Rylstone and Broke.

Relations with Older Units

Over much of the Sydney Basin the Narrabeen Group rests conformably on the Newcastle Coal Measures and correlatives. The relationship is gradational, but by definition the Narrabeen Group begins directly above the topmost coal seam. The topmost coal seam, in turn, is taken as the Wallarah, Bulli, and Katoomba Seams, but in the Lake Macquarie region a coal seam called the Vales Point Coal Member occurs in the Munmorah Formation of the Narrabeen Group, above the Wallarah Seam. Near the Lochinvar Dome, however, the Narrabeen Group rests unconformably on the Muree Sandstone (David, 1907), owing to uplift and erosion of the area during the time immediately preceding the laying down of Interval 12.

Correlation and Age

The formations in the Narrabeen Group are correlated on their stratigraphic position, lithology, and contained macrofloras and microfloras. A broad correlation is suggested by their stratigraphic position between the bottom and top of the group, that is, the topmost coal seam of the coal measures and the Hawkesbury Sandstone. In this way the Caley Sub-Group, the Munmorah Formation, and the Coal Cliff Sandstone are at least partly correlative as they are at the bottom of the sequence, as also are the Burralow, Newport, and Gosford Formations at the top. The Bulgo Sandstone and the Grose Sub-Group can be correlated in part not only because of their intermediate stratigraphic position, but also because of their similar lithology. The chocolate shales of the Narrabeen Group can be used as marker beds over limited areas. The most extensive is the Bald Hill Claystone with its unique kaolinite lithology. To the north it has been traced subsurface into the claystone at Collaroy and westwards into the reddish shales of the Burralow Formation. Similarly, the Menai Claystone along the northern Illawarra coast has been traced into the Mount York Claystone in the Blue Mountains, and the Stanwell Park Claystone has been found to be continuous with the Katoomba Claystone.

Ward (1971) in his analysis of variation in the ratio of quartz to rock fragments in the group was able to show that vertical variation occurred at three fairly distinct levels, which he referred to as steps A, B, and C. Step A occurs at the base of the Scarborough and Burra-Moko Head Sandstones, step B near the base of the Tuggerah Formation and Menai and Mount York Claystones, and step C at the top of the Patonga Claystone and just below the Bald Hill Claystone.

Two distinct macrofloras (the older *Glossopteris* and the younger *Dicroidium-Hoegia* floras) exist within the Narrabeen Group, and afford a basis for time correlation. The microfloras are a more useful parameter for correlating: Helby (1970) has recognized palynological assemblage zones in the Sydney Basin Triassic rocks, and time correlations based on them are shown in Figure 44.

The age of the Narrabeen Group has been estimated directly from palaeontological evidence and indirectly from isotopic age determinations. Macrofloral and microfloral assemblages and fossil arthropods and vertebrates indicate that the group ranges from late Tatarian into the Middle Triassic. The intrusive dolerite at Prospect has a K/Ar age of 168 m.y. (mid-Jurassic), and the Moss Vale/Mittagong intrusives have a K/Ar age of 194 m.y. (late Triassic).

Fossils from the Narrabeen Group

The following fossils have been recorded:

Munmorah Formation

Raggatt (1969) lists the following:

Plantae: *Glossopteris browniana, Alethopteris, Phyllotheca, Schizoneura gondwanensis, Cladophlebis* cf. *roylei, Taeniopteris* cf. *mcclellandi, T.* sp., *Sphenopteris* sp., *Ginkgoites dilatata* var. *lata,* and *Rhipidopsis ginkgoides*

Arthropoda: *Estheria coghani*

Helby (1970) mentions that *Thinnfeldia callipteroides* Carpentier is a constant component of lowermost Narrabeen Group floral assemblages.

Coal Cliff Sandstone

Harper (1915) tentatively identified reptilian footprints as cf. *Ichnium gampsodactylum.*

Helby (1970) states he has found small undescribed pelecypods.

Beauchamp Falls Shale

McElroy (1969b) mentions the occurrence of *Dicroidium odontopteroides.*

Tuggerah Formation

Raggatt (1969) lists the following plants: *Alethopteris, Equisetum, Schizoneura gondwanensis, Sagenopteris salisburioides, Zeugophyllites* sp., *Dicroidium narrabeenense,* and an acritarch.

Tuggerah Formation in Kulnura No. 1

Crespin (1936) listed the following:

Foraminifera: *Verneuilina, Ammobaculites, Haplophragmium,* cf. *Haplophragmoides,* and cf. *Trochammina*

Conchostraca: *Cyzicus*

Various: a siliceous sponge; fish scales

Tuggerah Formation in Terrigal DDH No. 1

Evans (*in* Helby, 1970) has found acritarchs in a horizon which Helby considers an equivalent of the Tuggerah Formation.

Patonga Claystone

Helby (1970) mentions that the conchostracan *Cyzicus* is locally prominent throughout the section below the base of the Gosford Sub-Group.

Grose Sub-Group

From the Mulgoa No. 1 well Crespin (1960) recorded *Globochaeta* and microscopic wheels and rods of echinodermatan holothurian sclerites at 553.7, 554.4, and 677.6 m. The formation was probably the Burra-Moko Head Sandstone.

Gosford Formation

Dicroidium and *Hoegia* characterize the flora of this formation, and have been described in detail by Walkom (1925) and Burges (1935).

Plantae: *Phyllotheca australis, Todites narrabeenensis, Cladophlebis* cf. *roylei, Coniopteris* cf. *lobata, Caulopteris* sp., *Taeniopteris tenison-woodsi, T. triassica,* *T. undulata, T. wianamattae, Sphenopteris alata, Dicroidium feistmanteli, D. lancifolium, D. narrabeenense, D. odontopteriodes, Hoegia* sp., *Odontopteroides dubia, O. macrophylla, Carpolithus* sp., cf. *Beania* sp., cf. *Sphaereda* sp., *Bennettites* (*Williamsonia*), flowers and stem, *Ginkgoites* sp., *Baiera multifida* (*B. simmondsi*), *Rhipidopsis ginkgoides, R. narrabeenensis, R. cupressinoxylon novaevalesiae, Cedroxylon triassicum, Brachyphyllum angustum, Cyclostrobus sydneyensis,* and coralline algae.

Woodward (1890) and Wade (1940) listed the following vertebrates:

Selachii: Cestraciont shark, indet.

Dipnoi: *Gosfordia truncata* Smith Woodward

Palaeoniscidae, s.l.: *Apateolepis australis* Smith Woodward, *Myriolepis clarkei,* and *M. latus* Smith Woodward

Catopteridae: cf. *Brookvalia* spp.

Perleididae: *Tripelta dubia* (Smith Woodward), *Chrotichthys gregarius* (Smith Woodward), *Pristosomus gracilis* (Smith Woodward), *P. latus* Smith Woodward, *P. crassus* Smith Woodward, and *Zeuchthiscus australis* (Smith Woodward)

Cleithroepidae: *Cleithrolepis granulata* Egerton and *C. altus* Smith Woodward

Saurichthyidae: *Saurichthys gigas* Smith Woodward and *S. gracilis* Smith Woodward

Specimens of *Cleithrolepis* have also been obtained from Asquith, the Waterboard tunnel, and Lane Cove in the Sydney area, and from Katoomba.

Amphibia: Stephens (1887) described the brachyopid *Blinasaurus* (*Platyceps*) *wilkinsoni.* This is thought to be a larval stage of *Paratosaurus wadei.* Cosgriff (1967) described *P. wadei,* also from the Gosford area and suggested a Lower Triassic age for the Gosford vertebrate assemblage.

Helby (1970) mentions that pelecypods have been found in the upper portion of the Gosford Sub-Group.

Bald Hill Claystone

Conolly (1969) reported the occurrence, in thin sections, of Foraminifera and ostracods.

Packham (*in* Helby, 1970) has found coralline algae in the upper part of the Bald Hill Claystone at Avalon.

The Permo-Triassic Boundary

The position of the Permo-Triassic boundary was for long in doubt. The boundary between the Newcastle Coal Measures and correlatives and the Narrabeen Group has often been used as the Permo-Triassic boundary because it is so easily recognized. However, Walkom (1925) pointed out that the occurrence of *Glossopteris browniana, Schizoneura gondwanensis, Cladophlebis, Rhipidospsis,* and *Taeniopteris* in beds above the Bulli Seam indicated the continuance of the Permian macroflora into the Narrabeen Group. The best place for the boundary was where the *Glossopteris* flora declined and gave way to the *Dicroidium* flora. Helby (1971) has defined the boundary as coincident with the boundary between the *Protohaploxipinus reticulatus* and *Lunatisporites* (*Taeniaesporites*) *pellucidus* microfloral Assemblage Zones. Thus the basal units of the Narrabeen Group (Fig. 44) were deposited in the Upper Permian.

INTERVAL 13: HAWKESBURY SANDSTONE

The Hawkesbury Sandstone (Clarke, 1848) was the first formation studied in Australia. Hanlon et al. (1953) gave a detailed account of the various names by which the formation has been known, and Standard (1964, 1969), Conolly (1968), and Ward (1971) have presented comprehensive treatments of it.

The Hawkesbury Sandstone consists of orthoquartzite with some lenses of shale and conglomerate, but in the central area it is a protoquartzite. The quartz grains are of medium to coarse size, and subangular, with crystal facets due to overgrowths. Almost all the quartz was derived from igneous rocks, but some vein quartz is also present. Quartz pebbles are scattered throughout the sandstone or as very thin layers at the bottom of sandstone beds. The basal 0.6 m is commonly conglomeratic in the west, and beds of quartz cobbles with a westerly provenance occur in the northwest (Bilpin-Colo district).

The cement is commonly illite, but may be silica, kaolinite, siderite, limonite, or barite. Loughnan & Golding (1956) consider that the sandstone originally contained 10 to 15 percent of potash feldspar, from which the illite was derived.

The minor constituents include graphite (the most common), muscovite, chlorite, and feldspar (in the light fraction) and authigenic leucoxene, anatase, pyrite, and iron oxide, and detrital rutile, zircon, and tourmaline (in the heavy fraction).

Clay lenses up to about 1.5 m thick form some 6 percent of the formation. Black shale, containing syngenetic pyrite and marcasite, and streaks and sinuous lenses of coaly material, usually vitrain, are intercalated in the massive sandstone beds.

Cross-bedding is a distinctive feature of the formation. Osborne (1948) records both trough and planar cross-bedding. Trough bedding, with the upper portion eroded away, is typical of the Hawkesbury terrain; it was formed by continuous current action which removed much of previously formed cross-beds. The direction of deposition of the foreset cross-beds (Standard, 1969) is constantly to the northeast. The detritus forming the Hawkesbury Sandstone came chiefly from the southwest, but also from the west and northwest.

Other sedimentary structures include graded bedding, scour-and-fill, shale breccias, current ripple marks, and slumping.

The Hawkesbury Sandstone (Helby, 1970) remains the least understood and perhaps the most controversial rock unit in the Sydney Basin. The main points of contention include the areal distribution of the formation, its composition, and the environment of deposition. Standard (1969) and Ward (1971) consider that the Hawkesbury sediments were deposited by a fluvial system originating in the far southwest, but Conolly (1968) favours a hypothesis involving the operation of waves and tides on a delta.

