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PERMIAN SEDIMENTS BENEATH
THE MURRAY BASIN

by

P.E. O'BRIEN

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ABSTRACT

Two Permian sedimentary units have been recognised beneath the Cainozoic Murray Basin Sequence. The older consists of Lower Permian marine sediments equated with the Cape Jervis Beds which crop out in South Australia; the younger is the Upper Permian Coorabin Coal Measures.

The Cape Jervis Beds are confined to fault-controlled sub-basins and consist of diamictites, siltstones, sandstones and conglomerates which bear the imprint of glacio-marine sedimentary processes. Palaeontological evidence suggests that these sediments were deposited towards the end of the major late Palaeozoic glaciation of southeastern Australia; they are tentatively correlated with other glacial sequences in southeastern Australia. The hydrocarbon potential of these rocks is low because they are low in organic carbon, though suitable reservoir rocks may be present in places.

The Upper Permian Coorabin Coal Measure unconformably overlie the Cape Jervis Beds in the Ovens Graben, beneath the eastern Murray Basin, and, in places, overlap the edges of that structure. They are terrestrial sediments containing one thick, extensive coal seam. The subsurface distribution of the Coorabin Coal Measures suggests that they may be more extensive than is presently known.

INTRODUCTION

Permian sediments were discovered beneath the Murrary Basin in 1916 when a water bore penetrated coal beneath the eastern margin of the basin, near Oaklands. Subsequently, the sub-basins beneath the Cainozoic Murray Basin sequence have attracted intermittent interest as potential hosts to coal and hydrocarbons. This study re-assesses data gathered by governments and private exploration companies, and concentrates on the Lower Permian marine sediments which are present in most sub-basins. New sedimentological and petrographic descriptions of these rocks are presented, and well sections are re-interpreted. These interpretations are used with micropalaeontological data from the literature to infer palaeoclimatic changes during the Early Permian, and to correlate these sediments with similar sequences in southeastern Australia. The literature on the Upper Permian coal measures beneath the Murray Basin is reviewed, and the resource potential of these sediments is discussed.

Geological setting

The Murray Basin sediments are a thin Cainozoic sequence covering about 320 000 sq km of New South Wales, Victoria and South Australia. They are surrounded by exposed Palaeozoic and Precambrian rocks, except on the southwestern side where a thinly covered basement ridge, the Padthaway Ridge, separates the Murray Basin from the Otway Basin (Fig. 1).

Tertiary and Quaternary sediments form a continuous blanket up to 600 m thick covering at least eight sub-basins containing Devonian to Cretaceous sediments. Both the Murray Basin and the Sub-basin sediments rest on Lower to Mid-Palaeozoic metasediments and granite.

Geophysical work indicates up to 6 km of sediments in one sub-basin but, as yet, drilling has penetrated only 2100 m of pre-Tertiary sediments.

Previous investigations

Investigations of Permian sediments beneath the Murray Basin fall into three categories:

1. Brief examination of bore material obtained during groundwater investigations.
2. Exploration for Upper Permian coal.
3. Studies associated with petroleum exploration.

Many water bores have bottomed in Permian sediments so workers concerned with groundwater in the overlying Murray Basin sediments frequently note the lithologies and distribution of Permian rocks encountered during drilling. The most detailed examples of this type of work are Lawrence (1975), which documents and discusses Permian rocks encountered by several deep bores in Victoria, and Tickell (1978) which presents maps of Permian subcrop beneath the eastern Murray Basin in Victoria.

Interest in Permian coals in the Oaklands-Coorabin area has waxed and waned since their discovery. A small colliery operated intermittently from 1917 till 1958 and a number of drilling campaigns have been undertaken by Governments and private companies. The New South Wales Department of Mines undertook the first of these in 1920. It was followed in 1942 and 1943 by another involving several Commonwealth Government Departments as well as State authorities. The results of this drilling program and its associated geophysical surveys are summarised by Sturmfels (1950) and Thyer and Vale (1952). Renewed interest in the coals from 1970 onwards has led to extensive drilling programs by the New South Wales Department of Minerals and Energy and by private companies. Results of the drilling have been published by Palese (1974), Morgan (1977a, b) and McMinn (1981), reassessment of geophysical data by McIntyre (1975) and two seismic reflection traverses by Palmer (1977). Reports on drilling in the Oaklands-Coorabin area by private companies were not available at the time of writing, but reports of drilling in the Shepparton-Numurkah area have been made available by Western Mining Corp. (McLeod, 1977, 1978, 1979; Price, 1976).

