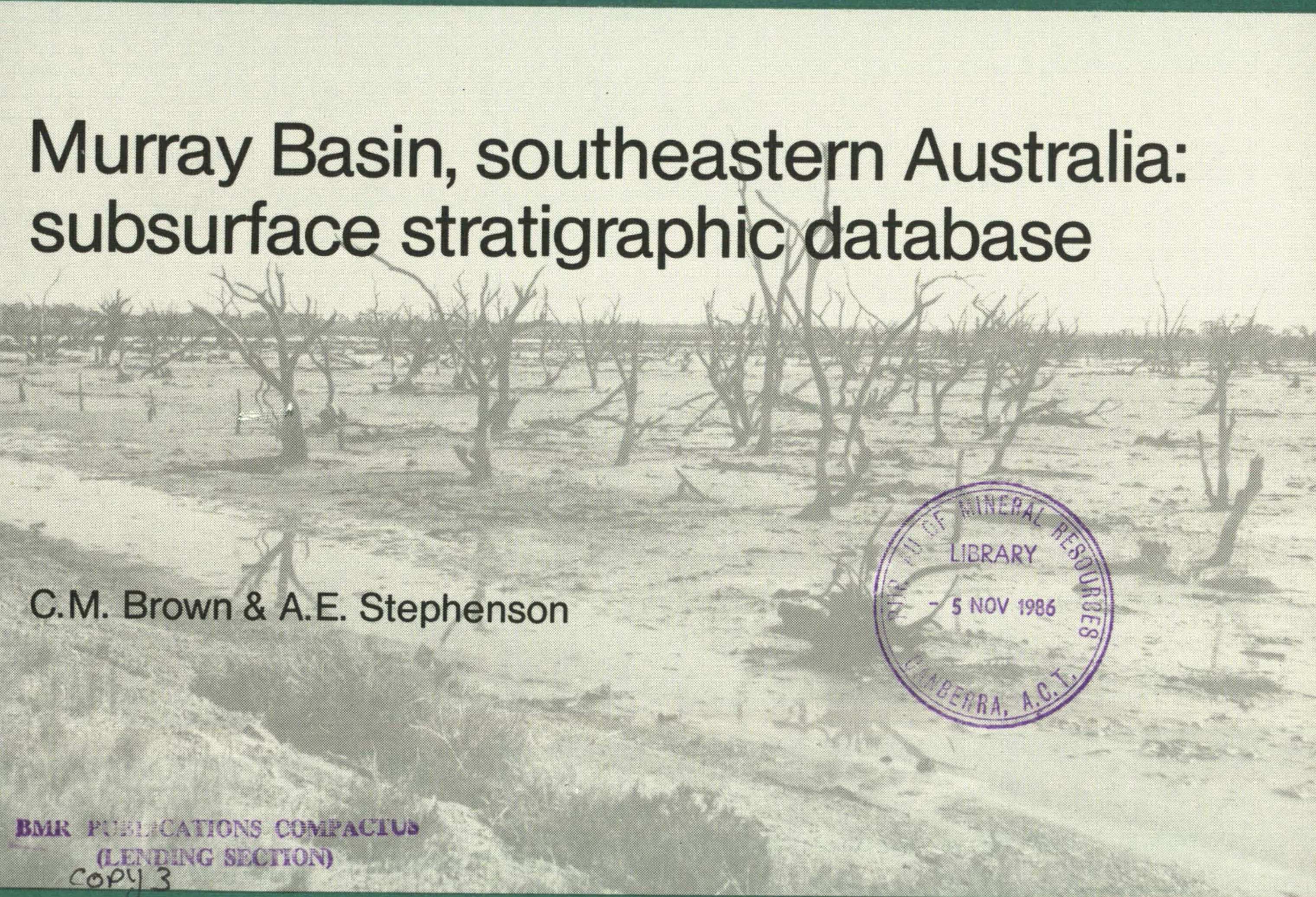
AUSTRALIA

Report 262

Murray Basin, southeastern Australia: subsurface stratigraphic database



C.M. Brown & A.E. Stephenson

Bureau of Mineral Resources, Geology & Geophysics

Department of Resources and Energy

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

REPORT 262

MURRAY BASIN, SOUTHEASTERN AUSTRALIA:
SUBSURFACE STRATIGRAPHIC DATABASE

Compiled

by

C.M. Brown & A.E. Stephenson

Division of Continental Geology

Prepared as a contribution to the joint Commonwealth and State
Murray Basin Hydrogeological Project

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ABSTRACT

This Report, including the accompanying microform appendices, documents the interpreted downhole stratigraphy of 3000 boreholes drilled into the Cainozoic succession of the Murray Basin, an important groundwater basin which underlies 320 000 km^2 of the semi-arid zone of southeastern Australia. The compilation has been prepared as a contribution to the Murray Basin Hydrogeological Project, a long-term study which is being undertaken by the Division of Continental Geology in conjunction with participating State geological surveys and water authorities.

A major objective of the hydrogeological project has been to establish a basin-wide stratigraphic framework by documenting the regional distribution, geometry, and depositional environments of the Tertiary stratigraphic units and major aquifers of the basin. For this purpose, interpretations of borehole stratigraphy were entered into a microcomputer database, established to facilitate the preparation of subsurface maps depicting concealed geology and aquifer geometry in the Murray Basin. Though emphasis has been placed on documenting the distribution of Cainozoic stratigraphic units, information about the underlying pre-Cainozoic units (Precambrian basement and Adelaidean to Lower Carboniferous sedimentary rocks overlain by thin discontinuous remnants of Permian, Triassic, and Cretaceous rocks preserved in poorly defined basins) derived from borelogs has also been entered into the database. The database can be accessed using a number of retrieval strategies, which allow sorting and extraction of data specific to a particular map sheet, stratigraphic unit, or regional aquifer. The major datasets which were generated are tabulated in the accompanying microform appendices.

We have taken the opportunity to critically assess the reliability of borehole data in terms of distribution, accuracy of locations and elevations, and quality of drillers' logs, and have highlighted those areas where we believe our stratigraphic interpretations could be improved by future investigations.

INTRODUCTION

This Report and the accompanying microform appendices document the interpreted downhole stratigraphy of 3000 boreholes drilled into the Cainozoic succession of the Murray Basin, an important groundwater basin located in the semi-arid zone of southeastern Australia (Fig.1). The compilation has been prepared as a contribution to the Murray Basin Hydrogeological Project, a long-term basin-wide study which is being undertaken by BMR in collaboration with the Geological Surveys of South Australia, Victoria, and New South Wales, and with the Water Resources Commission of New South Wales and the Rural Water Commission of Victoria. The primary aim of the hydrogeological project is to improve the understanding of the groundwater regime of the Cainozoic succession of the basin by examining it as a single entity, unencumbered by State boundaries. Since a knowledge of the geology of the basin is basic to the understanding of groundwater occurrence, a geological study of the Murray Basin was considered to be an essential prerequisite to the hydrogeological study. A major objective of the geological synthesis has been to establish a basin-wide subsurface stratigraphic framework by documenting the regional distribution, geometry, and depositional environments of the Tertiary stratigraphic units and major aquifers of the basin. The geological surveys and water authorities in each of the three States have undertaken extensive investigations of groundwater occurrence, but no basin-wide study has previously been attempted. The results of the systematic compilation of borehole data are summarised in the accompanying microform appendices, which record downhole stratigraphy, distribution of stratigraphic units and aquifers, and borehole localities. Brief summaries of both the regional geology and individual stratigraphic units are presented herein, but detailed descriptions and other aspects of the geological synthesis are reported elsewhere, in companion publications produced for the Murray Basin Hydrogeological Project (Brown, Jackson & others, 1982; Brown, 1983, 1985; Brown & Stephenson, 1985, in preparation).

Fig.1. Locality map

Interpretations of borehole stratigraphy were entered into a microcomputer database, from which the data contained in the accompanying microform appendices were derived. These provide a datasource of subsurface stratigraphic information, possibly unequalled in any other shallow sedimentary basin of similar size in Australia. We have used the borehole information to prepare subsurface maps and to develop an understanding of the concealed geology of the basin (Brown & Stephenson, in preparation), but much remains that may be achieved by use of this material. We are thus publishing the data for use by other workers in the Murray Basin - in fields such as hydrogeology - and for future, more detailed geological research. We have also documented the data in order to allow possible future revision of our interpretations. In addition, one of the objectives of our compilation is to highlight deficiencies in the distribution and reliability of borehole data; we have therefore made recommendations for future investigations, which may help to improve our understanding of the geology of the basin.

Development of a stratigraphic framework necessitated revision of existing schemes of stratigraphy and nomenclature that have been devised over the past several decades by the three State geological surveys and other researchers working in the basin. Differing concepts of the characteristics and status of particular formations have previously contributed to correlation difficulties, and to a lack of uniformity of stratigraphic nomenclature. The sections of this Report describing the stratigraphy of the basin have been organised to reflect a preferred hierarchy of names. However, many stratigraphic names are entrenched in the geological literature of each individual State, and we have therefore not attempted to redefine existing detailed nomenclature. The basic objective has been to clarify nomenclature correlation in order to allow lithostratigraphic units to be examined as single entities within a basin-wide stratigraphic framework. The stratigraphic schemes previously devised in each of the three States are shown in Figures 2, 3, and 4, and a basin-wide scheme, as used in this Report, is illustrated in Figure 5.

Fig.2. Stratigraphy of the Murray Basin in South Australia (from Ludbrook, 1961; note that the Knight Group is now known as the Renmark Group (Renmark beds of Harris,1966), and the Loxton Sands include the Parilla Sand).

The borehole study has entailed interpreting and compiling stratigraphic information from a dataset of several tens of thousands of unpublished water borelogs, stored in State survey and water authority archive files and microfiche retrieval systems, and made available to us by the participating organisations. The accompanying microform appendices also include the results of investigations previously undertaken by colleagues in State organisations. These have been compiled mainly from publications in the report series of the various State surveys, where much additional local detail is recorded (documented in the appropriate sections below). C.M. Brown was responsible for the structural design and development of the computerised database, and prepared the output datasets documented in the appendices. Brown also compiled stratigraphic interpretations from

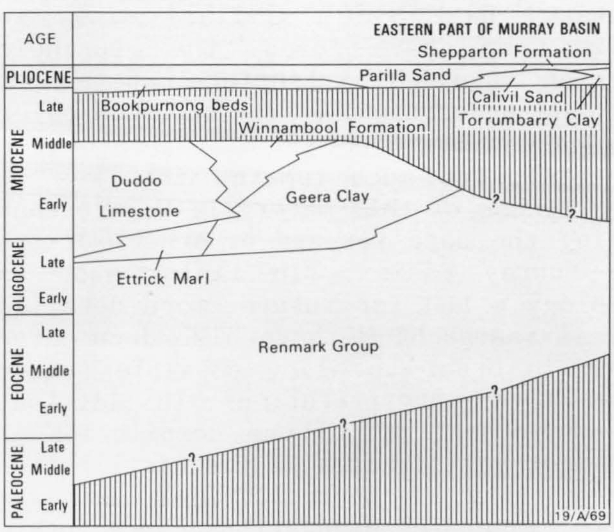

Fig.3. Stratigraphy of the Murray Basin in Victoria (from Lawrence & Abele, 1976).

664 boreholes from twelve 1:250 000 Sheet areas in New South Wales (Fig.6) and from 531 boreholes from 9 Sheet areas in Victoria; A.E. Stephenson compiled data from 1573 boreholes from 8 Sheet areas in South Australia.

Background to the Murray Basin Hydrogeological Project

The Murray Basin contains some of the most important agricultural land in Australia, and both surface water and groundwater are extensively used by irrigators and graziers. In recent years, various problems have developed as a consequence of a lack of knowledge about the effects of irrigation, and clearance of natural vegetation, upon the hydrologic system of the basin (Maunsell & Partners, 1979). These practices have been accompanied by rising groundwater-tables and discharge of saline water into river systems. Rising saline groundwater has resulted in areas of formerly productive agricultural land being turned into marshy saline wastelands, and trees have been killed by waterlogging of their roots. In some areas, orchards have been damaged by the use of saline river water for irrigation. In addition the quality of drinking water has deteriorated for many towns and cities (including Adelaide) which depend on water from the River Murray for their supplies.

AGE		MARINE	NON-MARINE
PLIOCENE	Late	Parilla Sand	Shepparton Formation
	Early	Bookpurnong beds	Calivil Sand
MIOCENE	Late		
	Middle	Winnambool Formation	No deposition
	Early		Olney Formation
OLIGOCENE		Geera Clay	
EOCENE	Late	Olney Formation	
	Middle	Warina Sand	Warina Sand
	Early		

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Fig.4. Stratigraphy of the Murray Basin in New South Wales (from Woolley & Williams, 1978).

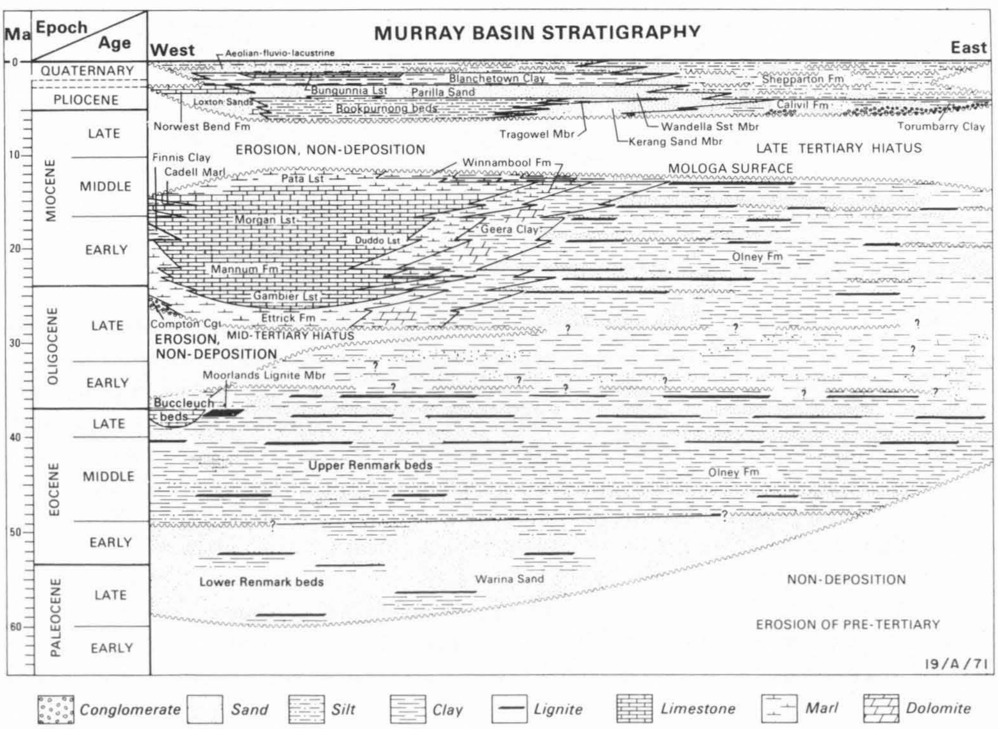

Fig.5. Cainozoic stratigraphy of the entire Murray Basin (based on Brown, 1983).

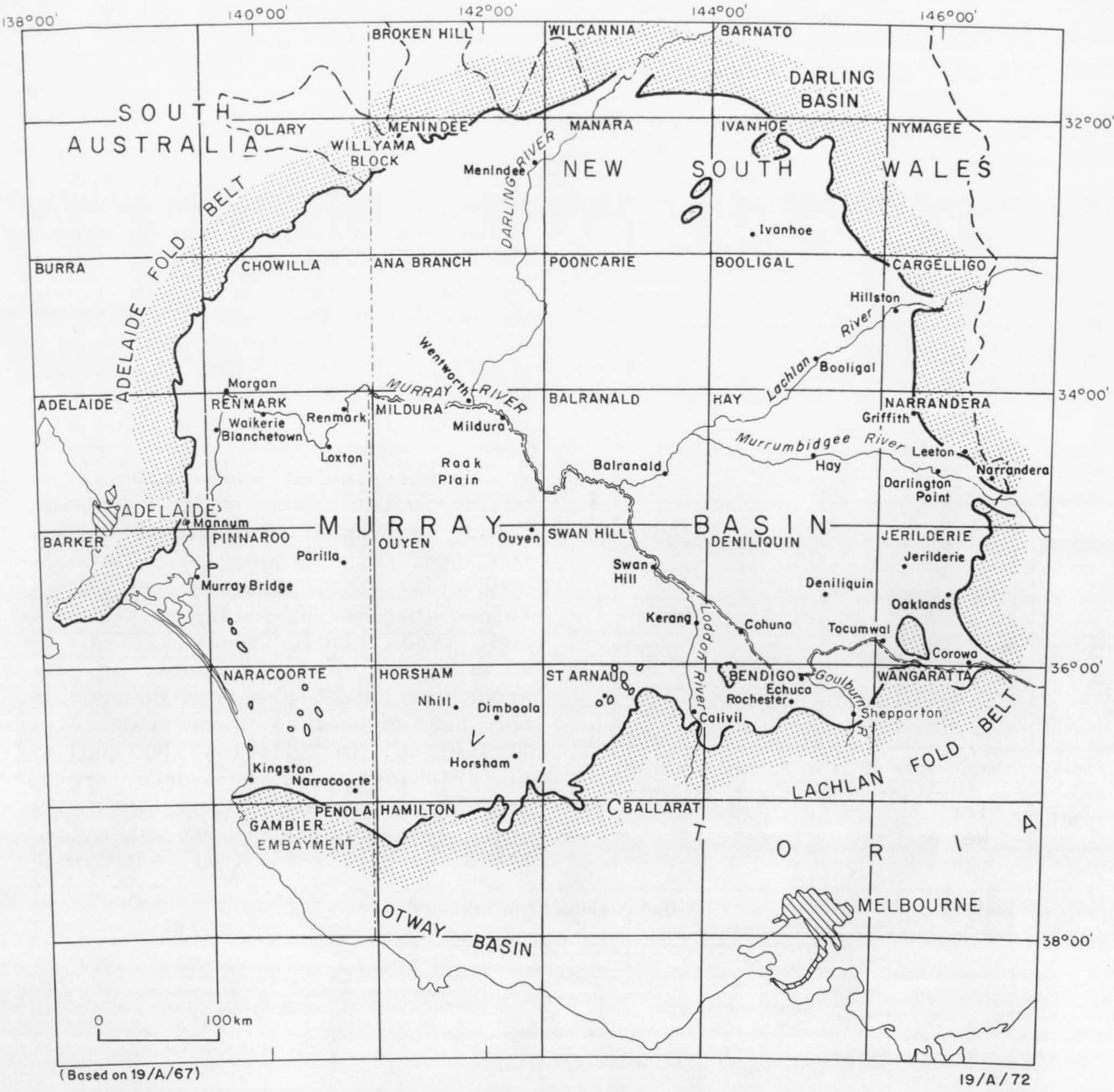

Fig.6. Index map of 1:250 000 Sheet areas.

Whilst there is some evidence that Quaternary climatic changes have caused salinisation of parts of the Murray Basin in the past, this is perhaps of little comfort to those communities in the basin which currently rely upon agriculture for their means of existence. At present, a major reason for the concentration of salts is that evaporation rates greatly exceed rates of rainfall. However, it is also now clear that the advent of European man and his agricultural practices have exacerbated problems within a previously fragile hydrologic regime. Part of the problem is due to the fact that saline groundwaters which have accumulated in the near-surface aquifers have not been flushed from the basin in recent geologic times, and part lies in current land use and water management policies. The Murray Basin Hydrogeological Project has been established, against this background of increasing salinity problems, to undertake basin-wide geological and hydrogeological studies.

Water is clearly the major geologic resource of the Cainozoic basin, but other minerals with exploration potential include poorly known but extensive deposits of Tertiary brown coal, and the heavy-mineral content of Pliocene beach sands (Johns, 1969; Colwell, 1979). In addition, small-scale Cainozoic deposits of gypsum, halite, and kaolin are exploited locally. The Cainozoic sequence is not prospective for hydrocarbons, but the prospectiveness of underlying Palaeozoic and Mesozoic infrabasins has not yet been adequately investigated. Other resources include Upper Permian coal in the underlying Oaklands Basin in New South Wales.

ACKNOWLEDGEMENTS

Compilation of the subsurface data from the Murray Basin was undertaken in 1981-84 in the Sedimentary Section of the Division of Continental Geology, BMR, under the supervision of W.J.Perry. The geological phase of the Murray Basin Hydrogeological Project was co-ordinated by a Steering Committee comprising W.J.Perry (BMR, Chairman), S.R.Barnett (Geological Survey of South Australia), C.R.Lawrence (Geological Survey of Victoria), D.H.Probert (Geological Survey of New South Wales), and D.R.Woolley (Water Resources Commission of New South Wales). The contributions of the Steering Committee members, and in particular the efforts of State personnel involved in the often complex task of assembling datasets from diverse sources, are gratefully acknowledged. In particular, access to background material previously compiled by R.M.Williams (Water Resources Commission of New South Wales), S.R.Barnett, D.R.Edwards, J.M.Lindsay, P.A.Rogers (Geological Survey of South Australia), C.R.Lawrence, P.G.Macumber, S.J.Tickell, W.G.Humphrys (Geological Survey of Victoria), W.R.Evans, and J.Kellett (BMR) is gratefully acknowledged. We particularly express thanks to W.J.Perry for support during the course of the study, and to P.Pangalos and G.Hawkes for technical assistance at various times during the life of the project. We are also grateful to A.N.Yeates, W.R.Evans, and D.L.Gibson for helpful comments on the manuscript. Thanks are also due to G.M.Bladon, who edited the Report. Figures in this Report were drafted under the supervision of M. Moffat of the Publications Subsection of the BMR Cartography Section.

SUBSURFACE STRATIGRAPHIC DATABASE

Borehole data sources

In New South Wales, details of bore identification, original drilling data, depths of aquifers, water quality, and coded descriptions of lithologic logs (where available) have been computerised and stored on microform by the Water Resources Commission. Their dataset contains several thousand water-bores, but few of these contain lithologic logs of sufficient detail for the identification of stratigraphic units; we have been able to make use of only 664 of them. Stratigraphic interpretations of the eastern part of the basin are largely based on unpublished data supplied by R.M. Williams of the Water Resources Commission, and on interpretations by Woolley & Williams (1978), with some additional interpretations by W.R. Evans of BMR. Additional borelogs were obtained from mineral exploration company reports held in open-file archives by the Geological Survey of New South Wales. Drilling for coal and uranium has been undertaken in the southeast of the basin by several exploration companies and by the Mines Department of New South Wales (Anglo American, 1970; Coles, 1972; Haynes, 1973; Palese, 1974; Yoo, 1981, 1982). Uranium exploration drilling around the northwest margins of the basin also provided additional stratigraphic control points (Wecker, 1971; Morgan, 1973).

In Victoria, records of drilling in the Murray Basin are housed by the Geological Survey of Victoria, where several hundred borehole lithologic logs are now stored on microform. Most of the 531 Victorian boreholes in this study were, however, extracted from regional groundwater reviews published by the Geological Survey during the past few years. Stratigraphic interpretations from northwest Victoria are largely based on those of Lawrence (1975), and those from the southeast Riverine Plain, in northern Victoria, are based on interpretations in Tickell & Humphrys (1979, 1980). Additional detailed stratigraphic control points were obtained from Chapman (1916), Crespin (1946), Gloe (1947), Johns & Lawrence (1964), and Macumber (1978b). Mineral exploration bores drilled in the southeast of the basin also provided additional stratigraphic control points (Techmin, 1973; Esso Australia, 1974; Western Mining Corporation, 1978a, 1978b). The database does not include the results of currently confidential mineral exploration drilling undertaken by Conzinc Riotinto Australia Ltd at various localities throughout the Victorian sector of the Murray Basin. Microform copies of the available mining company reports are held in open-file archives by the Geological Survey of Victoria.

