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GEOLOGY OF THE SYDNEY BASIN - A REVIEW

by

S.J. Mayne, Evelyn Nicholas, and A.L. Bigg-Wither

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PREFACE

The Sydney Basin study has been a team effort requiring a constant exchange of ideas and information between the BMR, companies, and the Department of Mines, New South Wales. S.J. Mayne, Evelyn Nicholas, and A.L. Bigg-Wither are the main authors of the compilation, but Marlene J. Raine and J.R. Rasidi were junior authors who also interpreted data and wrote important sections of the report. Supervision of the study programme and integration of the results was undertaken by D.J. Forman.

No member of this group has first hand knowledge of the Sydney Basin except from petrological examination of core and cuttings from the petroleum exploration wells. It may therefore seem inappropriate for them to undertake this review, but similar studies by petroleum exploration companies also form the basis for fundamental decisions on future mapping, geophysical and drilling programmes, and the taking up or relinquishing of leases. It is expected that the study will provide either a basis for these decisions or a framework within which more detailed studies may be undertaken.

CONTENTS

	Page
SUMMARY	2
INTRODUCTION	4
Definition of the Sydney Basin	4
Location of areas, districts, 1:250 000 Sheets, and subsidiary basins	5
Coalfields and coal districts	5
Correlation	5
Intervals	6
Isopach maps	7
Sand-shale ratio maps	7
Nomenclature of sedimentary rocks	8
Environment maps	8
Control points	8
History of petroleum exploration	8
1910 to 1916	9
1918 to 1938	10
1953 to 1970	11
Acknowledgements	12
BASEMENT ROCKS	
Lachlan Geosyncline	13
New England Geosyncline (Carboniferous)	13
New England Geosyncline (early Sakmarian)	14
Interval 1: Lochinvar and Allandale Formations and correlatives	14
SAKMARIAN TO KAZANIAN ROCKS	16
Interval 2: Rutherford and Farley Formations and correlative Pebbley Beach Formation	17
Interval 3: Greta Coal Measures and correlative Snapper Point Formation	18
Interval 4: Branxton Formation, excluding Muree Sandstone Member, and correlative Wandrawandian Siltstone	19
Interval 5: Muree Sandstone Member of Branxton Formation and correlative Nowra Sandstone	21
Interval 6: Mulbring Siltstone and correlative Berry Formation	22
UPPER KAZANIAN TO MIDDLE TRIASSIC ROCKS	
Interval 7: Lower part of Wallis Creek Formation and correlatives	23
Interval 8: Upper part of Wallis Creek Formation and correlatives	25

	Page
Interval 9: Four Mile Creek Formation and correlatives	26
Interval 10: Waratah Sandstone and Dempsey Formation and correlatives	27
Interval 11: Newcastle Coal Measures (excluding Waratah Sandstone) and correlatives	28
Interval 12: Narrabeen Group	29
Interval 13: Hawkesbury Sandstone	30
Interval 14: Wianamatta Group	30
IGNEOUS ROCKS	31
Permian igneous rocks	31
Mesozoic igneous rocks	31
Triassic	31
Jurassic	31
Cretaceous	32
Undifferentiated	32
Cainozoic igneous rocks	33
STRUCTURE	
Introductory review	33
Diastrophism recorded by angular unconformity in lower and middle Palaeozoic basement rocks	35
Diastrophism recorded by angular unconformity in Permo-Triassic rocks	36
Lower Sakmarian unconformities	36
Tartarian unconformities	36
Unconformity beneath Tomago Coal Measures	37
Unconformity beneath Narrabeen Group	37
Upper Triassic unconformity?	37
Diastrophism without unconformity	37
Permo-Triassic movements	37
Structural history	38
Summary of crustal structure	39
GEOPHYSICS	
Seismic	39
Data gathering and data quality	40
Velocity study	41
Interpretation	42

	Page
Base of Narrabeen Group	42
Base of Newcastle Coal Measures and correlatives	42
Top of Greta Coal Measures	42
Base of Rutherford and Pebbly Beach Formations	43
Gravity	43
Gravity features in the south	43
Gravity features in the north	44
Correlation of northern and southern gravity features	44
Interpretation	44
Magnetic anomalies	45
Magnetic basement	46
Interpretation	46
GEOLOGICAL HISTORY	
Sequence of events	48
ECONOMIC GEOLOGY	
Petroleum	52
Source, reservoir, and cap rocks	52
Structural traps	54
Stratigraphic traps	54
Generation and migration of petroleum	55
Conclusions	56
Oil shale	57
Coal	57
Phosphate	58
REFERENCES	
Published	59
Unpublished	74

APPENDICES

1. EARLY SAKMARIAN ROCKS	
Interval 1: Lochinvar and Allandale Formations and correlatives	81
2. SAKMARIAN TO KAZANIAN ROCKS	
Interval 2: Rutherford and Farley Formations and correlative Pebbley Beach Formation	92
Interval 3: Greta Coal Measures and correlative Snapper Point Formation	98

	Page
Interval 4: Branxton Formation, excluding Muree Sandstone Member, and correlative Wandrawandian Siltstone	105
Interval 5: Muree Sandstone Member of the Branxton Formation and correlative Nowra Sandstone	111
Interval 6: Mulbring Siltstone and correlative Berry Formation	116
Megalong Conglomerate	121
3. UPPER KAZANIAN TO MIDDLE TRIASSIC ROCKS	
Interval 7: Lower part of the Wallis Creek Formation and correlatives	123
Interval 8: Upper part of the Wallis Creek Formation and correlatives	129
Interval 9: Four Mile Creek Formation and correlatives	134
Interval 10: Waratah Sandstone and Dempsey Formation and correlatives	137
Interval 11: Newcastle Coal Measures (excluding Waratah Sandstone) and correlatives	141
Interval 12: Narrabeen Group	150
Interval 13: Hawkesbury Sandstone	172
Interval 14: Wianamatta Group	177

TABLES

1. Stratigraphic control points
2. Seismic surveys
3. Gravity and magnetic surveys
4. List of petroleum exploration wells, Sydney Basin
5. Formations of the Kuttung Group in part of the Hunter Valley region (after Engel et al., 1969)
6. Permian igneous rocks
7. Triassic igneous rocks
8. Jurassic igneous rocks
9. Cretaceous igneous rocks
10. Cainozoic igneous rocks
11. Velocity surveys
12. Porosity, permeability, and fluid saturation determinations, Sydney Basin
13. Principal producing coal seams in the Sydney Basin.

ILLUSTRATIONS

PLATES

1. 1:500 000 geological map of the Sydney Basin — Geol Surv. NSW.
2. Rock unit correlation of Sydney Basin wells — X AUS-3-18A
3. Rock unit correlation of Sydney Basin wells — 18B
4. Location of control points — 31
5. Structure, Bouguer anomalies, and gravity features, Sydney Basin — At back of Record — no number on plate.
6. Total magnetic intensity and geophysical interpretation (compilation) " " " "
7. Structure contour map, base of Narrabeen Group — X AUS-3-48
8. Structure contour map, base of Great Coal Measures and correlative Snapper Point Formation — 49
9. Structure contour map, base of Rutherford Formation and Pebbley Beach Formation — 50.

FIGURES

1. Location of areas, districts, 1:250 000 Sheets, and subsidiary basins
2. Coalfields and coal districts (after Joint Coal Board; Anon. 1969; Brannigan, 1969)
3. Time correlation of Permo-Triassic rocks
4. North-south section, southern area
5. Environment map symbols
6. Petroleum drilling activity, Sydney Basin, 1910-1970
7. Location of petroleum exploration wells to 30.6.1970
8. Relationship of major rock units, Singleton and Newcastle 1:250 000 Sheet areas
9. Relationship of major rock units, Sydney 1:250 000 Sheet area
10. Relationship of major rock units, Ulladulla, Wollongong, Sydney, and Newcastle 1:250 000 Sheet areas
11. Isopach map, Interval 1, Allandale and Lochinvar Formations and correlatives
12. Sand-shale ratio map and section, Interval 1, Allandale and Lochinvar Formations and correlatives
13. Environment map, Interval 1, early Sakmarian
14. Isopach map, Interval 2, Farley and Rutherford Formations and correlative Pebbley Beach Formation
15. Sand-shale ratio map and section, Interval 2, Farley and Rutherford Formations and correlative Pebbley Beach Formation
16. Environment map, Interval 2, Sakmarian to early Artinskian
17. Isopach map, Interval 3, Greta Coal measures and correlative Snapper Point Formation

18. Sand-shale ratio map and section, Interval 3, Greta Coal Measures and correlative Snapper Point Formation

19. Environment map, Interval 3, Artinskian

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

21. Sand-shale ratio map and section, Interval 4, Branxton Formation (excluding Muree Sandstone Member) and correlative Wandrawandian Siltstone

22. Environment map, Interval 4, late Artinskian and Kungurian

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

24. Environment map, Interval 5, lower Kazanian

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

26. Sand-shale ratio map and section, Interval 6, Mulbring Siltstone and correlative Berry Formation

27. Environment map, Interval 6, Kazanian

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

29. Sand-shale ratio map and section, Interval 7, lower part of Wallis Creek Formation and correlatives

30. Environment map, Interval 7, upper Kazandian to lower Tatarian

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

32. Sand-shale ratio map and section, Interval 8, upper part of Wallis Creek Formation and correlatives

33. Environment map, Interval 8, lower Tatarian

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

35. Sand-shale ratio map and section, Interval 9, Four Mile Creek Formation and correlatives

36. Environment map, Interval 9, middle Tatarian

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

38. Sand-shale ratio map and section, Interval 10, Waratah Sandstone and Dempsey Formation and correlatives

39. Environment map, Interval 10, upper Tatarian

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

41. Sand-shale ratio map and section, Interval 11, Newcastle Coal Measures (excluding Waratah Sandstone) and correlatives

42. Environment map, Interval 11, upper Tatarian

43. Diagrammatic relationship of rock units within Narrabeen Group

44. Palynological zones in intervals 11-14. Based on Helby (1970)

45. Isopach map, Interval 12, Narrabeen Group

46. Sand-shale ratio map and section, Interval 12, Narrabeen Group

47. Environment map, Interval 12, Lower Triassic

48. Isopach map, Interval 13, Hawkesbury Sandstone

49. Environment map, Interval 13, Middle Triassic

50. Formations of Wianamatta Group (after Herbert, 1970)

51. Isopach map, Interval 14, Wianamatta Group

52. Environment map, Interval 14, Middle Triassic

53. Oscillograms and tectonograms for the Permian and Lower and Middle Triassic (of the Sydney Basin)

54. Crustal structure at latitude of Sydney

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

56. Partial reconstruction of Gondwanaland showing fold belts, incipient rifts, and the Permian pole

57. Diagram relating environments of deposition, intervals, and time

58. Oil shale deposits

59. Production of oil shale

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

61. Depth of overburden, top of Newcastle Coal Measures and correlatives

SUMMARY

The Sydney Basin is a 380 km long subdivision of the Tasman Geosyncline of eastern Australia, with an onshore area of about 36 000 km^2 situated along the east coast of New South Wales south of latitude $32^{\circ}S$. About 5 000 m of Permian and Triassic sedimentary rocks are preserved.

The older pre-Permian basement comprises two subdivisions of the Tasman Geosyncline: the Lachlan Geosyncline along the western and southern margins of the basin and the New England Geosyncline in the north and northeast. The Lachlan Geosyncline consists of lower and middle Palaeozoic sediments, lavas, and batholiths which have been accreted to the Australian craton, and the New England Geosyncline is fundamentally similar but of Carboniferous to Lower Triassic age.

The oldest sediments in the basin consist of about 200 m of valley-fill conglomerate and heterogeneous diamictite laid down as marginal and shallow marine deposits in the arc-rear belt of the New England Geosyncline. Cratonwards the sediments are highly glacigene, arcwards they are volcanogene. Minor coal seams occur in many places.

Broadly speaking the succeeding sediments were laid down around the margins of the basin during a fluctuating marine advance followed by a fluctuating marine regression. During the advance the chief sediment deposited was silt and fine sand (Branxton Formation, Wandrawandian Siltstone, Mulbring Siltstone, and Berry Formation). Temporary regressions followed by transgression are marked by the Greta Coal Measures - Snapper Point Formation and Muree Sandstone Member - Nowra Sandstone. The advance, which culminated during the Kazanian, was followed by a major regression allowing coal swamps to develop in a complex environment marginal to the retreating sea (Illawarra Coal Measures and correlatives). This retreat was interrupted by two minor transgressions: during the earlier the Kulnura Marine Tongue was formed, and during the later the Dempsey Beds and correlatives.

The Hunter-Bowen orogenic movements, which perhaps coincided with climatic changes, terminated the great coal swamps towards the close of the Permian. Delta-prograding with but slight coal formation and with ephemeral marine advances followed and lasted till the end of recorded sedimentation in the Anisian. These delta deposits make up the Narrabeen and Wianamatta Groups. The intervening Hawkesbury Sandstone was formed in tidal flats and offshore bars.

Igneous activity in the Sydney Basin was associated with three events: the development of the Permo-Carboniferous New England Geosyncline, the development of the Mesozoic New Zealand Geosyncline, and the formation of the Tasman Rift Valley and Tasman Sea in the Cretaceous and Tertiary.

Earth movements related to the growth of the New England Geosyncline (intrusion of batholiths and isostatic readjustment) caused minor folding and faulting especially in the Hunter Valley where noteworthy unconformities exist on the Lochinvar Dome. Rifting during the later Mesozoic cut obliquely through the orogenic belts and was the precursor to the development of the Tasman Sea by seafloor spreading. The steep continental slope marks the general line of this rifting. During the upper Cainozoic the Kosciusko Movement produced plateaux and basins within the Sydney Basin.

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

INTRODUCTION

The study of the Sydney Basin by the Sedimentary Basins Study Group of the Petroleum Exploration Branch within the Bureau of Mineral Resources was undertaken with the co-operation of the Department of Mines, New South Wales, who prepared a 1:500 000 geological map (Pl. 1). The literature was reviewed and an annotated bibliography prepared (Mayne et al., 1970). The Permian palynology was reviewed by Evans (1967) and a detailed petrological examination made of 13 petroleum exploration and stratigraphic wells (Alcock, 1968a, b; Hawkins & Ozimic, 1967; Jensen & Bryan, 1969; Mayne, 1968, 1969; Nicholas, 1968, 1969; Ozimic, 1968, 1969, 1971; Pitt, 1968, and Raine, 1969). From this study a basinwide correlation of rock units was made (Pls 2-4).

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 1.2 inches. 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.

Isopach maps were prepared, using geological control only for some units, and geological and seismic control where possible for other units. Sand-shale ratio maps were prepared using geological control.

The stratigraphy and geological history are described with reference to isopach, sand-shale ratio, and environment maps where appropriate. The structure is described with reference to structure contour maps, a structure map, the depth to magnetic basement contour map, and the Bouguer gravity anomaly map. The history of petroleum exploration and future prospects are discussed.

Definition of the Sydney Basin

The Sydney Basin in eastern New South Wales (Fig. 1) overlaps the sedimentary rocks of the Lachlan Geosyncline to the west, is limited to the northeast by the Hunter Thrust, and probably to the east by the continental slope. It is partly separated from Permo-Jurassic rocks of the Oxley Basin to

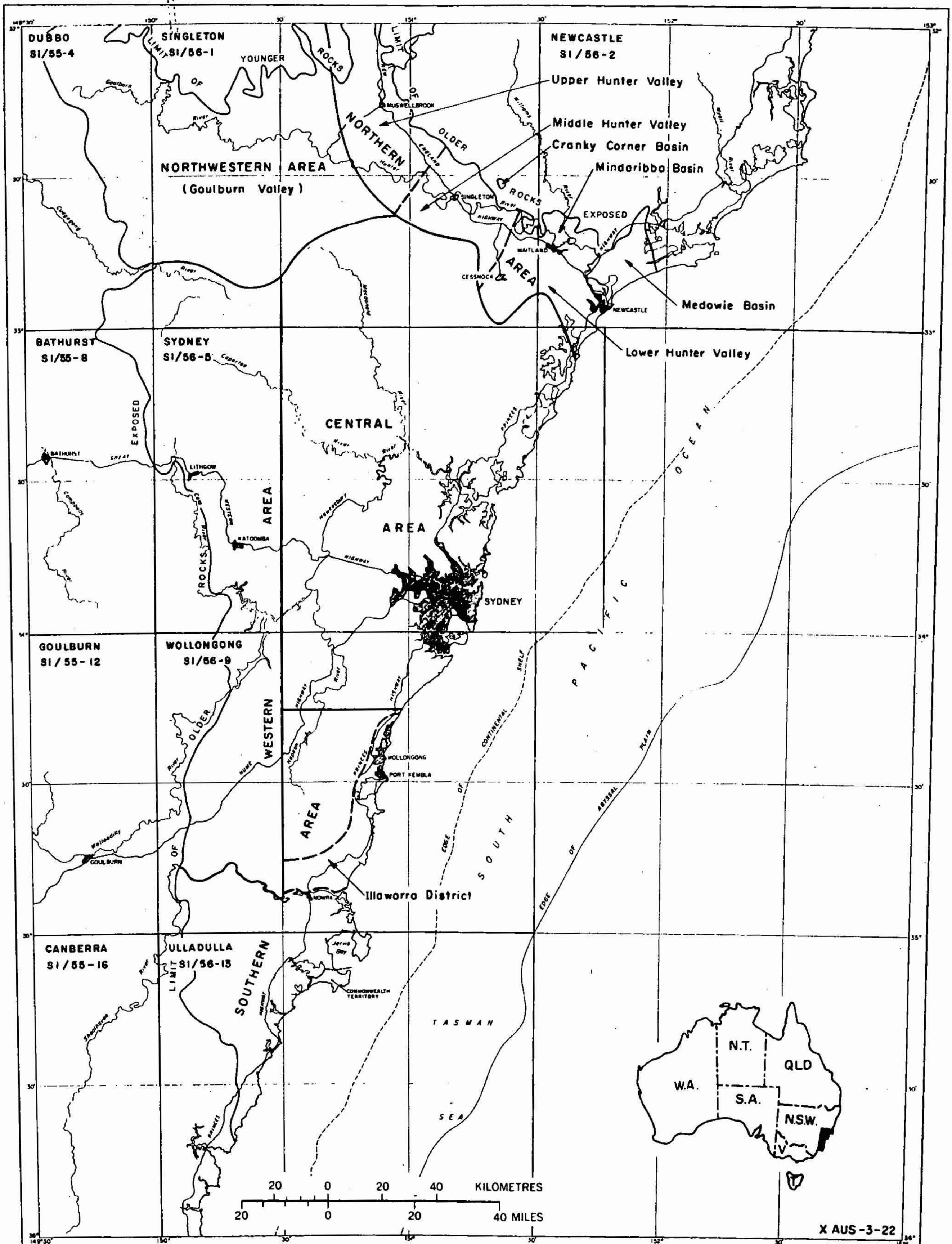

Fig. 1. Location of areas, districts, 1:250 000 Sheets, and subsidiary basins

To accompany Record No. 1972/76

the northwest by a structural high. It covers about 36 000 km^2 onshore and about 1 6000km^2 offshore to the edge of the continental shelf. The maximum aggregate thickness of sedimentary rocks in the basin is about 4 800 m, but maybe up to 5 900 m. These are alternating marine and non-marine rocks of Permian age and mainly non-marine rocks of Triassic age.

Permian shoshonites occur in the southern part of the basin, many Mesozoic volcanic plugs, sills, and dykes intrude the sedimentary rocks, and Tertiary volcanic flows occur in some areas. There is abundant volcanic ash in the Tatarian and Triassic strata.

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

Description of the Sydney Basin requires reference to a number of areas. However, there are no generally accepted physiographic or geomorphological subdivisions and the various land, agricultural, and broadcast divisions are unsuited to a geological description. Accordingly, the Sydney Basin has been informally subdivided into five areas, the southern, western, central, northwestern, and northern areas (Fig. 1). The northwestern and northern areas are coincident with the parts of the Goulburn Valley and the Hunter Valley respectively, that occur within the Sydney Basin boundaries. 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 coal reserves. Six coalfields, the Northern, Western, Central, Southwestern, Southern, and Clyde River have been named (Fig. 2); the Northern Coalfield has been subdivided into five Coal Districts. Coal has been produced from all the coalfields except the Clyde River field. The Central Coalfield is no longer producing.

Correlation

Plates 2 to 4 and Figure 3 show the rock unit correlation that forms the basis of this basin study. The rock units (Pls 2-4) have been correlated on the basis of tracing their lateral continuity, lithological identity,

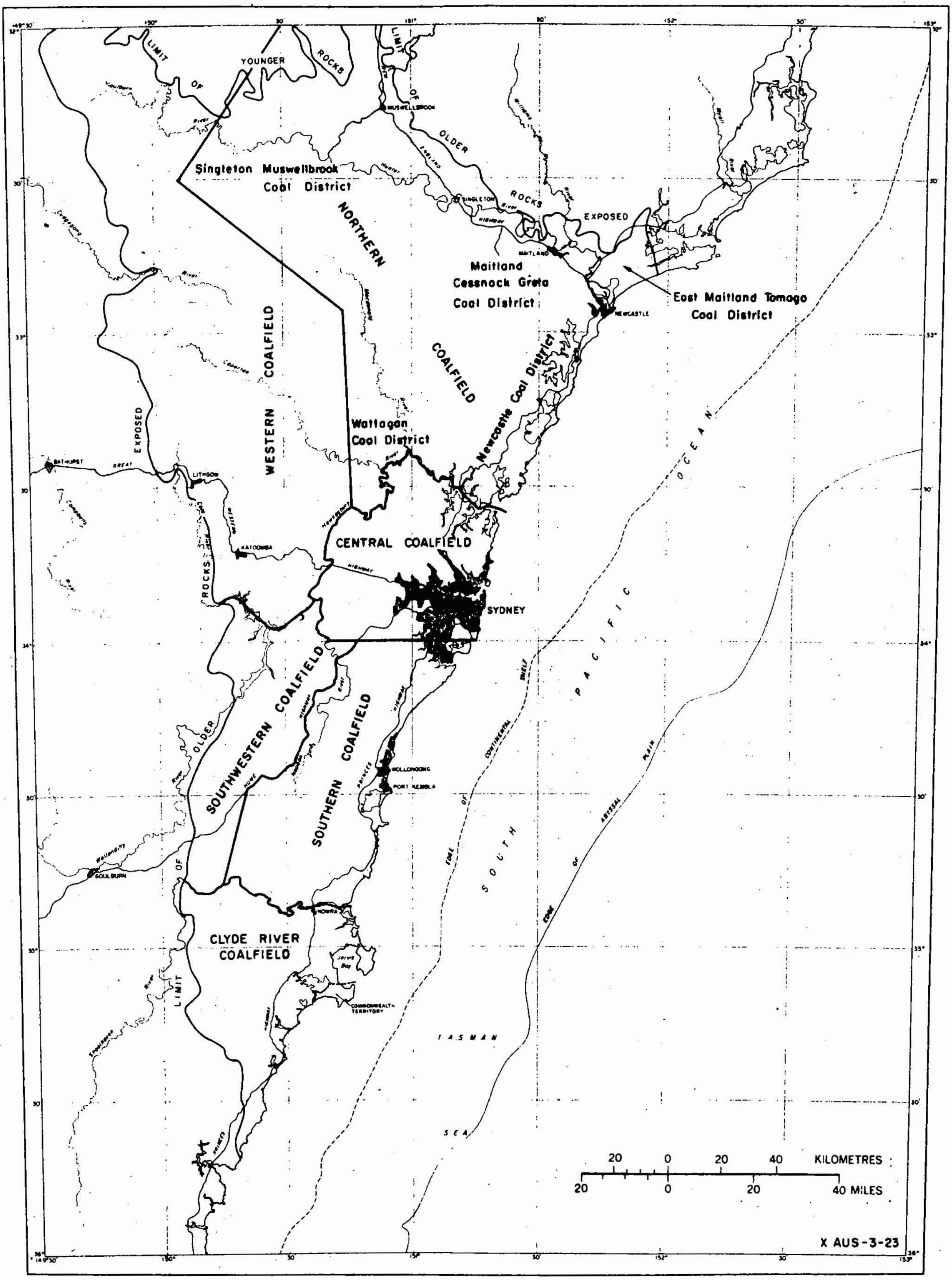

Fig.2 Coalfields and coal districts (after Joint Coal Board; Anon,1969; & Brannigan,1969a)

To accompany Record No 1972/76

System	Series	Stage	Interval	WESTERN AREA	NORTHERN AREA	CENTRAL AREA	SOUTHERN AREA: ILLAWARRA DISTRICT	SOUTHERN AREA: CLYDE RIVER COALFIELD
TRIASSIC	LOWER AND MIDDLE		14	WIANAMATTA GROUP		WIANAMATTA GROUP	WIANAMATTA GROUP	
TRIASSIC	LOWER AND MIDDLE		13	Hawkesbury Sandstone		Hawkesbury Sandstone	Hawkesbury Sandstone	
TRIASSIC	LOWER AND MIDDLE		12	NARRABEEN GROUP: GROSE SUB-GROUP; CALEY SUB-GROUP		NARRABEEN GROUP: GOSFORD FORMATION; CLIFTON SUB-GROUP	NARRABEEN GROUP: GOSFORD FORMATION; CLIFTON SUB-GROUP	
PERMIAN	UPPER	TATARIAN	7 – 11	ILLAWARRA COAL MEASURES (Western and Southwestern Coalfield)	SINGLETON COAL MEASURES: WOLLOMBI COAL MEASURES (UPPER HUNTER); NEWCASTLE COAL MEASURES (LOWER HUNTER); WITTINGHAN COAL MEASURES (UPPER HUNTER); TOMAGO COAL MEASURES (LOWER HUNTER)	ILLAWARRA COAL MEASURES (Central Coalfield); SHOALHAVEN GROUP: Budgong Sandstone	ILLAWARRA COAL MEASURES (Southern Coalfield); SHOALHAVEN GROUP: Budgong Sandstone	
PERMIAN	UPPER	KAZANIAN	6	SHOALHAVEN GROUP: Berry Formation	MAITLAND GROUP: Mulbring Siltstone	SHOALHAVEN GROUP: Berry Formation	SHOALHAVEN GROUP: Berry Formation	Berry Formation
PERMIAN	UPPER	KAZANIAN	5	SHOALHAVEN GROUP: Megalong Conglomerate	MAITLAND GROUP: Muree Sandstone Member	SHOALHAVEN GROUP: Nowra Sandstone	SHOALHAVEN GROUP: Nowra Sandstone	Nowra Sandstone
PERMIAN	LOWER	KUNGURIAN ?	4	SHOALHAVEN GROUP: Megalong Conglomerate	MAITLAND GROUP: Branxton Formation	SHOALHAVEN GROUP: Wandrawandian Siltstone	SHOALHAVEN GROUP: Wandrawandian Siltstone	Wandrawandian Siltstone
PERMIAN	LOWER	ARTINSKIAN	3	SHOALHAVEN GROUP: Megalong Conglomerate	GRETA COAL MEASURES	SHOALHAVEN GROUP, CONJOLA SUB-GROUP: Snapper Point Formation	SHOALHAVEN GROUP, CONJOLA SUB-GROUP: Snapper Point Formation	Snapper Point Formation
PERMIAN	LOWER	ARTINSKIAN ?	2	SHOALHAVEN GROUP: Megalong Conglomerate	DALWOOD GROUP (Skeletar Formation and Gyarran Volcanics (MUSWELLBROOK)): Farley Formation; Rutherford Formation	SHOALHAVEN GROUP, CONJOLA SUB-GROUP: Pebbley Beach Formation	SHOALHAVEN GROUP, CONJOLA SUB-GROUP: Pebbley Beach Formation	Pebbley Beach Formation
PERMIAN	LOWER	SAKMARIAN	1	SHOALHAVEN GROUP: ? ? ?	DALWOOD GROUP (Skeletar Formation and Gyarran Volcanics (MUSWELLBROOK)): Allandale Formation; Lochinvar Formation	SHOALHAVEN GROUP, CONJOLA SUB-GROUP: Wasp Head Formation ?	SHOALHAVEN GROUP, CONJOLA SUB-GROUP: Wasp Head Formation	? ? Clyde Coal Measures ? ?; Wasp Head Formation

To accompany Record No 1972/76

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Fig. 3. Time correlation of Permo-Triassic rocks

stratigraphical position, and structural relationships. To a degree that is difficult to estimate this correlation of rock units has also been built up taking account of palaeontological age estimates, particularly in areas where lateral continuity, stratigraphical position, and structural relationships are not well known.

The time correlation chart (Fig. 3) relates the rock units to the periods, epochs, and ages of the geological time scale based on palaeontological age estimates of the contained fossils. Recognizing fourteen basinwide lithological subdivisions (called 'Intervals') of the sedimentary rocks (see p. 6 and Pls 2-3) with an aggregate thickness of about 4 800 m deposited over a period of about 80 million years it can be seen that the average basinwide lithological subdivision is about 340 m thick and was deposited in 6 million years, provided deposition was continuous. The precision of palaeontological age dating throughout the Basin is such that the temporal equivalence over wide areas of each lithological subdivision cannot be proven.

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 western and southern areas. The Triassic rocks have been removed by erosion in the northern area, but a complete sequence of Permian rocks is exposed. Only Triassic rocks are exposed in the central area, but Upper Permian coal measures and Lower Permian rocks have been penetrated by the deeper petroleum exploration wells. The names applied to the Lower Permian stratigraphic units in the southern area are extended into the subsurface of the central area (Fig. 4).

The stratigraphic correlations are based on a combination of palaeontological evidence, lithology, order of stratigraphic superposition, and seismic evidence, the details of which are included in the appendices at the back of this Bulletin.

Intervals

There is no adequate way of recognizing time-rock units throughout the Sydney Basin, yet 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). The interval differs from the currently recognized and named time-rock and rock units. It is a purely practical and informal internal subdivision of the rocks into widespread units that have genetic significance appropriate to the purpose and scale of the study. The boundaries of an interval are taken at lithological changes in the sequence in such a way that they approximate time lines as closely as possible. Unfortunately however, due to the limitations in palaeontological dating, the extent to which the interval boundaries follow time cannot be proven and consequently the conclusions drawn in the text regarding palaeogeography, environmental analysis, and geological history are inherently unreliable. 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.

Isopach maps

The isopach maps of each interval are partly interpretative and partly objective. The interpreted original thickness of the interval is shown as far as possible beyond the margins of outcrop of the interval, 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 maps are objective so far as the geological control allows. The sand-shale ratio patterns are applied in areas of geological control only.

The maps all show sand-shale ratio, as carbonate rocks are virtually absent. Coal has been ignored in the lithofacies calculations but is shown diagrammatically on 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 down-buckling or up-warping was greatest. They also depict the lateral relations between various named and unnamed stratigraphic units comprising the interval.

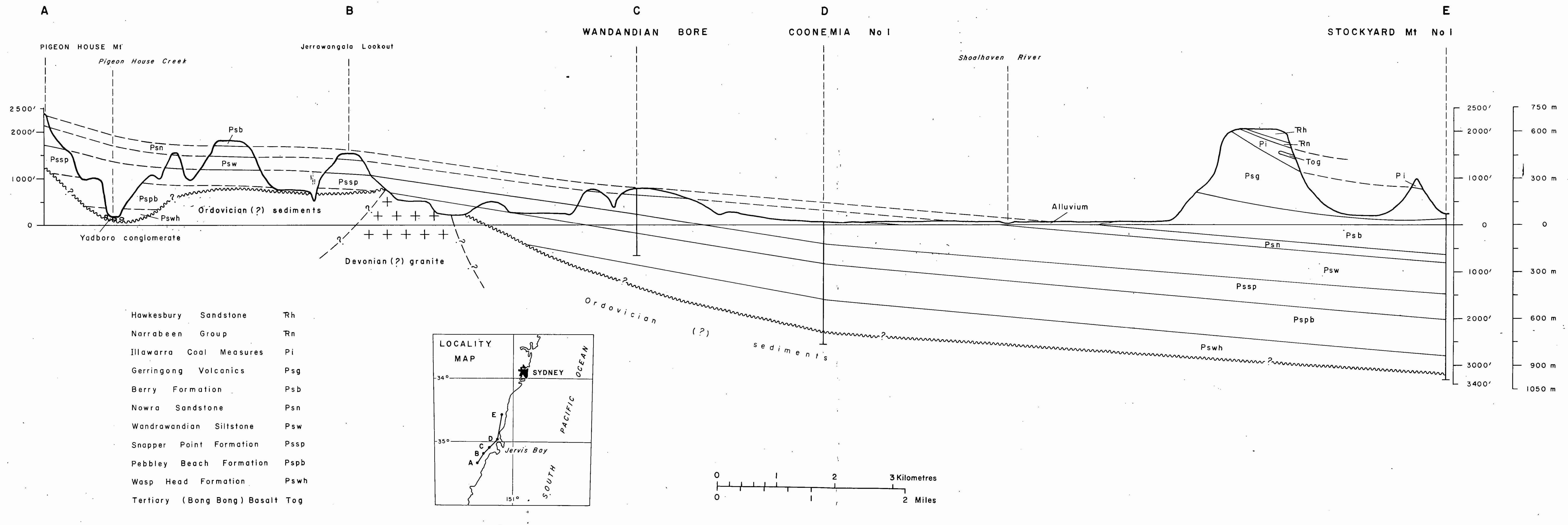

Fig.4 North-South Section Southern Area Sydney Basin

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Nomenclature of sedimentary rocks

The modified Wentworth-Udden scale (Lane et al., 1947) was used for grainsize classification. The sandstone classification of Pettijohn (1957) was generally used for specific rock names, with the following modifications: (1) the term quartz greywacke was used to distinguish quartz-rich rocks (sand and gravel composed of more than 75% quartz) in which detrital matrix was prominent (15-50% total rock); (2) the term greywacke was 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 was a turbidite.

Environment maps

An environment map has been drawn for each interval. The environments selected are shown in Figure 5. The maps show the areal distribution of predominent environments in the interval.

It is important to note that the environments shown are most probably not contemporaneous in a single moment of geological time or even over an interval of time. They show the areal distribution of the most predominent environments operating during the deposition of the basinwide lithological interval, but time correlation is not sufficiently refined to be able to prove whether or not they are contemporaneous. In fact after compilation of the environment maps a consideration of the changes of environment with time leads the authors to the conclusion, brought out in the geological history, that the environments and the sedimentary rocks deposited in them, must transgress time.

Control points

Plate 4 shows the control used for the study, including water bores, deep exploratory holes drilled on the coalfields, and 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.

NOTE:

Maps and figures were prepared before BMR introduced the use of the metric system, and hence measurements are given in imperial units.

I CONTINENTAL AREAS, NON-DEPOSITIONAL

Uplands

Lowlands

II CONTINENTAL AREAS, DEPOSITIONAL

Fluvial

III MARGINAL AREAS, DEPOSITIONAL

Deltaic complex or alluvial fan, floodplain, coastal swamp, lagoon, tidal flat, beach, and estuary complex

IV MARINE AREAS, DEPOSITIONAL

Sub-littoral (open circulation)

Terrigenous detritus

Low-energy

Medium-energy

High-energy

V VOLCANIC AREAS

Area where mapped interval contains volcanic rocks

VI GLACIAL AREAS

Area where mapped interval contains ice-rafted material

Fig. 5. Environment map symbols

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, Veevers, & others (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.	9.5 km E of Singleton on Hunter R.	McKellar (1969)
13.	Belford No. 1	Ozimic (1968)
14.	1.5 km W of Branxton in railway cutting	McKellar (1969)
15.	From 0.75 km N of Greta to Branxton	McKellar (1969)
16.	Cranky Corner Basin	Rattigan et al. (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)

* The symbols used are explained in the reference on Plate 1

Table 1 (cont.)

Name or Location of Control Point		Reference
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 " " No. 2	Stuntz (pers. comm., 1970)
37.	DM " " No. 4	Stuntz (pers. comm., 1970)
38.	DM " " 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 Ra.	McKellar (1969)
50.	Mt Vincent-Quarrybylong rd	McKellar (1969)
51.	Heaton	Jones (1939)
52.	Capertee	Carne (1908a, 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)

Table 1 (cont.)

Name or Location of Control Point		Reference
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 (1966)
74.	Budgewoi No. 1	AOG (1966)
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 No. 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 (1962)
102.	Kirkham No. 1	Raine (1969)
103.	Badgelly No. 1	AOG (1966c)

Table 1 (cont.)

Name or Location of Control Point		Reference
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)
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 Record
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 (1969)
127.	Point Perpendicular bore	Smart (1962b)
128.	Tomerong-Nerriga rd	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 R. and Claydons Cr.	McElroy & Rose (1962)
133.	S. bank of Conjola Cr. below bridge on Princes Highway	McElroy & Rose (1962)
134.	0.75 km N of Pigeon House Cr.-Clyde R. junction	McElroy & Rose (1962)

Table 1 (cont.)

	Name or Location of Control Point	Reference
135.	2.5 km SE of Yadboro Cr.-Clyde R. 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 (1971)

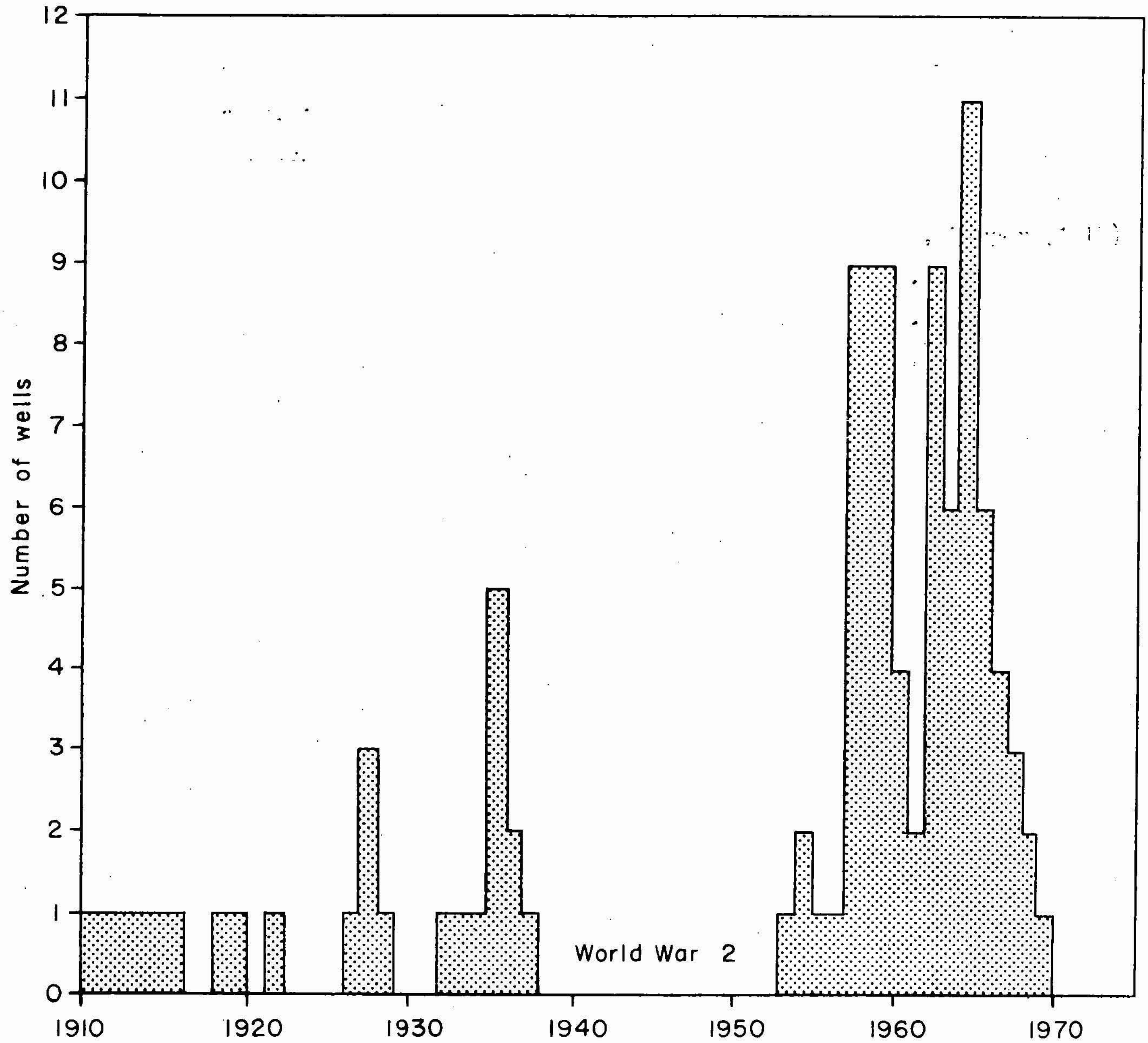

Fig. 6 Petroleum drilling activity, Sydney Basin, 1910 - 1970

To accompany Record No 1972/76

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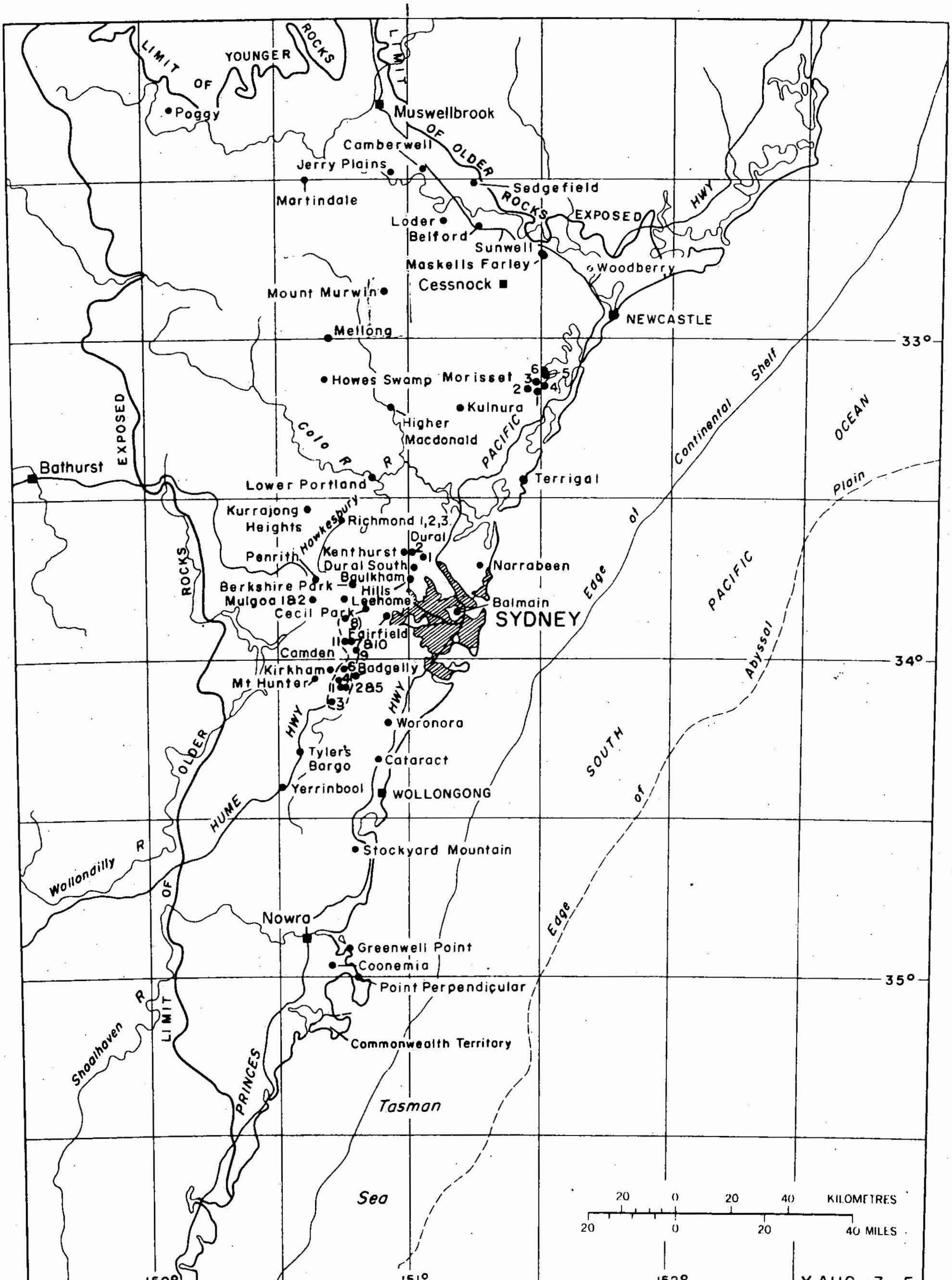

Fig. 7 Location of petroleum exploration wells to 30·6·1970

To accompany Record No 1972/72

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, gave the first geological account of Permo-Carboniferous strata on the south coast of New South Wales and briefly described the rocks in the vicinity of Batemans Bay and the newly discovered Clyde River. The Reverend W.B. Clarke was the first to recognize the Sydney Basin as a geological entity: in 1847 he predicted that the coal seams cropping out around the margins of the basin were part of a single sedimentary unit that is present 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, valuable basic geological information was provided by officers of the Geological Survey of New South Wales, who undertook field mapping in various localities and compiled their own information, together with that available from mining and petroleum exploration companies, and from Universities at Sydney and Newcastle, on coloured geological maps at 1:250 000 scale. This work was then extended to the publication in 1969 of a coloured 1:500 000 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 Nos 1 and 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 locates the petroleum exploration 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, 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 (1924) wrote an encouraging report on the petroleum potential of the Sydney Basin, and in 1925 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 Nos 1 and 2 were core holes, and No 3 was drilled with a cable tool rig. Small shows of gas were 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 £2 260 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. Few details are known concerning this well, but it was suspended at a depth of 1 082.7 m in 1935; some gas was recorded. In the northern part of the Sydney Basin, W.J. Maskell drilled Farley No 1 to a depth of 1 636 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 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 3 240 m^3 per week was attained.

1954 to 1970

When drilling resumed in the Sydney Basin in 1954 greater use was made of available geological and geophysical data. The work was done mainly by substantial soundly based Australian companies, aided in some cases by cash payments resulting from the Commonwealth Government's 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 costs of drilling and geophysical operations for approved projects in petroleum search. Other Commonwealth assistance in the Sydney Basin 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 Sydney Basin (Table 4, Fig. 7). All the wells have been onshore. 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 located 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).

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

TABLE 2. SEISMIC SURVEYS

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

* Surveys shown on Plate 4

TABLE 3. GRAVITY AND MAGNETIC SURVEYS

	Name of Survey	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	1962-63	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 & bathymetric survey	1971	BMR (in press)

* Surveys shown on Plate 6

	Name of Survey	Date	Reference
	Gravity Surveys		
*	Sydney Basin N.S.W. gravity	1954-56	AOG (no report available)
	Sydney district gravity	1950-56	Hancock et al. (no report available)
	Singleton area gravity	1955-63	AOG (no report available)
*	Gravity survey PEL 59	1961	Smart (1962b)
*	Helicopter gravity training survey and southern N.S.W.	1966	Lodwick et al. (1968)
	BMR marine gravity, magnetic, seismic and bathymetric survey	1971	BMR (in press)

* Surveys shown on Plate 5

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	267.5 deepest	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	"	W: 0-15.3; H:15.3-305; N: 305-769.5; UCM: 769 TD
Yerrinbool Oil Prospecting Syndicate	Yerrinbool No. 1	34°23'S 150°31'E	1921-22	682.6	Gas traces	"	H: 0-133.9; N: 133.9-269; UCM: 269-362.3; S362.3-TD
Oil and Gas Investigations Ltd	Loder Dome No. 1	32°38'S 151°08'E	1926-27	729.3	Gas trace	"	
Belford Dome Ltd	Belford Dome No. 1 " " " 2 " " " 3	32°39'S 151°17'E	1927	472.8	Gas trace	"	
Mr W.J. Maskell	Farley No. 1	32°45'S 151°31'E	1935-36	1636	486 m^3 gas; p/d; oil traces	"	D: 0-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

Table 4 (Cont.)

