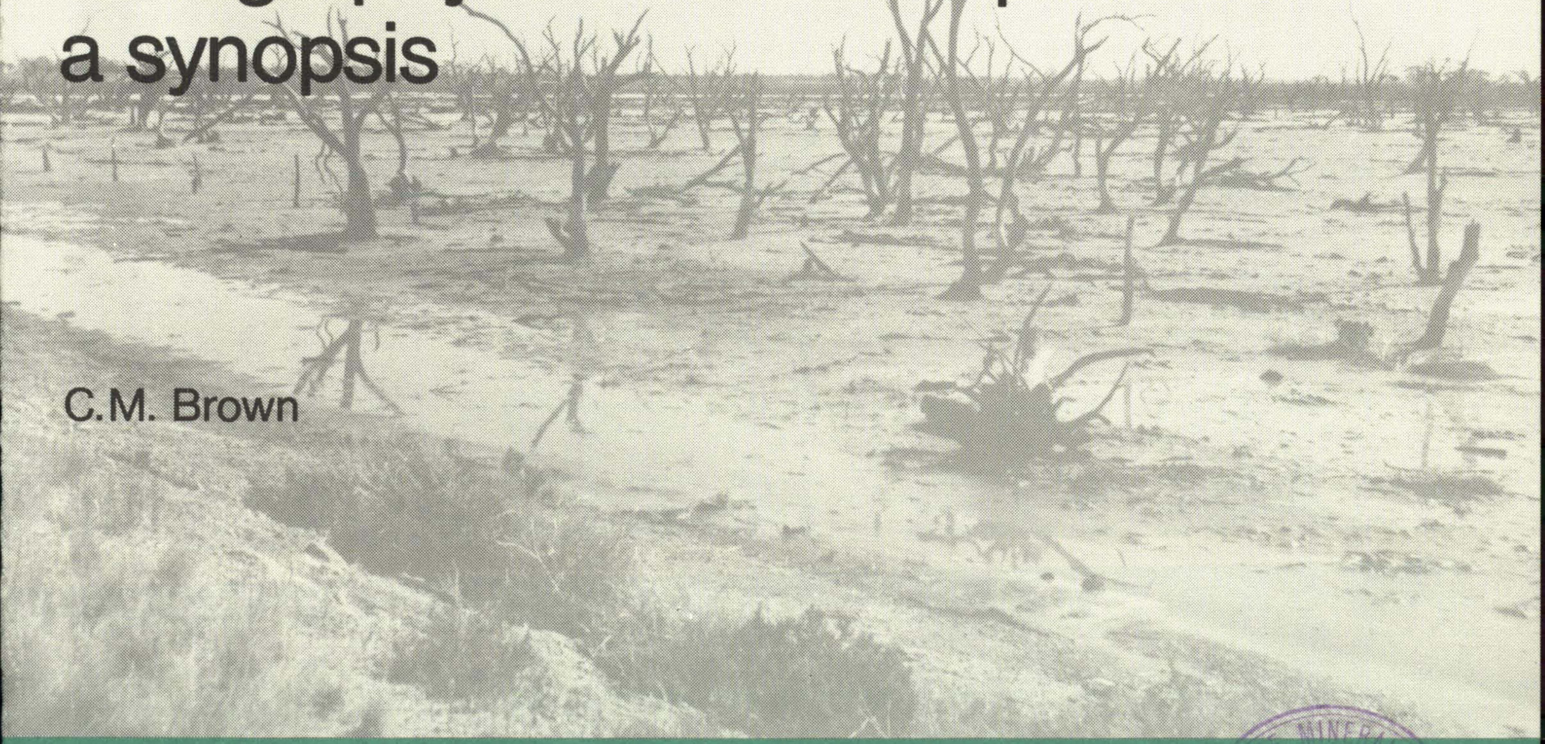
Report 264

Murray Basin, southeastern Australia: stratigraphy and resource potential – a synopsis



C.M. Brown

Bureau of Mineral Resources, Geology and Geophysics

Department of Resources and Energy

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

REPORT 264

MURRAY BASIN, SOUTHEASTERN AUSTRALIA: STRATIGRAPHY AND RESOURCE POTENTIAL - A SYNOPSIS

A contribution to the ESCAP Atlas of Stratigraphy for IGCP Project 32: Stratigraphic correlation between sedimentary basins in the ESCAP region

by

C.M. Brown

Division of Continental Geology

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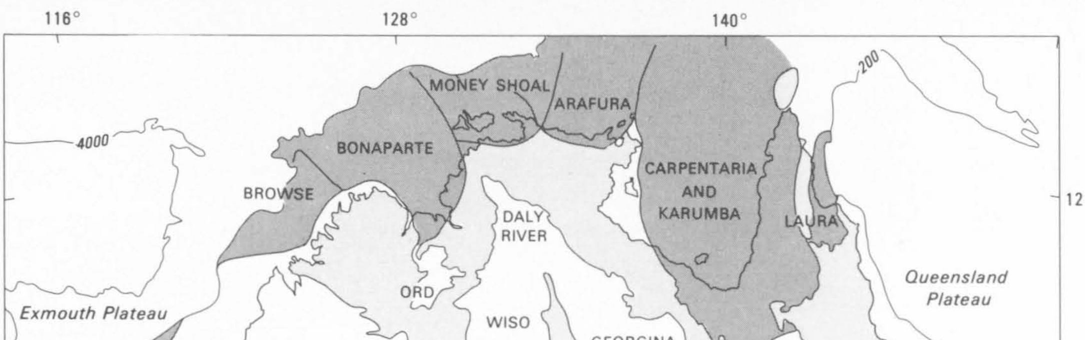
PREFACE

IGCP Project No. 32 aims to produce an atlas of stratigraphic columns and brief explanatory notes to be used for correlation in and between the sedimentary basins of the ESCAP region (U.N. Economic and Social Commission for Asia and the Pacific). Objectives of the project are to determine the nature, structure, thickness and facies of sedimentary sequences within the region in order to further knowledge of the distribution of economic minerals, particularly hydrocarbons. The following report, prepared as a contribution to the ESCAP Atlas of Stratigraphy, emphasises stratigraphic correlations within the Cainozoic Murray Basin, an important groundwater basin which extends over some 320 000 km^2 of the semi-arid zone of southeastern Australia. In Australia, groundwater has long been regarded as an important geologic resource, but it is only in recent years that stratigraphic studies have been undertaken to document the distribution and aquifer characteristics of lithostratigraphic units of the major onshore basins as an aid to management of groundwater resources.

The Murray Basin atlas sheet and accompanying explanatory notes form part of a series of contributions prepared by the Bureau of Mineral Resources for the ESCAP Atlas of Stratigraphy. Previous atlas sheets from Australia prepared for the U.N. Mineral Resources Development Series show correlated stratigraphic columns from the Carnarvon, Laura, Sydney, Carpentaria, Karumba, Bonaparte Gulf, Money Shoal, Arafura, and Browse Basins (see illustration below).



Australian basins for which contributions to the ESCAP Atlas of Stratigraphy have been prepared.

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ABSTRACT

The Murray Basin is a low-lying saucer-shaped intracratonic basin of Tertiary fluvial and shallow-marine sediments which are generally thin (<200-300 m) in the north, east, and south but thicken to 600 m in the west central part of the basin. Framework tectonics have provided the primary control on development of the basin, but within the Cainozoic succession at least three major depositional sequences show an apparently close correlation with global cycles of relative coastal onlap and offlap (i.e., relative rise and fall in sea-level), and this apparent correlation with eustatic or tectono-eustatic influences has been emphasised in the description given below.

The Tertiary succession is locally underlain by poorly defined infrabasins preserved in graben-like troughs and depressions. These contain thick sequences of ?Upper Silurian to Lower Carboniferous sedimentary rocks, locally overlain by thin discontinuous remnants of Permian, Triassic, and Cretaceous rocks. The poorly known stratigraphic successions of these infrabasins are also briefly described in the following report. Our current knowledge of the subsurface geology of the basin has mainly been generated by investigation for and exploitation of groundwater.

In addition to groundwater other resources include Upper Permian coal and Cainozoic alluvial gold, gypsum, halite, and kaolin deposits. Other minerals with exploration potential include poorly known but extensive deposits of Tertiary brown coal and the heavy-mineral content of Pliocene beach sands. The Cainozoic sequence is not prospective for hydrocarbons, but the prospectiveness of the underlying infrabasins has not yet been adequately investigated.

INTRODUCTION

The Australian continent is characterised by frequent and prolonged periods of drought, and groundwater has been long regarded as an important geologic resource. In recent years therefore, stratigraphic studies have been undertaken to document the regional distribution, geometry, and aquifer characteristics of lithostratigraphic units of the major onshore basins as an aid to management of groundwater resources. The following account emphasises stratigraphic correlations within the Cainozoic succession of the Murray Basin, an important inland groundwater basin located in the semi-arid zone of southeastern Australia (Fig.1). The poorly known stratigraphic successions of underlying infrabasins - containing ?Upper Silurian-Devonian to Lower Carboniferous, Permian, Triassic, and Cretaceous sedimentary rocks - are also described.

The Murray Basin is a low-lying, saucer-shaped, intracratonic basin of 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). In the west the Cainozoic sediments overlie and onlap Proterozoic and lower Palaeozoic rocks of the Adelaide Fold Belt, Kanmantoo Fold Belt, and Willyama Basement Block, which together form subdued mountain ranges flanking the western margin of the basin (Fig.2). To the east and south the basin overlies and is flanked by Cambrian to Lower Carboniferous rocks of the Lachlan Fold Belt, forming the present-day 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 younger, foreland basin component of the Lachlan Fold Belt). The southwest boundary of the Murray Basin is here taken as the Padthaway Ridge - a lower Palaeozoic basement high, almost entirely concealed by a thin condensed Cainozoic sequence - which separates the Murray Basin succession from both the Southern Ocean and from the contiguous Cainozoic sequence of the Gambier Embayment of the adjacent Otway Basin. In the north the basin sediments are linked to the Cainozoic cover of the Great Artesian Basin via a narrow corridor of sediment beneath the Darling River flood plain.

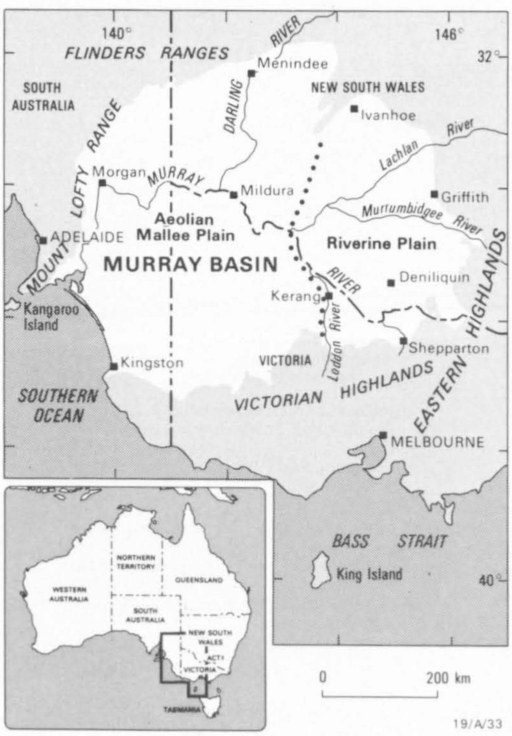

Fig.1. Locality map

Structural elements beneath the Murray Basin have been defined mainly by regional gravity and aeromagnetic trends which, in combination with limited borehole evidence, suggest that Proterozoic and lower Palaeozoic basement is block-faulted, and that the Cainozoic sequence is locally underlain by poorly defined infrabasins preserved in graben-like troughs and depressions (Fig.3). These contain thick sequences of ?Upper Silurian to Lower Carboniferous sedimentary rocks (mainly Devonian) which are in part equivalent to weakly deformed rocks of the Darling Basin to the north and in part equivalent to moderately deformed rocks of the Melbourne Trough and Grampians area in the Victorian Highlands to the south (Fig.2). Locally, the troughs contain thin discontinuous erosional remnants of Permian, Triassic, and Cretaceous platform cover (Fig.2).