Most of the 1573 borelogs used from South Australia have been extracted from a dataset of 27 800 microfiche records of water, petroleum, and stratigraphic bores provided by the Geological Survey of South Australia. These were logged by many different well-site geologists and drillers. Other major sources of stratigraphic data include a review of the hydrogeology of the Murray Basin in South Australia (O'Driscoll, 1960), and a series of reports by Edwards (1979, 1981a, 1981b, 1982a, 1982b, 1983) on the results of a stratigraphic drilling program recently undertaken by the Geological Survey of South Australia. These sources have provided excellent interpretations of geological logs, which largely agree with our current perceptions of the stratigraphy of the basin. Minor additional borehole data are incorporated on the 1:250 000 scale geological maps of the basin. These include bores in RENMARK* (Firman, 1972), CHOWILLA (Rogers, 1978), and PINNAROO (Rogers, 1980). In addition, a biostratigraphic log of stratigraphic bore Oakvale 1 was provided by Lindsay (1983).

Petroleum exploration wells have provided much useful data, particularly about the deeper sediments of the Murray Basin and underlying Devonian, Permian, Triassic, and Cretaceous infrabasins. Exploration drilling has been summarised by the Bureau of Mineral Resources (1964), Thornton (1974, 1976), Bembrick (1974), Evans (1977), Brown, Jackson & others (1982), and Sniffen (1985). Petroleum exploration well completion reports, in addition to reports on deep stratigraphic bores, are listed in Table 1. The accompanying appendices do not, however, include the results of currently confidential petroleum exploration drilling undertaken in western New South Wales by Comserv Pty Ltd and Esso Australia Ltd between 1980 and 1984.

Data organisation

Interpretations of formation boundaries within boreholes have been stored in a microcomputer database to allow retrieval of individual bore records, and to facilitate production of structure contour and isopach maps depicting the subsurface geology and aquifer distribution in the Murray Basin. Bore records are sorted into alphanumeric order (i.e., 1102, 33334, 4602, Wentworth 1) for each of the twenty-eight 1:250 000 Sheet areas (Fig.6), which are listed alphabetically. All measurements are in metres. The following datafields are

---

* Names of 1:250 000 Sheet areas are printed in capitals.

TABLE 1. PETROLEUM EXPLORATION WELLS AND STRATIGRAPHIC BORES

Petroleum well	Latitude	Longitude	Year	Depth	Company	Reference
Balranald 1	34 39 20 S	143 29 32 E	1962	403	Woodside (Lakes Entrance) Oil Company NL	(Benbow, 1962)
Berangabah 1	32 17 30 S	144 28 00 E	1967	436	Texam Oil Corporation	(Ranneft, 1968)
Berri North 1	34 12 17 S	140 38 06 E	1967	945	Beach Petroleum NL	(Laws & Heisler, 1967)
Berri South 1	34 22 03 S	140 38 01 E	1966	663	Beach Petroleum NL	(Gausden & Watts, 1966)
Blantyre 1	32 09 15 S	143 09 40 E	1965	2269	Mideastern Oil NL	(Campe & Cundill, 1965)
Booligal 2	33 35 15 S	144 56 30 E	1970	611	NSW Oil and Gas Company NL	(Haskell, 1970a)
Bundy 1	35 03 00 S	144 31 18 E	1962	419	Woodside (Lakes Entrance) Oil Company NL	(Shiels, 1962)
Canopus 1	33 23 03 S	146 40 51 E	1952	290	South Australian Department of Mines	(Ludbrook, 1961)
Company Bore	34 07 18 S	140 41 08 E	1910	550	Loxton Farm Company	(Thornton, 1974)
Coonalpyn 1	35 40 00 S	140 00 00 E	1958	208	Murray Basin Oil Syndicate	(Thornton, 1974)
Dolmoreve 1	33 30 00 S	144 00 06 E	1967	471	Texam Oil Corporation	(Ranneft, 1967)
Donna 1	33 29 15 S	138 55 14 E	1964	701	Geoil Ltd	(Thornton, 1974)
Ennisvale 1	33 18 15 S	141 11 23 E	1983	1231	Esso Australia Ltd	(Sniffen, 1985)
Hay 1	34 54 23 S	144 50 29 E	1970	350	NSW Oil and Gas Company NL	(Haskell, 1970b)
Holey Box 1	33 05 00 S	144 31 00 E	1967	349	North Star Oil of Australia	(Texam Oil Corporation, 1967)
Ivanhoe 1	32 54 11 S	144 17 51 E	1963	666	North Star Oil Corporation	(Brundall, 1964)
Jerilderie 1	35 15 00 S	145 58 00 E	1962	1329	Australian Oil and Gas Corporation	(Wright & Stuntz, 1962)
Keith 1	36 10 00 S	140 45 00 E	1958	292	Murray Basin Oil Syndicate	(Thornton, 1974)
Killendoo 1	34 41 01 S	145 04 09 E	1964	837	Amalgamated Petroleum Exploration Pty Ltd	(Haites & Stewart, 1964)
Lake Victoria 1	34 03 15 S	141 20 53 E	1964	754	Australian Oil and Gas Corporation	(Grasso, 1964)
Loxton 1	34 34 00 S	140 39 00 E	1956	488	Australian Oil and Gas Corporation	(Ludbrook, 1956)
Loxton 2	34 32 46 S	140 35 49 E	1963	550	Beach Petroleum NL	(Laws, 1963)
Monash 1	34 12 00 S	140 29 57 E	1964	1050	Beach Petroleum NL	(Walter, 1965)
Morkalla 1	34 22 25 S	141 09 55 E	1970	783	Associated Australian Oil Fields NL	(Derrington & Anderson, 1970)
Mount Emu 1	32 19 56 S	143 32 33 E	1970	1450	Planet Oil Exploration Co. Pty Ltd	(Haskell & Wiltshire, 1970)

TABLE 1. PETROLEUM EXPLORATION WELLS AND STRATIGRAPHIC BORES (continued)

Petroleum well	Latitude	Longitude	Year	Depth	Company	Reference
Nadda 1	34 38 05 S	140 53 45 E	1970	1041	Associated Australian Oilfields NL	(Derrington & Anderson, 1970)
Nambucurra 1	33 19 38 S	142 50 09 E	1970	263	NSW Oil and Gas Company	(Haskell, 1970b)
North Renmark 1	34 07 00 S	140 41 00 E	1962	1225	Australian Oil Corporation	(Grasso, 1963)
Nulla Nulla 1	33 37 36 S	141 01 19 E	1983	1119	Esso Australia Ltd	(Sniffen, 1985)
Oakvale 1	32 59 03 S	140 54 09 E	1981	176	South Australian Department of Mines & Energy	(Lindsay, 1983)
Olney 1	34 05 55 S	141 01 12 E	1964	614	Victorian Department of Mines	(Lawrence, 1975)
Pamamaroo 1	32 10 22 S	142 29 42 E	1983	798	Esso Australia Ltd	(Sniffen, 1985)
Pinnaroo 1	35 17 00 S	140 35 00 E	1958	390	Murray Basin Oil Syndicate	(O'Driscoll, 1960)
Popiltah 1	33 22 39 S	141 41 31 E	1983	1003	Esso Australia Ltd	(Sniffen, 1985)
Shaugh Bore	35 57 10 S	140 46 54 E	1946	283	South Australian Department of Mines	(Thornton, 1974)
Sunset 1	34 16 30 S	141 06 25 E	1970	1001	Associated Australian Oilfields NL	(Derrington & Anderson, 1970)
Tailem Bend 1	35 11 17 S	139 31 15 E	1956	81	Murray Basin Oil Syndicate	(Thornton, 1974)
Tararra 1	33 20 12 S	141 15 49 E	1967	1935	Australian Oil and Gas Corporation	(Boyd & Heisler, 1967)
Urana 1	35 16 33 S	146 00 10 E	1962	675	Amalgamated Petroleum Exploration Pty Ltd	(Amalgamated Petroleum, 1962)
Umalee 1	32 48 31 S	144 03 27 E	1981	176	New South Wales Department of Mineral Resources	(Yoo, 1981)
Waikerie 2W	34 12 54 S	139 57 46 E	1965	256	South Australian Department of Mines	(Lindsay & Bonnett, 1973)
Waikerie 27W,28W	34 11 34 S	139 58 48 E	1969	383	South Australian Department of Mines	(Lindsay & Bonnett, 1973)
Wentworth 1	33 48 45 S	141 58 15 E	1961	634	Australian Oil and Gas Corporation Ltd	(Rose, 1962)
Yellangip 1	36 07 43 S	142 24 52 E	?	227	Victorian Department of Mines	(Lawrence, 1975)

APPENDIX 1
MURRAY BASIN SUBSURFACE STRATIGRAPHIC DATABASE

MAP SHEET	BOREHOLE NO.	LATITUDE	LONGITUDE	ELEVATION	TOTAL DEPTH
Booligal	30406	33 29 14 S	145 18 35 E	112	199
Booligal	30407	33 26 38 S	145 19 56 E	115	232
Booligal	30408	33 23 21 S	145 20 06 E	116	179
Booligal	30409	33 20 19 S	145 20 18 E	115	198
Booligal	30410	33 16 55 S	145 19 53 E	116	153
Booligal	30411	33 13 27 S	145 20 48 E	115	179
Booligal	30412	33 11 21 S	145 18 28 E	114	158
Booligal	30413	33 09 37 S	145 20 13 E	115	112
Booligal	30414	33 06 26 S	145 20 27 E	117	145
Booligal	30415	33 03 59 S	145 23 41 E	119	174
Booligal	30416	33 09 06 S	145 12 21 E	106	159
Booligal	30417	33 15 01 S	145 11 32 E	108	203
Booligal	30418	33 21 42 S	145 10 33 E	110	230
Booligal	36284	33 21 45 S	145 01 01 E	105	192
Booligal	36296	33 12 18 S	145 00 37 E	105	186
Booligal	36304	33 40 17 S	145 02 43 E	102	?213+
Booligal	36312	33 27 17 S	145 04 14 E	105	263
Booligal	36321	33 20 45 S	145 51 01 E	101	190
Booligal	36329	33 34 26 S	144 58 39 E	101	235
Booligal	4243	33 03 55 S	144 29 02 E	?88	375
Booligal	BOOLIGAL 2	33 35 20 S	144 57 15 E	100	811
Booligal	HOLEY BOX 1	33 05 10 S	144 32 26 E	?74	349
Burra	6730-0004	33 45 45 S	139 25 14 E	?120	101
Burra	6730-0019	33 34 40 S	139 17 35 E	?180	72
Burra	6730-0029	33 50 54 S	139 27 03 E	?95	52
Burra	6730-0030	33 51 40 S	139 25 26 E	?105	92
Burra	6730-0037	33 51 13 S	139 17 09 E	?170	64
Burra	6730-0045	33 55 40 S	139 16 11 E	?200	42
Burra	6730-0135	33 41 14 S	139 20 06 E	?140	129
Burra	6730-0136	33 40 58 S	139 20 04 E	?140	130
Burra	6730-0137	33 40 15 S	139 19 12 E	?150	142
Cargelligo	30044	33 22 41 S	145 33 19 E	124	146
Cargelligo	30045	33 21 14 S	145 32 42 E	123	143
Cargelligo	30046	33 19 38 S	145 31 36 E	123	152
Cargelligo	30047	33 17 48 S	145 31 12 E	122	148
Cargelligo	30104	33 16 23 S	145 31 11 E	122	100
Cargelligo	30105	33 14 59 S	145 30 14 E	122	146
Cargelligo	30172	33 23 47 S	145 32 39 E	123	117
Cargelligo	30173	33 25 46 S	145 31 16 E	122	90
Cargelligo	30174	33 27 30 S	145 30 10 E	119	122
Cargelligo	30256	33 32 45 S	145 31 07 E	118	91
Cargelligo	30258	33 31 20 S	145 31 19 E	118	126
Cargelligo	30261	33 34 22 S	145 30 40 E	116	126
Cargelligo	30262	33 36 40 S	145 30 58 E	115	79
Chowilla	6830-0009	33 33 07 S	139 42 15 E	?100	83
Chowilla	6830-0018	33 51 15 S	139 49 15 E	?45	219
Chowilla	6830-0034	33 33 42 S	139 35 51 E	?110	92
Chowilla	6830-0070	33 58 50 S	139 48 23 E	35	66
Chowilla	6830-0071	33 52 41 S	139 49 24 E	46	70
Chowilla	6830-0072	33 45 37 S	139 47 06 E	52	86

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Fig.7. Example of the tabulation of boreholes - from Microform Appendix 1.

recorded for each borehole record:

(1) Name of 1:250 000 Sheet area
(2) Borehole number/name
(3) Locality - latitude and longitude
(4) Total depth
(5) Surface elevation
(6) Depth to top of each Cainozoic unit interpreted in the bore
(7) Thickness of each of the Cainozoic units encountered
(8) Elevation of top of each Cainozoic unit encountered (relative to sea level)
(9) Elevation of base of each Cainozoic unit encountered (relative to sea level)
(10) Depth to top of pre-Cainozoic units and stratotectonic elements
(11) Additional comments, mainly about the interpretation of formation boundaries and identification of basement type.

Microform appendices

The stratigraphic database can be accessed using a number of retrieval strategies, which allow sorting and extraction of data specific to a particular Sheet area, stratigraphic unit, or regional aquifer. The major datasets that were generated are tabulated, in Microform Appendices 1 to 7, whose contents are described below.

Microform Appendix 1 lists all boreholes which were used in the subsurface study, and records for each one the 1:250 000 Sheet area, borehole number/name, latitude and longitude, surface elevation, and total depth (see sample of output in Fig.7).

Microform Appendix 2 contains separate lists of boreholes which have encountered each of the major Cainozoic stratigraphic units. For each subsurface encounter of a unit the lists record the 1:250 000 Sheet area, borehole number/name, latitude and longitude, interpreted depth at which the borehole encountered the unit, thickness of the unit, and elevation of the top and base of the unit relative to sea level (e.g., Fig.8). Borehole data are listed for the following stratigraphic units: Tew - Warina Sand (Victoria and New South Wales); Ter - Renmark Group (including Teo - Olney Formation in all three States, but excluding Warina Sand in Victoria & New South Wales which is listed separately); Teb - Buccleuch beds; Toc - Compton Conglomerate; Toe - Ettrick Formation; Tmg - Geera Clay; Tml - combined calcarenite formations of the Murray Group (Gambier Limestone, Mannum Formation, Morgan Limestone, and Pata Limestone - all in South Australia - and the Duddo Limestone - in Victoria and New South Wales); Tmw - Winnambool Formation; Tpb - Bookpurnong beds; Tpc - Calivil Formation; Tps - Loxton Sands and Parilla Sand; Tpn - Norwest Bend Formation; TQs - Shepparton Formation; Qpc - Blanchetown Clay and Bungunnia Limestone; Qpl - Coomandook Formation; Qfr - Pooraka Formation; and Qpb - Bridgewater Formation.

Microform Appendix 3 documents the pre-Cainozoic units encountered in the subsurface (recorded by letter symbols referring to System, Series, and/or rock type; thus Kl = Lower Cretaceous and SDg = Siluro-Devonian granitoid). For each unit the list records the 1:250 000 Sheet area, borehole number/name, latitude and longitude, and interpreted depth at which the unit was encountered (e.g., Fig.9). The letter symbols are deciphered in Figure 10 - but note that in Appendices 3 and 4, CO (not ꞒO), Cv and Cm (not Ꞓv and Ꞓm), P (not P̲), and pC (not pꞒ) are used as abbreviations for Cambro-Ordovician, Cambrian, Proterozoic, and Precambrian units respectively.

Microform Appendix 4 documents the interpreted stratigraphy of the 3000 borelogs used in the subsurface study, recording for each borehole the 1:250 000

APPENDIX 2

RENMARK GROUP (Teo/Ter)

MURRAY BASIN SUBSURFACE STRATIGRAPHIC DATABASE

MAP SHEET	BOREHOLE NO.	LATITUDE	LONGITUDE	RENMARK GROUP (Teo/Ter) DEPTH	THICKNESS	R.L.TOP	R.L.BASE
Menindee	19886	32 14 31 S	141 47 50 E	?83	?16+	?30	14+
Menindee	19964	32 32 00 S	142 03 57 E	?55	27+	?4	-23+
Menindee	22272	32 46 22 S	141 28 17 E	87	13+	-2	-15
Menindee	23864	32 39 10 S	141 38 09 E	?74	6+	-7	-13+
Menindee	23879	32 48 45 S	141 21 58 E	116	3+	-37	-40+
Menindee	32550	32 17 30 S	141 44 19 E	?93	57+	?24	-33+
Menindee	34967	32 45 18 S	141 28 38 E	80	8+	0	-8+
Menindee	49019	32 31 00 S	141 34 59 E	?124	?40	?-17	?-57
Menindee	49020	32 32 11 S	141 31 22 E	?78	?76	?34	?-42
Menindee	49021	32 31 19 S	141 27 36 E	?89	?39	?30	?-9
Menindee	49024	32 33 56 S	141 27 52 E	59	84+	50	-34+
Menindee	49025	32 37 39 S	141 28 28 E	61	?61	35	?-26
Menindee	49026	32 33 06 S	141 27 12 E	61	96+	51	-45+
Menindee	49030	32 39 46 S	141 07 59 E	91	49	?18	-31
Menindee	49033	32 48 57 S	141 07 17 E	99	59	-6	-65
Menindee	49035	32 54 17 S	141 08 10 E	55	36+	28	-8+
Menindee	49036	32 11 48 S	142 01 05 E	?60	58+	?44	-14+
Menindee	49037	32 11 42 S	142 04 41 E	?76	69+	?33	-36+
Menindee	49038	32 13 58 S	142 07 04 E	?49	?38	?76	38
Menindee	49039	32 12 03 S	142 13 51 E	?64	58+	?17	-41+
Menindee	49041	32 10 51 S	142 11 29 E	69	82+	20	-62+
Menindee	49042	32 09 05 S	142 08 11 E	20	97	76	-21
Menindee	49043	32 07 42 S	142 05 41 E	82	17+	20	3+
Menindee	49044	32 08 39 S	142 00 59 E	50	69+	?61	-8+
Menindee	49045	32 06 13 S	142 02 54 E	49	114+	64	-50+
Menindee	49046	32 05 31 S	142 05 03 E	?47	?59+	?68	9+
Menindee	49047	32 05 19 S	142 08 27 E	76	64	39	-25
Menindee	49050	32 07 16 S	142 16 26 E	?40	?36	?69	33
Menindee	49052	32 16 54 S	142 08 22 E	32	120+	48	-72+
Menindee	49053	32 16 52 S	142 03 04 E	32	46	55	9
Menindee	49054	32 19 28 S	142 06 05 E	59	64+	21	-43+
Menindee	49055	32 19 09 S	142 09 42 E	?61	91+	?13	-78+
Menindee	49056	32 18 58 S	142 00 48 E	?76	?49	?12	-37
Menindee	49057	32 21 15 S	142 06 17 E	89	63+	-7	-70+
Menindee	49058	32 23 46 S	142 00 52 E	62	90+	17	-73+
Menindee	49059	32 26 14 S	142 02 41 E	?52	?100+	?23	-77+
Menindee	49060	32 24 00 S	142 09 19 E	70	82+	-1	-83+
Menindee	49061	32 22 08 S	142 08 37 E	64	90+	13	-77+
Menindee	49062	32 28 23 S	142 07 06 E	56	96+	14	-82+
Menindee	49063	32 29 56 S	142 02 01 E	64	88+	-4	-92+
Menindee	49064	32 33 38 S	141 59 59 E	64	88+	-5	-93+
Menindee	49065	32 34 03 S	141 53 09 E	70	82+	-8	-90+
Menindee	49066	32 33 51 S	141 48 16 E	70	82+	6	-76+
Menindee	49067	32 33 01 S	141 42 48 E	79	73+	7	-66+
Menindee	49068	32 36 51 S	141 39 35 E	?70	?82+	?12	-70+
Menindee	49069	32 37 55 S	141 44 49 E	75	16+	-2	-18+
Menindee	49070	32 36 41 S	141 49 57 E	76	47+	-6	-53+
Menindee	49071	32 35 47 S	141 56 44 E	93	59+	-10	-69+
Menindee	49072	32 40 12 E	141 58 03 E	111	41+	-36	-77+
Menindee	49073	32 40 21 S	141 49 58 E	73	79+	-4	-83+

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Fig.8. Example of the tabulation of Cainozoic stratigraphic data - from Microform Appendix 2.