Company or Operator	Name of Well	Co-ordinates	Date Drilled	Total Depth (m)	Hydrocarbons	Status	Stratigraphy+ (m)
Natural Gas and Oil Corporation Ltd	Balmain No. 1	North Sydney	1932-37	895.8 coal shaft; 610 bore hole; TD 1505.8	3.240 m^3 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	"	H: 0-94.6; N: 94.6-82 UCM: 1445.7; S: 1445. TD
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	"	H: 0-222.7; N: 222.7-889.1; UCM: 889.1-1390.8; S: 1390.8-TD
"	Dural (East) No. 1	33°41'S 151°03'E	1956-57	1586.9	Gas trace at 934.2 & 1073.9 m	"	H: 0-263.8; N: 263.8-841.8; UCM: 1520.7; Dolerite Sill: 1520.7-
"	Dural (East) No. 2	33°40'S 151°01'E	1957-58	1971.8	20 000 m^3 gas p/d at 1014.1 m	"	H: 0-276.6; N: 276.6-875.4; UCM: 875.4-1674 Dolerite Sill: 1518.9-1557.6; S: 1674.5-TD
"	Morisset No. 1	33°10'S 151°29'E	1957	174.2	Gas trace	"	N: 0-112.5; UCM: 112.5 TD
	" No. 2	33°10'S 151°27'E	1957	223.9		"	N: 0-198.9; UCM: 198.9 TD
"	" No. 3	33°08'S 151°29'E	1957	158.3		"	N: 0-129; UCM: 129-TD
"	" No. 4	33°09'S 151°31'E	1957	221.4		"	N: 0-79.6; UCM: 79.6-TD
"	" No. 5	33° 'S 151° 'E	1957	83		"	N: 0-47; UCM: 47-TD
"	" No. 6	33°06'S 151°31'E	1958	92.4		"	N: 0-46.7; UCM 46.7-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	Camden No. 1	34°05'S 150°43'E	1957	693	Dry gas at 357.8 m, 368.7 m and 413.3 m, 13 500 cu mpd	Abandoned	Triassic & UCM
"	" No. 2	34°05'S 150°44'E	1958	680.2	Dry gas at 328.2 & 518.2 m	"	Triassic & UCM
"	" No. 3	34°09'S 150°43'E	1958	558.2	Dry gas at 278.8 m	"	Triassic
"	" No. 4	34°05'S 150°42'E	1958	576.5	Dry gas at 355.9 & 368.7 m	"	Triassic
"	" 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	"	Triassic
"	" 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	"	W: 0-?; H: ?-287.9; N: 287.9-TD
"	" No. 7	33°57'S 150°47'E	1959	520	1890 m^3 at 411.8 m & 2700 m^3 p/d at bottom	"	W: 0-111.3; H: 111.3-311.7; N: 311.7-TD
"	" No. 8	33°53'S 150°44'E	1959	641.1	Dry gas at 531.3 m	"	W: 0-87.2; H: 87.2-299. N: 299.2-TD
"	" No. 9	33°58'S 150°48'E	1959	641.7	Dry gas at 410.5, 424, 549 m	"	W: 0-119; H: 119-323.3; N: 323.3-TD
"	" No. 10	33°56'S 150°46'E	1959	531.6	13 500 m^3 p/d at 530.7 m	"	W: 0-102.2; H: 102.2-298.9; N: 298.9-TD
"	" No. 11	33°57'S 150°45'E	1960	618.8	Dry gas at 502 m and 534.7 m	"	W: 0-83.9; H: 83.9-271.5; N: 271.5-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	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
"	Cecil Park No. 1	33°52'S 150°51'E	1964-65	697.2	617.9-623.7 m gave 5 400 m^3 gas p/d waning	"	W: 0-160.7; H: 160.7-389.5; N: 389.5-TD
"	Cecil Park No. 2	0.8 km south of No. 1	1964	689.9	Minor gas	"	W: 0-139.7; H: 139.7-357.2; N: 357.2-TD
"	Kirkham No. 1	34°02'S 150°42'E	1964	2563.8	Dry	"	W: 0-113; H: 113-310.5 N: 310.5-748.5; UCM: 748.5-1302.4; S: 1302.-2547.7; D: 2547.7-TD
"	Badgelly No. 1	34°03'S 150°48'E	1964	660.6	Gas at 365.7 & 381.6 m	"	
"	Leehome No. 1	33°49'S 150°45'E	1965	664.6		"	W: 0-96.7; H: 96.7-304.1; N: 304.1-TD
"	Belford No. 1*	32°39'S 151°17'E	1964-65	1175.5	Gas shows at 13 levels	"	M: 0-393.5; GCM: 393.5-506.3; D: 506.3-TD
"	Camberwell No. 1*	32°32'S 151°06'E	1965	1908.1	Oil trace at about 720 m	"	M: 0-658.8; GCM: 658.8-1186.5; D: 1186.5-TD
"	Martindale No. 1 and 1A*	32°30'S 150°37'E	1967	1182.2	Dry	"	UCM: 0-683.2; M: 683.2-1034; GCM: 1034-TD
"	Berkshire Park No. 1	33°46'S 150°47'E	1968	1091.9	Dry	"	W: 0-122; H: 122-323.3; N: 323.3-1024.8; UCM: 323.3-TD
"	Higher Macdonald No. 1*	33°12'S 150°55'E	1968	628.3	Dry	"	N: 24-4-589.3; UCM; 589.3-TD
"	Lower Portland No. 1	49 km N of Windsor	1968	890	Dry	"	H: 0-141.8; N: 141.8-825; UCM: 825-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	Mulgoa No. 2*	33°49'S 150°38'E	1958-59	1717.2	12 gas shows below 396.5 yielded 1 080 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
"	Baulkham Hills No. 1	33°45'S 151°01'E	1960-61	1069.9	Minor gas	"	H: 0-244; N: 244-832; UCM: 832-TD
"	Mt Hunter No. 1	34°04'S 150°39'E	1962	1071.2	14 gas horizons yielded 1 080 m^3 p/d, waning	"	Base of N: 640.5; UCM: 640.5-976; S: 976-TD
"	Loder No. 1*	32°38'S 151°08'E	1963	2063.9	Oil & gas shows in Branxton, Farley, & Rutherford Fms	"	M: 0-689.3; GCM: 689.3-774.7; D: 774.7-TD
"	Mt Murwin No. 1*	32°51'S 150°55'E	1963	887.6	Minor gas shows from UCM	"	H: 0-82.4; N: 82.4-772.6; UCM: 772.6-TD
"	Mellong No. 1	33°00'S 150°42'E	1964	905.9	Minor gas shows	"	H: 0-112.9; N: 112.9-756.4; UCM: 756.4-TD
"	Woronora No. 1*	34°12'S 150°55'E	1963-64	2314	Minor gas shows	"	H: 0-164.7; N: 164.7-512.4; UCM: 512.4-1189.5; S: 1189.5-2279. B: 2279.9-TD
"	Kenthurst No. 1	33°40'S 150°59'E	1963	1066.6	310 m^3 gas p/d at 436.8 m	"	H: 0-258; N: 258-855.5; UCM: 855.5-TD
"	Fairfield No. 1	33°52'S 150°55'E	1964	854.9	Gas at 544 & 835.7 m	"	W: 0-72.6; H: 72.6-311.4; N: 311.4-TD
"	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

Table 4 (Cont.)

Company or Operator	Name of Well	Co-ordinates	Date Drilled	Total Depth (m)	Hydrocarbons	Status	Stratigraphy+ (m)
Sun Oil Co.	Sunwell No. 1	32°44'S 151°30'E	1953	632.6	Minor gas show	Suspended	D
Central Coast Oils N.L. = Alkane Exploration Terrigal N.L.	Terrigal No. 1 & 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	"	UCM: 0-58.9; M: 58.9-1396.9; GCM: 1396.9-1462.8; D: 1462.8-TD
L.H. Smart Oil Exploration Co. Ltd	Greenwell Point No. 1	34°45'S 150°43'E	1962	51.9	Dry	"	S: 0-TD
"	Greenwell Point No. 2	"	"	140	Dry	"	S: 7.6-TD
Exoil N.L.	Kurrajong Heights No. 1*	33°32'S 150°37'E	"	Started at 1450.3, TD at 2785.3	Dry	"	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	"	177.5	Dry	"	S: 3.1-TD
Farmout Drillers N.L.	Stockyard Mt No. 1*	34°36'S 150°47'E	"	1072.4	Gas trace	"	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	"	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	

Table 4 (Cont.)

Company or Operator	Name of Well	Co-ordinates	Date Drilled	Total Depth (m)	Hydrocarbons	Status	Stratigraphy+ (m)
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	"	W: 0-36.6; H: 36.6-24 N: 241-832.7; UCM: 832.7-1714.1; S: 1714. 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	"	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	"	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	"	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

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

The BMR carried out a marine, gravity, magnetic, seismic, and bathymetric survey in April 1971. The survey covered about 1 900 line kilometres in the offshore Sydney Basin area. The quality of the seismic records was generally poor.

Longreach Oil Ltd carried out a marine seismic survey in April 1971. An offshore well, Sealion No. 1, is proposed to test a structure outlined by the survey.

ACKNOWLEDGEMENTS

We are grateful to several organisations who have provided basic data and encouragement. In particular, the Australian Oil and Gas Corporation Ltd provided many geological and geophysical reports, and the Geological Survey of New South Wales conducted some of the Bureau officers on an informative tour of representative outcrops, as well as providing base maps and core, and appointing Mr J. Stuntz as liason officer for the project: his assistance was of great value, and he has reviewed the text of this Bulletin. Thanks are also due to the management of the Planet group of companies, to Alkane Petroleum (formerly Central Coasl Oil), L.H. Smart Oil Exploration Co., Alliance Oil Development Australia N.L., Esso Standard Oil N.L., and Genoa Oil N.L., all of whom have provided useful information and, in some cases, valuable discussions.

All members of the Sedimentary Basins Study Group since late in 1966 have contributed to this study, but only those who wrote this Bulletin have been given authorship. The other members include M.A. Reynolds, K.G. Smith, R. Bryan, A.R. Jensen, P.J. Alcock, P.J. Hawkins, R.P.B. Pitt, S. Ozimic, M.J. Raine, J.I. Raine, D.J. Forman, J. Rasidi, K. Rixon, and B.G. West.

BASEMENT ROCKS

The basement to the Sydney Basin includesrocks of the Lachlan and New England Geosynclines. The boundary between the Sydney Basin and the New England Geosyncline is generally well defined, but in places the exact position of the boundary is uncertain. The sequence in the Sydney Basin comprises gently folded sedimentary rocks with relatively few volcanic rocks, whereas the New England Geosyncline comprises a thicker sequence of strongly folded sedimentary rocks, with a comparatively large proportion of volcanic rocks, all of which have been intruded by granite. In the Sydney Basin, the basal part of the Permian sequence contains abundant volcanic rocks, and the base of the sedimentary succession in the Basin is taken arbitarily at the top of this lowermost Permian sequence. In recognition of the arbitrary nature of this boundary, particularly from the point of view of petroleum exploration, the lowermost Permian rocks are described here as Interval 1.

LACHLAN GEOSYNCLINE

Rocks of the Lachlan Geosyncline (Packham, 1960; Pl. 1) crop out west of, and unconformably underlie part of, the Sydney Basin. The geosynclinal rocks include 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 the mountainous borderlands in the west, and that much of the detritus was of glacigene origin. Clasts of quartz and feldspar, derived from igneous rocks, are a conspicuous component of the Permian and Triassic sedimentary rocks.

NEW ENGLAND GEOSYNCLINE (Carboniferous)

Rocks of the New England Geosyncline (Packham, 1960; Pl. 1) crop out northeast of, and underlie the northeastern part of, the Sydney Basin. In the area adjacent to the Sydney Basin most of the Carboniferous rocks are of continental origin ('Kuttung Group'). These continental rocks and their marine correlatives were deposited in upper Visean, Namurian, Westphalian, and Stephanian times. Much of the sequence in the New England Geosyncline consists of lavas and pyroclastics, or sediments derived from their disintegration. Many rocks units of local extent have been mapped in the geosyncline, and the nomenclature is confusing. Nevertheless the formations within the 'Kuttung

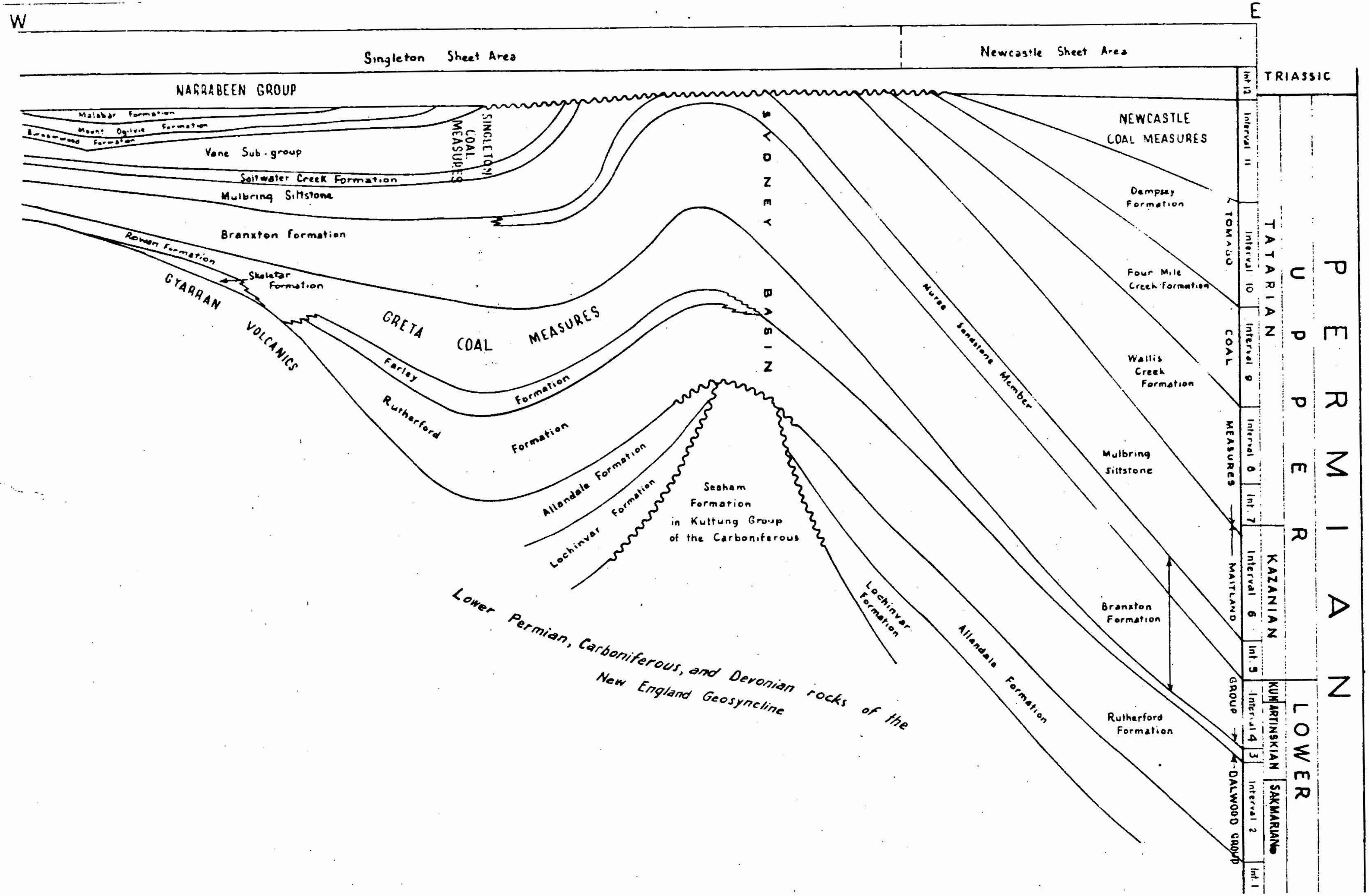

Fig. 8 Relationship of major rock units, Singleton and Newcastle 1:250000 Sheet areas

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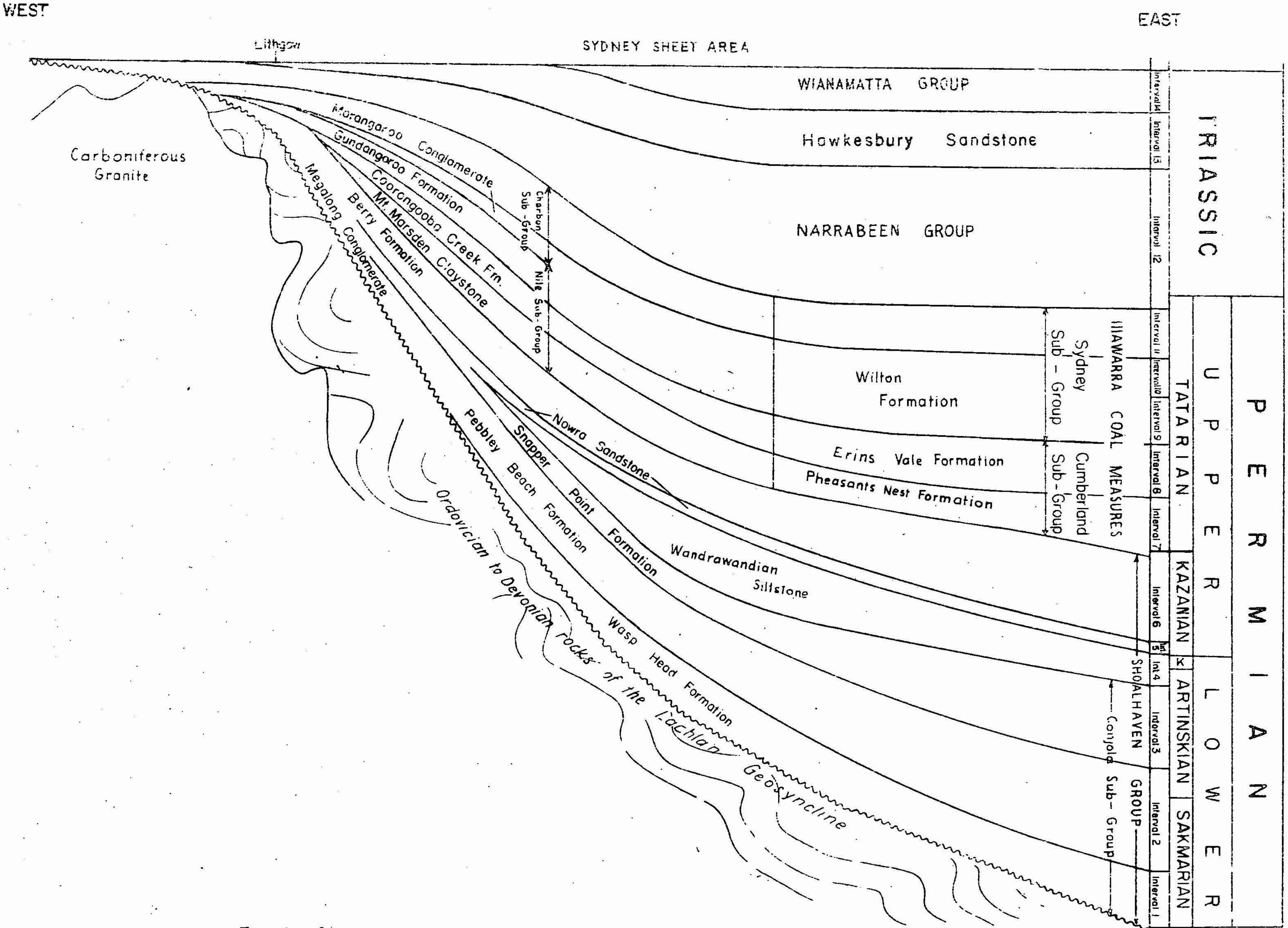

Fig 9. Relationship of major rock units, Sydney 1:250000 Sheet area

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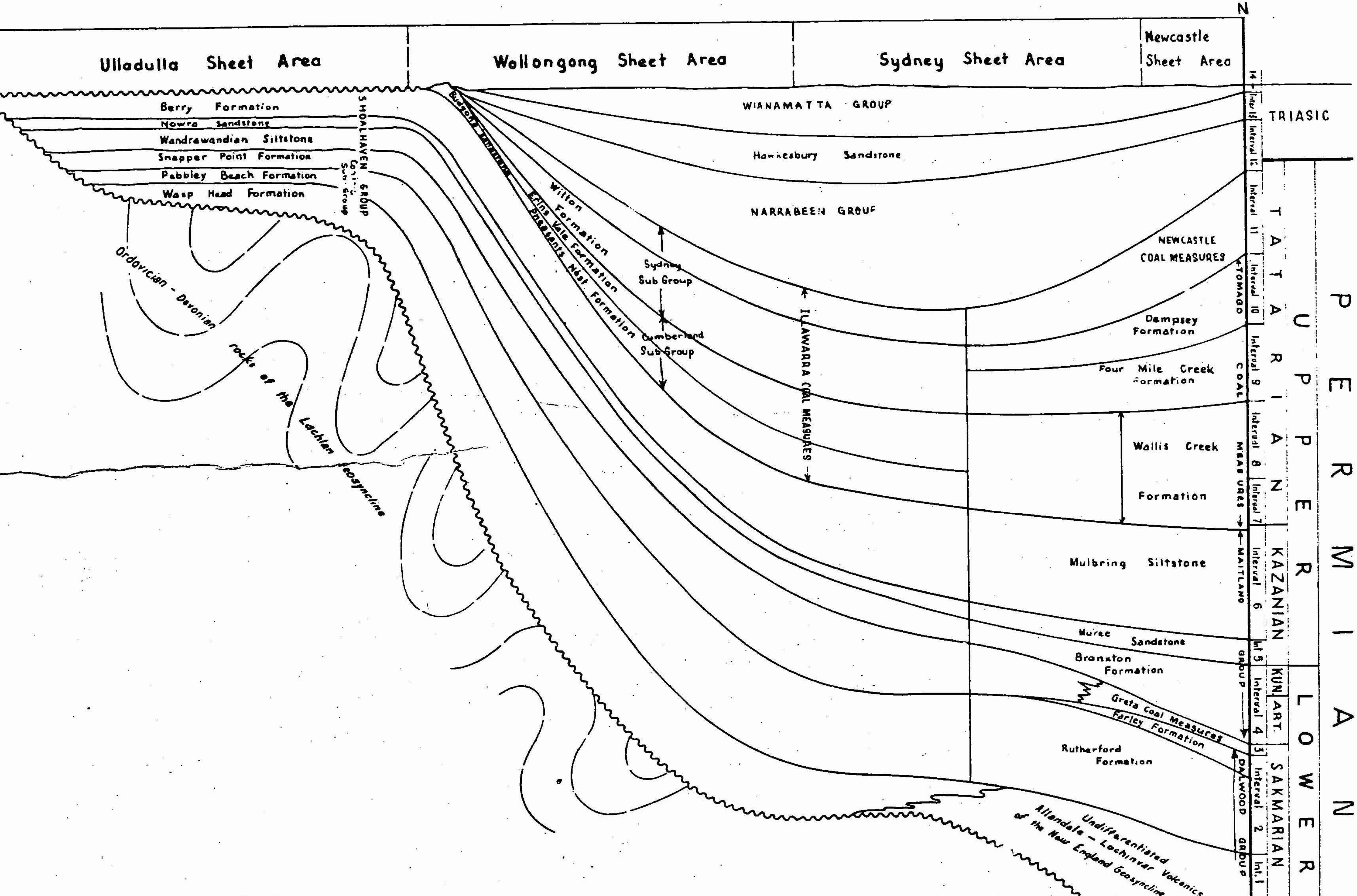

Fig. 10 Relationship of major rock units, Ulladulla, Wollongong, Sydney, and Newcastle 1:250000 Sheet area

X AUS -3-218

Group' in a part of the Hunter Valley region are briefly described in Table 5.

The youngest rocks of the New England Geosyncline, beneath the Sydney Basin, were deposited in the lower Sakmarian. They include the Lochinvar Formation, Allandale Formation, Gyarran Volcanics, and the Skeletar Formation. Because these rocks lie with only suspected local unconformity beneath the Sydney Basin they have been described as Interval 1 in the text and appendix.

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.

Kuttung-like rhyolite fragments have been found in a 'Triassic diatreme' (Osborne, 1920) at The Basin (Nepean River).

NEW ENGLAND GEOSYNCLINE (Early Sakmarian)

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 of the interval is given in Figure 11. Figure 12 is a sand-shale ratio map and section. Palaeoenvironments are shown in Figure 13.

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 area. 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 of the interval penetrated in the deep wells. This suggests that the interval was deposited in a northwesterly trending trough in the northern area where it is over 900 m (3 000 ft) thick. In the southern area it is unconformable

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 Johnson 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

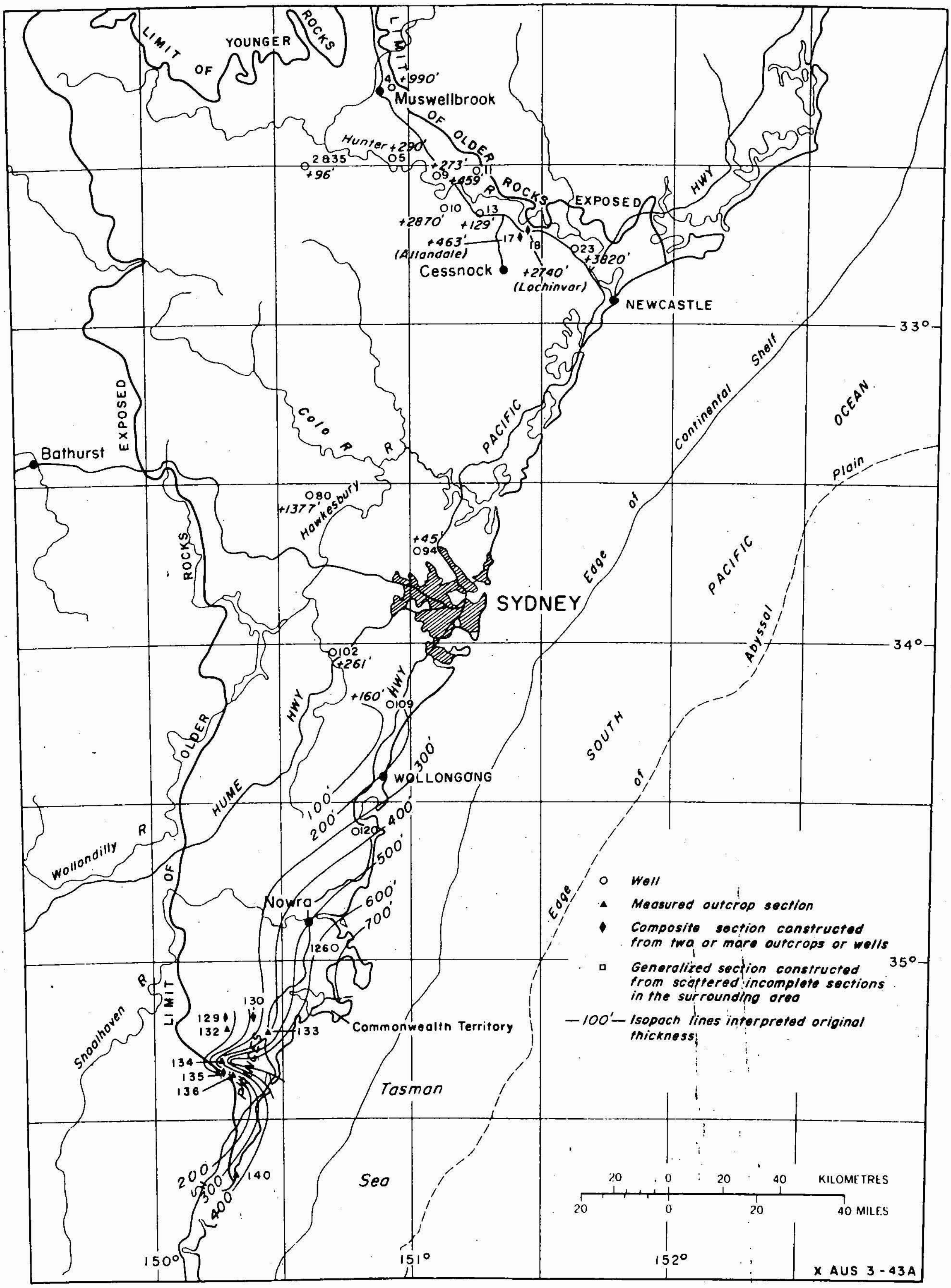

Fig. II. Isopach map, Interval I, Allandale, and Lochinvar Formations and correlatives

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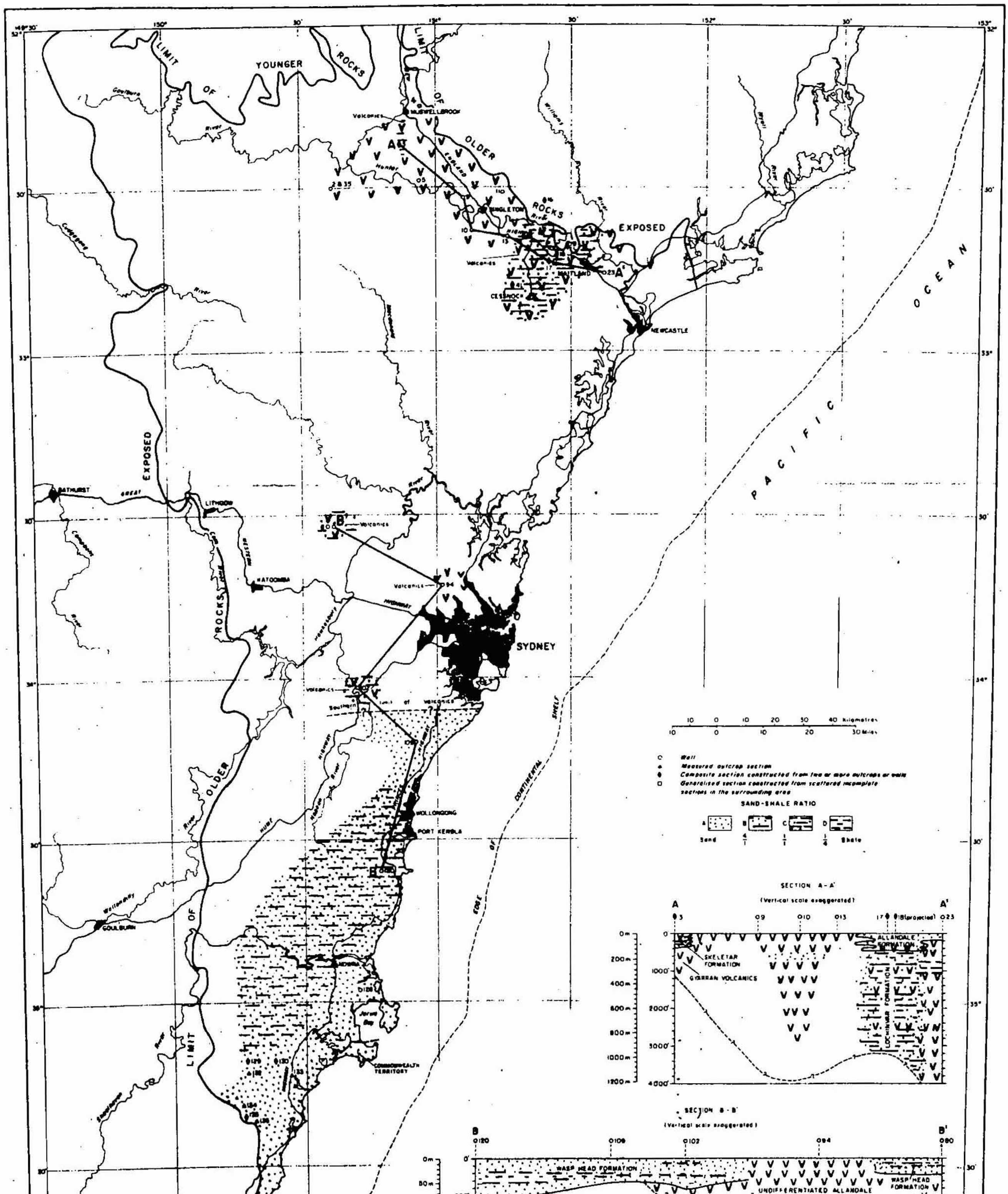

Fig. 12 Sand-shale ratio map and section, Interval I, Allandale and Lochinvar Formations and correlatives

To accompany Record No 1972/76

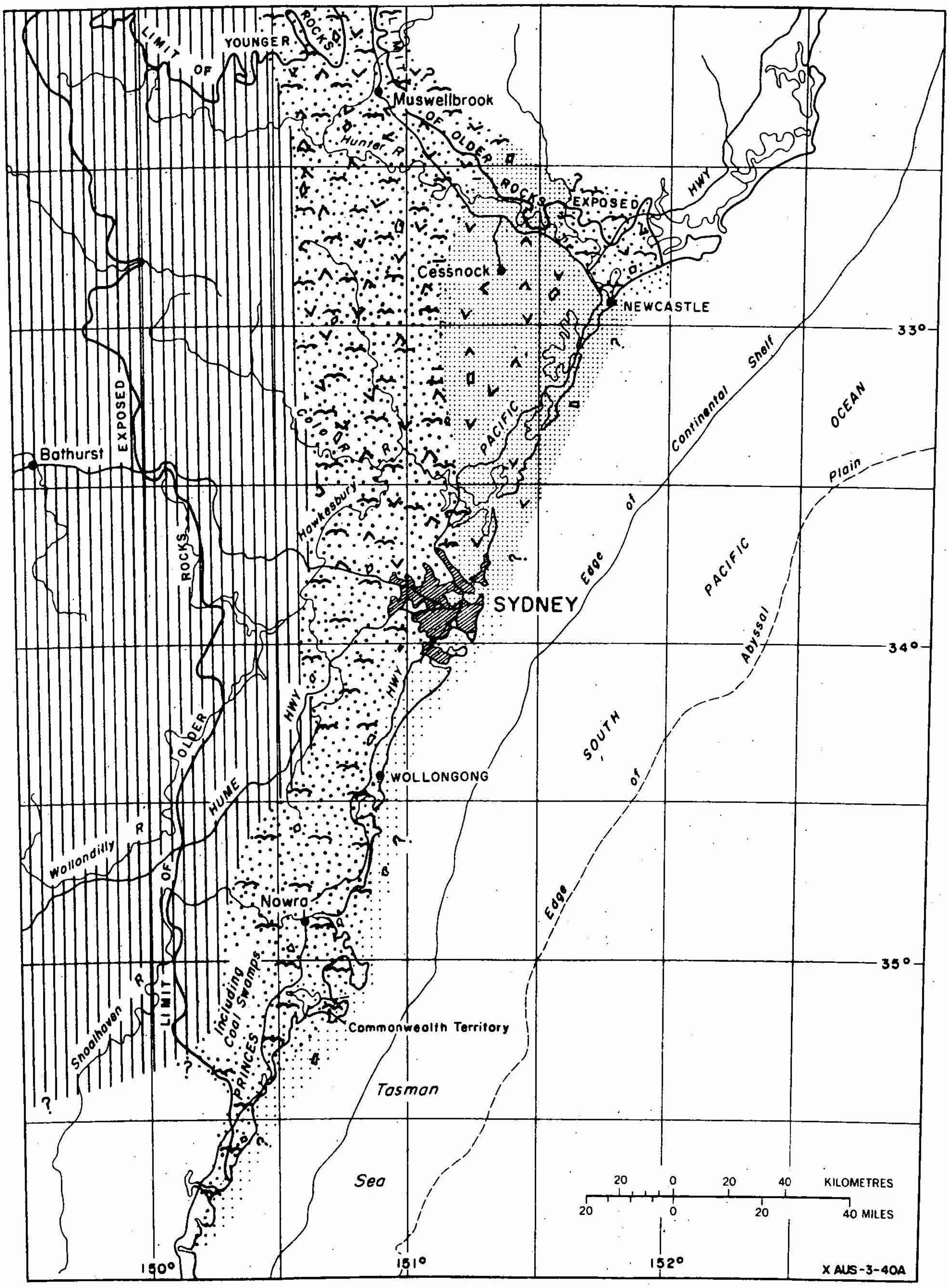

Fig. 13. Environment map, Interval I, early Sakmarian

To accompany Record No 1972/76

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 indicate that the sediment in the northern trough was derived from the New England Geosyncline to the northeast, whereas the sediment deposited on the southern shelf was derived from the Lachlan Geosyncline to the south and west. The proportion of volcanics increases to the northwest and northeast of the Lochinvar Anticline. Predominantly volcanic sequences occur in the deep wells in the middle and upper part of the Hunter Valley and 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 environment (fluvial), 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 on the basis 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 southern area the available lithological data suggests that the sedimentary rocks correlated with the Wasp Head Formation - mainly lithic sandstone and siltstone - are fluvial in origin. Marine fossils are absent and the rocks contain carbonaceous material. Conglomerates fill old drainage channels (Herbert, in prep.) and there are localized coal measures.

The Wasp Head, Lochinvar, and Allandale Formations all contain erratic boulders and pebbles which 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 of rocks has been sub-divided.

Intervals 2 to 6 contain three natural groupings in the northern Sydney Basin, two dominantly marine sequences are 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) the boundaries of Intervals 2 to 5 become lost in a conglomeratic shoreline sequence, and only the youngest interval can be identified.

Interval 2 contains the Rutherford and Farley Formations and their correlative, the Pebbly Beach Formation, which range in age from Sakmarian to early Artinskian. Interval 3 contains the Greta Coal Measures and 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 contains 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.

The conclusions of the study, together with sand-shale ratio maps and isopach maps, are given in the text. Details of lithology, correlations and age, and relations with older units are given in Appendix 2.

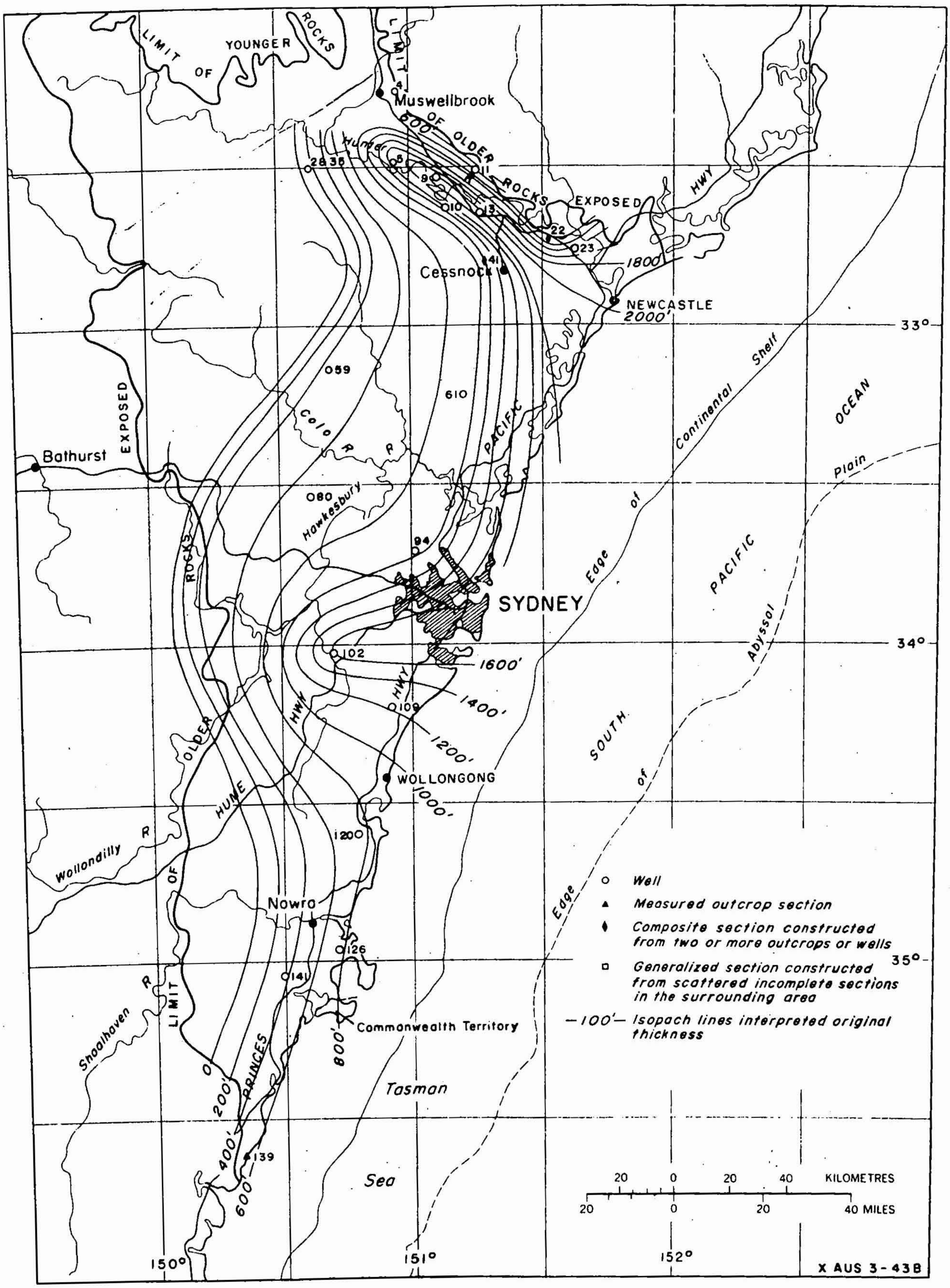

Fig. 14. Isopach map, Interval 2, Farley and Rutherford Formations and correlative Pebbley Beach Formation

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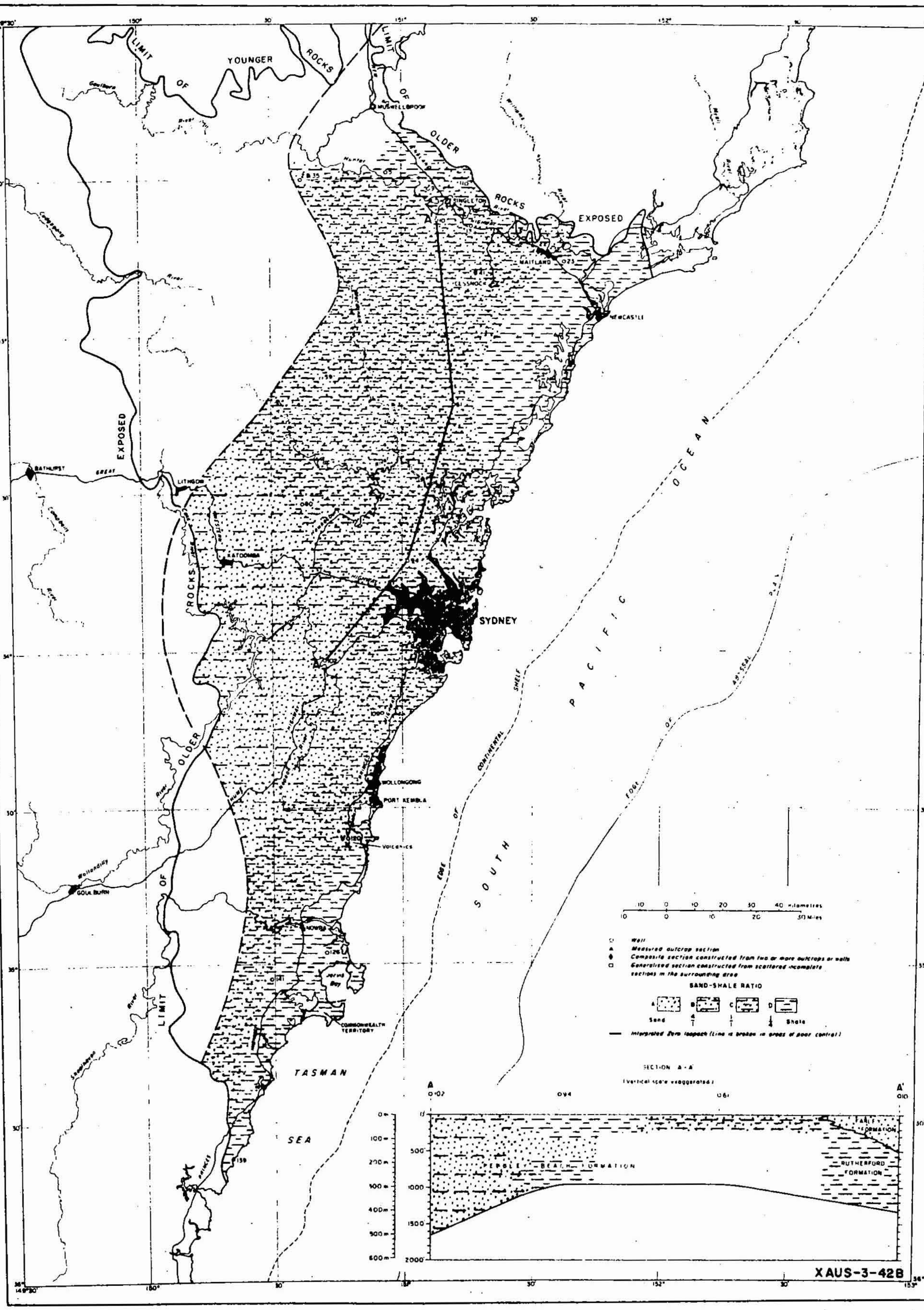

Fig. 15. Sand-shale ratio map and section, Interval 2, Farley, and Rutherford Formations and correlative Pebbley Beach Formation

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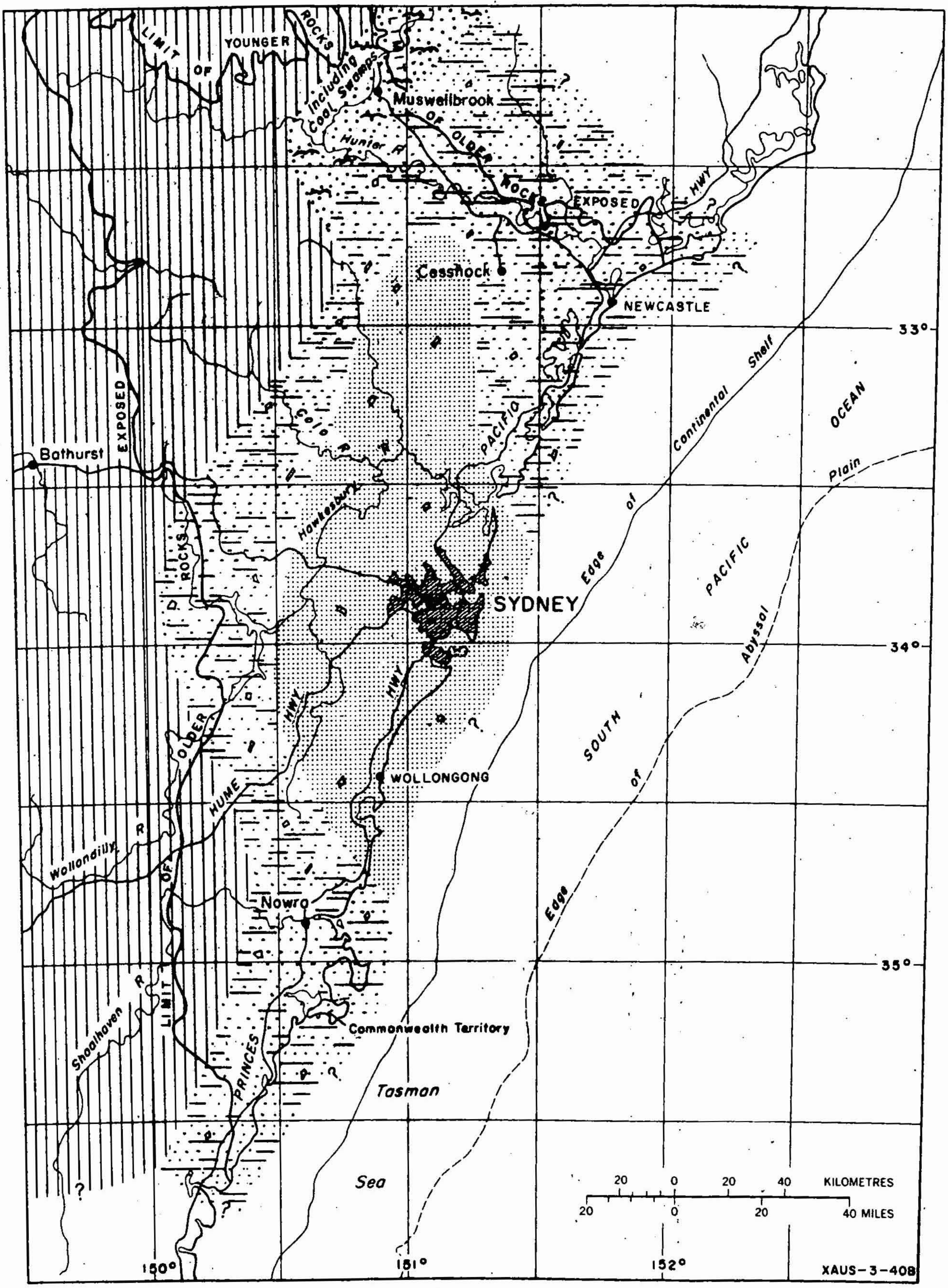

Fig. 16. Environment map, Interval 2, Sakmarian to early Artinskian

To accompany Record No 1972/76

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. 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 of the interval is given in Figure 14. Figure 15 is a sand-shale ratio map and section. Palaeoenvironments are shown in Figure 16.

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

Conclusions

The interval is over 600 m (2 000 ft) thick (Fig. 14) in a narrow northwesterly trending depression in the northern part of the Sydney Basin, and exceeds 480 m (1 600 ft) in a broader westerly trending depression beneath Sydney. From these areas and the east coast the interval thins toward an interpreted zero isopach.

Thinning of the interval over 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 more widespread movement in the New England area which is indicated by the rapid thinning to 60 m (200 ft) to the northeast.

The sand-shale ratio map (Fig. 15) shows areas with a low sand-shale ratio centered around Newcastle in the north and Jervis Bay in the south and a westerly 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 it 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 interval was deposited 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 quiet marine deposition. Brachiopods and pelecypods occur throughout the interval in these areas and also in the Pebbley Beach Formation cropping out 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).

Burrow structures occur throughout the interval and together with carbonaceous material suggest a near-shore environment. Carbonaceous material including coal is particularly common in the northern area.

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 coal swamps are shown in the northwest (Fig. 16) 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, 8, 9, and 10. The thickness of the interval is given in Figure 17. Figure 18 is a sand-shale ratio map and section. Palaeoenvironments are shown in Figure 19.