The shallow-marine and fluvial sediments comprising the Tertiary Murray Basin succession form an extensive but generally thin cover with a maximum thickness of 600 m beneath the deeper, west-central part of the basin. Beneath northern, eastern, and southern areas the succession is generally less than 200-300 m thick (Plate 1). Framework tectonics have provided the primary control on development of the basin, but within the Cainozoic succession at least three major depositional sequences show an apparently close correlation with the second-order global cycles of relative coastal onlap and offlap (i.e., relative rise and fall in sea-level) as published by Vail & others (1977). This apparent correlation with superimposed eustatic or tectono-eustatic influences is emphasised in the description of the Cainozoic given below. Interpretation of the sedimentary record of the basin in

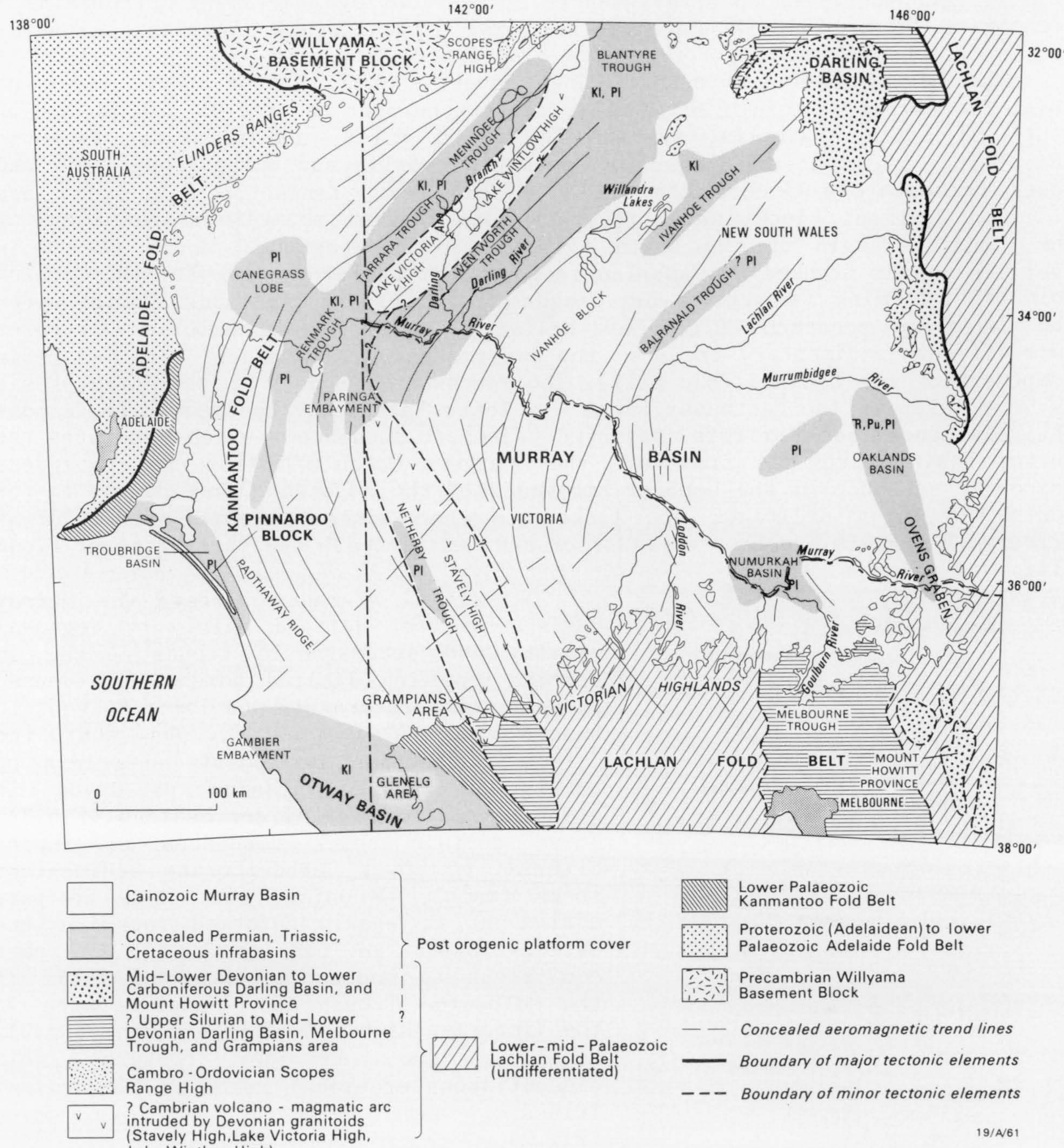

Fig.2. Framework tectonic elements and underlying infrabasins. Structural elements and fracture pattern concealed beneath the Murray Basin have been derived mainly from gravity and aeromagnetic trends.

terms of secondary, eustatic influences rather than local tectonic or palaeoclimatic influences has the added advantage of providing a framework for correlation and comparison with other Cainozoic sequences around the Australian margin (e.g., McGowran, 1978; Quilty, 1980) and possibly elsewhere in the ESCAP region.

In the west, the Tertiary sediments are almost entirely concealed beneath an arid and semi-arid landscape of Quaternary aeolian dunefields with minor fluvial and lacustrine geomorphic features (Fig.1). Farther east, where the basin and adjacent highlands are drained by the Murray, Murrumbidgee, and Lachlan Rivers, the Tertiary underlies flat-lying, fluvio-lacustrine sediments of the semi-arid Riverine Plain. In the west-central part of the basin the Murray River combines with the Darling River to form the largest drainage system in the Australian continent.

Our current knowledge of the subsurface geology of the basin has been generated mainly by investigation for, and exploitation of, groundwater, which is the major geologic resource of the basin and is extensively used for stock, irrigation, and town water supplies. One of the earliest groundwater studies concerned flooding in alluvial deep-lead gold workings in Cainozoic gravels in

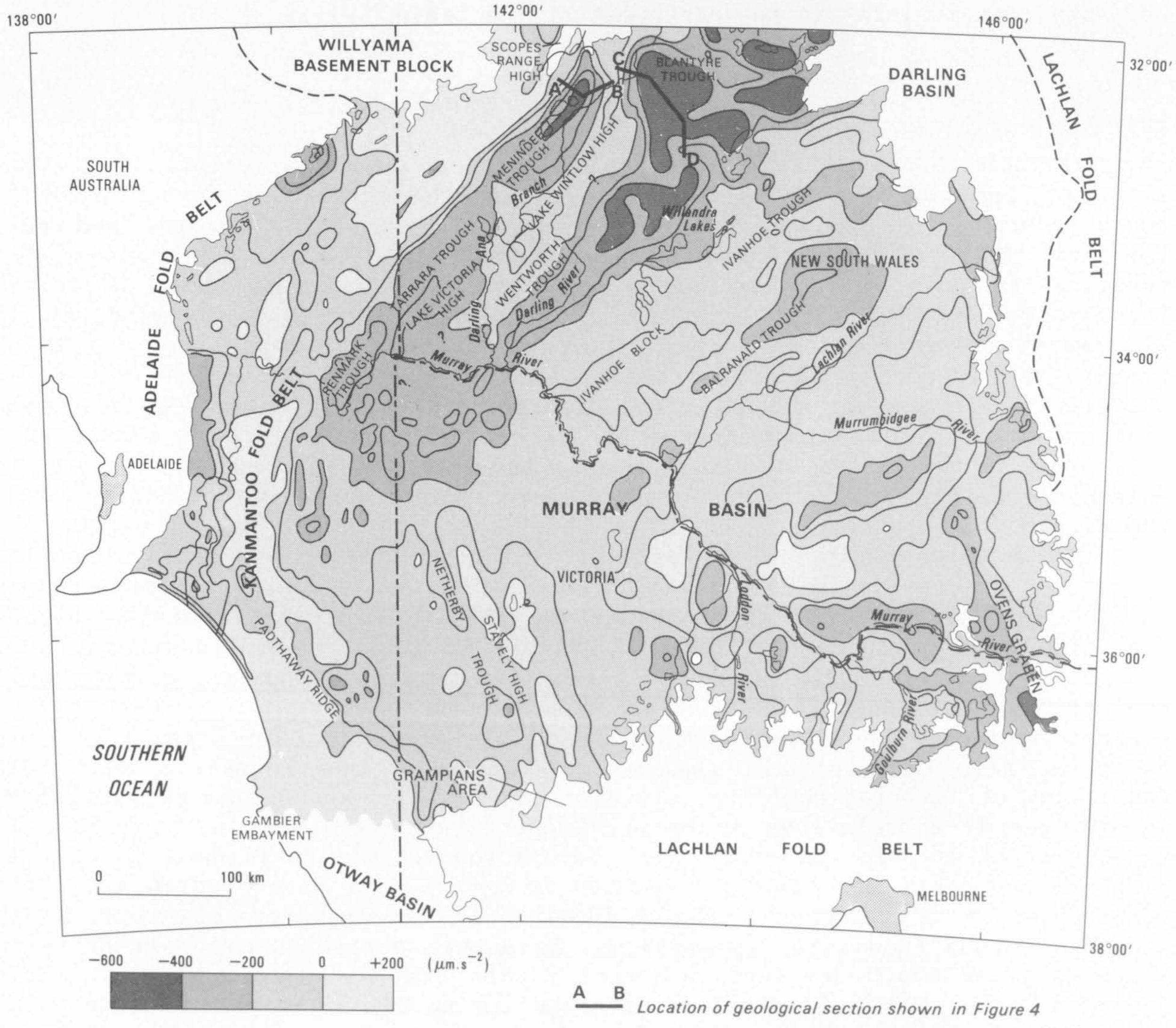

Fig.3. Bouguer gravity anomalies and structural elements beneath the Murray Basin. Structural elements defined mainly on geophysical character (based on BMR gravity data bank, and Anfiloff & others, 1976).

the tributary valleys draining the northern Victorian Highlands; the discovery of these rich alluvial deposits in the 1850s had prompted spectacular but short-lived gold rushes which, in conjunction with development of river trade on the Murray River, provided the initial stimulus for establishment of a number of agricultural communities in the Murray Basin. These, and later irrigation developments, now supply a large proportion of Australian agricultural produce. However, owing to increasing problems of land salinisation and rising groundwater-tables, the future viability of these communities is increasingly dependent on the controlled development and management of the water resources of the basin.

Other resources include Upper Permian coal in the Oaklands infrabasin in New South Wales (Fig.2), while other minerals with exploration potential include poorly known but extensive deposits of Tertiary brown coal and the heavy-mineral content of Pliocene beach sands. In addition, small-scale Cainozoic deposits of gypsum, halite, and kaolin are locally exploited. The Cainozoic sequence is not prospective for hydrocarbons, but the prospectiveness of the underlying infrabasins has not yet been adequately investigated, and proximity to the Moomba-to-Sydney gas pipeline has encouraged continuing hydrocarbon exploration activity, particularly in the northwest of the basin.

REGIONAL TECTONIC EVOLUTION

The Cainozoic Murray Basin sequence accumulated in an intracratonic tectonic setting after the breakup of Gondwanaland and the consequent formation of the southern margin of the Australian continent in the late Mesozoic and early Tertiary (Boeuf & Doust, 1975; Falvey & Mutter, 1981). The terranes which underlie it have a complex evolutionary history spanning the Proterozoic, Palaeozoic, and Mesozoic. Precambrian continental crust - exposed as the Willyama Basement Complex in the northwest - extends at least some little way beneath the western part of the basin (e.g., Doutch & Nicholas, 1978). It may underlie the Palaeozoic Kanmantoo and Lachlan Fold Belts (Rutland, 1976), either continuously or as rifted segments of Precambrian microcontinents separated by Palaeozoic former oceanic crust (e.g., Scheibner, 1976); alternatively the Palaeozoic fold belts represent younger crust that progressively accreted on to the Proterozoic cratonic margin.

The western margin of the Cainozoic basin is flanked and partly underlain by a thick succession of folded and thrust-faulted Adelaidean (Late Proterozoic) to Cambrian fluvio-deltaic, shallow-marine, and lagoonal clastics and carbonates (Adelaide Fold Belt: Parkin, 1969; Preiss,1979; Brown, Cooper & others, 1982) thought to have been deposited over a block-faulted epicratonic platform margin consisting of pre-Adelaidean high-grade metamorphics (Willyama Basement Block). Borehole evidence indicates that, east of the Adelaide Fold Belt, the Murray Basin is also underlain in the west by rocks of the Kanmantoo Fold Belt, consisting of Cambrian phyllite, slate, metagreywacke, and gneiss (Parkin, 1969; inter-regional correlations in Brown, Cooper & others, 1982; Cook, 1982). The tectono-stratigraphic environment of deposition of the Adelaidean to Cambrian platform sediments has been interpreted in terms of a late Precambrian rifted continental margin, whereas the predominantly deeper-water clastics of the Kanmantoo Group (now metamorphosed) may have been deposited over a continental slope and rise which developed adjacent to the cratonic margin in the Cambrian (von der Borch, 1980). Terminal deformation during the Delamerian Orogeny in the Late Cambrian-Early Ordovician resulted in folding and metamorphism to form the Kanmantoo Fold Belt, and foreland folding and thrusting to form the adjacent Adelaide Fold Belt. Deformation was accompanied by deposition of locally preserved Cambro-Ordovician shallow-marine to terrestrial sediments, now exposed in the Scopes Range area (Fig.2 ; Webby, 1978), and by postorogenic emplacement of granitoids. The Delamerian Orogeny can readily be attributed to subduction or strike-slip related convergent plate processes linked to early development of Lachlan Fold Belt terranes, but the precise tectonic evolution remains unclear (Scheibner, 1976; Cas, 1983).

The adjacent Lachlan Fold Belt is a composite tectonic feature consisting, at the present day, of a series of northerly trending, anticlinorial and synclinorial zones with horst-and-graben structures. Deformation ranges from intensely folded and metamorphosed to mildly folded. In the south and east, where the fold belt flanks and underlies the Murray Basin, it consists of Cambrian to Lower Carboniferous folded sediments, metasediments, and basic to intermediate volcanics intruded by granitoids. Structural zones within the fold belt are in places separated by linear greenstone belts, including serpentinised ophiolite complexes (regional correlations summarised in Packham,1969; Scheibner,1976; Vandenberg, 1978; Cas, 1983). The evolution of the fold belt, particularly in the Cambro-Ordovician, has been interpreted mainly in terms of the progressive development, accretion, and deformation of a number of subduction-related volcanic arcs and intervening marginal sea-floors (e.g., Scheibner, 1976; Crook, 1980). Subsequent tectonism is thought to have been associated mainly with superimposed rift-related volcanism and magmatism. In detail, a number of possible permutations of strato-tectonic elements have been proposed (e.g., Packham, 1973; Crook & Felton 1975; Scheibner, 1976; Cas & others, 1980; Crook, 1980; Powell, 1983), but no single interpretation has proved fully comprehensive, and evolution of the fold belt is the subject of continuing research (Cas, 1983). The fold belt may have developed a horst-and-graben character during the mid-Silurian to Early Devonian, and evolved to form a basin-and-range style province by the Early Carboniferous, when deformational events were terminated (Cas, 1983; Powell,1983). Folding and metamorphism of post-Ordovician components were less intense in the western part of the fold belt, where an extensive ?foreland zone of ?Upper Silurian to mid-Lower Devonian marine sediments and ?Upper Silurian-Devonian to Lower Carboniferous continental sediments flanked and partly blanketed the composite orogenic belt. These folded but unmetamorphosed rocks are now exposed in the western Darling Basin to the north, and are locally preserved beneath the Murray Basin. In contrast, equivalent Siluro-Devonian rocks of the eastern Darling Basin, exposed to the east of the Murray Basin, are intensely folded and partly metamorphosed.