Hawkesbury Sandstone in the Deep Wells

Kirkham No. 1
(Raine, 1969)

	Thickness (m)
Orthoquartzite, light grey, very fine to fine-grained, grading into brownish black sideritic micaceous siltstone	6.1
Orthoquartzite, light grey, coarse-grained, with minor interbeds of dark sideritic siltstone. Cemented by kaolinite and quartz overgrowths; detrital graphite	33.5
Protoquartzite, fine to coarse, quartz-rich, slightly pebbly, with interbeds of dark micaceous, carbonaceous, sideritic and graphitic sandy illitic siltstone and mudstone	102.1
Protoquartzite, medium to coarse-grained, pebbly, with a few siltstone partings. Sideritic; graphite conspicuous	30.5
Protoquartzite, fine to coarse-grained, with minor interbeds of black kaolinitic mudstone. Quartz and coloured chert clasts; sideritic; graphitic	31.4
Total	203.6

Woronora No. 1
(Alcock, 1968b)

	Thickness (m)
Orthoquartzite, sideritic, limonitic, graphitic; clay cement; pebbles common towards base	73.2
Shale and interbedded siltstone; sideritic	9.1
Orthoquartzite, pebbly in part; some chert, carbonaceous material, and graphite	57.1
Orthoquartzite, pebbly, with interbeds of laminated sideritic shale	24.4
Total	163.8

Dural South No. 1
(Hawkins & Ozimic, 1967)

	Thickness (m)
Protoquartzite, fine to medium-grained, with some pebbly orthoquartzite and thin beds of siltstone. Graphitic; sideritic	204.3

Windeyers Hawkesbury River Bore
(Culey, 1910)

	Thickness (m)
Sandstone	10.8
Sandstone with ironstone bands	12.8
Shale and sandstone	11.3
Sandstone, broken	9.7
Sandstone	0.6
Shale and sandstone	5.2
Sandstone	0.6
Conglomerate	0.3
Sandstone	8.8
Total	60.1

Kulnura No. 1
(Ozimic, 1969)

	Thickness (m)
Sandstone, labile, medium-grained. Composed of quartz, with minor feldspar, lutite microclasts, and graphite. Siderite and hematite cement; matrix of chloritic silt (=type x)	12.2
Siltstone, grey to brown, micaceous, sideritic (=type y)	3.1

Sandstone (type x)	30.5
Siltstone (type y)	12.2
Sandstone (type x)	21.4
Siltstone (type y)	9.2
Sandstone (type x)	7.6
Siltstone (type y)	4.6
Sandstone (type x)	18.3
Siltstone (type y)	4.6
Sandstone (type x)	4.6
Siltstone (type y)	6.1
Sandstone (type x)	3.1
Siltstone (type y)	7.6
Sandstone (type x)	4.6
Siltstone (type y)	3.1
Sandstone (type x)	6.1
Siltstone (type y)	6.1
Sandstone (type x)	6.1
Total	171.1

Melong No. 1
(Mayne, 1969)

	Thickness (m)
Orthoquartzite, pale buff, medium-grained, with lenses of coarser sand and quartz gravel. Grains subangular, some with crystal regrowth; rare graphite, mica, and feldspar; white interstitial clay	112.8

Mount Murwin No. 1
(Mayne, 1968)

	Thickness (m)
Similar to Mellong No. 1 well	103.7

Howes Swamp No. 1
(Esso, 1970)

	Thickness (m)
Sandstone, quartzose, white, pale yellow to light grey, fine to coarse-grained, pebbly in places, graphitic; grains subrounded to angular; creamy clay cement. A little grey silty carbonaceous shale	96.0

Kurrajong Heights No. 1
(Pitt, 1968)

	Thickness (m)
Sandstone (ranging from protoquartzite to orthoquartzite), labile, medium-grained, conglomeratic near bottom, graphitic and sideritic, with thin grey layers of mudstone and claystone at irregular intervals	218.0

Relations with Older Units

The Hawkesbury Sandstone has a gradational contact with the Newport Formation with which it is a partial time equivalent laterally. In the southern area, however, there is an unconformity between the Hawkesbury Sandstone and the Clifton Sub-Group. Standard (1961) gave the following criteria for distinguishing the base of the Hawkesbury Sandstone from the underlying Narrabeen Group:

1. A decrease in the number and thickness of clay units.
2. A decrease in the proportion of clay cement, which makes the sandstone more friable.

3. An increase in foreset type cross-bedding.
4. A reduction of sandstone-mudstone interbedding.
5. A decrease in the proportion of sandstone lenses and scour-and-fill structures.
6. The marked decrease in the number of conglomerate layers in the northern part of the basin.
7. The increase in the content of quartz pebbles from less than 40 to over 90 percent.

Galloway (1967) has shown that it may be possible to distinguish the Hawkesbury Sandstone from Narrabeen Group sandstones by the differences in their heavy mineral content.

Correlation

In the southern, western, and northwestern areas where there are relatively few interbeds of claystone and siltstone in the Narrabeen Group it is difficult to distinguish the thick sandstone beds of the Narrabeen Group from the Hawkesbury Sandstone (Galloway, 1967; Dickson, 1969).

Age

Fossils are generally rare in the Hawkesbury Sandstone, but in a few localities they are abundant. Almost all occur in shale lenses within the sandstone and indicate a freshwater environment.

David (1950) listed the following plants from various shale beds: *Phyllotheca australis, Cladophlebis australis, Hymenophyllites dubius, Taeniopteris lentriculiformis, T. (Macrotaeniopteris) wianamattae, T. (Macrotaeniopteris)* sp., *Dicroidium odontopteriodes, D. feistmanteli, Ottelia praeterita,* and *Reinitsia spathulata.*

Wade (1935) described the following fish, for which he suggested a Middle Triassic age, from the Beacon Hill quarry at Brookvale, from shale 167 m above the base of the Hawkesbury Sandstone:

Dipnoi: *Ceratodus*

Palaeoniscidae: *Myriolepis* (2 spp.), *Agecephalichthys, Megapteriscus, Belichthys* (3 spp.), *Leptogenichthys,* and *Mesembroniscus*

Catopteridae: *Brookvalia* (3 spp.), *Beaconia, Dictyopleurichthys, Geintonichthys, Molybdichthys, Phlyctaenichthys,* and *Schizurichthys*

Perleididae: *Manliella* and *Procheirichthys*

Cleithrolepidae: *Cleithrolepis* (2 spp.)

Saurichthyidae: *Saurichthys* (2 spp.)

Pholidopleuridae: *Macrouephes* (2 spp.)

Semionotidae: *Promecosimina*

Family indeterminate: *Enigmathichthys*

Plates ascribed to the amphibian *Mastodonosaurus platyceps* have been found at Cockatoo Dock. The capitosaur *Parotosaurus (Subcyclatosaurus) brookvalensis* has been described from Brookvale by Cosgriff (1967), who considers it to be of mid-Triassic age, and Sherwin (1965) described footprints of stereospondylous amphibians resembling *Platyceps* or *Paracyclatosaurus*.

Tillyard (1925) and McKeown (1937) have described a number of arthropods, many from Brookvale. They include: insects (a large fauna), the xiphosuran *Austrolimulus fletcheri,* the merostomoid *Synaustrus brookvalensis,* a freshwater shrimp related to the still-living *Anaspides* of Tasmania, the conchostracans *Estheria* and *Cyzicus.*

Few fossil molluscs have been found. They include the freshwater pelecypod *Unio* (David, 1950), a small unidentified gastropod from Mount Yengo, and the gastropod *Tremonotus maideni* from Sydney (Etheridge, 1888).

INTERVAL 14: WIANAMATTA GROUP

Interval 14 records the last stage of deposition known in the Sydney Basin. The rocks were named the Wianamatta beds by Clarke (1848), and were later described by him as consisting predominantly of shale overlying the Hawkesbury Sandstone, together with fine sandstone, calcareous sandstone, and traces of coal. The beds were renamed the Wianamatta Group by Hanlon et al. (1953). Lovering (1954) defined a number of formations which he grouped into the Liverpool and Camden Sub-Groups. He gave a detailed description of the formations, and Herbert (1970a) re-interpreted the Bringelly Shale and associated sandstone layers. The formations in the Wianamatta Group are listed in Figure 50.

Liverpool Sub-Group

Mittagong Formation

The type section of the Mittagong Formation (Lovering & McElroy, 1969) is in the Gib Tunnel cutting near Mittagong. It consists of alternating bands and lenses of black shale and sandstone. The sandstones are calcareous and ripple-marked.

Ashfield Shale

Lovering & McElroy (1969) nominated the Potts Hill bores as type sections of the Ashfield Shale. The formation is about 30 m thick and consists of shale (rendered black with organic matter and iron sulphide), with some bands of sideritic mudstone and siltstone. There is an increase in sand towards the top. A band of calcareous cone-in-cone shale occurs well up in the formation, and a marker band of mottled sideritic mudstone near the base. Vitrain is common in the shale and there are thin lenses of impure coaly material.

Bringelly Shale

The type area of the Bringelly Shale (Lovering, 1954) is around Bringelly. The formation consists of grey-green to black shale with many bands and lenses of lithic sandstone. Herbert (1970a) has described four major sandstone bodies composed of volcanic detritus.

Plant debris is abundant in the shales.

The term 'Minchinbury Sandstone', which was used in the older literature, has been dropped by Herbert (1970a) because it is not known which of the four major sandstones within the Bringelly Shale to which it refers.

Camden Sub-Group

Potts Hill Sandstone

The type section of the Potts Hill Sandstone (Lovering, 1954) is in the Water Board quarry at Potts Hill. The formation is about 7.5 m thick and consists of massive lithic sandstone with some dark shale lenses. Iron oxide and sideritic nodules are common, and current-bedding is shown.

Annan Shale

The type section of the Annan Shale (Lovering, 1954) is on the Hume Highway on the south side of the Razorback Range. The formation is about 10 m thick and consists of dark shale with lenses of labile sandstone. Iron oxide nodules and plant debris are common.

Razorback Sandstone

The type section of the Razorback Sandstone (Lovering, 1954) is along the Hume Highway on the north side of the Razorback Range. The formation is about 18 m thick and consists of massive lithic sandstone with some thin lenses of dark shale. The cross-bedding dips to the south; iron oxide concretions and calcite veins are common. Unidentifiable plant remains are widespread.

Picton Formation

The type section of the Picton Formation (Lovering, 1954) is along the Hume Highway on the south side of the Razorback Range. It is about 30 m thick and consists of a lower sequence composed chiefly of dark shale and an upper sequence of massive sandstone from 6 to 18 m thick. The cross-bedding in the sandstone dips to the south.

Prudhoe Shale

No type section of the Prudhoe Shale (Lovering, 1954) has been defined. The thickest sequence of about 36 m is under Mount Prudhoe, the highest point in the Razorback Range. The lower part of the formation consists of grey-green shale with labile sandstone lenses, overlain by a massive sandstone which caps Mount Prudhoe.

Relations with Older Units

The Mittagong Formation at the base of the Wianamatta Group is generally conformable on the Hawkesbury Sandstone. The black shales are similar to those in the underlying Hawkesbury Sandstone and overlying Ashfield Shale, and for this reason the formation was formerly known as 'The Passage Beds'.