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

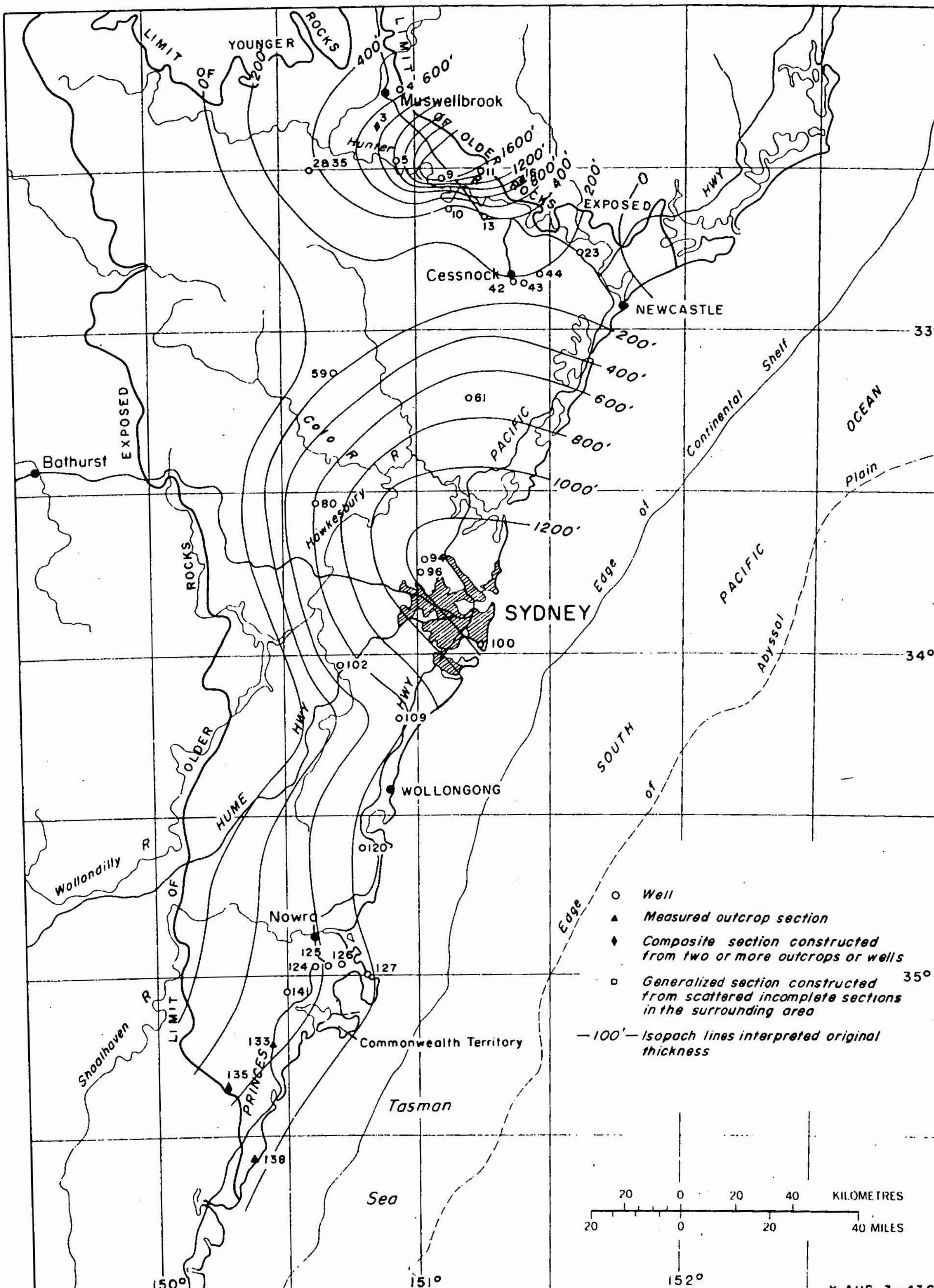

Fig. 17. Isopach map, Interval 3, Greta Coal Measures and correlative Snapper Point Formation

To accompany Record No. 1972/76

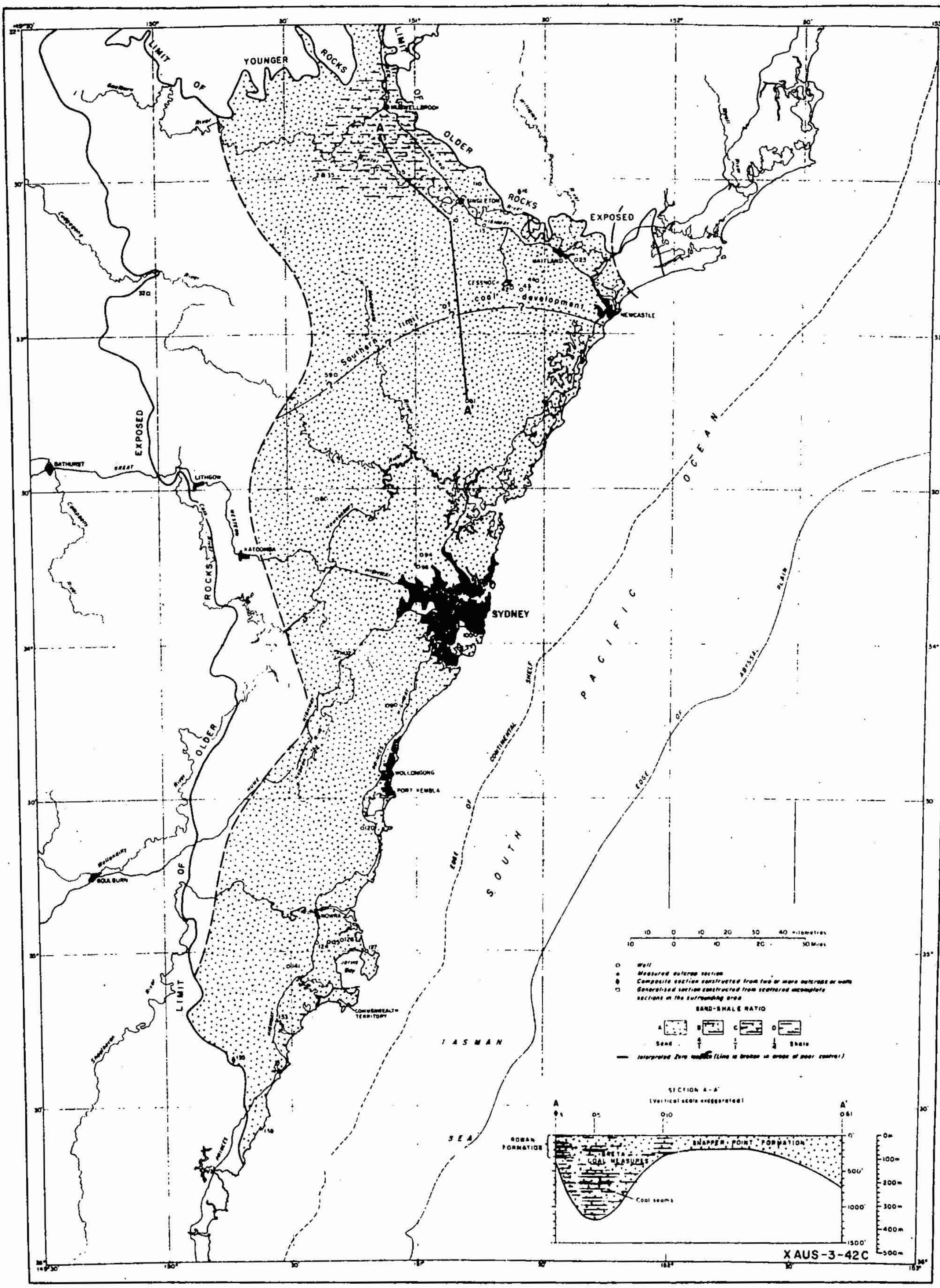

Fig. 18. Sand-shale ratio map and section, Interval 3, Greta Coal Measures and correlative Snapper Point Formation

To accompany Record No 1972/76

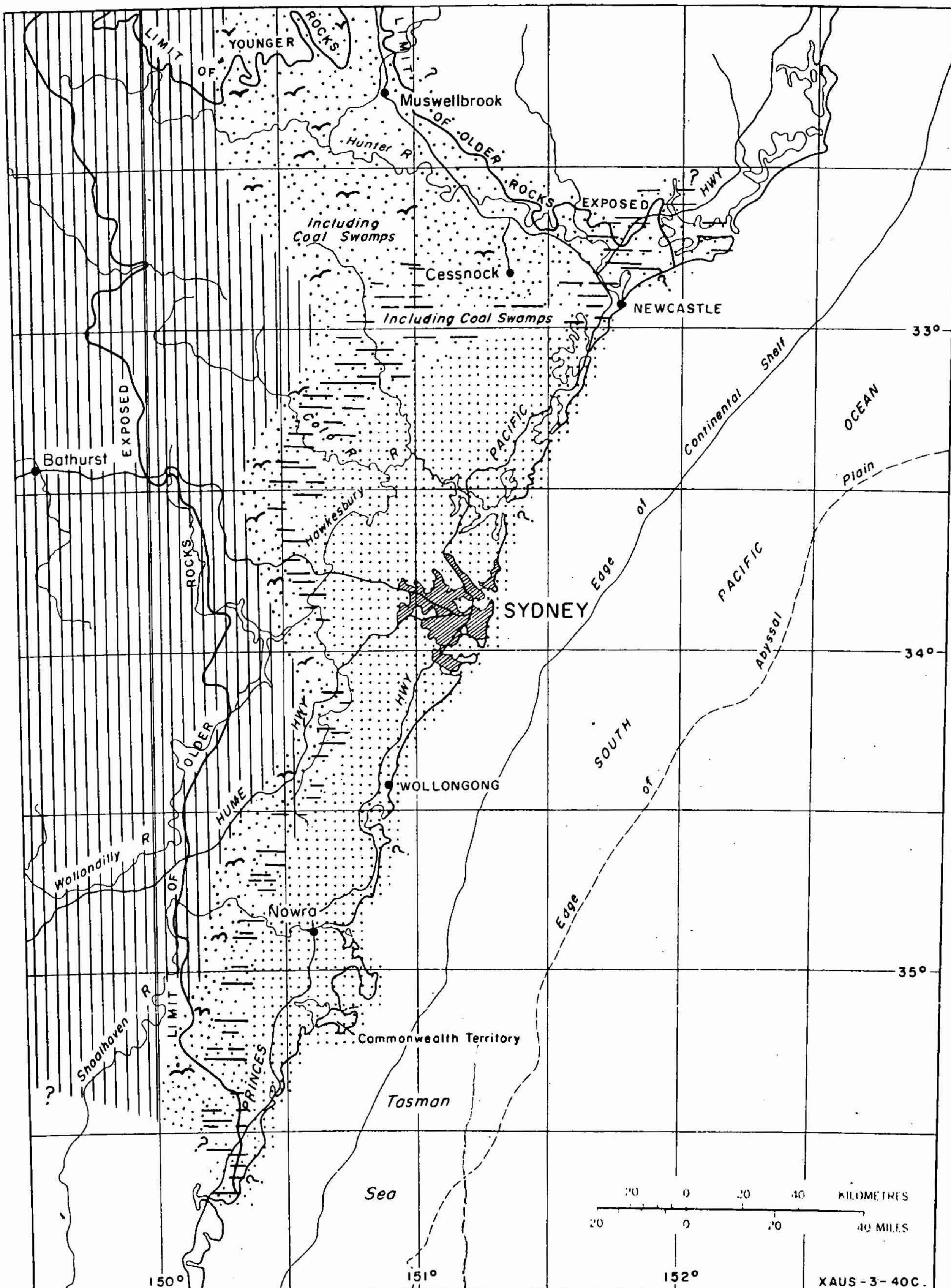

Fig. 19. Environment map, Interval 3, Artinskian

Conclusions

The Greta Coal Measures are up to 480 m (1 600 ft) thick (Fig. 17) in an easterly trending depression in the north that is cut off structurally by the Hunter Thrust along the northeastern margin of the basin. The measures thin southward to 30 to 60 m (100-200 ft) over a westerly trending arch, and to the east and west to interpreted zero isopachs. South of the westerly trending arch, the Snapper Point Formation thickens to over 390 m (1 300 ft) in a depression beneath Sydney and thins westward to an interpreted zero isopach.

The sand-shale ratio (Fig. 18) is high in the southern and central areas where the Snapper Point Formation is predominantly a fine to medium-grained pebbly protoquartzite. In the northern area the ratio is high in the Greta Coal Measures deposited around the southeasterly margin of the trough (Fig. 17) where conglomerate, with phenoclasts derived largely from volcanics of the New England Geosyncline, is a characteristic part of the sequence, particularly in outcrops on the Lochinvar Anticline. The coarsening and thickening of the conglomerates toward the northern end of the anticline suggests 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 are a major component of the sequences between the coal seams.

The interval was deposited during a marine regression from the northern area and the coal swamps which developed in the upper Hunter Valley in the Sakmarian (Interval 2) extended into the lower Hunter Valley as the sea retreated. 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 or else not as sheltered from the open sea as it was 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. 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 of the interval is given in Figure 20. Figure 21 is a sand-shale ratio map and section. Palaeoenvironments are shown in Figure 22.

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

Conclusions

Interval 4 is thickest in a northerly trending depression (Fig. 20) extending along the whole length of the Sydney Basin. Some 120 m (400 ft), or less, of sediment was deposited in the depression to the south and about 210 m (700 ft) in the centre of the basin. The thickness of sediment in the depression increases rapidly from the centre of the basin to over 900 m (3 000 ft) in the north adjacent to the Hunter Thrust. From the depression, the sedimentary rocks thin westward to an interpreted zero isopach. East of the depression the sedimentary rocks thin into the offshore Sydney 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 with distance from the zero isopach in the west. An increase in the ratio of sand to shale in the northern part of the depression may indicate that some of the detritus was derived from the north along the axis of the trough. The sequence consists characteristically of pebbly fine-grained silty sandstone and sandy siltstone with conglomeratic horizons in the north.

Interval 4 was deposited in a sea (Fig. 22) that transgressed again over the northern area, and also extended farther west. The marine fossils, including pelecypods and brachiopods together with laminated bedding, and burrow structures, indicate a quiet sublittoral marine depositional environment protected from strong tidal action. The coarser clastic material was possibly ice-rafted.

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

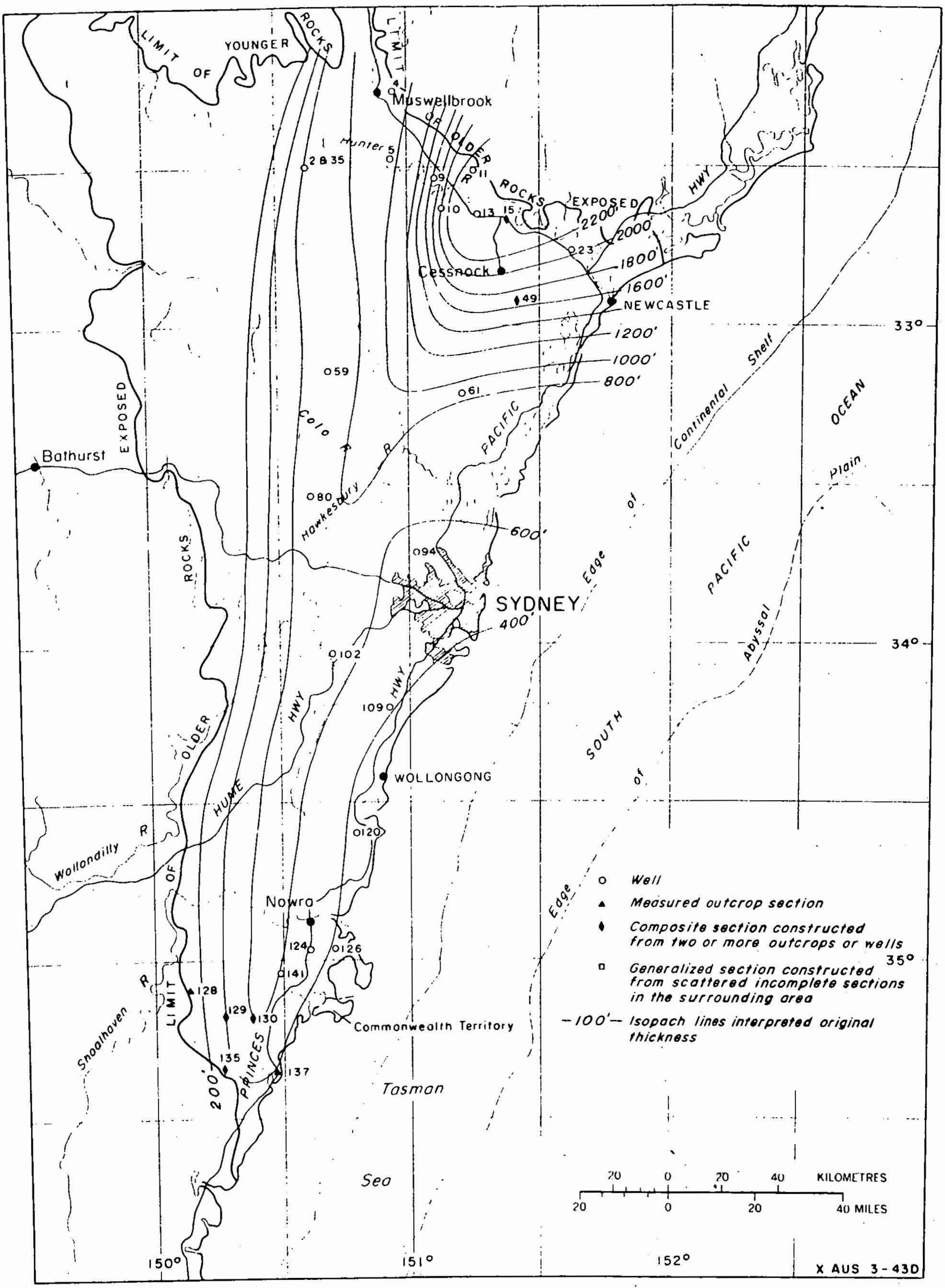

Fig. 20. Isopach map, Interval 4, Branxton Formation (excluding Muree Sandstone Member) and correlative Wandrawandian Siltstone

To accompany Record No 1972/76

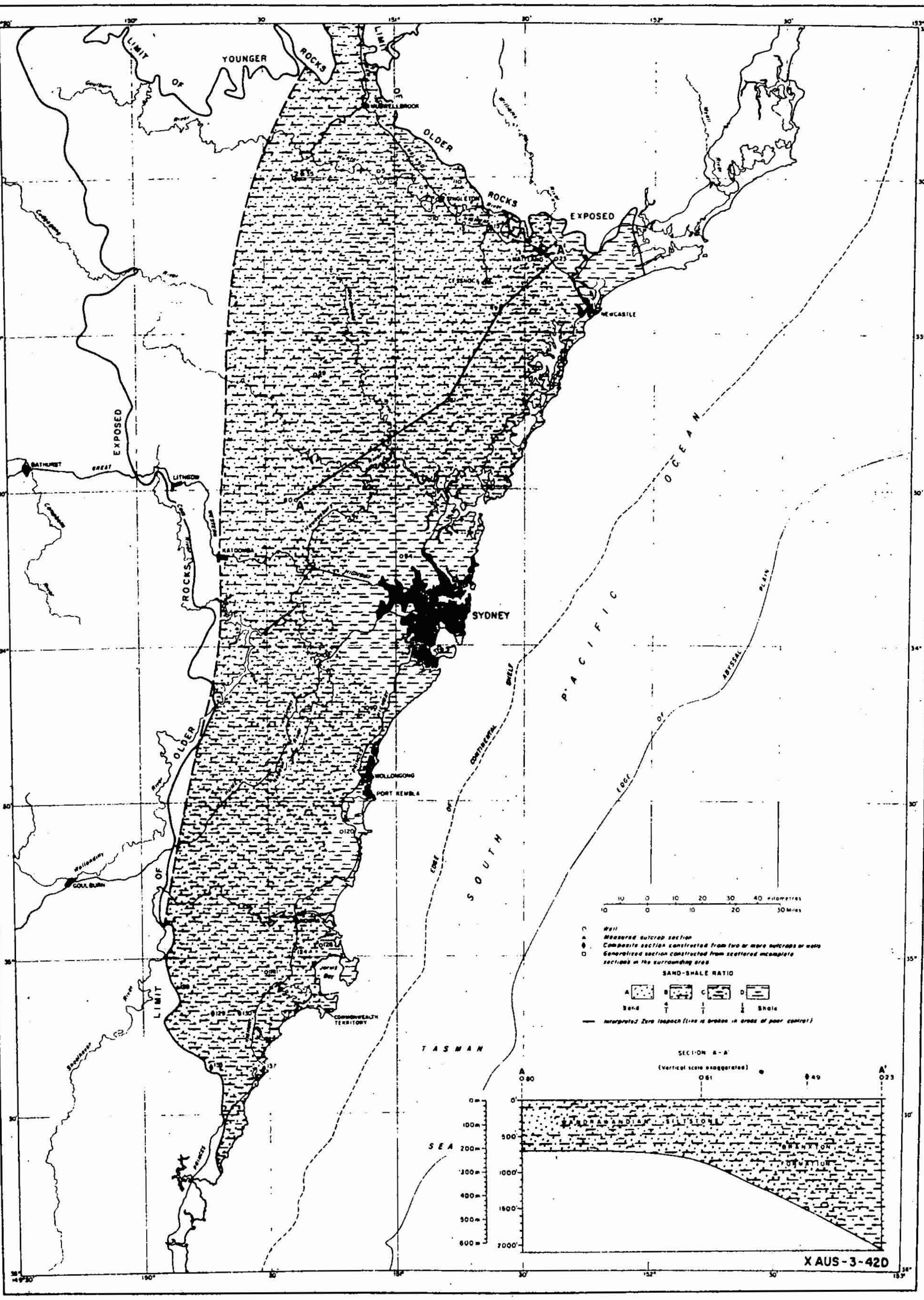

Fig. 21. Sand-shale ratio map and section, Interval 4, Branxton Formation (excluding Muree Sandstone Member) and correlative Wandrawandian Siltstone

To accompany Record No 1972/76

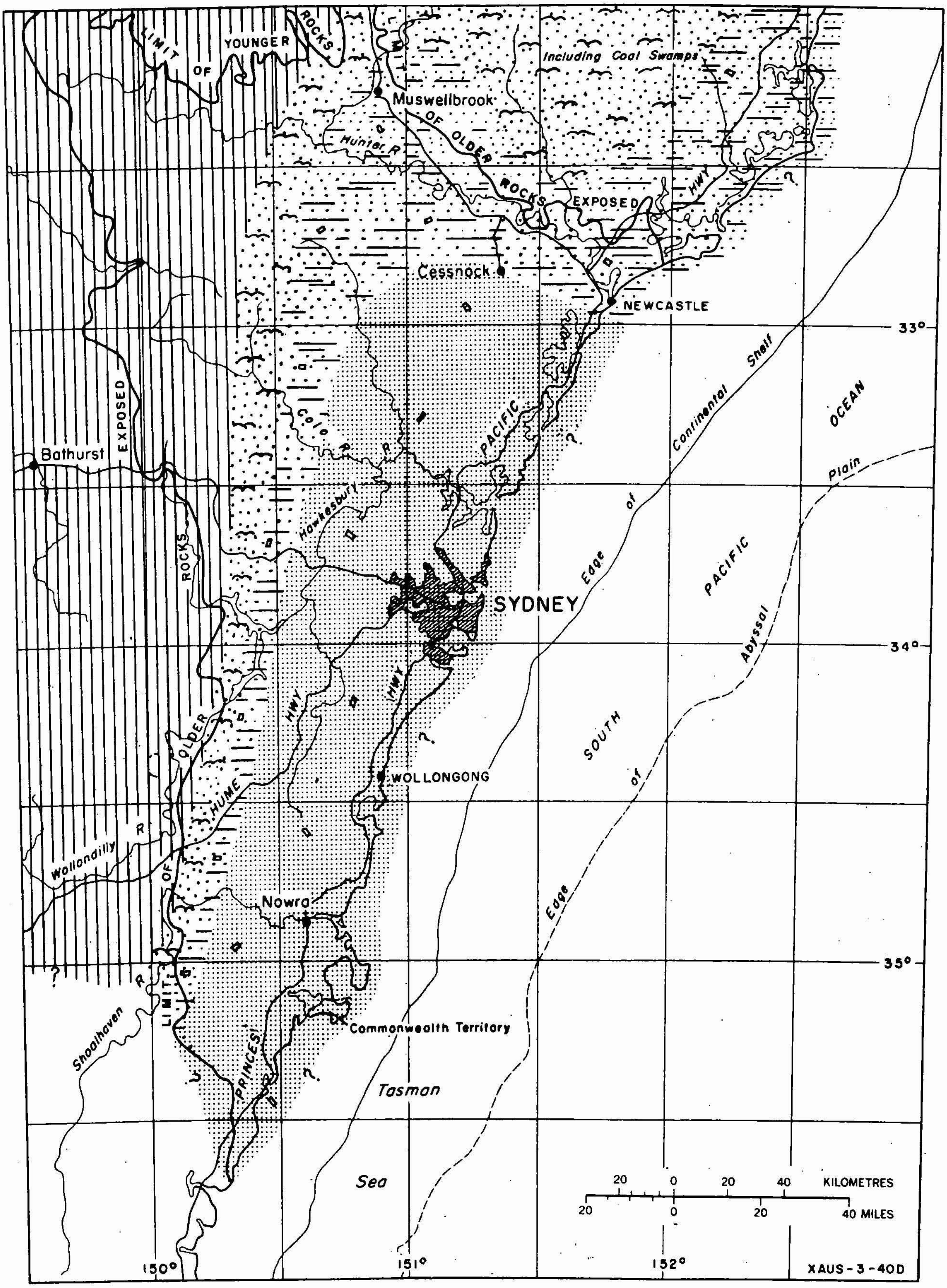

Fig.22. Environment map, Interval 4, late Artinskian and Kungurian

To accompany Record No 1972/76

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 of the interval is given in Figure 23. Insufficient detail is available to provide a lithofacies map. Palaeoenvironments are shown in Figure 24.

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

Conclusions

Interval 5 reaches a maximum of about 90 m (300 ft) in the southern and central areas (Fig. 23), but to the northeast, in East Maitland No. 1, the thickness increases to 180 m (600 ft). In the northern area it thins westward and beyond the Singleton area it can no longer be recognized either as a mappable unit, or in the subsurface. Probably it interfingers with the upper part of the Branxton Formation (Fig. 8). In the central area it is tentatively identified in the subsurface as a thin unit as far west as Howes Swamp No. 1 and Kurrajong Heights No. 1. At the southern end of the western area, in the Tallong district, it interfingers with the Megalong Conglomerate (McElroy & Rose, 1966).

The interval was 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 depositional environment (Fig. 24) was near-shore marine, similar to that during the deposition of the Snapper Point Formation. The characteristic lithology is a pebbly protoquartzite with siltstone partings, conglomeratic in the north, coarse-grained in the south, and medium or fine-grained in the centre of the basin, indicating northerly and southerly source areas. Cross-bedding is very common in the upper part of the Nowra Sandstone. Palaeocurrent measurements indicate a dominantly southerly source (Paix, 1968; McKelvey et al., 1971).

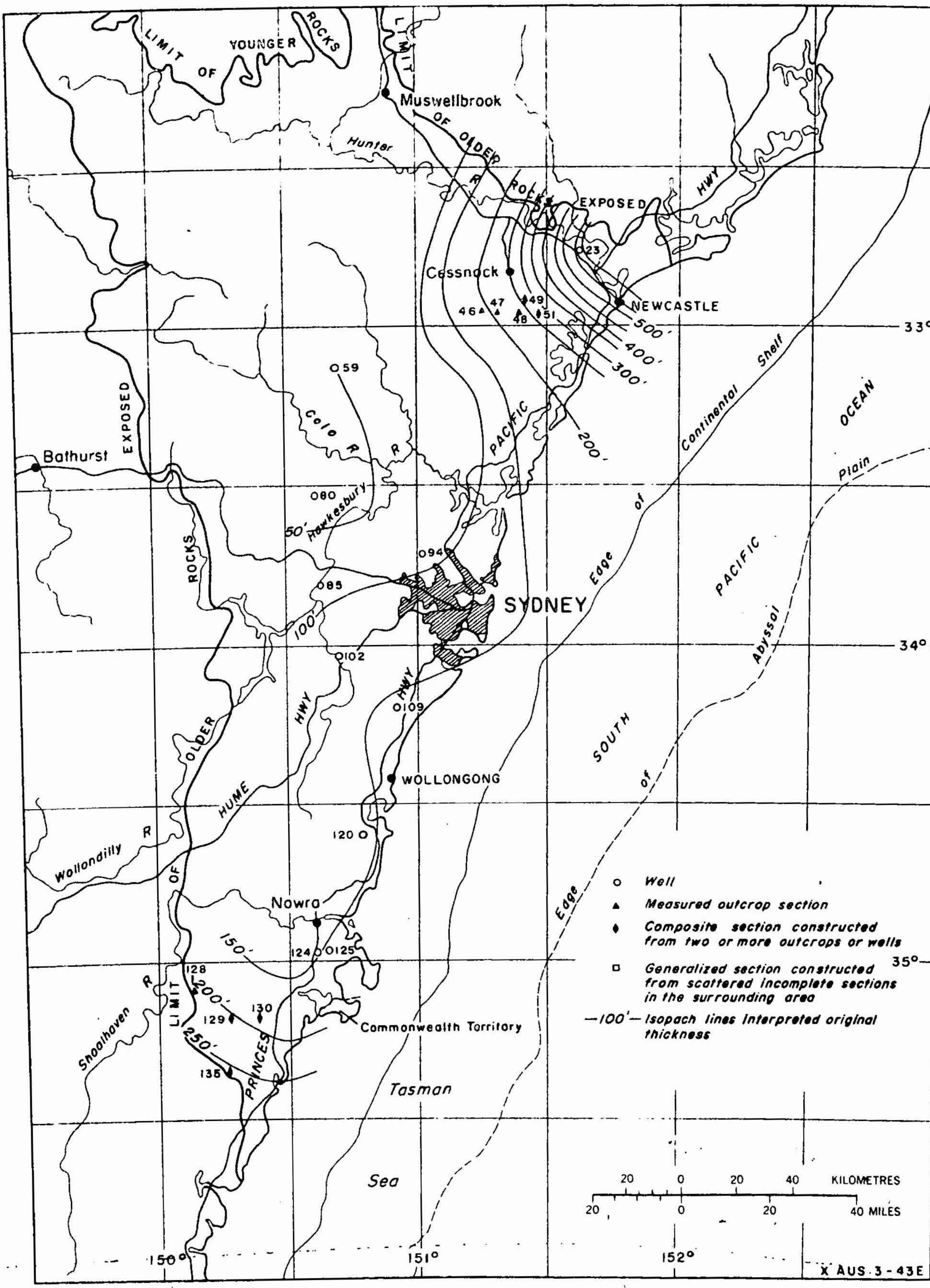

Fig. 23. Isopach map, Interval 5, Muree Sandstone member of Branxton Formation and correlative Nowra Sandstone

To accompany Record No 1972/76

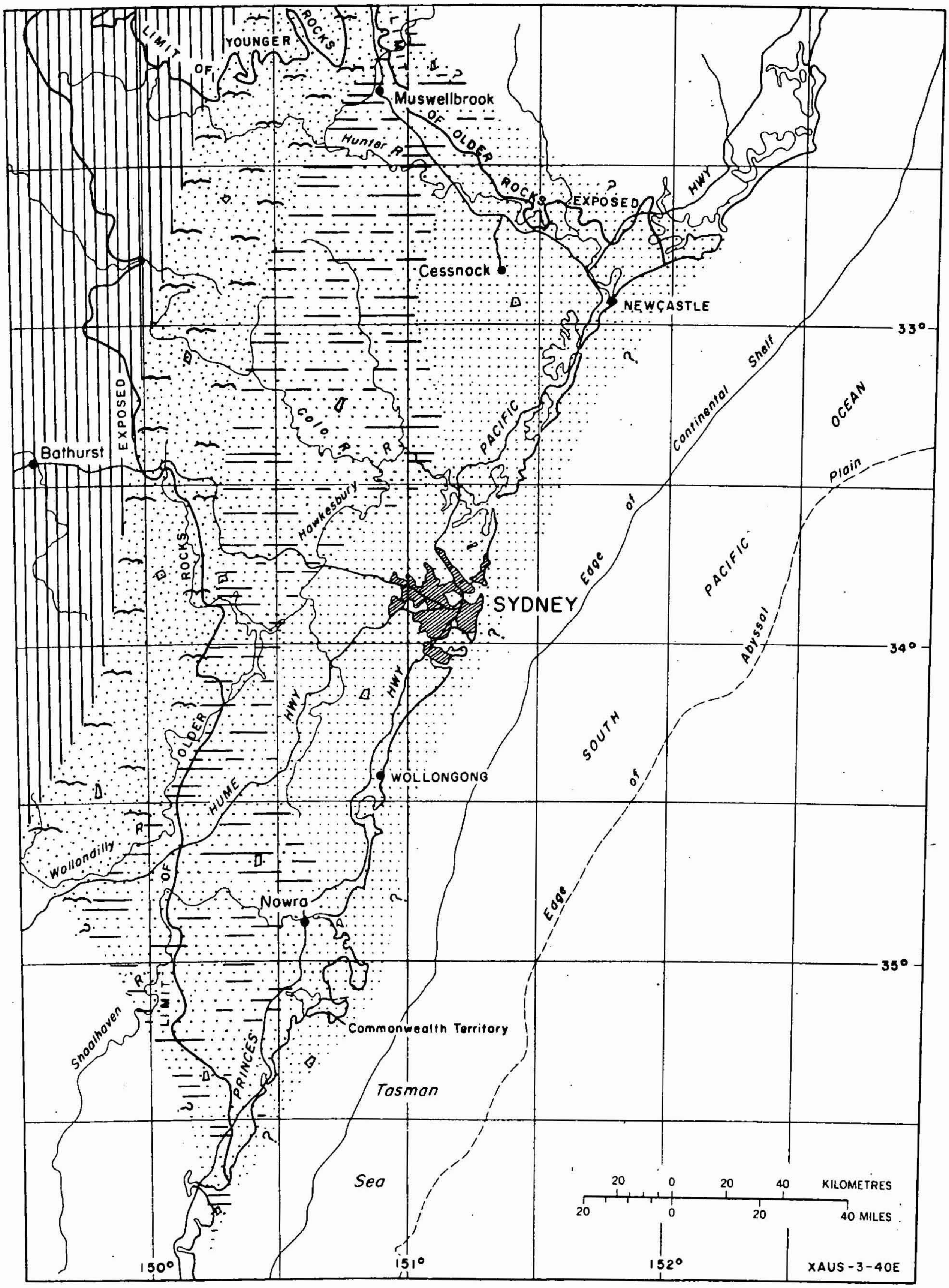

Fig.24. Environment map, Interval 5, lower Kazanian

To accompany Record No 1972/76

Three units are recognized in the type section of the Muree Sandstone Member - two cliff-forming sandstone units separated by a unit of interbedded siltstone and sandstone. Three similar units are also 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. However, the subsurface extension of the Muree Sandstone Member and the Nowra Sandstone in the central area is probably equivalent to the upper two units and represents only the transgressive phase.

Interval 6: Mulbring Siltstone and Correlative Berry Formation

The Mulbring Siltstone and the Berry Formation are included in Interval 6. 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 of the interval is given in Figure 25. Figure 26 is a sand-shale ratio map and section. Palaeoenvironments are shown in Figure 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 (1 500 ft) in a depression called the Macdonald Depression. From there it is interpreted to thin eastward over an arch called the Kulnura Arch (about Cessnock) before thickening farther east to 510 m (1 700 ft) west of Newcastle (East Maitland No. 1).

The arch and complimentary depression probably developed during gentle warping which accompanied deposition of the Mulbring Siltstone.

The sand-shale ratio (Fig. 26) is low in the north and south and along the present coastline, and increases to the west. The main rock type is siltstone and poorly sorted fine-grained sandstone. Marine fossils have been found in all areas except on the western margins north of the Shoalhaven River. The macrofossils include pelecypods and brachiopods. Foraminifera have been recorded in surface exposures of the Mulbring Siltstone in the northern area and in wells in the central area. The marine fossils, together with burrow and scallop structures and the fine grainsize indicate a sheltered sublittoral marine

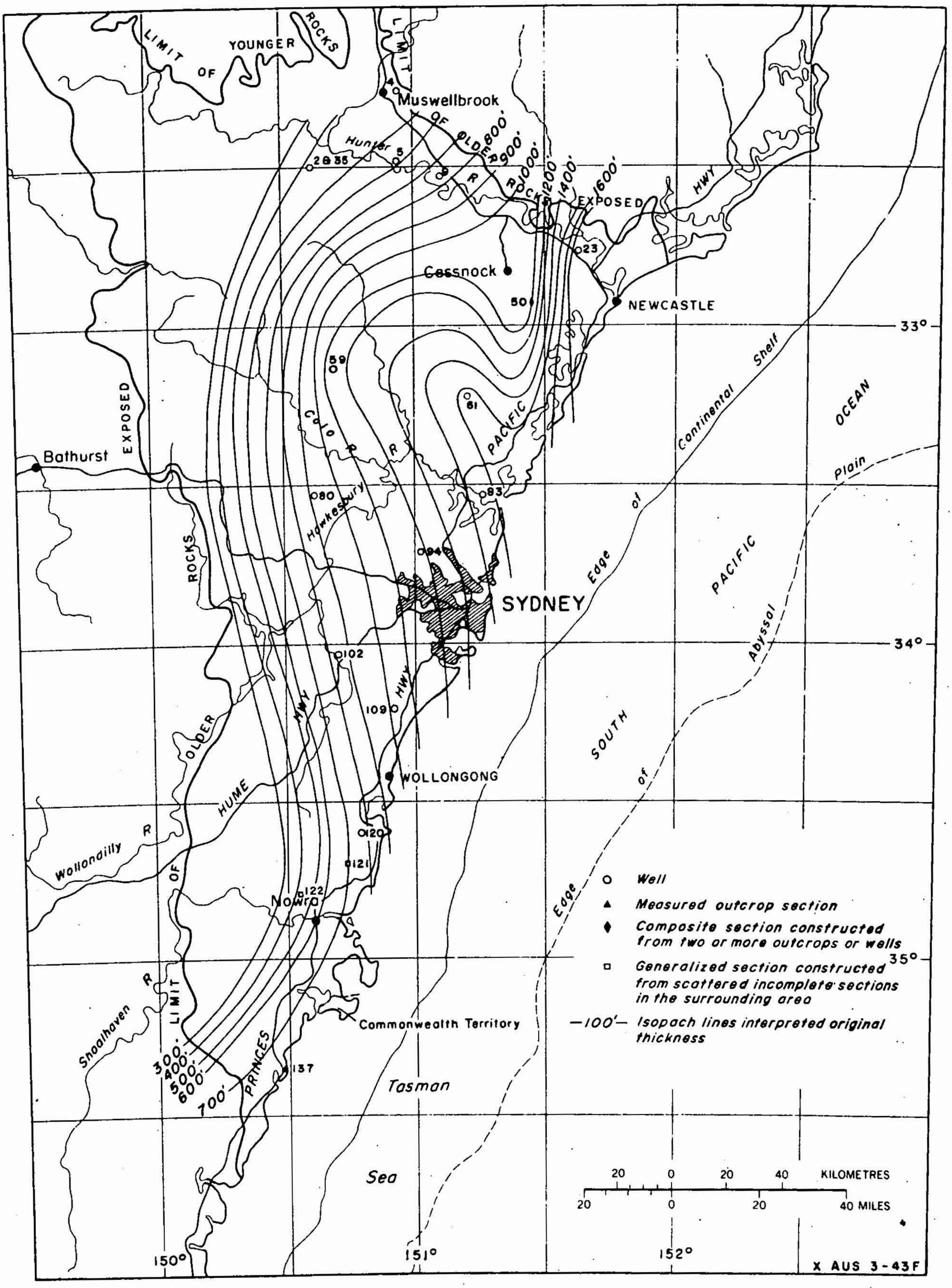

Fig. 25. Isopach map, Interval 6, Mulbring Siltstone and correlative, Berry Formation

To accompany Record No. 1972/76

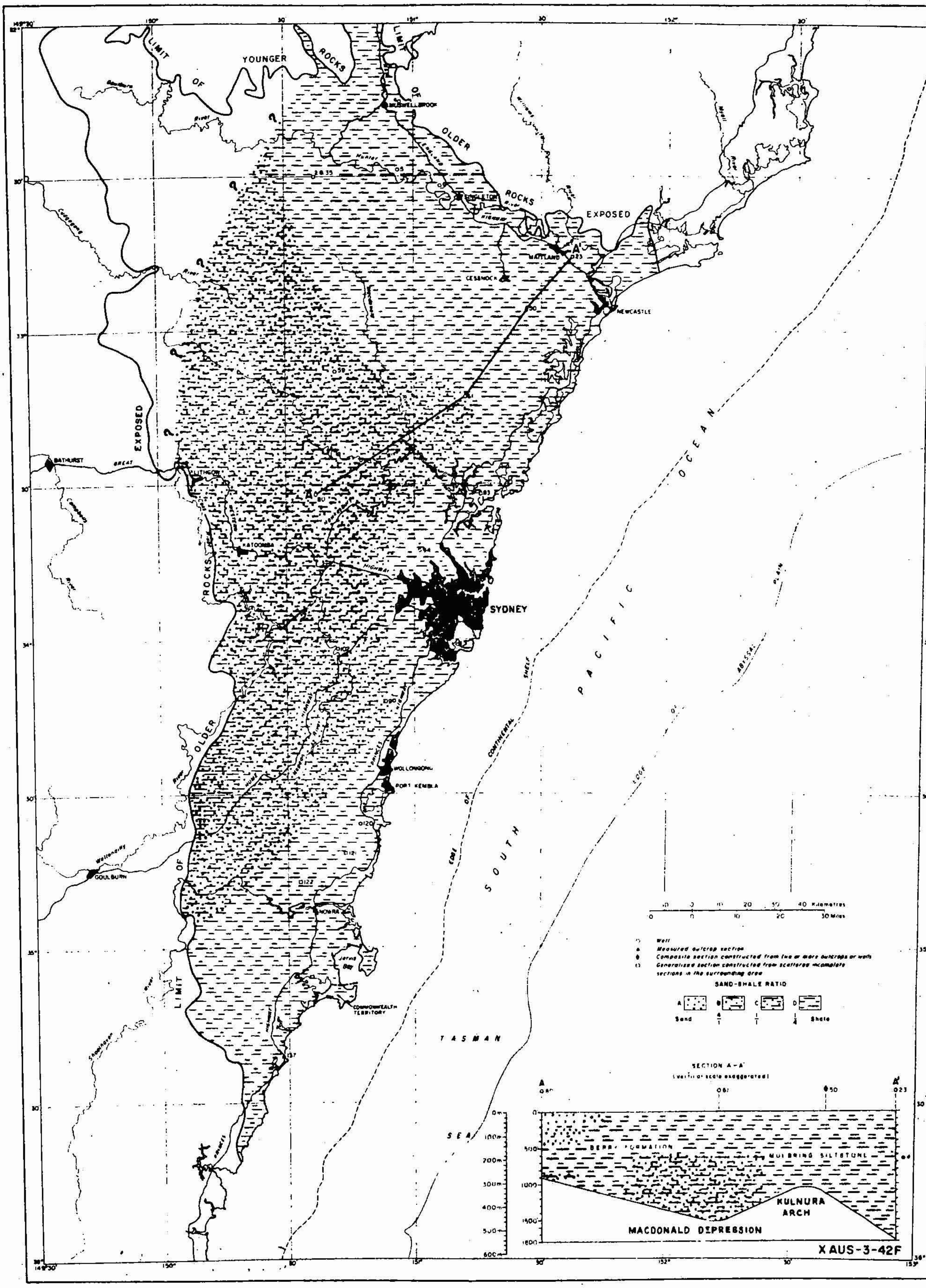

Fig. 26. Sand-shale ratio map and section, Interval 6, Mulbring Siltstone and correlative Berry Formation

To accompany Record No.1972/76

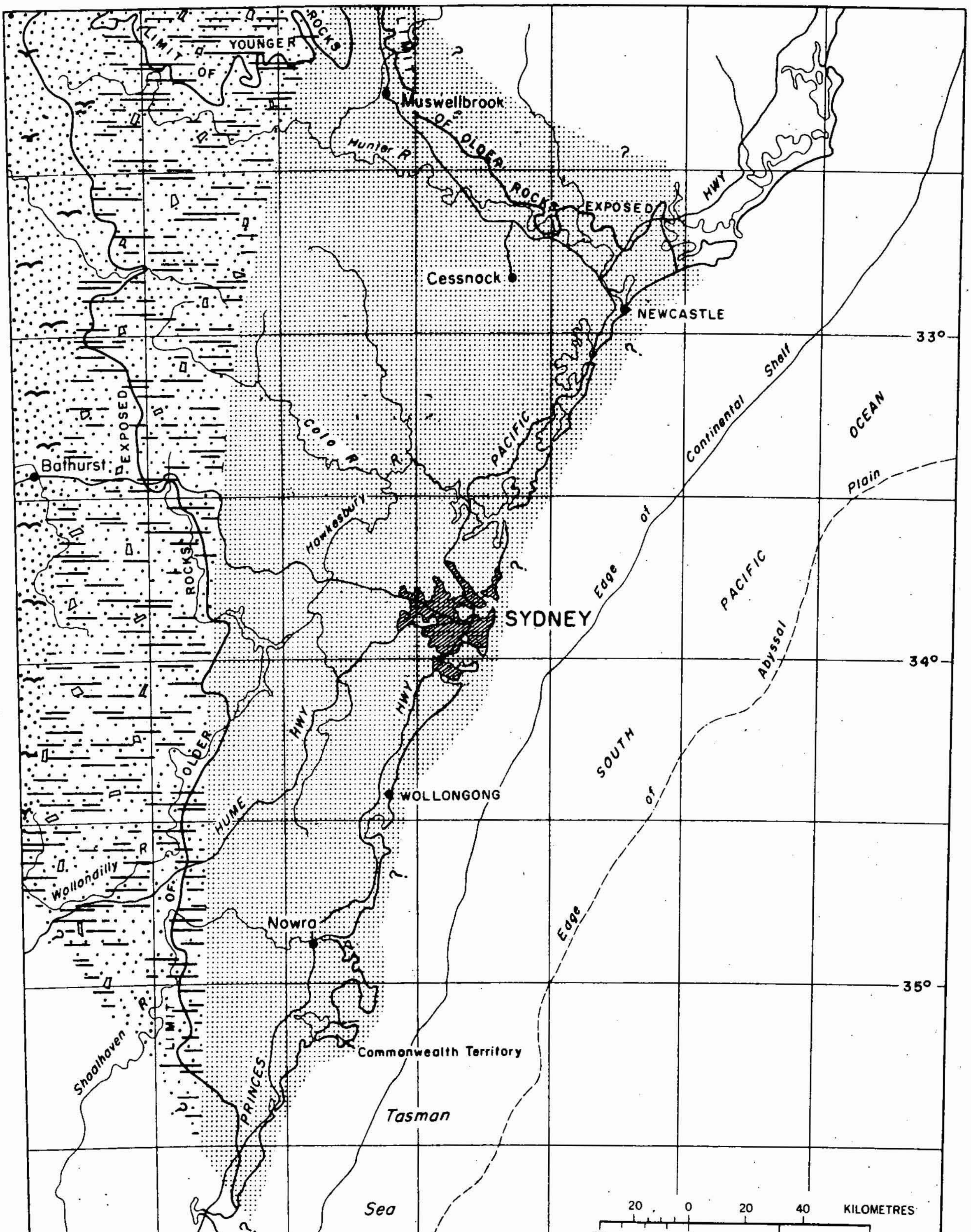

Fig.27. Environment map, Interval 6, Kazanian

To accompany Record No 1972/76

environment (Fig. 27) similar to that in earlier transgressions (Intervals 2 and 4). The interval was deposited in deeper 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. 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 brought the dominantly marine deposition to an end. In the western part of the basin Interval 6 contains probable ice-rafted material, the youngest occurrence 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.

Interval 7 contains the lower part of the Wallis Creek Formation and its correlatives; Interval 8 contains the upper part of the Wallis Creek Formation and correlatives; Interval 9 contains the Four Mile Creek Formation and correlatives; Interval 10 contains the Waratah Sandstone and Dempsey Formation and correlatives; Interval 11 contains 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, 8, 9, 10, and 11 and the lower part of Interval 12 are of Tatarian age, the upper part of Interval 12, and Interval 13, are of Lower Triassic age, and Interval 14 is of Middle Triassic age (see also Fig. 44).