?UPPER SILURIAN-DEVONIAN TO LOWER CARBONIFEROUS INFRABASINS

At the eastern margin of the Murray Basin, northerly trending Silurian-Devonian sedimentary rocks of the Lachlan Fold Belt are intensely folded, faulted, and partly metamorphosed. Deformation diminishes westwards, and ?Upper Silurian to Lower Carboniferous marine and non-marine rocks of the Darling Basin, which crop out to the northeast of the Murray Basin, are broadly folded but unmetamorphosed, and form a transitional province between the Lachlan Fold Belt orogenic domain and younger, overlying, platform cover infrabasins (Doutch & Nicholas, 1978). To the south of the Murray Basin, folded marine to non-marine successions of the Melbourne Trough, and non-marine rocks of the Grampians area - correlatives of the Darling Basin - are exposed in the flanking Victorian Highlands. Bouguer gravity anomalies, aeromagnetic trends, and limited seismic and borehole evidence suggest that equivalent thick block-faulted ?Upper Silurian-Devonian to Lower Carboniferous infrabasins are preserved beneath the Murray Basin in poorly defined graben-like troughs. The structure of these troughs is characterised by arcuate northeasterly trends beneath the northern

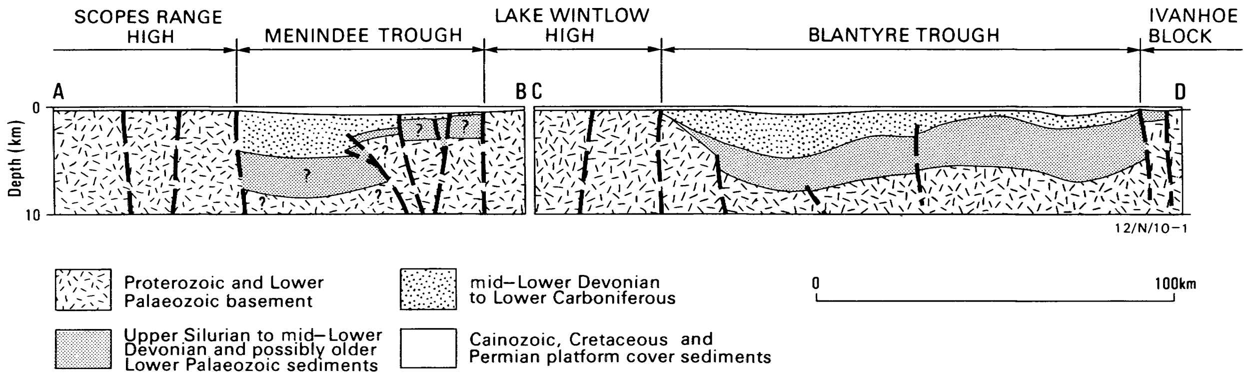

Fig.4. Interpreted geologic section beneath the western Murray Basin (after Evans, 1977; based on seismic data from Alliance, 1968; Beaver, 1973). Line of section shown in Figure 3.

and western Murray Basin and north-northwesterly trends beneath the southern half of the basin (Fig.3). Interpretation of seismic data suggests that the troughs beneath the western Murray Basin may contain up to 6 km of block-faulted but relatively undeformed ?Upper Silurian-Devonian sedimentary rocks (Evans, 1977; Bauer & others, 1979), which may - however - include older Cambro-Ordovician and Silurian rocks (Fig.4).

On the basis of correlation with the Darling Basin succession to the northeast and the Melbourne Trough and Grampians areas of the Lachlan Fold Belt to the south, the thick succession underlying the western Murray Basin can tentatively be divided into two major sequences (Fig.5). The lower sequence is thought to consist of up to 4 km of ?Upper Silurian to mid-Lower Devonian marine siltstone and shale. In the top few hundred metres, these grade upwards into regressive shallow-marine sandstone bodies (equivalent to the Amphitheatre Group and Winduck Group of the Darling Basin - Baker, 1978; Glen, 1979, 1982). The correlative, thick, moderately deformed, deeper-water marine sedimentary rocks of the Melbourne Trough also grade upsequence into Lower Devonian shallow-marine sandstone (Vandenberg & others, 1976; Garratt, 1980, 1983).

The upper depositional sequence is thought to consist of up to ?6 km of block-faulted, broadly warped mid-Lower Devonian to Lower Carboniferous coarse-grained fluviatile and lacustrine sandstone, conglomerate, and minor red shale (equivalent to the Mulga Downs Group of the Darling Basin - Packham, 1969; Webby, 1972; Glen,1979).

The presence of Middle to Upper Devonian non-marine clastics has been confirmed in the west and north by several petroleum exploration wells (Bembrick, 1974; Thornton, 1974,1976), but only three wells and one stratigraphic bore, in northern areas, have encountered Lower Devonian marine clastics (Evans, 1977; Brown, Jackson & others, 1982). As discussed by Brown, Jackson & others (1982) the presence of ?Upper Silurian-Lower Devonian marine clastics has not yet been unequivocally established in the westernmost troughs, where the thick succession may be entirely continental and may include correlatives of the mainly non-marine, ?Upper Silurian-Lower Devonian quartzose sandstone, red siltstone, and mudstone exposed at the southern margin of the basin in the Grampians area (Grampians Group of Spencer-Jones, 1976).

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).

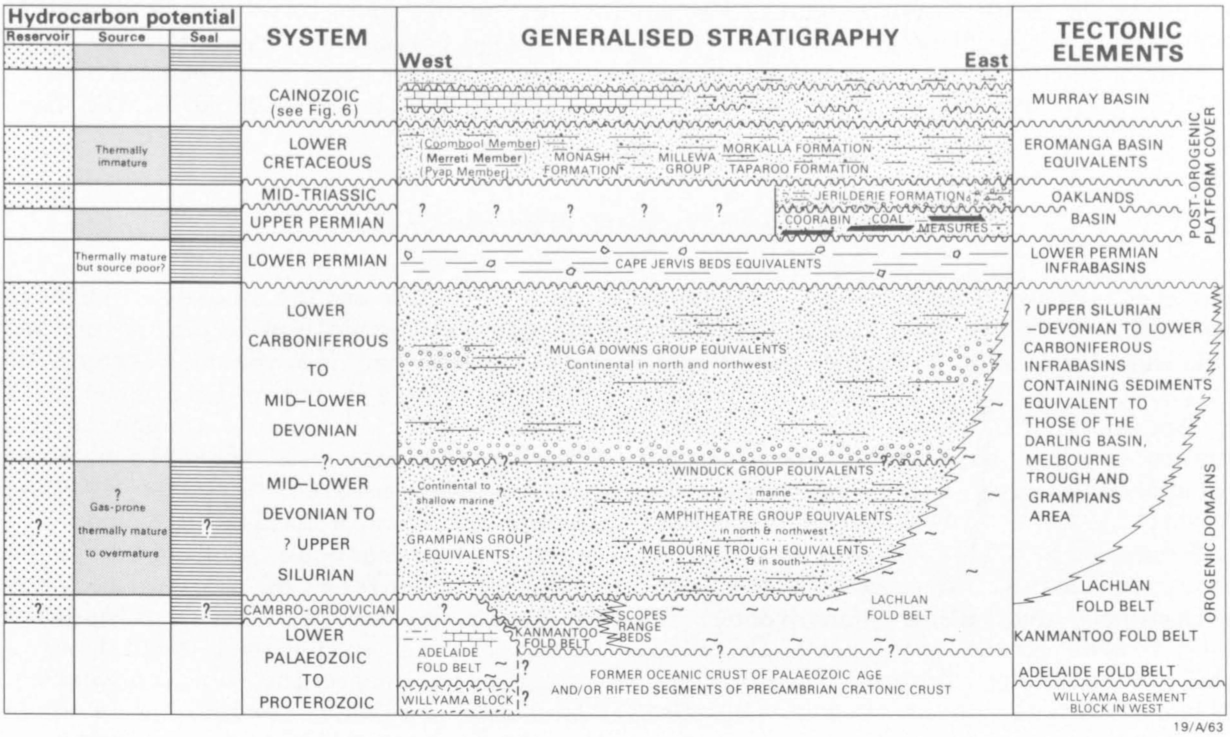

Fig.5. Generalised stratigraphy and summary of hydrocarbon prospectiveness in the Murray Basin and underlying infrabasins.

PERMIAN AND TRIASSIC PLATFORM COVER

Extensive but discontinuous remnants of Lower Permian glacio-marine deposits are preserved as relatively thin veneers within several of the infrabasins underlying the Murray Basin (Figs.2,5). They consist mainly of diamictite, with minor siltstone, sandstone and conglomerate, and contain cold-water foraminiferal and palynomorph assemblages indicating a Lower Permian age (O'Brien, 1981). They are currently unnamed but may correlate with the Cape Jervis beds in the Yorke Peninsula area, west of the Murray Basin in South Australia (Foster, 1974). The thickest sequence penetrated to date is 888 m in Jerilderie No.1 (Wright & Stuntz, 1963) in the Oaklands Basin, but generally only a few hundred metres are preserved. The diamictites have been interpreted mainly as compound paratills (O'Brien, 1981) composed of shallow-marine platform sediments admixed with a variable quantity of poorly sorted ice-rafted debris generally characterised by angular granitic clasts. In the south, possible glacial mudflows and tills deposited by grounded ice have also been tentatively identified (O'Brien, 1981), suggesting close proximity to a glaciated landmass to the south (Crowell & Frakes, 1971).

In the Oaklands Basin, the Lower Permian sequence is disconformably overlain by a composite Upper Permian unit consisting of at least three disconformably stacked upward-fining cyclic fluvial sequences (Coorabin Coal Measures; Morgan, 1977; Yoo, 1982). The fluvial sequences each consist of channel conglomerates grading up to point-bar sandstones which are overlain by siltstone, mudstone, carbonaceous clay, and coal deposited in a flood-plain environment. Equivalent non-marine rocks of Late Permian age may possibly occur within other troughs elsewhere beneath the Murray Basin but have not yet been located.

No Jurassic sedimentary rocks have as yet been identified beneath the Murray Basin, but in the Oaklands Basin the Upper Permian unit is disconformably overlain by mid-Triassic quartzose sandstone, pebble conglomerate, and mudstone deposited in a fluvial environment (Jerilderie Formation; Morgan, 1977). The Triassic rocks were previously thought to be of Palaeogene age because they are lithologically similar to basal Tertiary sands occurring elsewhere in the basin, and hence are possibly more widely distributed than is currently known.

LOWER CRETACEOUS PLATFORM COVER

Residual thin remnants of fluviatile and shallow-marine Lower Cretaceous sedimentary rocks have been intersected by several petroleum exploration wells drilled into the troughs underlying the western and northern Murray Basin (Figs.2,5; Table 1; Plate 1). Thornton (1974) proposed a three-fold subdivision of Aptian-Albian rocks (Monash Formation) underlying the Renmark Trough in South Australia. The basal unit (Pyap Member) consists of pale grey friable sandstone interbedded with minor mudstone, coal, and conglomerate, and was initially deposited in a fluviatile environment grading up into a marine environment as indicated by the occurrence of glauconite, arenaceous foraminifera and dinoflagellates. The succeeding Merreti Member consists of marine mudstone, siltstone, and minor sandstone, and is in turn overlain by Aptian-Albian interbedded green and grey chloritic volcanolithic siltstone, sandstone and shale (Coombool Member) deposited in a fluvio-lacustrine environment. In adjacent areas of northwest Victoria, Lawrence (1976a) recognised a mainly fluviatile and lacustrine Lower Cretaceous succession (Millewa Group) with only minor marine influences, and adopted a two-fold subdivision comprising basal medium to coarse quartz sandstone (Taparoo Formation) overlain by interbedded siltstone, mudstone, and minor sandstone (Morkalla Formation). To the northeast, in New South Wales, Albian marine and Aptian-Neocomian non-marine carbonaceous rocks have been encountered in the Ivanhoe Trough area (Fig.2; Byrnes, 1980).

The volcanolithic component in the uppermost Lower Cretaceous rocks in the Renmark Trough can be correlated with volcanolithic non-marine sedimentary rocks exposed at the northern margin of the adjacent Otway Basin to the south (Evans & Hawkins, 1967). The provenance of the volcanolithic material has not been identified, but is thought to be related to late Mesozoic rift-drift volcanism associated with the breakup of Gondwanaland to form the southern margin of the Australian continent (Boeuf & Doust, 1975; Falvey & Mutter, 1981). The basal quartzose rocks in the Renmark Trough and in northwest Victoria are thought to have been derived from quartz-rich metamorphic or polycyclic sedimentary terranes.