The sandstone lenses, however, are finer-grained than the Hawkesbury Sandstone, and almost always somewhat calcareous. There is probably an irregular erosional surface at the base of the Mittagong Formation in some areas.

Correlations and Age

Many fossils have been found in the Wianamatta Group, especially in the Ashfield Shale; the assemblage indicates that the group is of upper Anisian (Middle Triassic) age.

Etheridge (1888) described the following freshwater pelecypods from the basal beds of the Ashfield Shale and the Mittagong Formation: *Unio*(?) *wianamattensis, U. dunstani,* and *Unionella bowralensis.*

Smith-Woodward (1908) described the following fish from the Ashfield Shale, 30 m above the Hawkesbury Sandstone, at the Sydney suburb of St Peters: *Pleuracanthus parvidens, Sagenodus laticeps, Palaeoniscus crassus, Elonichthys armatus, E. semilineatus, Myriolepis pectinata, Elpisopholis dunstani, Platysomus* sp., *Acentrophorus* sp., *Palaeoniscus antipodeus, Semionotus formosus, Cleithrolepis granulata,* and *Pholidophorus australis.*

Tillyard (1916) described the following insects from the same beds at St Peters: *Notoblattites aubcostalia, Mesotitan giganteus, Klaterites wianamattensis, Metrorhynchites sydneiensis, Etheridgea petricia,* and *Mesorhynchophora dunstani.*

Chilton (1917) described the freshwater isopod *Phreatoicus wianamattensis* from the base of the Ashfield Shale.

Lovering & McElroy (1969) listed the following plants from the Ashfield Shale: *Phyllotheca australis, Cladophlebis australis, Gleichenia*(?) *dubia, Microtaeniopteris wianamattae, Sphenopteris* sp., *Dicroidium odontopteroides, D. feistamanteli, Pecopteris tenuifolia, Cycadopteris scolopendrina, Pterophyllum*(?), and *Baiera simmondsi.*

The following amphibians have also been found in the Ashfield Shale (Cosgriff, 1967): *Paracyclotosaurus davidi, Notobrachyops picketti, Mastodonosaurus,* and *Bothriceps.*

Helby (*in* Herbert, 1970a) has recorded the following acritarchs from the Bringelly Shale: *Micrhystridium, Baltisphaeridium,* and *Veryhachium.*

Some doubt has been cast on the authenticity of the recovery of Foraminifera and ostracods from the 'Minchinbury Sandstone' within the Bringelly Shale (Chapman, 1909; Love & Bembrick, 1963).

Phyllotheca-like plant-remains occur in both the shale and sandstone of the Bringelly Shale, and Lovering & McElroy (1969) list the following plants which were described by M'Coy (1847) and which were probably collected from the Potts Hill Sandstone: *Dicroidium odontopteroides, Odontopteris microphylla, Pecopteris? tenuifolia,* and *Phyllotheca hookeri.*

Helby (1970) has shown that Zonule C of the *Falcisporites* Assemblage Zone (see Fig. 44) occurs in the Ashfield Shale, and Zonule D assemblage throughout the rest of the Wianamatta Group. He has shown that Zonule D is older than early Jurassic.

The Prospect teschenitic dolerite, which intrudes the Ashfield Shale, has a K/Ar age of about 168 m.y., that is, Lower Jurassic. The Ashfield Shale is therefore probably older than Lower Jurassic.

LIST OF SEDIMENTARY ROCK UNITS

Rock Unit	*Stratigraphic Position*	*Age*	*Area*	*Interval*
Abbey Green Seam	bottom seam of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Adamstown Sub-Group	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Alcheringa Seam	middle of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Allandale Formation	middle of Dalwood Gp	Sakmarian	Lochinvar Anticline, Hunter Valley	1
Allans Creek Formation	Illawarra Coal Measures	Tatarian	Southern Coalfield	11
America Creek Seam	middle of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Annan Shale	in Camden Sub-Gp of Wianamatta Gp	M. Triassic (Anisian)	southwest-Central Area	14
Appin Formation	middle of Illawarra Coal Measures	Tatarian	Southern Coalfield	11
Appletree Flat Sub-Group	base of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Archerfield Formation	lower part of Wittingham Coal Measures	l. Tatarian	upper Hunter Valley	7
Ashfield Shale	at, or near, base of Wianamatta Gp	Triassic (Scythian-Anisian)	Central Area	14
Austinmer Sandstone	lower part of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Australasian Seam	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Awaba Tuff Member	near top of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Bald Hill Claystone	near top of Narrabeen Gp	L. Triassic (Scythian)	south-Central Area	12
Balgownie Seam	near top of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Banks Wall Sandstone	top of Grose Sub-Gp (=Grose Sst) in Narrabeen Gp	L. Triassic (Scythian)	Western Area	12
Bar Beach Formation	lower part of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Bargo Claystone	lower part of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Bayswater Seam	bottom of Burnamwood Fm	m. Tatarian	upper Hunter Valley	9
Beauchamp Falls Shale	base of Narrabeen Gp	u. Tatarian	Western Area	12
Belmont Conglomerate Member	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Bend Creek Seam	middle of Illawarra Coal Measures	u. Tatarian	Southwestern Coalfield	11

Rock Unit	*Stratigraphic Position*	*Age*	*Area*	*Interval*
Berry Formation	top of Shoalhaven Gp	Kazanian	southern half of basin	6
Brimlow Seam	middle of Illawarra Coal Measures	u. Tatarian	Southwestern Coalfield	11
Big Ben Seam	middle of Tomago Coal Measures	l. Tatarian	lower Hunter Valley	9
Blackmans Flat Conglomerate	lower Illawarra Coal Measures	u. Tatarian	Western Coalfield	11
Brimstone Seam	lower Illawarra Coal Measures	u. Tatarian	Southwestern Coalfield	11
Bogey Hole Formation	lower part of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Boolaroo Sub-Group	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Borehole Seam	lowest seam in Newcastle Coal Measures	Tatarian	lower Hunter Valley	11
Branxton Formation	bottom of Maitland Gp	Artinskian-Kungurian	Hunter Valley	4
Bringelly Shale	Liverpool Sub-Gp of Wianamatta Gp	Triassic (Scythian-Anisian)	Central Area	14
Broughton Sandstone Member	upper part of Shoalhaven Gp	u. Kazanian	Illawarra District	7
Budgong Sandstone	base of Illawarra Coal Measures	l. Tatarian	Southern Coalfield	7
Bulga Formation	lower part of Wittingham Coal Measures	l. Tatarian	upper Hunter Valley	7
Bulgo Sandstone	middle of Narrabeen Gp	L. Triassic (Scythian)	south-Central Area	12
Bulli Seam	top of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Bunnyong Sandstone	middle of Illawarra Coal Measures	u. Tatarian	Western Coalfield	11
Burnamwood Formation	Wittingham Coal Measures	Tatarian	upper and middle Hunter Valley	9
Burragorang Claystone	upper part of Illawarra Coal Measures	u. Tatarian	western and Southwestern Coalfields	11
Burralow Formation	top of Narrabeen Gp	L. Triassic (Scythian)	Western Area	12
Burra-Moko Head Sandstone	middle and lower part of Grose Sub-Gp in Narrabeen Gp	L. Triassic (Scythian)	Western Area	12
Buttai Seams	middle of Tomago Coal Measures	m. Tatarian	lower Hunter Valley	9
Caley Sub-Group (=Caley Formation)	lower units of Narrabeen Gp	uppermost Tatarian	Western Area	12
Camden Sub-Group	upper sub-group of Wianamatta Gp	Triassic (Scythian-Anisian)	Central Area	14
Cape Horn Seam	upper part of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Cardiff Sub-Group	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11

Rock Unit	*Stratigraphic Position*	*Age*	*Area*	*Interval*
Cessnock Sandstone	basal member of Branxton Fm; conformable on Greta Coal Measures	u. Artinskian	lower and middle Hunter Valley	4
Chaenomya Beds	top of Mulbring Sltst	u. Kazanian	middle Hunter Valley	6
Charbon Sub-Group	upper part of Illawarra Coal Measures	mid-Tatarian	Western Coalfield	10, 11
Charlestown Conglomerate Member	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Charlton Formation	near bottom of Wolombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Clifford Formation	middle of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Clifton Sub-Group	lowest three formations of Narrabeen Gp	L. Triassic (Scythian)	mid-Central area	12
Clwydd Sandstone	near base of Caley Sub-Gp of Shoalhaven Gp	near top of Tatarian	Western Area	12
Clyde Coal Measures	near base of Conjola Sub-Gp of Shoalhaven Gp	Sakmarian	Clyde R. in far south of basin	1
Coal Cliff Sandstone	base of Narrabeen Gp	uppermost Tatarian	south-Central Area	12
Colemans Creek Formation	middle of Illawarra Coal Measures	u. Tatarian	Southwestern Coalfield	11
Conjola Sub-Group	lower part of Shoalhaven Gp; unconformable on lower and middle Palaeozoic	Sakmarian	Southern Area	1-3
Coorongooba Creek Sandstone (=Coorongooba Formation)	in Nile Sub-Gp of Illawarra Coal Measures	Tatarian	Western Area	8
Croudace Bay Formation	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Cumberland Sub-Group	lower Illawarra Coal Measures	Tatarian	Central Area	7, 8
Currumbene Siltstone Member	in Nowra Sst	Kazanian	Southern Area	5
Dalwood Group	above Kuttung Gp	Sakmarian	Hunter Valley	1, 2
Darkes Forest Sandstone	lower part of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Dempsey Formation	top of Tomago Coal Measures	Tatarian	lower Hunter Valley	10
Dirty or Middle River Seam	middle of Illawarra Coal Measures	u. Tatarian	Western Coalfield	11
Dochra Siltstone Member	in Mulbring Sltst	Kazanian	middle Hunter Valley	6
Donaldsons Seam	middle of Tomago Coal Measures	l. Tatarian	lower Hunter Valley	9
Doyles Creek Sub-Group	Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11

Rock Unit	Stratigraphic Position	Age	Area	Interval
Dudley Seam	lower part of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Eckersley Formation	upper part of Illawarra Coal Measures	Tatarian	Southern Coalfield	11
Eleebana Formation	upper part of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Erins Vale Formation	in lower part of Illawarra Coal Measures	l. Tatarian	Southern Coalfield	8
Fairford Claystone Bed	Burnamwood Fm	m. Tatarian	upper Hunter Valley	9
Farley Formation	top of Dalwood Gp	Sakmarian	Hunter Valley	2
Fassifern Seam	upper part of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Fenestella Zone (=*Fenestella* Shale)	within Branxton Fm	Artinskian-Kungurian	lower and middle Hunter Valley	4
Fern Valley Seam	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Figtree Coal Members	lower part of Illawarra Coal Measures	l. Tatarian	Illawarra District	7
Four Mile Creek Formation	Tomago Coal Measures	Tatarian	lower Hunter Valley	9
Foybrook Formation	lower part of Wittingham Coal Measures	l. Tatarian	upper Hunter Valley	7
Gillans Creek Seam	upper part of Illawarra Coal Measures	u. Tatarian	Southwestern Coalfield	11
Glendon Siltstone Member	in Mulbring Sltst	Kazanian	middle Hunter Valley	6
Glen Gallic Sub-Group	top of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Gosford Formation	top of Narrabeen Gp	L. Triassic (Scythian)	mid-Central Area	12
Gosforth Shale	base of Lochinvar Fm	Sakmarian	lower Hunter Valley	1
Govetts Leap Sandstone	in Caley Sub-Gp of Narrabeen Gp	near top of Tatarian	Western Area	12
Great Northern Seam	near top of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Greigs Creek Seam	top unit of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Greta Coal Measures	above Dalwood Gp; below Branxton Fm	m. Sakmarian/ u. Artinskian	Hunter Valley	3
Grose Sub-Group (=Grose Sandstone)	middle of Narrabeen Gp	L. Triassic (Scythian)	Western Area	12
Gundangaroo Formation	top of Nile Sub-Gp of Illawarra Coal Measures	Tatarian	Western Coalfield	9
Gyarran Volcanics	Dalwood Gp	early Sakmarian	upper Hunter Valley	1