APPENDIX 3

MURRAY BASIN SUBSURFACE STRATIGRAPHIC DATABASE PRE-CAINOZOIC GEOLOGY

Kl - lower Cretaceous ; TRm - mid Triassic
Pu - upper Permian ; Pl - lower Permian

DEPTH TO TOP OF UNIT

MAP SHEET	BOREHOLE NO.	LATITUDE	LONGITUDE	Kl	TRm	Pu	Pl
Jerilderie	Co 3	35 34 46 S	146 11 53 E	-	?	40?	?
Jerilderie	Co 4	35 31 48 S	146 12 45 E	-	-	68	?
Jerilderie	DM CADELL 1	35 00 38 S	145 50 09 E	-	194	266	-
Jerilderie	DM WOOD 1,1A	35 06 20 S	145 38 12 E	-	220	-	296
Jerilderie	DM YANKOSOUTH 1	35 00 47 S	145 44 24 E	-	195	348	377
Jerilderie	JERILDERIE 1	35 17 00 S	145 58 20 E	-	143	362	431
Jerilderie	Oak 1	35 36 09 S	146 00 00 E	-	109	187	?
Jerilderie	Oak 10	35 53 43 S	146 08 15 E	-	-	-	140
Jerilderie	Oak 11	35 40 20 S	146 03 39 E	-	-	99	?
Jerilderie	Oak 12	35 36 09 S	145 56 55 E	-	?114	125	148
Jerilderie	Oak 13	35 38 28 S	146 05 14 E	-	-	103	117
Jerilderie	Oak 14	35 32 55 S	146 01 54 E	-	164	198	?
Jerilderie	Oak 15	35 26 17 S	145 47 53 E	-	122	163	178
Jerilderie	Oak 16	35 30 30 S	145 59 04 E	-	96	257	?
Jerilderie	Oak 17	35 27 51 S	146 04 47 E	-	160	176	?
Jerilderie	Oak 18	35 25 11 S	145 49 56 E	-	143	262	?
Jerilderie	Oak 2	35 27 10 S	145 59 09 E	-	111	270	310
Jerilderie	Oak 3	35 36 39 S	146 08 01 E	-	-	63	127
Jerilderie	Oak 4	35 33 50 S	145 57 08 E	-	140	207	?
Jerilderie	Oak 5	35 28 37 S	145 53 18 E	-	111	283	?
Jerilderie	Oak 6	35 25 34 S	146 10 47 E	-	-	98	?
Jerilderie	Oak 7	35 41 42 S	146 06 20 E	-	-	93	102
Jerilderie	Oak 8	35 42 16 S	146 11 24 E	-	-	-	95
Jerilderie	Oak 9	35 47 52 S	146 08 50 E	-	-	-	97
Jerilderie	URANA 2	35 16 39 S	146 00 55 E	-	125	220	265
Manara	11868	32 22 45 S	143 56 47 E	66?	-	-	-
Manara	17860	32 02 20 S	143 55 26 E	-	-	-	36
Manara	27970	32 05 41 S	143 52 20 E	-	-	-	21
Manara	27971	32 07 21 S	143 53 44 E	-	-	-	33
Manara	3581	32 08 30 S	142 31 16 E	?	-	-	?57
Manara	4516	32 27 42 S	142 41 33 E	176?	-	-	-
Manara	5653	32 07 02 S	143 46 27 E	79?	-	-	?
Manara	6360	32 24 13 S	143 24 27 E	33?	-	-	?
Manara	6394	32 07 44 S	143 54 17 E	12?	-	-	?
Manara	6398	32 03 56 S	143 56 25 E	10?	-	-	?
Manara	BLANTYRE 1	32 09 15 S	143 09 40 E	-	-	-	236
Mildura	LAKE VICTORIA 1	34 03 15 S	141 20 53 E	543	-	-	-
Mildura	MORKALLA 1	34 22 34 S	141 09 03 E	578	-	-	-
Mildura	OLNEY 1	34 05 55 S	141 01 12 E	594	-	-	-
Mildura	SUNSET 1	34 16 33 S	141 06 02 E	638	-	-	-
Naracoorte	6825-0117	36 05 02 S	139 43 45 E	-	-	-	154
Naracoorte	6825-0118	36 06 17 S	139 45 00 E	-	-	-	111
Narrandera	36040	34 51 28 S	145 44 01 E	-	237	?	?
Narrandera	36275	34 40 47 S	145 37 00 E	-	?	318?	?
Narrandera	DM MORTON 1	34 51 36 S	145 34 07 E	-	-	-	194
Narrandera	DM WALOONA 1	34 51 37 S	145 42 29 E	-	211	307	336
Pinnaroo	6826-0322	35 43 00 S	139 35 25 E	-	-	-	76
Pinnaroo	6826-0518	35 49 46 S	139 42 01 E	-	-	-	73
Renmark	6929-0001	34 11 16 S	140 30 08 E	537	-	-	-
Renmark	7028-0001	34 34 12 S	140 38 41 E	402	-	-	-

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Fig.9. Example of the tabulation of the boreholes which have encountered pre-Cainozoic units - from Microform Appendix 3.

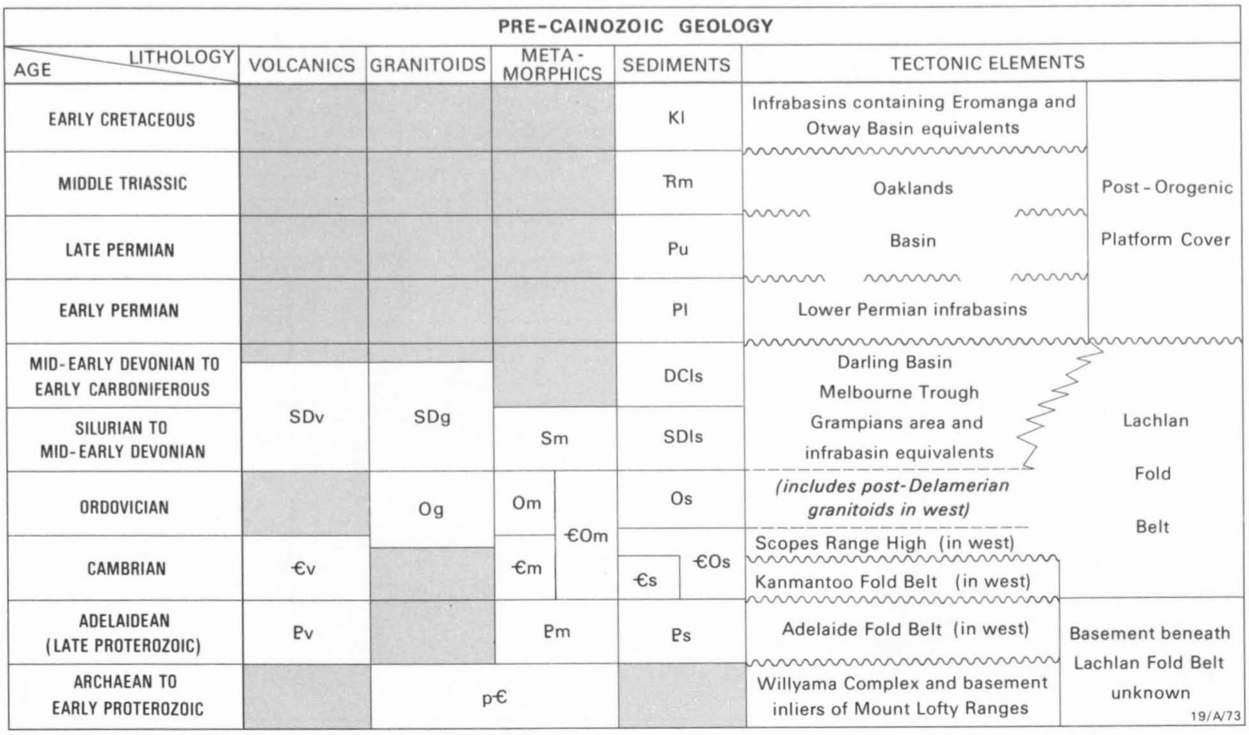

Fig.10. Pre-Cainozoic lithologic units and tectonic elements. The letter symbols provide a reference to the symbols used for pre-Cainozoic units in Appendices 3 and 4 (see accompanying text for an explanation).

Sheet area; borehole number/name; latitude and longitude; surface elevation of bore site; total depth of borehole; depth, thickness, and elevations (relative to sea level) of the top and base of each Cainozoic stratigraphic unit encountered; and depth and identification of underlying pre-Cainozoic units (e.g., Fig.11). Borehole data from each of the twenty-eight 1:250 000 Sheet areas shown in Figure 6 are recorded.

Microform Appendix 5 records for each of the major regional aquifers shown in Figure 12 the boreholes that have encountered it, and lists for each borehole the 1:250 000 Sheet area, borehole number/name, latitude and longitude, and interpreted depth, thickness, and elevation of the top and base (relative to sea level) of the aquifer (e.g., Fig.13).

Microform Appendix 6 contains the 28 Murray Basin 1:250 000 map sheets (Fig.6), on which are shown the locations of each of the 3000 boreholes used in the subsurface study.

Microform Appendix 7 contains (1) a map and list of parishes and their assigned numbers in the Victorian part of the Murray Basin, and (2) a map of counties and 'hundreds' (equivalent to parishes) in South Australia; borehole numbering systems in Victoria are based on the numbers assigned to parishes, whereas those in South Australia are based on 1:100 000 Sheet areas (currently) and on numbers assigned to hundreds (formerly); see 'Borehole numbering systems' (below).

In the appendices, a '+' symbol attached to a thickness figure, or elevation of base figure, indicates that the borehole terminated within a given unit and that the thickness and relative level of the base of that unit are greater than the figures given (i.e. 'thickness 51+' indicates a thickness of greater than 51 m; 'relative level base -150+', however, indicates that the elevation of the base of the unit relative to sea level is at a level below -150 m). A '?' symbol attached to a depth, thickness, or depth relative to sea-level figure indicates uncertainty of interpretation of either the

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BOREHOLE NO : OLNEY 1 — 1:250 000 MAP SHEET : Mildura

LATITUDE : 34 05 55 S LONGITUDE : 141 01 12 E GROUND ELEVATION: 64

BOREHOLE STRATIGRAPHY — TOTAL DEPTH: 614

CAINOZOIC GEOLOGY	DEPTH	THICKNESS	R.L.TOP	R.L.BASE
SURFICIAL UNIT : Qdw		12		
BLANCHETOWN CLAY (Qpc)	-	-	-	-
LOXTON SANDS/PARILLA SAND (Tps)	12	75	52	-23
BOOKPURNONG BEDS (Tpb)	87	?13	-23	?-36
GEERA CLAY (Tmg)	-	-	-	-
WINNAMBOOL FORMATION (Tmw)	?100	?21	?-36	-57
MURRAY GROUP LIMESTONE (Tml)	121	128	-57	-185
ETTRICK FORMATION (Toe)	249	14	-185	-199
OLNEY FORMATION (Teo/Ter)	263	128	-199	-327
WARINA SAND (Tew/Ter)	391	203	-327	-530
TOTAL CAINOZOIC	0	594	64	-530

PRE-CAINOZOIC GEOLOGY	K1	DC1s	SD1s	COs	COm	Cm
DEPTH	594	?	?	?	?	?

COMMENTS :Lower Cretacaous Monash Formation Millewa Group at base.

BOREHOLE NO : SUNSET 1 — 1:250 000 MAP SHEET : Mildura

LATITUDE : 34 16 33 S LONGITUDE : 141 06 02 E GROUND ELEVATION: 52

BOREHOLE STRATIGRAPHY — TOTAL DEPTH: 998

CAINOZOIC GEOLOGY	DEPTH	THICKNESS	R.L.TOP	R.L.BASE
SURFICIAL UNIT : Qdw		?30		
BLANCHETOWN CLAY (Qpc)	-	-	-	-
LOXTON SANDS/PARILLA SAND (Tps)	30	85	22	-63
BOOKPURNONG BEDS (Tpb)	115	19	-63	-82
GEERA CLAY (Tmg)	-	-	-	-
WINNAMBOOL FORMATION (Tmw)	134	25	-82	-107
MURRAY GROUP LIMESTONE (Tml)	159	125	-107	-232
ETTRICK FORMATION (Toe)	284	17	-232	-249
OLNEY FORMATION (Teo/Ter)	301	151	-249	-400
WARINA SAND (Tew/Ter)	452	186	-400	-586
TOTAL CAINOZOIC	0	638	52	-586

PRE-CAINOZOIC GEOLOGY	K1	DC1s	SD1s	COs	COm	Cm
DEPTH	638	-	-	-	-	921

COMMENTS :Lower Cretaceous sediments over phyllite, dark green slate of probable Kanmantoo Group at base

19/A/90

Fig.11. Example of the tabulation of the downhole stratigraphy interpreted for individual boreholes - from Microform Appendix 4.

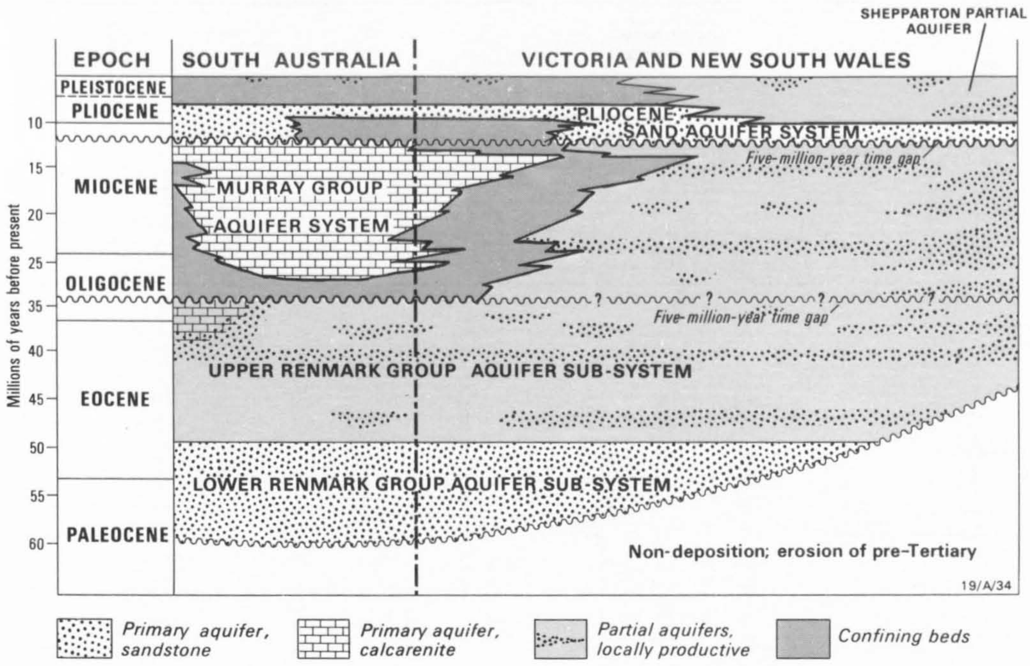

Fig.12. Aquifers of the Murray Basin.

stratigraphy or relative elevation. An unattached '?' symbol listed against a unit indicates that the unit may occur below the total depth in the borehole. In contrast, a '-' symbol indicates that the unit is known to be absent in the borehole.

Borehole numbering systems

In each of the three States, different numbering systems have been devised by the relevant authorities to identify boreholes drilled in the Murray Basin (described below). In the appendices, petroleum exploration wells and deep stratigraphic bores are identified by name, whereas the water-bores are referred to by the numbers assigned to them.

In New South Wales, water-bores entered into the files of the Water Resources Commission have been numbered sequentially, and no geographic or time significance can be placed on the numbers, except that older bores clearly have been assigned lower numbers. Certain blocks of numbers were, however, reserved for drilling programs undertaken by the Water Resources Commission (e.g., 21 000 to 21 999; 25 000 to 25 999; 30 000 to 30 999; and 36 000 to 36 999). Other blocks of numbers were reserved for special projects, such as sets of private monitoring bores or mineral exploration drilling programs (e.g., 40 000 to 40 999; 46 000 to 46 999; and 49 000 to 49 999).

In Victoria, boreholes are currently named after parishes. Each parish has an assigned number, and this is frequently used as a prefix to the bore number. Bores drilled by State authorities are numbered sequentially within parishes, commencing with the number '1'. Private water and mineral exploration bores drilled before 1969 were numbered sequentially from 8000. Since 1969, only mineral exploration bores have been numbered sequentially from 8000, whilst private water-bores have been numbered sequentially from 10 000; for example 1404-8001 refers to an observation bore drilled in the Parish of Pranjip.

In South Australia, boreholes are currently assigned a series of numbers, which include the number of the 1:100 000 Sheet area, the number of the bore within that Sheet area, and a numerical code that records the type of bore. The bores are also cross-referenced to an earlier system which organised them according to location within the local government subdivisions of county,

APPENDIX 5

MURRAY GROUP AQUIFER

MURRAY BASIN SUBSURFACE STRATIGRAPHIC DATABASE

				MURRAY GROUP AQUIFER			
MAP SHEET	BOREHOLE NO.	LATITUDE	LONGITUDE	DEPTH	THICKNESS	R.L.TOP	R.L.BASE
Horsham	271-1	36 46 20 S	142 17 22 E	-	-	-	-
Horsham	340-1	36 55 55 S	141 51 45 E	?	?	?	?
Horsham	454-1	36 33 08 S	141 39 00 E	84	26	74	48
Horsham	488-1	36 50 32 S	141 58 25 E	-	-	-	-
Horsham	488-2	36 51 22 S	142 04 05 E	-	-	-	-
Horsham	488-3	36 48 03 S	142 04 26 E	-	-	-	-
Horsham	524-1	36 59 38 S	142 15 42 E	-	-	-	-
Horsham	548-3	36 37 57 S	141 51 27 E	41	18	82	64
Horsham	548-4	36 38 11 S	141 54 21 E	-	-	-	-
Horsham	55-1	36 20 18 S	141 39 30 E	66	89	63	-26
Horsham	55-5	36 20 11 S	141 39 58 E	101	26+	54	28+
Horsham	55-7	36 20 10 S	141 40 26 E	68	74	62	-12
Horsham	569-6	36 59 34 S	141 16 40 E	-	-	-	-
Horsham	642-1	36 22 16 S	141 52 52 E	68	42	67	25
Horsham	702-1	36 43 11 S	141 28 53 E	81	12	81	69
Horsham	702-5	36 43 22 S	141 27 50 E	71	6+	81	75+
Horsham	733-1	36 44 00 S	141 35 42 E	-	-	-	-
Horsham	803-1	36 39 48 S	142 17 01 E	-	-	-	-
Horsham	804-2	36 35 25 S	141 39 21 E	85	24	77	53
Horsham	810-1	36 49 03 S	141 37 54 E	-	-	-	-
Horsham	812-8001	36 34 50 S	142 12 12 E	-	-	-	-
Horsham	825-3	36 22 46 S	141 14 57 E	74	76	73	-3
Horsham	825-4	36 22 46 S	141 14 57 E	73	80	74	-6
Horsham	947-1	36 52 46 S	142 18 43 E	-	-	-	-
Horsham	986-1	36 21 54 S	141 08 11 E	52	100	71	-29
Mildura	1184-1	34 45 57 S	142 19 40 E	167	82	?-117	?-199
Mildura	128-8001	34 55 05 S	141 01 58 E	58	10+	-5	-15+
Mildura	128-8002	34 59 57 S	141 01 08 E	55	8+	-8	-16+
Mildura	1338-8001	34 12 18 S	140 58 46 E	?	?	?	?
Mildura	1338-8002	34 05 53 S	140 58 18 E	?	?	?	?
Mildura	1641-8001	34 29 06 S	141 17 18 E	157	92	-102	-194
Mildura	1961-8001	34 21 22 S	142 12 54 E	171	84	-122	-206
Mildura	2005-8005	34 50 28 S	141 01 57 E	46	15+	-4	-19+
Mildura	2005-8008	34 59 18 S	141 29 58 E	131	84+	-82	-166+
Mildura	36464	34 16 06 S	142 24 32 E	?	?	?	?
Mildura	LAKE VICTORIA 1	34 03 15 S	141 20 53 E	137	106	-107	-213
Mildura	MA-12-1	34 23 21 S	142 01 30 E	?	?	?	?
Mildura	MORKALLA 1	34 22 34 S	141 09 03 E	131	126	-90	-216
Mildura	OLNEY 1	34 05 55 S	141 01 12 E	121	128	-57	-185
Mildura	SUNSET 1	34 16 33 S	141 06 02 E	159	125	-107	-232
Naracoorte	6824-0222	36 51 36 S	139 51 02 E	10	68	-8	-76
Naracoorte	6824-0432	36 58 01 S	139 54 39 E	27	69	-16	-85
Naracoorte	6824-0446	36 48 23 S	139 51 55 E	22	24	-19	-43
Naracoorte	6824-0754	36 36 49 S	139 52 52 E	-	-	-	-
Naracoorte	6824-0844	36 51 36 S	139 53 50 E	13	37	-8	-45
Naracoorte	6825-0028	36 18 47 S	139 46 19 E	?	?	?	?
Naracoorte	6825-0044	36 17 22 S	139 50 53 E	41	1+	-6	-7+
Naracoorte	6825-0046	36 18 03 S	139 51 22 E	?	?	?	?
Naracoorte	6825-0050	36 20 35 S	139 46 58 E	?	?	?	?
Naracoorte	6825-0083	36 17 39 S	139 53 04 E	?	?	?	?

19/A/91

Fig.13. Example of the tabulation of borehole data for each of the major regional aquifers encountered by drilling - from Microform Appendix 5.

hundred, and section (listed in Microform Appendix 7). In areas of high bore density, 1:100 000 Sheet areas are further subdivided into larger-scale maps, each of which has its own unique number within the 1:100 000 Sheet area. For example, the bore identified as 'WAIKERIE S-403-01 6829 002 SW 00046' contains the following information:

(1) the borehole is number 46 within the 1:100 000 Sheet area numbered 6829;
(2) it is located in the area of the larger-scale map number 2 within Sheet area 6829;
(3) the letters SW indicate that it is a stratigraphic well;
(4) under the old classification it was recorded as bore number 1 in Section 403 in the Hundred of Waikerie (County Albert).

In the Murray Basin subsurface stratigraphic database, we have simplified all bore numbers in South Australia to an eight-digit number that records the number of the 1:100 000 Sheet area and the number of the bore within the Sheet area; thus, in the example above, the borehole number becomes 6829-0046. Some boreholes, referred to in older reports, particularly north of the River Murray, did not fit into the old local government classification, and were described as 'out of hundreds', or 'out of counties'. These have now been assigned numbers, under the new classification, by the South Australian Department of Mines and Energy.

ASSESSMENT OF DATA RELIABILITY

The reliability of subsurface data in a given area depends on factors such as the density of boreholes in that area, the depth reached, and the quality of the available borelogs. The downhole stratigraphic data which we have compiled in the Murray Basin subsurface stratigraphic database are unevenly distributed and of variable quality. Consequently, the reliability of our interpretations also varies from area to area in the basin. Despite this variation, the stratigraphic data from the 3000 borelogs documented in the appendices have proved sufficiently reliable to enable us to develop a basin-wide subsurface stratigraphic framework (summarised below). However, owing to the increasing importance of hydrogeological investigations in the basin, we take this opportunity to critically assess the reliability of borehole data in terms of the distribution of the boreholes, the accuracy of locations and elevations, and the quality of drillers' logs. These factors are not especially critical to our understanding of the concealed geology of the basin, but may prove relevant to future assessment and modelling of the groundwater resources of the basin. Comments regarding our interpretations of borehole stratigraphy, in addition to recommendations for future investigations, are summarised in subsequent sections of this Report.

Borehole distribution

In New South Wales, extensive groundwater investigation and drilling programs undertaken by the Water Resources Commission have provided detailed coverage of areas flanking the eastern margin of the basin. Elsewhere in New South Wales, however, few stratigraphic control points are available from areas underlying the western Riverine Plain, the Willandra Lakes area, or the lower Darling River region, where interpretations of subsurface stratigraphy have therefore been based on correlation between widely spaced data points (e.g., see borehole locality maps for BALRANALD, BOOLIGAL, DENILIQUIN, HAY, and POONCARIE in Microform Appendix 6). In the northwest of the basin, near Menindee, a relatively even distribution of widely spaced boreholes is available, but we recommend the drilling of a new, fully cored stratigraphic bore in order to provide detailed lithostratigraphic and biostratigraphic control. The stratigraphy in the west of the basin in New South Wales, as documented in the appendices, has in part been determined by extrapolation of borehole interpretations from adjacent Victorian and South Australian parts of the basin.

In Victoria, detailed hydrogeological investigations have been undertaken by the Geological Survey in the southeastern Riverine Plain and around the northern flanks of the Victorian highlands. In northwestern Victoria, detailed groundwater investigations have also been undertaken in the Lake Tyrrell and Raak Plains areas. In addition, a relatively dense network of bores is located in a narrow zone extending westwards from Ouyen to the State border. A widely distributed bore network provides adequate stratigraphic control over much of the rest of northwest Victoria, though extensive parts of MILDURA, OUYEN, and SWAN HILL have few stratigraphic boreholes.

A dense network of boreholes is available throughout much of the South Australian part of the basin, where most properties are partly dependent on groundwater. However, areas with suitable supplies of surface water, such as the western part of NARACOORTE, contain few bores. Sparsely populated areas, such as CHOWILLA, contain widely spaced bores. In addition, wildlife reserves normally contain few, if any, bores.

In most areas of the basin, water-bores were terminated as soon as the drilling contractor struck good-quality groundwater. Consequently, in those areas underlain by near-surface aquifers with good water, few bores have been drilled into the deeper parts of the Cainozoic succession.