Essentially the Lower Cretaceous succession can be interpreted in terms of a transgressive-regressive cycle related to partial marine incursion of an epeiric sea by invasion from the north. It can thus be correlated with the Cretaceous Eromanga Basin succession of the Great Artesian Basin to the north (Senior & others, 1978). 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.

CAINOZOIC SEDIMENTATION

Framework tectonics have clearly provided the primary control on development of the Murray Basin. However, within the Murray Basin succession, at least three major Cainozoic depositional sequences have been identified, each consisting of a package of genetically related formations separated by disconformities (Fig.6). These sequences reflect either secondary eustatic, tectonic, or palaeoclimatic influences, or various permutations of all three.

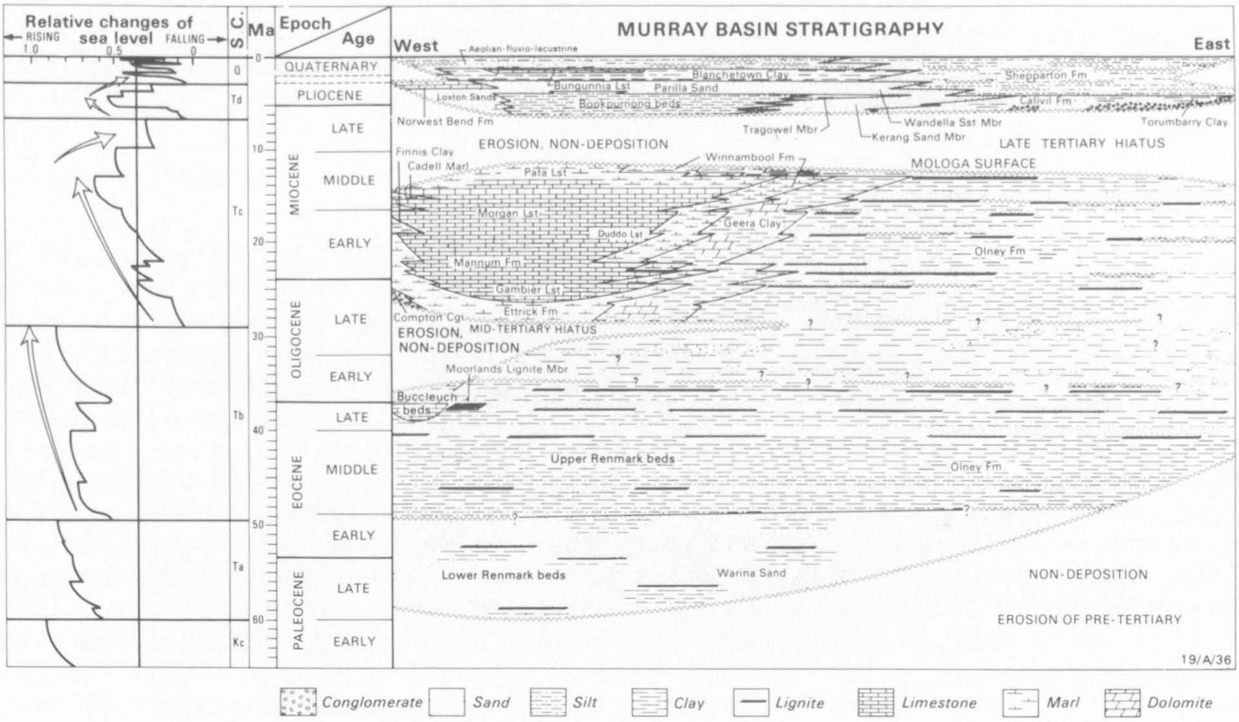

Fig.6. Eustatic interpretation of Cainozoic stratigraphy of the Murray Basin. Relative changes in sea level are based on the global relative coastal onlap curve of Vail & others (1977).

Jones & Veevers (1982) proposed a model of local tectonic cycles to account for the depositional sequences. They suggested that subsidence and sedimentation in the basin occurred as a consequence of periods of uplift and Cainozoic volcanism in the adjacent southeast highlands of Australia, and that non-depositional hiatuses can be correlated with uplift and erosion of the basin accompanied by tectonic settling and volcanic quiescence in the highlands.

In contrast, Ollier (1982) suggested that the detailed chronology of uplift history of the eastern highlands is currently not well understood, and proposed an alternative rift-valley model to explain uplift and geomorphic development of the highlands during the last 80 Ma. In addition, Brown (1983) suggested that fluctuations in the supply and preservation of sediment in the Murray Basin can readily be accommodated by eustatic or tectono-eustatic models, involving sea-level changes and related intrabasinal isostatic adjustments. This apparent correlation of the sedimentary history with superimposed eustatic or tectono-eustatic influences is emphasised in the description of the Cainozoic given below. Unlike the tectonic cycle model, the tectono-eustatic interpretation does not require tectonic cycles of uplift and settling of either the basin or the adjacent highlands to explain the sedimentary record of the Murray Basin. Within each depositional sequence, palaeoclimatic factors have also markedly influenced sediment type and sedimentation rates, but these are not discussed in this Report.

Despite the great areal extent of the Murray Basin (320 000 km^2), structure contours on the base of the Tertiary indicate that the deepest sediments occur at depths of only around 600 m in the west central part of the basin (Plate 1). In addition, despite evidence of minor differential subsidence over underlying infrabasins, each of the depositional sequences forms a thin but remarkably continuous veneer of sediment (e.g., cross-section A-A' in Plate 1 is 850 km long). The Cainozoic history of the basin has been characterised by slow relative subsidence rates, minimal compaction rates, and low rates of sediment supply and/or preservation. The basin succession therefore forms an extensive but thin blanket of sediment, and was deposited over a topographically flat, low-lying, and tectonically stable platform that was potentially susceptible to partial flooding by epicontinental seas.

Paleocene-Eocene-Early Oligocene

At the base of the Murray succession (Fig.6), unconsolidated medium to coarse quartz sands of Paleocene-Eocene age occur in the deeper and more central parts of the basin (Warina Sand of the Renmark Group, and synonymous lower Renmark beds in South Australia; Harris, 1966; Thornton, 1974; Lawrence, 1975). Borehole logs indicate that the unit forms a massive multistorey sand body thought to have been deposited mainly in a fluviatile, braided-channel environment, with minor thin, lenticular intercalations of finer sediment deposited in lacustrine and flood-plain environments. The unit is overlain by a much more widely distributed blanket of unconsolidated, thinly bedded carbonaceous sand, silt, clay, and peaty coal, which extends beneath almost the entire Murray Basin (Olney Formation of the Renmark Group, and synonymous upper Renmark beds in South Australia; Harris, 1966; Pels, 1969; Lawrence, 1975; Woolley, 1978). The Olney Formation was mainly deposited in fluvio-lacustrine, meandering-channel, flood-plain, and extensive swamp environments. Palaeoclimates are generally thought to have been characterised by warm temperatures and high rainfall (Kemp, 1978).

Relative sea-level appears to have remained high throughout the Eocene period of deposition, and in the west the upper part of the fluviatile sequence includes paralic and minor marine components. In the southwest, these components are intercalated with Upper Eocene to Lower Oligocene shallow-marine glauconitic calcareous clays, carbonaceous sands with thin limestone lenses, and bryozoan limestone (Buccleuch beds; Ludbrook, 1961). The rate of sediment supply mainly balanced the rates of rise in sea level, crustal subsidence, and compaction, and hence marine transgression in the Late Eocene appears to have been confined to southwestern and deeper, west central parts of the basin. The Warina Sand ((and lower Renmark beds) appear to correlate with the second-order cycle Ta of Vail & others (1977), and the lower Olney Formation (and upper Renmark beds) and Buccleuch beds appear to correlate with cycle Tb (Fig.6). To date, however, little evidence has been found to substantiate a major disconformity at the boundary between these two units, although this may reflect poor age control within the basal sandstone unit.

In the southwest, deposition of the Olney Formation was restricted to the Eocene-Early Oligocene, but, in the north and east, deposition of similar sediments continued until the Middle Miocene. During this extended period of sediment accumulation (Eocene to Middle Miocene) only a few hundred metres of sediment were preserved, and hence deposition was probably punctuated by a number of stratal breaks. The most prominent of these is thought to have occurred in the early Late Oligocene (or possibly late Early Oligocene), accompanying a major fall in sea level (Fig.6). However the extent and duration of this break are uncertain. Oligocene-Miocene components of the Olney Formation are lithologically indistinguishable from Eocene-Lower Oligocene components, and hence the variously dated components are herein regarded as parts of a single unit.

Oligocene-Middle Miocene

The major but short-lived fall in sea level in the early Late Oligocene was followed by a further progressive rise in sea level (Fig.6) which resulted in a dramatic change in sedimentation patterns in the western Murray Basin, and can

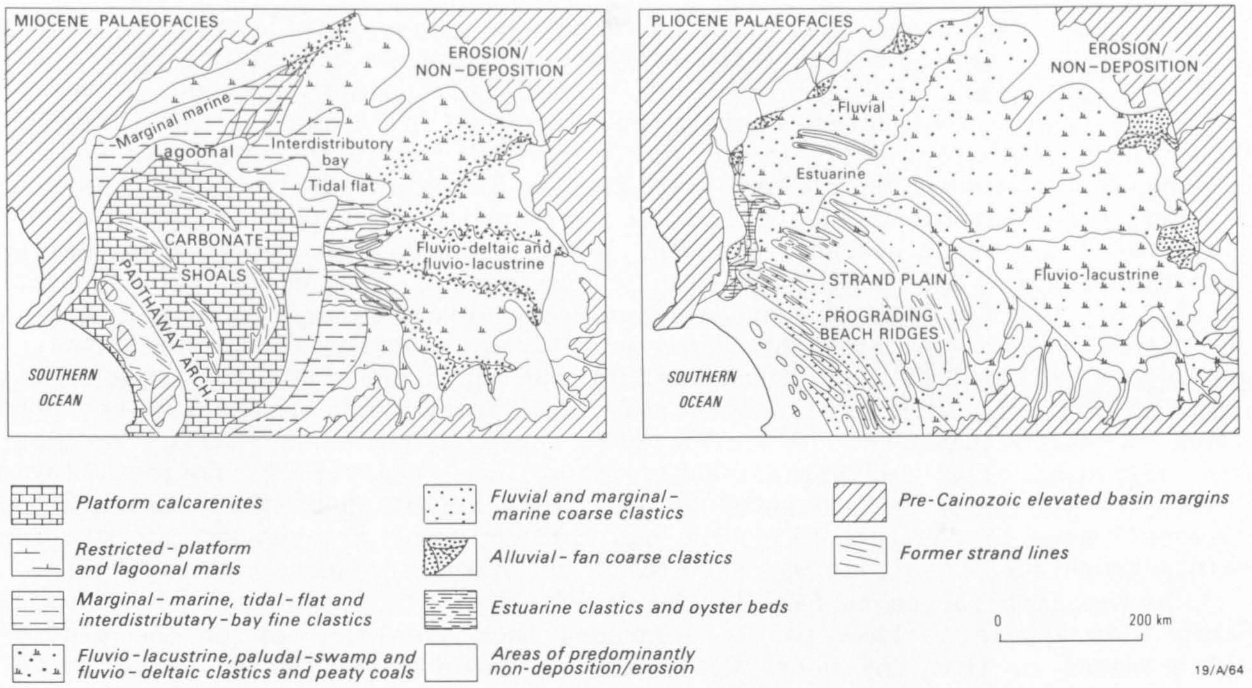

Fig.7. Interpreted Miocene and Pliocene palaeogeography.

be correlated with deposition of the component formations of the Late Oligocene to Middle Miocene Murray Group sequence (Ettrick Formation, Gambier Limestone, Mannum Formation, Morgan Limestone, Pata Limestone, Duddo Limestone, Geera Clay, Winnambool Formation). Though deposition of non-marine sediments continued in the east and north (younger components of the Olney Formation), in the west the rates of terrigenous sediment input did not initially balance the combined rates of rise in sea level and crustal subsidence, and hence the Murray Basin was partly flooded by a shallow-marine sea. This initial lack of sediment supply, in combination with the marine transgression, favoured development of a carbonate platform sequence.

Transgression of the shallow epicontinental sea reached a maximum in the Early Miocene. Palaeogeographic reconstructions (Fig.7) suggest that the marine platform in the southwest was flanked to the east and north by a narrow zone of shallow to restricted-marine and lagoonal environments. These were in turn bordered by a shallow to marginal-marine zone - including extensive interdistributary bays and tidal flats - further flanked by peat-forming swamps and deltaic and fluvial environments.

During the initial marine transgression, in the Oligocene, glauconitic calcareous clays (marls) of the Ettrick Formation (Ludbrook, 1961) accumulated over the platform. As sea level continued to rise, the calcareous clays were replaced upsequence by Late Oligocene to mid-Miocene shallow-marine calcarenites (Fig.6). These consist of the coarse-grained skeletal debris of a mainly temperate-zone assemblage of echinoderms, bryozoans, molluscs, and benthic foraminifera, and include a high quartz sand content (Gambier Limestone, Mannum Formation, Morgan Limestone, Pata Limestone, Duddo Limestone; Ludbrook, 1961,1963; Lindsay & Bonnett, 1973; Lawrence, 1975). Towards the top of the calcarenite succession the Pata Limestone is characterised by a high content of marl. In places a prominent unit of marl is present between the Mannum Formation and the Morgan Limestone, and is locally differentiated as the Cadell Marl. A similar intercalation of terrigenous clay, within the Mannum Formation, at the western margin of the basin, is locally differentiated as the Finnis Clay (Ludbrook, 1961).