The conclusions of the study, together with sand-shale ratio, isopach, and environment maps, are given in the text. Details of 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 of sandstone and shale

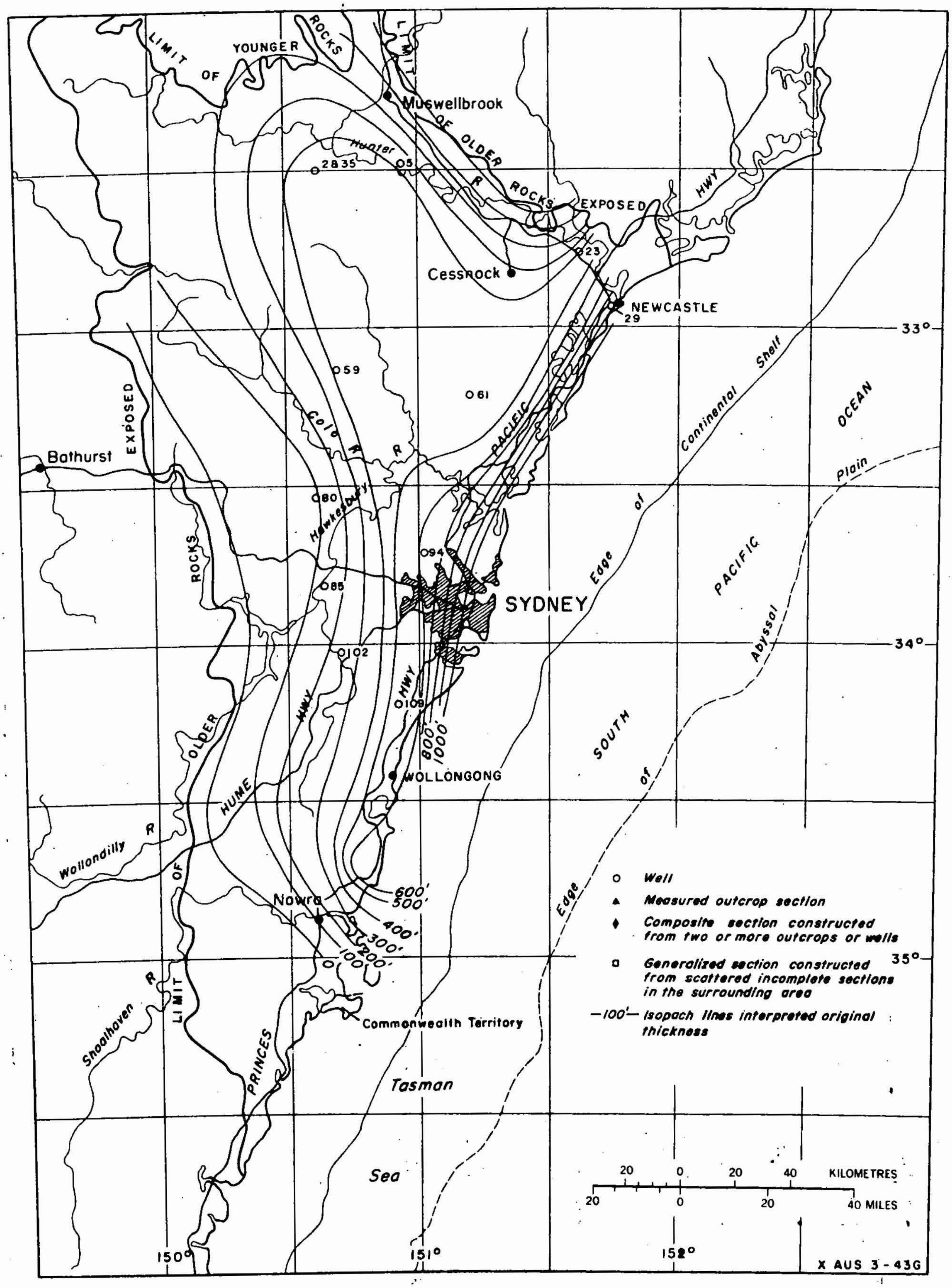

Fig.28 Isopach map, Interval 7, lower part of Wallis Creek Formation and correlatives

To accompany Record No. 1972/76

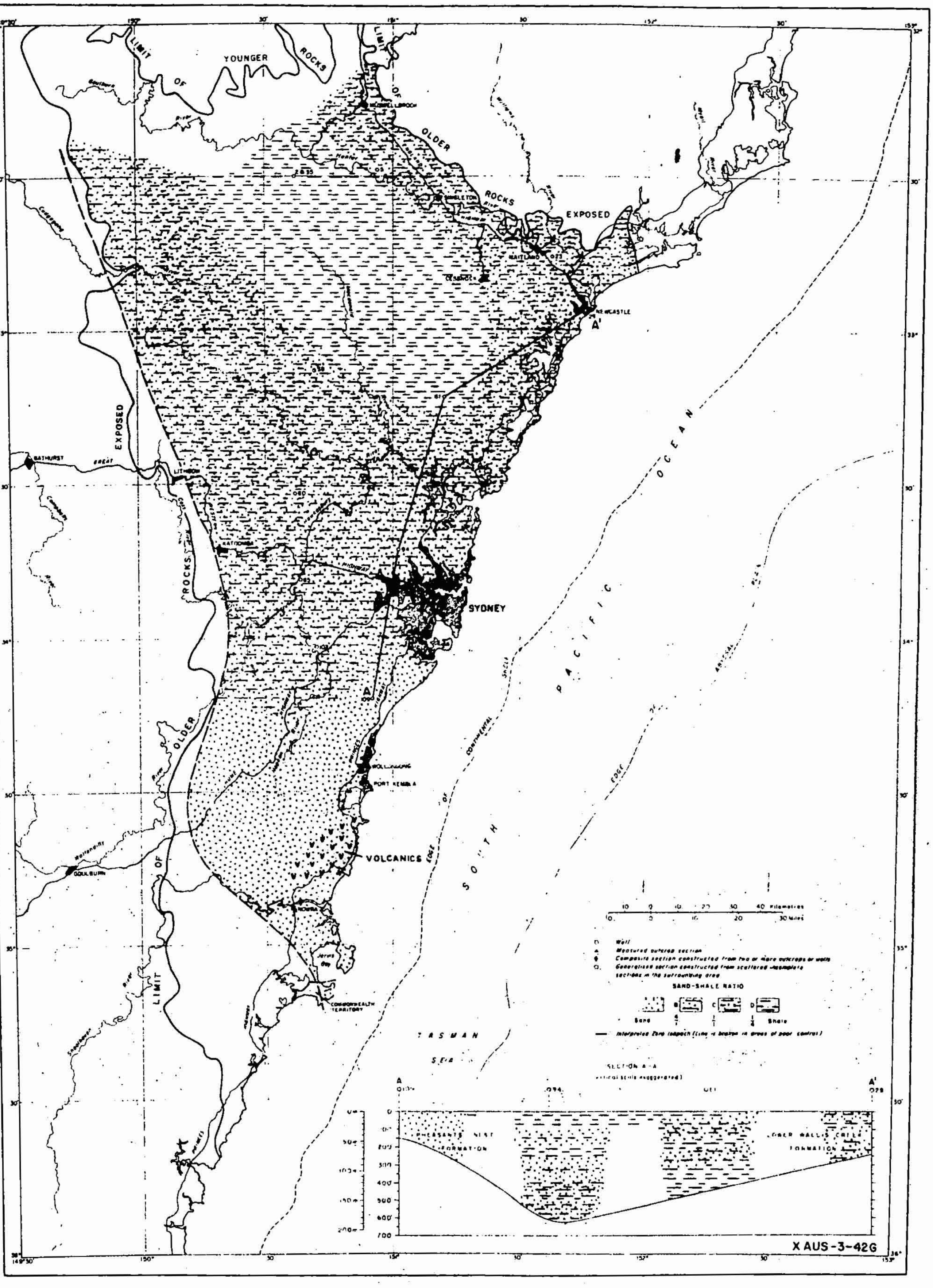

Fig. 29. Sand-shale ratio map and section, Interval 7, lower part of Wallis Creek Formation and correlatives

To accompany Record No. 1972/76

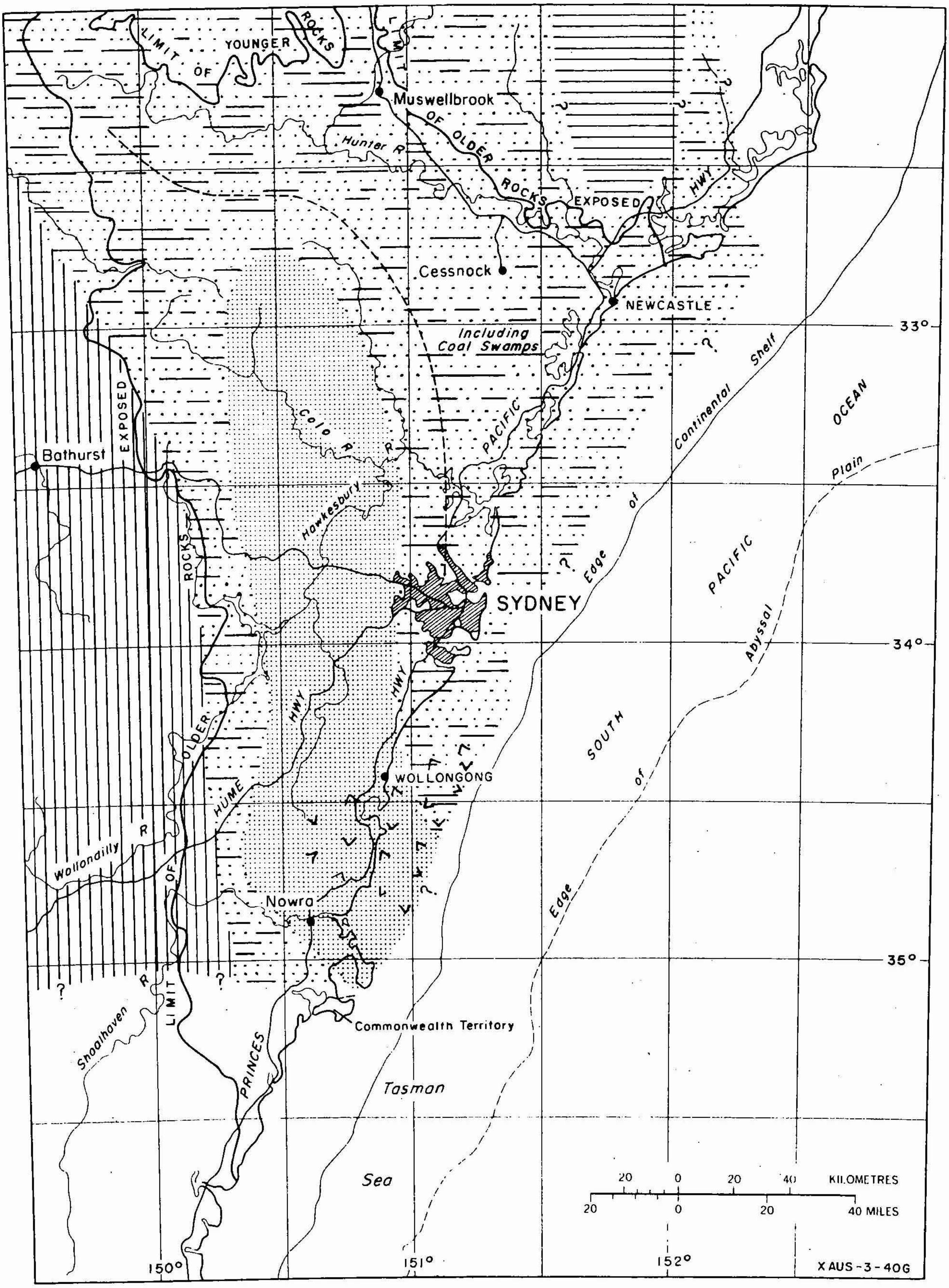

Fig. 30. Environment map, Interval 7, upper Kazanian to lower Tatarian

To accompany Record No. 1972 / 76

with interbedded coal seams and its correlatives the Mount Marsden Claystone, the Budgong Sandstone, the 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 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 of the interval is given in Figure 28. Figure 29 is a sand-shale ratio map and section. Palaeoenvironments are shown in Figure 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 (1 000 ft) in the Macquarie Depression, a narrow belt along the present coastline (Fig. 28). From the Macquarie Depression the interval is interpreted to thin to the west over the Kulnura Arch and thickens 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 have an influence on thickness and type of sediment laid down until the early Triassic. Sediment removed by erosion over the Lochinvar Anticline has been restored in Figure 28.

The sand-shale ratio map (Fig. 29) shows a gradual change from a high sand-shale ratio in the south to a low sand-shale ratio in the north, especially in the Macdonald Depression.

A shallow sea (Fig. 30) with active volcanoes existed in the southern area, where the 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 Sydney 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. Marginal to the sea was a belt where an emergent sea floor composed of the silt and mud of the Berry Formation and the Mulbring Siltstone was 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 sandstone and shale beds 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

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 are included in Interval 8. The distribution of the Upper Permian coal measures in which the interval occurs is given in Plate 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 of the interval is given in Figure 31. Figure 32 is a sand-shale ratio map and section. Palaeoenvironments are shown in Figure 33.

Details of 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 (600 ft) in the Macdonald Depression. It is interpreted to thin slightly over the Kulnura Arch and then it 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 low sand-shale ratio in the Macdonald and Macquarie Depressions to the east.

Interval 8 contains a marine tongue. At its maximum a shallow sea existed over the southern and middle part of the Sydney Basin (Fig. 33). The Coorongooba Creek Sandstone in this area contains a calcarenite (Goldbery, 1969) that was probably deposited after a partial reworking of the underlying carbonate lenses of the Mount Marsden Claystone. At its maximum this shallow sea extended as shallow flats over much of the area which had been occupied by the coal swamps

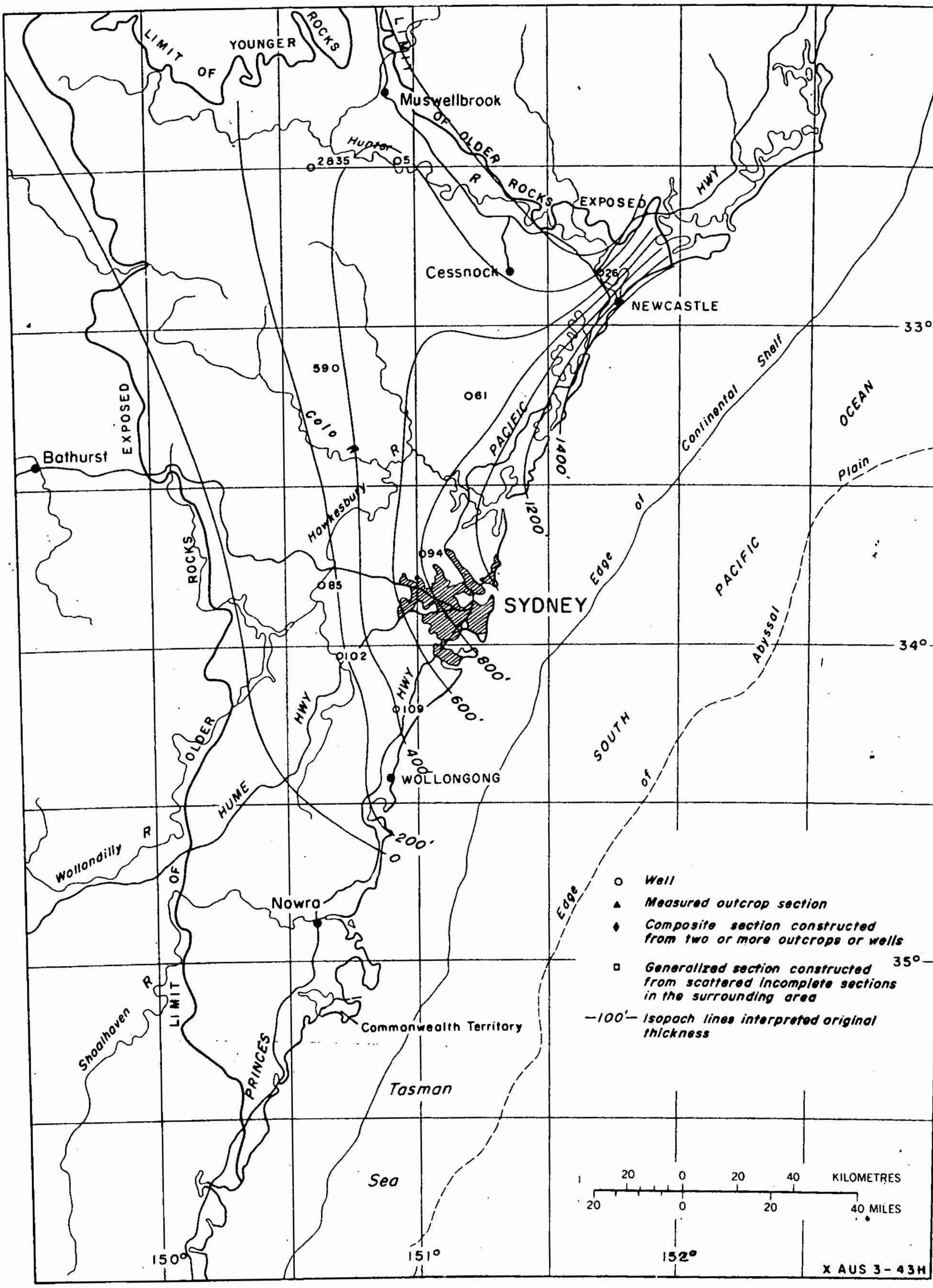

Fig.31 Isopach map, Interval 8, upper part of Wallis Creek Formation and correlatives

To accompany Record No. 1972/76

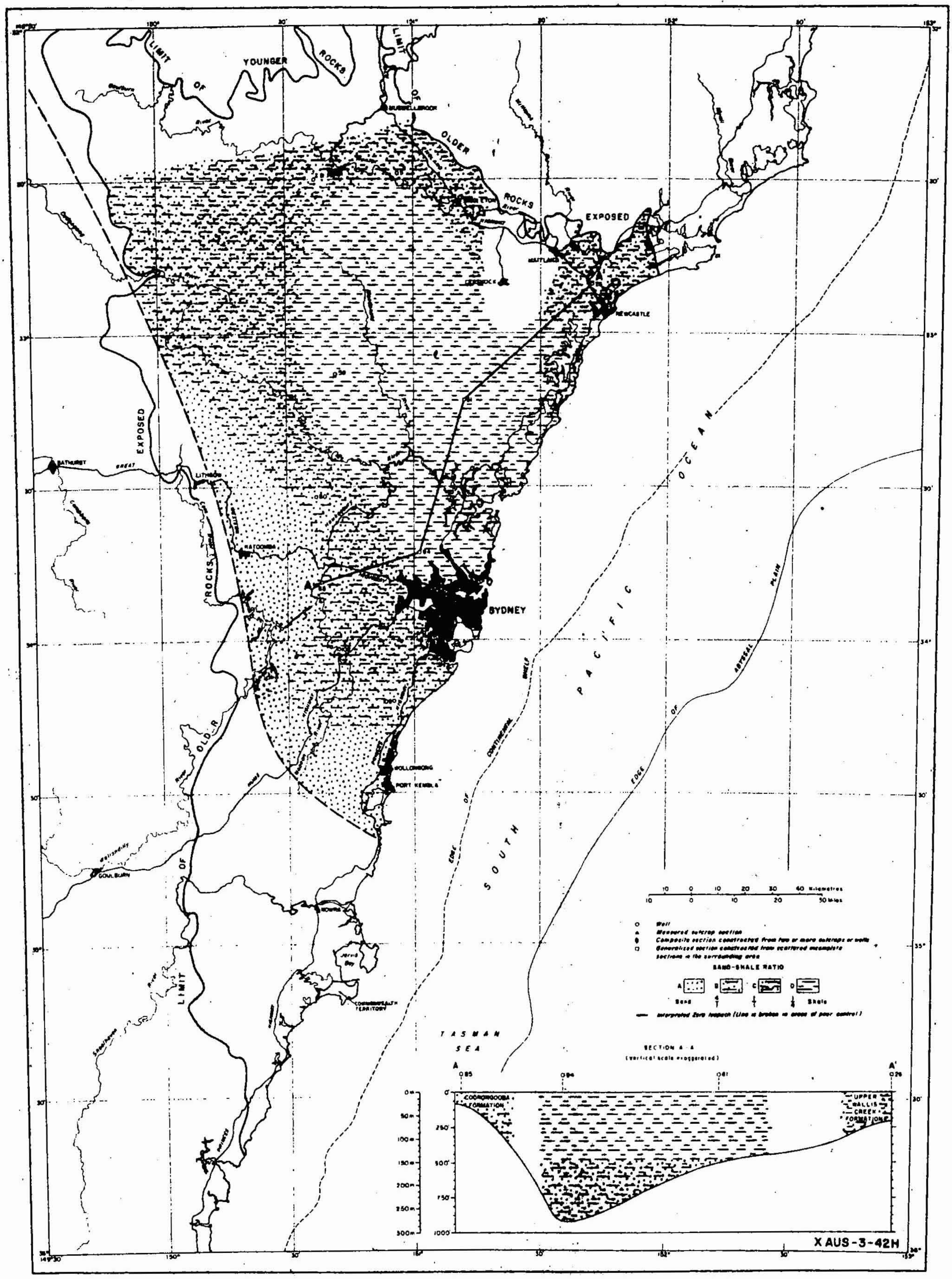

Fig.32. Sand-shale ratio map and section, Interval 8, upper part of Wallis Creek Formation and correlatives

To accompany Record No.1972/76

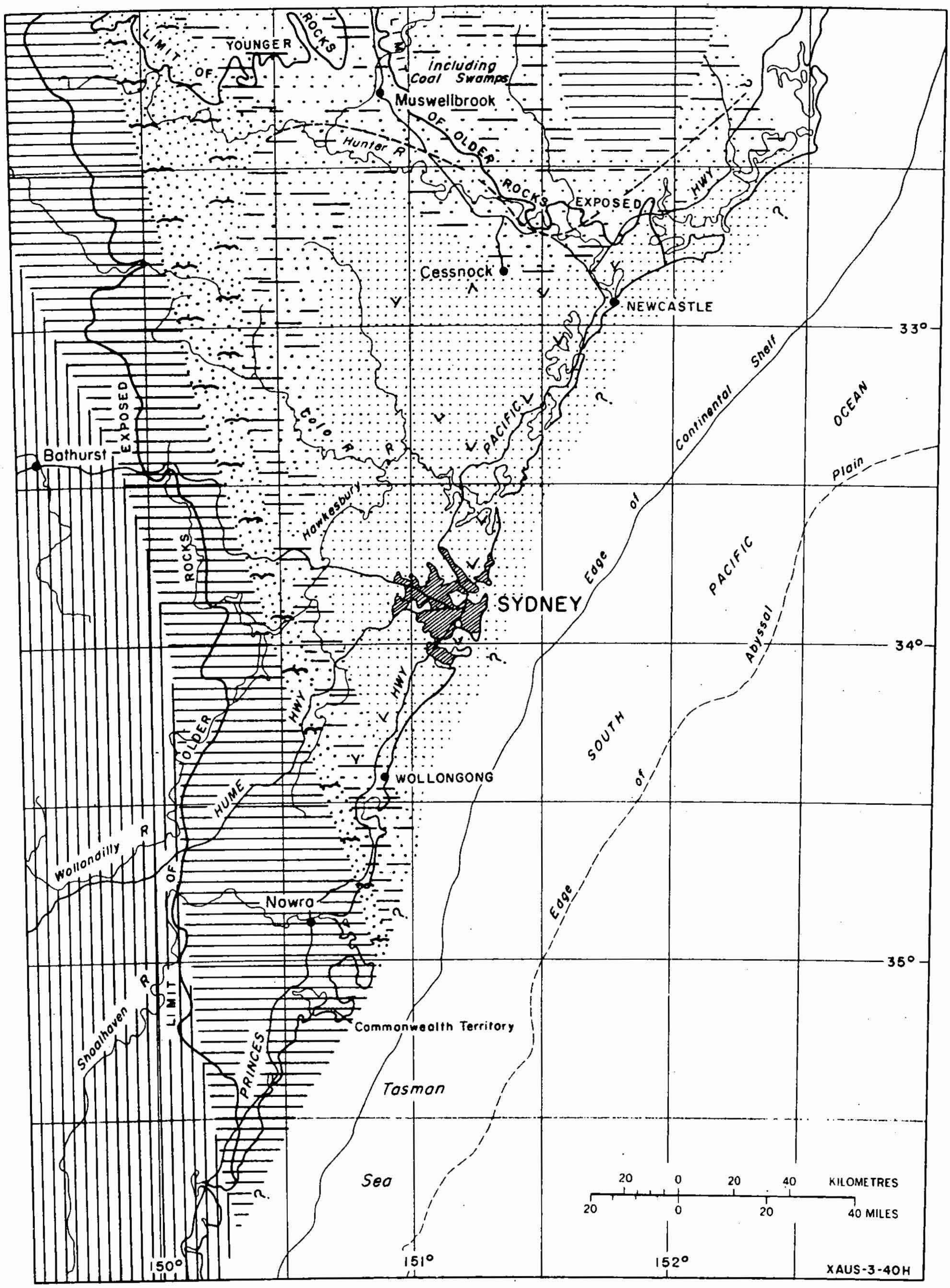

Fig.33. Environment map, Interval 8, lower Tatarian

To accompany Record No.1972/76

of Interval 7, and its presence 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, 8, 9, and 10. The thickness of the interval is given in Figure 34. Figure 35 is a sand-shale ratio map and section. Palaeoenvironments are shown in Figure 36.

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

Conclusions

Interval 9 is up to 450 m (1 400 ft) thick in the Macquarie Depression, thins over the Kulnura Arch to an interpreted zero isopach at the northern end, and thickens to about 670 m (2 200 ft) in the Macdonald Depression (Fig. 34). Elsewhere it thins gradually westward and southward to the interpreted zero isopach near the present margin of the basin. The Macquarie Depression extended northward into New England. Sediment removed by erosion over the Lochinvar Anticline has been restored in Figure 34.

The sand-shale ratio map (Fig. 35) shows a low sand-shale ratio in the west, and a gradual increase to the east.

All of Interval 9 consists of beds of fluvial or deltaic (marginal) origin, containing 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. Coal swamps were less abundant away from the Hunter Valley, and in the Southern Coalfield there is only one lenticular coal seam, and in the Western Coalfield only coal laminae and fossil wood. It seems therefore that the coal swamps of the Northern Coalfield gave place to a more elevated terrain where swamps were fewer and forest trees more prominent.

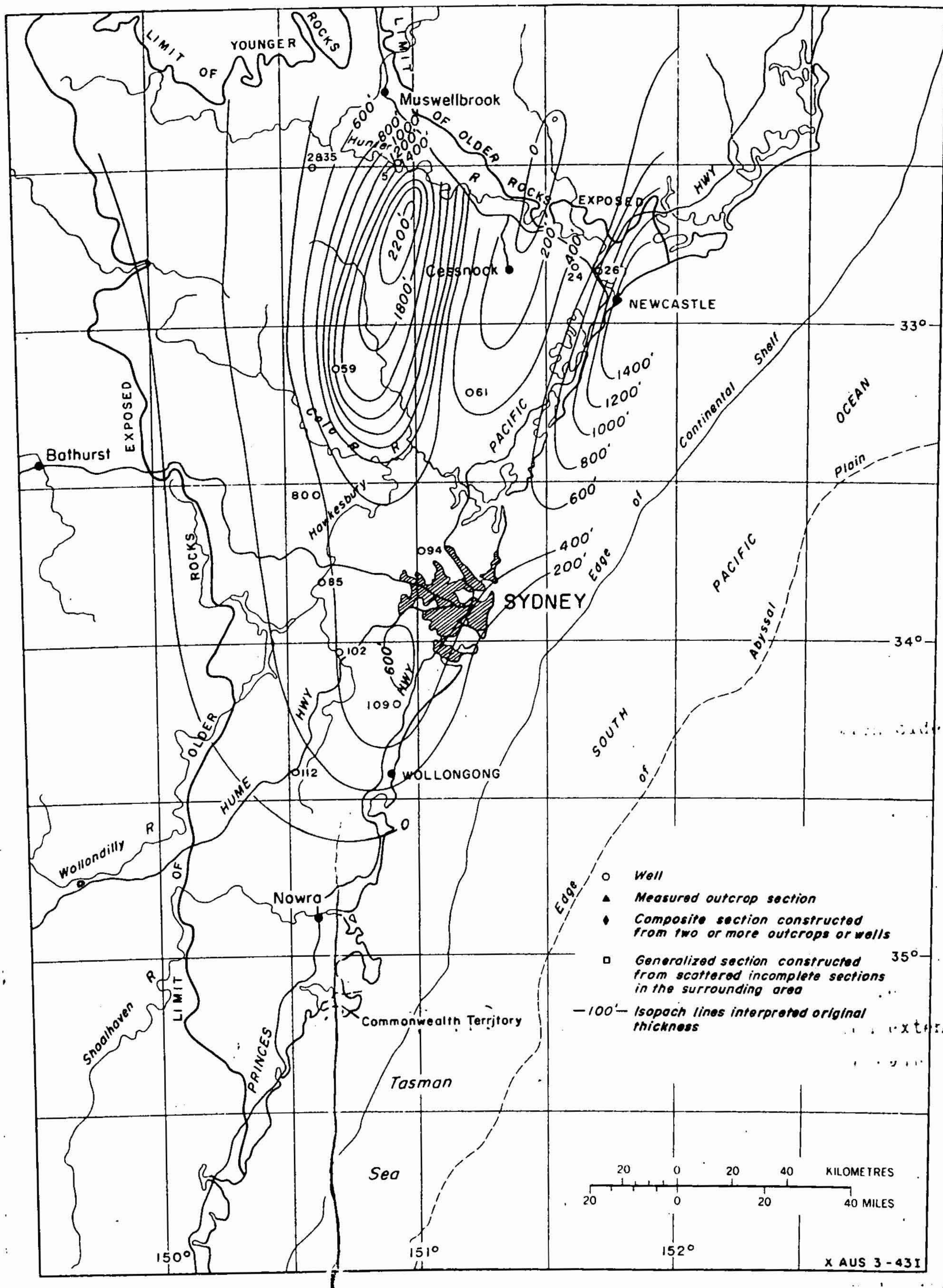

Fig. 34. Isopach map, Interval 9, Four Mile Creek Formation and Correlatives

To accompany Record No. 1972/76

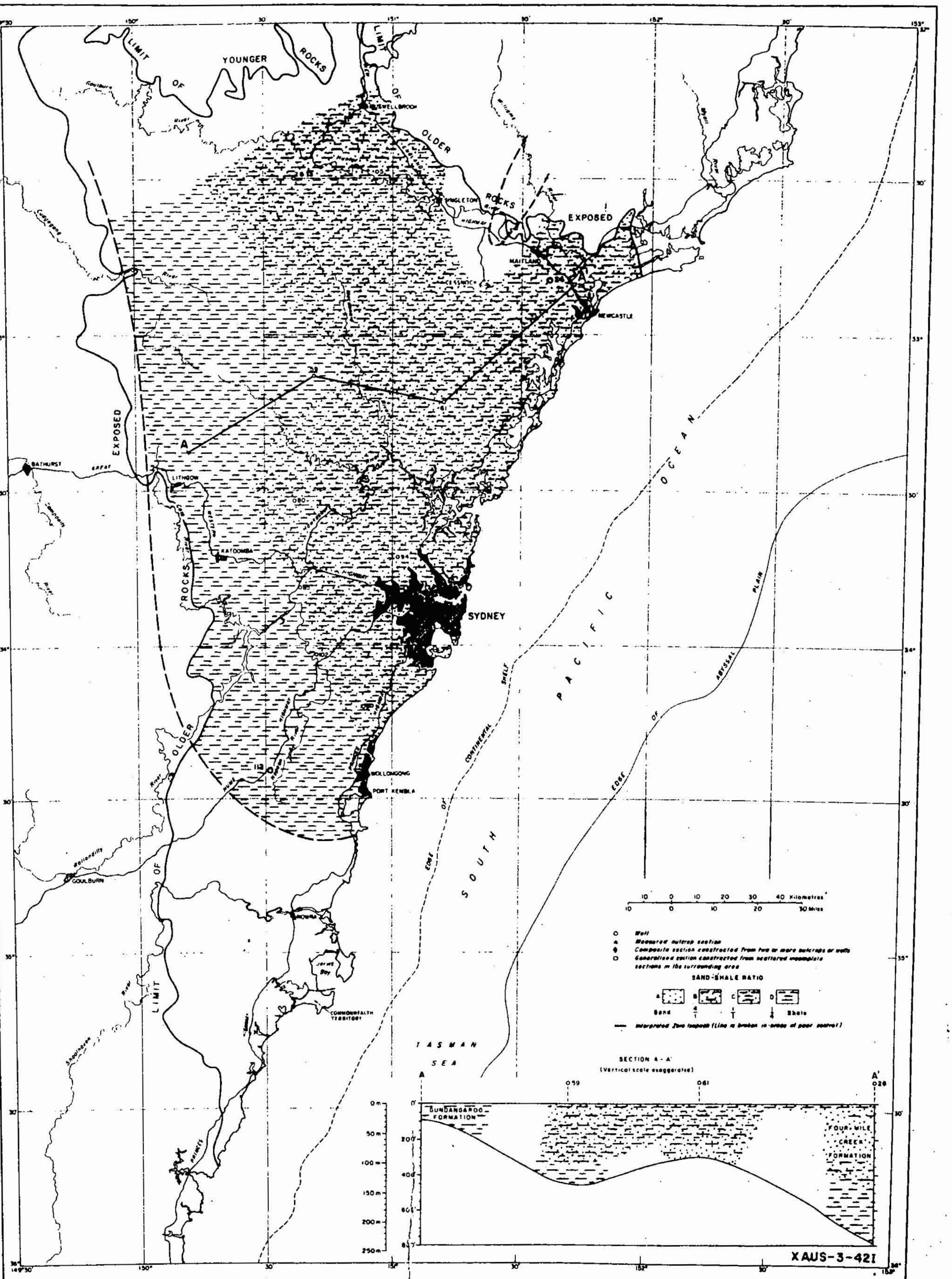

Fig. 35 Sand-shale ratio map and section, Interval 9, Four Mile Creek Formation and correlatives

To accompany Record No. 1972 / 76

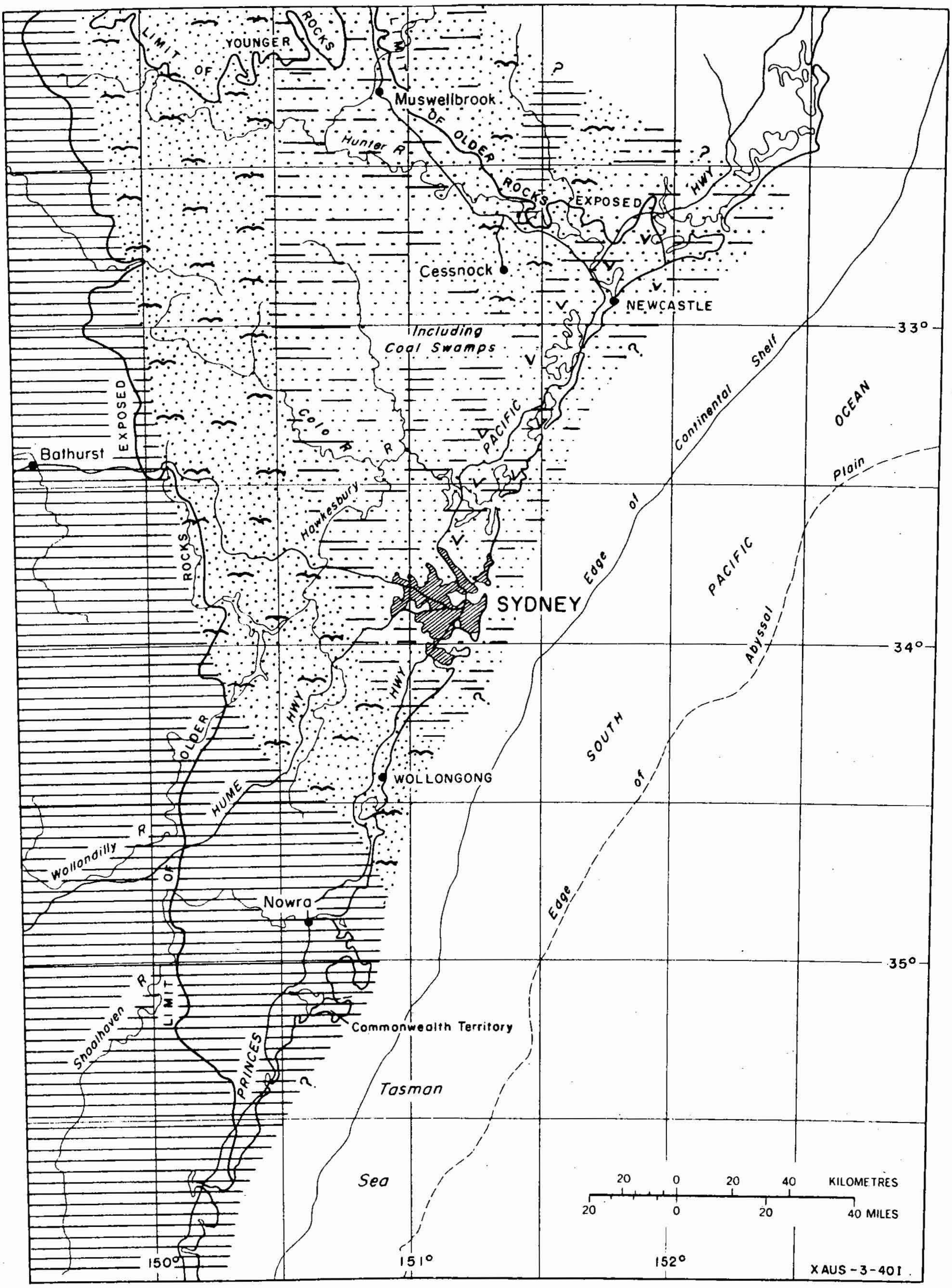

Fig. 36. Environment map, Interval 9, middle Tatarian

To accompany Record No. 1972/76

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. 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 of the interval is given in Figure 37. Figure 38 is a sand-shale ratio map and section. Palaeoenvironments are shown in Figure 39.

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

Conclusions

Interval 10 is 500 m (1 600 ft) thick in the Macquarie Depression, thins over the Kulnura Arch to an interpreted zero isopach at the northern end, and thickens to 130 m (400 ft) in the Macdonald Depression (Fig. 37). The presence and 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 Macquarie Depression extended into New England.

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 of Interval 8, that is, to a marine transgression.

Interval 10 contains a minor marine tongue underlain and overlain by terrestrial sediments, At its maximum (Fig. 39) the shallow sea transgressed as far west as Mulgoa, where foraminifera are present. The presence of the plant impressions and fossil wood in the coarser-grained clastic sediments, above and below the marine tongue, suggests that sparsely vegetated swamps developed in the marginal areas, flanked on the landward side by fluvial deposits.

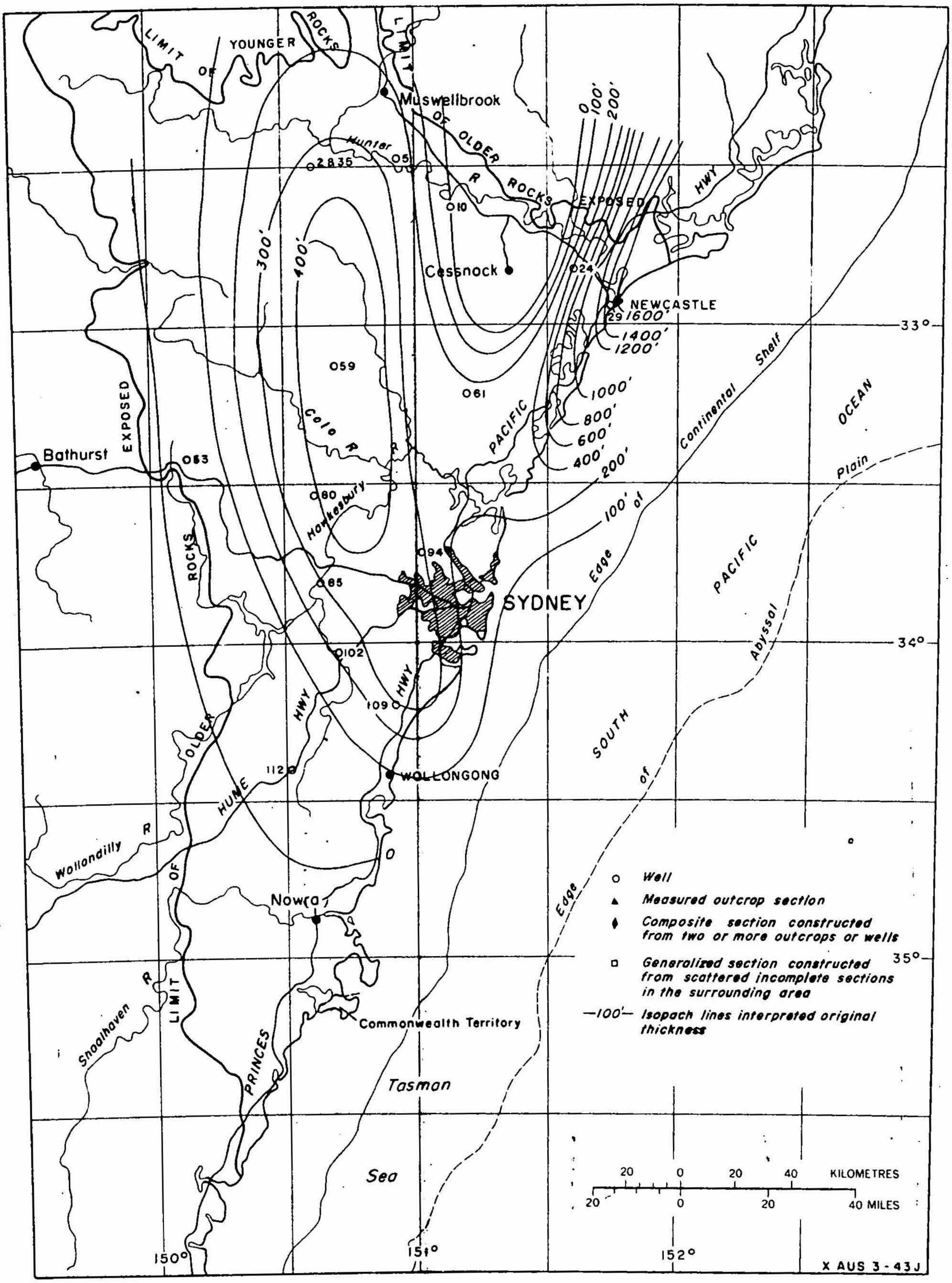

Fig. 37. Isopach map, Interval 10, Waratah Sandstone and Dempsey Formation and correlatives

To accompany Record No. 1972/76

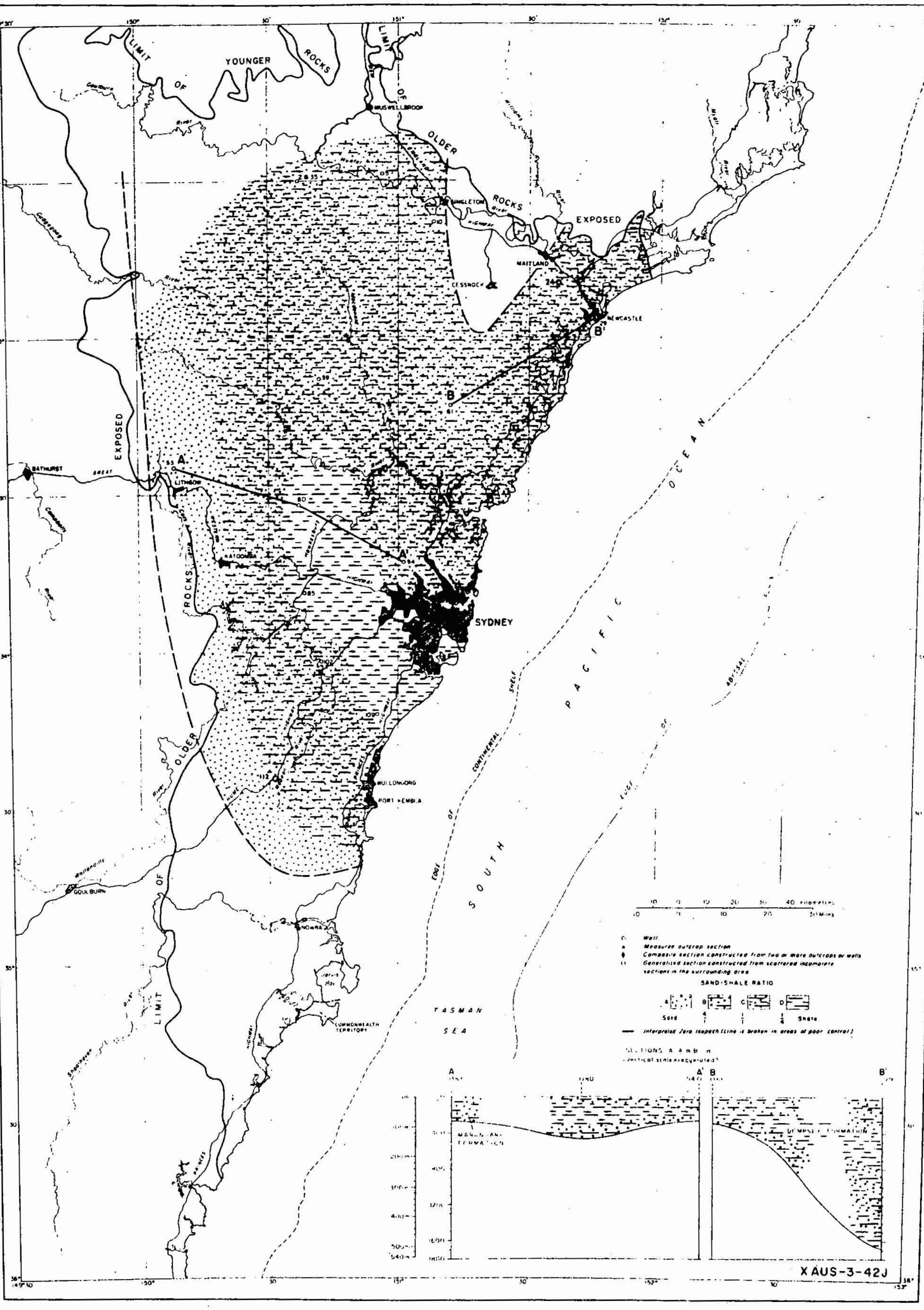

Fig. 38 Sand-shale ratio map and section, Interval 10, Waratah Sandstone, and Dempsey Formation and correlatives

To accompany Record No 1972/76

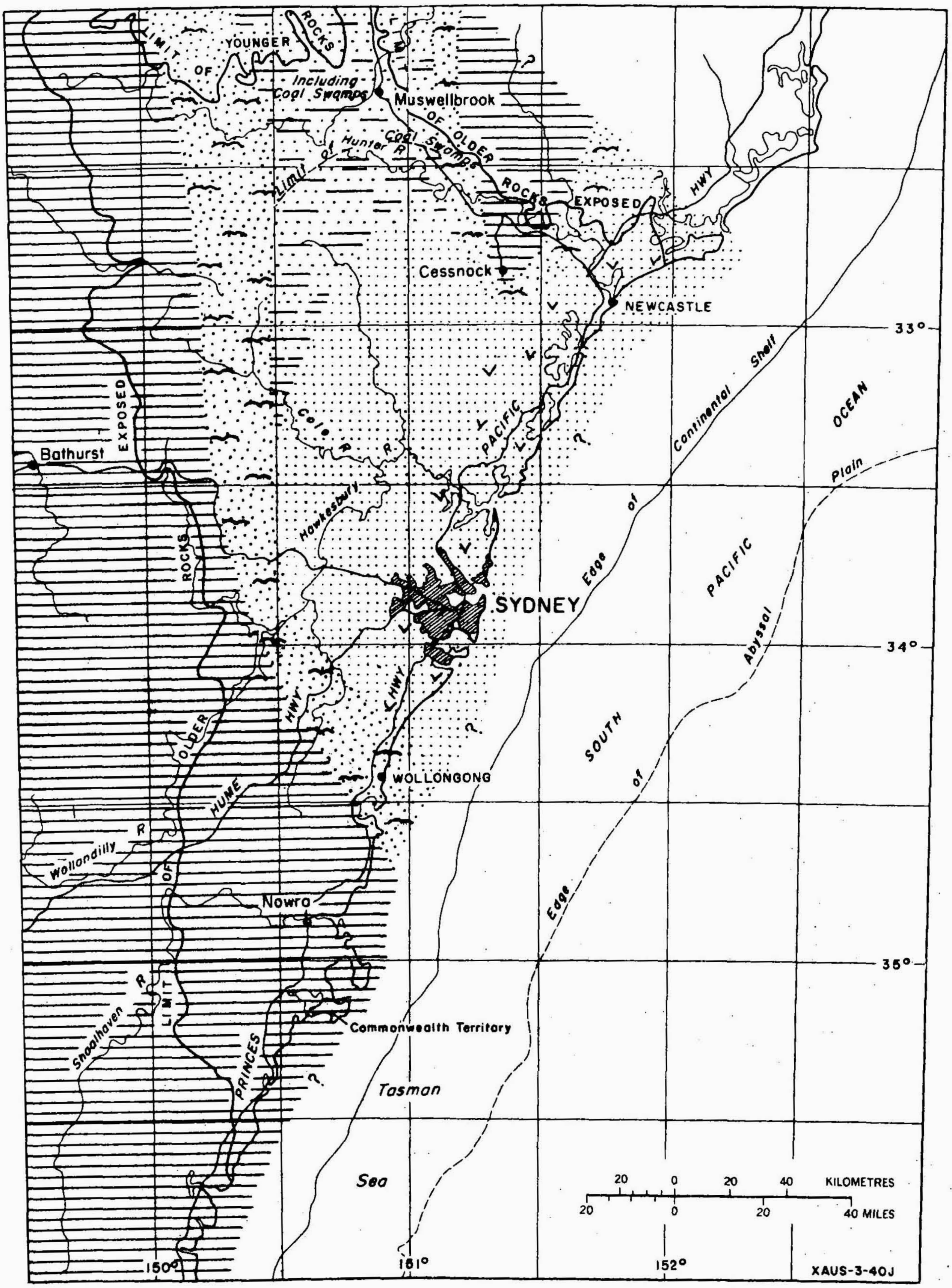

Fig. 39. Environment map, Interval 10, upper Tatarian

To accompany Record No 1972/76

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

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 are included in Interval 11.

The distribution of the Newcastle Coal Measures is given in Plate 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 of the interval is given in Figure 40. Figure 41 is a sand-shale ratio map and section. Palaeoenvironments are shown in Figure 42.

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

Conclusions

Interval 11 is 430 m (1 400 ft) thick in the Macquarie Depression and thins to a zero isopach around the northern end of the Kulnura Arch (Fig. 40). Figure 40 shows the presently preserved thickness in the Lochinvar Anticline area. An unknown quantity of sediment was removed by erosion before deposition of the overlying Narrabeen Group. It thickens again to 430 m (1 400 ft) 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. The Macquarie Depression extended into New England, and there was a slight thinning near Dural.

The sand-shale ratio map (Fig. 41) shows that most of the interval has a low sand-shale ratio. The sand-shale ratio increases in the middle part of the western area possibly due to the growth of a delta, the sediments of which were derived from the granitic hinterland to the west. Another area of comparatively high sand-shale ratio occurs in the lower Hunter Valley where a considerable thickness of coarse clastics is believed to have been laid down as fanglomerates derived from the north and northeast.

Almost all of the Sydney Basin was covered by coalescing deltas (Fig. 42) which in the north and northeast were built up 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 formed. Volcanism continued in the region east of the present coast, and extensive tracts were buried under ash falls.