Accuracy of location of boreholes

Locations of boreholes used in this database were mainly derived from file sources, and - although some were plotted on unreliable topographic maps when they were drilled - they are considered to be sufficiently accurate for the development of reliable subsurface stratigraphic models of the basin. Borehole localities in the western New South Wales part of the basin are currently being checked for hydrogeological purposes, but the results are not yet available. The latitudes and longitudes annotated in the appendices were derived from digital plots, prepared in BMR, from borehole locality plans at a variety of scales supplied by State authorities.

Surface elevation of boreholes

Most petroleum exploration wells, stratigraphic bores, and groundwater observation bores in the basin are accurately levelled. However, the surface elevations of the majority of water-bores used in this study have not been surveyed, and hence the derived depth, thickness, and relative-level estimates are unlikely to be entirely accurate. We therefore suggest that detailed hydrogeological investigations are likely to be hampered by a lack of an evenly distributed network of boreholes with accurately surveyed surface elevations.

Levelling of boreholes has varied in quality from elevations which are accurate to the nearest centimetre in recent stratigraphic bores, to a total absence of a recorded elevation for most water-bores. The drillers of many water-bores originally estimated elevation to the nearest 'ten or twenty-five feet'. Following conversion from imperial to metric units this has resulted in an inordinate number of bores with apparently accurate surface elevations of say 46 m, 61 m or 76 m, which are in reality accurate only to within 10 m.

For some bores, we have had to estimate elevations from the appropriate 1:100 000 and 1:250 000 topographic maps, most of which have a contour interval of 20 m. In flat-lying areas these estimates may be relatively accurate, but, in the more rugged terrain near the basin margins, estimates of surface elevations are likely to be less accurate; for example, we suspect that our estimated elevations of bores drilled in BURRA, OLARY, and parts of ADELAIDE and CHOWILLA are likely to contain inaccuracies. Bores which contain useful stratigraphic information, but for which the estimated elevation is thought to be dubious, have been included in this Report, even though they are unsuitable for the purpose of structure contouring. Elsewhere, in the undulating aeolian landscapes of the western Murray Basin, estimates of surface elevations of some boreholes may contain errors of up to 20 m.

Boreholes with measured elevations are mainly levelled to the Australian Height Datum, but, in South Australia, some bores recorded in older reports were levelled against a geographic datum in Adelaide which was 105.78 feet (32.21 m) above the AHD. Fortunately, bores using this datum are readily identified when compared with more recently drilled holes in the same area. The Geological Survey of South Australia has recently undertaken a program of levelling existing bores, which will help to alleviate the problem of unreliable borehole elevations in that State. Similar programs are required elsewhere in the basin if borehole data are to be fully utilised.

Quality of lithologic logs of boreholes

The quality of lithologic logs of boreholes is highly variable throughout the basin. In South Australia, for example, the available dataset of 27 800 bore records proved to contain some 5000 suitable logs; because many of these are concentrated in very small areas, we have selected only the deepest and most reliable logs for the database. In places with a high density of bores, such as in RENMARK and PINNAROO, the criteria that we adopted to select bores were, firstly, the quality of the geologic log and, secondly, the location, in order to allow a reasonable spacing between data points while ensuring that as wide an area as possible was covered.

In northern and central parts of the basin, where bore data are sparse, we have attempted to interpret bores with poor-quality lithologic logs. A number of difficulties were experienced in interpreting drillers' logs from such water-bores; for example, such terms as 'boiling drift', 'rock', and 'sludge' have been tentatively interpreted in the context of the general stratigraphy of the particular part of the basin in which the bore was drilled.

GEOLOGY OF THE MURRAY BASIN AND UNDERLYING STRATOTECTONIC ELEMENTS - A SUMMARY

The following summary of the geology of the Murray Basin and underlying stratotectonic elements is presented as a reference to the stratigraphic units listed in the appendices. A synoptic description of each individual stratigraphic unit is given in Table 2, but detailed descriptions are documented elsewhere (Brown & Stephenson, in preparation). In the following text the letter symbols in brackets correspond to the symbols used in the appendices to denote particular stratigraphic units or stratotectonic assemblages. These are identical with symbols used on a 1:1 000 000 geological map of the basin (Brown & Stephenson, 1985).

Tectonic framework

The Murray Basin is a low-lying saucer-shaped intracratonic basin containing thin flat-lying Cainozoic sediments which extend over an area of 320 000 km^2 of southeast South Australia, western New South Wales, and northwest Victoria (Fig.1). The Cainozoic succession unconformably onlaps Proterozoic basement rocks of the Willyama and Broken Hill Basement Blocks in the northwest, and Proterozoic and lower Palaeozoic sedimentary rocks and metasediments of the Adelaide and Kanmantoo Fold Belts in the west (Fig.14). The Proterozoic and lower Palaeozoic tectonic elements together form subdued mountain ranges flanking the western margin of the basin. To the east and south, the basin is flanked by deformed Cambrian to Lower Carboniferous rocks of the Lachlan Fold Belt, forming the ranges of the Eastern Highlands. To the north, the Cainozoic sequence onlaps low hills of folded Upper Silurian to Lower Carboniferous sedimentary rocks of the Darling Basin (a late-stage component of the Lachlan Fold Belt). The southwest boundary of the basin is here taken as the Padthaway Ridge, a largely concealed basement high of lower Palaeozoic rocks, which separates the Murray Basin succession from the Southern Ocean and from the contiguous Cainozoic sequence of the Gambier Embayment of the adjacent Otway Basin; however, Cainozoic stratigraphic units which occur onshore between the southwest flank of the Padthaway Ridge and the coast are also included in the database.

Pre-Cainozoic stratotectonic elements

At the western margin of the Murray Basin (Fig.14), the Cainozoic sediments are flanked by a thick succession of folded and thrust-faulted Adelaidean (Late Proterozoic) to Cambrian fluvio-deltaic, shallow-marine, and lagoonal clastics, with minor carbonates and tillites (P̲s - sedimentary rocks of the Adelaide Fold Belt; Parkin, 1969; Thomson, 1969; Preiss,1979; Rutland & others, 1981; Brown, Cooper & others, 1982). Minor Late Proterozoic volcanics (P̲v) and metamorphics (P̲m) also occur. To the northwest the Adelaidean rocks are virtually unmetamorphosed, but metamorphic grade increases to the southeast, towards the margin of the Murray Basin. Beneath the western margin of the basin, Adelaidean rocks have been encountered by mineral exploration bores in MENINDEE (Wecker, 1971; Morgan, 1973), and by stratigraphic bores in CHOWILLA and OLARY (Rogers, 1978; Lindsay, 1983; listed in Microform Appendix 3). The Adelaidean sedimentary rocks are thought to have been deposited over high-grade metamorphics of the Willyama and Broken Hill Basement Blocks (pЄ; Willis & others, 1983).

East of the Adelaide Fold Belt, Cambrian phyllite, slate, metagreywacke, and gneiss crop out on the eastern flanks of the Mount Lofty Ranges, and are thought to underlie much of the southwestern Murray Basin (Єs - sediments, and Єm - metamorphics, of the Kanmantoo Fold Belt; Thomson, 1969; Daily & Milnes, 1972, 1973; Daily & others, 1976; Von der Borch, 1980; Brown, Cooper & others, 1982; Cook, 1982). Folding and metamorphism of the Kanmantoo Fold Belt, and foreland folding and thrusting of the Adelaide Fold Belt, occurred in the Late Cambrian-Early Ordovician (Delamerian Orogeny). Deformation was accompanied by deposition of locally preserved shallow-marine and non-marine sediments of Cambro-Ordovician age (ЄOs; e.g., in the Scopes Range area, Fig.14; Webby, 1978) and both accompanied and followed by synorogenic and postorogenic emplacement of granitoids (Og). The metamorphics and Ordovician granitoids have been encountered in boreholes in the Padthaway Ridge area of southeast South Australia. Similar metamorphics also crop out in the Glenelg area in western Victoria, and are herein correlated with the metamorphics of the Kanmantoo Fold Belt. They are thought to be Cambrian in age, but probably also include metamorphosed rocks of Adelaidean age.

The Lachlan Fold Belt is a composite tectonic feature which flanks the Murray Basin to the east, south, and north, and underlies much of the basin (Packham,1969; Douglas & Ferguson, 1976; Rutland, 1976; Scheibner,1976; Vandenberg, 1978; Cas, 1983). Where exposed in the topographically elevated areas, it mainly consists of northerly trending anticlinorial and synclinorial folded slate belts and granite terrains. The fold belt is also intensely fractured by superimposed, northerly trending horst-and-graben structures. Deformation ranges from intensely folded, faulted, and metamorphosed to the east and south of the basin, to mildly folded but block-faulted to the north of the basin. In the south and east, the fold belt consists of Cambrian to Lower Carboniferous folded sediments (ꞒOs, Os, SDls, DCls), metasediments (ꞒOm, Om), and basic to intermediate volcanics (SDv) intruded by granitoids (Og, SDg). Structural zones within the Lachlan Fold Belt are, in places, separated by northerly trending linear greenstone belts (Ꞓv), including basic volcanic and possible serpentinised ophiolite complexes.

Beneath the Murray Basin, rocks of the Lachlan Fold Belt have been

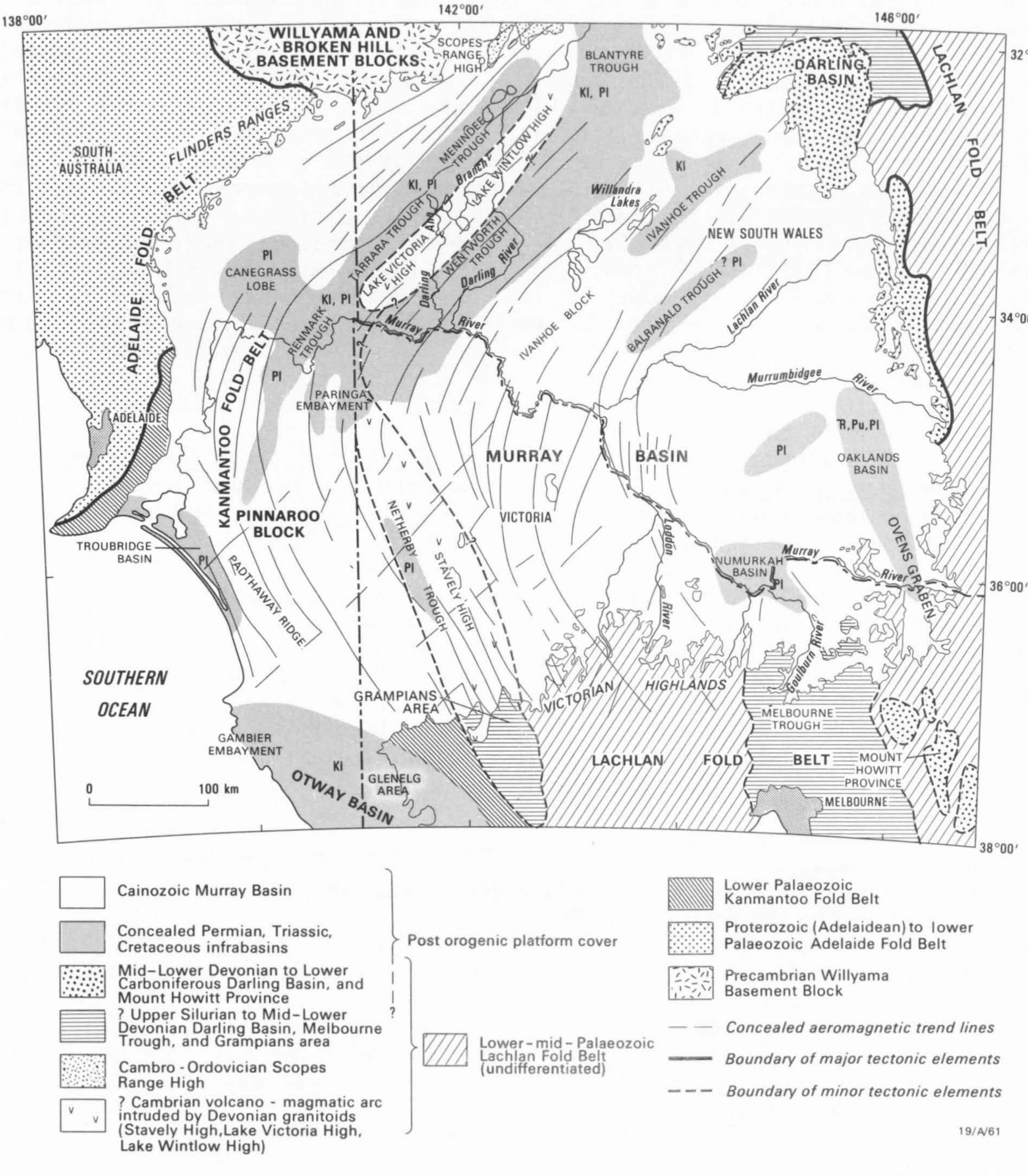

Fig.14. Framework tectonic elements and underlying infrabasins.

encountered in several hundred of the boreholes listed in Microform Appendix 3. Many of these are clustered around the basin margins, where correlation of the basement type with the exposed rocks of the adjacent fold belt is relatively simple. Towards the more central parts of the basin, there are far fewer data points, and correlations are correspondingly less certain. Comments regarding identification of basement types are presented in the individual bore summaries in Microform Appendix 4.

Regional aeromagnetic and Bouguer gravity data indicate the presence of arcuate structural zones which trend to the north-northwest beneath the southern Murray Basin and to the northeast beneath the northern and western Murray Basin (Fig.14). These geophysically defined arcuate trends parallel those apparent in the adjacent Adelaide Fold Belt to the west. The trends beneath the southern Murray Basin are also contiguous with structural trends exposed in the adjacent Victorian highlands to the south. However, beneath the northern Murray Basin, the northeasterly aligned trends contrast with north-northwesterly structural trends apparent in intensely deformed Palaeozoic rocks of the Lachlan Fold Belt exposed at the eastern margin of the basin. This discontinuity is particularly well expressed in the gravity data (e.g., fig.4 of Wyatt & others, 1980).

Folding and metamorphism of post-Ordovician components were less intense in the northwestern part of the Lachlan Fold Belt, where an extensive former ?foreland zone of ?Upper Silurian to Lower Carboniferous (mainly Devonian) sedimentary rocks (SDls, DCls) flanks and partly blankets the composite orogenic belt. These rocks, now exposed in the Darling Basin to the north, are block-faulted, broadly folded, and indurated, but are unmetamorphosed, and form a transitional province between the Lachlan Fold Belt orogenic domain and younger platform cover sequences (Doutch & Nicholas, 1978). Infrabasins containing similar block-faulted Devonian sedimentary rocks underlie northern and western areas of the Murray Basin.

<u>?Upper Silurian-Devonian to Lower Carboniferous infrabasins concealed beneath the Murray Basin</u>. Interpretations of gravity, aeromagnetic, and seismic data suggest that troughs beneath the western and northern Murray Basin contain thick block-faulted but relatively undeformed, ?Upper Silurian to Lower Carboniferous sedimentary rocks (Evans, 1977; Bauer & others, 1979). Similar but thinner sedimentary accumulations extend over intervening basement highs beneath the northern Murray Basin, and are contiguous with the weakly deformed sediments of the Darling Basin to the north. Petroleum exploration wells, such as Tarrara No.1 (Boyd & Heisler, 1967) and Blantyre No.1 (Campe & Cundill, 1965), in addition to several water-bores in MANARA, indicate that these rocks are mainly Devonian in age, but the troughs may also contain older Palaeozoic rocks. On the basis of correlation with areas of outcrop to the north, the thick succession can tentatively be divided into two major sequences (Brown, Jackson & others, 1982).

The lower sequence is thought to consist of ?Upper Silurian to mid-Lower Devonian marine siltstone and shale with shallow-marine sandstones towards the top (SDls - equivalent to the Amphitheatre Group and Winduck Group of the Darling Basin; Baker, 1978; Glen, 1979, 1982).

The upper depositional sequence consists of thick block-faulted, broadly warped mid-Lower Devonian to Lower Carboniferous coarse-grained fluviatile and lacustrine sandstone, conglomerate, and minor red shale (DCls - equivalent to the Mulga Downs Group of the Darling Basin; Packham, 1969; Webby, 1972; Glen, 1979). As discussed by Brown, Jackson & others (1982) the presence of ?Upper Silurian-Lower Devonian marine rocks has not yet been established in the westernmost troughs (Menindee, Tarrara, and Renmark Troughs, Fig.14), where the succession may be entirely continental and may include correlatives of ?Upper Silurian-Lower Devonian quartzose sandstone, red siltstone, and mudstone (Grampians Group of Spencer-Jones, 1976) exposed in the Grampians area, to the south of the Murray Basin.

Development of the Lachlan Fold Belt was terminated in the Early Carboniferous, and was followed by deposition of thin Permian to Recent postorogenic platform cover sediments (Doutch & Nicholas, 1978).

Permian, Triassic, and Cretaceous platform cover. Petroleum exploration wells, mineral exploration bores, and deep stratigraphic bores have revealed the presence of thin erosional remnants of Permian (Pl, Pu), Triassic (TRm), and Cretaceous (Kl) platform cover sediments in many of the troughs and depressions beneath the Murray Basin (Fig.14).

Widespread but discontinuous remnants of Lower Permian glaciomarine sediments (Pl) consist mainly of shallow-marine diamictite, with minor siltstone, sandstone, and conglomerate, and are often characterised by the presence of angular granite clasts (O'Brien, 1981).

In the Oaklands Basin, overlying Ordovician rocks of the Ovens Graben (Fig.14), the petroleum exploration well Jerilderie No.1 (Wright & Stuntz, 1962) and numerous boreholes drilled by the Mines Department of New South Wales and mineral exploration companies have indicated that the Lower Permian sedimentary rocks (Pl) are disconformably overlain by extensive Upper Permian rocks (Anglo American, 1970; Coles, 1972; Haynes, 1973; Palese, 1974; Yoo, 1981, 1982), which form a composite unit consisting of at least three disconformably stacked upward-fining fluvial sequences - including coal seams (Pu - Coorabin Coal Measures; Morgan, 1977). Equivalents of these non-marine Upper Permian sedimentary rocks may occur within other troughs elsewhere in the basin, but have not yet been identified. In the Oaklands Basin, the Upper Permian rocks are in turn disconformably overlain by a mid-Triassic unit of fluvial quartzose sandstone, pebble conglomerate, and mudstone (TRm - Jerilderie Formation; Morgan, 1977). The Triassic sediments were previously thought to be Palaeogene in age; they are lithologically similar to basal Tertiary sands occurring elsewhere in the basin, and hence may be more widely distributed than is currently known.

Jurassic rocks have not yet been identified beneath the Murray Basin, but thin remnants of fluviatile and shallow-marine Lower Cretaceous sediments (Kl) have been intersected by petroleum exploration wells and deep bores (e.g., Olney No.1; Lawrence, 1975) drilled into the troughs and depressions beneath the western and northern Murray Basin (Fig.14; Evans & Hawkins, 1967). In the Renmark Trough in South Australia, Thornton (1974) identified three members within a sequence of Aptian-Albian rocks (Kl - Monash Formation). The basal Pyap Member consists of pale grey, weakly cemented sandstone interbedded with minor mudstone, coal, and conglomerate; it is mainly fluvial, but towards the top includes glauconitic marine intercalations. The succeeding Merreti Member consists of marine mudstone, siltstone, and minor sandstone. It is overlain by the Coombool Member, a fluvio-lacustrine unit of greenish grey chloritic volcanolithic siltstone, sandstone, and shale.

In adjacent areas of northwest Victoria, Lawrence (1976a) identified a mainly fluviatile and lacustrine succession containing only minor marine influences (Kl - Millewa Group, consisting of two component formations). Medium to coarse quartz sandstone at the base (Taparoo Formation) is overlain by interbedded siltstone, mudstone, and minor sandstone (Morkalla Formation).

To the northeast, in New South Wales, scattered occurrences of Albian marine and Aptian-Neocomian non-marine carbonaceous rocks have been encountered in the Ivanhoe area (Fig.14; Byrnes, 1980).

The extent of Lower Cretaceous rocks beneath the Murray Basin is uncertain, and they may be lithologically more variable and more widely distributed than is currently known.

The Cainozoic succession of the Murray Basin forms an extensive blanket of sediment, and consists of a maximum thickness of about 600 m preserved in the deeper, west central part of the basin. In the northern, eastern, and southern parts of the basin, the sediments are generally less than 200-300 m thick. Within the Tertiary succession, at least three major depositional sequences (Paleocene-Eocene to Lower Oligocene, Oligocene-Middle Miocene, and Upper Miocene-Pliocene) have been identified (Brown, 1983, 1985; Brown & Stephenson, in preparation). Each sequence consists of a package of genetically related formations separated by disconformities. Non-marine sand, silt, clay, and carbonaceous sediments predominate in the east and north, but each of the depositional sequences includes marine sediments in the centre and southwest. Each sequence also forms a thin but remarkably continuous veneer of sediment, despite evidence of minor differential subsidence over underlying infrabasins (e.g., cross-sections shown in Brown & Stephenson, 1985). The Cainozoic succession therefore appears to have been deposited over a topographically flat low-lying platform that was potentially susceptible to partial flooding by epicontinental seas. In terms of basin geometry, the sediments of the basin could probably be more accurately described as forming a thin platform cover succession rather than a true basinal sequence.

Tertiary depositional sequences

Paleocene-Eocene-Lower Oligocene depositional sequence. At the base of the Tertiary succession (Fig.5), deep bores drilled into the more central parts of the Murray Basin (listed in Microform Appendix 2) have encountered a fluvial unit of unconsolidated medium to coarse quartz sands with minor intercalated carbonaceous fine sand and clay (Tew - Warina Sand of the Renmark Group, Ter; Tew includes equivalent 'lower Renmark beds' in South Australia; Harris, 1966; Thornton, 1974; Lawrence, 1975). Limited palynological evidence suggests that this unit is mainly of Paleocene-Eocene age. Borehole logs indicate that it consists of massive multistorey sand bodies which coalesce to form an extensive sand sheet.

Numerous boreholes throughout the basin indicate that the Warina Sand is overlain by a much more widely distributed blanket of unconsolidated, thinly bedded fluvio-lacustrine carbonaceous sand, silt, clay, and peaty coal, which extend across most of the Murray Basin (Teo - Olney Formation of the Renmark Group, Ter; Teo includes equivalent 'upper Renmark beds' in South Australia; Harris, 1966; Pels, 1969; Lawrence, 1975; the distribution of the Renmark Group is shown in Fig.15). The Olney Formation appears to conformably overlie the Warina Sand, but the exact relationship between the two units is unclear owing to poor age control within the basal sandstone unit. Deposition of the Olney Formation was restricted to the Eocene-Early Oligocene in the west, but continued into the Middle Miocene in the north and east. During this extended period of sediment accumulation (Eocene to Middle Miocene) only 300 m of sediment were preserved, and deposition was probably intermittent. The succession thus contains a number of stratal breaks, both locally and on a regional scale. The most prominent hiatus occurred in the early Late Oligocene (or possibly late Early Oligocene), accompanying a fall in sea level (Brown, 1985), but the extent and duration of the break may vary across the basin. Oligocene-Miocene components of the Renmark Group are lithologically indistinguishable from Eocene-Lower Oligocene components, and the variously dated components are herein regarded as parts of a single lithologically distinct unit.