To the north and east the calcarenites grade into a narrow zone of glauconitic calcareous clays of the Winnambool Formation (Lawrence, 1975), which contains well preserved macrofossils - including abundant bryozoans - and was deposited in the restricted-platform and lagoonal environments. The Winnambool Formation is lithologically similar to the Ettrick Formation, and is essentially a younger diachronous equivalent (see Fig.6). The glauconitic calcareous clays in turn grade laterally into extensive terrigenous fine clastics of the Geera Clay (Lawrence, 1975; Lawrence & Abele, 1976), deposited in the marginal-marine, interdistributary-bay and tidal-flat environments. The Geera Clay consists mainly of black, locally carbonaceous clay with minor dolomite, and is characterised by an abundant but much less diverse fauna dominated by gastropods, milliolids, and ostracods. To the north and east the Geera Clay in turn interfingers with sand, silt, clay, and peaty coal of the fluvial upper Olney Formation (Lawrence, 1975). As noted above, the Miocene fluvial sediments are lithologically indistinguishable from the underlying Eocene fluvial sediments, and hence are included in the Olney Formation of the Renmark Group. Palaeoclimates in the Late Oligocene and Early Miocene are thought to have been mainly temperate - cool and wet with minor periods which were warm and humid.

As sea level began to fall in the mid-Miocene, the Winnambool Formation and Geera Clay appear to have partly prograded back over the top of the platform calcarenites so that the Geera Clay partly envelopes the marls, which in turn partly envelope the calcarenites. A further dramatic fall in sea level in the Late Miocene can be correlated with development of the Mologa Surface, a land surface associated with weathering and erosion in the basin and active entrenchment of adjacent highland valleys (Macumber, 1978a). This was followed by initiation of the last major depositional sequence of the basin, which in turn can be correlated with a short-lived rise in sea level in the Late Miocene-Pliocene.

Late Miocene-Pliocene

Palaeogeographic reconstructions of the Pliocene suggest that a fluvial flood plain in the east and north was flanked to the southwest by an extensive strand-plain environment of prograding beach ridges, and was connected to the Southern Ocean by a zone of fluvial and estuarine environments located towards the western margin of the basin (Fig.7). Essentially, the rise in sea level in the Late Miocene resulted in deposition of marine clay and marl of the Bookpurnong beds, marginal-marine sand of the lower Loxton Sands and Parilla Sand, and coarse-grained quartzose sand and gravel of the fluvial Calivil Formation (Lawrence & Abele, 1976; Macumber, 1978a). Intercalations of white kaolinitic clay within the Calivil Formation are locally differentiated as the Torumbarry Clay. The Calivil Formation was deposited in a ?braided-stream-channel environment, and forms a sand sheet underlying much of the eastern and northern Murray Basin. As a consequence of rising base levels (rising sea level) and diminished potential for erosion, the locus of deposition appears to have extended up the entrenchments within the previously incised palaeovalleys (see above), which were then backfilled to form the youngest of several Tertiary deep-lead systems of northern Victoria.

The subsequent marine regression resulted in formation of the prograding series of Pliocene beach ridges and inter-ridge fluvial and estuarine quartz sand deposits of the strand plain (upper Loxton Sands and Parilla Sand; Ludbrook, 1961; Firman, 1973; Lawrence, 1975; Macumber, 1978a). At the western margin of the basin, estuarine oyster beds of the Norwest Bend Formation delineate the location of a Pliocene ancestor of the River Murray. In the east, the Pliocene regression can be correlated with an increase in sediment supply, and with deposition of fine-grained clastics and polymictic sand and gravel of the Shepparton Formation by aggradation in a flood-plain environment (Lawrence, 1975). The coarser sediment component was transported within confined channels to the shoreline, where it was reworked and incorporated into the prograding beach complexes of the Parilla Sand.

Palaeoclimates during this late Cainozoic period are thought to have been characterised by increasing seasonal aridity (Bowler, 1982).

Quaternary

In the east of the Murray Basin, widespread aggradational fluvio-lacustrine sedimentation continued into the Quaternary (further Shepparton Formation), resulting in development of the Riverine Plain. Farther west the Tertiary is partly overlain by a thin veneer of Pleistocene lacustrine clay (Blanchetown Clay; Firman, 1973; Lawrence, 1975). In the west, the basin surface is currently one of deflation, and is largely blanketed by extensive Pleistocene and Holocene aeolian dune deposits with associated calcretes. A number of groundwater discharge lake complexes with associated gypsum deposits occur within the aeolian terrain. At the present-day, in South Australia, the drainage system is entrenched within the Tertiary succession to form the River Murray Gorge. The gorge is thought to have developed as a consequence of middle and late Pleistocene glacio-eustatic low sea stands, and to have been partly backfilled during the Flandrian postglacial rise in sea level (Twidale & others, 1978). The Quaternary geology and complex morphostratigraphy of the basin have been extensively studied, and summaries published by Butler & others (1973), Firman (1973), Lawrence (1976b), Bowler & Magee (1978), Twidale & others (1978), and in various papers in Storrier & Kelly (1978) and Storrier & Stannard (1980).

EUSTACY AND CAINOZOIC BASINAL CYCLES

Framework tectonics have provided the primary control on development of the Murray Basin, and palaeoclimatic factors have also clearly influenced sediment type and sedimentation rates. The above description, however, emphasises the secondary influence of relative sea-level change superimposed on a comparatively stable tectonic framework. Depositional sequences in the Murray Basin appear to correlate well with the global second order cycles of Vail & others (1977), but detailed third-order cycles have been identified only locally and incompletely in the basin (Lindsay, 1983). Marine regressions have not been found to be as instantaneous as the global coastal onlap curve suggests. In addition, the magnitude of real (as opposed to relative) sea-level changes in the Murray Basin may not be as great as the global changes estimated by Vail & Hardenbol (1979) and Vail & Mitchum (1979) using the seismic stratigraphic method - particularly if eustatic influences have been amplified by enhanced intrabasinal isostatic subsidence associated with sediment loading.

In recent years, several alternative methods have been used to calibrate global sea-level changes in the Cainozoic (e.g., Bond, 1978, 1979; Pitman, 1978), but as shown by Brown & Fisher (1980) and Falvey & Deighton (1982) there is little agreement between workers regarding the magnitude, and, in many instances, the timing, polarity and causes of global eustatic events. In addition, Watts (1982) has proposed that some eustatic events can be explained by tectonic flexuring associated with lithospheric cooling at passive margins. However, the thermal models which have been proposed do not appear to adequately account for transgressions of epeiric seas deep into intracratonic basins such as the Murray Basin.

Despite the above limitations on the applicability of the relative coastal onlap curves of Vail & others (1977), sediment accumulation in the Murray Basin and adjacent highland valleys appears to have been particularly sensitive to global eustatic or tectono-eustatic influences, and to consequent fluctuations in the erosive and depositional potential of the fluvial systems that traversed the basin (Brown, 1983). Thus, deposition of laterally extensive packages of intercalated fluvio-deltaic, paralic, and shallow-marine sediments in the Murray Basin appears to correlate with major periods of high global sea level, whereas non-preservation because of erosion/non-deposition appears to correlate with periods of lowered sea level.

RESOURCE POTENTIAL

Groundwater

Groundwater is the major geologic resource of the basin; it is extensively exploited for stock and irrigation purposes, and increasingly for town water supplies. The Cainozoic succession is essentially water-saturated, but each of the three Tertiary depositional sequences described above contains a major regional aquifer in addition to a number of partial aquifers (Fig.8; O'Driscoll, 1960; Lawrence, 1975; Woolley & Williams, 1978; Reed, 1980; Tickell & Humphrys, 1980). At the base of the succession, the semiconfined to confined Paleocene to Miocene Renmark Group aquifer is a composite of sand of the Warina Sand and sand and partial aquifers of the Olney Formation. Intercalated sand and carbonate of the Buccleuch beds in the southwest of the basin are also included in the Renmark Group aquifer. In the east the aquifer produces good-quality water and, despite increases in salinity, remains suitable for stock purposes in many western areas. Because it is deeper than the other aquifers, the Renmark Group aquifer is not well developed, but its potential is likely to be increasingly investigated in the north and east.

The Miocene Murray Group aquifer consists of calcarenite of the Gambier Limestone, Mannum Formation, Morgan Limestone, Pata Limestone (South Australia), and Duddo Limestone (Victoria and New South Wales). It mainly contains water of

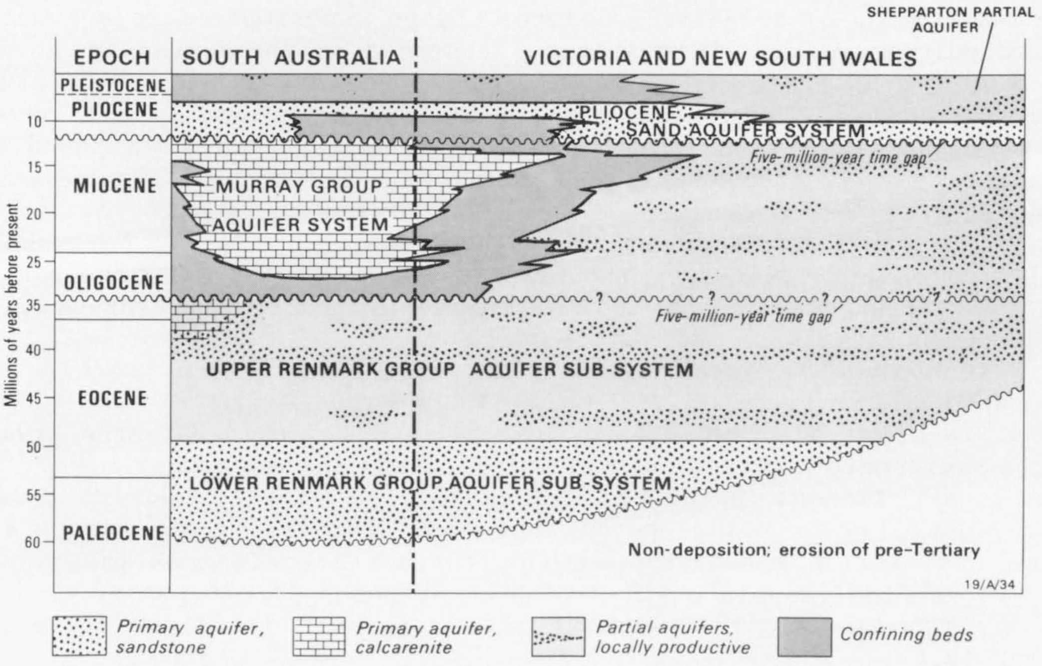

Fig.8. Regional aquifers in the Cainozoic succession of the Murray Basin.

good quality, except in the northwest, and is extensively exploited in the centre and west of the basin, in South Australia and western Victoria (O'Driscoll, 1960; Lawrence, 1975).

The uppermost, near-surface, Pliocene sand aquifer is a composite of the Calivil Formation, Loxton Sands, and Parilla Sand. The aquifer is partly confined beneath the Shepparton Formation in the east and locally beneath the Pleistocene Blanchetown Clay in the west. In the east, groundwater from the fluvial Calivil Formation is locally exploited at the basin margins, but beneath much of the Riverine Plain the aquifer generally contains highly saline groundwater (Macumber, 1978b). In the west and north, marine, estuarine, and fluvial sands of the aquifer (Loxton Sands and Parilla Sand) are mainly unconfined, and contain highly saline waters which locally intersect the surface to form groundwater discharge lake complexes and salinas (Macumber, 1980; Teller & others, 1982). In addition, beneath irrigation districts and areas where trees have been cleared the groundwater-table is slowly rising owing to excess water draining through to the saturated zone. As a consequence, land salinisation, water-logging of tree roots, and discharge of saline groundwater into the arterial rivers of the basin have, in recent years, emerged as major problems of surface and groundwater management, and necessitate continuing programs of hydrogeological investigation. The River Murray provides water to the cities of Adelaide and Whyalla, in addition to many of the towns of the Murray Basin, and hence the complex recharge-discharge interactions between saline groundwater and surface water in the basin have also been increasingly investigated in recent years (Maunsell & Partners, 1979).

<u>Cainozoic evaporite, kaolin, alluvial gold, and heavy mineral deposits</u>

Evaporation rates greatly exceed precipitation, and the western Murray Basin has been subjected to an arid or semi-arid climatic regime for much of the Late Pleistocene and Holocene. In consequence the basin contains large potential reserves of gypsite and selenite, which are locally exploited for the manufacture of plaster and for agricultural purposes. Extensive thin deposits occur in remnant lacustrine and aeolian dune sediments associated with relict late Quaternary groundwater discharge or terminal lake complexes (McLaughlin, 1966; Bembrick, 1974). Halite salinas also occur within some of the modern lake complexes and salt is seasonally harvested from Lake Tyrell and nearby ephemeral lakes in northwest Victoria (Teller & others, 1982).

In the Oaklands-Coorabin area lenticular occurrences of white kaolinitic clay are mined for refractory purposes (Bembrick, 1974). The clays are mainly intercalated within the Pliocene Calivil Formation (Torumbarry Clay; Fig.6), and are thought to have been derived from granitic terrane to the south during a prolonged period of weathering associated with the Late Miocene depositional hiatus (Mologa Surface).