Rock Unit	Stratigraphic Position	Age	Area	Interval
Hargrave Seam	upper part of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Hartley Hill Seam	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Hartley Vale Claystone	top of Caley Sub-Gp in Narrabeen Gp	on Permo-Triassic boundary	Western Area	12
Hawkesbury Sandstone	above Narrabeen Gp; below Wianamatta Gp	Triassic (Scythian and/or Anisian)	widely distributed, mainly in Central Area	13
Hebden Seam	near bottom of Wittingham Coal Measures	l. Tatarian	upper Hunter Valley	7
Higgins Creek Sandstone	Charbon Sub-Gp	m. Tatarian	Southwestern Coalfield	10
Hillsdale Seam	near top of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Hobden Gully Seam	upper part of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Homeville Coal Member	in Greta Coal Measures	l. Artinskian	lower and middle Hunter Valley	3
Horseshoe Creek Sub-Group	in Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Illawarra Coal Measures	above Maitland Gp or Shoalhaven Gp; below Narrabeen Gp	Tatarian	Central, Western, and Southern Areas	7-11
Irondale Seam	middle of Illawarra Coal Measures	u. Tatarian	Western Coalfield	11
Ivanhoe or 'Vertebraria' Sandstone	middle of Illawarra Coal Measures	u. Tatarian	Western Coalfield	11
Jamberoo Sandstone Member	upper part of Shoalhaven Gp	u. Kazanian	Illawarra District	7
Kahibah Formation	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Katoomba Claystone Member	middle of Burra-Moko Head Sst in Grose Sub-Gp of Narrabeen Gp	L. Triassic (Scythian)	Western Area	12
Katoomba Seam	top of Illawarra Coal Measures	Tatarian	Western Coalfield	11
Kembla Sandstone	middle of Illawarra Coal Measures	m. Tatarian	Southern Coalfield	11
Kiama Sandstone Member	upper part of Shoalhaven Gp	u. Kazanian	Illawarra District	7
Kitchener Formation	in upper part of Greta Coal Measures	l. Artinskian	lower Hunter Valley	3
Kooloo Seam	bottom seam of Illawarra Coal Measures	u. Tatarian	Southwestern Coalfield	11
Kotara Formation	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Kulnura Marine Tongue	in Erins Vale Fm of lower part of Illawarra Coal Measures	Tatarian	eastern half of Sydney Basin	8

Rock Unit	Stratigraphic Position	Age	Area	Interval
Kurri Kurri Conglomerate	in Greta Coal Measures	l. Artinskian	lower Hunter Valley	3
'Kuttung Group'	below Dalwood Gp	Carboniferous	lower Hunter Valley	—
Lacys Creek Sandstone	middle of Illawarra Coal Measures	u. Tatarian	Southwestern Coalfield	11
Lambton Sub-Group	base of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Lawrence Sandstone	upper part of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Lidsdale Seam	lower part of Illawarra Coal Measures	u. Tatarian	Western Coalfield	11
Lithgow Seam	lowest coal seam in Illawarra Coal Measures	Tatarian	Western Coalfield	11
Liverpool Sub-Group	lower Sub-Gp of Wianamatta Gp	Triassic (Scythian-Anisian)	Central Area	14
Lochinvar Formation	base of Dalwood Gp	Sakmarian	Hunter Valley	1
Lower Pilot Seam	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Lucernia Seam	middle of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Maitland Group	conformable on Greta Coal Measures; below Singleton Coal Measures	Kungurian/ u. Kazanian	Hunter Valley	4-6
Malabar Formation	in upper part of Wittingham Coal Measures	Tatarian	upper and middle Hunter Valley	9, 10
Mangrove Sandstone Member	in upper part of Gosford Fm	L. Triassic (Scythian)	Hawkesbury R. Valley in mid-Central area	12
Marrangaroo Conglomerate	base of Charbon Sub-Gp of Illawarra Coal Measures	m. Tatarian	Western Coalfield	10
Megalong Conglomerate	unconformable on middle Palaeozoic; basin margin equivalent of Shoalhaven Gp	Sakmarian/ l. Kazanian	Western Area	1-6
Menai Claystone Member	middle of Bulgo Sst in Narrabeen Gp	L. Triassic (Scythian)	south-Central area	12
Merewether Conglomerate Member	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Middle River or Dirty Seam	middle of Illawarra Coal Measures	u. Tatarian	Western Coalfield	11
Minchinbury Sandstone	in Liverpool Sub-Gp of Wianamatta Gp	Triassic (Scythian-Anisian)	Central Area	14
Mittagong Formation	base of Wianamatta Gp	Triassic (Scythian-Anisian)	southwest-Central Area	14
Monkey Place Creek Tuff Member	near bottom of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Montrose Seam	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11

Rock Unit	Stratigraphic Position	Age	Area	Interval
Moon Island Beach Sub-Group	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Mount Arthur Coal Member	Burnamwood Fm	m. Tatarian	upper Hunter Valley	9
Mount Hutton Formation	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Mount Marsden Claystone (=Mount Marsden Formation)	base of Nile Sub-Gp of Illawarra Coal Measures	l. Tatarian	Western Coalfield	7
Mount Ogilvie Formation	in middle part of Wittingham Coal Measures	Tatarian	upper and middle Hunter Valley	9
Mount York Formation	in Grose Sub-Gp Narrabeen Gp	L. Triassic (Scythian)	Western Area	12
Mulbring Siltstone	top of Maitland Gp	Kazanian	Hunter Valley	6
Munmorah Formation	base of Clifton Sub-Gp of Narrabeen Gp	uppermost Tatarian	mid-Central Area	12
Muree Sandstone Member	top of Branxton Fm	l. Kazanian	Hunter Valley	5
Nalleen Tuff	upper part of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Narrabeen Group	above youngest Tatarian coal measures	latest Permian (Tatarian)/L. Triassic (Scythian)	widely distributed	12
Nattai Seam	top of Illawarra Coal Measures	u. Tatarian	Southwestern Coalfield	11
Neath Sandstone	base of Greta Coal Measures	Artinskian	lower Hunter Valley	3
Newcastle Coal Measures	below Narrabeen Gp	u. Tatarian	lower Hunter Valley	11
Newport Formation	top of Narrabeen Gp	L. Triassic (Scythian)	south-Central Area	12
Nile Sub-Group	lower part of Illawarra Coal Measures	Tatarian	Western Coalfield	7-9
Nobbys Seam	lower part of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Nobbys Tuff Member	lower part of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Novice Sandstone	middle of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Nowra Sandstone	in upper part of Shoalhaven Gp	l. Kazanian	southern half of basin	5
Ourimbah Sandstone Member	in middle part of Gosford Fm of Narrabeen Gp	L. Triassic (Scythian)	mid-Central Area	12
Patonga Claystone	top of Clifton Sub-Gp in Narrabeen Gp	L. Triassic (Scythian)	mid-Central Area	12
Paxton Formation	top of Greta Coal Measures	m. Artinskian	lower Hunter Valley	3

Rock Unit	Stratigraphic Position	Age	Area	Interval
Pebbley Beach Formation	middle of Conjola Sub-Gp of Shoalhaven Gp	u. Sakmarian/ l. Artinskian	southern part of Southern Area	2
Pelton Coal Member	Paxton Fm of Greta Coal Measures	Artinskian	lower Hunter Valley	3
Pheasants Nest Formation	base of Illawarra Coal Measures	l. Tatarian	Southern Coalfield	7
Picton Formation	in Camden Sub-Gp of Wianamatta Gp	M. Triassic (Anisian)	southwest-Central Area	14
Pigeon House Creek Siltstone	base of Conjola Sub-Gp of Shoalhaven Gp	Sakmarian	southern part of Southern Area	1
Pikes Gully Seam	lower part of Wittingham Coal Measures	l. Tatarian	upper Hunter Valley	7
Pinegrove Formation	middle of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Potts Hill Sandstone	in Camden Sub-Gp of Wianamatta Gp	M. Triassic (Anisian)	southwest-Central Area	14
Prudhoe Shale	top of Wianamatta Gp	M. Triassic (Anisian)	southwest-Central Area	14
Rathluba Seam	lower part of Tomago Coal Measures	l. Tatarian	lower Hunter Valley	7
Ravensfield Sandstone Member	base of Farley Fm	Artinskian	lower Hunter Valley	3
Razorback Sandstone	in Camden Sub-Gp of Wianamatta Gp	M. Triassic (Anisian)	southwest-Central Area	14
Redmanvale Creek Formation	near top of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Reids Mistake Formation	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Rowan Formation	upper part of Greta Coal Measures	Artinskian	upper Hunter Valley	3
Rutherford Formation	top of Dalwood Gp	Sakmarian	Hunter Valley	2
Saltwater Creek Formation	base of Wittingham Coal Measures	l. Tatarian	middle and upper Hunter Valley	7
Scarborough Sandstone	lower part of Narrabeen Gp	top of Tatarian	south-Central Area	12
Scotch Derry Seam	middle of Tomago Coal Measures	l. Tatarian	lower Hunter Valley	8
Seaham Formation	top of 'Kuttung Gp'	near Permian-Carboniferous boundary	Hunter Valley	—
Shepherds Hill Formation	lower part of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Shoalhaven Group	unconformable on lower and middle Palaeozoic; conformable beneath Illawarra Coal Measures	l. Sakmarian/ u. Kazanian	southern half of basin	1-6
Singleton Coal Measures	above Mulbring Sltst; beneath Narrabeen Gp	Tatarian	middle and upper Hunter Valley	7-11