Towards the top of the Olney Formation in the west, micropalaeontological evidence from several petroleum exploration wells and stratigraphic bores (e.g., Lawrence & Abele, 1976) indicates that the unit includes paralic and minor marine components. In the southwest, water-bores in PINNAROO and NARACOORTE indicate that these components interfinger with Late Eocene (? to Early Oligocene) shallow-marine sediments of the Buccleuch beds (Teb; Fig.16; Ludbrook, 1961), which consist of glauconitic calcareous clay, carbonaceous sand with thin limestone lenses, and bryozoan limestone. Deposition of the Buccleuch beds was mainly confined to a palaeogeographic feature known as the Buccleuch Embayment (Fig.17).

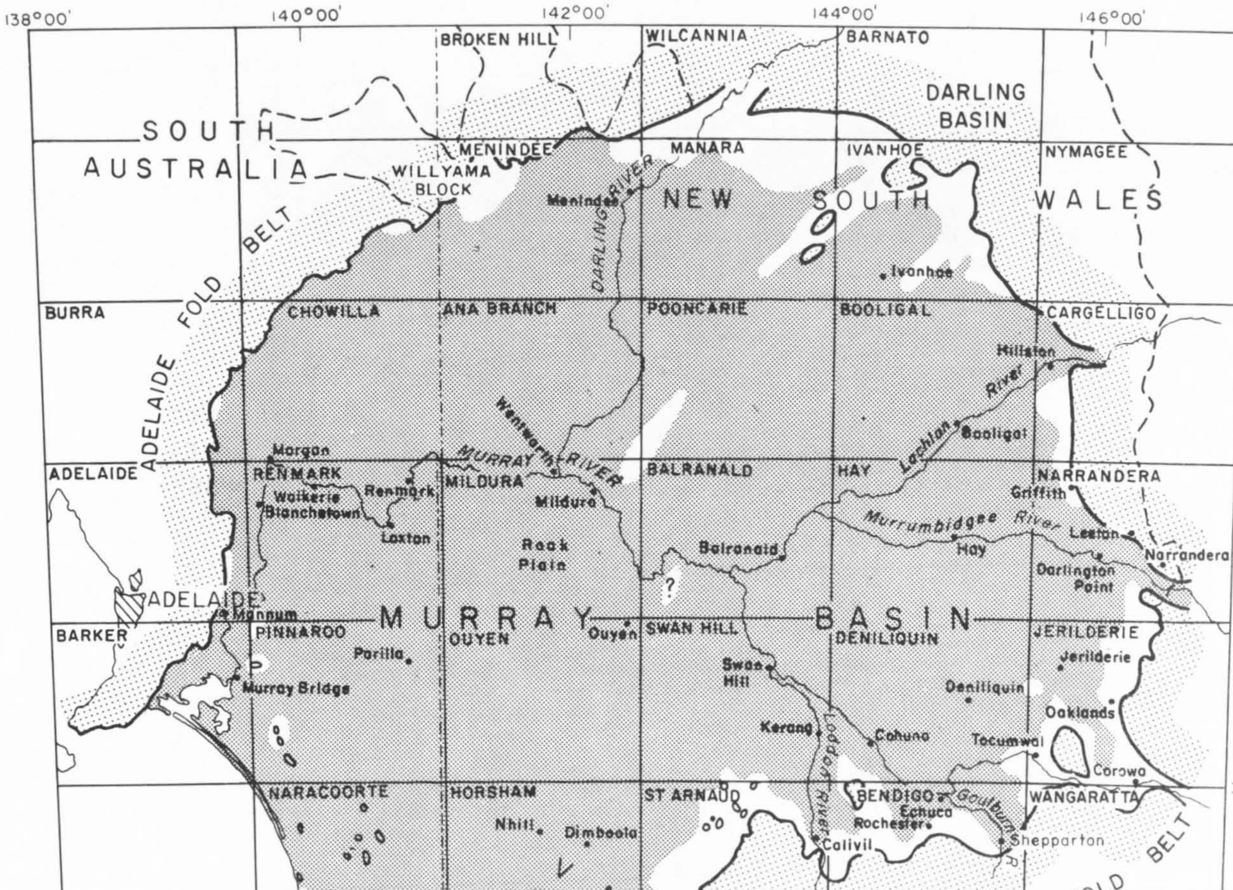

Fig.15. Distribution of the Renmark Group.

Oligocene-Middle Miocene depositional sequence. A major relative rise in sea level in the mid-Oligocene was accompanied by a major change in sedimentation patterns in the western Murray Basin, and can be correlated with deposition of the component formations of the Oligocene to Middle Miocene Murray Group sequence (Toe - Ettrick Formation, Fig.18; Tml - Gambier Limestone, Mannum Formation, Morgan Limestone, Pata Limestone, Duddo Limestone, Fig.19; Tmw - Winnambool Formation, Fig.20; Tmg - Geera Clay, Fig.21). Palaeogeographic reconstructions suggest that a shallow-marine platform in the southwest was flanked to the east and north by a narrow zone of restricted marine and lagoonal environments. These were in turn bordered by a marginal marine zone - including extensive interdistributary bays and tidal flats - further flanked by peat-forming swamps and deltaic and fluvial environments (see palaeogeographic diagrams in Brown, 1985; Brown & Stephenson, 1985, in preparation).

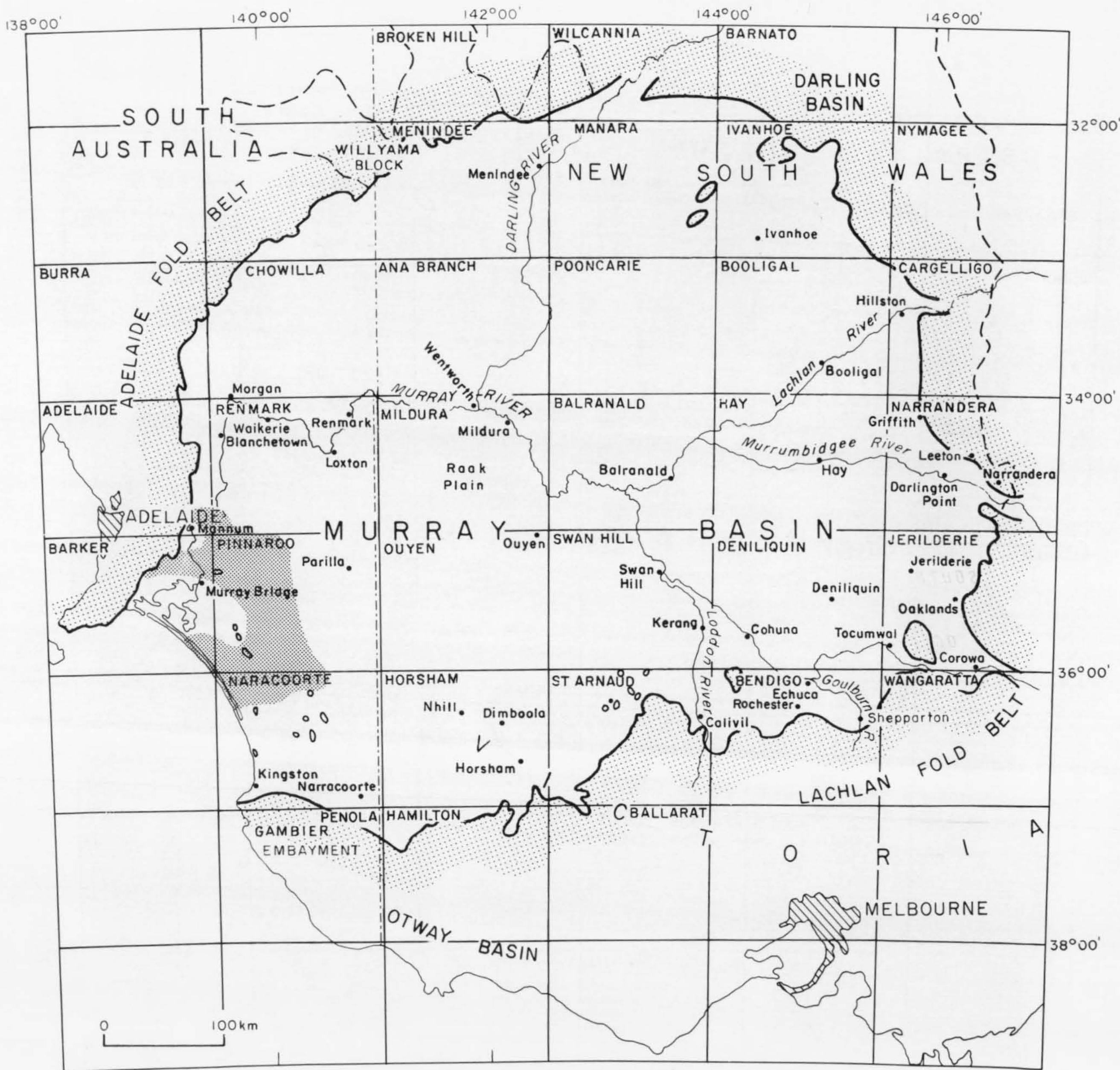

Fig.16. Distribution of the Buccleuch beds.

During the initial marine transgression in the Oligocene, glauconitic calcareous clay (marl) of the Ettrick Formation (Ludbrook, 1961) accumulated over the platform. As sea level continued to rise, the calcareous clay was succeeded by shallow-marine Late Oligocene to Middle Miocene calcarenite consisting of coarse-grained skeletal debris and quartz sand (Tml; Ludbrook, 1957, 1961, 1963; Lindsay & Bonnett, 1973; Lawrence, 1975). To the north and east, the calcarenite grades into a narrow zone of glauconitic calcareous clay (Tmw - Winnambool Formation; Lawrence, 1975) deposited in the restricted platform and lagoonal environments; the Winnambool Formation is essentially a younger diachronous equivalent of the lithologically similar Ettrick Formation. The calcareous clay in turn grades laterally into extensive black, locally carbonaceous clay with minor dolomite (Tmg - Geera Clay; Lawrence, 1975; Lawrence & Abele, 1976); these were deposited in the marginal marine,

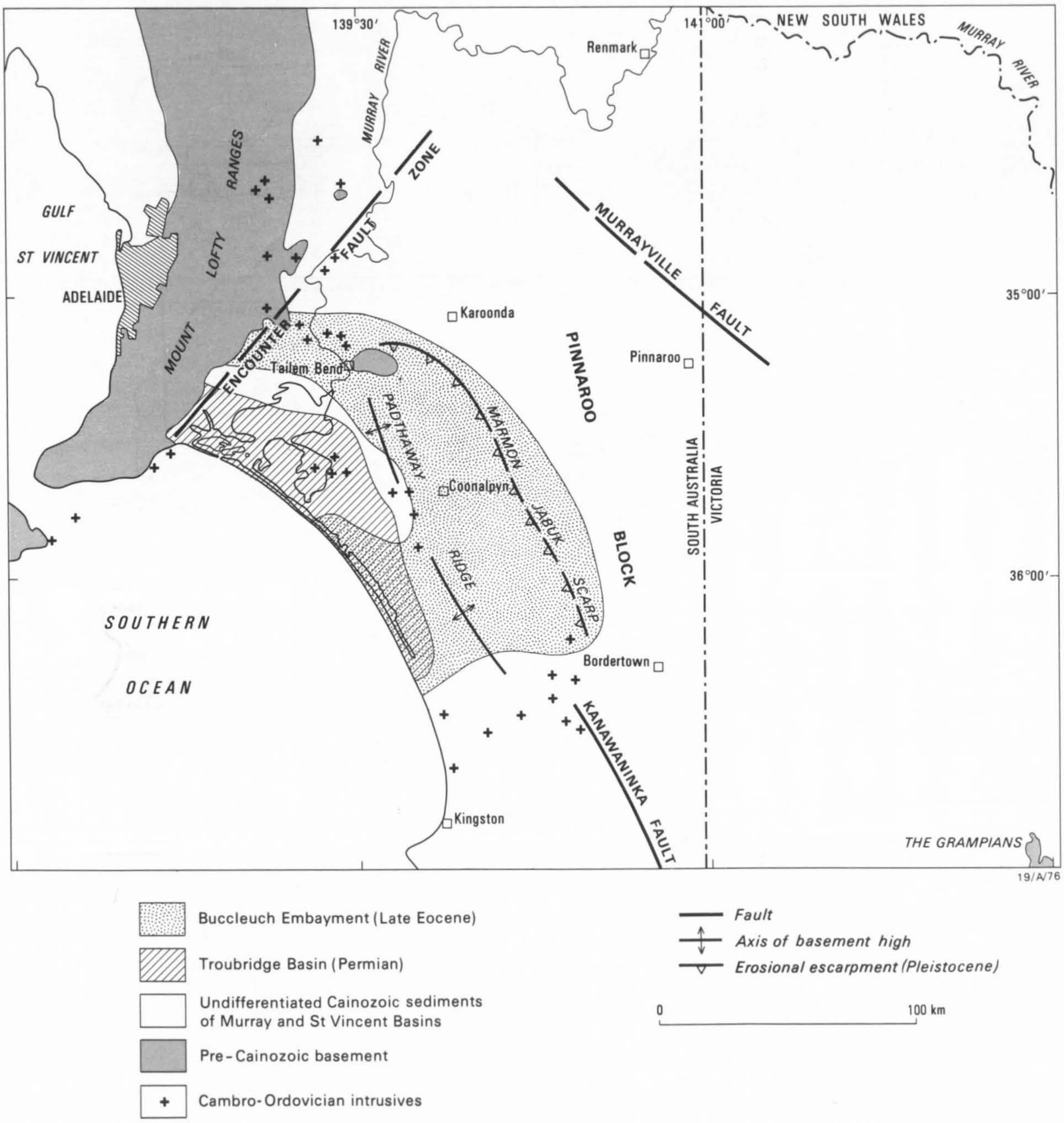

Fig.17. Location of the Buccleuch Embayment.

interdistributary-bay and tidal-flat environments. To the north and east the Geera Clay in turn interfingers with fluvio-lacustrine sand, silt, clay, and peaty coal (further Teo - Olney Formation). As noted above, the Miocene fluvial sediments are lithologically indistinguishable from the underlying Eocene fluvial sediments, and hence are included in the Olney Formation. Deposition of the Murray Group sequence was terminated in the Middle Miocene by a further major marine regression.

In the southwest of the basin, and particularly in southeast South Australia, many thousands of water-bores have been drilled into water-bearing calcarenite of the Murray Group. Only the deeper bores with good-quality lithologic logs have therefore been listed in Microform Appendix 2. Fewer bores have been drilled into the Ettrick Formation, Winnambool Formation, and Geera Clay, and hence - for these formations - all boreholes with reasonable

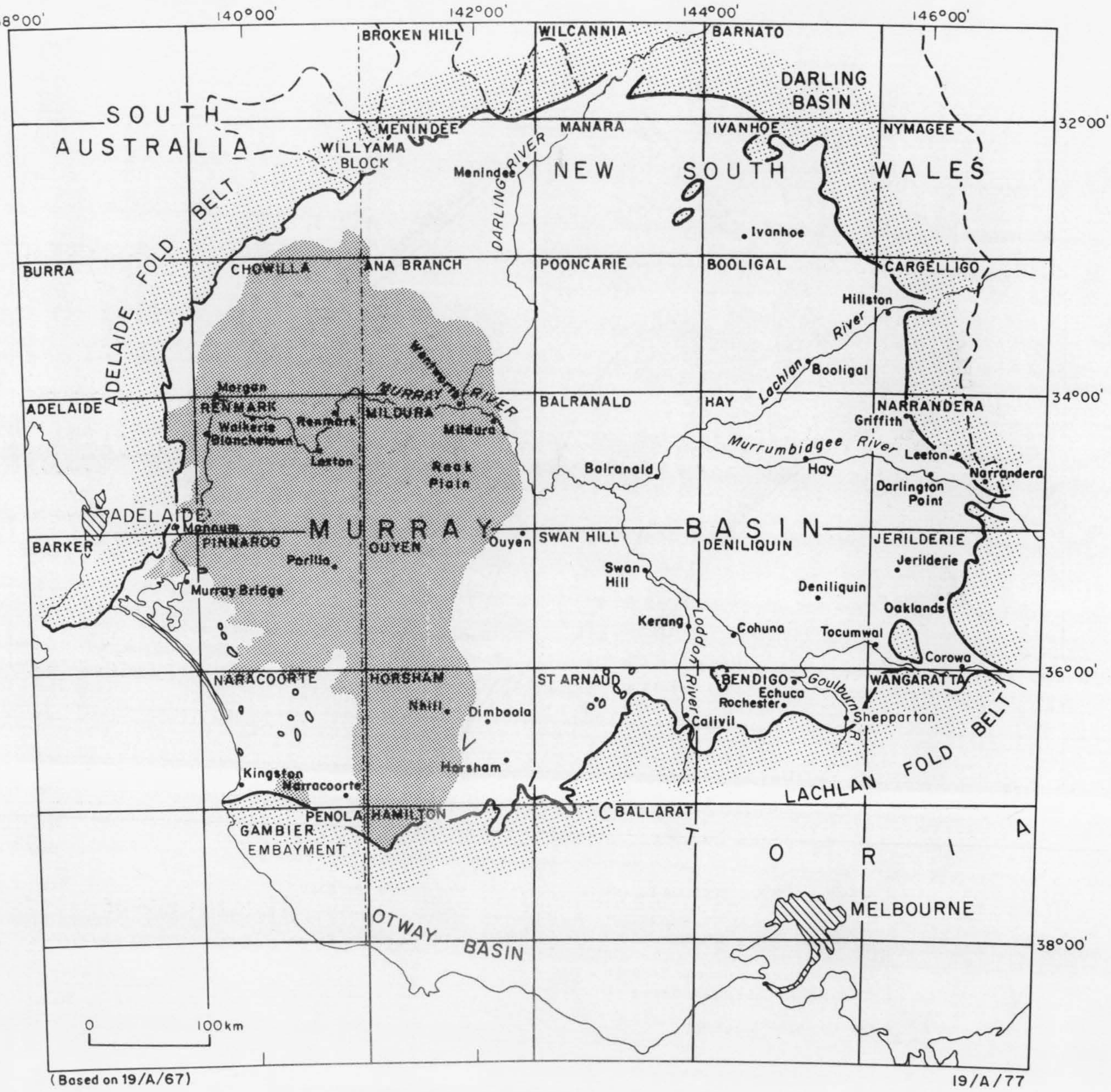

Fig.18. Distribution of the Ettrick Formation.

lithologic logs have been included in the microform datasets.

Upper Miocene-Pliocene depositional sequence. Initiation of the last major Tertiary depositional sequence of the basin can be correlated with a further short-lived marine transgression in the Late Miocene-Pliocene (Brown, 1983). Palaeogeographic reconstructions suggest that a fluvial flood plain in the east and north was flanked to the west and south by an extensive strand-plain environment of prograding beach ridges separated by inter-ridge fluvial and estuarine quartz sand deposits (Brown, 1985; Brown & Stephenson, 1985). In the west the flood plain was connected to the Southern Ocean by a zone of fluvial and estuarine environments that roughly coincided with the present-day course of the River Murray.

The marine transgression in the Late Miocene initially resulted in the

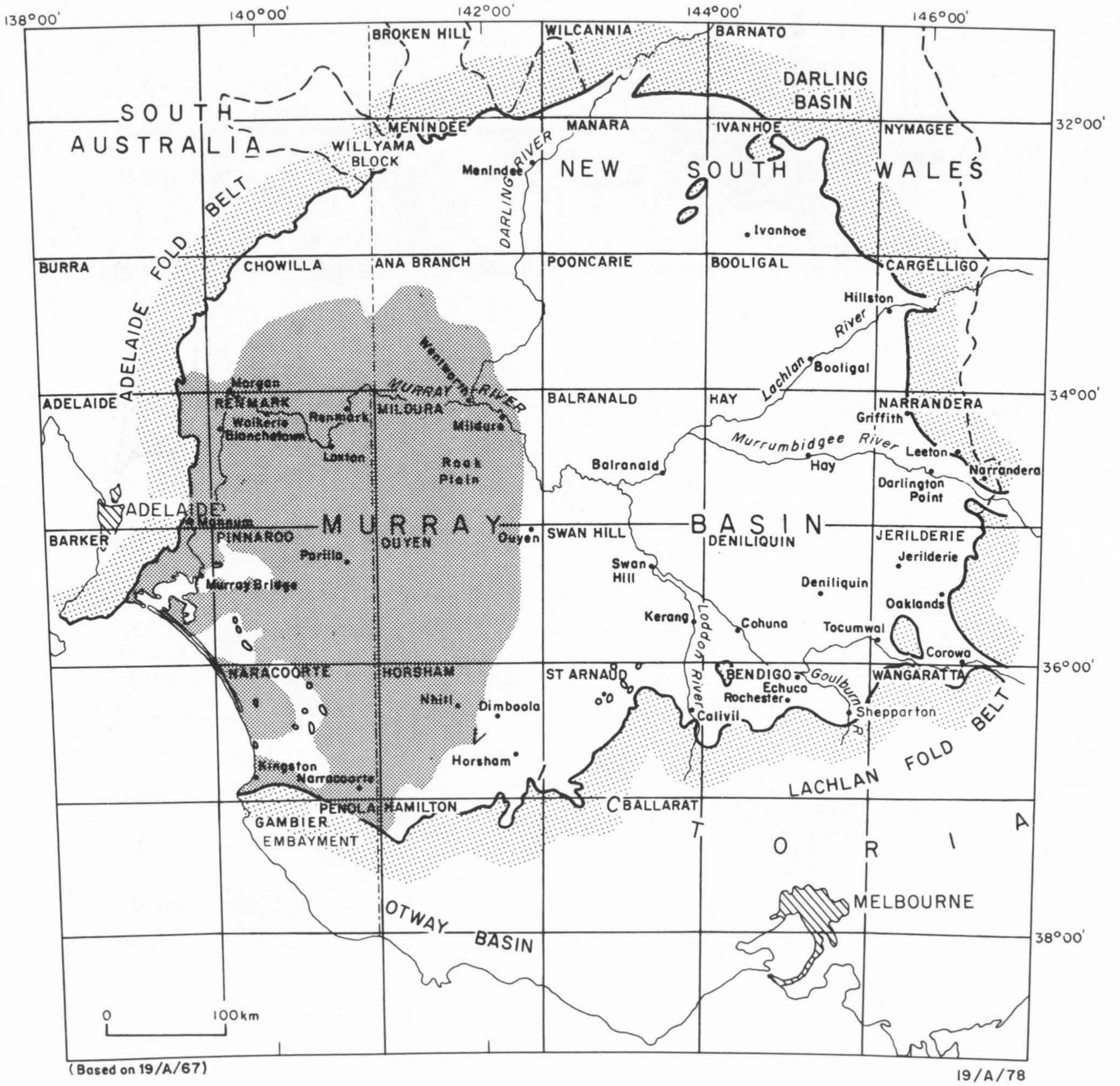

Fig.19. Distribution of the Murray Group calcarenite formations.

deposition of marine clay of the Bookpurnong beds (Tpb; Fig.22) and marginal marine sand of the basal Loxton Sands and Parilla Sand (Tps; Fig.23). Coarse-grained quartzose sand and gravel of the fluvial and fluvio-lacustrine Calivil Formation were deposited farther inland, where they form a sand sheet underlying much of the eastern and northern Murray Basin (Tpc; Fig.24; Lawrence & Abele, 1976; Macumber, 1978a). They were also deposited within previously incised highland palaeovalleys at the basin margins, which were backfilled to form the youngest of several Tertiary gold-bearing deep-lead systems in northern Victoria.