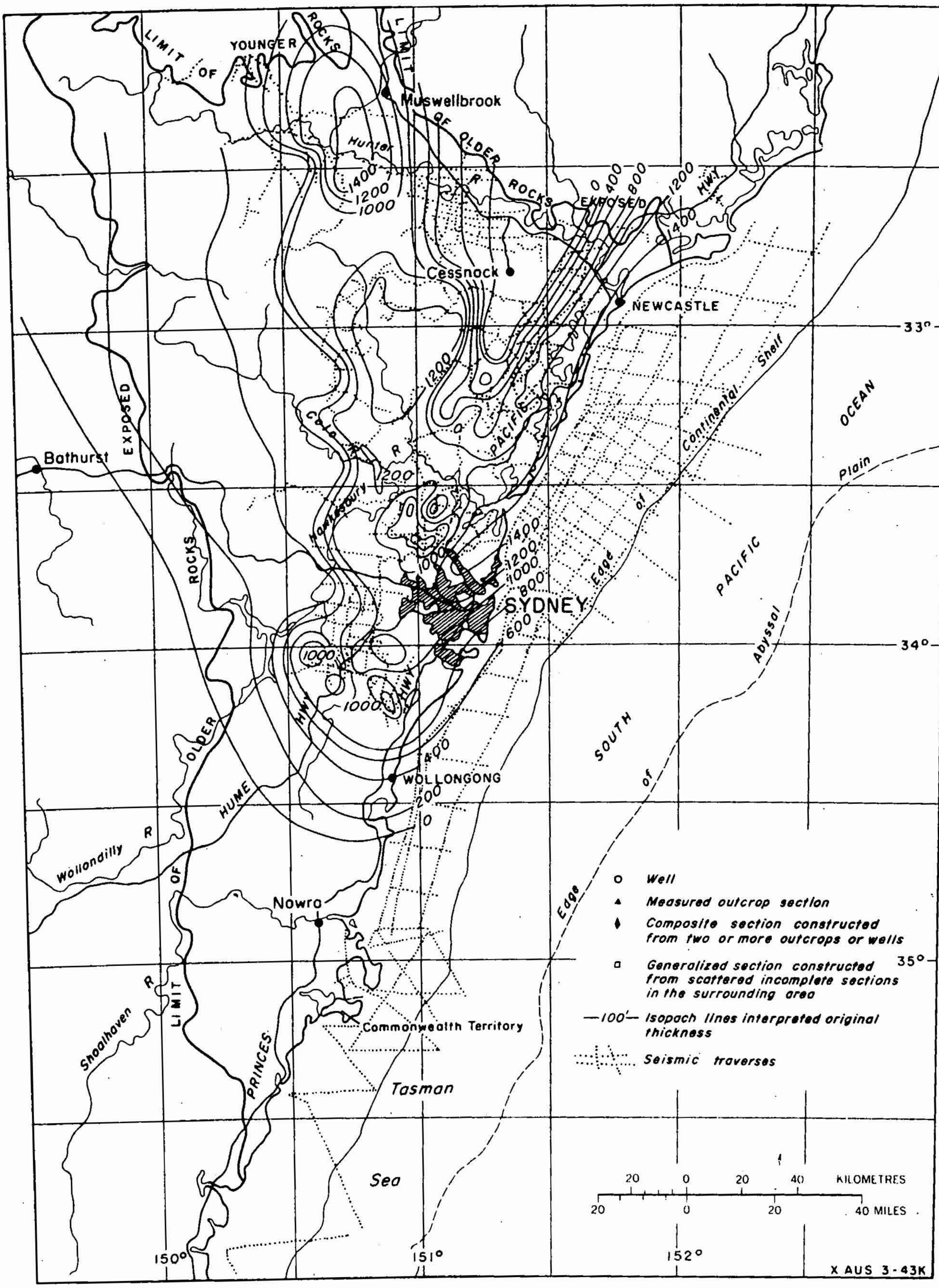

Fig. 40. Isopach map, Interval II, Newcastle Coal Measures (excluding Waratah Sandstone) and correlatives

To accompany Record No 1972/76

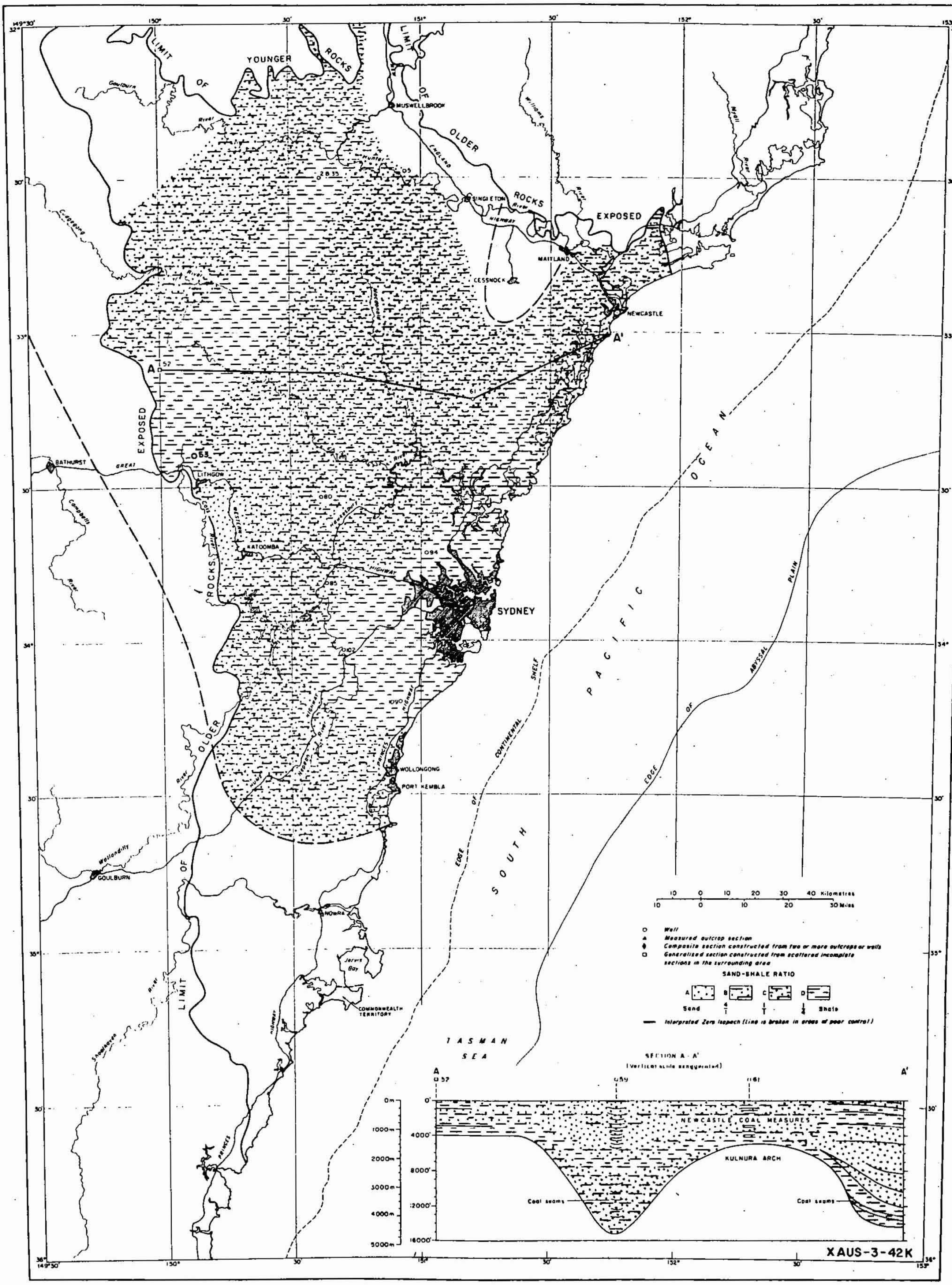

Fig. 41. Sand - shale ratio map and section, Interval II, Newcastle Coal Measures (excluding Waratah Sandstone) and correlatives

To accompany Record No 1972/76

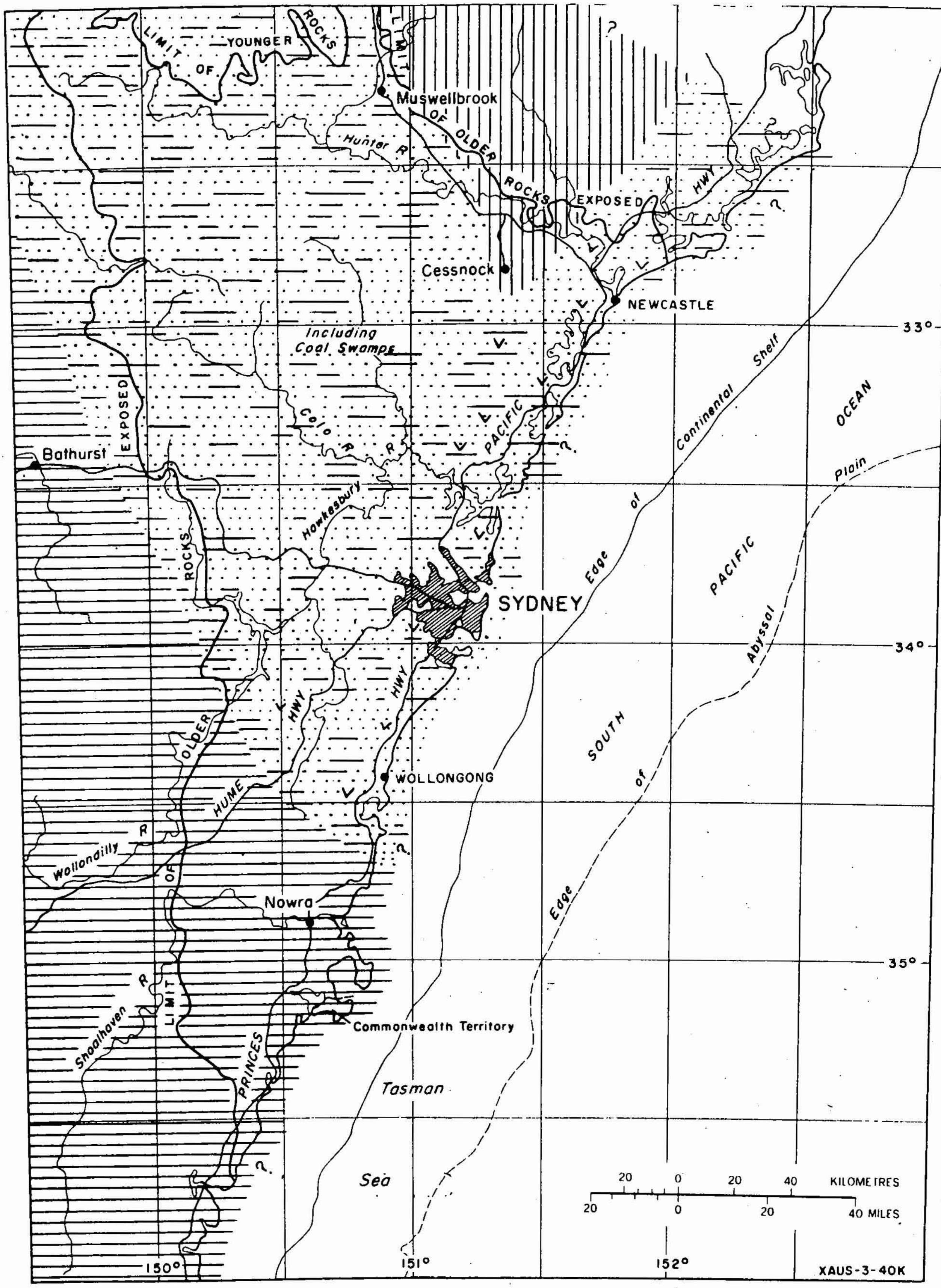

Fig.42. Environment map, Interval II, upper Tatarian

To accompany Record No 1972/76

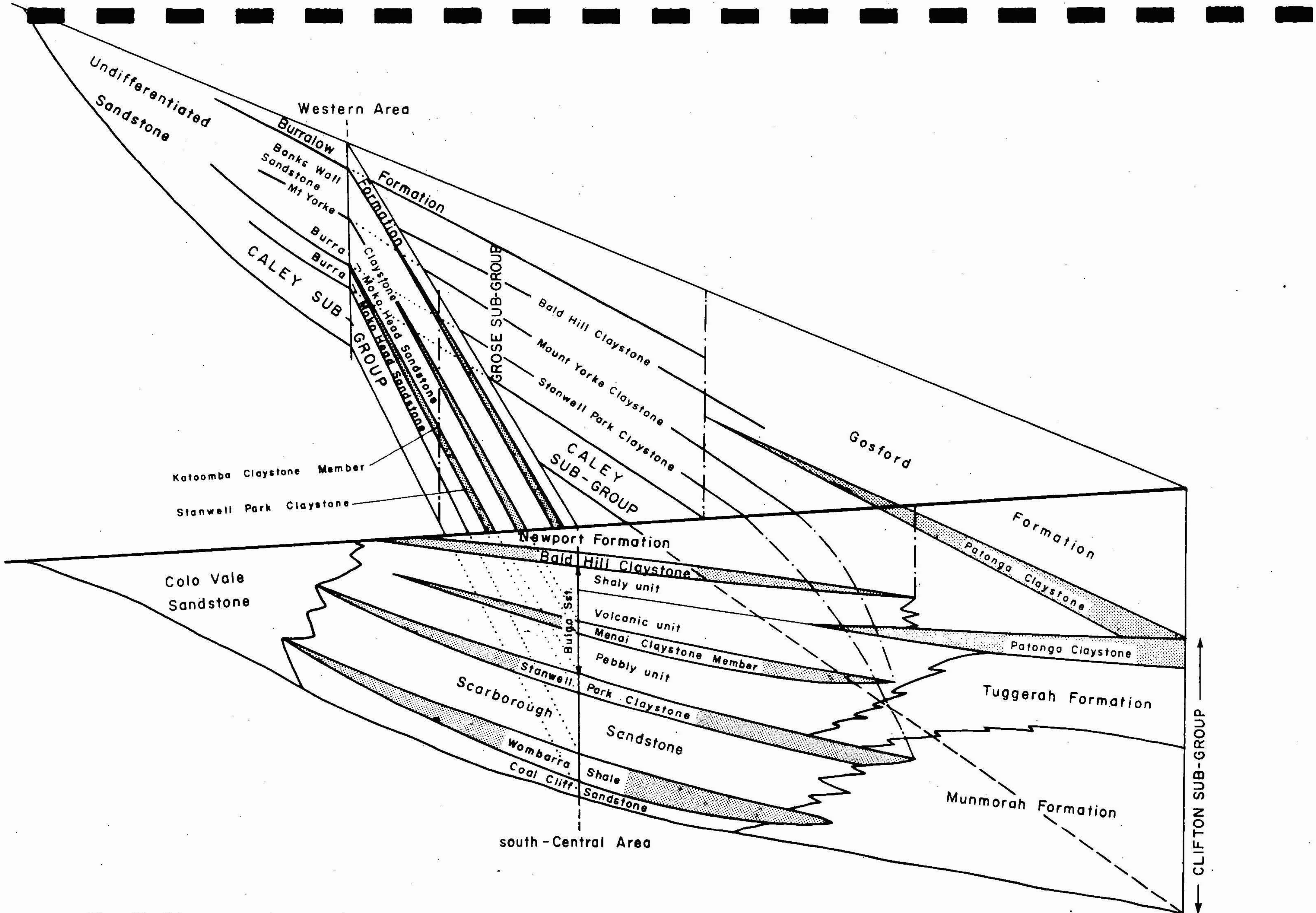

Fig. 43. Diagrammatic relationship of rock units within Narrabeen Group

To accompany Record No 1972/76

X AUS - 3 - 27

Bringelly Shale	Falcisporites assemblage zone	zonule D	
Ashfield Shale			
Mittagong Formation			
Hawkesbury Sandstone		zonule C	Hawkesbury Sandstone
Newport Formation		zonule B	Gosford Formation
Bald Hill Claystone		zonule A	
Bulgo Sandstone	Protohaploxipinus samoilovichii assemblage zone		Patonga Claystone
Stanwell Park Claystone	Lunatisporites pellucidus assemblage zone TRIASSIC		Tuggerah Formation
Scarborough Sandstone	PERMIAN Protohaploxipinus reticulatus assemblage zone		Munmorah Formation
Wombarra Shale			
Coal Cliff Sandstone			
Coal Measures	Dulhuntyispora assemblage zone		Coal Measures

Fig.44. Palynological zones in Intervals 11-14. Based on Helby (1970)

X AUS-3-25

To accompany Record No 1972/76

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. A summary of the lithology of the rocks and their relationships, correlations, and age is given in Plates 2 and 3 and Figures 3, 8, 9, 10, 43, and 44. The thickness of the interval is given in Figure 45. Figure 46 is a sand-shale ratio map and section. Palaeoenvironments are shown in Figure 47.

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

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, with sediments up to 90 m (300 ft) thick on the basin edge, 90 to 510 m (300-1 700 ft) on the basin slope, and from 510 to 720 m (1 700-2 400 ft) on the floor of the basin, which has its centre near Kulnura. The area of the Lochinvar Anticline was covered by sediment lying 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 of deltas over the coal measures and to their eventual coalescence, so that pro-delta 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, 1970). 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 Geosyncline; the quartz-lithic suite in the north and northeast was derived from the New England Geosyncline; 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 shale beds in the Narrabeen Group is due to weathering on the Triassic delta plains (see Appendix 3).

The overall succession of sedimentary facies (Ward, 1971) is one of declining fluvial activity, which passes from active braided streams to the swampy lowlands of a deltaic plain with ephemeral lagoons.

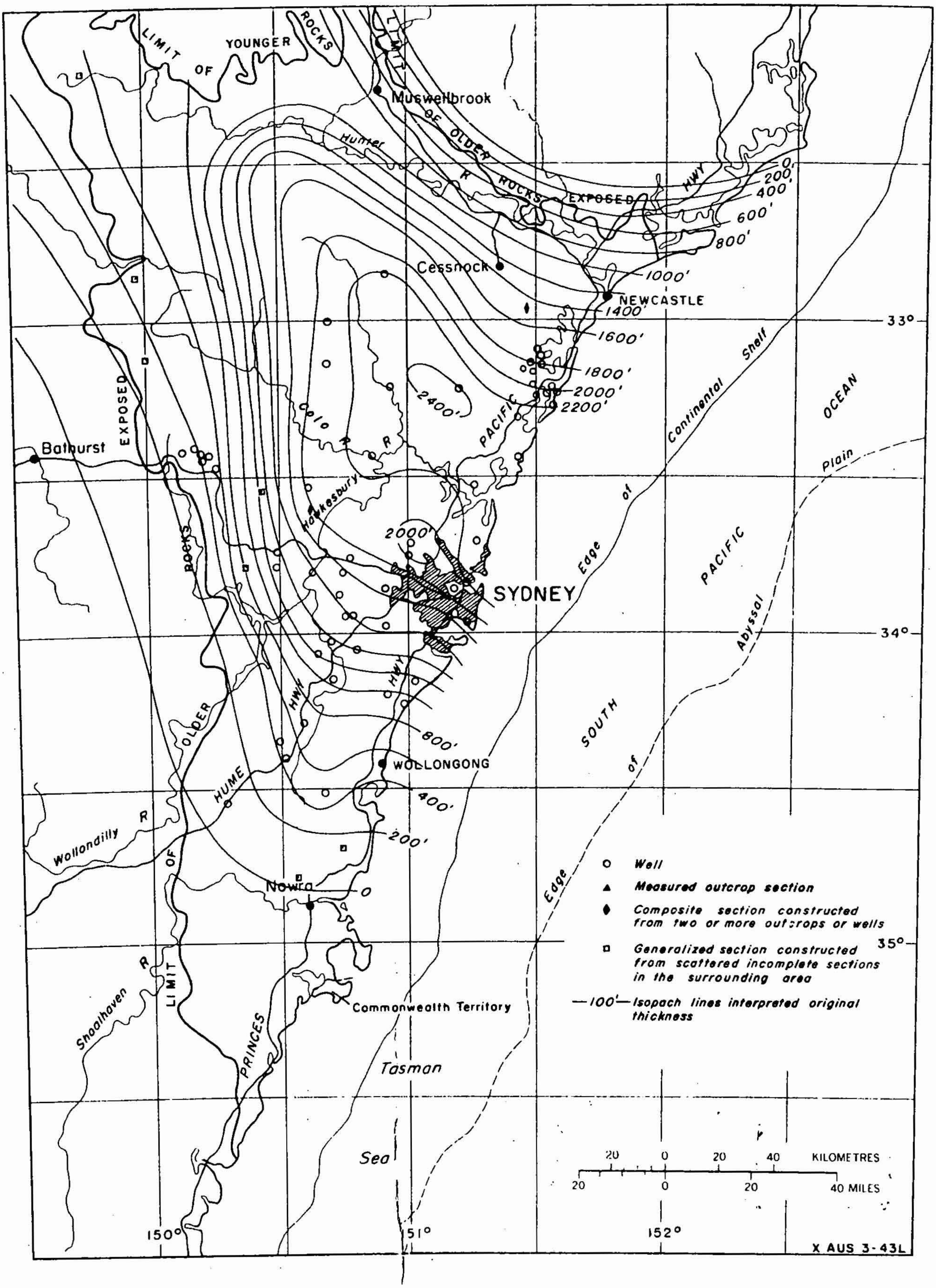

Fig. 45. Isopach map, Interval 12, Narrabeen Group

To accompany Record No 1972/76

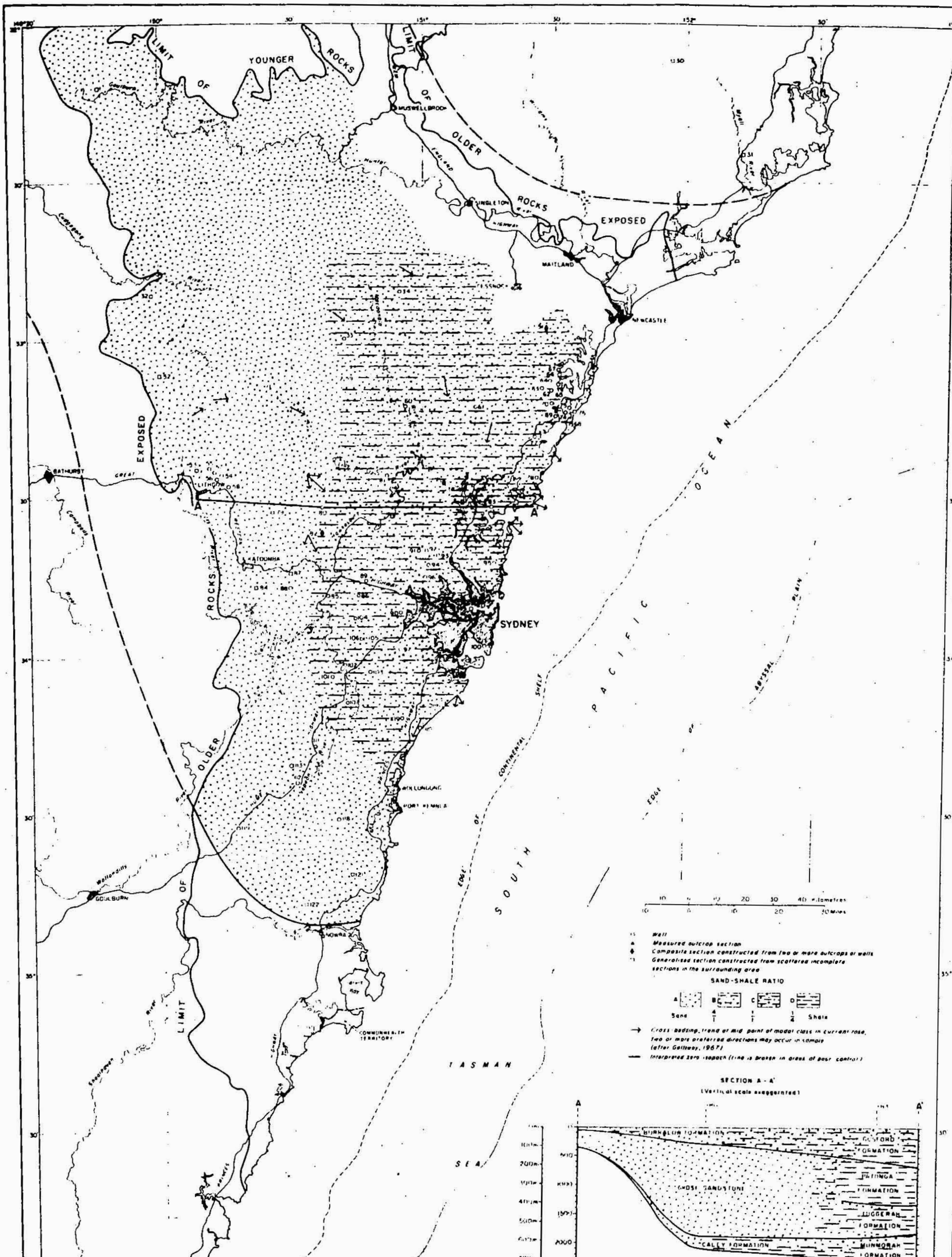

Fig.46 Sand-shale ratio map and section, Interval 12, Narrabeen Group

To accompany Record No 1972/76

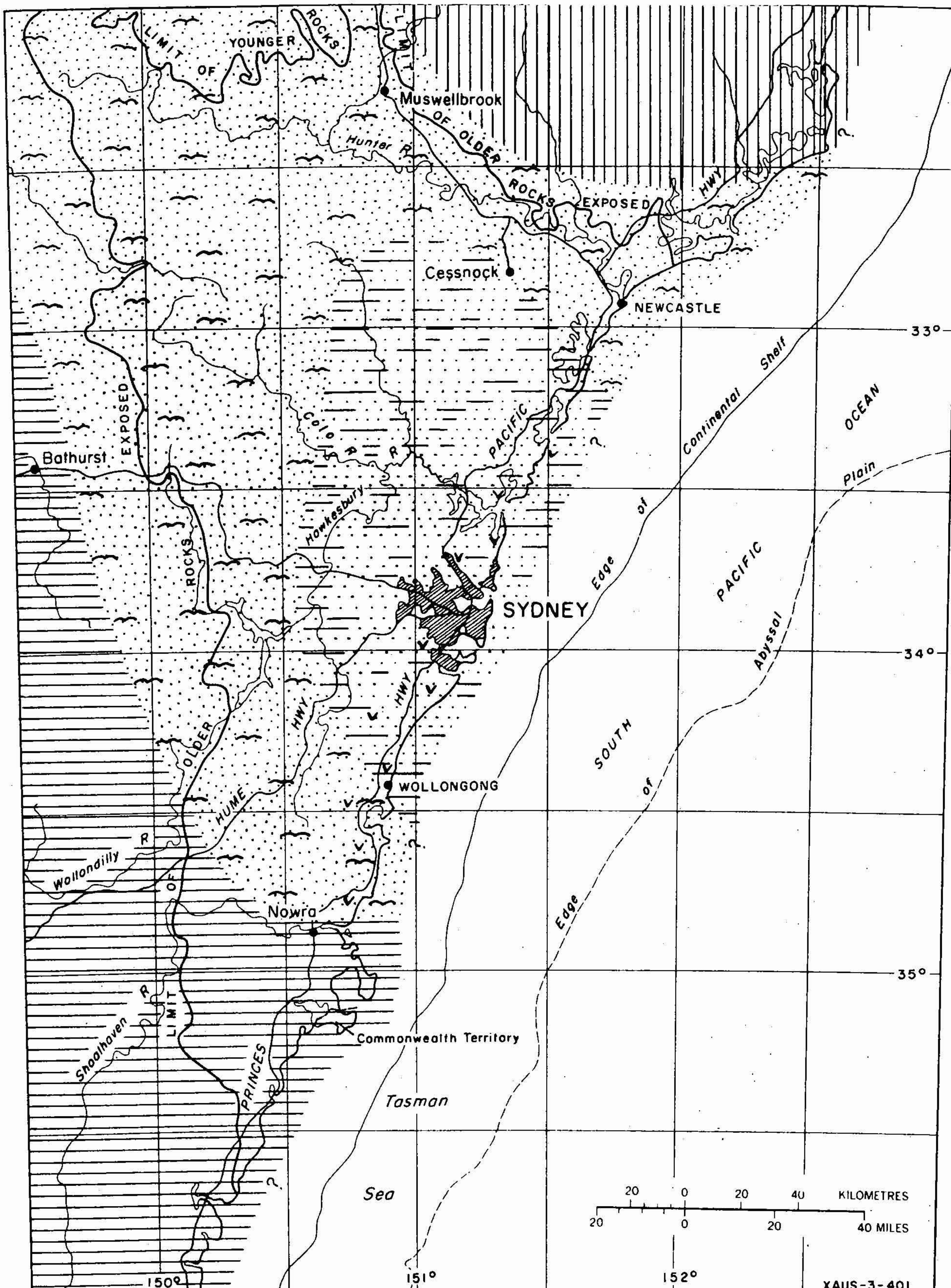

Fig.47. Environment map, Interval 12, Lower Triassic

To accompany Record No 1972/76

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 its thickness in Figure 48. A summary of the lithology of the rocks and their relationships, correlations, and age is given in Plates 2 and 3 and Figures 3, 8, 9, 10, and 44. The thickness of the interval is given in Figure 48. Palaeoenvironments are shown in Figure 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 (800 ft) along the present coastline.

The interval 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 reduced to base level. Transient lagoons supported populations of fish adapted to brackish conditions.

Interval 14: Wianamatta Group

The Wianamatta Group comprises the youngest rocks of the Permo-Triassic sequence still existing in the Sydney Basin. It 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 given in Figure 51 and palaeoenvironments are shown in Figure 52.

Conclusions

The work of Lovering (1954) and Herbert (1970) 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 amount of lithic sand carried by the river systems was derived from nearby intermittent volcanoes.

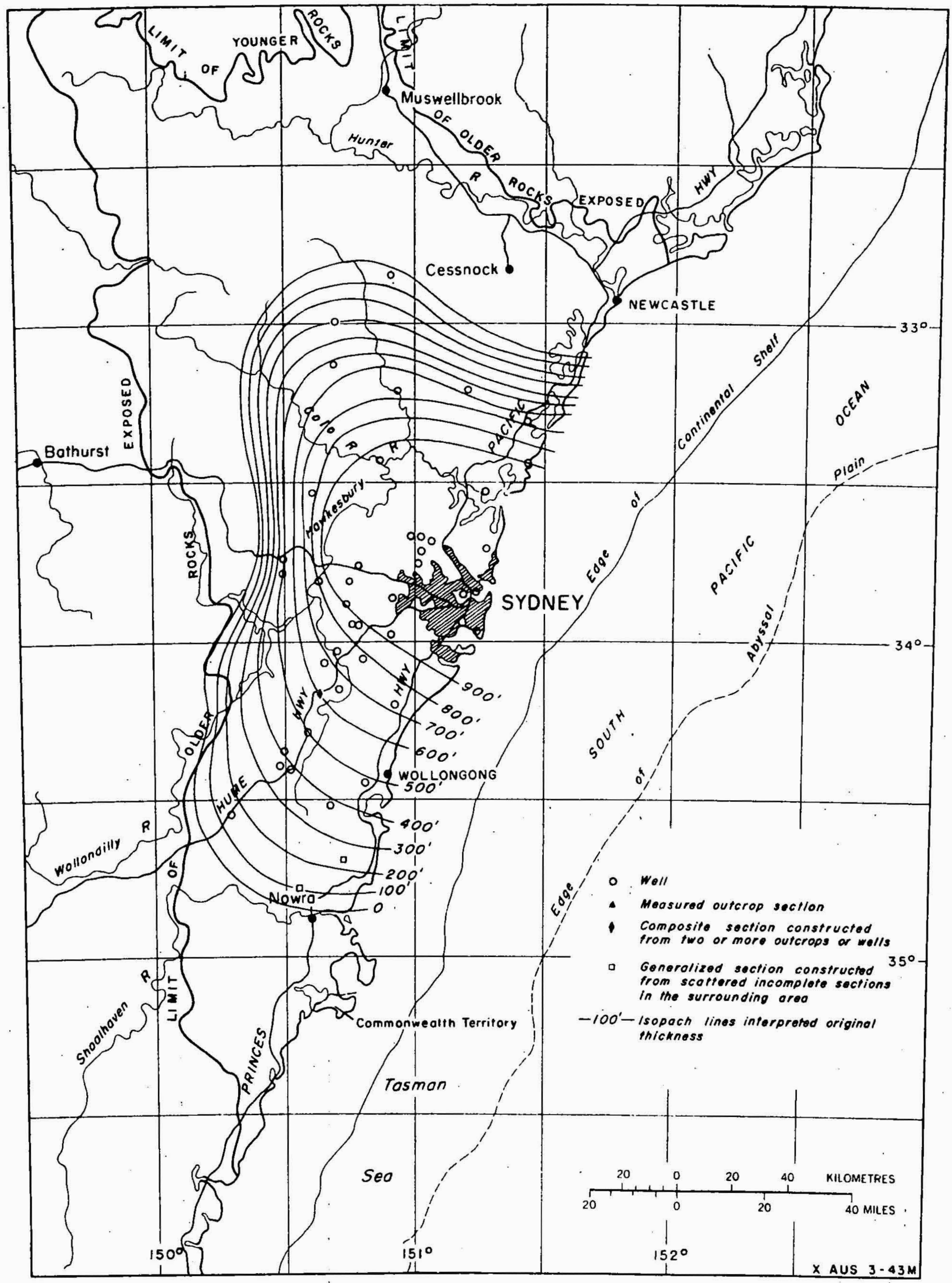

Fig. 48. Isopach map, Interval 13, Hawkesbury Sandstone

To accompany Record No 1972/76

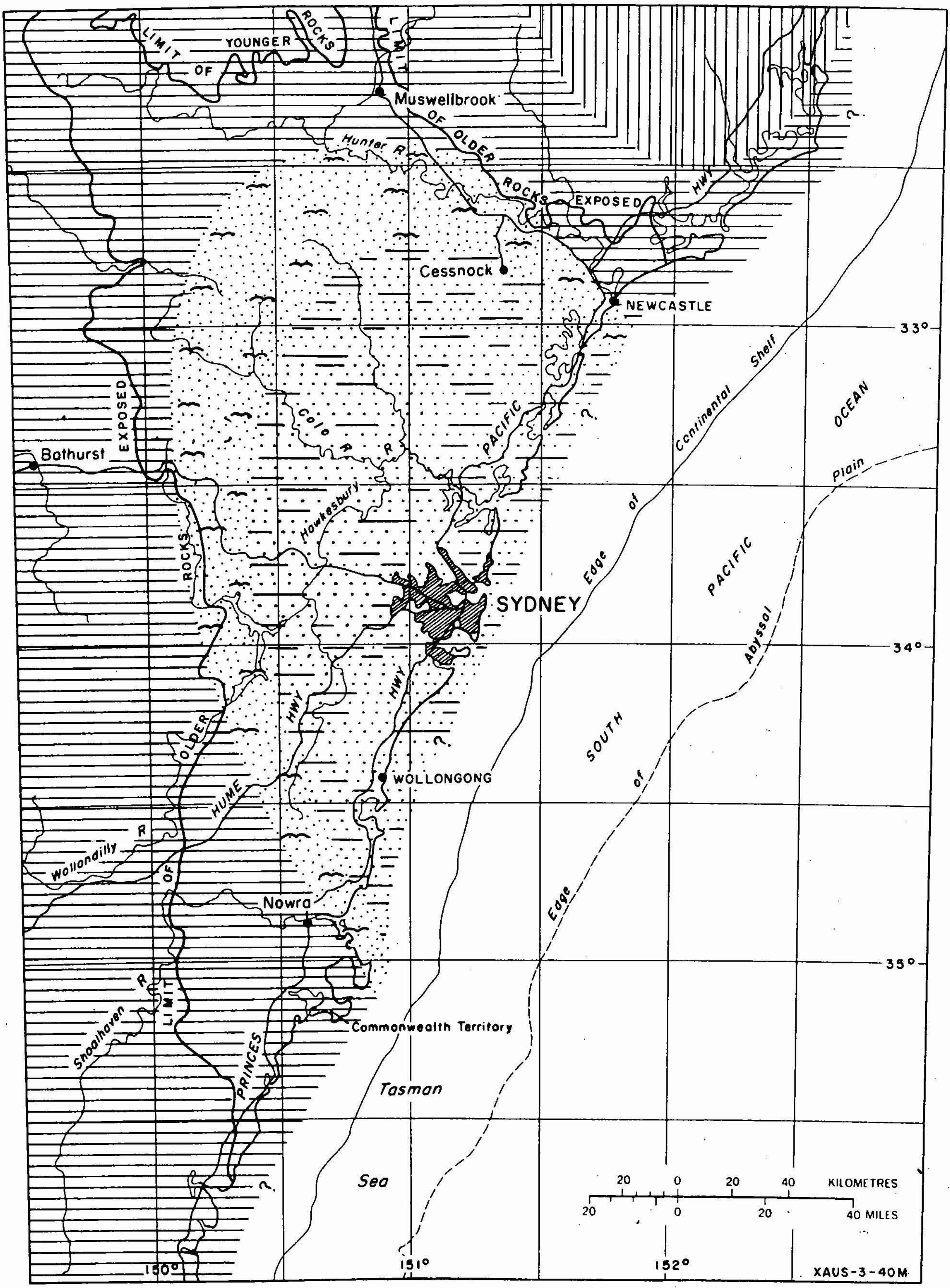

Fig.49. Environment map, Interval 13, Middle Triassic

To accompany Record No 1972/76

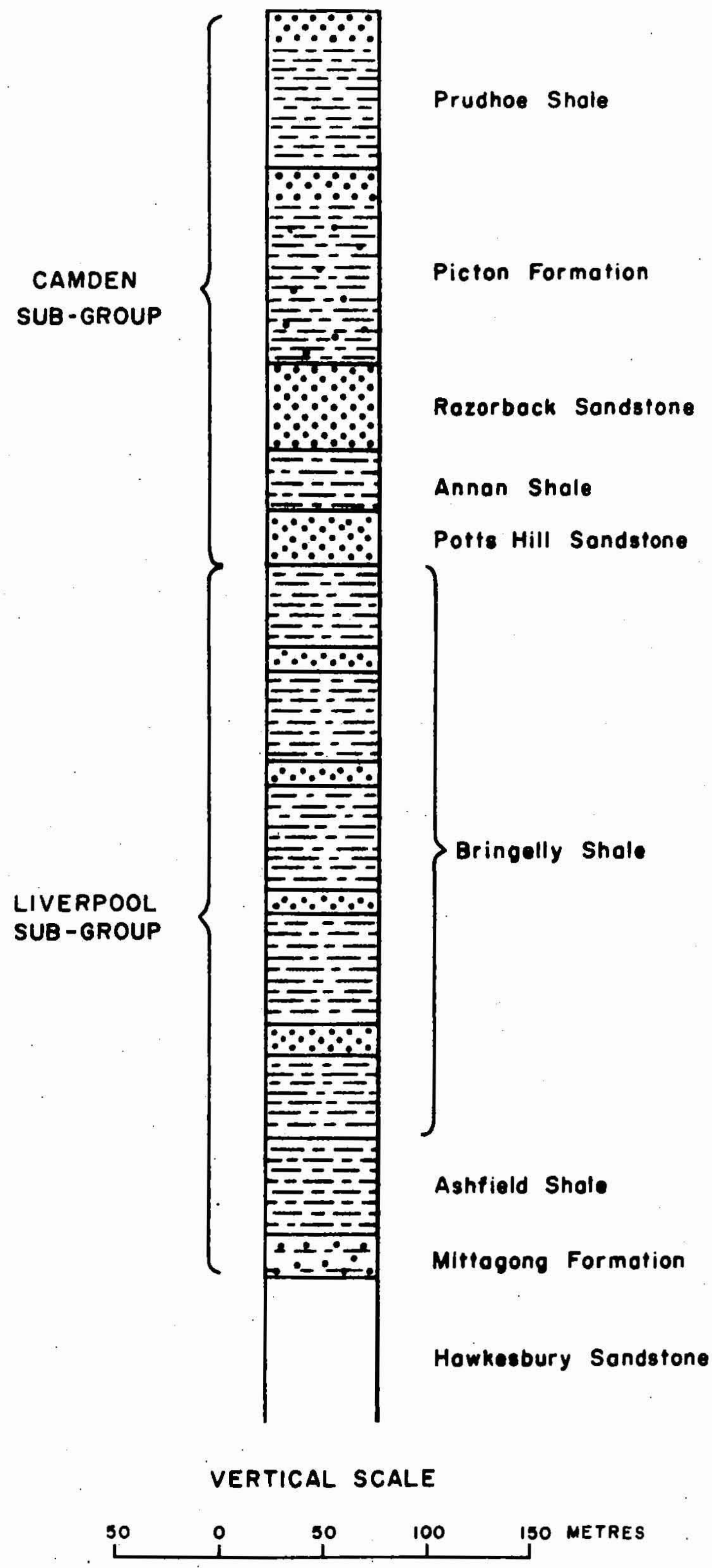

Fig. 50 Formations of Wianamatta Group (after Herbert, 1970)

To accompany Record No1972/76

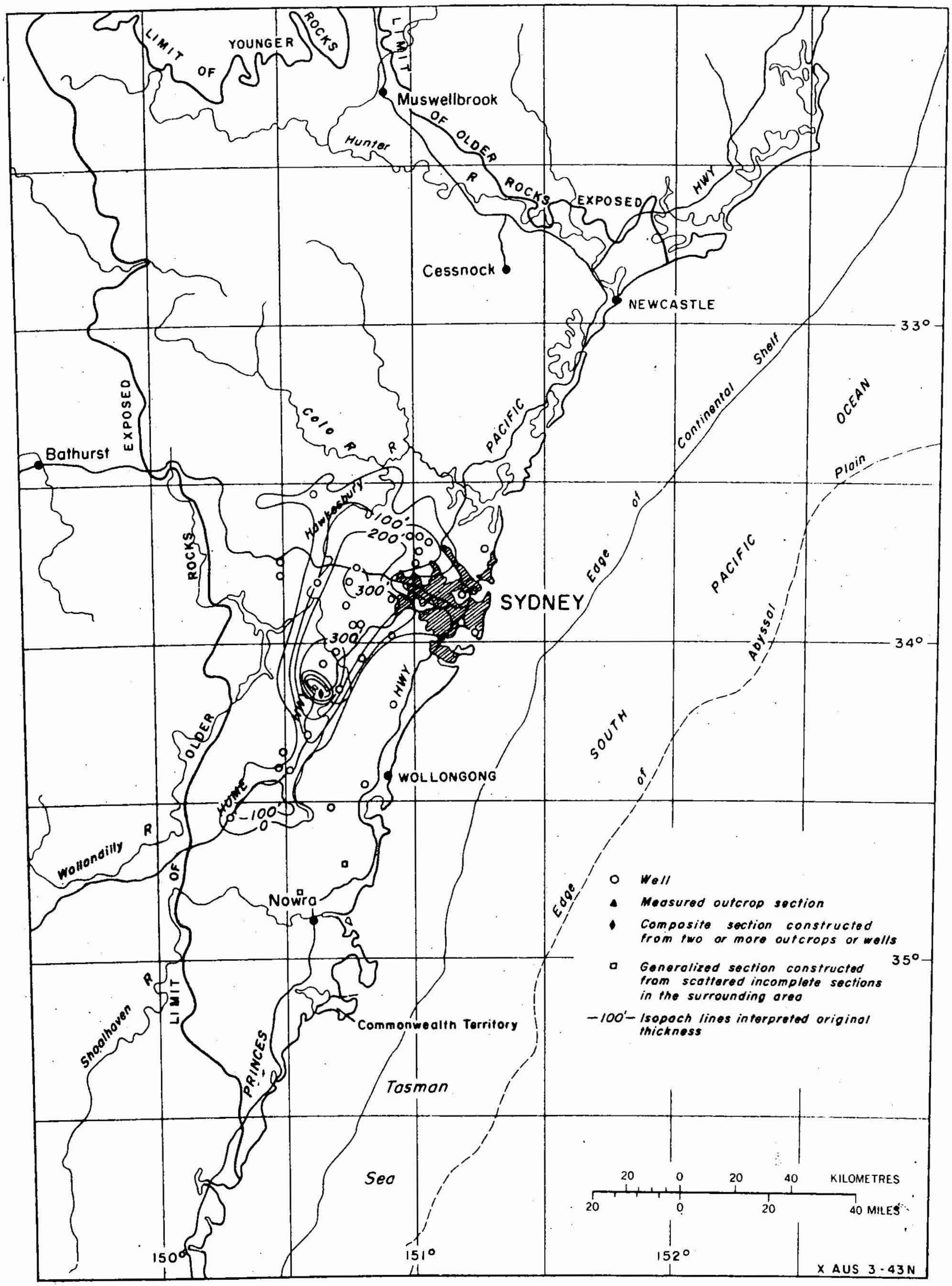

Fig. 51. Isopach map, Interval 14, Wianamatta Group

To accompany Record No 1972/76

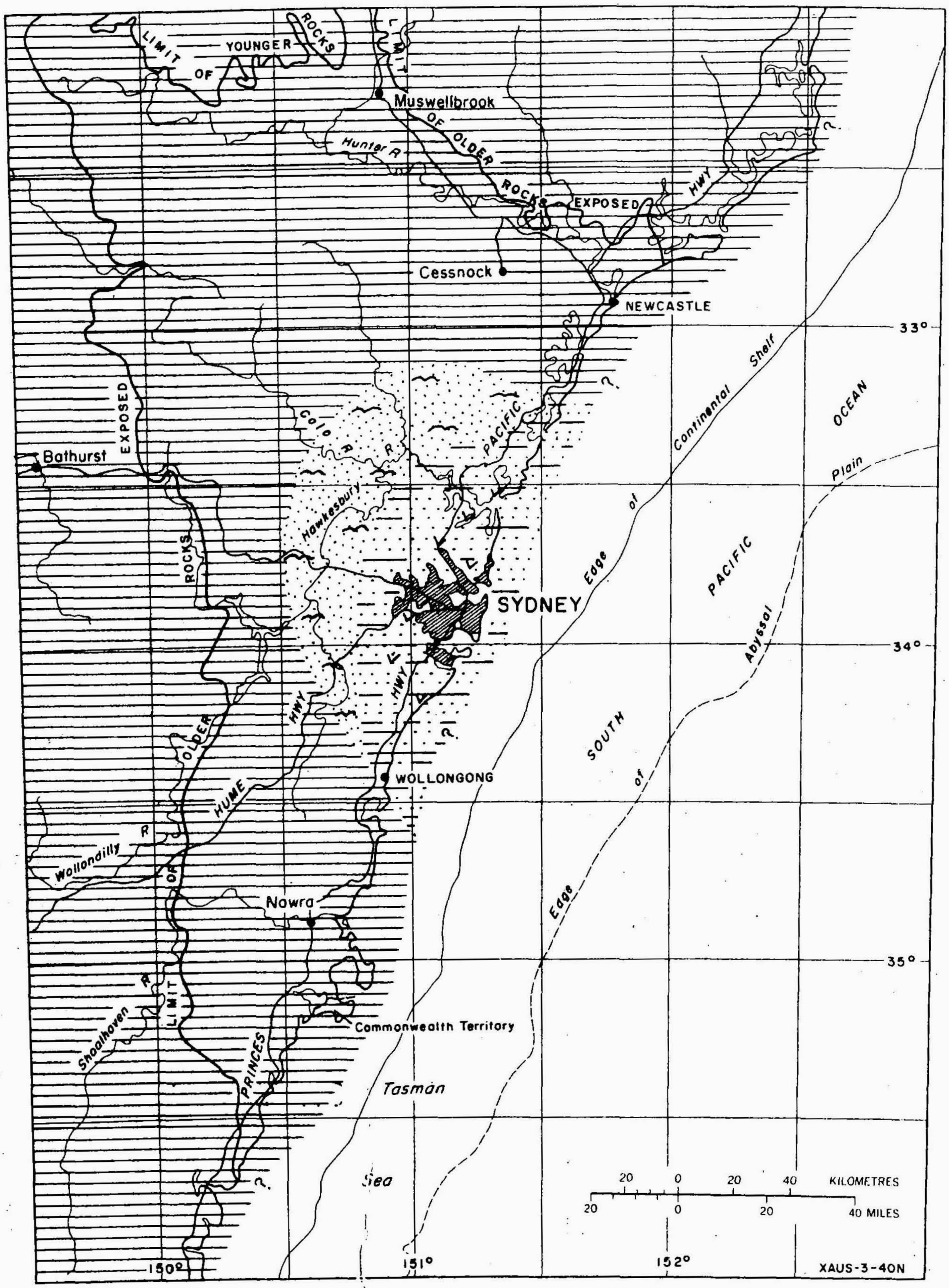

Fig.52. Environment map, Interval 14, Middle Triassic

To accompany Record No 1972/76

IGNEOUS ROCKS OF THE SYDNEY BASIN

Permian, Triassic, Jurassic, and Cainozoic hypabyssal and volcanic rocks occur in the Sydney Basin. They are chiefly mafic in composition. A few have been isotopically dated, but most are dated by 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 tuff. The intrusions and flows originated from a shoshonitic magma (Joplin, 1964), but some at least of the tuffs are felsic in composition (Leitch, 1968). Tuffs are numerous and widespread, and with bentonitic clay, occur mostly in the Newcastle Coal Measures.

Mesozoic Igneous Rocks

There are many igneous intrusions in the Permian sequence in the Sydney Basin the age of which is unknown, although most of them are thought to be Jurassic.

Triassic

Most of the Triassic igneous rocks are volcanic. They include basalt flows and plugs, breccia pipes, and abundant tuff and ash that occur either in beds or as contaminants in the sediments (Table 7).

Jurassic

There are three isotopically dated Jurassic igneous rocks in the Sydney Basin (Table 8). They belong to the alkaline series, which is found in tectonically stable areas as flows, sills, dykes, plugs, stocks, and laccoliths. In the Sydney Basin which is presumed to have been stable in the Jurassic there are many alkaline intrusions, most commonly of teschenitic dolerite, and these are ascribed to the Jurassic along with the dated occurrences.

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	Berkely Latite feldspar, K/Ar, 252 m.y. Bombo Latite, feldspar K/Ar 240 m.y. 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)	Emplaced irregularly into sediments of the Conjola Sub-Group	K/Ar, 240 m.y. J.R. Richards (pers. comm. 1971)	
Currambene Dolerite	Potassic porphyritic trachybasalt	Gellatly in Ozimic (1971)	Intruded into unconsolidated sediments of Wandrawandian Siltstone and Nowra Sandstone	K/Ar 234 $\pm$ 6 m.y. Webb in Ozimic (1971)	Possibly a laccolith
Stockyard Mountain No. 1	Porphyritic basalt	Alcock (1968)	Intruded between Wandrawandian Siltstone and Nowra Sandstone	Assumed	
Nobbys Tuff	Tuff altered to claystone	McKenzie (1962)	In Lambton Sub-group near base of Newcastle Coal Measures (see Appendix 3)	Tatarian	Most persistent of numerous tuff layers: forms a marker horizon
Fern Valley Tuff	Tuff altered to claystone		In Adamstown Sub-group of Newcastle Coal Measures (see Appendix 3)		Very persistent and attains maximum thickness of 29 m

Table 6 (cont.)

Name or Locality	Rock Type	Reference	Relationships	Age	Remarks
Awaba Tuff	Tuff altered to claystone		In Moon Island Beach Sub-group 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	
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)	Occurs as interbeds in Wittingham Coal Measures. No evidence as to whether flows or sills	Tatarian	One claystone layer is 6 m (20 ft) thick, and there are 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	

Table 6 (cont.)

Name or Locality	Rock Type	Reference	Relationships	Age	Remarks
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	K/Ar, 194 m.y. (Triassic-Jurassic boundary)	
Central area, particularly near Sydney - e.g. The Basin, Hornsby, Dundas, Erskine Pass, Minchinbury, Plumpton	Basalt and breccia	Adamson (1969) Herbert (1970a)	Diatremes in Wianamatta Group. Necks and plugs	Microfloras in coal fragments are Triassic as young as the Ashfield Shale	Some volcanoes were active during formation of Bringelly Fm. Adamson lists about 10 necks in Sydney region. One at South Colah has radiating basalt dykes
Moss Vale/ Mittagong area	'gabbroic, dioritic and syenitic bodies'	O'Reilly (1971)	Intrusive into Hawkesbury Sandstone	Older than 194 m.y., younger than Hawkesbury Sandstone (mid-Triassic)	
Eastern part of Sydney Basin	'Chocolate shales'	Loughnan (1963)	Interbeds in Narrabeen Group	Lower and Middle Triassic	Detritus of volcanogenic origin is a widespread contaminant in Narrabeen Group
Dural South No. 1	Tuff altered to claystone	Hawkins & Ozimic (1967)	Interbeds in Narrabeen Group	Lower and Middle Triassic	

TABLE 8. JURASSIC IGNEOUS ROCKS

Name or Locality	Rock Type	Reference	Relationships	Age	Remarks
Prospect Hill Lopolith	Teschenitic dolerite	Wilshire (1967)	Emplaced in Ashfield Shale of Wianamatta Group	K/Ar on biotite, 168 m.y. Evernden & Richards (1962)	
Mount Gibraltar, Mittagong	Microsyenite	Boesen et al. (1961)		K/Ar on hornblende, 178 m.y. Evernden & Richards (1962)	
Umbiella Creek near Kandos	Nephelinite	McDougal (pers. comm. 1971)	Plug in Triassic rocks	K/Ar on whole rock, about 179 m.y.	
Tillynambulan Mountain (Gingenbullen)	Dolerite	Browne (1933) Boesen et al. (1961)	Possibly a denuded sill; on Liverpool Sub-group	Assumed younger than Middle Triassic	100 m thick; contains augite, pigeonite, olivine, rarely quartz
Mount Jellore	Trachyte and essexite	Taylor & Mawson (1903)	Intrusive into Hawkesbury Sandstone	Assumed Jurassic	
Mount Flora	Essexite, dolerite, teschenite, syenite	Whitbread (1947)	Multiple sills and small dykes		Essexite is intruded by teschenite and both by syenite. Much hydrothermal metamorphism
Nattai Dome	Solvsbergite	Whiting & Relph (1969)	Intrusion near top of Illawarra Coal Measure	Assumed Jurassic	Has caused anthracitization of the Bend Creek Seam
Cordeaux Dolerite near Wollongong	Dolerite	Harper (1915), Sussmilch (1923)	Surrounded by Hawkesbury Sandstone and Narrabeen Group. Considered a flow by Harper, and a denuded teschenite sill by Sussmilch	Assumed Jurassic	Texture, aphanitic to gabbroidal

Table 8 (cont.)