Cainozoic gravel and sand forming the deep-lead systems of the valleys draining the northern Victorian highlands contain high-yield auriferous placer deposits. The relatively shallow, higher-level components were extensively worked during the latter half of the 19th century, but greater depth of burial, and flooding of shafts, prevented basinward exploitation (Hunter, 1909; Whiting & Bowen, 1976). In western Victoria, investigation of former strand lines of Pliocene beach/dune deposits has locally indicated the presence of thin bands containing a mineralogically mature suite of opaques, tourmaline, rutile, and zircon comprising up to 20 per cent of the bands (Colwell, 1979). Landsat scenes, aerial radiometric surveys, and borehole data have indicated the presence of a potentially prospective, extensive strand plain (Fig.7), which has not yet been fully investigated.

Coal

Sub-bituminous, Upper Permian coal was mined intermittently from the Coorabin Coal Measures in the Oaklands infrabasin in New South Wales from 1917 to 1959 when flooding caused production to cease (Bembrick, 1974). Several thin coal seams occur at the top of point-bar sequences (Morgan, 1977), and the thickest of these locally attains a thickness of up to 12 m. In recent years, drilling programs undertaken by the Mines Department of New South Wales have greatly extended the known limits of the coalfield, and large reserves have been inferred (Palese, 1974; Yoo, 1982). The feasibility of renewed mining is currently being investigated in the south, but mining is currently constrained farther north by unfavourable depths of burial beneath water-saturated Tertiary sediments.

Groundwater investigations over the past several decades have indicated the presence of poorly known but extensive deposits of Tertiary brown coal within Late Eocene to mid-Miocene sediments of the basin. The coal occurs in thin discontinuous seams, and consists of peat, soft brown coal, and lignite, which generally have a low calorific value and high moisture, sulphur, and ash content. No currently economic deposits have been located yet, but the occurrence of a number of subeconomic coalfields around the western margin of the basin in South Australia (Johns, 1975) has encouraged continuing investigations.

Hydrocarbons

A number of petroleum exploration wells have intersected Cretaceous, Permian, and Middle to Upper Devonian sedimentary rocks beneath the Cainozoic Murray Basin, but no significant indications of hydrocarbons have been encountered so far. The degree of deformation of sedimentary rocks of the tectonic elements flanking the Murray Basin suggests that prospectiveness is confined to the postorogenic platform cover successions, and to underlying block-faulted but relatively undeformed rocks preserved in the graben-like troughs underlying the western Murray Basin (Figs.2,5).

In a comprehensive review of the petroleum geology of western New South Wales, Evans (1977) suggested that hydrocarbons may occur within regressive Lower Devonian sandstone reservoirs of shallow-marine or deltaic facies, and may have been generated from and sealed by Lower Devonian marine shale, now preserved beneath the western Murray Basin. The available but limited geochemical data indicate that the marine Lower Devonian rocks lack an oil-prone source and currently have low hydrocarbon source potential, but were probably a source for gas in the past (Brown, Jackson & others, 1982). The Lower Devonian rocks are probably thermally mature to overmature, even on the margins of the troughs, and it seems unlikely that any hydrocarbons trapped in Lower Devonian reservoirs could have survived at depth within the troughs. Prospectiveness within the Lower Devonian rocks therefore appears to be confined to the flanks of troughs, where potential reservoir rocks at shallow depths are likely to have been suitably juxtaposed relative to potential source rocks.

The overlying Middle Devonian to Lower Carboniferous continental clastic sequence contains excellent reservoir rocks, but despite the formation of suitable structures during graben formation the sequence appears to contain few suitable source rocks or seals. In addition, the deep burial of potential Lower Devonian source rocks during the terminal stages of deformation of the Lachlan Fold Belt may have contributed to an early generation, migration, and maturation of hydrocarbons which may have resulted in their subsequent escape through the coarse continental clastics before deposition of the overlying thin platform cover successions.

The few analyses currently available from the Lower Permian rocks also indicate poor potential in terms of source richness (Brown, Jackson & others, 1982); however, the results also indicate that the Permian rocks are thermally mature for oil generation, which suggests that if source-rich rocks equivalent to those of the Late Permian of the Oaklands infrabasin were to be discovered elsewhere beneath the basin then the prospectiveness of the Permian would be greatly enhanced. No Jurassic sedimentary rocks have been discovered as yet, and the thin Cretaceous and Cainozoic successions appear to be thermally immature in terms of source potential, although the Cretaceous contains both suitable reservoir rocks and seals (Thornton, 1974).

In summary, although the results of exploration activity undertaken to date suggest that the hydrocarbon prospectiveness of the infrabasins beneath the Murray Basin is limited, these results need to be viewed in the context of an inadequately explored basin.

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TABLE 1. Boreholes used in compilation of Plate 1 (depths in metres)

Borehole	Drilled by	Year	Depth	Sub-basin
Balranald No.1	Woodside Oil Company Pty Ltd NL	1962	403	Balranald Trough
Berri North No.1	Beach Petroleum NL	1967	945	Renmark Trough
Bordertown bore	South Australian Department of Mines	1937	183	Padthaway Ridge
Bundy No.1	Woodside Oil Company Pty Ltd NL	1962	419	Bundy Trough
Canopus No.1 bore	South Australian Department of Mines	1952	290	Canegrass Lobe
Jerilderie No.1	Australian Oil and Gas Corporation Ltd	1962	1329	Oaklands Basin
Lake Victoria No.1	Australian Oil and Gas Corporation Ltd	1964	754	Lake Victoria High
Loxton No.2	Beach Petroleum NL	1963	550	Renmark Trough
Nadda No.1	Associated Australian Oilfields NL	1970	1041	Paringa Embayment
Naracoorte No.2 bore	South Australian Department of Mines	1950	163	Padthaway Ridge
North Renmark No.1	Australian Oil Corporation	1962	1225	Renmark Trough
Pinnaroo No.1	Murray Basin Oil Syndicate	1956	390	Pinnaroo Block
Shaugh bore	South Australian Department of Mines	1946	259	Pinnaroo Block
Sunset No.1	Associated Australian Oilfields NL	1970	1001	Paringa Embayment
Wentworth No.1	Australian Oil and Gas Corporation Ltd	1961	634	Wentworth Trough

REFERENCES

ALLIANCE (Oil Development Australia), 1968 - Lake Wintlow seismic survey, P.E.L.52, New South Wales by Geophysical Associates Pty Ltd. Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts File 68/3031 (unpublished).

ANFILOFF, W., BARLOW, B.C., MURRAY, A., DENHAM,D., & SANDFORD, R., 1976 - Compilation and production of the 1976 Gravity Map of Australia. BMR Journal of Australian Geology & Geophysics, 1(4), 273-276.

BAKER, C.J., 1978 - Geology of the Cobar 1:100 000 sheet. Geological Survey of New South Wales, Sydney.

BAUER, J.A., MATHUR, S.P., STAGG, H.M.J., & HARRISON, P.L., 1979 - A proposal for a seismic survey in the western Darling Basin, New South Wales. Bureau of Mineral Resources, Australia, Record 1979/25.

BEAVER (Exploration Australia, NL), 1973 - Menindee regional seismic survey, P.E.L.'s 193,197, New South Wales, by G.E.S. Pty Ltd. Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts File 73/250 (unpublished).

BEMBRICK, C.S., 1974 - Murray Basin. In MARKHAM, N.L., & BASDEN, H.,(Editors) - The mineral deposits of New South Wales. Geological Survey of New South Wales, Sydney, 555-568.

BOEUF, M.G., & DOUST, H., 1975 - Structure and development of the southern margin of Australia. The APEA Journal 15(1), 33-43.

BOND, G.C., 1978 - Speculations on real sea-level changes and vertical motions of continents at selected times in the Cretaceous and Tertiary periods. Geology, 6, 247-250.

BOND, G.C., 1979 - Evidence for some uplift of large magnitude in continental platforms. Tectonophysics, 61, 285-305.

BOWLER, J.M., 1982 - Aridity in the late Tertiary and Quaternary of Australia. In BARKER, W.R., & GREENSLADE, P.J.M., (Editors) - EVOLUTION OF THE FLORA AND FAUNA OF ARID AUSTRALIA. Peacock Publications, Frewville, South Australia.

BOWLER, J.M., & MAGEE, J.W., 1978 - Geomorphology of the Mallee region in semi-arid northern Victoria and western New South Wales. Proceedings of the Royal Society of Victoria, 90, 5-25.

BROWN, A.V., COOPER, R.A., CORBETT, K.D., DAILY, B., GREEN, G.R., GRINDLY, G.W., JAGO, J., LAIRD, M.G., VANDENBERG, A.H.M., VIDAL, G., WEBBY, B.D., & WILKINSON, H.E., 1982 - Late Proterozoic to Devonian sequences of southeastern Australia, Antarctica and New Zealand and their correlation. Geological Society of Australia, Special Publication 9.

BROWN, C.M., 1983 - Discussion: A Cainozoic history of Australia's Southeast Highlands. Journal of the Geological Society of Australia, 30, 483-486.

BROWN, C.M., JACKSON, K.S., LOCKWOOD, K.L., & PASSMORE, V.L., 1982 - Source rock potential and hydrocarbon prospectivity of the Darling Basin, NSW. BMR Journal of Australian Geology & Geophysics, 7, 23-33.

BROWN, L.F., & FISHER, W.L., 1980 - Seismic stratigraphic interpretation and petroleum exploration. American Association of Petroleum Geologists, Continuing Education Course Note Series, 16.

BUTLER, B.E., BLACKBURN, G., BOWLER, J.M., LAWRENCE, C.R., NEWELL, J.W., & PELS, S., 1973 - A geomorphic map of the Riverine Plain of southeastern Australia. Australian National University Press, Canberra.

BYRNES, J.G., 1980 - The Great Australian Basin in southwestern N.S.W. and adjoining states. Geological Survey of New South Wales, Report (unpublished).

CAS, R., 1983 - Palaeogeographic and tectonic development of the Lachlan Fold Belt, southeastern Australia. Geological Society of Australia, Special Publication 10.

CAS, R.A.F., POWELL, C.McA., & CROOK, K.A.W., 1980 - Ordovician palaeogeography of the Lachlan Fold Belt: a modern analogue and tectonic constraints. Journal of the Geological Society of Australia, 27, 19-31.

COLWELL, J.B., 1979 - Heavy minerals in the late Cainozoic sediments of southeastern South Australia and western Victoria. BMR Journal of Australian Geology & Geophysics, 4, 83-97.

COOK, P.J., 1982 - The Cambrian palaeogeography of Australia and opportunities for petroleum exploration. The APEA Journal 22(1), 42-64.

CROOK, K.A.W., 1980 - Forearc evolution in the Tasman Geosyncline: the origin of the southeast Australian continental crust. Journal of the Geological Society of Australia, 27, 215-232.

CROOK, K.A.W., & FELTON, E.A., 1975 - Tasman Geosyncline greenstones and ophiolites. Journal of the Geological Society of Australia, 22, 117-131.

CROWELL, J.C., & FRAKES, L.A., 1971 - Late Palaeozoic glaciation of Australia. Journal of the Geological Society of Australia, 17, 115-155.

DOUTCH, H.F., & NICHOLAS, E., 1978 - The Phanerozoic sedimentary basins of Australia and their tectonic implications. Tectonophysics, 48, 365-388.

EVANS, P.R., 1977 - Petroleum geology of western New South Wales. The APEA Journal 17(1), 42-49.

EVANS, P.R., & HAWKINS, P.J., 1967 - The Cretaceous below the Murray Basin. Bureau of Mineral Resources, Australia, Record 1967/137.

FALVEY, D.A., & MUTTER, J.C., 1981 - Regional plate tectonics and the evolution of Australia's passive margins. BMR Journal of Australian Geology & Geophysics, 6, 1-29.

FALVEY, D.A., & DEIGHTON, I., 1982 - Recent advances in burial and thermal geohistory analysis. The APEA Journal 22, 65-81.

FIRMAN, J.B., 1973 - Regional stratigraphy of surficial deposits in the Murray Basin and Gambier Embayment. Geological Survey of South Australia, Report of Investigation, 39.

FOSTER, C.B., 1974 - Stratigraphy and palnology of the Permian at Waterloo Bay, Yorke Peninsula, South Australia. Transactions of the Royal Society of South Australia, 98, 29-42.

GARRATT, M.J., 1980 - Melbourne Trough: sedimentation and environments. In COOK, P.J., (Editor), Australian Sedimentology Specialist Group, Conference, Canberra, A.C.T., December, 1980, Abstracts, 54.

GARRATT, M.J., 1983 - Silurian to Early Devonian facies and biofacies patterns for the Melbourne Trough, central Victoria. Journal of the Geological Society of Australia, 30, 121-147.

GLEN, R.A., 1979 - The Mulga Downs Group and its relation to the Amphitheatre Group southwest of Cobar. Geological Survey of New South Wales, Quarterly Notes 36, 1-10.

GLEN, R.A., 1982 - Nature of late-Early to Middle Devonian tectonism in the Buckambool area, Cobar, New South Wales. Journal of the Geological Society of Australia, 29, 127-138.

HARRIS, W.K., 1966 - New and redefined names in South Australian lower Tertiary stratigraphy. Geological Survey of South Australia, Quarterly Notes 20, 1-3.

HUNTER, S.B., 1909 - The deep leads of Victoria. Geological Survey of Victoria, Memoir 7.

JOHNS, R.K., 1975 - Tertiary coal in South Australia. In TRAVES, D.M., & KING, D., (Editors) - ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA, VOLUME 2: COAL. Australasian Institute of Mining and Metallurgy, Melbourne, Monograph Series, 6, 366-371.

JONES, J.G., & VEEVERS, J.J., 1982 - A Cainozoic history of Australia's Southeast Highlands. Journal of the Geological Society of Australia, 29, 1-12.