The subsequent marine regression in the Pliocene resulted in deposition of the extensive quartz sand sheet of the prograding strand plain (Tps - upper Loxton Sands and Parilla Sand; Fig.23; Ludbrook, 1961; Firman, 1973; Lawrence, 1975; Macumber, 1978a). During a minor subsequent high stand of sea level, in

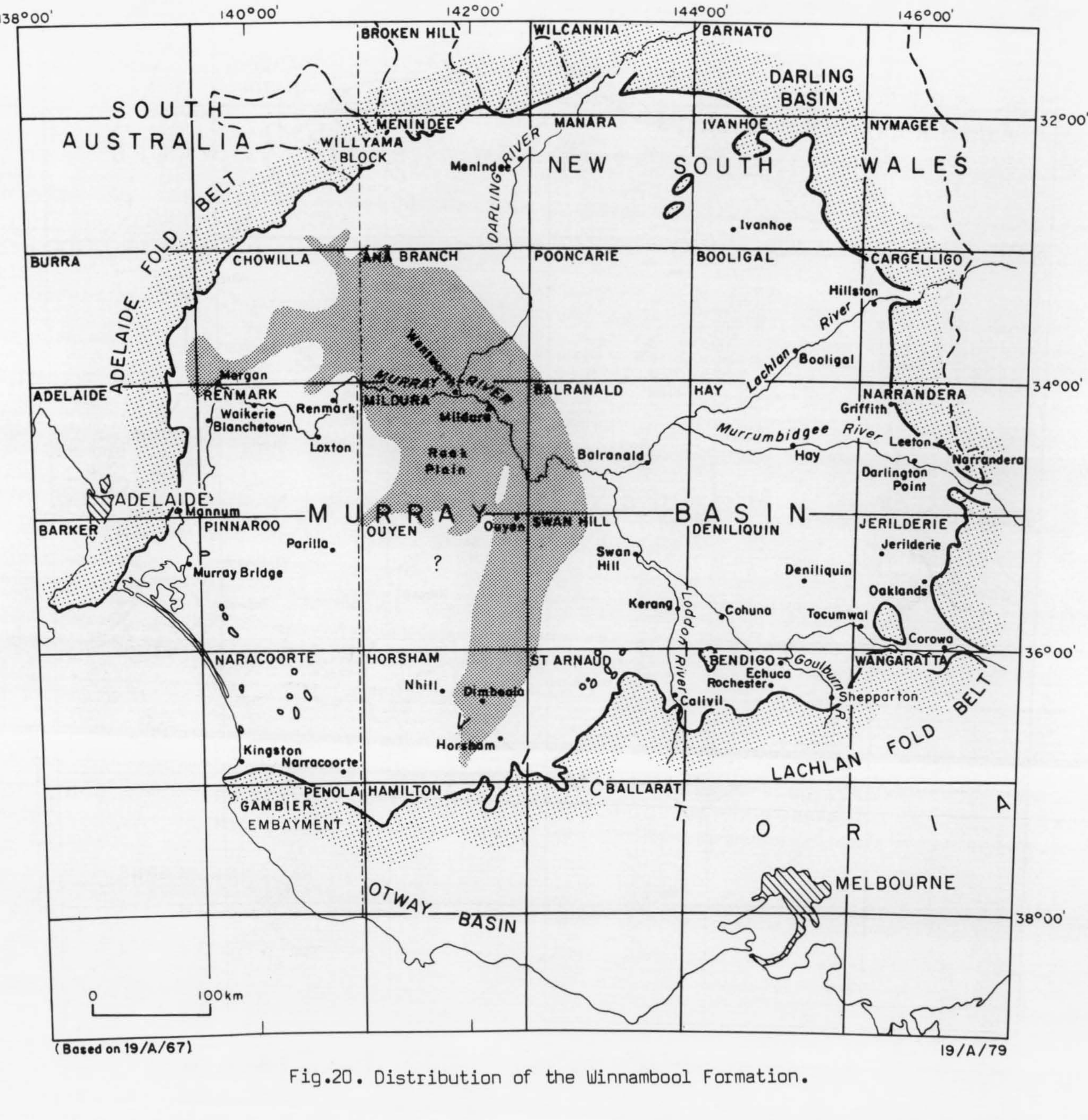

Fig.20. Distribution of the Winnambool Formation.

the Late Pliocene (Twidale & others, 1978), oyster beds of the Pliocene Norwest Bend Formation were deposited in an ancestral estuary of the River Murray at the western margin of the basin (Tpn; Fig.25; Ludbrook, 1961). In the east the Pliocene regression can be correlated with deposition of fine-grained clastics and polymictic sand and gravel of the Shepparton Formation by aggradation in a flood plain-environment (TQs; Fig.26; Lawrence, 1975).

Quaternary sediments

In the east and north of the Murray Basin, aggradational fluvio-lacustrine sedimentation continued into the Pleistocene, resulting in the development of the flat-lying Riverine Plain (further TQs - Shepparton Formation; Fig.26). Farther west the Tertiary is partly overlain by a thin veneer of Pleistocene

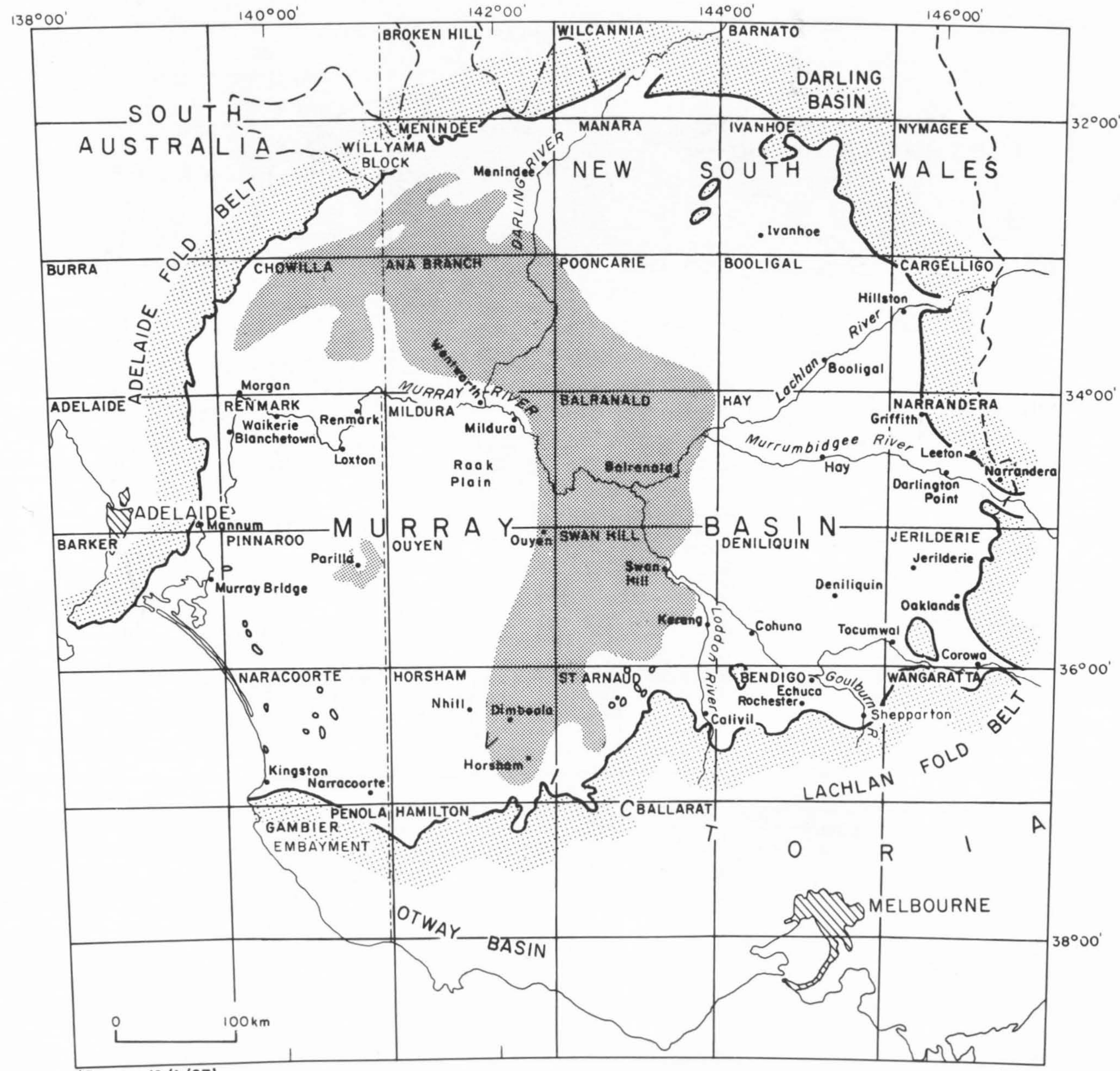

Fig.21. Distribution of the Geera Clay.

fluvio-lacustrine clay (Qpc - Blanchetown Clay; Firman, 1973; Lawrence, 1975), almost entirely concealed beneath an arid and semi-arid landscape of Quaternary aeolian dunefields (Qdw - Woorinen Formation; Qdm - Molineaux Sand in South Australia and Lowan Sand in Victoria). Surface drainage is almost entirely absent in the west, apart from the entrenched courses of the Murray and Darling Rivers. Farther east, the Riverine Plain is drained by the extensive distributary networks of the Murray, Murrumbidgee, Lachlan, Ovens, Goulburn, and Loddon Rivers. Fluvial sedimentation continues within the confined flood plains of these modern rivers, which are entrenched within older fluvial and aeolian landscapes (Qa - Coonambidgal Formation and other undivided alluvial deposits).

Throughout the basin, small but numerous and widely distributed occurrences of lacustrine surficial units are also present (Ql - lacustrine clays; Qly - Yamba Formation and other undivided saline lake deposits). Lunette deposits

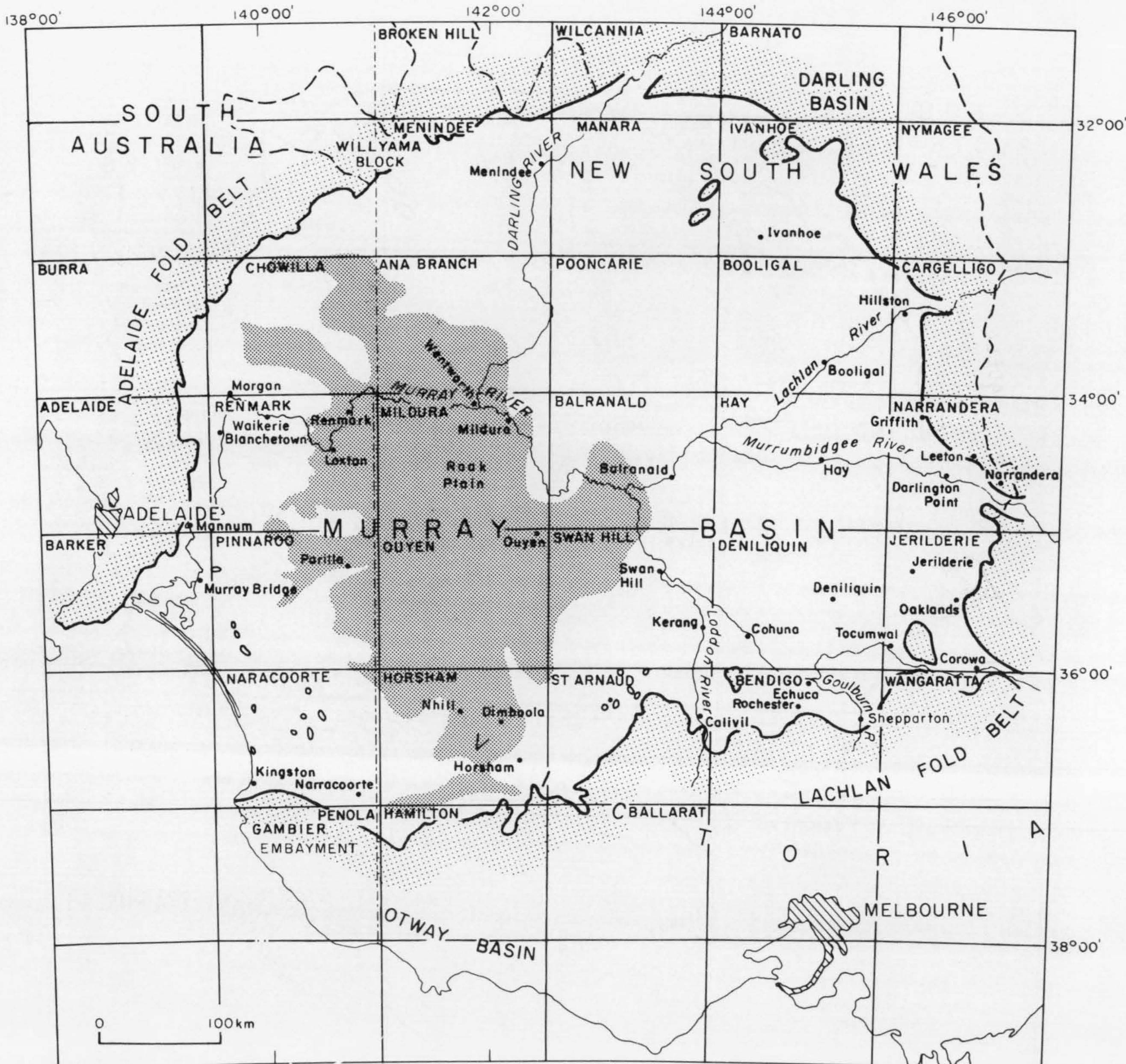

Fig.22. Distribution of the Bookpurnong beds.

(Qdl) are associated with former and present-day lakes. Small areas of fluvial-derived aeolian dune deposits (Qad - 'source bordering dunes') are associated with both relict and active river channels. At the margins of the basin, coarse colluvial and alluvial deposits form extensive coalesced fans, talus cones, and scree slopes (Qfr - Pooraka Formation and other undivided colluvial and residual accumulations). Many of these surficial units are essentially morphostratigraphic in character, rather than conventionally lithostratigraphic (Brown & Stephenson, 1985).

In coastal areas, Quaternary deposits include shallow and marginal-marine sediments (Qpl - Coomandook Formation; Qpu - unnamed algal dolomites), a number of prograding beach-ridge and dune complexes (Late Pleistocene Qpb - Bridgewater Formation; Holocene Qhe - Semaphore Sand), and back-ridge lagoonal and inter-ridge fluvial and lacustrine sediments (Pleistocene Qcl - Padthaway

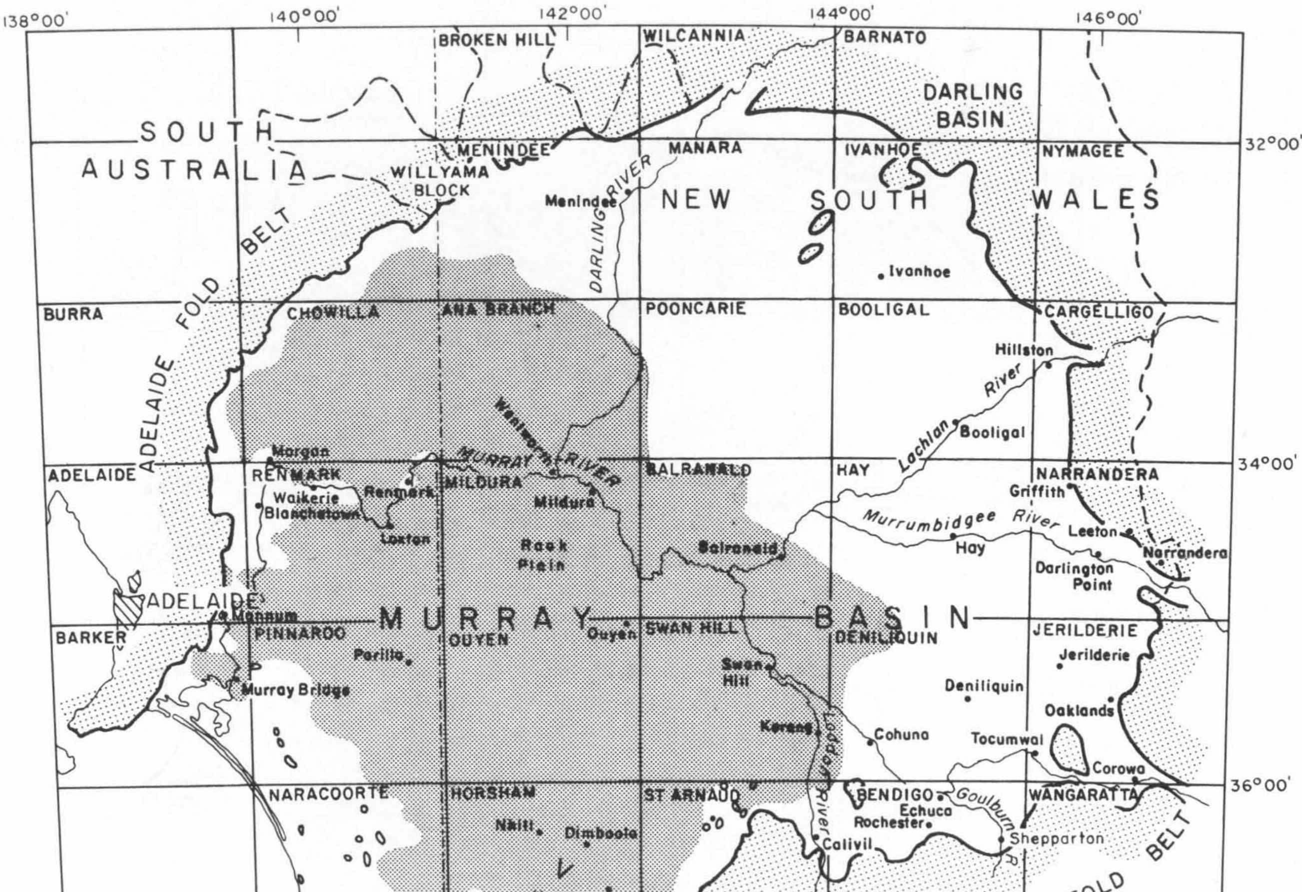

Fig.23. Distribution of the Loxton Sands and Parilla Sand.

Formation; Holocene Qho - St. Kilda Formation).

The Quaternary geology and complex morphostratigraphy of the basin have been extensively studied, and summaries have been published by Butler & others (1973), Firman (1973), Lawrence (1976b), Bowler & Magee (1978), and Twidale & others (1978), and in various papers in both Storrier & Kelly (1978) and Storrier & Stannard (1980).

REGIONAL GROUNDWATER AQUIFERS OF THE MURRAY BASIN

The Cainozoic succession of the Murray Basin is essentially water-saturated, but each of the three Tertiary depositional sequences described above contains a major regional groundwater aquifer (Fig.12). Groundwater obtained from these

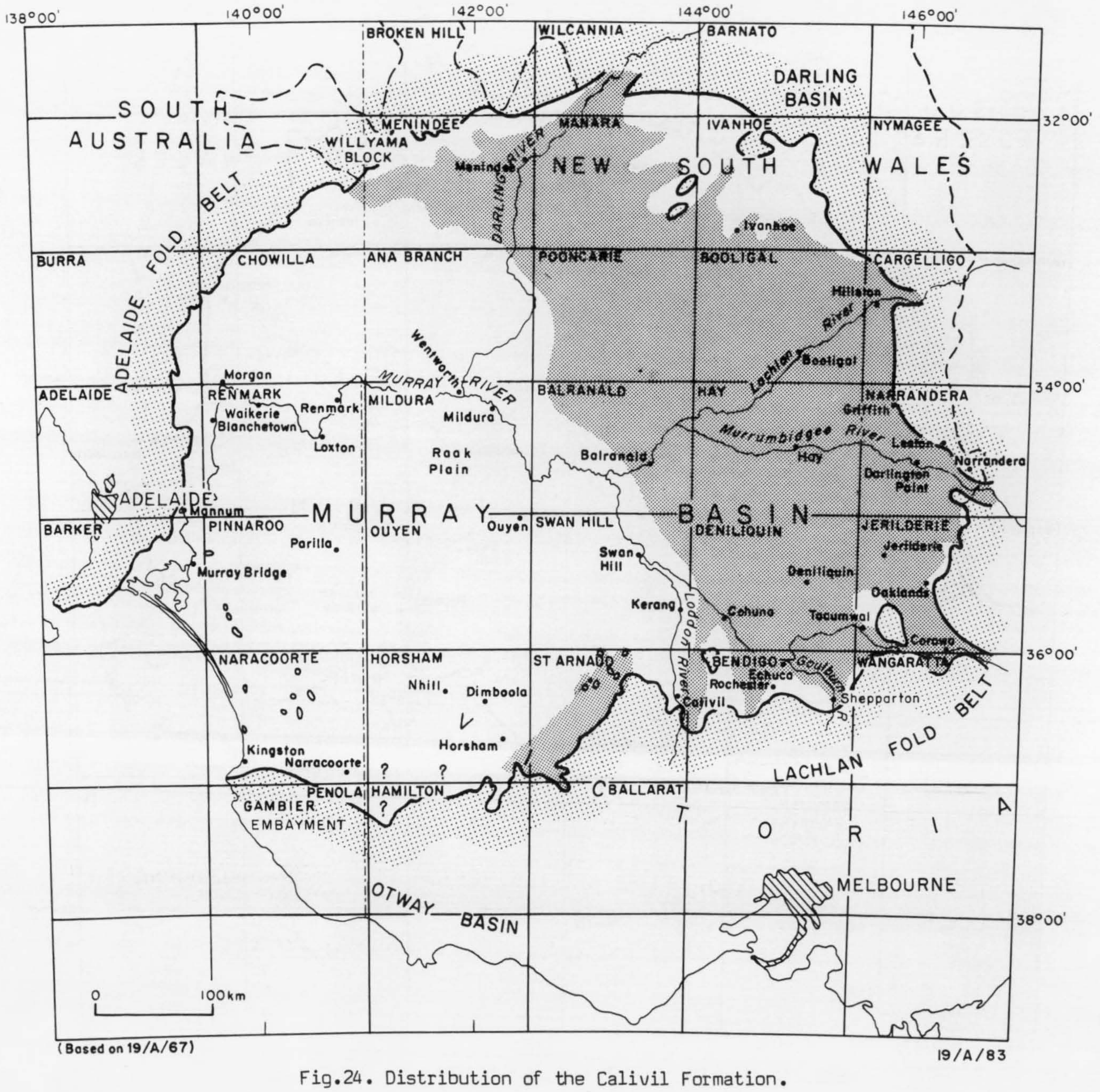

Fig.24. Distribution of the Calivil Formation.

aquifers is the major geologic resource of the basin; it is extensively exploited for stock and irrigation purposes, and increasingly for town water supplies.

At the base of the succession, the semi-confined to confined Paleocene to Miocene Renmark Group aquifer comprises the Warina Sand (including the lower Renmark beds in South Australia), sands of the Olney Formation (including the upper Renmark beds in South Australia), and sands and carbonates of the Buccleuch beds in the southwest of the basin. In the east the aquifer produces good-quality water and in many places in the west it remains suitable for stock, despite increases in salinity. Because of its greater relative depth the aquifer is not well developed, but its potential is likely to be increasingly investigated in the north and east.