Name or Locality	Rock Type	Reference	Relationships	Age	Remarks
Nebo, near Wollongong	Teschenite-picrite	Edwards (1953)	In basal Narrabeen Group. Probably a sill	Assumed Jurassic	Encountered in bore-holes, 79 m thick. Thought by Edwards to be same body as that at Cordeaux
Mount Murray, near Wollongong	Teschenite	Edwards (1953)	In Narrabeen Group and topmost Illawarra Coal Measures. Probably a sill	Assumed 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 Group	Assumed Jurassic	
Western Coal-field; Tonbong Mountain, Growee near Rylstone, Bocable and Mount Danger near Bylong	Teschenitic dolerite	Vallance (1969)	Sills in Triassic and upper Permian	Assumed Jurassic	
Far northwest Sydney Basin: Barrigan Cr. phonolites, The Porcupine, Mount Stormy, Davids Mountain, Bald Mountain, The Pinnacle	Phonolite and tinguaite	Carne (1903), Sussmilch (1933) Day (1961)	Laccoliths and sills in Triassic rocks	Assumed Jurassic	Thought by Sussmilch to lie along an EW line of monoclines and faults. Undersaturated

Table 8 (cont.)

Name or Locality	Rock Type	Reference	Relationships	Age	Remarks
Murrumbo and Wollar	Microsyenite	Day (1961)	Sills	Assumed Jurassic	Undersaturated
Middle and Upper Hunter Valley; Martindale No. 1	Syenite?	Nicholas (1969)	Sill between Intervals 7 and 8 in Wittingham Coal Measures	Assumed Jurassic	33.6 m thick; contains K-feldspar, pyroxene, biotite and chlorite
Martindale No. 1A	?	Nicholas (1969)	Sill within Wollombi Coal Measures	Assumed Jurassic	48.8 m thick, Fine-grained, mafic; contai-ns hornblende and abundant chlorite, with minor pyroxene and biotite
Savoy Sill	Teschenite with syenite intrusions	Raggatt & Whit-worth (1932)	Sill in western part of Muswellbrook Antic-line; in Greta Coal Measures	Assumed Jurassic	90 m thick. Teschenite consists of labradorite augite, and little olivine. Syenite cont-ains Na-feldspar and arfvedsonite
Plashett Sill	Dolerite and aplite	Raggatt & Whit-worth (1930)	Sill in trough of small syncline	Assumed Jurassic	
Howick Sill	Pink trachyte and dolerite	Veevers (1960)	Sill in Wittingham Coal Measures	Assumed Jurassic	8 m thick, 1.5 km long
Fordwick Sill at Broke	Dolerite	Raggatt & Whit-worth (1930)	Sill in Wollombi Coal Measures	Assumed Jurassic	
Marulla Sill at Wingen	Dolerite with basalt plug and dyke	Raggatt (1938)	Sill in Wittingham Coal Measures	Assumed Jurassic	75 m thick, 13km long

Table 8 (Cont.)

Name or Locality	Rock Type	Reference	Relationships	Age	Remarks
Carrington Sill	Diorite with syenite veins	Veevers (1960)	Sill in Wittingham Coal Measures	Assumed 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 (Evans, 1967)	Assumed 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 of alkali olivine basalt parent-age	Boesen & Ritchie (1971)	A plug intrusive into Narrabeen Group	Assumed Jurassic	
Bulli Colliery Sill	Analcite basalt	Harper (1915)	Sill in upper Illawarra Coal Measures	Assumed Jurassic	
Botany Bay	Syenite	Stuntz (pers. comm. 1970)	Near top of Illawarra Coal Measures, probably a laccolith	Assumed Jurassic	Encountered in DM Cape Banks No. 1 bore between 2385 and 2495 ft

Cretaceous

Several intrusions of potassium-rich igneous rocks in the Sydney Basin have been assigned to the Cretaceous on the basis of their overall resemblance to dated occurrences, one within the basin and others along the eastern seaboard of Australia.

Undifferentiated

Card (in Harper, 1915) recognized three types of dykes and sills in the Triassic rocks of the Sydney Basin: these are syenite-tinguaite (nephelinitic), basaltic, and monchiquitic; 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 in the Sydney district, and 48 in the Newcastle district. Nashar & Catlin (1960) described a swarm of 60 dykes in the Port Stephens district, some of which are aligned roughly north-south, others roughly east-west. They are up to 5 m wide. Taylor & Mawson (1903) write of the Mittagong district being 'permeated' with trachytic dykes. Raggatt (1938) writes that in the upper Hunter Valley basaltic dykes and sills are 'too numerous to list or show on a map'.

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). Dykes of the first group are usually thick and persistent, being up to 5 km long and 15 m wide. Dykes of the second group tend to occur as extensive swarms of small impersistent dykes. Dykes of the third group are small and sparse, and have the same average strike as associated faults.

The post-Triassic dykes and sills have damaged the coal seams - a dyke often branches into a sill or a series of sills that may entirely replace a coal seam. The coal has been altered for a few centimetres to several metres. In places the coal is cindered, with emplacement of calcite, pyrite, and stringers of dyke material. In a few places the coal is not cindered, but loses volatiles and is upgraded in rank. In the Bulli Pass Colliery a natural coke was formed, and in the Mount Alexander Colliery, at Mittagong, a sub-bituminous coal was upgraded to anthracite. The igneous rocks have also been altered near the coal, and at the contact they have been converted to 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.

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	K/Ar on biotite, 93 m.y. Evernden & Richards (1962)	Just south of present extent 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 Sandstone	Cretaceous? assumed	A potassium-rich suite resembling that at Mount Dromedary
O'Hara Head, Bawley Point	Coarse-grained essexite	Vallance (1969)	Intrusive into Conjola Sub-Group	Assumed	Similar to rock at Mount Dromedary
Budderoo Lamprophyre at Wallaya in Southern Coalfield	Mica lamprophyre	Harper (1915), Hanlon et al. (1953)	Intrusive into Hawkesbury Sandstone	Assumed	Resembled Good Day Mountain Complex. Originally called a monzonite

TABLE 10. CAINOZOIC IGNEOUS ROCKS

Name or Locality	Rock Type	Reference	Remarks
Mittagong Province			
Robertson	Analcite basanite	Harper (1915), O'Reilly (in press)	Many flow remnants, the 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 (in press)	
Wingello	Basalt	Harper (1915), Craft (1931)	Occupy valleys eroded in Tertiary sediments
Nerriga Province			
Endrick River	Basalt	Craft (1931)	Largest is about 21 km long in Tertiary river valley. Several flows, with total thickness of 12 m;stream-drift between flows
Sassafras	Olivine basalt	Craft (1931) Vallance (1969)	Largest flow about 10 km long and up to 3 km wide
Airlie Province			
Dairy Mountain near Rylstone	Olivine and aegirine-augite phonolite	Day (1961), Wellman & McDougall (in press)	Diamonds in stream gravels
Nullo Mountain, east of Rylstone	Basalt monchiquite	Browne (1933), Day (1961), Wellman & McDougall (in press)	
Jimmy Jimmy	Olivine trachyte	Day (1961)	
Ulan	Olivine nephelinite	Browne (1925)	
Katoomba part of Abercrombie Province			
The Peak, Yarranderie	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 (1908a)	
Mounts Caley, Banks, Tomah, Irvine, Wilson and Tootie	Basalt	Carne (1908a), Crook (1961), Adamson (1969)	

Gold has been found in a diorite dyke in the Moss Vale district.

Cainozoic Igneous Rocks

Wellman & McDougall (1972, in press) distinguish 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. The Katoomba part of the Abercrombie province contains basalt of Miocene age. The rocks were dated by K/Ar measurements.

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).

The structures developed during three main periods of diastrophism: (1) Upper Permian movements which are commonly but loosely called the Hunter-Bowen Orogeny, (2) possible Upper Triassic movement, and (3) late Tertiary epeirogenic movement during the Kosciusko Epoch. The structural history is poorly understood as it is not always possible to tell the time when particular structures developed. Therefore 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 (1907), Raggatt (1938), Osborne (1950), Voisey (1959), and Booker (1960). Raggatt and Booker described the structures in the Hunter Valley in some detail.

The northwesterly trending Hunter Thrust zone of reverse faults 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.

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

The Muswellbrook Anticline is the largest 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. The best mapped of these (Raggatt, 1938) is the Kulnura Anticline and Dural Dome, an apparent continuation of the Lochinvar Anticline. 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 dome axis.

The most prominent feature to the west is the Lapstone Monocline (David, 1896, 1902; Standard, 1964; Galloway, 1967; Branagan, 1969) which extends from Bargo to Upper Colo on the 1:500 000 geological map (Pl. 1). Galloway (1967) showed that it continued northwards to Mount Kindarun. The monocline passes into the Nepean Fault at its southern end south of Wallacia.

Branagan (1969) 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, 1969). 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 around St Georges Basin and Jervis Bay. The Point Perpendicular Fault runs parallel with and close to the coast on the southern side of Jervis Bay, and extends across the mouth of the bay to Point Perpendicular on its northern side. The structures on Plate 5, in addition to those shown on Plate 1, are after Paix (1968), Bowman (in prep.), and Bembrick & Holmes (in prep.).

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 in Lower and Middle Palaeozoic Basement Rocks

The sedimentary rocks of the Sydney Basin along the western and southern margins and in the Southern area are unconformable on lower and middle Palaeozoic rocks of the Lachlan Geosyncline that were deformed in several orogenies culminating in the Kanimblan Orogeny about the middle of the Carboniferous. During the Devonian-Carboniferous the locus of geosynclinal sedimentation shifted to the New England Geosyncline, and after the Kanimblan Orogeny no further sediments were deposited in the Lachlan Geosyncline. There is unconformity between Middle Carboniferous granodiorite and Upper Carboniferous volcanics in the New England Geosyncline sequence 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 Geosyncline. Local unconformities developed at the beginning and the end of the Permian, and are exposed in the Lochinvar Anticline.

Lower Sakmarian unconformities

One local angular unconformity has been mapped beneath the Allandale Formation on the Lochinvar Anticline (David, 1907) and is 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 in the Permian and the folding that it indicates is shown diagrammatically on the tectonograms of Figure 53.

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

Tartarian unconformities

Two angular unconformities have been mapped in Tartarian sedimentary rocks exposed in the Lochinvar Anticline. One occurs beneath the Newcastle Coal Measures and the other beneath the Narrabeen Group. Both these events which resulted in the development of unconformities are shown on the tectonograms of 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, and the Mulbring Siltstone on the southeast flank. The Tomago Coal Measures are absent, except in the northeast near Maitland. The simplest explanation of this relationship is that, 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 anticlinal area was then buried beneath the Newcastle Coal Measures which onlapped progressively over both the Mulbring Siltstone and the Muree Sandstone Member.

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

Upper Triassic unconformity?

Regional considerations suggest folding and erosion in the Upper Triassic before deposition of 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 it overlaps onto the Permian sequence and rocks of the Tasman Geosyncline to the northwest. This relationship and the existence of an Upper Triassic unconformity between the Bowen and Surat Basins in Queensland give 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 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 Tartarian regression and transgression, and (7) the middle Tartarian regression and transgression.

Structural History

The preceeding sections have summarized the folding and faulting and the age and stratigraphic position of unconformities. We presume that folding and faulting movements which are largely local occurred in a relatively short space of time and are recorded as angular unconformities, whereas broad vertical movements of the crust take place over much longer periods of time and are recorded in the sedimentary record as disconformity, onlap, offlap, facies change, and variation in the rate of sedimentation. The broad vertical movements are summarized by the oscillograms and the folding and faulting movements by the tectonograms of Figure 53.

The tectonograms do not identify the structures that developed during each pulse of folding and faulting. The difficulty of this task can be appreciated by remembering that the sedimentary rocks over the Lochinvar Anticline were folded and eroded twice in the lower Sakmarian and twice in the Tartarian and were folded again after the Triassic sediments were deposited. The same structure has also been faulted. It is therefore difficult to define the nature of the deformation which, together with erosion, produced each unconformity even if the two Sakmarian unconformities were excluded on the grounds that there is too little known about them to draw reliable conclusions. Most of the folding and faulting of the Lochinvar Anticline and other structures in the Hunter Valley developed during the two Tartarian movements which are loosely referred to the Hunter-Bowen Orogeny. However, isopach maps of the Narrabeen Group show a depression south of the Lochinvar Anticline which suggests that the Kulnura Anticline and Dural Dome had not yet developed in this area. These structures, and other similar structures in the central area, developed 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). This 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 was greatest in the late Miocene and early Pliocene. The peneplain was uplifted to form the Southern Highlands and the highlands of New England and 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 rejuvenation of the old river

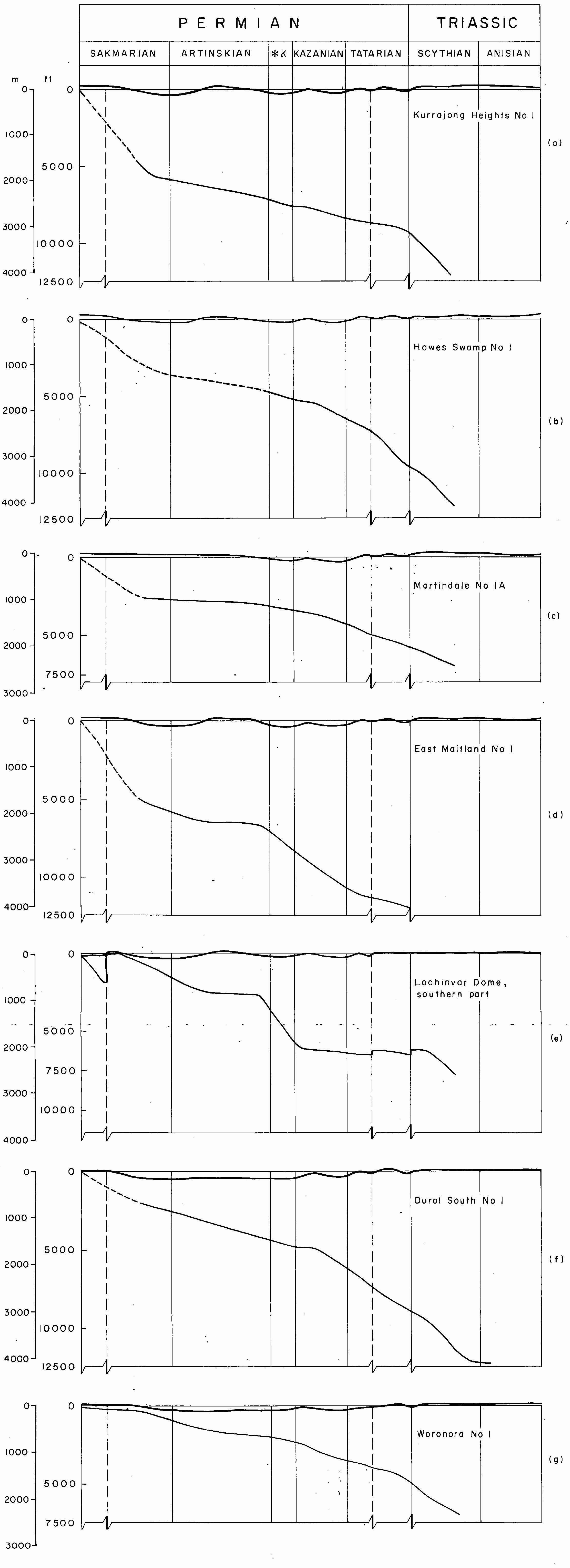

Fig.53 Oscillograms (curves of broad vertical movements and facies change) and tectonograms (lines indicating diastrophism which has produced unconformity) for the Permian and Lower Triassic of the Sydney Basin. Upper line represents position of surface of deposition relative to sea level. Lower line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

* KUNGURIAN

XAUS 3-3-38

To accompany Record No. 1972/76

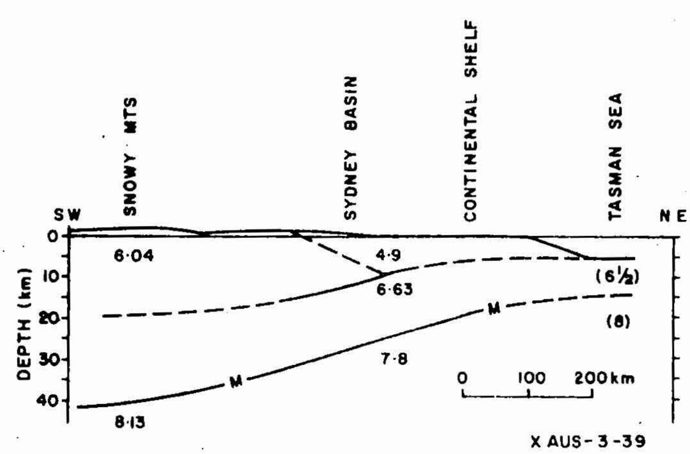

Fig.54. Generalized cross-section of crust from northeast to southwest, across Sydney Basin. M is the Mohorovičić discontinuity, the numbers are velocities in km/s. (from Doyle et al., 1966)

To accompany Record No. 1972/76

systems and the initiation of new ones has resulted in the deep dissection of the uplifted peneplain as witnessed by the gorges of the lower Shoalhaven, Wollondilly, Cox, and Grose Rivers. 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 low-lying 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 formed, or at least underwent further movement, at this time (Jaeger & Brown, 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).

The following features have 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 the Pebbley Beach Formation (Pl. 8), together with an isopach map of the Newcastle Coal Measures and correlatives (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 of 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 play-back 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 quality of reflection from the correlative 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 of the basin there is no evidence of reflection from the base of the Pebbley Beach Formation.

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 Australia 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 Height 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

<u>Velocity study</u>

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 $V_i = V_o + \underline{a}\,Z$ (where V_i is instantaneous velocity at depth in ft/sec, V_o is velocity at zero depth in ft/sec, $\underline{a}$ 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 $\underline{a}$ and feeding these into the equation $V_i = V_o + \underline{a}\,Z$ until the time-depth curve of the equation approximates the time-depth curve from the survey.

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 arbitrarycontours (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 sedimentary rocks. The time contours from the interpretation of the marine surveys (Longreach, 1969) were converted into depth contours using a water bottom velocity function of $V_i = 10\,700$ ft/sec $+ 0.55\,Z$.

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 section and traced throughout. It became evident that much of this tracing was unreliable and therefore only four horizons that could be traced basinwide with varying degrees of reliability were chosen for mapping.

Base of the Narrabeen Group. This horizon may be identified with fair to good reliability in most parts of the basin and this 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 1450 ft 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 Formation and the Allandale Formation was interpreted on the east side of the anticline.

No reflections can be detected from the base of the Pebbley Beach Formation. We have no evidence of a velocity contrast between the Pebbley Beach Formation and the Wasp Head Formation. The 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 Sydney 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, the other the Wollondilly-Blue Mountains Gradient Zone (Pl. 5) by Day (1969). Across the Coastal Gradient Zone the Bouguer anomalies increase

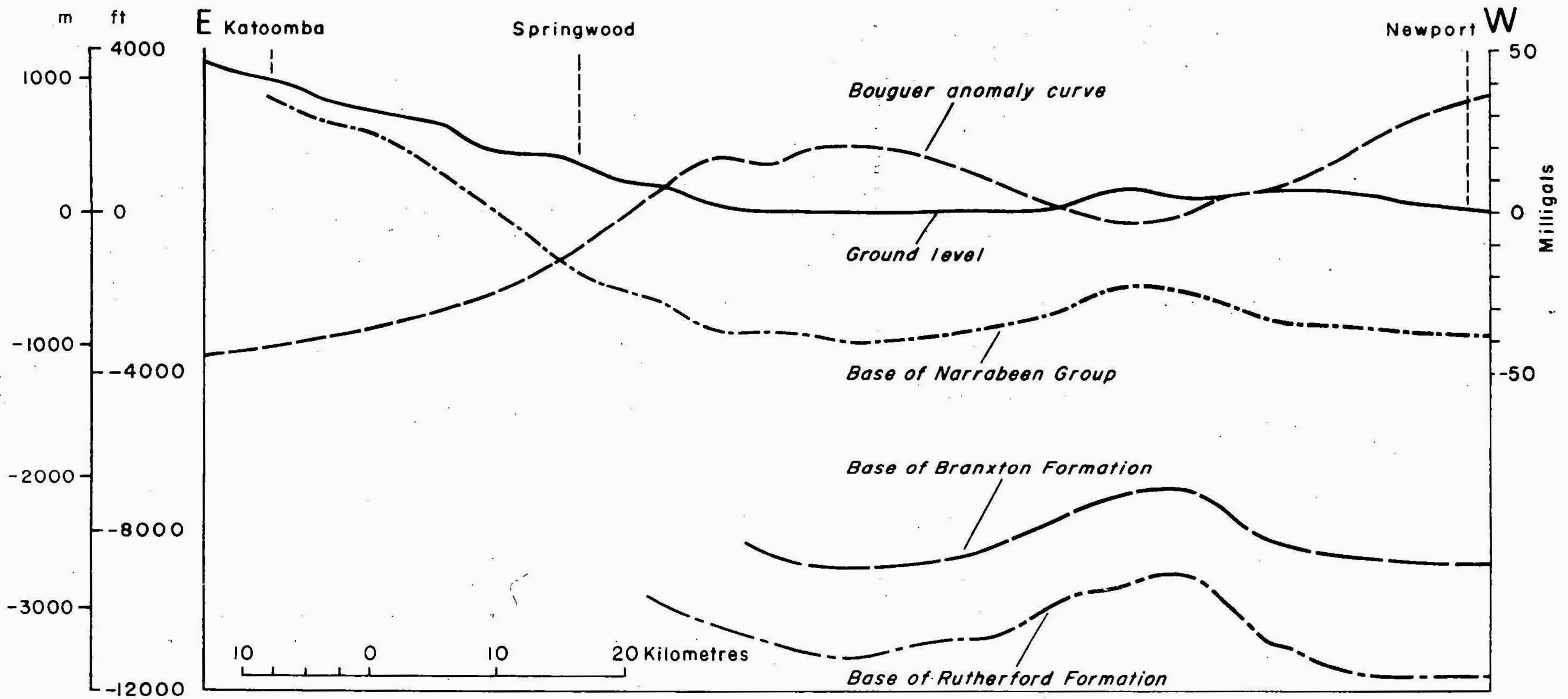

Fig. 55. Cross-section between Katoomba and Newport showing relationship between topography, structure, and Bouguer anomalies

To accompany Record No 1972/76

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eastward from +10 mgals to +50 mgals, at the rate of about 1.8 mgal/km. Across the Wollondilly-Blue Mountains Gradient Zone the Bouguer anomalies increase eastwards from -40 mgals to +10 mgals at about 1 mgal/km.

West of Sydney the two gradient zones are separated by an undulating gravity platform that contains 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 appears to be an extension of the Wollondilly-Blue Mountains Gradient Zone. It dies out farther north. 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 an extension of the gravity high east of the Wollondilly-Blue Mountains Gradient Zone in the south. Similarly, the Gwydir Gravity Low and its southerly extension 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 was 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 in the area 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: either the Bouguer anomaly pattern developed after sedimentation ceased in the onshore Sydney Basin or the pattern developed 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 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) shows 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 western flank of the Lochinvar Anticline and disappear southward beneath 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.

Interpretation of the depth to magnetic basement by the contractors was hampered by the wide spacing of 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 Allendale volcanics in the north and with the unconformity between the Lachlan Geosyncline and the Permian sediment in the south. Magnetic basement therefore is the base of the Sydney Basin as defined in this report. However, local intrusive and extrusive igneous rocks within and overlying the sediments of the Sydney Basin (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. Anomalies may be expected to arise from Tertiary volcanics and intrusions cropping out at the surface, but most of these occur in the north which was covered by the Sydney Basin survey for Australian Oil and Gas Corporation Ltd (1955). The report of this survey could not be obtained and the map that accompanies the report was the only data 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. The estimated depth to magnetic basement in this area is the depth to the Gerringong Volcanics. Offshore, a well defined are containing high-frequency magnetic intensity contours (Pl. 6) is interpreted as a sequence of sediments 2 000 - 4 000 m thick, which contain either shallow intrusive plugs or shallow volcanics, or both, at depths of only 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 trends northerly, is clearly defined by high-frequency contours. The magnetic basement deepens from the western margin toward a deep trough with a maximum depth exceeding 4 000 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 gives a depth of 3 000 m and the other in the east gives a depth of 1 800 m. The presence of this fault is questionable. The anomalies could arise from igneous intrusions or else the depth estimates may need revision. In fact Kulnura No. 1 was drilled without reaching basement, to about 160 m more than the depth to magnetic basement shown on the map.

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 4 800 m.

A slight basement high between Mount Coricudgy and Muswellbrook, which Stuntz (19~~71~~69) 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

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. 56):

1. Australia was a part of the protocontinent of Gondwanaland during the upper Palaeozoic, and that the South Pole lay 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. Extensional rifting during the late Mesozoic sundering of Gondwanaland cut obliquely through the Permo-Triassic accretion, so that an 'eastern' sliver of the continent was detached to form the present day microcontinent of Lord Howe Ridge and New Zealand.

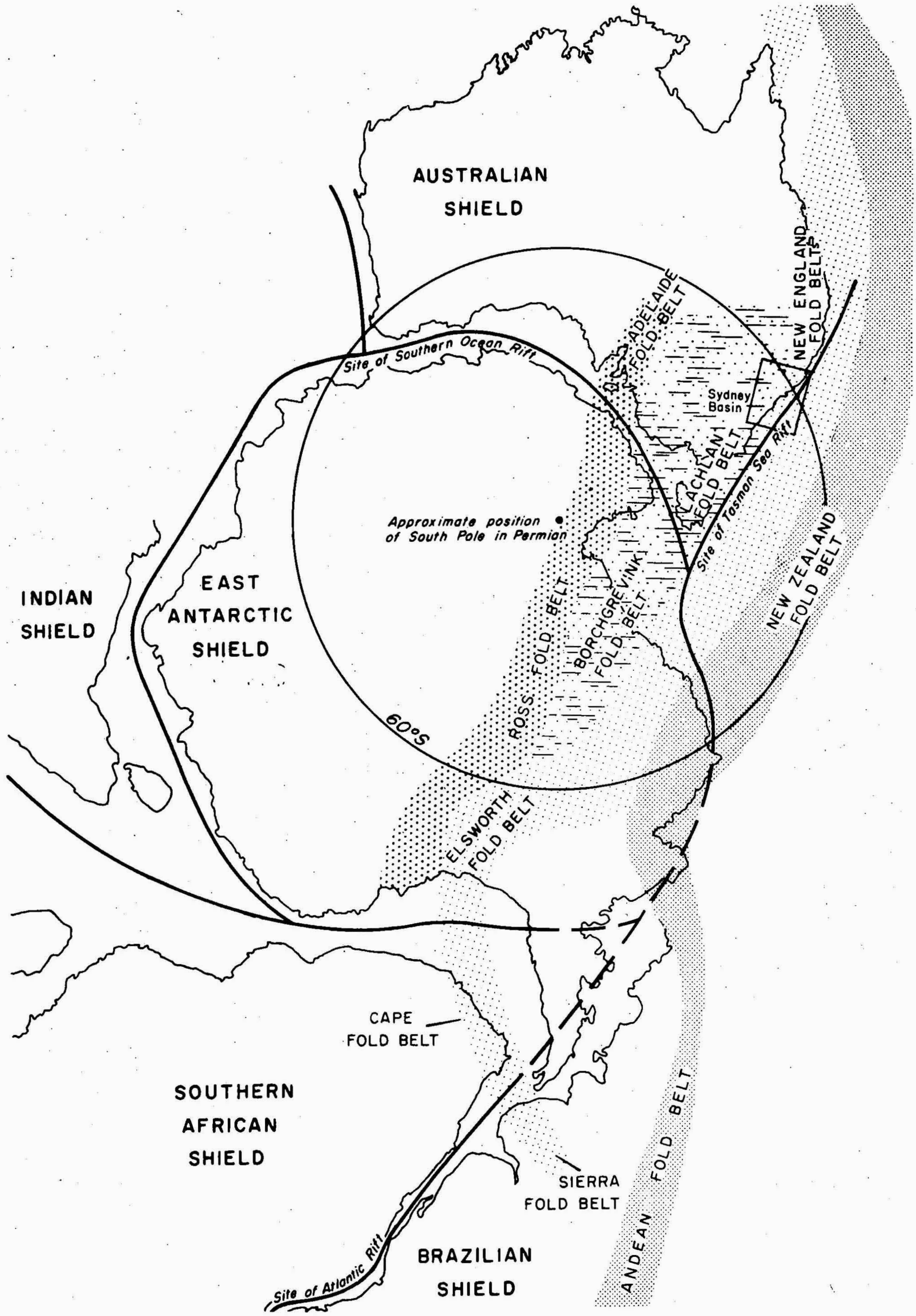


Fig. 56 Partial reconstruction of Gondwanaland showing fold belts, incipient rifts, and the Permian pole

To accompany Record No 1972/76

XAUS - 3 - 41

A present day situation rather like that of the Sydney Basin at the end of the Palaeozoic is presented by Malaya-Sumatra and the Mentawai subduction zone. The Straitsof Malacca with its densely vegetated fringing lowlands is 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, ~~1969~~). 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 Permian marine sedimentary rocks indicates deposition in quiet waters, sheltered from waves and currents. The island arc provided the barrier behind which the sediment accumulated in a sediment trap between it and the continental block.

Sedimentation was also influenced by the waxing and waning of continental glaciers (Crowell & Frakes, 1971) and by the reduction of the cratonic oldland to geomorphic senility.

Crowell & Frakes interpret the evidence for late Palaeozoic glaciation in Australia to indicate the spreading of continental ice sheets rapidly northward and eastward at the end of the Carboniferous, the glaciation reaching a maximum in late Sakmarian or early Artinskian time. The advance of the ice sheet corresponds with a shift of palaeolatitude for Australia (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) in a multidisciplinary assessment of the problems posed by the new global tectonics discounts the necessity for polar wandering to explain the glaciation. He considers it to have occurred in a period of glacial maxima, related to episodic changes in average world temperature resulting in the alternation of periods of glacial maxima with periods of evaporite maxima.

Sequence of Events (Fig. 57)

The sea entered the basin in the early Sakmarian probably from both the north and south. Active volcanism continued in the island arc and a thick sequence of basaltic, andesitic, and rhyolitic volcanics and interbedded fluvial or marine sediments accumulated (in the eugeosyncline) in the north, while

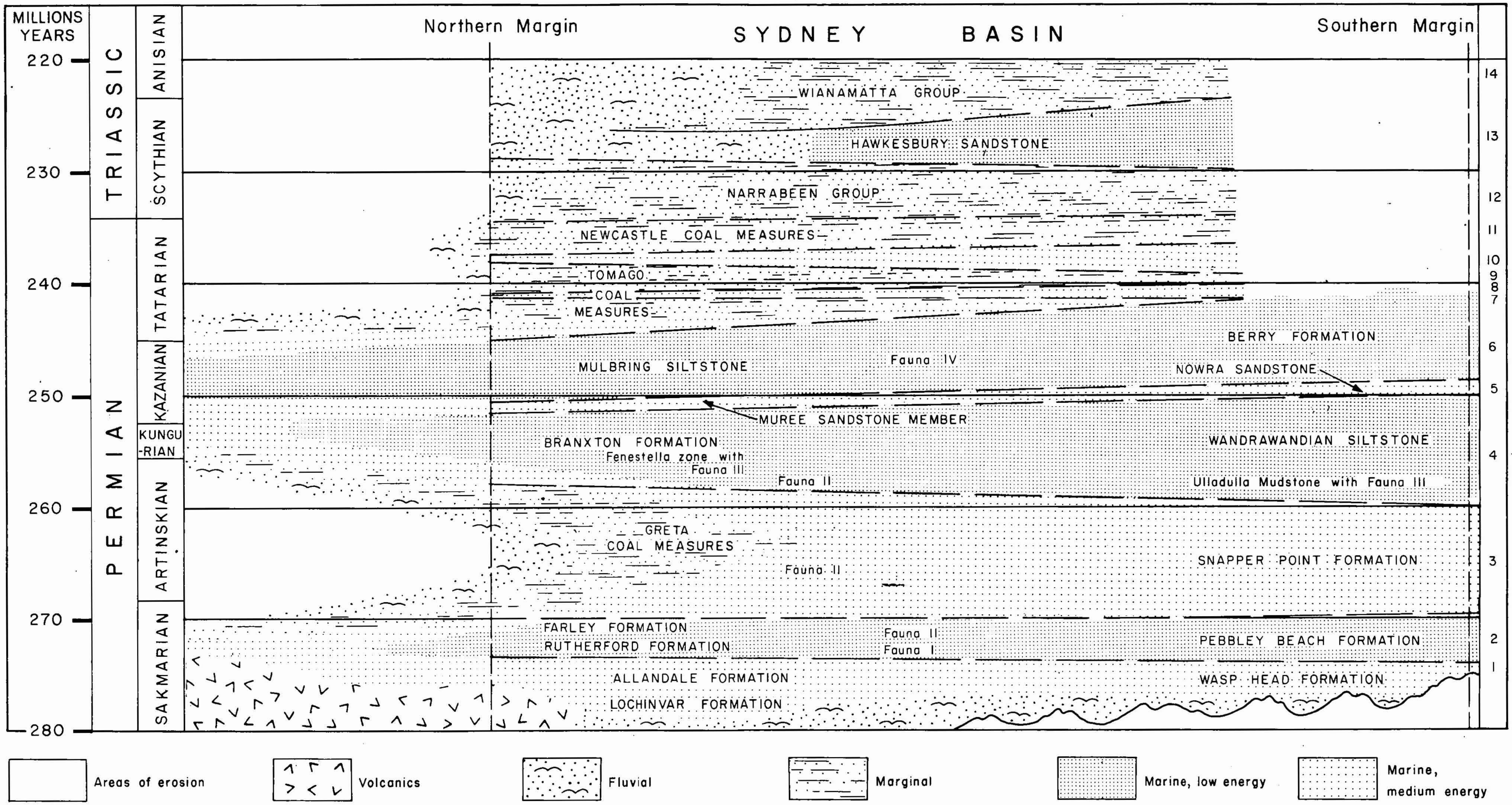


Fig.57 Diagram relating environments of deposition, Intervals, and time.

XAUS-3-37

To accompany Record No. 1972/76

fluviatile, paludal, and marine sediments were laid down on the craton to the south (Interval 1). Coal swamps developed in favourable marginal areas in the south (Clyde Coal Measures) and there was minor coal development (Garretts Seam) on the northeast margin. After volcanism ceased, later in the Sakmarian, 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 magmatic arc in the New England area.

Late in the Sakmarian and continuing 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 the Nowra Sandstone (Interval 5). The transgression reached its maximum in the middle Kazanian breaching the gap between the Sydney and Bowen Basins. The connexion remained open until marine regression in the upper Kazanian brought dominance of marine sedimentation in Sydney Basin to an end: henceforth marginal conditions were more in evidence.

The upper Kazanian regression allowed coal swamps to 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). Recrudescence of igneous activity began in middle Kazanian time with outbursts of volcanic ash, and was continued in one form or another into the Cainozoic as one aspect 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-Tartarian 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 were the most extensive in the history of the Sydney Basin and marked the culmination of coal development. Explosive volcanicity continued on a large scale east of the present coastline: volcanogenic material is common in the epiclastics of the adjacent coal measures and there are 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 predominantly swampy lowlands of the Sydney Basin gave place to an environment less suitable to the accumulation of coal; it is not known whether this was due to climatic change or to the development of alluvial plains over the sites of the old coal swamps, or both (Interval 12). There were minor changes of sea level which resulted in the advance and retreat of delta-front conditions in the complex 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 braided streams spread out over the Narrabeen delta-plain now lying practically at sea level. It is likely that this great flat was subject 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 was laid down as the Hawkesbury Sandstone (Interval 13). It is assumed (op. hoc) 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 were errupting explosively in the central and eastern parts of the plain. The deposits of the Wianamatta Group are the youngest preserved in the Sydney Basin apart from riverine gravels; and except in the Razorback Range the Wianamatta Group has been eroded to its basal formation. 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 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 2 000 m thick.

5. The zeolites in the coal measures have been attributed to diagenesis, but they could have been formed in the zeolite facies 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 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 ~~(Kear 1967; Kingma, 1971)~~.

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 geosynclinal accretion (the New Zealand geosyncline). Sea-floor spreading carried this eastern sliver of the continent away as the Lord Howe Rise and New Zealand; the part which 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 are probably related to this sea-floor spreading which resulted in the formation of the Tasman Sea. A great deal 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.

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 been discussed in the Introduction to this Record. 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 (4 229 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 of the Sydney Basin are prospective for petroleum. Economic basement in the south and west is the rocks of the Lachlan Geosyncline, and to the north the Allandale Formation. The prospective section in the Sydney Basin is generally about 800 m in the southern area, 2 300 m in the central area, and 1 600 m in the northern area, and reaches a maximum in the Macquarie Syncline near Newcastle of about 5 900 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. In actual fact the oil shale deposits in the upper Coal Measures are proven 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 1 330 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).

The two most widespread marine sandstones the Muree Sandstone Member and correlatives and the Snapper Point Formation, are impermeable in areas drilled to date. The low permeability in the basin is due in part to lack of sorting resulting in sediments with two modes of grainsize, 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 polymineralic 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, petrological studies by the Bureau suggest that in the petroleum exploration wells studied, which give a fairly good coverage of the onshore Sydney Basin, the loss of porosity and permeability is due to large amounts of cement, in places, and to the high proportion of silt-sized 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 Sydney Basin. Gas has been found in the Camden area, but although in places the initial flow was 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), Wononora Anticline (Wononora No. 1), a small structural high south of Lake Illawarra, (Stockyard Mountain No. 1), and 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 4 V(1-42), C11(36-50), C10(44-50), H(1-26) and 8 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. The Greta Coal Measures and the Branxton Formation (including the Muree Sandstone Member) do not show any thinning. The Mulbring Siltstone pinches out on the sides of the anticline and the Singleton Coal Measures thin rapidly and are unconformable on the Muree Sandstone Member at the centre of the anticline.

There are two locally developed 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: Firstly the Lochinvar Formation may have been laid down against a ridge and was then onlapped by the Allandale Formation. Following this the Farley and Rutherford Formations were deposited over the ridge. Alternatively it is possible that there was continuous upward movement, fairly rapid at first, so that the Lochinvar Formation was not deposited on the top, then slower movement as the Allandale, Farley and Rutherford Formations were laid down. Regional subsidence with local fluctuations lasted throughout the deposition of the Greta Coal Measures and the Branxton Formation. When local uplift recurred during the deposition of the Mulbring Siltstone and the Singleton Coal Measures unconformities developed on the Lochinvar Anticline. These movements seem to have stopped 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 inportance 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 takes place during 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 utilises 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 accumulations of petroleum in the sediments. It seems likely that the wells drilled in the basin are representative of the general conditions and that permeability is low everywhere.

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.

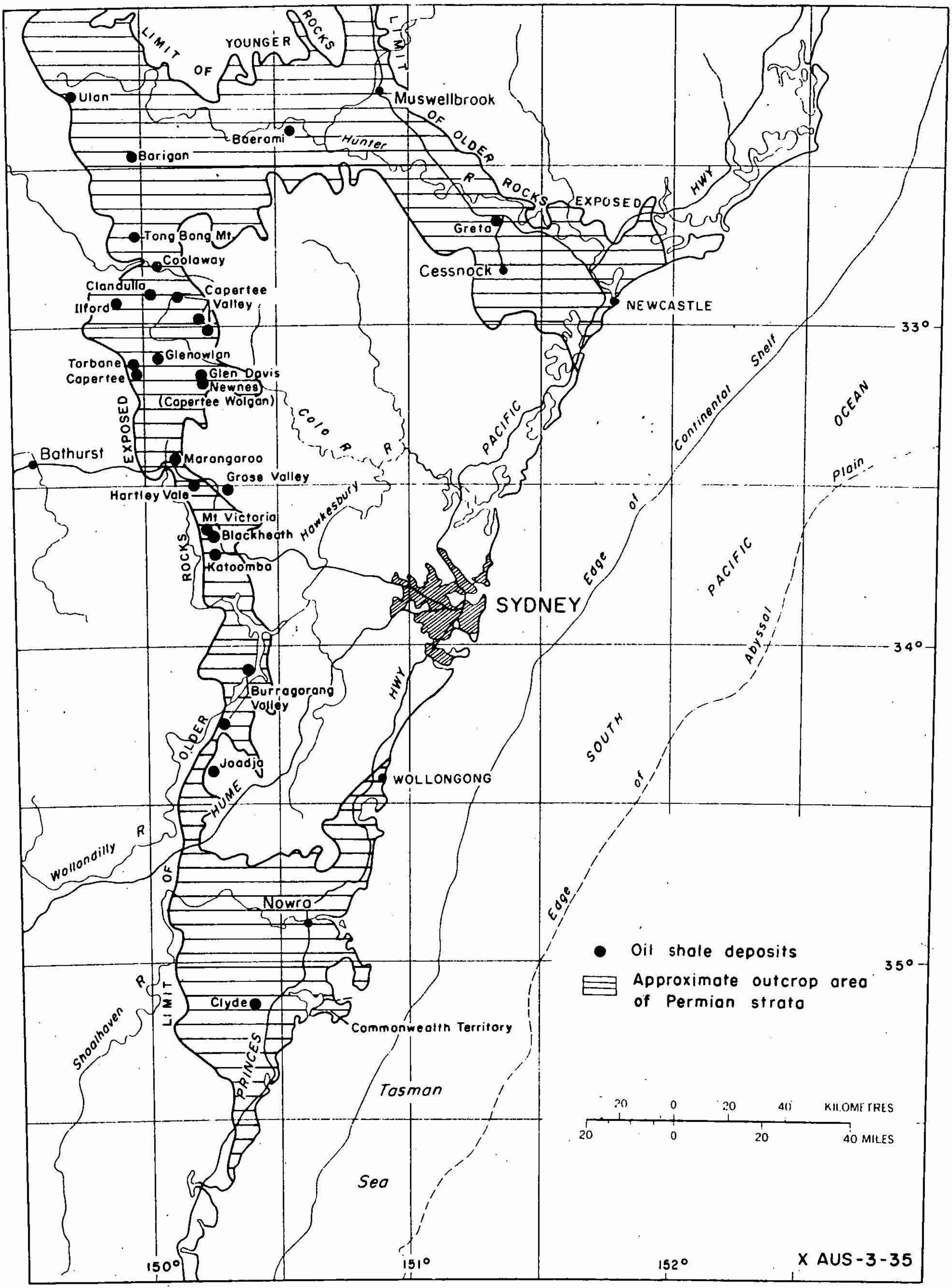
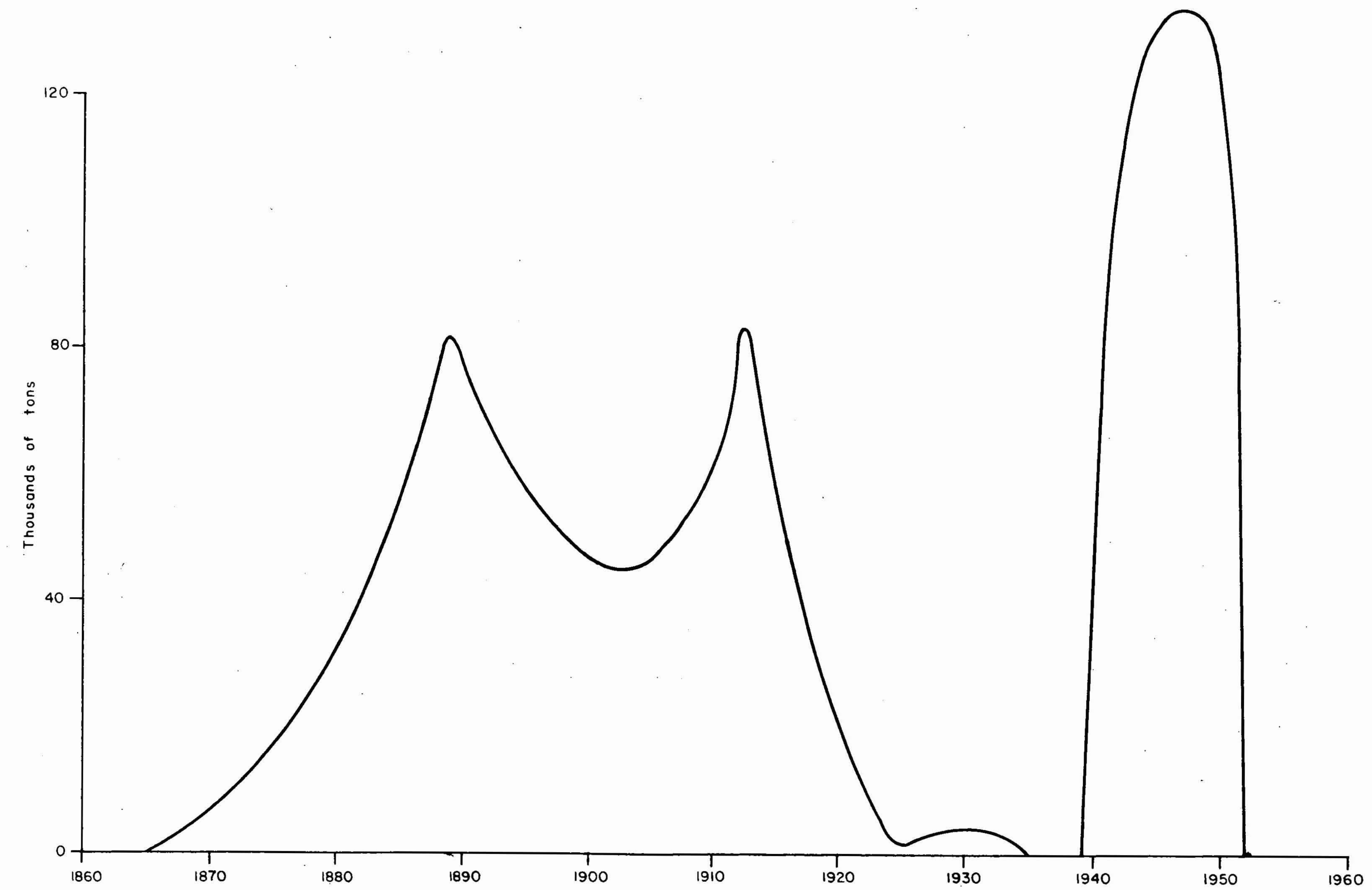


Fig. 58 Oil shale deposits

To accompany Record No.1972/76



To accompany Record No. 1972/76

Fig. 59 Production of oil shale

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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 and Turner (1965) compiled the following yields:

Deposit	Yield (l per ton)
Glen Davies	200-450
Mount Coolaway	1 000
Baerami	250-400
Hartley Vale	700
Marrangaroo	1 100

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 the irregular deposits caused the industry in the west to close 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 estimates of their reserves (after Mead & Ferranti, 1971). Figure 60 (after Mead & Ferranti, 1971) shows the areas in which these reserves are located.

The structure contour maps (Pls 6, 7) show the depths below sea level to the top of the Newcastle Coal Measures and correlatives and the Greta Coal Measures and correlatives, which may serve as a guide to further prospecting for coal. Mead & 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

TABLE 12. POROSITY, PERMEABILITY, AND FLUID SATURATION DETERMINATIONS
(BMR, Petroleum Technology Laboratory)

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	"	"	93	"
Jerrys Plains No. 1	1545.1	6.3	"	"	18	"
Martindale No. 1A	1181.1	14	"	"	n.d.	n.d.
Woronora No. 1	2245.8	2	"	"	34	nil
Dural South No. 1	3050.4	8	"	"	n.d.	n.d.
Kirkham No. 1	2501.6	4	"	"	-	-
	2561.9	3	"	"	-	-
Kurrajong Heights No. 1	2377.1	16	"	"	n.d.	n.d.
	2434.4	15	"	"	"	"
	2487.8	0	"	"	"	"
	2521.0	10	"	"	"	"
	2607.9	4	"	"	"	"
Stockyard Mountain No. 1	922.0	4	"	"	"	"
	999.4	5	"	"	"	"
	1041.2	4	"	"	nil	nil
	1070.4	4	"	"	n.d.	n.d.
Coonemia No. 1	626.9	1.9	n.d.	0.39	22	nil
	794.8	1.6	"	nil	36	"
Interval 2						
Loder No. 1	815.0	7	nil	nil	n.d.	n.d.
	906.2	7	"	"	"	"
	950.9	13	"	"	"	"
	1079.0	10	"	"	"	"
	1163.4	9	"	"	"	"
Camberwell No. 1	1246.7	13	nil	nil	nil	n.d.
	1723.0	11	"	"	n.d.	"
Jerrys Plains No. 1	1004.3	9.4	"	"	30	nil
	1006.9	7.6	"	"	31	"
	1009.5	6.7	"	"	24	"

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
Woronora No. 1	1942.2	4	nil	nil	n.d.	n.d.
	2034.2	3	"	"	"	"
	2138.5	2	"	"	91	nil
Dural South No. 1	2758.7	3	"	"	n.d.	n.d.
	2920.2	4	"	"	"	"
Kirkham No. 1	2072.7	6	"	"	-	-
	2183.7	6	"	"	-	-
	2305.6	8	"	"	-	-
	2400.7	6	"	"	-	-
Kurrajong Heights No. 1	2144.9	4	"	"	n.d.	n.d.
	2247.9	4	"	"	"	"
	2328.7	9	"	"	"	"
Stockyard Mountain No. 1	762.9	4	"	"	"	"
	825.1	7	"	"	"	"
Coonemia No. 1	365.1	5.6	n.d.	"	7.8	nil
	508.6	1.9	"	"	24	"
Wollongong No. 1	305.1	5.9	0.1	0.1	15	"
Wollongong No. 2A	303.7	5.7	0.1	0.1	27	"
Interval 3						
Loder No. 1	718.4	5	nil	1 (fracture)	29	nil
Camberwell No. 1	744.6	8	"	nil	nil	"
	751.4	13	"	"	"	"
	957.9	7	"	"	5	"
	1074.4	7	"	2	3	"
Jerrys Plains No. 1	715.8	9.1	"	nil	12	"
	719.0	8.2	"	"	31	"
	721.3	9.1	"	"	18	"
	725.4	8.5	"	"	14	"
	729.6	6.3	"	"	16	"
	859.6	6.3	"	"	26	"
	863.4	6.2	"	"	21	"
	1001.8	8.8	"	"	30	"
Martindale No. 1A	1051.4	9	"	"	24	tr
Wononora No. 1	1761.7	5	"	"	n.d.	n.d.
	1854.1	7	"	"	8	nil

Table 12 (Cont.)