Rock Unit	Stratigraphic Position	Age	Area	Interval
Skeletar Formation	top of Dalwood Gp (this Bulletin) or base Greta Coal Measures (see Appendix 1)	early Sakmarian	upper Hunter Valley	1
Snapper Point Formation	upper part of Conjola Sub-Gp	m. Artinskian	southern part of Southern Area	3
Stafford Seam	lower part of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Stanwell Park Claystone	near middle of Narrabeen Gp	base of Triassic (Scythian)	south-Central Area	12
Strathmore Formation	middle of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Sydney Sub-Group	upper part of Illawarra Coal Measures	Tatarian	Central Area	9-11
Tabarag Member	in Burralow Fm of Narrabeen Gp	L. Triassic (Scythian)	Western Area	12
Tallong Conglomerate	base of Conjola Sub-Gp	earliest Sakmarian	western part of Clyde R. Coalfield	1
Tighes Hill Formation	lower part of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Tickhole Formation	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Tomago Coal Measures	above Mulbring Sltst; below Newcastle Coal Measures	l. and m. Tatarian	lower Hunter Valley	7-10
Tongarra Seam	in Illawarra Coal Measures	Tatarian	Southern Coalfield	11
Tuggerah Formation	middle of Clifton Sub-Gp in Narrabeen Gp	L. Triassic (Scythian)	mid-Central Area	12
Ulladulla Mudstones	near base of Wandrawandian Sltst	Artinskian	southern part of Southern Area	4
Unanderra Coal Member	lower part of Illawarra Coal Measures	l. Tatarian	Illawarra District	7
Undola Sandstone Member	base of top of Gosford Fm; below Hawkesbury Sst	L. Triassic (Scythian)	south of Botany Bay, Central Area	13
Upper Pilot Seam	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Vane Sub-Group	in lower part of Wittingham Coal Measures	Tatarian	middle and upper Hunter Valley	7, 8
'Vertebraria' or Ivanhoe Sandstone	middle of Illawarra Coal Measures	u. Tatarian	Western Coalfield	11
Victoria Pass Sandstone	middle of Caley Sub-Gp of Narrabeen Gp	u. Tatarian	Western Area	12
Victoria Tunnel Seam	lower part of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Wallarah Seam	top of Newcastle Coal Measures	Tatarian	lower Hunter Valley	11

Rock Unit	Stratigraphic Position	Age	Area	Interval
Wallis Creek Formation	base of Tomago Coal Measures	l. Tatarian	lower Hunter Valley	7
Wandrawandian Siltstone	middle of Shoalhaven Gp	Artinskian-Kungurian	southern half of basin	4
Waratah Sandstone	base of Newcastle Coal Measures	Tatarian	lower Hunter Valley	10
Warners Bay Formation	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Wasp Head Formation	base of Conjola Sub-Gp of Shoalhaven Gp	l. Sakmarian	southern part of Southern Area	1
Waterfall Gully Formation	middle of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Watts Sandstone	base of Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	10
Westley Park Sandstone Member	upper part of Shoalhaven Gp	u. Kazanian	Illawarra District	7
Whybrow Coal Member	top of Wittingham Coal Measures	u. Tatarian	middle Hunter Valley	9
Wilton Formation	Illawarra Coal Measures	m. Tatarian	Southern Coalfield	10, 9
Wittingham Coal Measures	above Mulbring Sltst; below Wollombi Coal Measures	l. and m. Kazanian	middle and upper Hunter Valley	7-10
Wollombi Coal Measures	below Narrabeen Gp	u. Tatarian	middle Hunter Valley	10, 11
Wollong Siltstone Member	in Branxton Fm	Kungurian	lower and middle Hunter Valley	4
Wombarra Shale	near base of Narrabeen Gp	uppermost Tatarian	south-Central Area	12
Wongawilli Seam	middle of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Woodford Seam	upper part of Illawarra Coal Measures	u. Tatarian	Western Coalfield	11
Woonona Coal Member	Wilton Fm	m. Tatarian	Southern Coalfield	9
Woronora Seam	middle of Illawarra Coal Measures	u. Tatarian	Southern Coalfield	11
Wyong Sandstone Member	in lower part of Gosford Fm of Narrabeen Gp	L. Triassic (Scythian)	mid-Central Area	12
Yadboro Conglomerate	base of Conjola Sub-Gp	Sakmarian	southern part of Southern Area	1
Yard Seam	lower part of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11

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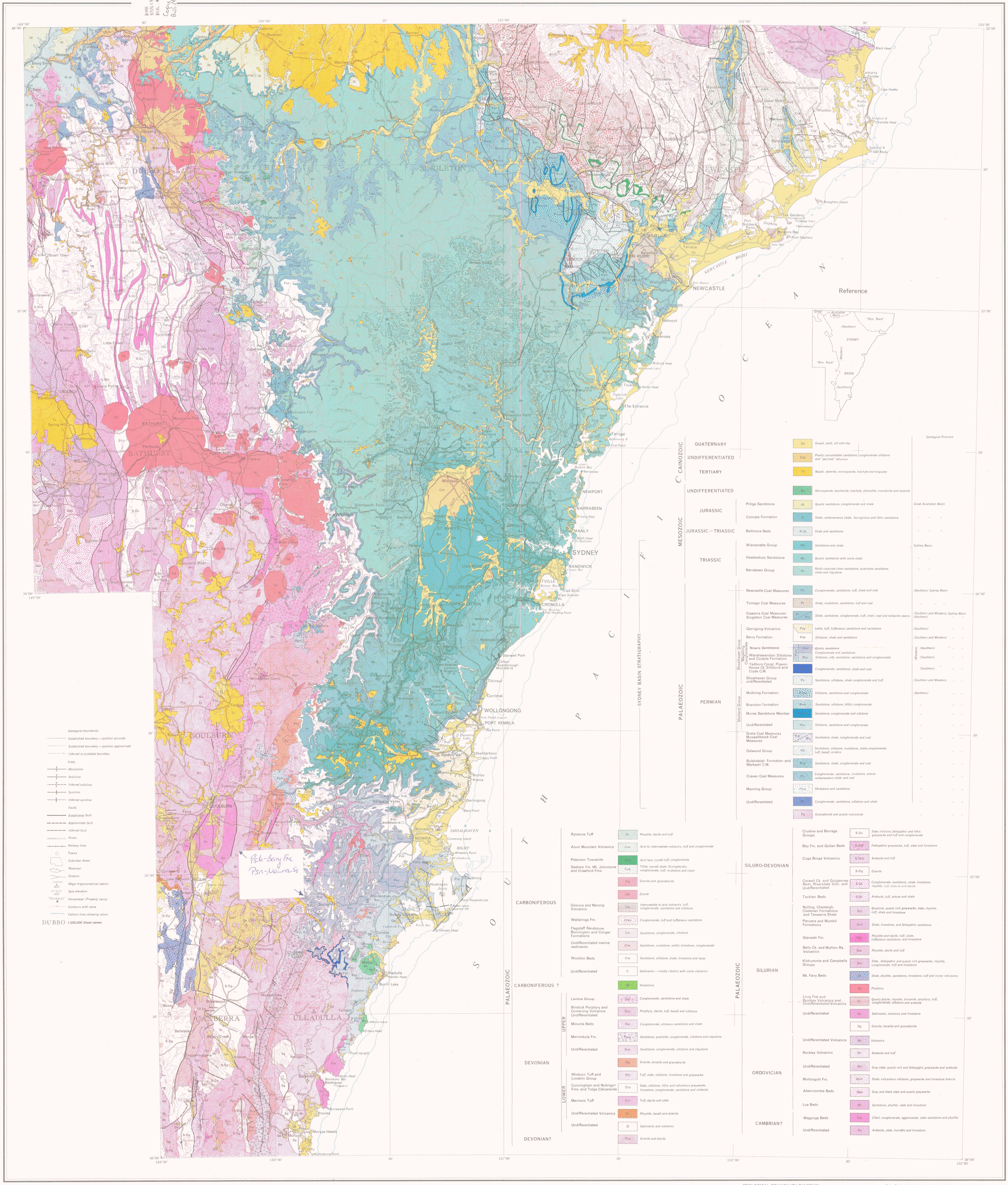
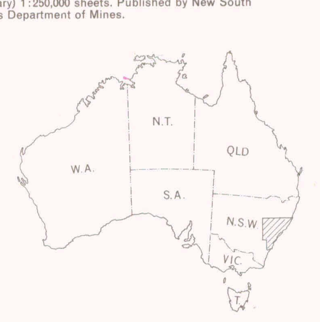
NEW SOUTH WALES 1:500,000

SYDNEY BASIN

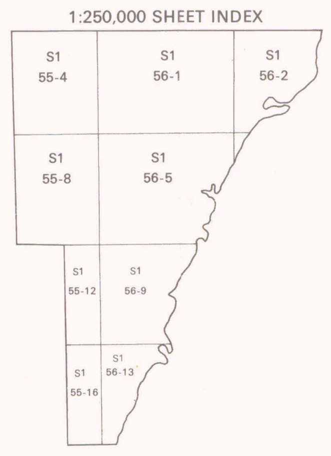
1:500,000 GEOLOGICAL SHEET (SPECIAL)



Compiled by Geological Survey of New South Wales, Division of Regional Geology from 1:250,000 Geological Sheets of the Department of Mines. Base compiled by Austral Cartographic Service, Canberra, in conjunction with the Geological Survey Cartographic Section from R.A.S.C. (Military) 1:250,000 sheets. Published by New South Wales Department of Mines.



1:250,000 SHEET INDEX



Scale 1:500,000

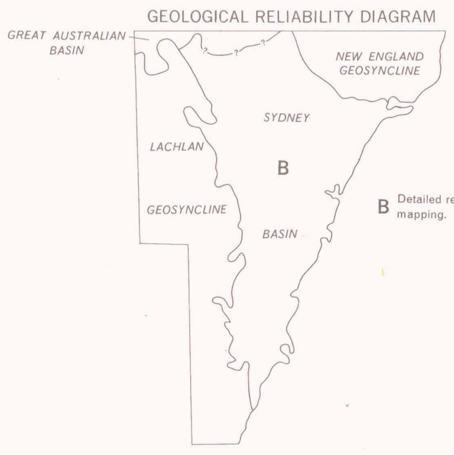
10 0 10 20 30 40 50 Statute Miles

10 0 10 20 30 40 Nautical Miles

20,000 0 20,000 40,000 60,000 Yards

10 0 10 20 30 40 50 Kilometres

GEOLOGICAL RELIABILITY DIAGRAM

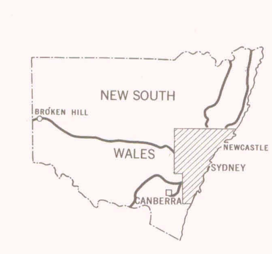


B Detailed reconnaissance mapping.