KEMP, E.M., 1978 - Tertiary climatic evolution and vegetation history in the southeast Indian Ocean region. Palaeogeography, Palaeoclimatology, Palaeoecology, 24, 169-208.

LAWRENCE, C.R., 1975 - Geology, hydrodynamics and hyrochemistry of the southern Murray Basin. Geological Survey of Victoria, Memoir 30.

LAWRENCE, C.R., 1976a - Lower Cretaceous, Murray Basin. In DOUGLAS, J.G., & FERGUSON, J.A., (Editors) - Geology of Victoria. Geological Society of Australia, Special Publication 5, 146-147.

LAWRENCE, C.R., 1976b - Quaternary, Murray Basin. In DOUGLAS, J.G., & FERGUSON, J.A., (Editors) - Geology of Victoria. Geological Society of Australia, Special Publication 5, 276-288.

LAWRENCE, C.R., & ABELE, C., 1976 - Tertiary, Murray Basin. In DOUGLAS, J.G., & FERGUSON, J.A., (Editors) - Geology of Victoria. Geological Society of Australia, Special Publication 5, 191-198.

LINDSAY, J.M., 1983 - Oligo-Miocene transgressive events in Geera Clay, Oakvale 1, northern Murray Basin. Geological Survey of South Australia, Quarterly Notes 85, 5-12.

LINDSAY, J.M., & BONNETT, J.E., 1973 - Tertiary stratigraphy of three deep bores in the Waikerie area of the Murray Basin. Geological Survey of South Australia, Report of Investigation, 38.

LUDBROOK, N.H., 1961 - Stratigraphy of the Murray Basin in South Australia. Geological Survey of South Australia, Bulletin 36.

LUDBROOK, N.H., 1963 - Correlation of the Tertiary rocks of South Australia. Transactions of the Royal Society of South Australia, 87, 5-15.

McGOWRAN, B., 1978 - Stratigraphic record of early Tertiary oceanic and continental events in the Indian Ocean region. Marine Geology, 26, 1-39.

McLAUGHLIN, R.J.W., 1966 - Geochemical concentration under saline conditions. Proceedings of the Royal Society of Victoria, 79, 569-577.

MACUMBER, P.G., 1978a - Evolution of the Murray River during the Tertiary Period: evidence from northern Victoria. Proceedings of the Royal Society of Victoria, 90, 43-52.

MACUMBER, P.G., 1978b - Hydrologic change in the Loddon Basin: the influence of groundwater dynamics on surface processes. Proceedings of the Royal Society of Victoria, 90, 125-128.

MACUMBER, P.G., 1980 - The influence of groundwater discharge on the mallee landscape. In STORRIER, R.R., & STANNARD, M.E., (Editors) - Aeolian landscapes in the semi-arid zone of south eastern Australia. Proceedings of a symposium held at Mildura, Victoria, Australia, on October 17-18, 1979. Australian Society of Soil Science Inc., Riverina Branch, 67-84.

MAUNSELL & PARTNERS, 1979 - Murray Valley salinity and drainage report. Prepared for the Murray Valley Salinity Study Steering Commitee. Department of National Development, Canberra.

MORGAN, R., 1977 - Stratigraphy and palynology of the Oaklands Basin, New South Wales. Geological Survey of New South Wales, Quarterly Notes 29, 1-6.

O'BRIEN, P.E., 1981 - Permian sediments beneath the Murray Basin. Bureau of Mineral Resources, Australia, Record 1981/60.

O'DRISCOLL, E.D.P., 1960 - The hydrology of the Murray Basin in South Australia. Geological Survey of South Australia, Bulletin 35.

OLLIER, C.D.,1982 - The Great Escarpment of eastern Australia: tectonic and geomorphic significance. Journal of the Geological Society of Australia, 29, 13-23.

PACKHAM, G.H., (Editor), 1969 - The geology of New South Wales. Journal of the Geological Society of Australia, 16.

PACKHAM, G.H., 1973 - A speculative Phanerozoic history of the southwest Pacific. In COLEMAN, P.J., (Editor) - THE WESTERN PACIFIC ISLAND ARCS, MARGINAL SEAS, GEOCHEMISTRY. University of Western Australia Press, 368-388.

PALESE, G., 1974 - Oaklands Basin coal drilling programme. Basic results of 22 bores drilled by the N.S.W. Department of Mines from August 1973 to February 1974. Geological Survey of New South Wales, Report GS 1974/090 (unpublished).

PARKIN, L.W., (Editor), 1969 - Handbook of South Australian geology. Geological Survey of South Australia.

PELS, S., 1969 - The Murray Basin. In PACKHAM, G.Y., (Editor) - The geology of New South Wales. Journal of the Geological Society of Australia, 16, 499-511.

PITMAN, W.C.III, 1978 - Relationships between eustacy and stratigraphic sequences of passive margins. Geological Society of America, Bulletin 89, 1389-1403.

POWELL, C.McA., 1983 - Tectonic relationship between the Late Ordovician and Late Silurian palaeogeographies of southeastern Australia. Journal of the Geological Society of Australia, 30, 353-373.

PREISS, W.V., 1979 - Adelaidean sedimentation in the Adelaide Geosyncline and Sturt Shelf. South Australian Department of Mines and Energy, Report Book 79/24.

QUILTY, P.G., 1980 - Sedimentation cycles in the Cretaceous and Cenozoic of Western Australia. Tectonophysics, 63, 349-366.

REED, J.A., 1980 - Murray Basin hydrogeological investigation data assessment - upper Murray and northern region. South Australian Department of Mines and Energy, Report Book 80/42.

RUTLAND, R.W.R., 1976 - Orogenic evolution of Australia. Earth-Science Reviews, 12, 161-196.

SCHEIBNER, E., 1976 - Explanatory notes on the tectonic map of New South Wales. Geological Survey of New South Wales.

SENIOR, B.R., MOND, A., & HARRISON, P.L., 1978 - Geology of the Eromanga Basin. Bureau of Mineral Resources, Australia, Bulletin 167.

SPENCER-JONES, D., 1976 - Grampians Group of western Victoria. In DOUGLAS, J.G., & FERGUSON, J.A., (Editors) - Geology of Victoria. Geological Society of Australia, Special Publication 5, 71-76.

STORRIER, R.R., & KELLY, I.D., (Editors), 1978 - The hyrogeology of the Riverine Plain of south east Australia. Proceedings of a symposium held at Griffith, N.S.W., Australia, on July 28-29, 1977. Australian Society of Soil Science, Inc., Riverina Branch.

STORRIER, R.R., & STANNARD, M.E., (Editors), 1980 - Aeolian landscapes in the semi-arid zone of south eastern Australia. Proceedings of a symposium held at Mildura, Victoria, Australia, on October 17-18, 1979. Australian Society of Soil Science, Inc., Riverina Branch.

TELLER, J.T., BOWLER, J.M., & MACUMBER, P.G., 1982 - Modern sedimentation and hydrology in Lake Tyrrell, Victoria. Journal of the Geological Society of Australia, 29, 159-175.

THORNTON, R.C.N., 1974 - Hydrocarbon potential of the western Murray Basin and infrabasins. Geological Survey of South Australia, Report of Investigation, 41.

THORNTON, R.C.N., 1976 - Murray Basin and associated infrabasins. In LESLIE, R.D., EVANS, M.J., & KNIGHT, C.L., (Editors) - ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA, VOLUME 3: PETROLEUM. Australasian Institute of Mining and Metallurgy, Melbourne, Monograph Series, 7, 91-94.

TICKELL, S.J., & HUMPHRYS, W.G., 1980 - The geology of the Riverine Plain in Victoria. Geological Survey of Victoria, Report 1979/135.

TWIDALE, C.R., LINDSAY, J.M., & BOURNE, J.A., 1978 - Murray Valley Gorge in South Australia: age and origin. Proceedings of the Royal Society of Victoria, 90, 27-42.

VAIL, P.R., MITCHUM, R.M., & THOMSON, S.III, 1977 - Global cycles of relative change of sea-level. In Seismic stratigraphy - applications to hydrocarbon exploration. American Association of Petroleum Geologists, Memoir 26, 83-97.

VAIL, P.R., & HARDENBOL, J., 1979 - Sea level change during the Tertiary. Oceanus, 22, 71-79.

VAIL, P.R., & MITCHUM, R.M., 1979 - Global cycles of relative change in sea-level from seismic stratigraphy. In Geological and geophysical investigations of continental margins. American Association of Petroleum Geologists, Memoir 29, 468-472.

VANDENBERG, A.H.M., 1978 - The Tasman Fold Belt system in Victoria. Tectonophysics 48, 267-297.

VANDENBERG, A.H.M., GARRATT, M.J., & SPENCER-JONES, D., 1976 - Silurian-Middle Devonian. In DOUGLAS, J.G., & FERGUSON, J.A., (Editors) - Geology of Victoria. Geological Society of Australia, Special Publication 5, 45-76.

VON DER BORCH, C.C., 1980 - Evolution of Late Proterozoic to early Palaeozoic Adelaide Fold Belt, Australia: comparisons with post-Permian rifts and passive margins. Tectonophysics, 70, 115-134.

WATTS, A.B., 1982 - Tectonic subsidence, flexure and global changes in sea-level. Nature, 297, 469-474.

WEBBY, B.D., 1972 - Devonian geological history of the Lachlan Geosyncline. Journal of the Geological Society of Australia, 19(1), 99-123.

WEBBY, B.D., 1978 - History of the Ordovician continental platform shelf margin of Australia. Journal of the Geological Society of Australia, 25, 41-63.

WHITING, R.G., & BOWEN, K.G., 1976 - Economic geology, gold. In DOUGLAS, J.G., & FERGUSON, J.A., (Editors) - Geology of Victoria. Geological Society of Australia, Special Publication 5, 434-451.

WOOLLEY, D.R., 1978 - Cainozoic sedimentation in the Murray drainage basin. Proceedings of the Royal Society of Victoria, 90, 61-65.

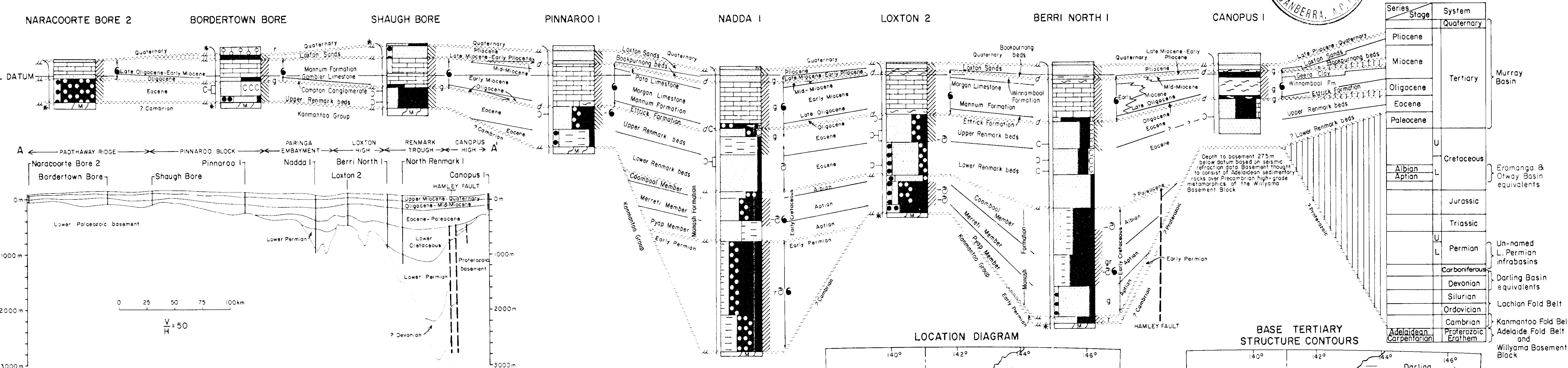
WOOLLEY, D.R., & WILLIAMS, R.M., 1978 - Tertiary stratigraphy and hydrogeology of the eastern part of the Murray Basin, New South Wales. In STORRIER, R.R., & KELLY, I.D., (Editors) - The hydrogeology of the Riverine Plain of south east Australia. Proceedings of a symposium held at Griffith, N.S.W., Australia, on July 28-29, 1977. Australian Society of Soil Science Inc., Riverina Branch, 45-65.