The calcarenites of the Oligocene-Miocene Murray Group (Gambier Limestone,

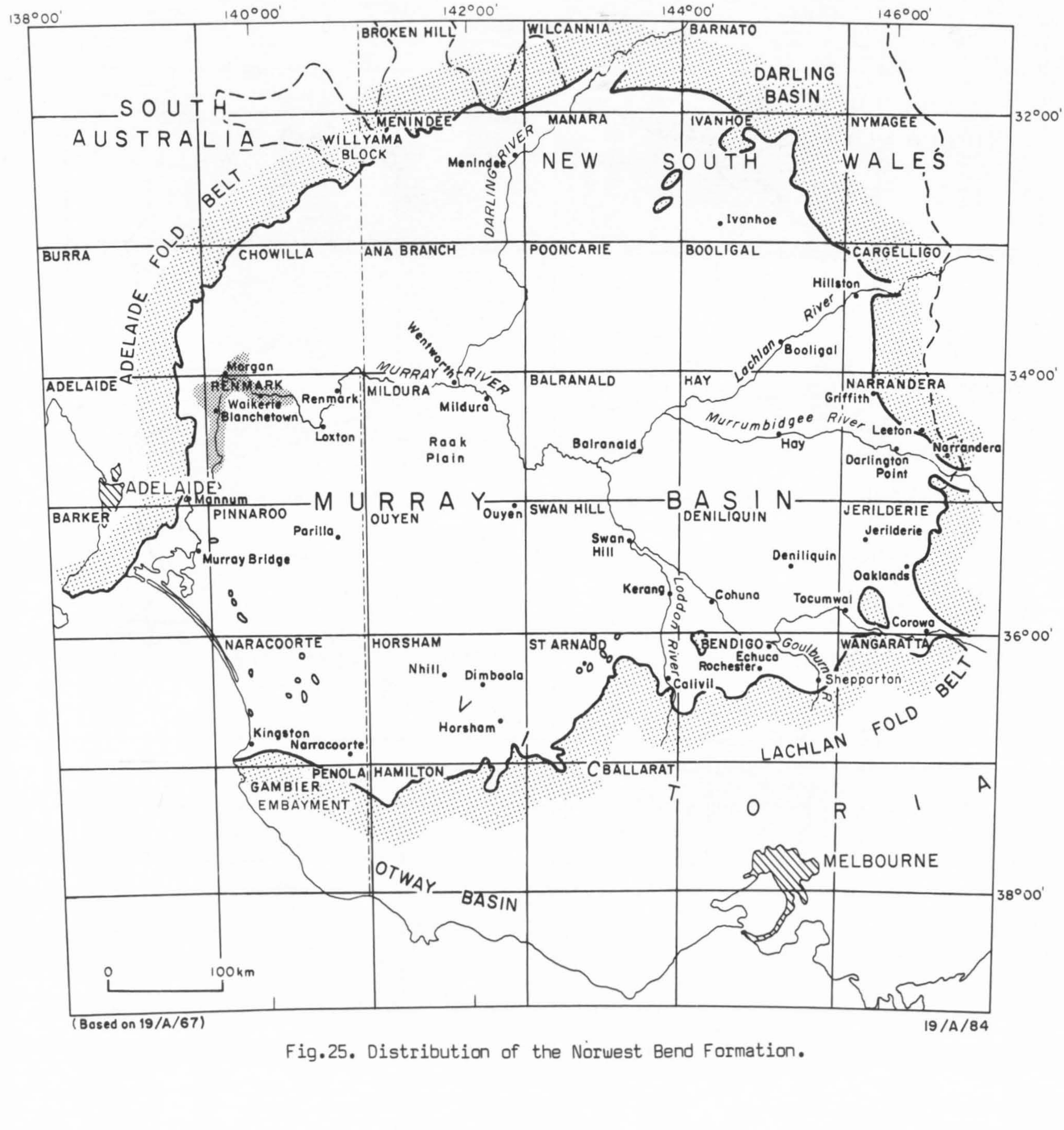

Fig.25. Distribution of the Norwest Bend Formation.

Mannum Formation, Morgan Limestone, Pata Limestone, Duddo Limestone) form the most productive aquifer in the Murray Basin. The combination of skeletal debris and quartz sand in the calcarenites has resulted in high intergranular porosities. In the south the presence of sinkholes also suggests the local development of solution cavities within the aquifer. It contains water of good quality, except in the northwest, and is extensively exploited in the centre and west (O'Driscoll, 1960; Lawrence, 1975).

The uppermost, near-surface, Pliocene sand aquifer is a composite of the Calivil Formation, Loxton Sands, Parilla Sand, and Norwest Bend Formation. It is partly confined beneath the Shepparton Formation in the east and north, where groundwater from the fluvial Calivil Formation is locally exploited at the basin margins (Macumber, 1978b). Beneath much of the Riverine Plain, however, the aquifer contains highly saline water. In the north and west, marine, estuarine,

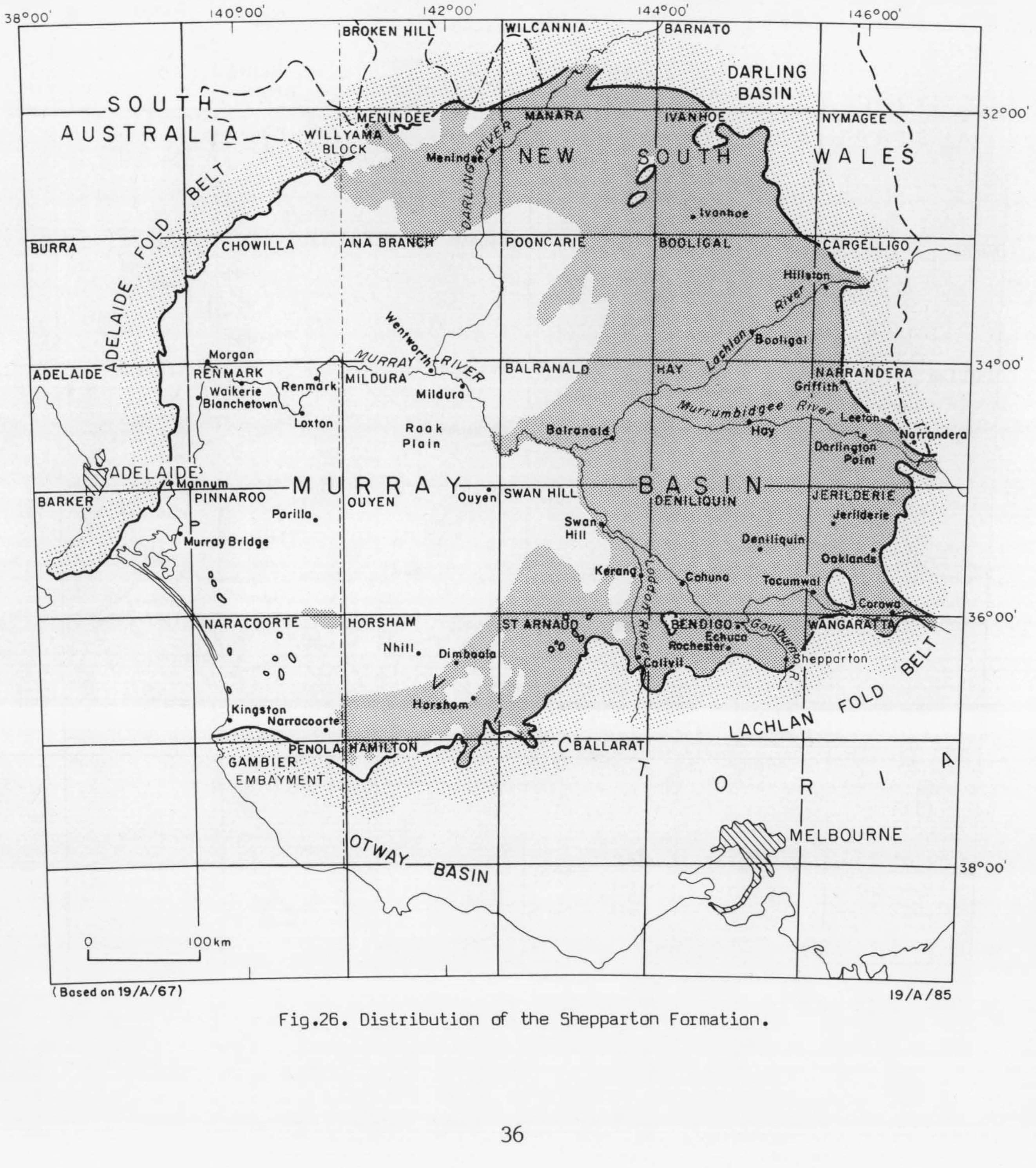

Fig.26. Distribution of the Shepparton Formation.

and fluvial sands (Loxton Sands and Parilla Sand) are mainly unconfined, and contain highly saline near-surface groundwaters.

As discussed in the introduction, in several districts, highly saline groundwater locally intersects the surface in groundwater discharge lake complexes and salinas (McLaughlin, 1966; Macumber, 1980; Teller & others, 1982; unit Qly - distribution shown in Brown & Stephenson, 1985). In many areas, shallow local aquifers also occur within the Shepparton Formation, and to a lesser extent within other Quaternary units where local recharge from rivers and lakes has occurred. Boreholes which have encountered each of the three major aquifers, in addition to the Shepparton aquifer, are listed in Microform Appendix 5.

Hydrogeological investigations have been summarised in South Australia by O'Driscoll (1960), Reed (1980), and Barnett (1980, 1981a, 1981b, 1983); in Victoria by Lawrence (1975), Macumber (1978b), Tickell (1977), and Tickell & Humphrys (1980); and in New South Wales by Gibbons & others (1972) and Woolley & Williams (1978).

STRATIGRAPHIC CORRELATIONS AND COMMENTS ON IDENTIFICATION OF STRATIGRAPHIC UNITS

During the course of this study, lithostratigraphic units of the Murray Basin were examined as single entities within a basin-wide framework. Differing concepts of the characteristics and status of many units have previously contributed to correlation difficulties, and to a lack of uniformity of stratigraphic nomenclature that could be resolved only from a basin-wide perspective. This study has therefore allowed us to clarify several stratigraphic problems. We present the significant correlations below, along with recommendations for future uniformity of stratigraphic nomenclature, and comment on some of the criteria used to identify the units. Each of the units is briefly described in Table 2; detailed descriptions of the units are documented elsewhere (Brown & Stephenson, in preparation).

(1) At the base of the Murray Basin succession, the Renmark Group (Vic. and NSW; Lawrence, 1975) correlates with the Renmark beds (SA; Harris, 1966). The Warina Sand and overlying Olney Formation of the Renmark Group correlate with the lower and upper Renmark beds respectively (Fig.5). We suggest that the nomenclature of the Renmark Group and its component formations be adopted throughout the basin.

In South Australia, most bores which penetrate the Renmark Group (Renmark beds) have intersected only Eocene components of the upper unit (Olney Formation); the lower unit (Warina Sand) has been intersected in only a few bores in the deeper parts of the basin. In the appendices the two units have not been differentiated in the South Australian part of the basin.

In the Moorlands area (PINNAROO) a subeconomic series of Eocene coal seams is known as the Moorlands Lignite Member of the Olney Formation of the Renmark Group (formerly upper Renmark beds; Harris, 1966). The member has not been differentiated in the appendices, but is referred to in the comments attached to bore records in Microform Appendix 4. We suggest that the name also be applied to similar coal seams of Eocene to Middle Miocene age which occur within the Olney Formation elsewhere within the basin.

(2) The Buccleuch beds beneath the southwest of the basin are a lithologically diverse assemblage of marine sediments. Ludbrook (1961) divided the unit into 'A', 'B', and 'C' members', but further investigation will be required before the components of the unit can be elevated to formation status, and only

undifferentiated Buccleuch beds have been documented in the appendices.

(3) In the northwest, a grey sand unit occurs between the Eocene Olney Formation and the Oligocene Ettrick Formation. Lindsay & Bonnett (1973) correlated this unit in CHOWILLA and part of RENMARK with the Buccleuch beds and - on the basis of foraminifera collected from the grey sand unit in two bores drilled near Waikerie - suggested that deposition of the Buccleuch beds continued into the Oligocene. There are, however, two other possibilities: firstly, that the grey sand unit is indeed of Oligocene age, and is a marine component of the mainly fluvial Olney Formation (this is the view which has been taken for bores listed in the appendices); and, secondly, that the unit is a correlative of the Oligocene Compton Conglomerate - not the Buccleuch beds (S.R. Barnett, Geological Survey of South Australia, personal communication, 1984). A corollary of both these alternatives is that deposition of the Buccleuch beds could have been restricted to the Buccleuch Embayment (Fig.17) during the Eocene-Early Oligocene. A similar sand unit which occurs below the Geera Clay in bores in ANABRANCH and MENINDEE is also included in the Olney Formation in the appendices.

(4) The Oligocene Compton Conglomerate (basal unit of the Murray Group in South Australia; Ludbrook, 1961) is a lithologically diverse and geographically patchy unit which can be correlated with the basal Yanac Member of the Ettrick Formation in western Victoria (Lawrence, 1966). Its lithologies include green glauconitic marine clay, poorly fossiliferous sandstone, dark humic clay, and ferruginised pebble conglomerate thought to have been deposited over a major, early Late Oligocene (or late Early Oligocene) disconformity surface. The unit is in places difficult to distinguish from the lithologically similar underlying Buccleuch beds of Eocene age and the overlying Ettrick Formation of Oligocene age. The geographic distribution of the Compton Conglomerate is patchy, but it appears to occur more commonly in the Buccleuch Embayment (Fig.17) and in CHOWILLA than elsewhere.

(5) The Ettrick Formation was originally named the Ettrick Marl in South Australia (Ludbrook, 1961), and the Netherby Marl in Victoria (Lawrence, 1966) before being renamed the Ettrick Marl (Lawrence, 1975). Locally, the formation is lithologically diverse, and we therefore suggest that the name Ettrick Formation be adopted throughout the basin.

(6) In places, the calcareous clays of the Ettrick Formation can be confused with younger, lithologically similar sediments of the Winnambool Formation. Based on the ages assigned to these two units, we regard the Ettrick Formation as being mainly Oligocene in age and the Winnambool Formation as being mainly Miocene in age. In reality, however, we suspect that the Ettrick Formation and Winnambool Formation are one and the same time-transgressive unit. They are almost impossible to distinguish on lithology alone, but, whereas the Ettrick Formation underlies almost the entire southwest of the basin (Fig.18), the Winnambool Formation is confined in distribution to an arcuate zone underlying the west central part of the basin (Fig.20). Thus distribution and age are criteria that can be applied to distinguish the formations in most areas. We suggest that, where practicable, Oligocene calcareous clays be assigned to the Ettrick Formation, and Miocene equivalents be assigned to the Winnambool Formation. In some bores in northern South Australian and southwest Victorian parts of the basin, Miocene calcareous clays (marls), which we believe to be part of the Winnambool Formation, were previously placed in the Ettrick Formation.

In places the Winnambool Formation grades laterally into Miocene calcarenites (Tml) of the Murray Group. Some bores contain transitional marly limestones which in CHOWILLA, for example, were described by Ludbrook (1961) and Rogers (1978) as 'Morgan-Mannum equivalents'; in the database we have placed such 'marly' sediments of Miocene age in the the Winnambool Formation. Similarly, the Cadell Marl (Fig.5) at the western margin of the basin, and other calcareous clays such as the 'middle marly unit' of the Morgan Limestone (Lindsay & Bonnett, 1973), are probably also correlatives of the Winnambool Formation.

In some bores in northwestern Victoria, calcareous clays (marls), previously logged as Late Miocene-Pliocene Bookpurnong beds (e.g. in Olney No.1, Lawrence, 1975; Lawrence & Abele, 1976) have been found to be a composite of the Miocene Winnambool Formation and the disconformably overlying Bookpurnong beds. Fortunately, in many bores, the Bookpurnong beds typically contain an abundant bivalve-rich megafauna which can be used to distinguish between the two units.

(7) In South Australia, Oligocene-Miocene calcarenites of the Murray Group have been subdivided into four separate units on biostratigraphic grounds (Gambier Limestone, Mannum Formation, Morgan Limestone, and Pata Limestone; Ludbrook, 1961). In this database these subdivisions have been combined into one lithostratigraphic unit (Tml), which is equivalent to the Duddo Limestone in the western Victorian and western New South Wales parts of the basin (Lawrence, 1975; Woolley & Williams, 1978). We do, however, suggest that the South Australian nomenclature be retained in a biostratigraphic context. Towards northern areas, the skeletal calcarenites contain an increasingly high proportion of quartz sand grains, and in drillers' logs the unit is frequently described as 'shelly quartz sand'.

In South Australia, two minor units - Cadell Marl and Finnis Clay (Ludbrook, 1961) - interfinger with the calcarenites, but have not been differentiated in the appendices.

(8) In the north, black marginal-marine clays of Oligocene-Miocene age, which we refer to the Geera Clay, were previously described as 'Pata Limestone equivalents' (Ludbrook, 1961). The uppermost part of the Geera Clay is certainly a time-equivalent of the Middle Miocene Pata Limestone. However, much of it in the north and east is also a time-equivalent of the Oligocene-Miocene Ettrick Formation, Winnambool Formation, Mannum Formation, Morgan Limestone, and Olney Formation.

In some bores in the north, marginal-marine black clays of the Oligocene-Miocene Geera Clay are difficult to differentiate from overlying marine clays of the Late Miocene-Pliocene Bookpurnong beds. As noted above, however, the Bookpurnong beds typically contain an abundant bivalve-rich megafauna, and generally are lighter than the dark reducing muds of the Geera Clay. In places the Geera Clay is also difficult to differentiate from interfingering lacustrine clays of the Olney Formation of the Renmark Group; in general, however, the Olney Formation is characteristically carbonaceous with peat and coal horizons. It is also lithologically more variable than the Geera Clay, and contains extensive intercalations of silt and sand.

(9) In boreholes within the entirely non-marine section in eastern areas of the basin, the top of the Renmark Group can generally be determined by the occurrence of abundant carbonaceous material, while the Calivil Formation is characterised by the presence of quartz sand with a white kaolinitic matrix, and the overlying Shepparton Formation contains mottled clays and multicoloured sands. These distinctive lithologies are well developed beneath the eastern and northern parts of the Riverine Plain (Woolley, 1978; Woolley & Williams, 1978). However, beneath the tributary valleys at the basin margins in the northern

Victorian highlands the Renmark Group, Calivil Formation, and Shepparton Formation each contain coarse-grained sands and conglomerates with a kaolinitic matrix (e.g., Tickell & Humphrys, 1980). In some boreholes, formation boundaries can be difficult to identify in the absence of palynological control. Similarly, in many boreholes beneath the western Riverine Plain, the Calivil Formation consists mainly of clay, and does not provide a sufficiently distinctive marker unit between the Olney Formation and the Shepparton Formation. In addition, at the western margin of the Riverine Plain beneath the confluence of the Murray and Murrumbidgee Rivers, carbonaceous sand, silt, and clay - thought to have been deposited in deltaic environments - are herein included in the Calivil Formation (i.e., 'Bookpurnong beds equivalents' in Balranald No.1 and Bundy No.1; Ludbrook, 1962; Shiels, 1962). These sediments are lithologically similar to those of the underlying Eocene and Miocene Olney Formation, but are stratigraphically equivalent to the Pliocene Calivil Formation and Bookpurnong beds.

(10) In South Australia, the Pliocene Loxton Sands were thought to have been deposited in marginal-marine, estuarine, and fluvial environments, whereas the overlying Pliocene Parilla Sand was thought to be entirely fluvial in origin. In contrast, in Victoria and New South Wales, the entire equivalent Pliocene sand unit has been named Parilla Sand, and was considered to be entirely marine to marginal-marine. During the compilation of the subsurface data in the appendices, we experienced difficulties in differentiating the Loxton Sands from the Parilla Sand in places, and have therefore combined these units into a single Pliocene sand unit (Tps), forming a composite sand sheet. We have, however, identified marine, marginal-marine, estuarine, and fluvial elements, and - as described above - we interpret the Pliocene sand sheet as a composite strand-plain deposit.

Descriptions of the Loxton Sands, Parilla Sand, and Calivil Formation are similar on drillers' logs. However, the Calivil Formation is generally buried beneath sediments of the Shepparton Formation, whereas the Loxton Sands and Parilla Sand are near-surface units generally not overlain by the Shepparton Formation. At the western margins of the basin, the Loxton Sands and Parilla Sand are readily distinguished from the Quaternary Pooraka Formation (outwash material) by the degree of sorting and relative cleanness of the Pliocene sands.

(11) Correlations of most Quaternary units of the basin are not discussed in this Report. However, unnamed fluvial sediments of unknown but probable Pleistocene age in NARACOORTE are herein correlated with similar sediments of the Shepparton Formation in adjacent parts of western Victoria (Horsham area).

RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

The stratigraphic data from the 3000 borelogs documented in the appendices have formed the basis for the development of a basin-wide subsurface stratigraphic framework for the Murray Basin. We also believe that these data provide a firm basis for future investigations. However, owing to the great size of the basin, and the complexity of facies relationships within the Tertiary sequence, no compilation can be considered entirely satisfactory, and we have therefore highlighted those areas where we believe our stratigraphic interpretations could be improved by future investigations.

(1) At the base of the succession, the Warina Sand is presumed to be conformably overlain by the Olney Formation, although the contact between these two formations has not been dated. Future investigations may prove the

relationship to be a disconformable one.

(2) Eocene-Lower Oligocene components of the Olney Formation are lithologically indistinguishable from Oligocene-Miocene components, and in this database the two components are regarded as parts of a single lithologic unit. Within the marine sediments in the southwest of the basin, a prominent hiatus is thought to have occurred in the early Late Oligocene (or late Early Oligocene) accompanying a fall in sea level. The extent and duration of this break within the Olney Formation are uncertain and require further investigation.

(3) In this Report, we consider marine sands at the top of the Olney Formation in the northwest to be marine intercalations within that formation. However, they may instead correlate with components of the marine Murray Group, and may prove to be a separate and distinct formation.

(4) Marine components within the Murray Basin succession are relatively well dated, and can readily be correlated with the international geological time scales. A major problem, however, exists in dating components within non-marine sections of the basin. In many areas, stratigraphic units are lithologically similar, and correlations depend on palynological control (e.g., Martin, 1984a, 1984b, 1984c). At present, however, the biostratigraphic framework of non-marine Tertiary sediments in interior basins of Australia is not well understood. Research currently being undertaken in the western Murray Basin will allow local palynological observations to be correlated directly with time scales based on marine assemblages (Truswell & others, 1985). Elsewhere in the basin, further research into palynological dating and correlation problems is required if the details of sedimentation patterns within the non-marine sections are to be fully understood. In particular, the non-marine formations beneath the western Riverine Plain are, in many boreholes, lithologically similar, and hence improved palynological age control from a fully cored stratigraphic bore in eastern BALRANALD or western HAY would greatly assist stratigraphic correlations. Stratigraphic control is also inadequate in eastern ANABRANCH and western POONCARIE.

(5) If existing borehole data in the northwest - in New South Wales - is to be effectively utilised, we also recommend that a fully cored stratigraphic bore be drilled in the Menindee area to provide detailed lithostratigraphic and biostratigraphic control.

(6) The South Australian part of the basin is well covered by borehole data points, except in BURRA. A stratigraphic borehole located in southeastern BURRA would provide a useful additional link between bores in ADELAIDE and OLARY.