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
Dural South No. 1	2444.8	3	nil	nil	n.d.	n.d.
	2615.9	6	"	"	"	"
Kirkham No. 1	1844.1	3	"	"	-	-
	1963.3	6	"	"	-	-
Kurrajong Heights No. 1	1953.8	5	"	"	n.d.	n.d.
	2053.1	6	"	"	"	"
Stockyard Mountain No. 1	495.9	8	"	"	nil	nil
	583.1	16	11	6	"	"
	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	"
	240.5	11	0.25	0.23	2.3	"
	276.2	3.5	0.1	0.1	22	"
	288.6	9.4	0.10	0.12	4.0	"
BMR Wollongong No. 2A	190.2	10	0.19	0.10	6.7	nil
	202.2	11	0.12	0.14	8.3	"
	257.9	8.9	0.13	0.14	6.2	"
	274.8	12	0.13	0.13	5.0	"
Interval 4						
Loder No. 1	166.4	7	nil	nil	n.d.	n.d.
	258.2	9	"	"	"	"
	338.6	10	"	"	9	nil
	426.4	12	"	"	n.d.	n.d.
	566.9	12	"	"	13	nil
Camberwell No. 1	629.7	10	"	"	n.d.	n.d.
Jerrys Plains No. 1	582.4	7	"	"	31	nil
Woronora No. 1	1654.1	5	"	"	n.d.	n.d.
Dural South No. 1	2292.2	5	"	"	"	"
Kirkham No. 1	1731.4	4	"	"	-	-
Kurrajong Heights No. 1	1687.4	6	"	"	n.d.	n.d.
	1780.9	6	"	"	"	"
	1865.4	5	"	"	"	"

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
Stockyard Mountain No. 1	316.1	2	nil	nil	n.d.	n.d.
	416.9	9	"	"	"	"
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	"
	70.7	3.1	0.1	0.1	13	"
	86.9	2.5	0.1	0.1	36	"
	133.1	3.2	0.1	0.1	60	"
Interval 5						
Woronora No. 1	1560.6	7	nil	nil	6	nil
Mulgoa No. 2	1522.2	9.4	"	"	-	-
	1522.5	10.5	"	"	-	-
	1523.4	8.6	"	"	-	-
	1523.7	9.8	5	"	-	-
	1524.0	10.3	nil	"	-	-
Kirkham No. 1	1586.0	9	"	"	-	-
Stockyard Mountain No. 1	266.1	6	"	"	n.d.	n.d.
Cataract No. 1	1229.7	6	"	"	-	-
	1230.4	5	"	"	-	-
	1238.2	6	"	"	-	-
	1246.6	4	"	"	-	-
BMR Wollongong No. 1	18.6	4.7	0.1	0.1	54	nil
	23.0	7.4	0.1	0.1	14	"
	27.0	9.9	0.16	0.15	7.9	"
Interval 6						
Woronora No. 1	1189.3	10	nil	nil	10	nil
	1366.1	8	"	"	30	"
	1482.5	1	"	"	100	"
Dural South No. 1	1943.3	10	"	"	n.d.	n.d.
	2146.0	4	"	"	"	"
Kirkham No. 1	1409.5	8	"	"	-	-
	1503.1	5	"	"	-	-

Table 12 (Cont.)

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
Kurrajong Heights No. 1	1419.1	11	nil	1 (fracture)	n.d.	n.d.
	1448.1	9	"	nil	"	"
	1542.3	7	"	"	"	"
	1627.8	6	"	"	"	"
Stockyard Mountain No. 1	93.6	3	"	"	"	"
	191.1	5	"	"	"	"
Cataract No. 1	940.6	9	"	"	-	-
	942.6	5	"	"	-	-
	1050.3	7	"	"	-	-
	1153.8	5	"	"	-	-
	1155.6	4	"	"	-	-
	1192.1	4	"	"	-	-
	1194.2	3	"	"	-	-
	1225.5	5	"	"	-	-
MR 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.	"	"
Woronora No. 1	587.4	32	"	"	"	"
	588.0	36	"	"	"	"
	588.1	n.d.	"	"	22	0.9
	915.6	15	nil	nil	60	nil
	1056.7	2	"	"	88	"
	1123.8	8	"	"	19	"
Mulgoa No. 2	1160.4	6	"	"	-	-
Dural South No. 1	1679.6	7	"	"	n.d.	n.d.
Berkshire Park No. 1	1090.1	14	n.d.	n.d.	30	nil
	1090.5	8	"	"	72	"
Higher Macdonald No. 1	622.9	14.6	nil	7	20	"
	623.0	13.7	"	2	40	"
	625.8	14.6	"	1	39	"

Table 12 (Cont.)

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
Kirkham No. 1	750.8	10	nil	nil	-	-
	752.6	12	"	"	-	-
	753.9	13	"	"	-	-
	755.7	8	"	"	-	-
	916.6	10	n.d.	n.d.	-	-
	918.5	11	nil	nil	-	-
	1004.4	6	"	"	-	-
	1005.0	8	"	"	-	-
	1005.6	9	"	"	-	-
	1006.2	10	"	"	-	-
	1006.8	9	"	"	-	-
	1124.2	8	"	n.d.	-	-
	1124.8	13	"	nil	-	-
	1125.4	12	"	"	-	-
	1205.6	10	"	"	-	-
	1206.2	12	"	"	-	-
	1206.8	11	"	"	-	-
	1207.4	12	"	"	-	-
	1208.0	12	"	"	-	-
	1283.3	7	"	"	-	-
	1285.1	6	"	"	-	-
Kurrajong Heights No. 1	890.9	12	"	"	n.d.	n.d.
	890.9	13	"	1	11	nil
	936.9-941.5	10	"	nil	n.d.	n.d.
	936.9-941.5	12	"	"	"	"
	936.9-941.5	10	"	"	18	nil
	1275.5-1279.8	13	2	5	nil	"
	1275.5-1279.8	13	2	3	n.d.	n.d.
	1275.5-1279.8	12	3	6	"	"
	1275.5-1279.8	12	nil	1	5	nil
Lower Portland No. 1	888.3	9	"	nil	51	"
Cataract No. 1	199.4	13	"	"	-	-
	372.0	19	"	"	-	-
	718.3	18	"	"	-	-

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
Interval 12						
Mount Murwin No. 1	192.0	13	n.d.	3	n.d.	n.d.
	531.3	15	"	n.d.	"	"
	592.2	14	"	8	"	"
	669.9	9	"	n.d.	"	"
	704.7	8	"	nil	"	"
Woronora No. 1	455.3	31	"	1330	5	nil
	487.3	27	"	n.d.	n.d.	n.d.
	487.6	26	"	"	21	nil
Mulgoa No. 2	450.2	16	nil	nil	-	-
	450.8	17.6	"	"	-	-
	451.1	17.5	3	"	-	-
	451.7	16.8	1	"	-	-
Berkshire Park No. 1	330.4	17	nil	"	39	nil
	331.4	19	"	1.4	23	"
	332.7	21	3	7	23	"
	740.8	14	nil	nil	51	"
	742.5	14	0.63	2	22	"
Higher Macdonald No. 1	352.5	16.7	6	n.d.	14	"
Kirkham No. 1	429.6	18	nil	nil	-	-
	522.8	10	"	"	-	-
	522.8	9	n.d.	"	-	-
	523.4	12	nil	"	-	-
	622.2	10	"	"	-	-
	622.8	16	"	"	-	-
	702.9	10	"	"	-	-
	704.2	13	"	"	-	-
	734.9	6	"	"	-	-
	739.2	8	"	"	-	-
	740.5	33	"	"	-	-
	744.1	5	"	"	-	-

Table 12 (Cont.)

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
Kurrajong Heights No. 1	217.3-223.4	18	nil	nil	n.d.	n.d.
	217.3-223.4	14	9	7	"	"
	217.3-223.4	13	n.d.	1	"	"
	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	"	"
	515.1	17	2	12	n.d.	n.d.
	629.7-635.8	7	nil	nil	"	"
	629.7-635.8	10	"	"	"	"
	629.7-635.8	17	10	16	"	"
	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	"	"
	840.3-845.8	16	1	8	"	"
	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	"
	309.6	20	214	246	27	"
Interval 13						
Kirkham No. 1	298.5	15	nil	nil	-	-
	300.9	16	"	"	-	-
Kurrajong Heights No. 1	213.0-216.1	18	"	"	3	nil
Lower Portland No. 1	128.0	8	"	"	21	"

n.d. = not detected

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	
	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	2 814 000 000
		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	
	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	1 227 000 000
		Lithgow Seam 76.2 m	
Southern and southwestern	Illawarra Coal Measures	Bulli Seam 0 m	
		Wongawilli Seam 39.6 m	3 076 000 000
		Tongarra Seam 67.0 m	

* Reserves estimated only for coal for which sufficient evidence from openings, boreholes, etc. was available to make judgement as to thickness, quality, and other properties.

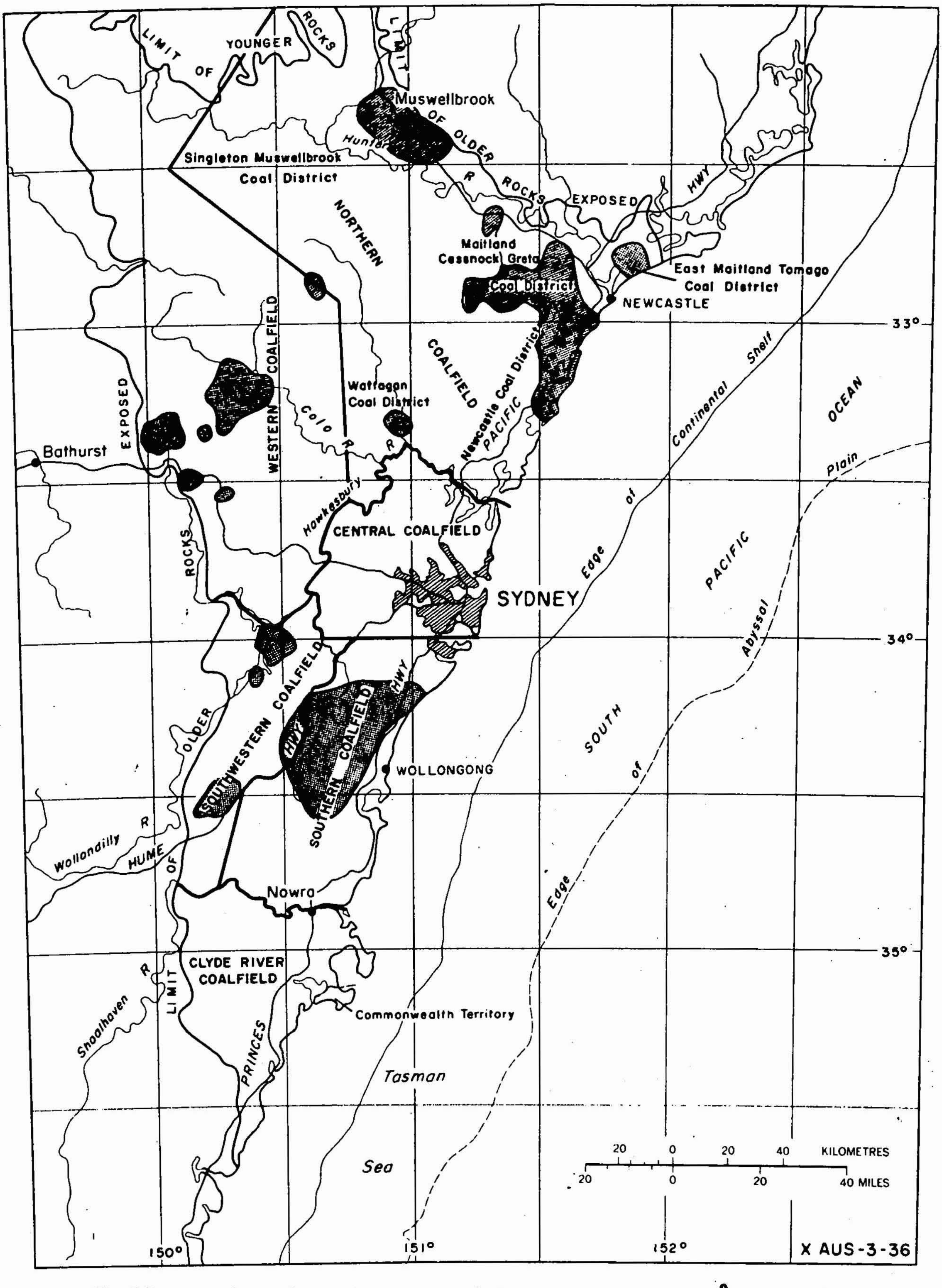

Fig.60 Location of coal reserves (after Mead & de Ferranti 1971)

To accompany Record No. 1972/76

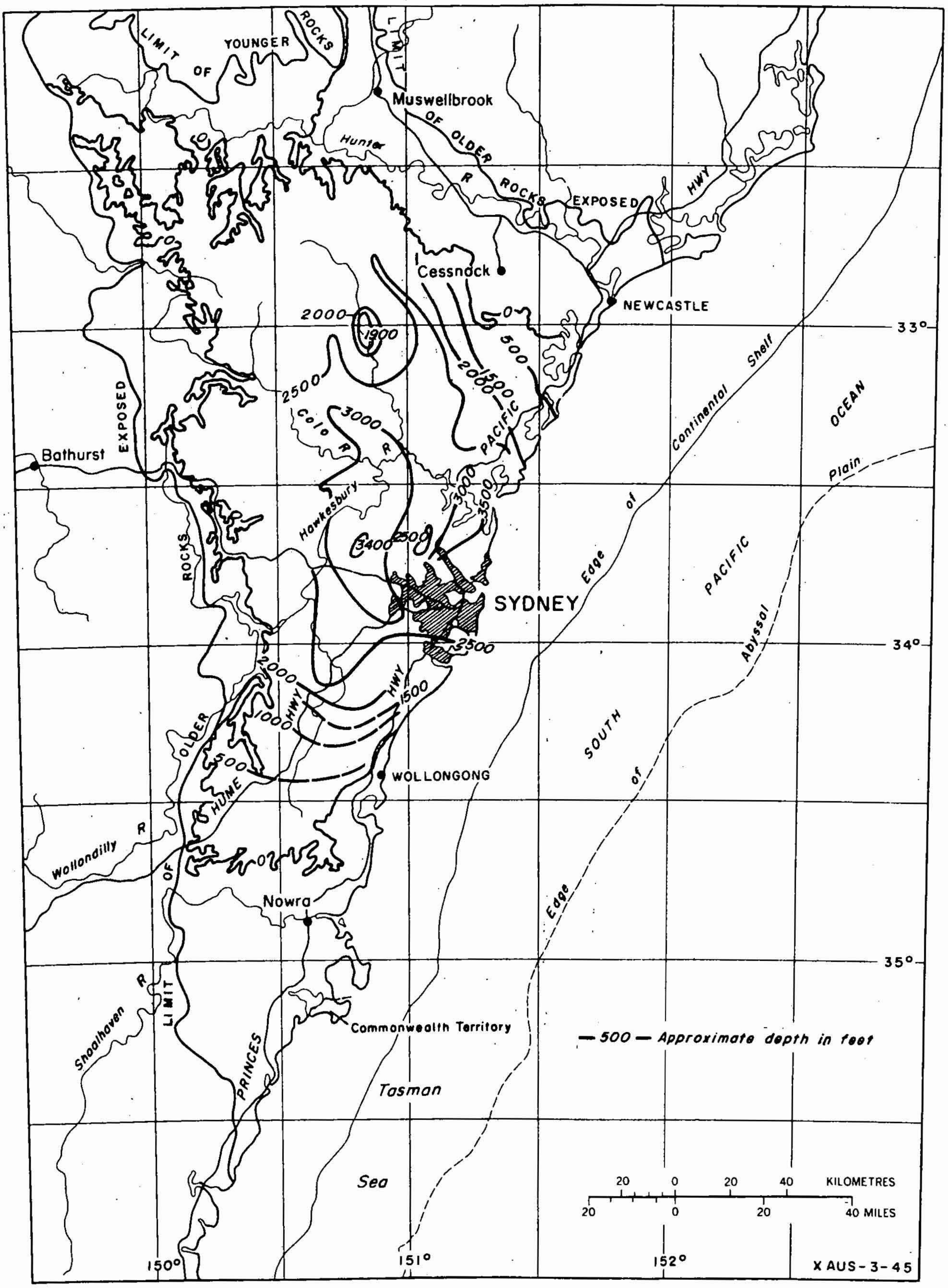

Fig. 61. Depth of overburden, top of Newcastle Coal Measures and correlatives

To accompany Record No 1972/76

coal measures may be intersected at less than 600 m below surface are worth prospecting.

Fig. 61 indicates approximately the depth of overburden over the top of the Newcastle Coal Measures and 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.

Lassak & Golding (1966) have suggested that phosphatic lenticles, beds, nodules, and concretions may be widespread within the upper 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 subjected to extensive transport, 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 nodule 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 Triassic Narrabeen Group. Loughnan & See (1967) have described dawsonite in the Greta Coal Measures at Muswellbrook. 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
'<u>Ptycomphalina</u>' Bed No. 2 (<u>Peruvispira</u>)	0.3
Sandy shale	5.5
'<u>Ptycomphalina</u>' Bed No. 1 (<u>Peruvispira</u>)	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, (Browne & Dun, 1924) which was named the Gosforth Shales (Osborne, 1949). A summary of the section which in this area, 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, 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 massive olivine-bearing types also occur. Volcanic breccia and lapilli tuff are the predominant pyroclastic rocks. The sandstones are poorly sorted and contain numerous lithic and feldspathic fragments. Erratic pebbles, of possible glacial origin, occur throughout the sedimentary rocks. Rattigan considers that in Osborne's descriptions 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~~b~~). 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 (1963a) included the Skeletar Formation in the Greta Coal Measures but Leitch (1969) considers that it should be included in the Gyarran Volcanics because of their lithological affinity.

Wasp Head Formation (Gostin & Herbert, in press)

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, in press; 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, which are 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 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 siltstone, 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 in the southern area. They also occur at Pigeon House Mountain, Budawang Creek, Dunnair 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 containing 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 are common	48.8

	Thickness (m)
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

<u>East Maitland No. 1</u> (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

<u>Kurrajong Heights No. 1</u> (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, 1968)

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

Stockyard Mountain No. 1 (Alcock, 1968)

	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; contains rounded to subangular (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, 1949b; 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 a slight angular discordance on the Pigeon House Creek Siltstone where it is developed, and elsewhere unconformably on lower Palaeozoic basement (McElroy & Rose, 1962). The Clyde Coal Measures are unconformable on lower Palaeozoic basement.

Interval 1 was intersected 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 is unconformable 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 metasulcata, 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 Reid's Dome Beds (called Undivided Freshwater Beds, Dickins, 1968) of the Springsure area, and all or part of the Lizzie Creek Volcanics (called Lower Bowen Volcanics, 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 Ptycomphalina 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 Neogerathiopsis sp. has also been collected (McElroy, 1969a).

Evans (1967b) has recorded the presence of 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, 1949b). 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) and Herbert (in prep.), 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, 1968b, 1971b; 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 Striatite and the absence of Marsupipollenites and Verrucosisporites indicates an older age than the Clyde Coal Measures, even as old as Evans' Stage 1. No microflora was examined from the Yadboro Conglomerate. 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 (1967, 19~~70~~69), 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, 19~~70~~69) 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 'Ptycomphalina' (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 'Ptycomphalina' (Peruvispira)	30.5
Tuff, plant-bearing	4.6
Grit, tuffaceous, bluish grey	67.1
Sandstone	47.2
Shale rock with 'Ptycomphalina' (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, in press)

The type area for the Pebbley Beach Formation is on the south coast (Gostin, 1968; Gostin & Herbert, in press; 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 subgroup 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, with 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 siderite and dolomite cement. Siltstone is pyritic and carbonaceous. Youngest horizon in well in which clasts of volcanic rock are common. Bivalves, and 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 and fine sandstone occurs at number of levels. Calcite and siderite cement. Poorly preserved bivalves and burrow structures	251.2
Total	393.8

Camberwell No. 1 (AOG, 1965)

	Thickness (m)
Farley Formation correlative	
Sandstone, fine to very fine-grained, silty, slightly calcareous, well consolidated	136.6

	Thickness (m)
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 and 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), with 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 and a protoquartzite interbedded with massive fine and coarse 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 and evidence of organic reworking	187.5
Mudstone, highly carbonaceous and pyritic, with laminae of sideritic fine-grained subgreywacke. Glendonites and 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, 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, rare plant fossils, and minor coal	74.7
Sandy siltstone with minor sandstone; burrow structures and 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

Woolongong (BMR) No. 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 and 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 the Pebbley Beach Formation onlaps lower Palaeozoic 'highs'.

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 *Gilledia culburrensis* Campbell, 1965. These species are not found in the underlying Wasp Head Formation but range up into the overlying Snapper Point Formation.

They consider that the presence of *Megadesmus nobilissimus* in the Pebbley 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 out crop 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, the coal having an aggregate thickness in places of 7.6 m. The name was later (David, 1889b, 1907) applied to all these coal measures in the Hunter Valley.

The Greta Coal Measures have been studied by Raggatt (1938b), Jones (1939), Booker (1953, 1960), Robinson (1956, 1963c), 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, 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 (119 ft). The formation is well exposed around the southern and eastern flanks of the Lochinvar Anticline.

Lower Homeville Coal Member

The type section (Reinhold, 1963) 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 (4 in).

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 often 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 often present near the top of the coal. The thickness is about 9 m (29 ft). 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 (51 ft). 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, 1963c) and the underlying Skeletar Formation (Raggatt, 1929a), constitute the Greta Coal Measures (Robinson, 1963c). In this Record 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, Hallet, 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, in press)

The type area for the Snapper Point Formation is on the south coast (Gostin, 1968; Gostin & Herbert, in press; 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.

<u>Interval 3 in the deep wells</u>

<u>Martindale No. 1A</u> (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.

<u>Jerrys Plains No. 1</u> (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

<u>Camberwell No. 1</u> (AOG, 1965b)

	Thickness (m)
Sandstone, fine-grained; coarse-grained and conglomeratic in part; clay matrix, red, green, and white chert fragments; interbedded shale and coal	388.6

	Thickness (m)
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	6.1 ?
Petromict conglomerate, with pebbles of quartz, chert, quartz sandstone, and volcanic rock grading into pyritic carbonaceous subgreywacke; cemented with siderite	21.3
Coal seam	3 ?
Protoquartzite, coarse-grained, pebbly, pyritic and carbonaceous; cemented with siderite and dawsonite	21.3
Total	85.2

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, with pebbles of sedimentary and volcanic rock, 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 area 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 rock. Silica and calcite cement, with siderite and pyrite in the siltstone. Brachiopods, pelecypods and Foraminifera. Churned bedding and burrow structures in core	160.6

Stockyard Mountain No. 1 (Alcock, 1968)

	Thickness (m)
Protoquartzite, medium to coarse-grained, with minor shale beds tending to be most abundant at top and bottom. Pebbles of quartz, and sedimentary, volcanic, and metamorphic rock. 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 No. 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 (A.L. Bigg-Wither, pers comm., 1971).

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, Malone, & Jensen, 1964), and also suggests correlation with the Farley Formation. The presence of Ambikella cf. undulosa and Ambikella 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, Fauna I being very similar to Fauna II (Dickins, 1964).

Stratigraphic evidence from the Muswellbrook area and Martindale No. 1[A] 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 comprising an upper half cropping out from the Brokenback Range, 8 km south of Cessnock to Bow Wow Gorge 5 km southwest of Mulbring, which is 509 m thick, and a lower part cropping out from a point 0.8 km north of Greta to Branxton, which is about 548 m thick. 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 Fenestalla 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*. Despite its name, the zone is distinguishable lithologically as well as on faunal grounds.

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 as 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 in the formation, the name has been applied because the rocks are relatively silty compared with those of 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 spudded 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) occurs throughout, and is very common in places.	390.1

	Thickness (m)
Greywacke, quartz greywacke, and sandy siltstone, commonly carbonaceous, essentially fine-grained, although with coarser intervals. Clasts of chert, shale, and low-grade metamorphic rocks, calcite and siderite cement and pyrite common in places. Marine fossils, mainly brachiopods and Bryozoa throughout, but more abundant toward 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, fresh and altered feldspar. Sodic plagioclase is partly or wholly replaced by calcite. Siderite and calcite cement occur throughout. Bryozoa concentrated in zone near top of unit. Laminae and burrow structures. Well spudded 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 a minor coal seam, occurs in lower part. Brachiopod shells and spines, and fenestellid Bryozoa common in upper part. Calcite, siderite, and silica cement and pyrite are 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 occur throughout. Dawsonite and silica cement common	73.2
Protoquartzite, fine-grained; contains pyrite and carbonaceous material. Quartz and chert pebbles occur throughout. Calcite, siderite, dawsonite, and silica cement. Churned bedding	137.2
Total	688.9

Camberwell No. 1 (AOG, 1966b)

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

Jerry Plains No. 1 (Esso, 1969)

	Thickness (m)
Sequence of interbedded sandstone, siltstone, and shale becoming 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 are milky quartz and chert. Dawsonite and calcite cement, abundant Foraminifera, brachiopods, and Bryozoa. Foraminifera identified (Crespin, 1964) 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 and 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 and scallop structures	73.2

	Thickness (m)
Subgreywacke, fine and coarse-grained, muddy, interlaminated in thick sequences with very fine subgreywacke and siltstone, and muddy very fine subgreywacke; all carbonaceous and micaceous, with scattered pebbles and rare cobbles. Calcite and siderite cement; pyrite. Cross-lamination and scallcp 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 quartz sandstone and shale beds. 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, with scattered pebbles. Carbonaceous, pyritic; sandy at top. Lamination, scallop structures, churned bedding, burrow structures and marine(?) shell fragments	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 and 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 and Berry Formations above. It must be emphasized that the sequence referred to here as the Wandrawandian Siltstone is the sequence between the units defined in the BMR well studies and company well completion reports as the Kedumba Creek Sandstone Member of the Berry Formation and the Nowra Sandstone, which are now recognized as the subsurface extensions of the Nowra Sandstone and Snapper Point Formation respectively (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 Bowen Basin, which occurs 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 collections and appears to be poorly developed in other areas of Permian outcrop in New South Wales. The *Fenestella* Zone contains *Strophalosia* cf.

jukesi or preovalis and 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 which are restricted to Faunas II and IV in Queensland, the mixture constituting the Eurydesma-Myonia corrugata fauna, later called the Ulladulla fauna (Runnegar, 1969). The following species are found in the Branxton Formation: Eurydesma hobartense, Myonia currugata, Neocrimites meridionalis, Ambikella cf. angulata, Ambikella cf. ovata, Gilledia culburrensis, Fletcherithyris amygdala, Fletcherithyris 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.

Runnegar (1967) gives the following species which occur in 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, Gilledia ulladullensis, Fletcherithyris amygdala.

The Ulladulla Mudstonesof Harper (1915) and Brown (1925a), which crop out at Ulladulla, were previously considered to be an upper silty phase of the Conjola Formation (McElroy & Rose, 1962). However, Dickins et al. (1969) consider that the sequence is in the correct structural position to be correlated with the lower part of the Wandrawandian Siltstone. The fauna is a mixture of Faunas II and IV in the Bowen Basin. It contains Deltopecten limaeformis, Strophalosia cf. preovalis, Terrakea sp. nov., Ambikella ingelarensis, Ambikella cf. undulosa in addition to those species marked thus *. 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, frequently conglomeratic or tillitic	39.6
Siltstone, interbedded with bench-forming units of sandstone from 0.3 to 0.6 m thick	22.9
Cliff-forming sandstone, frequently 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 (1938b) 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, north of the Shoalhaven River. According to McElroy & Rose (1962) it consists typically of quartz sandstone resembling the Triassic Hawkesbury Sandstone in composition, grainsize, texture, well defined cross-bedding, mode of outcrop, topography, and vegetation. 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 also distributed throughout the formation particularly in the western part of the area.

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

	Thickness (m)
Cross-bedded quartz sandstone	9
Cliff-forming quartz sandstone with evidence of graded bedding	9-15
Siltstone or silty sandstone	0-6
Massive quartz sandstone	4.6

Fossils are particularly common towards the base and in the siltstone units.

He considers the siltstone interval to be persistent enough to warrant member status, and proposed the name Currumbene Siltstone Member. The thickest outcrop of the siltstone was observed in the north bank of Currumbene Creek about 0.8 km below the falls at Falls Creek, where it is 9 m thick.

To the north and east the Nowra Sandstone lenses out into siltstone and is consequently 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 joints vary in direction from place to place, and 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 of cross-bedded and thick-bedded sandstone, a middle unit of interbedded sandstone and shale, and a lower unit of massive bedded sandstone.

Interval 5 in the deep wells

The Loder No. 1 and Belford No. 1 wells in the lower Hunter Valley spudded below the Muree Sandstone Member and the unit could not be identified in the deep wells in the middle and upper 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 show 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 showing 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 rock. 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
Protoquartzite, fine-grained, interbedded with fine-grained subgreywacke and siltstone. Minor beds of 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 the middle of sequence. Quartz and chert pebbles. Brachiopods common. Poorly sorted and bedded	39.6

BMR Wollongong No. 1 (Ozimic, 1971)

	Thickness (m)
Sandstone, coarse-grained, poorly sorted, pebbly in places. Calcite, siderite, and silica cement. Contains middle unit of sandy siltstone with fossil fragments. Spudded in Interval 5	31.5

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

	Thickness (m)
Sandstone, coarse-grained, poorly sorted, pebbly; calcite, siderite, and silica cement; contains middle unit of thinly bedded sandy siltstone with 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 (Plate 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 Kazanian in age.

Dickins et al. (1969) 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 and 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.

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) and two members, the Glendon Siltstone Member and Dochra Siltstone Member, 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. The member is about 1.5 m thick, and approximately 76 m above the

* = Blenheim Sub-Group of Back Creek Group

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 the member 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 from Mount Talaterang in the far south to the Capertee area (McElroy, 1962), and also in the Cambewarra Range in the southern area (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. Northwards from 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. They are elongated parallel to the bedding, and are thought to represent some type of seaweed. Similar structures have been described in the Dochra Siltstone Member (McKellar, 1969).

Camberwell No. 1 (AOG, 1966)

	Thickness (m)
Siltstone, light grey, finely micaceous, sandy in part, slightly carbonaceous. Rare fossil fragments. Well spudded in this unit. Upper part probably base of upper 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 incertus, 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 scattered throughout. Mainly calcite and dolomite cement; some siderite and anhydrite. Plant fragments, worm tubes, Foraminifera	94.5
Siltstone, as above, but more arenaceous sediment	259.1
Total	353.6

Crespin (1955) identified the following Foraminifera: *Digitina recurvata* (Crespin & Parr), *Reophax* cf. *aspersus* (Cushman & Waters), *Reophax* 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 claystone interbeds 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

	Thickness (m)
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. Sediments carbonaceous; siderite and calcite cement; pyrite. Burrows, bioturbation, lamination, cross-bedding. Brachiopods	266.1

Stockyard Mountain No. 1 (Alcock, 1968a)

	Thickness (m)
Shale grading into siltstone. Quartz sand and pyrite scattered throughout. Lamination, microcross-bedding, and 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.

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 overlies Silurian and Devonian sedimentary rocks unconformably.

Correlations and Age

McElroy & Rose (1966) consider that the Megalong Conglomerate in the Tallong area represents the western coalescence of the Conjola Sub-Group and the Nowra Sandstone, the Wandrawandrian Siltstone having lensed out in this area.

The conglomerate in the Tallong area has been studied more recently by Herbert (in press) 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 (Bembri~~dge~~ck & 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 that in other areas of the basin.

APPENDIX 3: UPPER KAZANIAN TO MIDDLE TRIASSIC ROCKS

INTERVAL 7: LOWER PART OF THE 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, 1969b; Britten, 1971) is in DM Warkworth DDH 1 from 479.7 to 495.3 m (1572.75 feet to 1624.3 feet). 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, 1971) is in DM Warkworth DDH 1 from 253.4 to 479.6 m (724.01 feet to 1572.75 feet). 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 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).

TABLE A. MEMBERS OF THE GERRINGONG VOLCANICS

(after Hanlon et al., 1953)

Cambewarra Latite Member Saddleback Latite Member	
	Jamberoo Sandstone Member
	Bumbo Latite Member
Broughton Sandstone Member (where Bumbo Latite and Blowhole Latite are missing)	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 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, but also of metamorphic, granitic, and sedimentary rocks. There are lenses of shale and siltstone, and abundant marine fossils, particularly towards the base. The sandstone becomes coarser-grained and cleaner towards the top; it is more thickly bedded and more quartzose and light grey to yellow-brown in colour. It is generally flat-bedded, the thickness of the beds increasing 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) has 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) suggested the name Gerringong Volcanics for the volcanics. The component members, which are often mentioned in the literature, are listed in Table A. Bowman (1970) added the Dapto Latite as the stratigraphically highest lava in the Gerringong volcanic facies. He and Raam reject the opinion of earlier writers that the basaltic detritus in the adjacent sandstone is volcanic ejecta, and consider it to be due to penecontemporaneous erosion of the lava flows. The presence of pillow structures in the lavas strongly suggests that they were errupted in shallow water (Raam, 1969).

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.

<u>Pheasants Nest Formation</u>

The type section of the Pheasants Nest Formation (Wood & Bunny, <u>in</u> 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 prostrata 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 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'.

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, 1968)

	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; thin coal layers. Clay, chloritic; calcite crystals	21.3
Subgreywacke with some interbeds of siltstone and trace of coal	30.5
Siltstone, thinly bedded; several thin coal seams	21.3
Subgreywacke, green and brown, abundant clasts of volcanic rock; 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; small coaly clasts and laminae	12.2
Siltstone and silty claystone, very carbonaceous; coaly laminae and plant fragments	9.2
Protoquartzite, as above	6.1
Claystone, silty, buff, soft; carbonaceous laminae common	18.3
Subgreywacke, calcareous; 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; 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 about 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 siltstone, grey, carbonaceous; 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 is immediately above the sandstone that has been interpreted as representing sublittoral conditions during the final regressive stage of the Mulbring Siltstone.

The Mount Marsden Formation lies conformably on the massive grey micaceous siltstone of the Berry Formation in the western area.

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 is arbitarily taken as beginning immediately above the last extensive marine sandstone of the Berry Formation.

In the absence of any 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

Lithological correlation of Interval 7 is based on the following grounds: (a) they are all conformable on siltstone of the Mulbring Siltstone or of the Berry Formation, and (b) they were all formed under shallow marine, estuarine, or coal-swamp conditions.

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 silida; Spirifer duodecimcostatus; S. convolutus; S. vespertilio; S. tasmaniensis; Gilledia uladullensis alta; Fletcherithyris amygdala; F. parkesi; Ingelarella subradiata.

Bryozoa: Stenopora crinita; S. gracilis; S. frandescens; Protoretepora ampla; Fenestella sp.

Pelecypoda: Stutchburia costata; Aviculopecten subquinquelineatus; A. lenuisulens; Merismopteria macroptera; Myonia carinata; M. valida; M. elongata; Atomodesma sp.; Megadesmus grandis; Astartila interpida; Vacunella curvata; V. etheridgei; Streblochondria engelhardti; Pyramus myiformis.

Hyolithida: Hyolithes lanceolatus

Gastropoda: Mourlonopsis strzeleckiana; Mourlonia (Walnichollisa) subcancellata; Warthia micromphala; Platyschisma sp.; Peruvispira norrisiana; Ptychomphalina sp.

Crinoidea: Tribrachiocrinus corrugatus; T. granulatus; T. clarkei; Philalocrinus konincki.

These fossils belong to Fauna IV (Dickins, 1964; Dickins et al., 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 occur in the carbonaceous layers present 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, Gangamopteris mosesi.

The age by K/Ar isotopic dating of the Berkeley Latite and the Bumbo Latite is 250 m.y. (i.e. Middle Permian, Evernden & Richards, 1962). the world-wide 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, 1969a) 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, while the Bulga Formation consists of siltstone and the Archerfield Formation of sandstone. Britten considers that they are partly marine in origin.

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 thin interbeds of shale and siltstone. The sandstone has a calcareous cement. 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 many siltstone lenses. 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 at the base and well sorted cross-bedded quartzofeldspathic sandstone at the top, 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) is a siltstone member within the Rins Vale Formation; it contains a few marine fossils.

Interval 8 in the deep wells

Kirkham No. 1 (Raine, 1969)

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

Woronora No. 1 (Alcock, 1968)

	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, with abundant feldspar and 10% quartz, partly dolomitic; 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, subangular, fine-grained	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

N.B. Between 1265 m and 1359.4 m there are fairly regular occurrences of a sparse microfauna, dominated by arenaceous Foraminifera.

Kulnura No. 1 (Ozimic, 1969)

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

N.B. 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 parts, with intervals of carbonaceous claystone and siltstone	39.6
Altered igneous rock. Lower less altered half considered to be syenite with 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 are correlated on the following lithological grounds: except for the Mount Marsden Claystone they all lie conformably on coal or carbonaceous shale of Interval 7; they 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, Frondicularia parri, Geinitzina sp., Ammodiscus milletianus, Ammodiscus mulbeenicites, Ammodiscus incertus, Ammodiscus multisinctus, Hyperamminoides acicule, Hyperamminoides spp., Ammobaculites sp., Trochamminoides anceps, and Agathammina sp.

Ostracoda: Canellina kulmensis, Macrocypris sp., Bythocypris sp., Bairdia sp., Cytherella aequisalus, 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, 1967). This species also occurs at the same horizon in the Dural East Nos. 1 and 2 wells (Crespin, 1957).

3. In the Balmain colliery bore the following fossils were found (Raggatt & Crespin, 1941) from 1447.8 m to total depth at 1504.2 m:

Foraminifera: Hyperamminoides sp., Trochammina sp.

Ostracoda : Healdia sp., 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 (David, 1907) is in the Electricity Commission's Wallis Creek DDH 10. It consists of interbedded shale, sandstone, mudstone, coal seams, and claystone. The coal seams include the Big Ben Seams, 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 occur towards the southwest of the Hunter Valley. The Althorpe Claystone Member is a useful marker tuff bed. 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 named coal members consistently developed. 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 1 064.7 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 recognized by the presence of a thick white chertlike illite-rich claystone known as the Fairford Claystone Bed, which 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. This is overlain by the Woonona Coal Member consisting of 3 m of coal, shale, and tuff (Bowman, 1970). The upper levels consist of dark grey shale with sandstone lenses.

Interval 9 in the deep wells

Kirkham No. 1 (Raine, 1969)

	Thickness (m)
Lithic sandstone, becomes volcanolithic downwards; thin coal layers	27.5
Subgreywacke, volcanolithic, interbedded with carbonaceous siltstone and a little coaly mudstone, coal laminae, and seams which are thicker below 1 113 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 (Alcock, 1968)

	Thickness (m)
Shale, carbonaceous, interbedded with minor volcanolithic subgreywacke with 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, and carbonaceous matter. Chlorite, siderite, calcite cement	50.3

	Thickness (m)
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; four occurrences of intermediate to mafic volcanic rock between 384.3 m and 405.7 m and two more near base. Two 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; minor lithic conglomeratic 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 1 387 and 1 393 m	137.2

	Thickness (m)
Coal, black, shiny, and dull, 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 have been correlated on lithology. They all contain abundant coal and carbonaceous shale, and lie stratigraphically above the 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 Upper Permian in age; pollen of the *Dulhuntyispora* Assemblage indicate 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 II).

Dempsey Formation

The type section for the Dempsey Formation (David, 1907) is in the Buttai Syndicate 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 is chiefly shale, whilst sandstone predominates in the upper half. Britten (1971) 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 polymict 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 more conglomeratic toward the edge of the basin, and toward 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, which comprise quartz, quartzite, porphyry, and rarely slate, 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, and 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 slight coal	44.2
Total	60.9

Woronora No. 1 (Alcock, 1969)

	Thickness (m)
Siltstone, laminated, grading down into grey shale with interbeds of mudstone and quartz greywacke	61.0
Sandy siltstone, grading into very fine fragments of polymict sandstone with abundant plagioclase and fragments of volcanic rock. 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, subangular to subrounded, fine-grained, moderately well sorted. 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, numerous clasts of volcanic rock, interbedded with minor sandy siltstone	39.5
Total	85.2

Martindale No. 1 (Nicholas, 1969)

	Thickness (m)
Siltstone, carbonaceous, grading into fine-grained sandstone	27.4

	Thickness (m)
Claystone, grey and white, with thin layers of volcanic rock	6.1
Shale, carbonaceous, with siltstone and thin coal	12.2
Subgreywacke, volcanogenic, with a few thin interbeds of carbonaceous pyritic siltstone	33.5
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 either disconformably on the marine Shoalhaven Group or unconformably on middle Palaeozoic rocks of the Lachlan geosyncline.

The Higgins Creek Conglomerate rests either 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 richly coal-bearing 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 and 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, 1889) 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 conglomerates extend over areas of up to 200 km^2 in irregular lenticular sheets; several lenses commonly occur on the one stratigraphic horizon. The sheets appear to be alluvial fans, and are up to 85 m thick.

The pebbles are mostly chert and quartzite, but 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 from a stream source, have been delineated.

The most uniform of the clastic rocks are the tuff beds, which can be traced over considerable distances. The tuff has been largely altered to a claystone-like rock.

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)

Conglomerate (Belmont Conglomerate Member), with minor sandstone and shale (Croudace Bay Formation; McKenzie, 1962)	26
Sandstone, tuffaceous; 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)

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, tuff (Kotara Formation; McKenzie, 1962)	17
Total	115

Lambton Sub-Group (McKenzie, 1962)

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. Units within it are correlated with units 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, 1971)	3
Tuff with minor shale (Nalleen tuff; Britten, 1971)	5
Coal, tuff, and siltstone (Hobden Gully Seam; Britten, 1971)	23
Total	53

Doyles Creek Sub-Group (Britten, 1971)

Shale and tuff (Waterfall Gully Formation; Britten, 1971)	14
Tuff, sandstone, shale, siltstone; minor coal (Pinegrove Formation; Britten, 1971)	45
Total	59

Horseshoe Creek Sub-Group (Britten, 1971)

Coal and shale with minor tuffaceous sandstone and siltstone (Lucernia Seam; Britten, 1971)	18
Shale and interbedded sandstone, with minor tuffaceous claystone (Strathmore Formation; Britten, 1971)	20
Coal with minor siltstone and sandstone (Alcheringa Seam; Britten, 1971)	24
Sandstone with subordinate shale and minor tuff and coal (Clifford Formation; Britten, 1971)	61
Total	123

Apple Tree Flat Sub-Group (Britten, 1971)

Shale, carbonaceous, and coal (Stafford Seam; Britten, 1971)	3
Tuff (Monkey Place Creek Tuff Member) with sandstone and shale (Charlton Formation; Britten, 1971)	17
Shale, carbonaceous, and coal (Abbey Green Seam; Britten, 1971)	8
Total	28

These four sub-groups have been correlated (Britten, 1971) 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, 1969; Anon., 1969) in the Western Coalfield:

	Thickness (m) min.	max.
Coal (Katoomba Seam; Carne, 1903)	0.3	- 2.4
Shale, 'chert', 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', sandstone	6.0	- 9.0
Carbonaceous shale, coal, 'chert', oilshale (Middle River or Dirty Seam; McElroy, 1967)	2.0	- 13.0
Shale, carbonaceous shale, 'chert', sandstone, 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, 1969)	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, ironstone	12.0	- 31.0
Coal (Lidsdale Seam; Branagan, 1969)	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
<u>Total</u> (minimum and maximum possible)	33.9	-205.8

The following units have been described (Branagan, 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 (Burgagorang Claystone; McElroy, 1959)	3.0	- 12.0
Shale, sandstone, '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, polymict, in places slightly conglomeratic (Lacys Creek Sandstone; McElroy & Relph, 1969). 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 (minimum and maximum possible)	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. They consist of a sequence of sandstone, conglomerate, siltstone, shale, coal, and tuff lying conformably on the Berry Formation 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, 1877)	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 with minor coal (Hargrave Seam; Hanlon, 1956)	0.0 - 0.5
Sandstone and shale	0.0 - 6.0
Shale, carbonaceous, with 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 constitute the Eckersley Formation)	0.0 - 37.0
Coal, carbonaceous shale, and tuffaceous shale; in middle a cream-coloured tuff, 'the Sandstone Band' (Wongawilli Seam; Hanlon, 1956)	8.0 - 12.0
Sandstone, pale grey, medium-grained, polymict, with minor conglomerate, shale, siltstone, and coal lenticles near base (Kembla Sandstone; Hanlon, 1956)	12.0 - 24.0

Shale, carbonaceous, coal, 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, polymict, with carbonaceous specks (Darkes Forest Sandstone; Bowman, 1971)	9.0 - 24.0
Shale, dark grey, and minor siltstone (Bargo Claystone, Bowman; 1971)	14.0 - 28.0
Sandstone, grey, fine, polymict; weathers to white clay (Austinmeer Sandstone; Bowman, 1971)	1.0 - 6.0
Coal, shale, sandstone (Tongarra Seam; Harper, 1915)	1.0 - 6.0
Total (minimum and maximum possible)	72.7 -249.6

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, 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, 1968)

	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 rock	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, 1969)

	Thickness (m)
Subgreywacke, grey-brown, subangular to subrounded, medium to coarse-grained, moderately well sorted, with 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 at base, with illitic claystone	39.6
Total	158.4

Kulnura No. 1 (Ozimic, 1969)

	Thickness (m)
Lithic subgreywacke, 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
Lithic subgreywacke, as above, interbedded with subsidiary siltstone and probably 6 coal seams. Siliceous claystone (illite 45%, silica 40%) 45 m thick overlying basal coal seam	70.1
Total	152.4

Martindale No. 1A (Nicholas, 1969)

	Thickness (m)
Shale, dark grey, interbedded with polymict sandstone; volcanogenic subgreywacke; carbonaceous streaks; carbonate cement throughout	48.8
Mafic igneous rock with abundant chlorite, some hornblende, biotite, and altered olivine	48.8
Subgreywacke, volcanogenic	18.3
Shale, dark grey, carbonaceous	51.8
Coal and grey carbonaceous shale overlying sandy conglomerate containing black, green, and grey chert	12.2
Siltstone, carbonaceous, sideritic, with coal laminae	9.1
Claystone, pale grey and white	9.1
Shale, carbonaceous, with very thin layers of protoquartzite and probably 6 coal seams	33.5
Total	187.6

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, polymict, grey, unconsolidated, very fine to medium-grained, poorly sorted, angular to subrounded, with 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 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, polymict, 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, 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 unconformable 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 11 and are overlain by the Narrabeen Group.

Many plant fossils have been found in Interval 11. Wilson (1969) liest the following plants: Glossopteris browniana, Glossopteris indica, Glossopteris ampla, Glossopteris communis, Glossopteris verticillata, Glossopteris angustifolia var. taeniopteroides, Glossopteris conspicua, Glossopteris tortuosa, Glossopteris spathulato-cordata, Glossopteris jonesii, Glossopteris stipanicicci, Glossopteris linearis, Glossopteris 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, 1967) 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 strata (see Fig. 44) are of Permian age, but the major part 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 area, the southern central Area, and the western area (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 (Wilkinson, 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 with jasper pebbles, green and blue shale, sandstone	21.0
Conglomerate with jasper pebbles, 3 beds of greenish shale, 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, 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, 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

	Thickness (m)
Shale, chocolate	1.2
Shale, grey	1.8
Sandstone	3.4
Sandstone, shale, 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, 1969) 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

	Thickness (m)
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 Member, the Ourimbah Sandstone Member, and the Mangrove Sandstone Member at Wyong, but McDonnell (1969) described eight major sand units, from 12 to 45 m thick at Terrigal, separated from one another 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 sandstone, 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 Kildare a conglomerate-sand-silt-sand point-bar sequence is repeated thrice 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, conglomerate	3.7
Sandstone and conglomerate	3.7
Sandstone, shaly	3.7
Shale, chocolate	1.7

	Thickness (m)
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, 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, polymict	9.6
Siltstone, sideritic	27.5

	Thickness (m)
Sandstone (75%), fine-grained, polymict, interbedded with sideritic siltstone (25%)	57.2
Sandstone, medium-grained, polymict, poorly cemented; scattered quartz and chert pebbles	91.5
Total	190.0

Patonga Claystone

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

Tuggerah Formation

	Thickness (m)
Sandstone, fine-grained, polymict, 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, polymict, poorly sorted; coloured chert pebbles; sideritic, clayey. Minor layers of siltstone	243.4
Total thickness of Narabeen Group	652.0

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%); minor red-brown claystone. Sideritic	324.8
Siltstone, grey-grown, 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 sandstone beds, one of which is named the Otford Sandstone Member (Hanlon et al., 1953). There are also thin beds of conglomerate. Loughnan (1963) records that the Wombarra Shale contains 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) is on the coast between Coal Cliff and Clifton. It 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 several units within the Stanwell Park Claystone in the Metropolitan Colliery bore. The upper 22 m consists of red-brown claystone and clay breccia in which quartz is relatively dificient; residual volcanic textures are discernible. The lower 25 m consists predominantly of green-grey fine-grained lutite with subordinate greenish lithic sandstone and conglomerate in which quartz is abundant. Some pebbles show fluidal or trachytic fabrics.