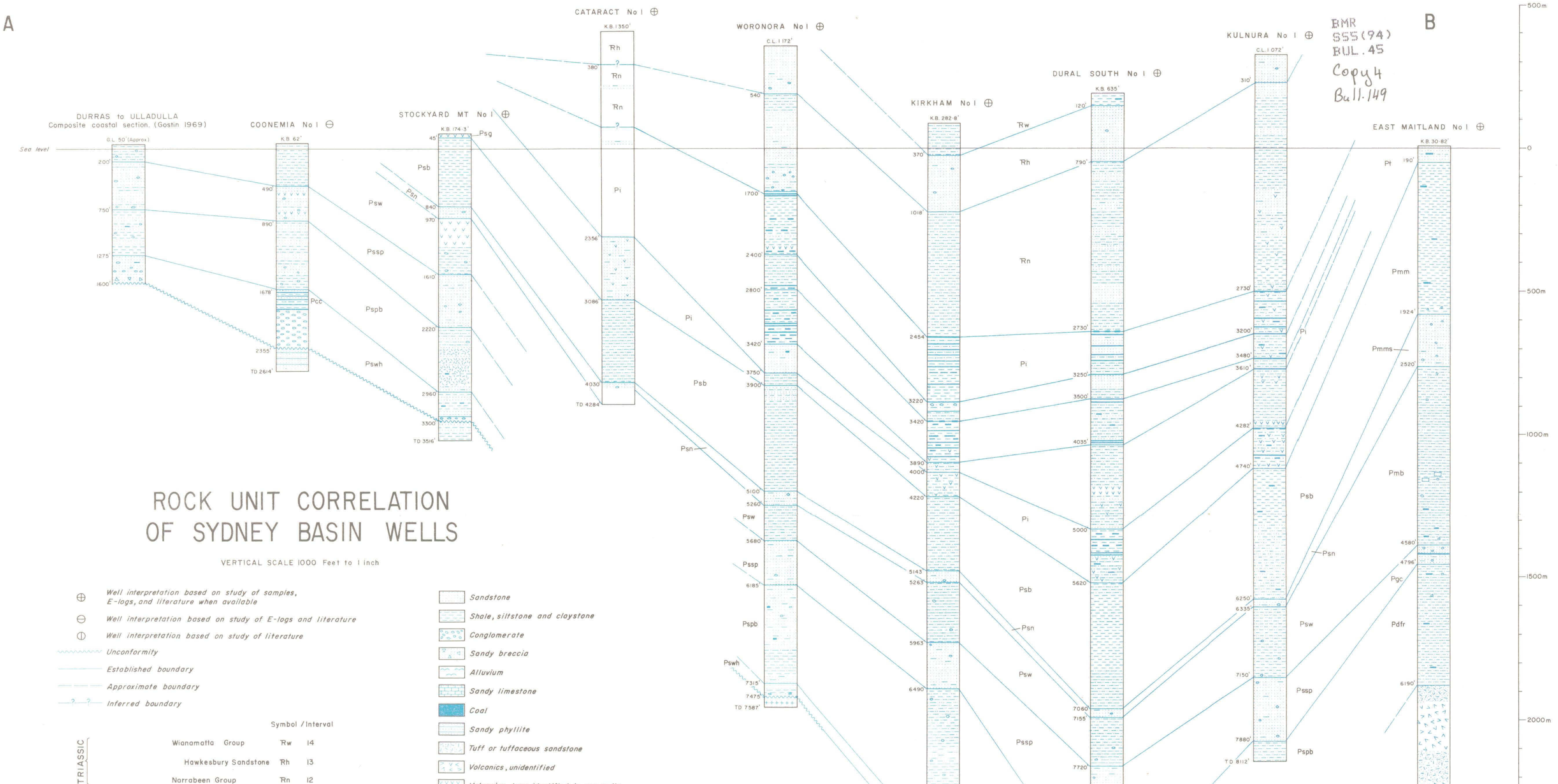
Major Geological Contributors: Geological Survey of New South Wales, Universities of Sydney, N.S.W. and Newcastle, Australian Oil and Gas Corporation Ltd.

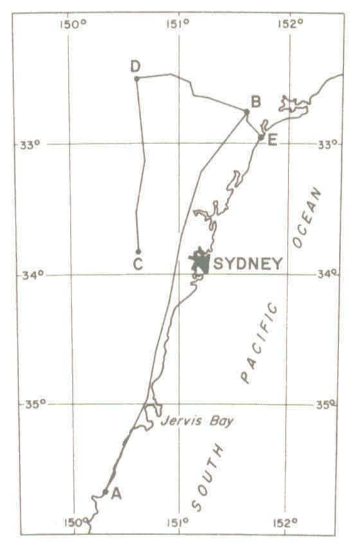
Compiled by: R. L. Brunker and G. Rose 1967

Drawn by: Mercury Press Pty. Ltd., Hobart.



V. C. N. Blight, Government Printer, New South Wales—1969





ROCK UNIT CORRELATION OF SYDNEY BASIN WELLS

VERTICAL SCALE 1000 Feet to 1 inch

⊕ *Well interpretation based on study of samples, E-logs, and literature when available*

⊖ *Well interpretation based on study of E-logs and literature*

⦶ *Well interpretation based on study of literature*

Unconformity

Established boundary

Approximate boundary

Inferred boundary

Sandstone

Shale, siltstone and claystone

Conglomerate

Sandy breccia

Alluvium

Sandy limestone

Coal

Sandy phyllite

Tuff or tuffaceous sandstone

Volcanics, unidentified

Volcanics, type identified in appendix

Granodiorite

TRIASSIC

	Symbol / Interval	
Wianamatta Group	℞w	14
Hawkesbury Sandstone	℞h	13
Narrabeen Group	℞n	12
Illawarra Coal Measures	Pi	7-11
Singleton Coal Measures	Pnt	7-11
Newcastle Coal Measures	Pn	11
Tomago Coal Measures	Pt	7-10

PERMIAN

NORTHERN AREA

	Symbol / Interval	
Maitland Group		
Mulbring Siltstone	Pmm	6
Muree Sandstone Mbr	Pmms	5
Branxton Formation	Pmb	4
Greta Coal Measures	Pgc	3
Dalwood Group		
Farley – Rutherford Formations Undiff.	Pdfr	2
Farley Formation	Pdf	2
Rutherford Formation	Pdr	2
Allandale – Lochinvar Formations Undiff.	Pdal	1

SOUTHERN AREA

	Symbol / Interval	
Shoalhaven Group		
Gerringong Volcanics	Psg	7
Berry Formation	Psb	6
Nowra Sandstone	Psn	5
Wandrawandian Siltstone	Psw	4
Conjola Sub-Group		
Snapper Point Formation	Pssp	3
Pebbley Beach Formation	Pspb	2
Wasp Head Formation	Pswh	1
Clyde Coal Measures	Pcc	1

XAUS — 3 — 18 A

ROCK UNIT CORRELATION OF SYDNEY BASIN WELLS

VERTICAL SCALE 1000 Feet to 1 Inch

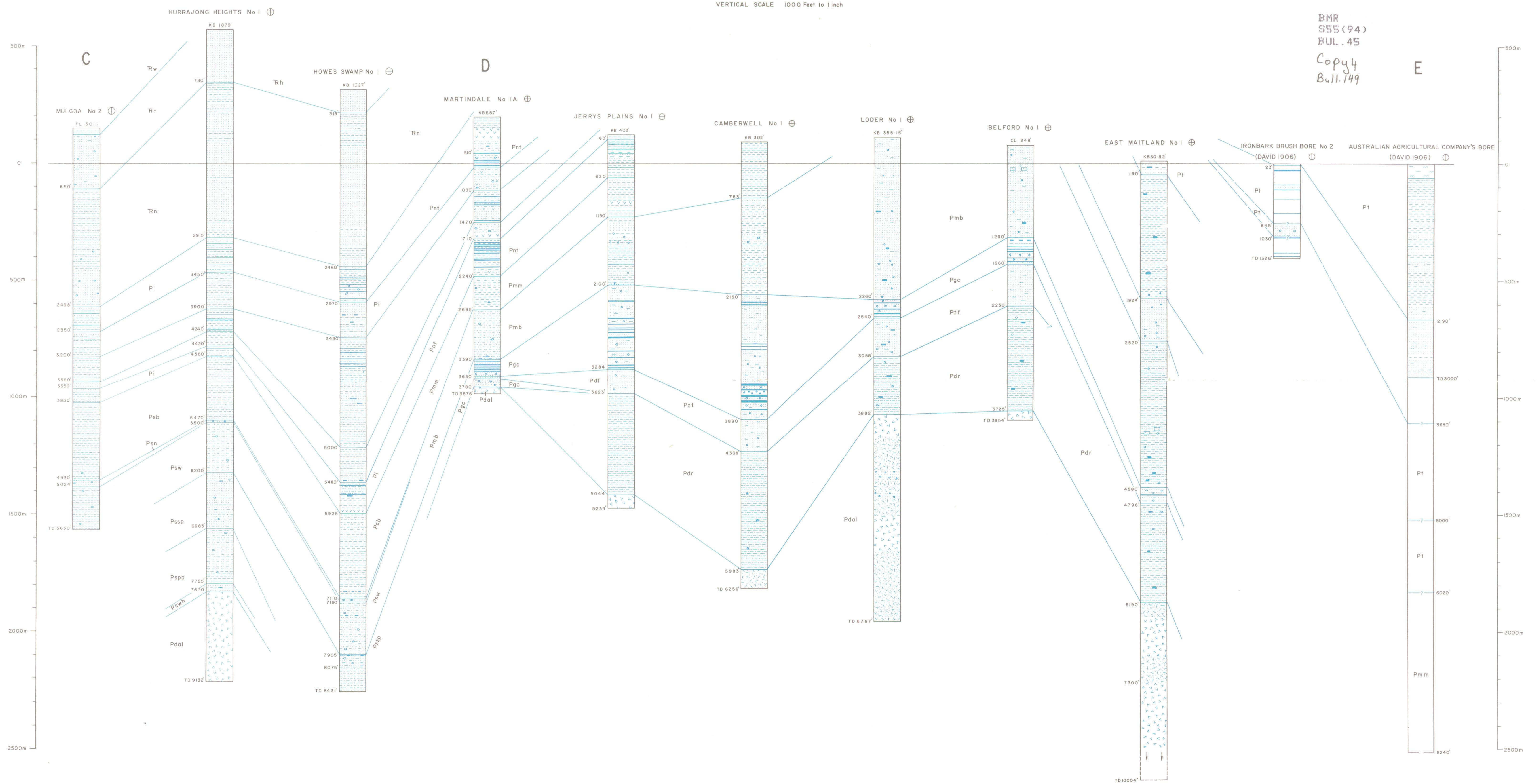
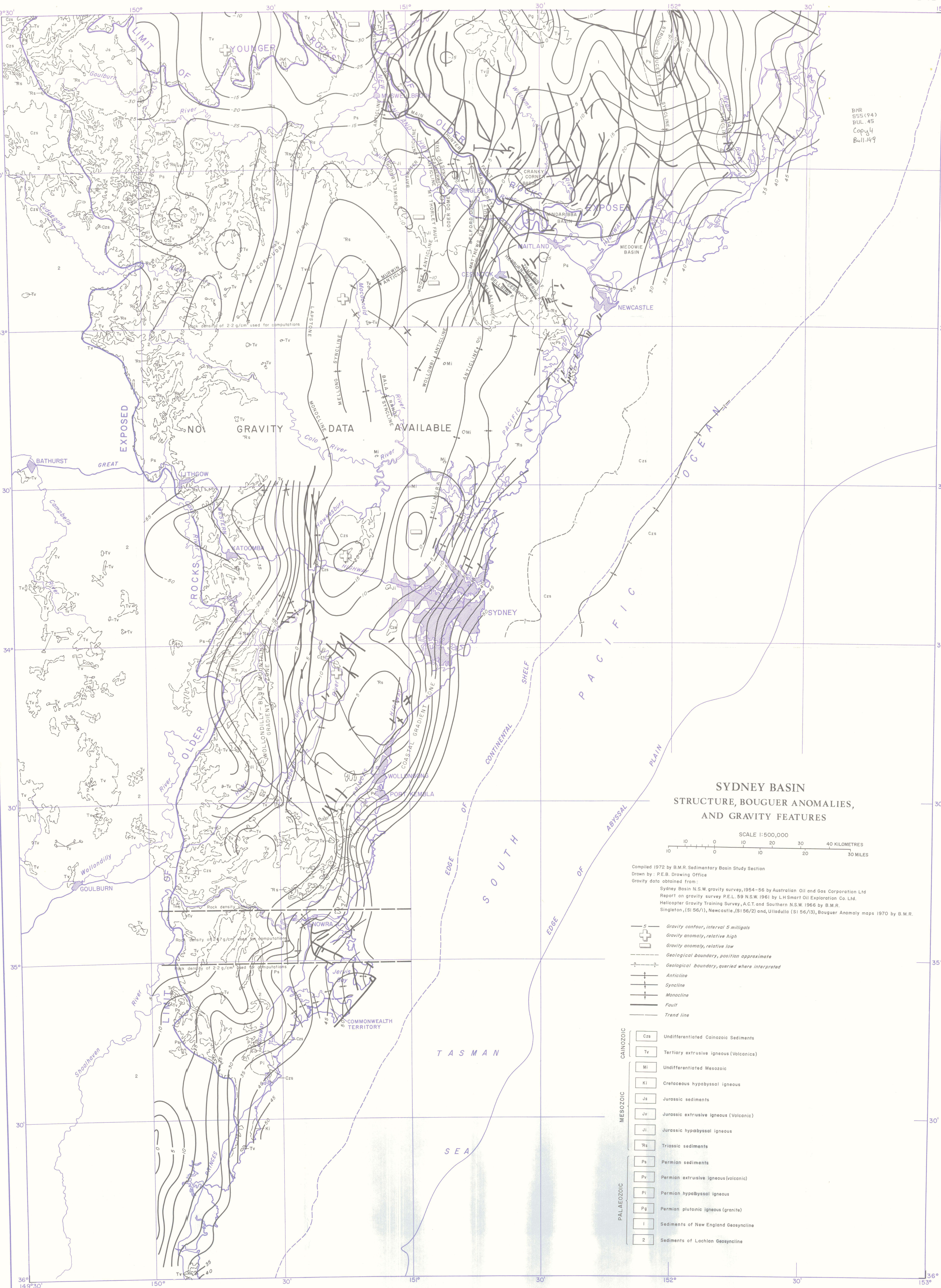