(7) In western RENMARK and PINNAROO, few bores have penetrated below the Murray Group aquifer to the Renmark Group aquifer. Consequently, as in other areas of the basin, surprisingly little is known about this important aquifer, despite the high density of boreholes in South Australia.

(8) Selected bores should be accurately levelled, particularly if long-term regional hydrogeological studies are to be successfully undertaken.

(9) The locations of boreholes used in this database have mainly been transcribed from file sources. Although these are accurate enough for regional stratigraphic purposes, we suggest that the location of key bores be checked in the field before detailed hydrogeological studies are undertaken.

TABLE 2. CAINOZOIC STRATIGRAPHIC UNITS OF THE MURRAY BASIN

Unit : Qho - St. Kilda Formation
Age : Holocene

Lithology: unconsolidated mud, silt, sand, shell debris; minor ephemeral salt crusts of gypsum, halite.

Depositional Environment: estuarine, coastal lake, and swamp.

Geomorphic Expression and Distribution: forms littoral lake complexes, partly emergent estuarine flats, and salinas; occurs in the Lake Alexandrina area at the mouth of the River Murray and in other coastal lakes of southeastern South Australia.

Unit : Qhl
Age : Holocene

Lithology: unconsolidated to weakly lithified fossiliferous micritic and dolomitic mud, dolomite; minor quartz sand, clay, shell detritus, calcareous algal biolithite.

Depositional Environment: restricted, brackish to marine, lagoonal.

Geomorphic Expression and Distribution: locally exposed around margins of the Coorong and other coastal lake complexes.

Unit : Qhe - Semaphore Sand
Age : Holocene

Lithology: unconsolidated, locally mobile white calcareous fossiliferous quartz sand; minor humic debris, calcareous rhizoliths.

Depositional Environment: coastal beach and associated aeolian dune.

Geomorphic Expression and Distribution: forms present-day coastal beach and dune complexes, forming a barrier which separates the Coorong from the Southern Ocean.

Unit : Qa - Coonambidgal Formation and other alluvial deposits
Age : Quaternary, mainly Late Pleistocene to Holocene

Lithology: unconsolidated grey, brown micaceous silty clay, silt, polymictic sand, gravel.

Depositional Environment: fluvial, fluvio-lacustrine, channel, and flood-plain environments of existing rivers.

Geomorphic Expression and Distribution: forms flat low-lying deposits in narrow meander belts, anastomosed distributaries, and confined flood plains; occurs in widely distributed active and recently active channels incised within older fluvial sediments of the Riverine Plain and adjacent tributary highland valleys; in the west, occurs in the flood plains of the Murray and Darling Rivers and in areas of internal drainage within the aeolian landscape.

Unit : Qdb - Bunyip Sand
Age : Quaternary, probably entirely Holocene

Lithology: unconsolidated, locally mobile pale red-brown quartz sand; minor calcareous rhizoliths.

Depositional Environment: fluvial-derived source-bordering aeolian dune.

Geomorphic Expression and Distribution: forms elongate hummocky dunefields east of and adjacent to the River Murray in South Australia.

Unit : Qad
Age : Quaternary, mainly Late Pleistocene to Holocene

Lithology: unconsolidated, locally mobile pale orange, yellow siliceous sand; locally includes abundant micaceous and lithic grains.

Depositional Environment: fluvial-derived source-bordering aeolian dune.

Geomorphic Expression and Distribution: forms elliptical mounds and elongate hummocky dune complexes adjacent to active and former river channels; widely distributed throughout the Riverine Plain; in the west, occurs on the eastern (leeward) side of channels in the Murray and Darling drainage systems.

Unit : Qdm - Molineaux Sand (SA), Lowan Sand (Vic.)
Age : Quaternary, mainly Late Pleistocene to Holocene

Lithology: unconsolidated, locally mobile, yellow, grey, pale orange well sorted medium to fine frosted quartz sand; in southwest, includes marine-derived calcareous skeletal aeolianite; older components weakly modified by pedogenesis contain minor calcareous filamental rhizoliths, calcrete glaebules, iron-cemented pisoliths.

Depositional Environment: aeolian dune.

Geomorphic Expression and Distribution: forms irregular to subparabolic, locally linear sharp-crested, densely packed dunes with narrow interdune corridors and minor sand plains; occurs within extensive, easterly trending tongue-like dunefields extending from coastal areas and east of the River Murray in South Australia into western Victoria, where it forms the Sunset Desert, Big Desert, and Little Desert.

Unit : Qdu
Age : Quaternary, mainly Late Pleistocene to Holocene

Lithology: unconsolidated, locally mobile red-brown, pale orange siliceous sand; consists of medium to fine quartz grains admixed with humic debris and fragmented calcareous and gypsic filamental rhizoliths; weakly modified by pedogenesis.

Depositional Environment: aeolian dune.

Geomorphic Expression and Distribution: forms sharp-crested irregular to subparabolic, locally linear dunes with narrow interdune depressions; occurs within elongate, easterly trending dunefields; occurs in the northwest, mainly east of the Darling River and west of the Riverine Plain.

Unit : Ql
Age : Quaternary, mainly Late Pleistocene to Holocene

Lithology: friable to plastic, finely laminated grey clay, silty clay, humic clay, grey palaeosols; locally includes medium to fine sand.

Depositional Environment: lacustrine and associated strand-line environments.

Geomorphic Expression and Distribution: occurs in flood-plain lakes and swamps, interdune deflation hollows, and coastal lake complexes; widely distributed throughout the fluvial and aeolian landscapes of the basin, but mainly associated with active and recently active flood plains of the Riverine Plain; forms extensive lake complexes associated with the Darling River, Darling Anabranch, and Willandra Creek system.

Unit : Qly - Yamba Formation and other saline lake deposits
Age : Quaternary, mainly Late Pleistocene to Holocene

Lithology: friable pale grey gypsite, gypsiferous clay with selenite crystals, grey pelletal gypsum-quartz sand aggregates; locally includes grey clay with crystalline gypsum mush under black sulphide-rich mud with ephemeral salt crusts of gypsum, halite, bischofite, thenardite, mirabilite; in places associated with mounds and sheets of quartz sand cemented by ferricrete, calcrete, and silcrete.

Depositional Environment: lacustrine, evaporitic, and aeolian environments of ephemerally active playas maintained by groundwater discharge and by deflation of lake floors.

Geomorphic Expression and Distribution: forms aeolian-modified gypsite flats; active salinas occur in topographic lows as irregularly shaped lake complexes entrenched within relict pedestals of former lake floors; mainly occurs in association with active and relict terminal lakes and groundwater discharge zones entrenched within the aeolian landscape in the west; relict deposits occur in the north, and active salinas also occur adjacent to the coast.

Unit : Qdl
Age : Quaternary, mainly Late Pleistocene to Holocene

Lithology: poorly consolidated brown, red, yellow, grey siliceous sand, silty clay, clay-pellet aggregates, gypsic clay pellets, pale grey gypsite; older components increasingly modified by pedogenesis include intercalated red calcareous and gypsiferous palaeosols with calcrete glaebules, rhizoliths; locally capped by white mobile well sorted quartz sand.

Depositional Environment: aeolian dune environment adjacent to deflated lake floors and shores.

Geomorphic Expression and Distribution: forms single and multiple lunettes (crescentic, transverse dunes), concave to west, located on eastern side of lake basins; locally flanked by blowout dunes of mobile white sand; widely distributed throughout the basin but particularly well developed adjacent to the lakes of the Darling River and Darling Anabranch and former lakes of the Willandra Creek system.

Unit : Qdp
Age : Quaternary, mainly Late Pleistocene to Holocene

Lithology: unconsolidated red, brown clayey siliceous sand and clay-pellet aggregates admixed with loamy soils; sand component consists of medium to fine quartz grains with red clay cutans; modified by pedogenesis, forming iron and carbonate-cemented nodules grading to calcrete hardpans.

Depositional Environment: aeolian sand sheet and associated lacustrine and claypan environments.

Geomorphic Expression and Distribution: forms extensive flat to gently undulating plains, locally with numerous fluvio-lacustrine depressions, particularly in the north; includes narrow aeolian-modified sand plains adjacent to rivers and lakes of Darling River system.

Unit : Qdw - Woorinen Formation
Age : Quaternary, mainly Late Pleistocene to Holocene

Lithology: unconsolidated red-brown siliceous silty sand, red calcareous silty clay, sandy clay, clay-pellet aggregates; sand component consists of medium to fine quartz grains with red clay cutans admixed with humic debris and fragmented calcareous tap-root and filamental rhizoliths; partly modified by pedogenesis, forming intercalated red calcareous palaeosols with gypsiferous and soft to resistant carbonate glaebules, grading to cemented calcrete hardpans which locally form massive brecciated sheets.

Depositional Environment: aeolian dune and swale.

Geomorphic Expression and Distribution: forms extensive dunefields of discontinuous east-west oriented dunes with subdued crests and flanks separated by broad swales and sand plains; widely distributed; underlies much of aeolian landscape of the western Murray Basin.

Unit : Qpu
Age : Late Pleistocene

Lithology: well cemented pale grey fine-grained dolomitic algal boundstone with intraclasts of sandstone, calcarenite, dolomite; in places capped by sheet calcrete.

Depositional Environment: marginal-marine, lacustro-lagoonal.

Geomorphic Expression and Distribution: forms flat coastal plain in southeast South Australia.

Unit : Qcl - Padthaway Formation
Age : Late Pleistocene

Lithology: unconsolidated sand, silt, sandy variegated clay, peat, calcareous clay (marl), freshwater limestone.

Depositional Environment: lacustro-lagoonal, swamp, minor lunette, and locally colluvial environments between stranded beach ridges.

Geomorphic Expression and Distribution: occurs in coastal areas of southeast South Australia, where it forms widespread low-lying plains and wetlands with minor lunettes.

Unit : Qpb - Bridgewater Formation
Age : Late Pleistocene

Lithology : poorly consolidated pale yellow, pinkish brown fine to coarse fossiliferous calcareous sand, calcarenite; locally capped by calcrete.

Depositional Environment: coastal beach and associated aeolian dune.

Geomorphic Expression and Distribution: forms series of stranded elongate beach ridges subparallel to present coastline; occurs in coastal and adjacent inland areas of southeast South Australia, extending into adjacent areas of western Victoria.

Unit : Qca - Bakara Calcrete, Rippon Calcrete and other calcrete deposits
Age : Quaternary, Early Pleistocene to Holocene

Lithology: strongly cemented pale grey massive sheet calcrete, calcrete rubble, friable white and cream rhizolithic and nodular calcrete; includes intraclasts of various lithologies set in calcrete matrix.

Depositional Environment: pedogenic, groundwater, lacustrine, and biogenic environments of diagenesis.

Geomorphic Expression and Distribution: locally forms massive resistant sheets, particularly in South Australia; elsewhere, calcrete rubble underlies much of the aeolian landscape in the west, and calcrete glaebules and rhizoliths occur in many soil profles throughout the basin.

Unit : Qfr - Pooraka Formation and other colluvial and residual deposits
Age : Quaternary, Early Pleistocene to Holocene

Lithology: unconsolidated red-brown, poorly sorted clayey sand, gravel, conglomerate, breccia; local calcrete intercalations and cappings; in places cemented by ferruginised, silicified matrix.

Depositional Environment: colluvial sheet-wash, alluvial-fan, and residual lag environments.

Geomorphic Expression and Distribution: forms extensive coalesced low-angle fans, high-angle talus cones and scree slopes; colluvial aprons occur throughout the highlands flanking the Murray Basin, but are particularly well developed in the northwest, where extensive coalesced fans of Pooraka Formation onlaps the Mount Lofty and Flinders Ranges.

Unit : Qpl - Coomandook Formation
Age : Early Pleistocene

Lithology: partly lithified grey, cream fossiliferous medium-grained quartz sand, calcareous sand, calcarenite, sandy clay; characteristically contains lithic clasts and skeletal debris derived from older limestone.

Depositional Environment: shallow-marine.

Geomorphic Expression and Distribution: occurs beneath the coastal area of southeastern South Australia; entirely concealed.

TABLE 2. (continued)

Unit : Qpc - Blanchetown Clay and associated Bungunnia Limestone
Age : Early Pleistocene

Lithology: poorly consolidated to friable, well laminated greenish grey, red-brown clay; locally mottled, silty, sandy, calcareous, and gypsiferous; includes minor intercalated quartz sand, ostracod sand; contains calcareous, gypsiferous, siliceous nodules; overlain in west by well cemented flaggy dolomitic limestone consisting of laminated micrite, oomicrite, oolitic and pisolitic calcarenite, oolitic algal biolithite.

Depositional Environment: mainly freshwater lacustrine; locally saline lacustrine and fluvial environments.

Geomorphic Expression and Distribution: mainly concealed; locally exposed in river cliffs and lake margins; erosional remnants underlie the aeolian sediments of much of the west central part of the basin.

Unit : TQs - Shepparton Formation
Age : Late Tertiary to Quaternary

Lithology: unconsolidated to poorly consolidated mottled variegated clay, silty clay with lenses of coarse to fine polymictic sand and gravel; partly modified by pedogenesis, forming intercalated red-brown palaeosols.

Depositional Environment: fluvio-lacustrine, flood-plain, channel, and levee environments; minor aeolian.

Geomorphic Expression and Distribution: forms extensive flat alluvial flood plains traversed by remnant traces of inactive meandering palaeochannels; underlies the Riverine Plain in the east; extends to the west around the northern flanks of the Victorian highlands, and underlies a veneer of aeolian sand around the northern fringes of the basin.

Unit : TQv - 'Newer Volcanics'
Age : Late Tertiary to Quaternary

Lithology: basaltic lava, agglomerate, scoria, tuff, and related volcaniclastic sediments.

Depositional Environment: widespread subaerial volcanoes.

Geomorphic Expression and Distribution: extensive lava and pyroclastic fields in western Victoria contain numerous small remnant cones, plugs, maars; elsewhere in the Eastern Highlands, isolated scoriaceous cones, basaltic plugs, and flows occur in highland valleys and form stranded interfluves.

Unit : TQl
Age : Late Tertiary to Quaternary

Lithology: duricrust of red massive to pisolitic ferruginous subsoil underlain by mottled clay over pallid zone of white kaolinitic clay.

Depositional Environment: composite lateritic duricrust developed over elevated surfaces in environments exposed to deep chemical weathering.

Unit : TQl (continued)

Geomorphic Expression and Distribution: forms residual flat to gently undulating surfaces, locally deeply dissected to form steep-sided remnants; erosional remnants occur throughout the flanking highlands, but are particularly extensive over the Dundas Tableland, and over parts of the Mount Lofty and Flinders Ranges.

Unit : Tpn - Norwest Bend Formation
Age : Pliocene

Lithology: partly cemented pale grey, brown, yellow coquinoid limestone with fossiliferous quartz sand matrix; characterised by oyster beds.

Depositional Environment: estuarine.

Geomorphic Expression and Distribution: exposed in cliffs of River Murray gorge; elsewhere concealed; confined in distribution to areas adjacent to the present-day course of the River Murray at the western margin of the basin in South Australia.

Unit : Tps - Loxton Sands, Parilla Sand
Age : Late Miocene to Pliocene (mainly Pliocene)

Lithology: unconsolidated to weakly cemented yellow-brown fine to coarse well sorted quartz sand, sandstone, with minor clay, silt, pebbly conglomerate; locally includes fine to coarse shelly sandstone, poorly sorted micaceous quartz sand and gravel; marine shell and trace fossils occur in places; locally ferruginised and pyritic; towards top, contains interstitial white kaolinitic or gibbsite clay matrix, locally capped by sandy pisolitic ferruginous duricrust.

Depositional Environment: composite sand sheet deposited in strand-plain and fluvial environments - including shallow-marine, beach, and estuarine - flanked and locally overlain by fluvial.

Geomorphic Expression and Distribution: topographically prominent subparallel stranded beach ridges with inter-ridge fluvial sediments underlie almost the entire southwestern Murray Basin; estuarine and fluvial components are exposed in River Murray cliffs in the west; fluvial components underlie much of the northwest of the basin; mainly concealed.

Unit : Tpc - Calivil Formation
Age : Late Miocene to Pliocene

Lithology: poorly consolidated pale grey, poorly sorted coarse to granular quartz sand, conglomerate, with white kaolinitic matrix; includes thick intercalations of kaolin, thin lenses of carbonaceous clay; grainsize diminishes basinward, where unit includes dark brown ferruginised and grey pyritic sand with minor interbedded carbonaceous silt and clay.

Depositional Environment: locally discontinuous sand sheet deposited in valley-fill, alluvial-fan, fluvio-lacustrine, and braided-channel environments.

Geomorphic Expression and Distribution: an extensive blanket underlies much of the Riverine Plain and northern fringes of the basin; fills previously eroded entrenchments within older units in adjacent highland valleys to form the youngest of the several gold-bearing deep-lead systems of northern Victoria; mainly concealed.

Unit : Tpb - Bookpurnong beds
Age : Late Miocene to Pliocene

Lithology: poorly consolidated to plastic brown, greenish grey calcareous clay (marl), silt, sand; highly fossiliferous, glauconitic, micaceous, and locally carbonaceous; characterised by molluscan macrofossils.

Depositional Environment: shallow-marine shelf.

Geomorphic Expression and Distribution: a thin blanket underlies west central parts of the basin; locally exposed on the banks of the River Murray in South Australia but almost entirely concealed.

Unit : Tmw - Winnambool Formation
Age : Late Oligocene to Middle Miocene

Lithology: poorly consolidated friable to plastic grey, blue-grey, pale green glauconitic, highly fossiliferous calcareous clay (marl) with intercalated skeletal calcisiltite, calcarenite, and dense micritic limestone; contains abundant well preserved and diverse faunas.

Depositional Environment: restricted-marine platform and lagoonal.

Geomorphic Expression and Distribution: entirely concealed; occurs in an arcuate zone underlying the west central part of the basin beneath western Victoria extending into north central areas in South Australia.

Unit : Tml - Gambier Limestone, Mannum Formation, Morgan Limestone, Pata Limestone (SA), Duddo Limestone (Vic. and NSW)
Age : Late Oligocene to Middle Miocene

Lithology: consolidated well bedded pale grey, yellow, white, cream coarse to medium, highly fossiliferous skeletal calcarenite, calcareous-cemented quartz sandstone, bioclastic limestone, weakly consolidated calcareous clay (marl); characterised by abundant fragmented skeletal debris of diverse, mainly temperate-water foramol, fossil assemblages.

Depositional Environment: shallow-marine platform.

Geomorphic Expression and Distribution: underlies west central and southwestern parts of the basin; mainly concealed but forms cliffs of River Murray gorge; minor karstified outcrops in southwest.

Unit : Tmg - Geera Clay
Age : Late Oligocene to Middle Miocene

Lithology: poorly consolidated plastic to friable black, grey, dark green clay, silt, minor sand; commonly glauconitic, fossiliferous, calcareous, carbonaceous; locally includes sandy dolomitic intercalations; contains abundant low-diversity faunas.

Depositional Environment: shallow and marginal marine, interdistributary-bay, lagoonal, and tidal-flat.

Geomorphic Expression and Distribution: entirely concealed; occurs in an arcuate zone underlying western Victoria and northwestern parts of the basin in New South Wales and South Australia.

Unit : Toe - Ettrick Formation
Age : Late Oligocene to Early Miocene

Lithology: weakly lithified grey, green glauconitic, highly fossiliferous calcareous clay (marl), silt, sandy skeletal clay, with increasing intercalations of skeletal calcarenite towards top; lithologically more variable towards base, where it includes minor fossiliferous quartz sand, carbonaceous clay; contains abundant and diverse faunas.

Depositional Environment: shallow-marine, restricted platform to lagoonal.

Geomorphic Expression and Distribution: entirely concealed; underlies west central and southwestern parts of the basin, mainly in western Victoria and South Australia.

Unit : Toc - Compton Conglomerate
Age : Late Oligocene

Lithology: lithologically variable; includes partly cemented medium to coarse ironstone and quartz-pebble conglomerate with ferruginised matrix, dark brown humic clay, green glauconitic clay, red clay with pebble clasts, and yellow, brown, grey, poorly fossiliferous calcareous sandstone and clay (marl).

Depositional Environment: composite unit deposited in subaerial residual and associated transgressive shallow-marine environments.

Geomorphic Expression and Distribution: patchy subsurface distribution in the southwest of the basin in South Australia; entirely concealed.

Unit : Teb - Buccleuch beds
Age : Late Eocene to Early Oligocene

Lithology: poorly consolidated grey-brown carbonaceous clay with limonitic upper surface; underlain by friable carbonaceous sand with thin limestone lenses, further underlain by highly fossiliferous white bryozoan limestone with green-grey glauconitic calcareous clay (marl).

Depositional Environment: shallow-marine.

Geomorphic Expression and Distribution: entirely concealed; occurs beneath southwestern parts of the basin in South Australia (possible marine equivalents also occur in the deeper west central parts of the basin, but these are currently included in the Olney Formation of the Renmark Group).

Unit : Ter - undifferentiated Renmark Group (Vic. and NSW), Renmark beds (SA); see component formations Warina Sand (lower Renmark beds in SA) and Olney Formation (upper Renmark beds in SA)
Age : Palaeocene to Miocene

Unit : Teo - Olney Formation (including equivalent upper Renmark beds in South Australia)
Age : Eocene to Middle Miocene

Lithology: unconsolidated to poorly consolidated, thinly bedded dark brown, grey, black carbonaceous sand, silt, clay, brown coal, peat; commonly micaceous, pyritic, ferruginised; includes intercalations of poorly sorted fine to medium quartz sand, polymictic sand, sandy dolomite.

Depositional Environment: fluvio-lacustrine, meandering-channel, flood-plain, and swamp; towards top, in west, includes deltaic, paralic.

Geomorphic Expression and Distribution: forms a virtually continuous but thin blanket beneath almost the entire Murray Basin; absent beneath the margins of the basin and over some buried basement highs; entirely concealed within the basin, but possible equivalents are exposed in the valley of the Glenelg River to the south and as erosional remnants in adjacent areas of the Victorian highlands.

Unit : Tew - Warina Sand (including equivalent lower Renmark beds in South Australia)
Age : Paleocene to ?Early Eocene

Lithology: unconsolidated loose to friable grey, brown, poorly to well sorted medium to coarse quartz sand with minor intercalated fine sand, silt, clay, carbonaceous clay.

Depositional Environment: fluvial.

Geomorphic Expression and Distribution: confined in distribution to the deeper western and central parts of the basin; entirely concealed.

Unit : Tv - 'Older Volcanics'
Age : Paleocene to Miocene

Lithology: basaltic lava, agglomerate, tuff, small basalt plugs, dykes, associated volcaniclastic sediments.

Depositional Environment: subaerial volcanic.

Geomorphic Expression and Distribution: numerous small but widespread valley flows and hill-top cappings occur in highlands flanking the southern and eastern Murray Basin.

Unit : Ta
Age : Undifferentiated Tertiary

Lithology: unconsolidated to locally ferruginised, silicified, poorly sorted pebble to boulder conglomerate, granular to fine sand with sandy clay or kaolinitic matrix, minor silt, clay, kaolin intercalations.

Depositional Environment: high-level residual, valley-fill, alluvial, and colluvial.

Geomorphic Expression and Distribution: occurs throughout the highlands flanking the basin; erosional remnants exposed in highland valleys and stranded interfluves.

Unit : Czs - Undifferentiated Cainozoic deposits of small sedimentary basins exposed onshore east of Gulf St Vincent.

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MICROFORM APPENDICES