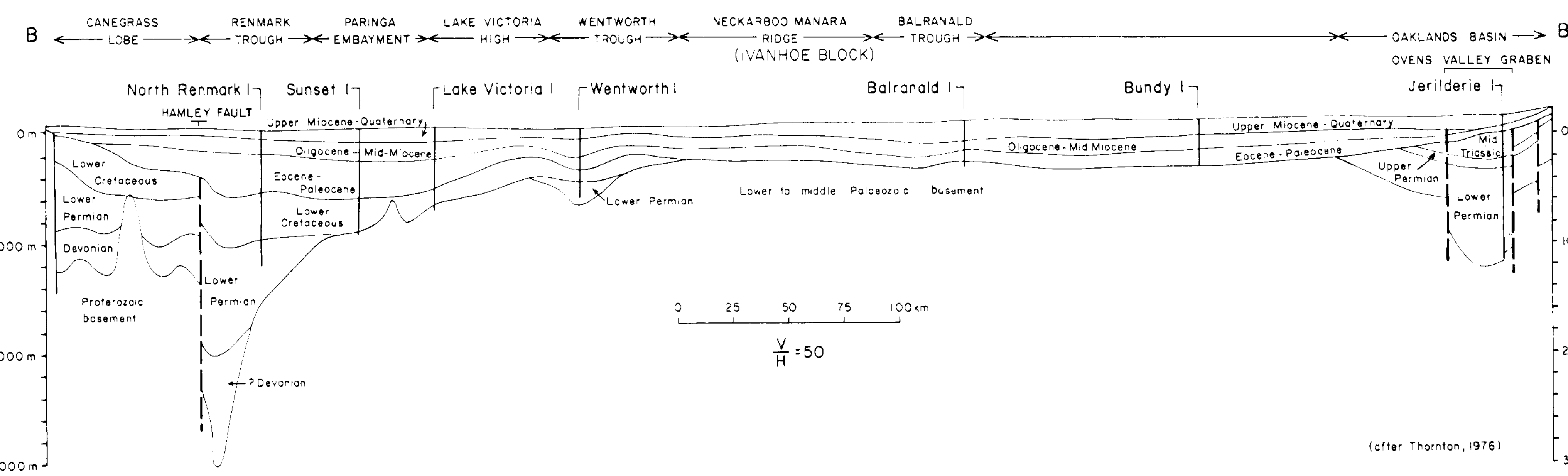
WRIGHT, A.J., & STUNTZ, J., 1963 - Well completion report, A.O.G. Jerilderie No.1, New South Wales. Australian Oil and Gas Corporation Limited (unpublished).

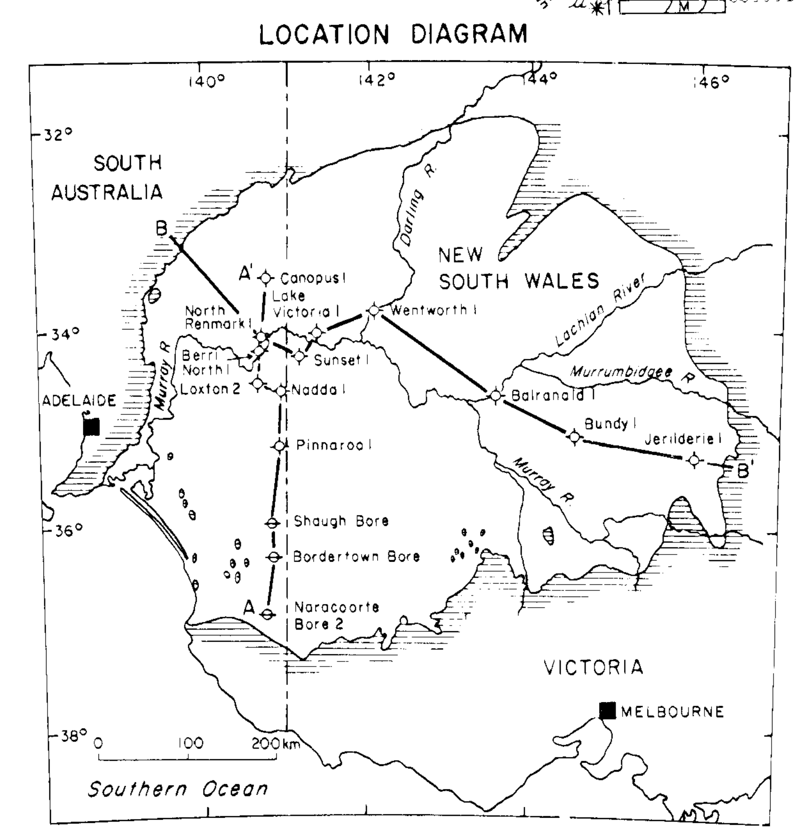
YOO, E.K., 1982 - Geology and coal resources of the northern part of the Oaklands Basin. Geological Survey of New South Wales, Quarterly Notes October, 15-27.

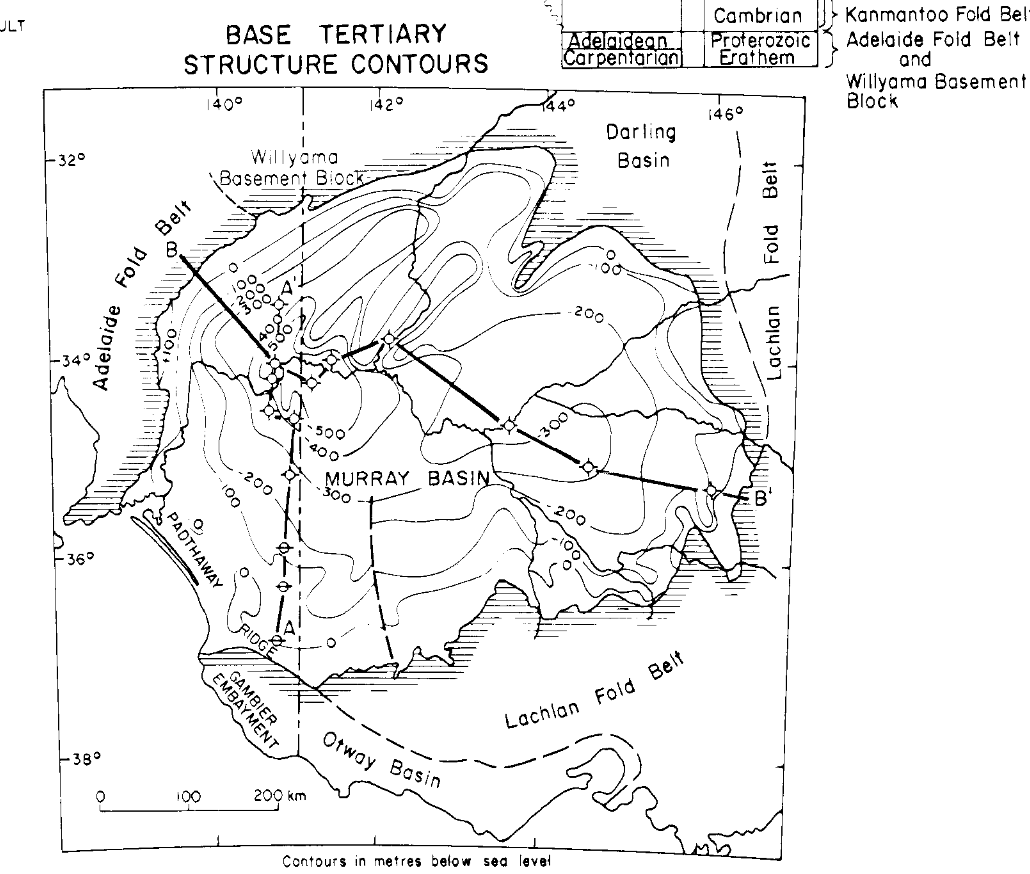
CROSS-SECTIONS AND REGIONAL CORRELATIONS ACROSS THE
MURRAY BASIN AND INFRABASINS, SOUTH AUSTRALIA, NEW SOUTH WALES AND VICTORIA

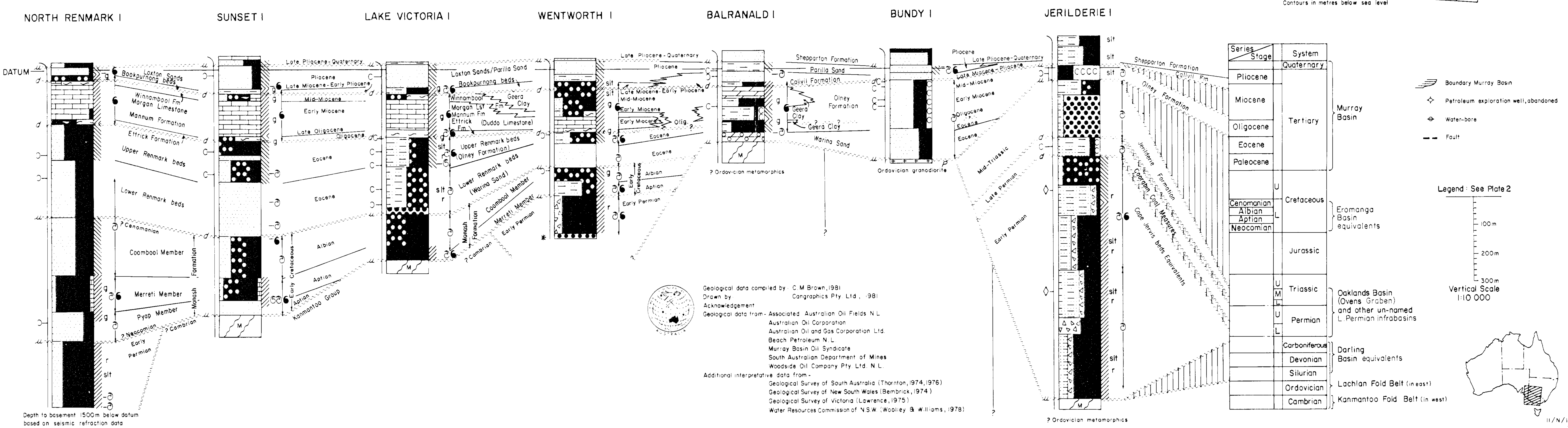
ESCAP ATLAS OF STRATIGRAPHY (IGCP PROJECT No.32)











Geological data compiled by C.M. Brown, 1981
Drawn by Cartographics Pty. Ltd., 1981
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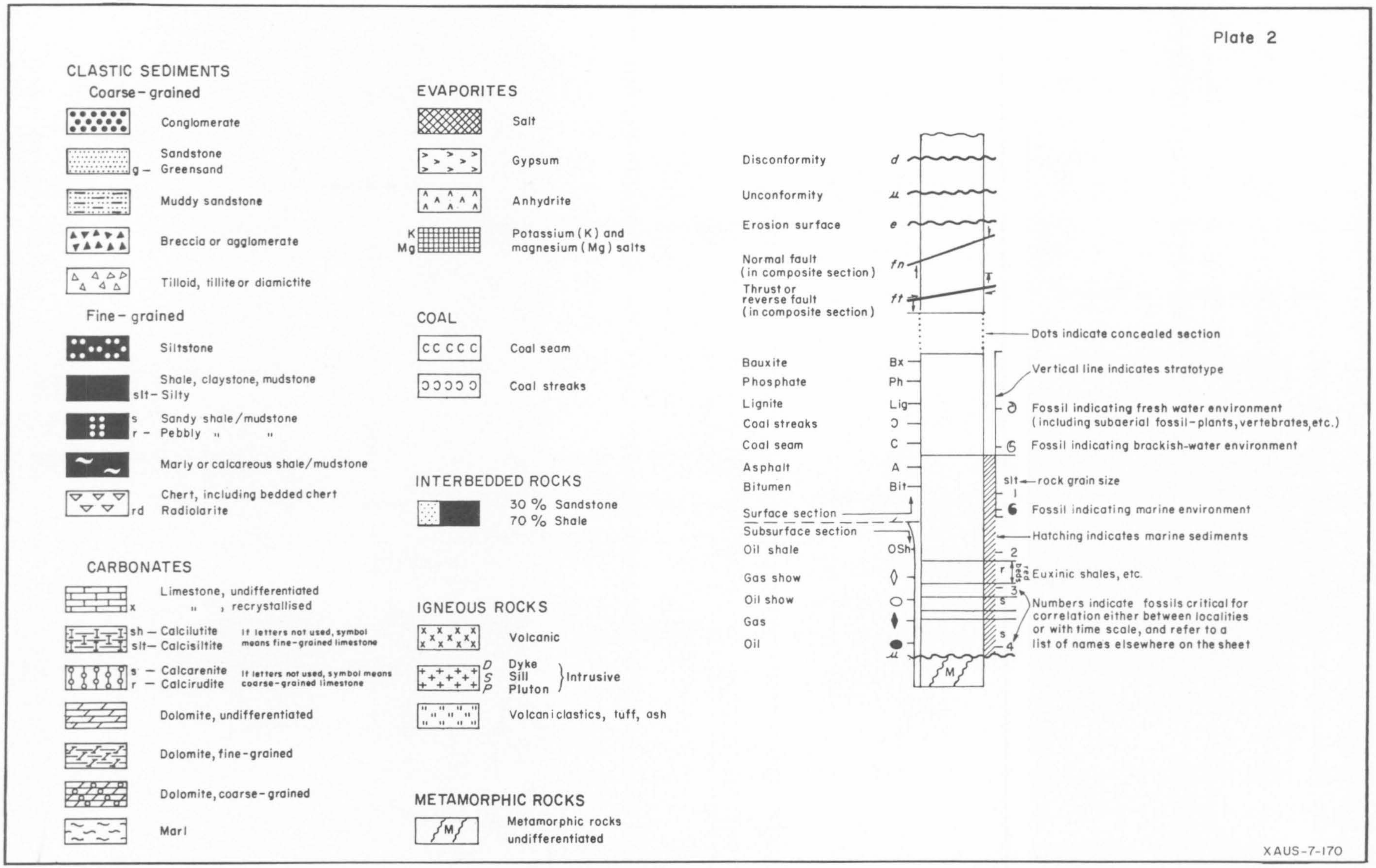
Geological data from - Associated Australian Oil Fields N.L.
Australian Oil Corporation
Australian Oil and Gas Corporation Ltd.
Beach Petroleum N.L.
Murray Basin Oil Syndicate
South Australian Department of Mines
Woodside Oil Company Pty. Ltd. N.L.
Additional interpretative data from -
Geological Survey of South Australia (Thornton, 1974, 1976)
Geological Survey of New South Wales (Bembrick, 1974)
Geological Survey of Victoria (Lawrence, 1975)
Water Resources Commission of N.S.W. (Woolley & Williams, 1978)



Legend for Plate I

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