PLATE 4

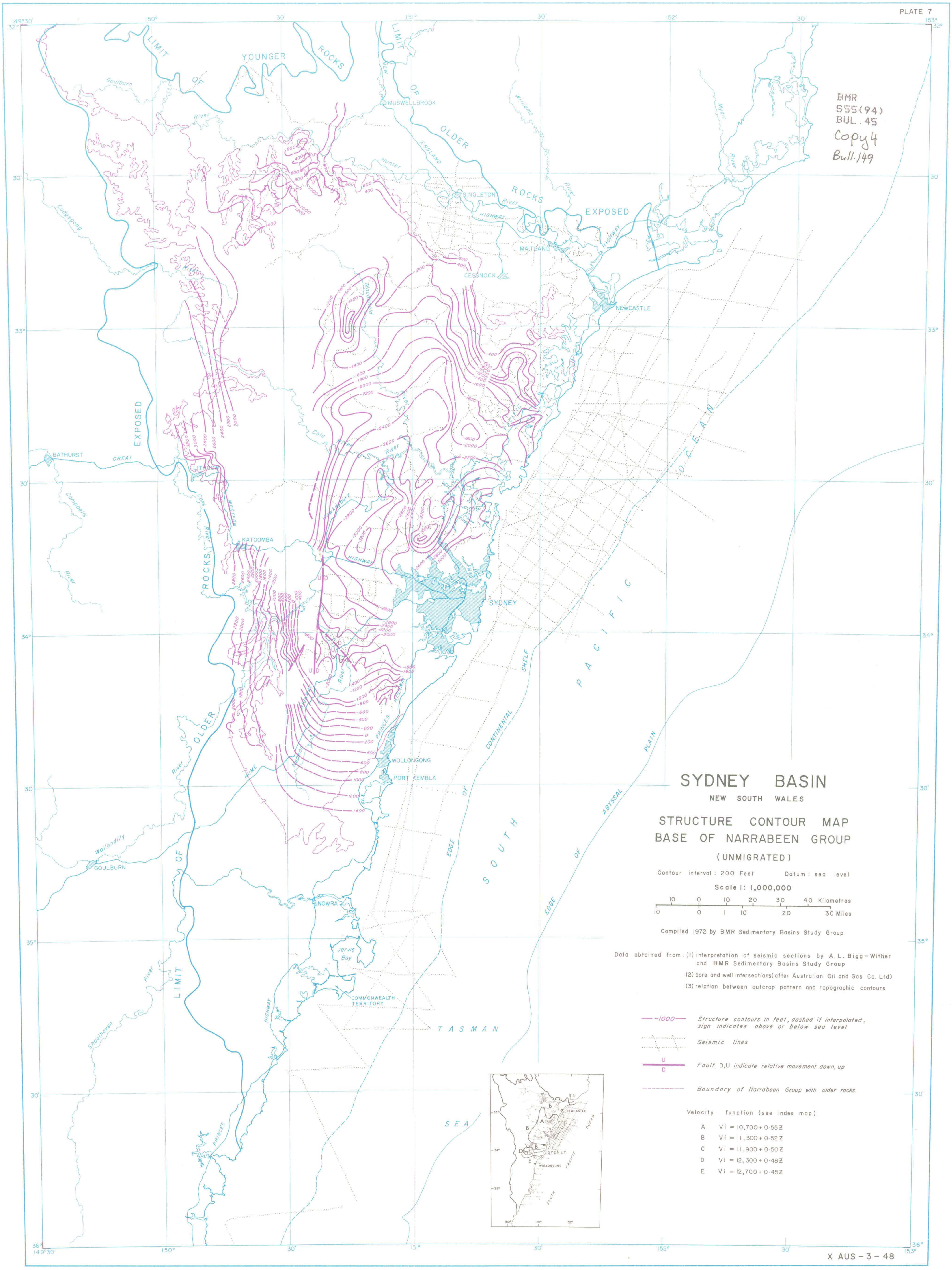

BMR
555(94)
BUL. 45
Copy 4
Bull. 149
SYDNEY BASIN
LOCATION OF CONTROL POINTS
SCALE 1:500,000
40 KILOMETRES
30 MILES
Compiled and issued by the Bureau of Mineral Resources, Department of National Development.
Topography based on Royal Australian Survey Corps and Division of National Mapping 1:250,000 Series.
Cartography by Petroleum Exploration Branch, Bureau of Mineral Resources.
Drawn by J.L.Mc Govern and N.Kozin
Tranverse Mercator Projection
GEOLOGICAL CONTROL
Well
Measured outcrop section
Composite section constructed from two or more outcrops or wells
Generalized section constructed from scattered incomplete sections in the surrounding area
GEOPHYSICAL CONTROL
Seismic survey index number
Seismic traverse identification (Lettered and/or numbered)
Seismic shot point numbers
N.T.
QLD
W.A.
S.A.
N.S.W.
VIC.
LIMIT OF YOUNGER ROCKS
LIMIT OF OLDER ROCKS EXPOSED
MUSWELLBROOK
SINGLETON
MAITLAND
CESSNOCK
NEWCASTLE
BATHURST
LITHGOW
KATOOMBA
SYDNEY
WOLLONGONG
PORT KEMBLA
GOULBURN
NOWRA
Jervis Bay
COMMONWEALTH TERRITORY
PACIFIC OCEAN
TASMAN SEA
EDGE OF CONTINENTAL SHELF
SOUTH EDGE OF ABYSSAL PLAIN
X AUS-3-31

PLATE 5



BMR 555(94) BUL. 45 Copy 4 Bull. 149

No.	NAME	DATE	CONTRACTOR	HEIGHT A.M.S.L.	P.E.L.	LICENSEE
1	Sydney Basin Test	1954	Adastra Hunting Geophysics P/L	4000 Feet	9, 10, 13	Aust. Oil and Gas Corp. Ltd.
2	Sydney Basin	1955	Adastra Hunting Geophysics P/L	4000 Feet	9, 10, 13	Aust. Oil and Gas Corp. Ltd.
3	West Maitland	1958	Adastra Hunting Geophysics P/L		11	P.E. Gould
4	Sydney-Nowra *	1962/63	Aero Service Ltd.	3500 feet Area 1A; 2000 Feet Areas 1-5	59, 60, 63, 64	L. H. Smart Oil Exploration Co. Ltd.
5	Terrigal x *	1964	Aero Service Ltd.	1500 Feet	70	Central Coast Oil P/L
6	Sydney-Newcastle x *	1966	Adastra Hunting Geophysics P/L	1500 Feet	70, 112	Shell Development (Aust.) P/L
7	Stanwell Park x *	1967	Wongela Geophysical P/L	M.S.L.		Coal Cliff Collieries P/L
8	Broken Bay Marine x *	1969	United Geophysical Corp.	M.S.L.	6	Longreach Oil Ltd.



LIMIT OF YOUNGER ROCKS
LIMIT OF OLDER ROCKS EXPOSED
MUSWELLBROOK
SINGLETON
MAITLAND
CESSNOCK
NEWCASTLE
BATHURST
LITHGOW
KATOOMBA
SYDNEY
WOLLONGONG
PORT KEMBLA
GOULBURN
NOWRA
Jervis Bay
COMMONWEALTH TERRITORY
PACIFIC OCEAN
TASMAN SEA
EDGE OF CONTINENTAL SHELF
SOUTH
EDGE OF ABYSSAL PLAIN
SYDNEY BASIN
NEW SOUTH WALES
STRUCTURE CONTOUR MAP
BASE OF NARRABEEN GROUP
(UNMIGRATED)
Contour interval: 200 Feet
Datum: sea level
Scale 1: 1,000,000
10 0 10 20 30 40 Kilometres
10 0 10 20 30 Miles
Compiled 1972 by BMR Sedimentary Basins Study Group
Data obtained from: (1) interpretation of seismic sections by A. L. Bigg-Wither and BMR Sedimentary Basins Study Group
(2) bore and well intersections (after Australian Oil and Gas Co. Ltd.)
(3) relation between outcrop pattern and topographic contours
-1000 Structure contours in feet, dashed if interpolated, sign indicates above or below sea level
Seismic lines
U D Fault. D,U indicate relative movement down, up
Boundary of Narrabeen Group with older rocks.
Velocity function (see index map)
A Vi = 10,700 + 0·55Z
B Vi = 11,300 + 0·52Z
C Vi = 11,900 + 0·50Z
D Vi = 12,300 + 0·48Z
E Vi = 12,700 + 0·45Z
BMR 555(94) BUL. 45
Copy 4
Bull. 149