In the older literature the Stanwell Park Claystone was variously 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 minor interbedded claystone. It has a banded appearance due to the weathering of soft layers. The type section, which is incomplete, is near Bulgo and Clifton and consists of:

	Thickness (m)
Sandstone, fine to medium-grained, light grey to pale reddish brown in places	2.5
Breccia, medium-grained	0.4
Sandstone, fine to medium-grained, light grey to pale reddish brown in places	0.7
Shale, reddish brown	·0.1
Sandstone, fine to medium-grained, light grey to pale reddish brown in places	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 in places	2.7
Shale, reddish brown	2.1
Sandstone, fine to medium-grained, light grey to pale reddish brown in places	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)	91.5 (approx)
Total	128.10(approx)

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 appear, under the microscope, to be tuffaceous. The type section, at Bald Hill north of Stanwell Park, consists of:

	Thickness (m)
Claystone, reddish brown; 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, reddish brown, fine-grained; 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 been referred to variously 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 showed that the formation thins to the east.

Garie Member of the Bald Hill Claystone

The Garie Member (Loughnan, 1969) consists of massive well crystallized kaolinite with minor 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 of the Garie Member is near Bulgo Headland at the top of the Bald Hill Claystone. It was given formation status by Bunny & Herbert (1971), 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:

	Thickness (m)
Sandstone, fine-grained, polymict; shows 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, polymict, indurated; honey-comb weathering	0.3
Shale, dark grey, rhythmically interbedded with fine-grained polymict 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, polymict, rhythmically interbedded with shale	0.9
Siltstone, grey	2.7
Sandstone, grey, coarse-grained, polymict	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 polymict silty protoquartzite	21.7
Claystone, chocolate, kaolinitic, pelletal, interbedded with minor subgreywacke	21.7
Protoquartzite, polymict, 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, 1968)

	Thickness (m)
Sandstone, polymict, very fine-grained, with very fine-grained protoquartzite	9.1
Shale interlaminated with siltstone; small amount of carbonaceous material	18.3
Claystone, red-brown; upper part oolitic. Minor layers of hard white claystone and grey shale	30.5
Orthoquartzite with minor layers of sandy siltstone. Chert clasts abundant	73.2
Sandstone, polymict, grey to red-brown; abundant clasts of red and green chert, claystone, iron oxide, and siderite	21.3
Orthoquartzite with minor layers of lutite; siderite and iron oxide	73.2
Protoquartzite with plentiful clasts of sedimentary rock, interbedded with grey and red-brown shale and minor siltstone	48.8
Orthoquartzite and protoquartzite with abundant red and green chert pebbles. Porosity moderate to high	30.5

	Thickness (m)
Subgreywacke, with abundant clasts of sedimentary rock, interbedded with shale and siltstone; calcareous cement	36.6
Subgreywacke, with abundant 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, 1970).

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 to 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 cms 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 Harley 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, 1970) 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. A continuous claystone layer in the middle of the formation has been used as a marker bed and informally named the Katoomba claystone member (Goodwin, 1970). The type section of the Burra-Moko Head Sandstone 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) occurs as a single bed of claystone, or as two closely spaced beds of claystone separated by a thin bed of sandstone. The claystone is commonly reddish brown, but ranges through mottled colours to light grey or white. It occurs between 102 m and 122 m above the base of the Sub-Group, which serves to distinguish it from the 'Katoomba claystone', which 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 shale layers are grey in the upper part, red-brown in the lower, and add a further 3.9 m to bring the total thickness of the formation to 112.8 m.

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		
Shale interbedded with sandstone layers towards top		16.4
Sandstone, flaggy; shale clasts		1.8
Shale, grey, with fine-grained sandstone		4.8
Claystone, red-brown		0.9
Total		106.0

The formation is entirely arenaceous at the western edge of 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

	Thickness (m)
Protoquartzite, medium-grained, with interbeds of siltstone. Clasts of coloured chert abundant; dawsonite, dolomite, and calcite present. Correlated with Caley Sub-Group	91.5
Total	654.2

Howes Swamp No. 1 (Esso, 1970)

Burralow Formation

	Thickness (m)
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

	Thickness (m)
Sandstone, buff, medium to coarse, subangular to angular; coloured clasts; poorly cemented with silica. Very small amount of siltstone	338.5

Caley Formation

	Thickness (m)
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 polymict conglomerate at the base is overlain by a polymict 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 are chiefly of volcanic rock, had a provenance in the northeast, that is, in New England. The quartz content came from the west, and 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. Quartz predominates in grains and pebbles. White clay matrix	44
Sandstone, conglomeratic. Numerous pebbles up to 1.5 cm across. Quartz predominates in both grains and pebbles. 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 with conglomeratic lenses. Red green and white pebbles of volcanic rock and quartz. Some ferruginous beds. White clayey matrix	8
Lithofacies A	
Conglomerate, pebbles up to 2.5 cm across. Pebbles of white volcanic rock, red and green aphanitic pebbles, pebbles of quartz, quartzite, and siltstone	24
Conglomerate, pebbles from 0.5 cm or less. Pebbles of white volcanic rock, red and green aphanitic pebbles, pebbles of 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 of these shales is the Bald Hill Claystone with its unique kaolinite lithology. It has been traced subsurface northwards to the claystone at Collaroy and westwards to the reddish shales of the Burralow Formation. Similarly the Menai Claystone of the northern Illawarra coast has been traced to the Mount York Claystone in the Blue Mountains, and the Stanwell Park Claystone has been traced to 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, Menai Claystone, and Mount York Claystone, 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 Fig. 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 possibly 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*, *Taeniopteris* sp., *Sphenopteris* sp., *Ginkgoites dilatata* var. *lata*, *Rhipidopsis ginkgoides*.

Arthropoda: *Estheria coghlani*

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 (1969) mentions the occurrence of *Dichroidium 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*, 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 Mulgoa No. 1 well, Crespin (1960) recorded Globochaeta and microscopic wheels and rods of echinodermatan holothurian sclerites at 553.7 m, 554.4 m, 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, Taeniopteris triassica, Taeniopteris undulata, Taeniopteris wianamattae, Sphenopteris alata, Dicroidium feistmanteli, Dicroidium lancifolium, Dicroidium narrabeenense, Dicroidium odontopteriodes, Hoegia sp., Odontopteroides dubia, Odontopteroides macrophylla, Carpolithus sp., cf. Beania sp. cf. Sphaereda sp., Bennettites (Williamsonia), flowers and stem, Ginkgoites sp., Baiera multifida (B. simmondsi), Rhipidopsis ginkgoides, Rhipidopsis narrabeenensis Rhipidopsis 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 Myriolepis latus Smith Woodward

Catopteridae: cf. Brookvalia spp.

Perleididae: Tripelta dubia (Smith Woodward), Chrotichthys gregarius (Smith Woodward), Pristosomus gracilis (Smith Woodward), Pristosomus latus Smith Woodward, Pristosomus crassus Smith Woodward, Zeuchthiscus australis (Smith Woodward)

Cleithroepidae: Cleithrolepis granulata Egerton, Cleithrolepis altus Smith Woodward,

Saurichthyidae: Saurichthys gigas Smith Woodward, Saurichthys 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 Paratosaurus 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 (1965, 1969), Branagan (1969), Conolly (1969), 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 & Goulding (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 commonest), 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 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 slump phenomena.

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 the Hawkesbury sediments to have been deposited by a fluvial system originating in the far southwest, Branagan (1969) envisages a fluviodeltaic environment, and Conolly (1969) favours a hypothesis involving the operation of waves and tides on a delta.

<u>Hawkesbury Sandstone in the deep wells</u>

<u>Kirkham No. 1</u> (Raine, 1969)

	Thickness (m)
Orthoquartzite, light grey, very fine to fine-grained, grading into brownish black sideritic micaceous siltstone	6.1

	Thickness (m)
Orthoquartzite, light grey, coarse-grained, with minor interbeds of dark sideritic siltstone. Kaolinite and quartz-overgrowth cement; 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, Alma G., 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, polymict, 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
type x (as above)	21.4
" y "	9.2
" x "	7.6
" y "	4.6
" x "	18.3
" y "	4.6
" x "	4.6
" y "	6.1
" x "	3.1
" y "	7.6
" x "	4.6
" y "	3.1
" x "	6.1
" y "	6.1
" 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), polymict, 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

Correlation of sandstone occurrences is difficult in the southern, western, and northwestern areas where the thick sandstone beds of the Narrabeen Group, whose claystone and siltstone interbeds tend to pinch out towards the margin of the basin (Galloway, 1967; Dickson, 1969), resemble the Hawkesbury Sandstone.

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) wiana mattae, T. (Macrotaeniopteris) sp., Dicroidium odontopteriodes, Dicroidium 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 (2spp.), Agecephalichthys, Megapteriscus, Belichthys (3 spp.), Leptogenichthys, Mesembroniscus; Catopteridae: Brookvalia (3 spp.), Beaconia, Dictyopleurichthys, Geintonichthys, Molybdichthys, Phlyctaenichthys, Schizurichthys; Perleididae: Manliella, Procheirichthys; Cleithrolepidae: Cleithrolepis (2 spp.); Saurichthyidae: Saurichthys (2 spp.); Pholidopleuridae: Macrouephes (2 spp.); Semionotidae: Promecosimina, and 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 (1969) described footprints of stereospondylous amphibians resembling Platyceps or Paracyclatosaurus.

Tillyard (1925) and McKeown (1937) have described a number of arthropods, many from Brookvale. These 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 ostracod Estheria, and the conchostracan 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. Lovering 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) gave 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 sideritic mudstone and siltstone bands. There is an increase in sand content 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. It 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) as incertae sedis. It was one or other of the four major sandstone bodies within the Bringelly Shale.

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. It 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 Annan Shale (Lovering, 1954) has its type section on the Hume Highway on the south side of the Razorback Range. It is about 10 m thick and consists of dark shale with lenses of greywacke-type sandstone. Iron oxide nodules and plant debris are common.

Razorback Sandstone

The Razorback Sandstone (Lovering, 1954) has its type section along the Hume Highway on the north side of the Razorback Range. It 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 section consisting of massive sandstone 6 to 18 m thick. The cross-bedding in the massive 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. Grey-green shale with greywacke-type sandstone lenses form the lower part, and a massive sandstone caps Mount Prudhoe.

Relations with Older Units

The Mittagong Formation, the basal formation of the Wianamatta Group, is generally conformable on the Hawkesbury Sandstone. Its black shale is very similar both to the black shale of the underlying Hawkesbury Sandstone and the overlying Ashfield Shale, and for this reason it was formerly known as the Passage Beds.

The sandstone lenses, however, are finer-grained than the Hawkesbury Sandstone, and almost always somewhat calcareous. An irregular erosional relationship probably exists in some areas.

Correlations and Age

Many fossils have been found in the Wianamatta rocks, especially the Ashfield Shale, and the total 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*, *Unio 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*, *Elonichthys semilineatus*, *Myriolepis pectinatus*, *Elpisopholis dunstani*, *Platysomus* sp., *Acentrophorus* sp., *Palaeoniscus antipodeus*, *Semionotus formosus*, *Cleithrolepis granulatus*, 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 basal Ashfield Shale.

Lovering & McElroy (1969) listed the following plants from the Ashfield Shale: *Phyllotheca australis*, *Cladophlebis australis*, *Gleichenia (?) dubia*, *Microtaeniopteris wianamattae*, *Sphenopteris* sp., *Decroidium odontopteroides*, *Dicroidium 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*, and *Mastodonosaurus*, *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 as having been described by McCoy (1847) probably 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 older than Lower Jurassic.

INDEX OF ROCK UNIT NAMES

Rock Unit	Stratigraphic Position	Age	Area	Interval
Allandale Formation	middle of Dalwood Gp	Sakmarian	Lochinvar Anticline, Hunter Valley	1
Allans Creek Formation	Illawarra Coal Measures	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
Ashfield Shale	at, or near, base of Wianamatta Gp	Triassic (Scythian-Anisian)	Central Area	14
Bald Hill Claystone	near top of Narrabeen Gp	L. Triassic (Scythian)	south-Central Area	12
Banks Wall Sandstone	top of Grose Sub-Gp (= Grose Sst) in Narrabeen Gp	L. Triassic (Scythian)	Western Area	12
Beauchamp Falls Shale	base of Narrabeen Gp	u. Tatarian	Western Area	12
Berry Formation	top of Shoalhaven Gp	Kazanian	southern half of Sydney Basin	6
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
Budgong Sandstone	base of Illawarra Coal Measures	l. Tatarian	Southern Coalfield	7
Bulgo Sandstone	middle of Narrabeen Gp	L. Triassic (Scythian)	south-Central Area	12

Rock Unit	Stratigraphic Position	Age	Area	Interval
Bulli Seam	top of Illawarra Coal Measures	Tatarian	Southern Coalfield	11
Burnamwood Formation	Wittingham Coal Measures	Tatarian	upper and middle Hunter Valley	9
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
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
Cardiff Sub-Group	middle of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Cessnock Sandstone	basal member of Branxton Fm, conformable on Greta Coal Measures	u. Artinskian	lower and middle Hunter Valley	4
Charbon Sub-Group	upper part of Illawarra Coal Measures	mid-Tatarian	Western Coalfield	10, 11
Clifton Sub-Group	three lowest formations of Narrabeen Gp	L. Triassic (Scythian)	mid-Central Area	12
Clwydd Sandstone	near base of Caley Sub-Gp of Narrabeen Gp	near top of Tatarian	Western Area	12
Clyde Coal Measures	base of Conjola Sub-Gp of Shoalhaven Gp	Sakmarian	Clyde R. in far south of Sydney Basin	1
Coal Cliff Sandstone	base of Narrabeen Gp	uppermost Tatarian	south-Central Area	12
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 the Illawarra Coal Measures	Tatarian	Western Area	8

Rock Unit	Stratigraphic Position	Age	Area	Interval
Cumberland Sub-Group	lower Illawarra Coal Measures	Tatarian	Central Area	7, 8
Dalwood Group	above Kuttung Gp	Sakmarian	Hunter Valley	1, 2
Dempsey Beds	top of Tomago Coal Measures	Tatarian	lower Hunter Valley	10
Doyles Creek Sub-Group	Wollombi Coal Measures	u. Tatarian	middle Hunter Valley	11
Eckersley Formation	upper part of Illawarra Coal Measures	Tatarian	Southern Coalfield	11
Erins Vale Formation	in lower Illawarra Coal Measures	l. Tatarian	Southern Coalfield	8
Farley Formation	top of Dalwood Gp	Sakmarian	Hunter Valley	2
Fenestella Zone (=*Fenestella* Shale)	within the Branxton Fm	Artinskian-Kungurian	lower and middle Hunter Valley	4
Four Mile Creek Formation	Tomago Coal Measures	Tatarian	lower Hunter Valley	9
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
Govetts Leap Sandstone	in Caley Sub-Gp of Narrabeen Gp	near top of Tatarian	Western Area	12
Grose Sub-Group (=Grose Sandstone)	middle of Narrabeen Gp	L. Triassic (Scythian)	Western Area	12
Greta Coal Measures	above Dalwood Gp, below Branxton Fm	m. Sakmarian to u. Artinskian	Hunter Valley	3
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
Hartley Vale Claystone	top of Caley Sub-Gp in Narrabeen Gp	on Permo-Triassic boundary	Western Area	12

Rock Unit	Stratigraphic Position	Age	Area	Interval
Hawkesbury Sandstone	above Narrabeen Gp and below Wianamatta Gp	Triassic (Scythian and/ or Anisian)	Sydney Basin	13
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-Shoalhaven Gps and below Narrabeen Gp	Tatarian	Central, Western, and Southern Areas	7-11
Katoomba Claystone Member	middle of Burra-Moko Head Sst in Grose Sub-Gp in 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
Kitchener Formation	in upper Greta Coal Measures	l. Artinskian	lower Hunter Valley	3
Kulnura Marine Tongue	in Erins Vale Fm of lower part of Illawarra Coal Measures	Tatarian	east half of Sydney Basin	8
Kurri Kurri Conglomerate	in Greta Coal Measures	l. Artinskian	lower Hunter Valley	3
Lambton Sub-Group	base of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	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
Maitland Group	conformable on Greta Coal Measures, and below Singleton Coal Measures	Kungurian-u. Kazanian	Hunter Valley	4-6

Rock Unit	Stratigraphic Position	Age	Area	Interval
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 to l. Kazanian	Western Area	1-6
Menai Claystone Member	middle of Bulgo Sst in Narrabeen Gp	L. Triassic (Scythian)	south-Central Area	12
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
Moon Island Beach Sub-Group	top of Newcastle Coal Measures	u. Tatarian	lower Hunter Valley	11
Mount Marsden Claystone (=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 in 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

Rock Unit	Stratigraphic Position	Age	Area	Interval
Narrabeen Group	above youngest Tatarian coal measures	latest Permian (Tatarian)- L. Triassic (Scythian)	Sydney Basin	12
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
Nowra Sandstone	in upper part of Shoalhaven Gp	l. Kazanian	southern half of Sydney 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
Pebbley Beach Formation	middle of Conjola Sub-Gp of Shoalhaven Gp	u. Sakmarian l. Artinskian	southern part of Southern Area	2
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
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
Razorback Sandstone	in Camden Sub-Gp of Wianamatta Gp	M. Triassic (Anisian)	southwest-Central Area	14

Rock Unit	Stratigraphic Position	Age	Area	Interval
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
Shoalhaven Group	unconformable on lower and middle Palaeozoic, conformable beneath Illawarra Coal Measures	l. Sakmarian to u. Kazanian	southern half of Sydney Basin	1-6
Singleton Coal Measures	above Mulbring Sltst and beneath Narrabeen Gp	Tatarian	middle and upper Hunter Valley	7-11
Skeletar Formation	top of Dalwood Gp (this Record) or base Greta Coal Measures (see Appendix 1)	early Sakmarien	upper Hunter Valley	1
Snapper Point Formation	upper part of Conjola Sub-Gp	m. Artin-skian	southern part of Southern Area	3
Stanwell Park Claystone	near middle of Narrabeen Gp	base of Triassic (Scythian)	south-Central Area	12
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 Clyde R. Coalfield	1
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

Rock Unit	Stratigraphic Position	Age	Area	Interval
Ulladulla Mudstones	near base of Wandrawandian Sltst	Artinskian	southern part of Southern Area	4
Undola Sandstone Member	base of top of Gosford Fm, below Hawkesbury Sst	L. Triassic (Scythian)	south of Botany Bay, Central Area	13
Vane Formation	in lower part of Wittingham Coal Measures	Tatarian	middle and upper Hunter Valley	7, 8
Victoria Pass Sandstone	middle of Caley Sub-Gp of Narrabeen Gp	u. Tatarian	Western Area	12
Wallarah Seam	top of Newcastle Coal Measures	Tatarian	lower Hunter Valley	11
Wandrawandian Siltstone	middle of Shoalhaven Gp	Artinskian-Kungurian	southern half of Sydney Basin	4
Waratah Sandstone	base of Newcastle Coal Measures	Tatarian	lower Hunter Valley	10
Wasp Head Formation	base of Conjola Sub-Gp of Shoalhaven Gp	l. Sakmarian	southern part of Southern Area	1
Wilton Formation	Illawarra Coal Measures	m. Tatarian	Southern Coalfield	10, 9
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
Wongallee Sandstone	base of Wollombi Coal Measures	Tatarian	middle Hunter Valley	10
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

INDEX OF GEOGRAPHICAL PLACE NAMES

(Not all names mentioned are necessarily marked on the map)

Name	Latitude	Longitude
Allandale	32°43'S	151°25'E
America Creek	34°27'S	150°49'E
Ashfield	33°53'S	151°07'E
Avalon	33°38'S	151°20'E
Avondale	34°30'S	150°43'E
Bald Mountain	32°41'S	150°01'E
Bargo	34°18'S	150°35'E
Barraba	30°23'S	150°36'E
Barrigan	32°28'S	149°59'E
Bawley Point	35°31'S	150°23'E
Bayswater	32°25'S	151°02'E
Beauchamp Falls	33°39'30"S	150°20'E
Bilpin	33°30'S	150°32'E
Botany Bay	33°58'S	151°12'E
Bocable	32°48'S	149°45'E
Botany Bay	33°58'S	151°10'E
Bow Wow Gorge	32°56'S	151°26'E
Branxton	32°40'S	151°22'E
Bringelly	33°56'S	150°44'E
Brake	32°45'S	151°06'E
Broken Bay	33°33'S	151°18'E
Brokenback Range	32°48'S	151°14'E
Brookvale	33°45'S	151°15'E
Budawang Creek	35°13'S	150°10'E
Bulgo	34°07'S	151°01'E
Bulli	34°20'S	150°55'E
Bunnair Creek	35°14'S	150°23'E
Burra Moko Head	33°35'S	150°20'E
Burragorang	34°04'S	147°38'E
Burralow Creek	33°37'S	150°40'E
Bylong	32°20'S	150°07'E
Cambewarra Range	34°47'S	150°36'E
Capertee	33°09'S	149°59'E

Clifton	34°15'S	150°58'E
Clyde River	35°43'S	150°12'E
Coal Cliff	34°15'S	150°59'E
Colo River	33°26'S	150°53'E
Coolah	31°50'S	149°52'E
Corang	35°12'S	150°01'E
Cordeaux	34°22'S	150°45'E
Coricudgy	32°49'S	150°21'E
Crampton Island	35°27'S	150°25'E
Cranky Corner	32°32'S	151°24'E
Currumbene	34°58'S	150°39'E
Dairy Mountain	32°43'S	150°03'E
Darkes Forest	34°14'S	150°55'E
Denman	32°23'S	150°41'E
Drakes Forest	29°58'S	150°45'E
Dundas	32°24'S	121°46'E
Durras	35°40'S	150°18'E
Endrick River	35°00'S	150°03'E
Erskine Park	33°49'S	150°47'E
Falls Creek	34°58'S	150°36'E
Farley	32°44'S	151°31'E
Garie Beach	34°10'S	151°04'E
Gingenbullen	34°32'S	150°19'E
Girvan	32°28'S	152°04'E
Glen Alice	33°03'S	150°10'E
Glen Davis	33°07'S	150°17'E
Good Dog Mountain	34°49'S	150°35'E
Gosford	33°26'S	151°21'E
Gosforth	32°40'S	151°29'E
Grose River	33°36'S	150°41'E
Greta	32°42'S	151°23'E
Growee Creek	32°25'S	150°07'E
Gundangaroo	33°07'S	150°13'E

Hartley Vale	33°32'S	150°14'E
Hawkesbury Lookout	33°39'S	150°39'E
Hornsby	33°42'S	151°06'E
Howick	32°28'S	150°57'E
Illawarra	34°30'S	150°30'E
Jerrys Plains	32°30'S	160°55'E
Jervis Bay	35°05'S	150°45'E
Kandos	32°51'S	149°58'E
Kedumba Creek	33°51'S	150°20'E
Kiama	34°41'S	150°52'E
Kildare	34°12'S	147°03'E
Lake Illawarra	34°32'S	150°50'E
Landslide Creek	35°19'S	150°16'E
Little Forest Creek	35°17'S	150°22'E
Lochinvar	32°43'S	157°27'E
Marrangaroo	33°26'S	150°07'E
Medowie	32°44'S	151°52'E
Megalong	33°44'S	150°15'E
Milton	35°19'S	150°26'E
Minchinbury	33°47'S	150°49'E
Mindaribba	32°40'S	151°35'E
Mittagong	34°27'S	150°27'E
Mona Vale	33°40'S	151°18'E
Moss Vale	34°33'S	150°23'E
Mount Banks	33°35'S	150°23'E
Mount Bright	32°50'S	151°17'E
Mount Caley	33°36'S	150°26'E
Mount Coricudgy	32°50'S	150°22'E
Mount Danger	32°21'S	150°28'E
Mount David	32°34'S	150°02'E
Mount Dromedary	32°44'S	145°53'E
Mount Flora	34°22'S	150°27'E
Mount Gibraltar	34°28'S	150°26'E

Mount Hay	35°58'S	147°58'E
Mount Jellore	34°23'S	150°23'E
Mount Kendarun	32°49'S	150°41'E
Mount Marsden	32°57'S	150°03'E
Mount Molong	33°06'S	150°26'E
Mount Murray	35°42'S	148°47'E
Mount Muruin	34°08'S	150°02'E
Mount Prudhoe	see Razorback Range	
Mount Stormey	32°31'S	150°03'E
Mount Tomah	33°32'S	150°21'E
Mount Tootie	33°27'S	150°31'E
Mount Wilson	33°30'S	150°24'E
Mount York	33°33'S	150°13'E
Mulbring	32°54'S	151°29'E
Mulgoa	33°50'S	150°40'E
Muswellbrook	32°16'S	150°54'E
Myall Range	32°59'S	151°20'E
Narrabeen	33°39'S	151°17'E
Nattai River	34°05'S	150°25'E
Nebo	34°15'S	150°52'E
Nerriga	35°07'S	130°05'E
Nowra	34°53'S	150°36'E
Nullo Mountain	32°43'S	150°14'E
Oakdale	34°05'S	150°31'E
O'Hara Head	35°34'S	150°23'E
Paterson	32°36'S	151°36'E
Peats Ridge	33°20'S	150°11'E
Picton	34°11'S	150°36'E
Pigeon House Mountain	35°21'S	150°15'E
Plumpton	33°45'S	150°51'E
Pointers Gap	35°17'S	150°21'E
Pokolbin	32°48'S	151°17'E
Port Jackson	33°51'S	151°16'E
Port Kembla	32°28'S	150°54'E
Port Stephens	32°42'S	152°10'E
Potts Hill	33°54'S	151°02'E
Prospect	33°49'S	150°54'E

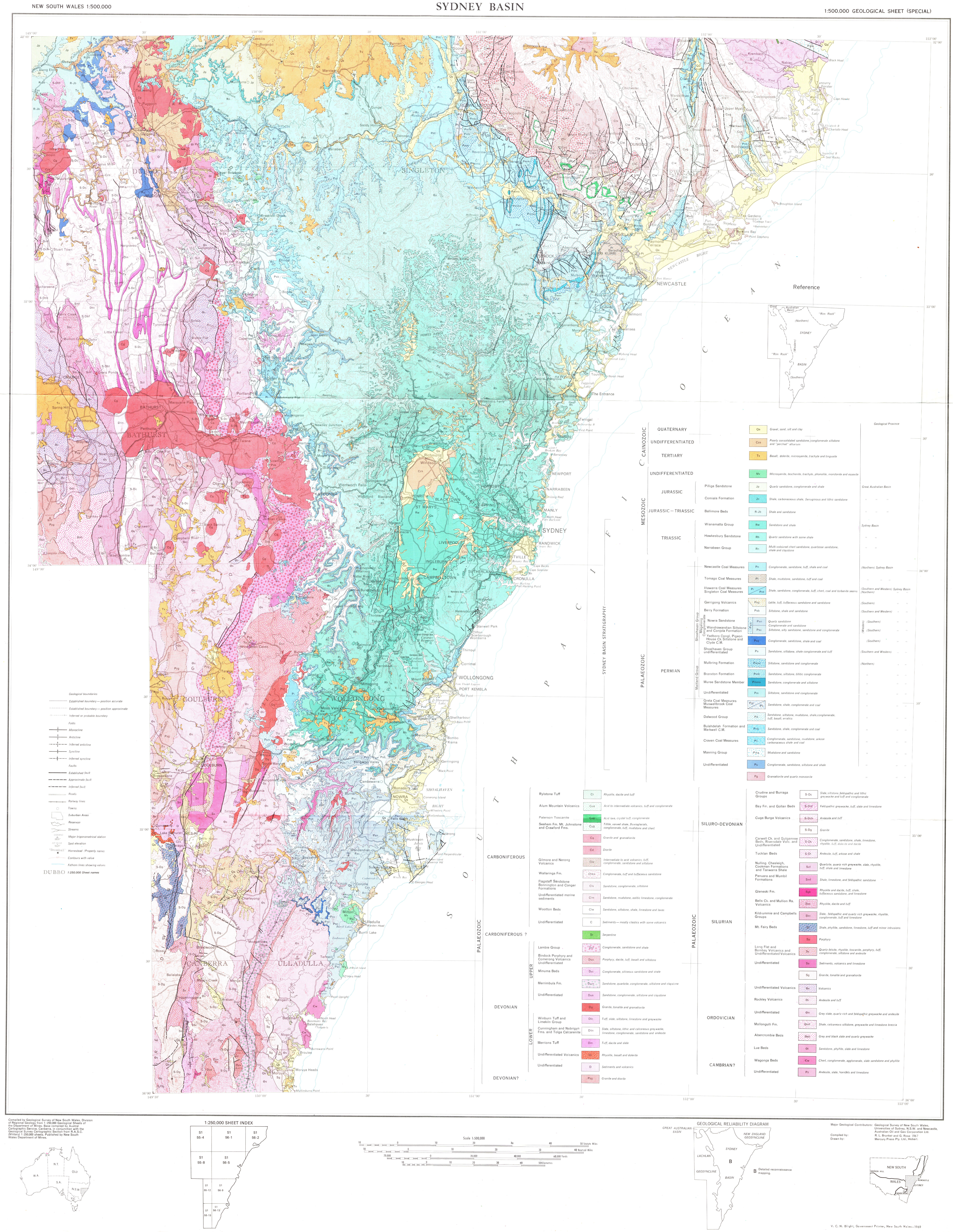
Putty	32°57'S	150°40'E
Pebbley Beach	35°37'S	150°20'E
Quilties Mountain	35°07'S	150°09'E
Raymond Terrace	32°46'S	151°45'E
Razorback Range	34°08'S	150°36'E
Reedy Creek	33°3'S	150°13'30"E
Reedy Creek	33°48'S	150°23'E
Richmond	33°36'S	150°46'E
Rixons Pass	34°21'S	150°53'E
Rylstone	32°48'S	149°58'E
Saint Peters	33°53'S	151°12'E
Sassafras	35°06'S	150°15'E
Savoy Trig	32°22'S	150°51'E
Scone	32°05'S	150°41'E
Singleton	32°24'S	151°11'E
Snapper Point	35°34'S	150°22'E
Stanwell Park	34°14'S	150°59'E
Tallaterang	35°19'S	150°19'E
Tallong	34°43'S	150°05'E
Terrigal	33°27'S	151°27'E
The Basin	33°52'S	150°37'E
The Castle	35°18'S	150°13'E
The Peak	35°18'S	150°06'E
The Pinnacle	33°40'S	147°57'E
The Porcupine	32°32'S	150°00'E
Tillynambulan	34°32'S	150°19'E
Tonbong	32°42'S	149°57'E
Tuggerah	33°19'S	151°25'E
Ulan	32°17'S	149°44'E
Ulladulla	35°21'S	150°28'E
Umbiella Creek	33°04'S	150°10'E
Undola	34°13'S	150°59'E
Upper Colo	33°25'S	150°44'E

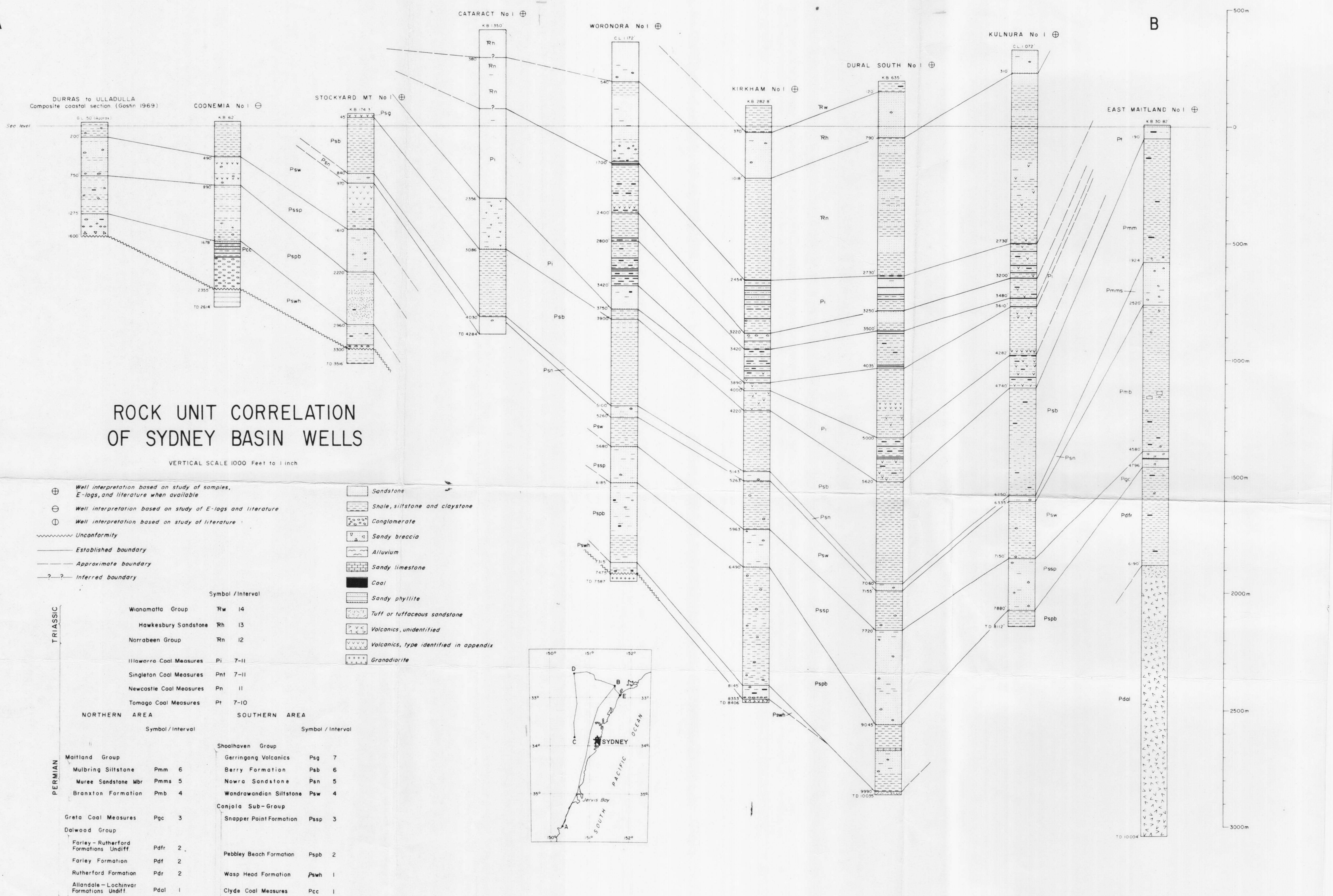
Victoria Pass	33°35'S	150°15'E
Wallacia	33°53'S	150°39'E
Wallawalong	33°03'S	151°16'E
Wallaya	34°42'S	150°38'E
Wallerawang	32°25'S	150°04'E
Wandandian Creek	35°06'S	150°29'E
Wasp Head	35°40'S	150°18'E
Werombi	33°59'S	150°35'E
West Maitland	32°44'S	151°33'E
Wingella	34°42'S	150°10'E
Wingen	31°53'S	150°53'E
Wollar	32°21'S	149°57'E
Wollondilly River	33°57'S	150°26'E
Wyong	33°17'S	151°21'E
Yadboro	35°19'S	150°14'E
Yallah	34°32'S	150°47'E
Yalwal Creek	34°56'S	150°24'E
Yerranderie	34°07'S	150°13'E

NEW SOUTH WALES 1:500,000

SYDNEY BASIN

1:500,000 GEOLOGICAL SHEET (SPECIAL)



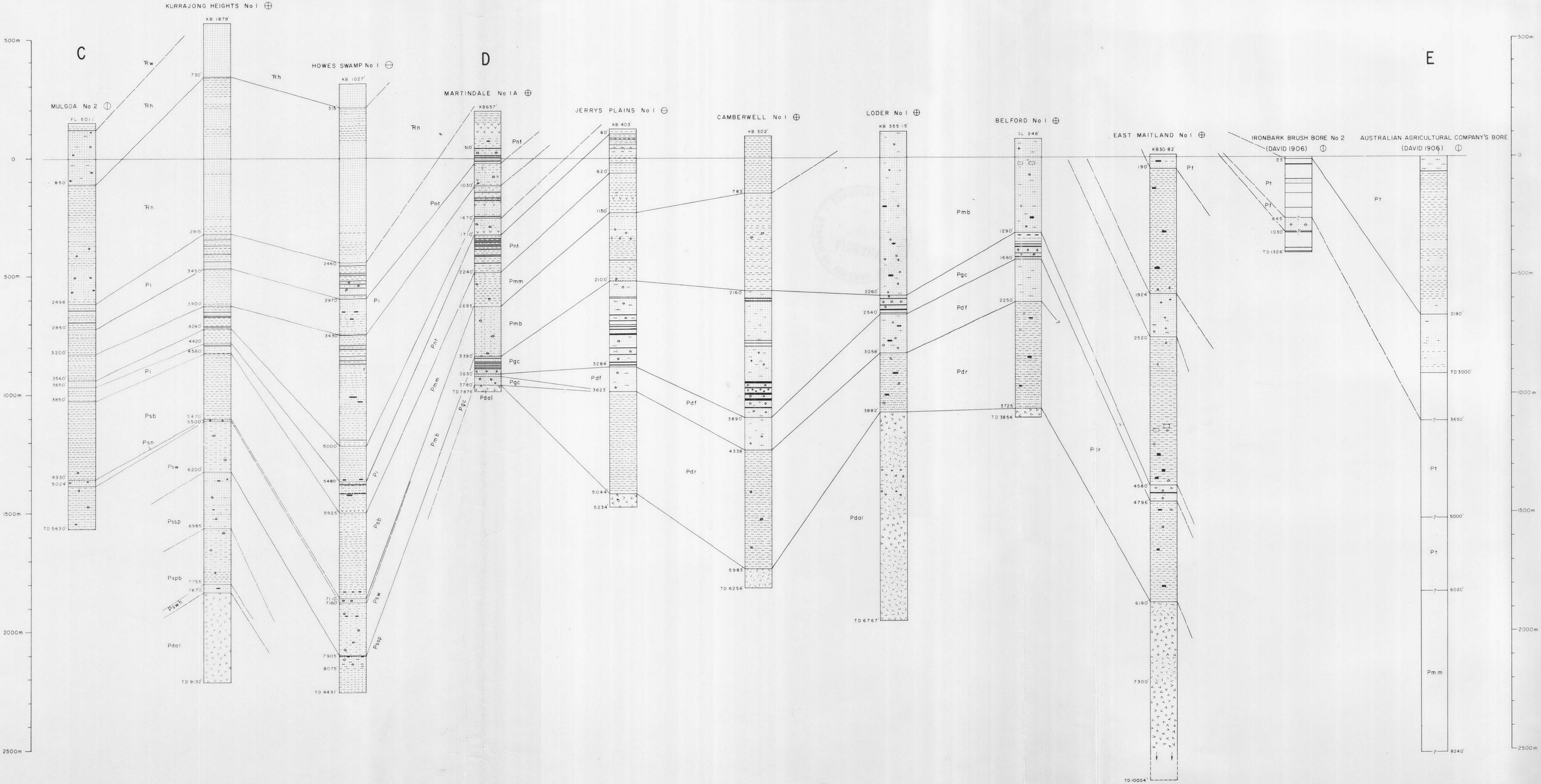


ROCK UNIT CORRELATION OF SYDNEY BASIN WELLS

VERTICAL SCALE 1000 Feet to 1 inch

ROCK UNIT CORRELATION OF SYDNEY BASIN WELLS

VERTICAL SCALE 1000 Feet to 1 Inch



To accompany Record No 1972/76

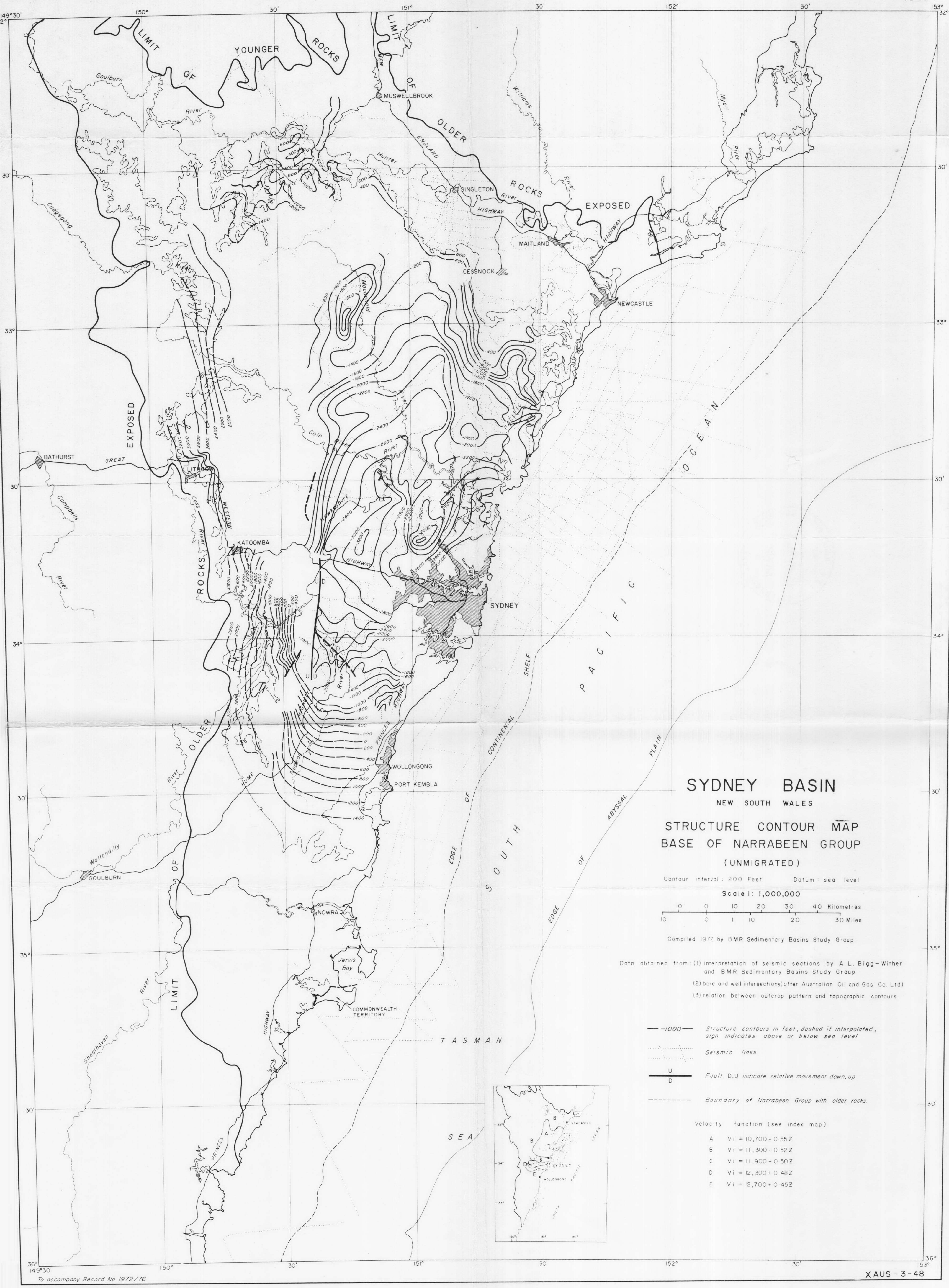
PLATE 5

To accompany Record No 1972/76

PLATE 6

To accompany Record No.1972/76

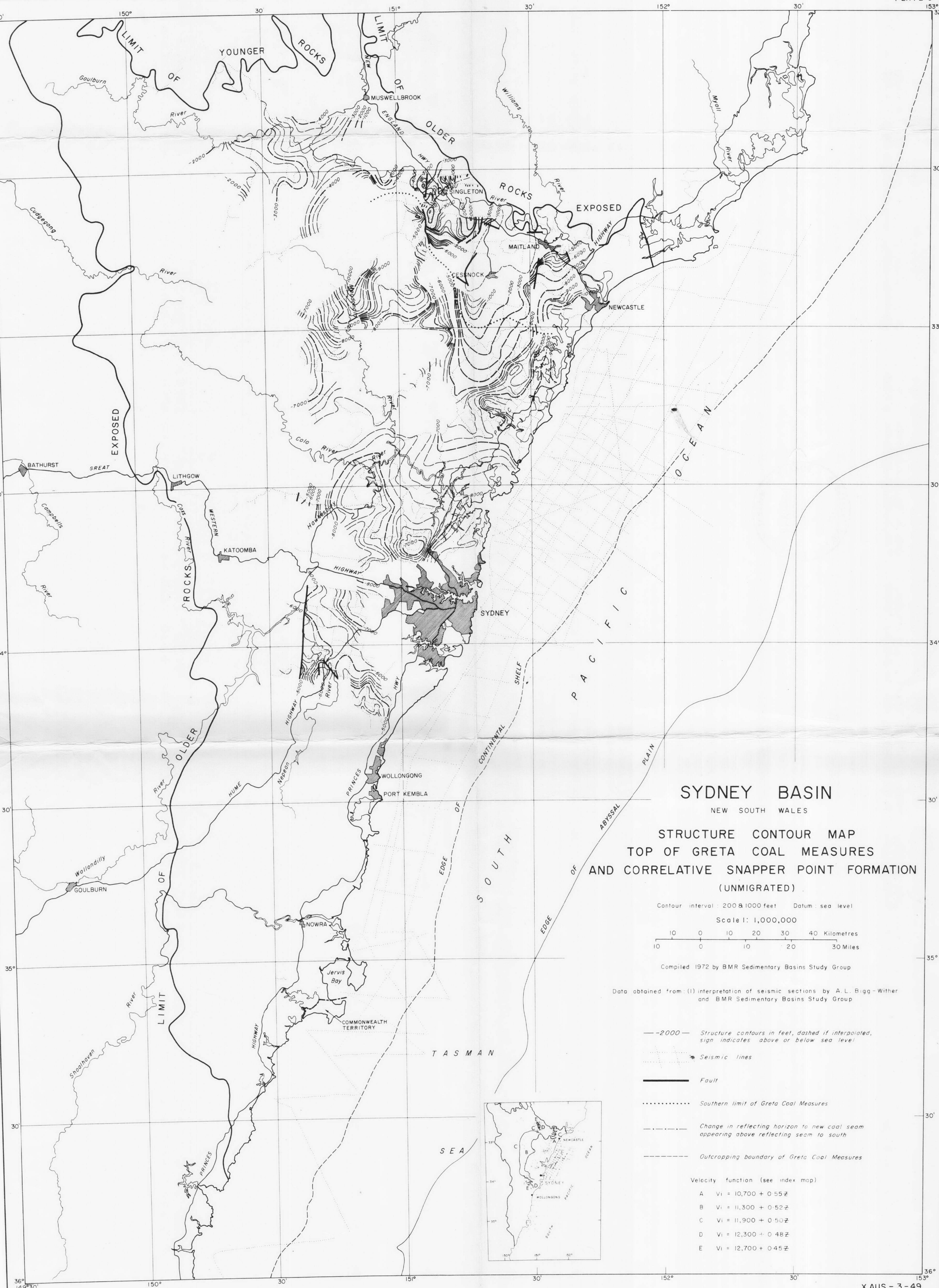
PLATE 7



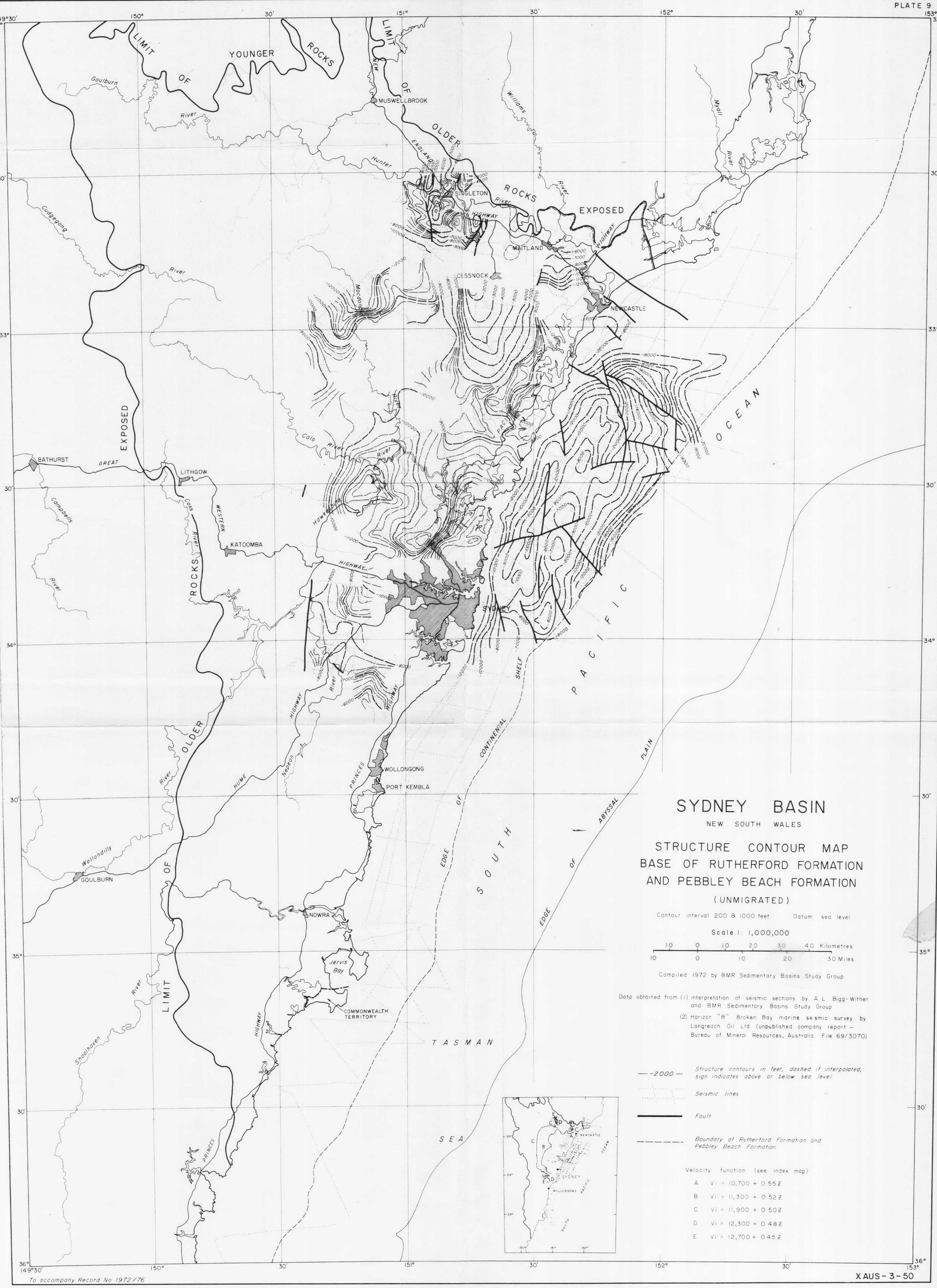
To accompany Record No 1972/76

XAUS-3-48

PLATE 8



To accompany Record No 1972/76


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
SOUTH
EDGE OF CONTINENTAL SHELF
EDGE OF ABYSSAL PLAIN