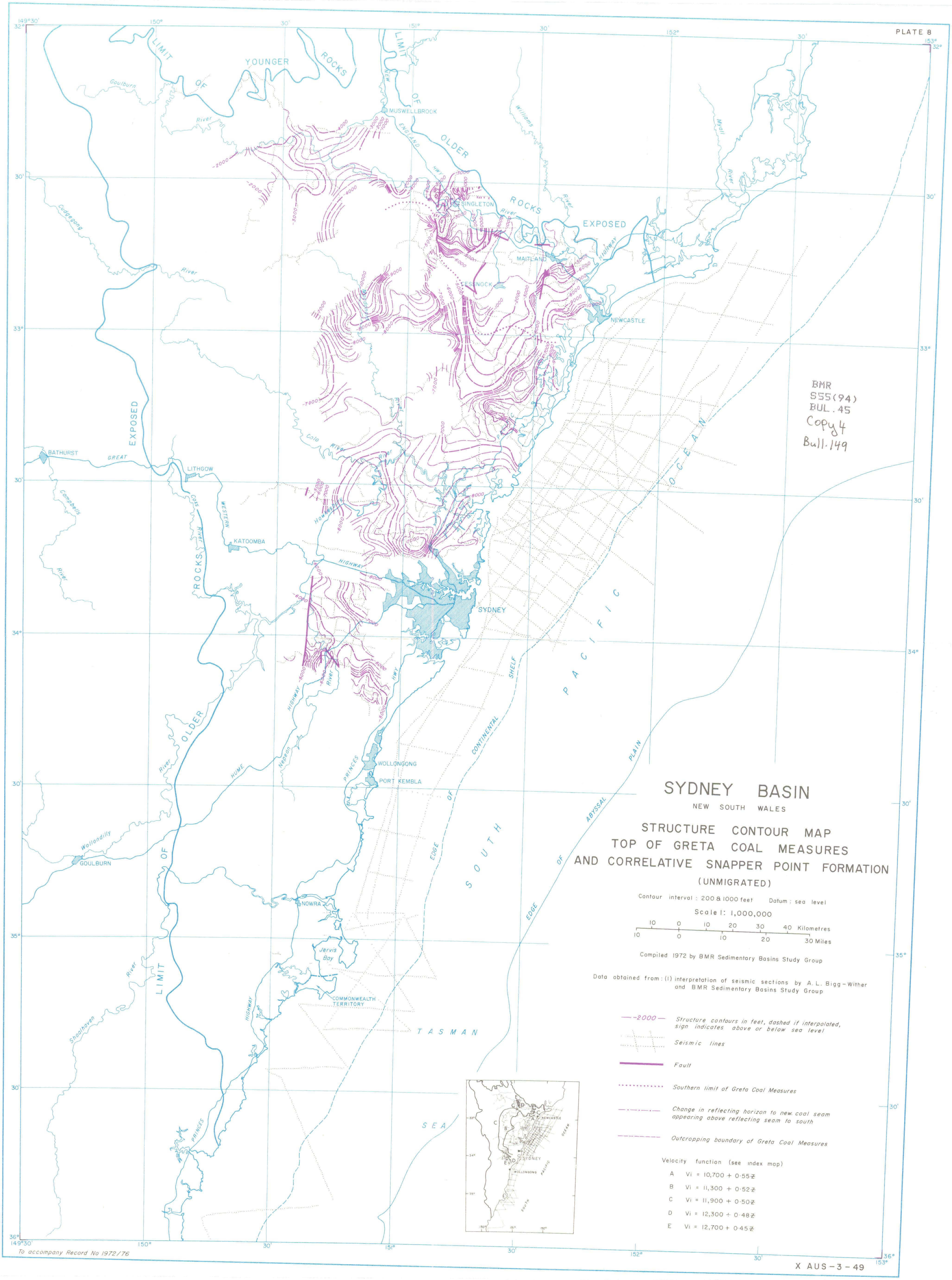


PLATE 8
SYDNEY BASIN
NEW SOUTH WALES
STRUCTURE CONTOUR MAP
TOP OF GRETA COAL MEASURES
AND CORRELATIVE SNAPPER POINT FORMATION
(UNMIGRATED)
Contour interval : 200 & 1000 feet Datum : sea level
Scale 1: 1,000,000
10 0 10 20 30 40 Kilometres
10 0 10 20 30 Miles
Compiled 1972 by BMR Sedimentary Basins Study Group
Data obtained from: (1) interpretation of seismic sections by A.L. Bigg-Wither and BMR Sedimentary Basins Study Group
-2000 Structure contours in feet, dashed if interpolated, sign indicates above or below sea level
Seismic lines
Fault
Southern limit of Greta Coal Measures
Change in reflecting horizon to new coal seam appearing above reflecting seam to south
Outcropping boundary of Greta Coal Measures
Velocity function (see index map)
A Vi = 10,700 + 0·55z
B Vi = 11,300 + 0·52z
C Vi = 11,900 + 0·50z
D Vi = 12,300 + 0·48z
E Vi = 12,700 + 0·45z
LIMIT OF YOUNGER ROCKS
LIMIT OF OLDER ROCKS EXPOSED
MUSWELLBROOK
SINGLETON
MAITLAND
CESSNOCK
NEWCASTLE
BATHURST
LITHGOW
KATOOMBA
SYDNEY
WOLLONGONG
PORT KEMBLA
GOULBURN
NOWRA
Jervis Bay
COMMONWEALTH TERRITORY
PACIFIC OCEAN
TASMAN SEA
SOUTH EDGE OF CONTINENTAL SHELF
EDGE OF ABYSSAL PLAIN
BMR
555(94)
BUL. 45
Copy 4
Bull. 149
To accompany Record No 1972/76
X AUS-3-49

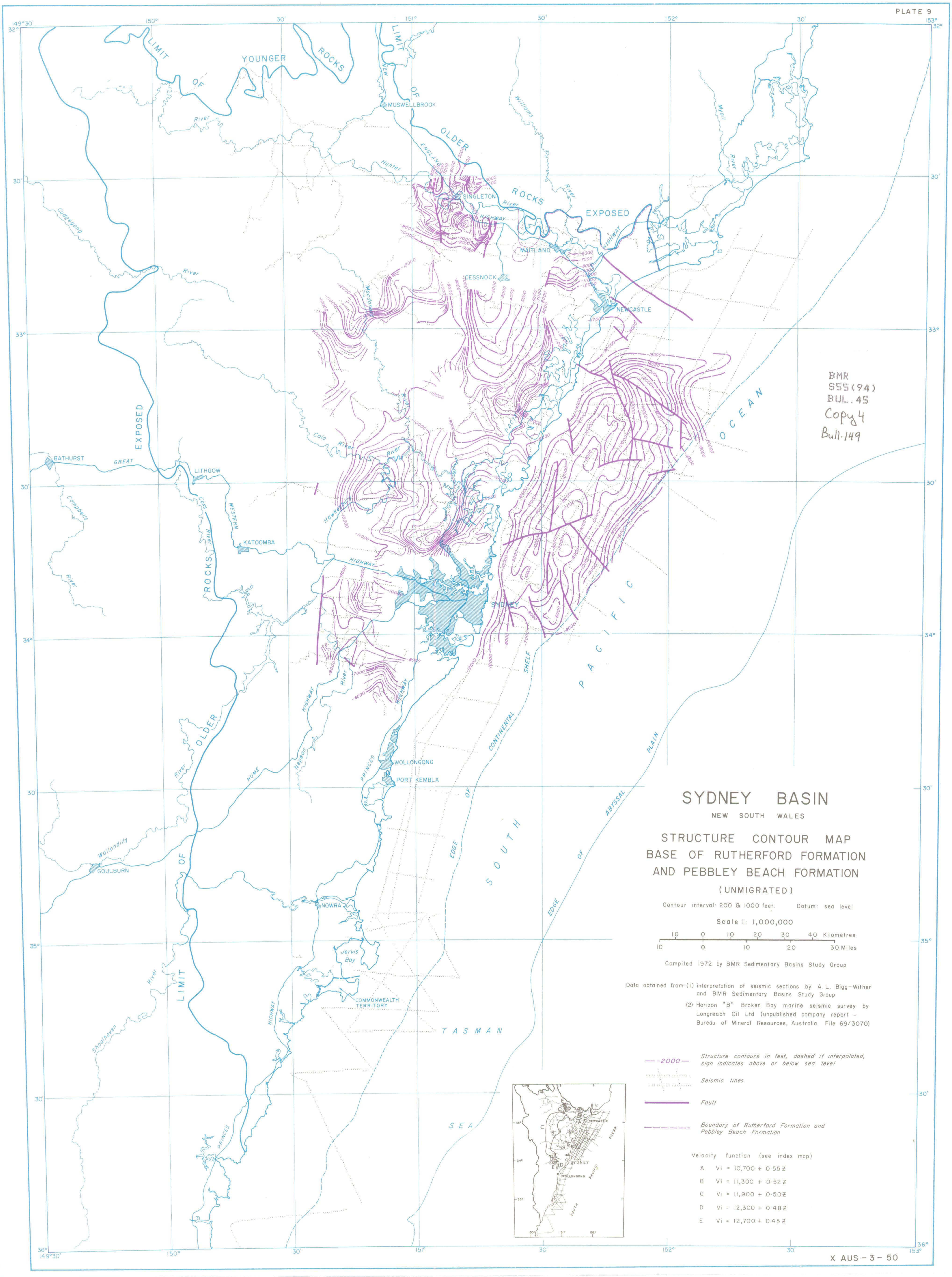


PLATE 9
SYDNEY BASIN
NEW SOUTH WALES
STRUCTURE CONTOUR MAP
BASE OF RUTHERFORD FORMATION
AND PEBBLEY BEACH FORMATION
(UNMIGRATED)
Contour interval: 200 & 1000 feet. Datum: sea level
Scale 1: 1,000,000
10 0 10 20 30 40 Kilometres
10 0 10 20 30 Miles
Compiled 1972 by BMR Sedimentary Basins Study Group
Data obtained from (1) interpretation of seismic sections by A. L. Bigg-Wither and BMR Sedimentary Basins Study Group
(2) Horizon "B" Broken Bay marine seismic survey by Longreach Oil Ltd (unpublished company report - Bureau of Mineral Resources, Australia. File 69/3070)
-2000 Structure contours in feet, dashed if interpolated, sign indicates above or below sea level
Seismic lines
Fault
Boundary of Rutherford Formation and Pebbley Beach Formation
Velocity function (see index map)
A Vi = 10,700 + 0·55 Z
B Vi = 11,300 + 0·52 Z
C Vi = 11,900 + 0·50 Z
D Vi = 12,300 + 0·48 Z
E Vi = 12,700 + 0·45 Z
LIMIT OF YOUNGER ROCKS
LIMIT OF OLDER ROCKS EXPOSED
MUSWELLBROOK
SINGLETON
MAITLAND
CESSNOCK
NEWCASTLE
BATHURST
LITHGOW
KATOOMBA
SYDNEY
WOLLONGONG
PORT KEMBLA
GOULBURN
NOWRA
Jervis Bay
COMMONWEALTH TERRITORY
PACIFIC OCEAN
TASMAN SEA
EDGE OF CONTINENTAL SHELF
EDGE OF ABYSSAL PLAIN
SOUTH
GREAT WESTERN HIGHWAY
HUME HIGHWAY
PRINCES HIGHWAY
NEW ENGLAND HIGHWAY
PACIFIC HIGHWAY
Hunter River
Williams River
Myall River
Cudgegong River
Colo River
Hawkesbury River
Nepean River
Wollondilly River
Shoalhaven River
Campbells River
Coxs River
149°30' 150° 30' 151° 30' 152° 30' 153°
32° 30' 33° 30' 34° 30' 35° 30' 36°
X AUS-3-50