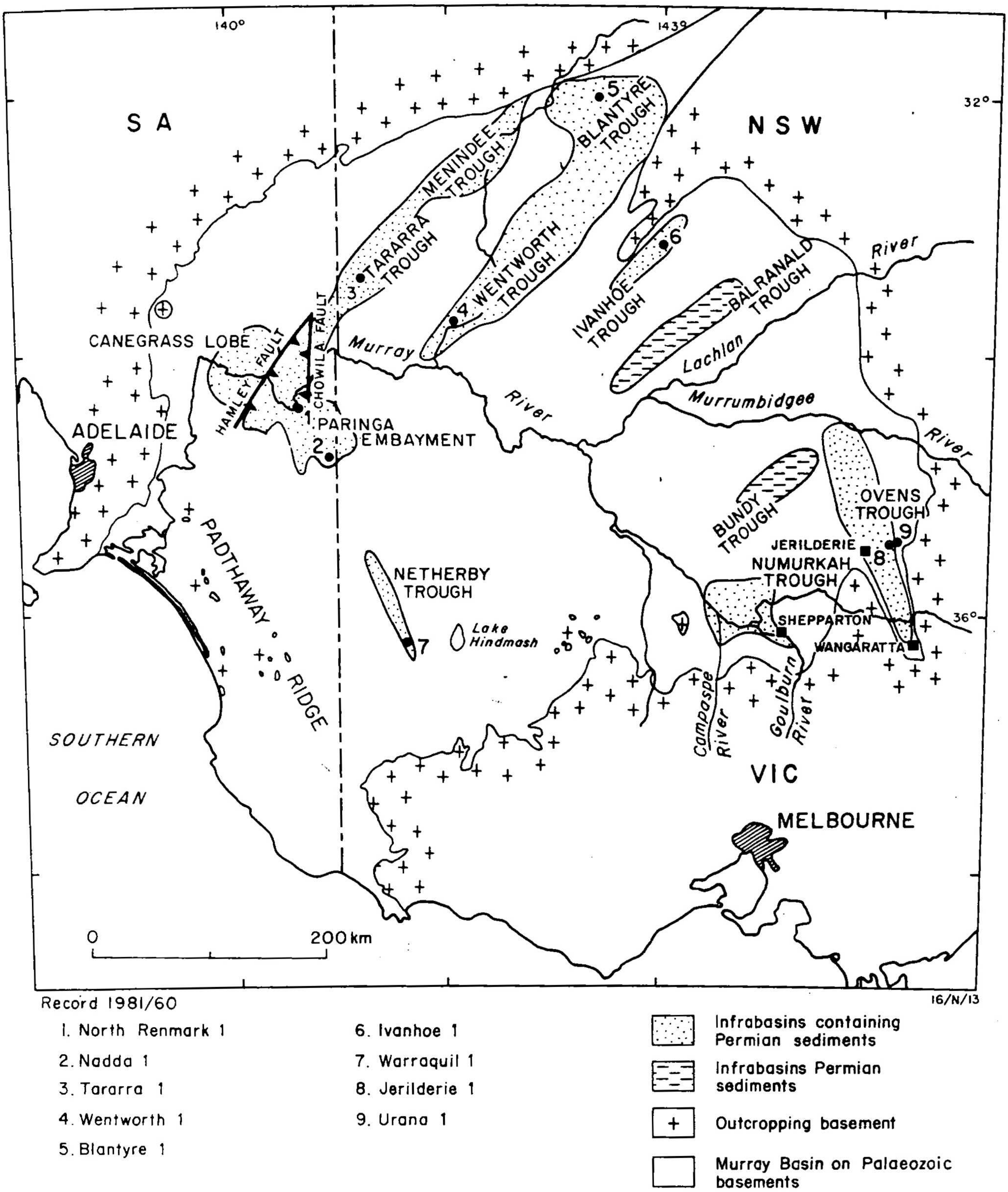


Fig. 1 Sub-basins beneath the Murray Basin and petroleum exploration wells

Exploration for petroleum in the Murray Basin was most intense during the 1960s. Most holes were drilled as stratigraphic tests of sub-basins detected by geophysical methods, and not all holes intersected Permian sediments. Those that did are listed in Table 1, with the year they were completed and the licenses. Of these wells, only Urana No. 1 was unsubsidised so material was available for study from the other seven.

Palaeozoic Sub-basins

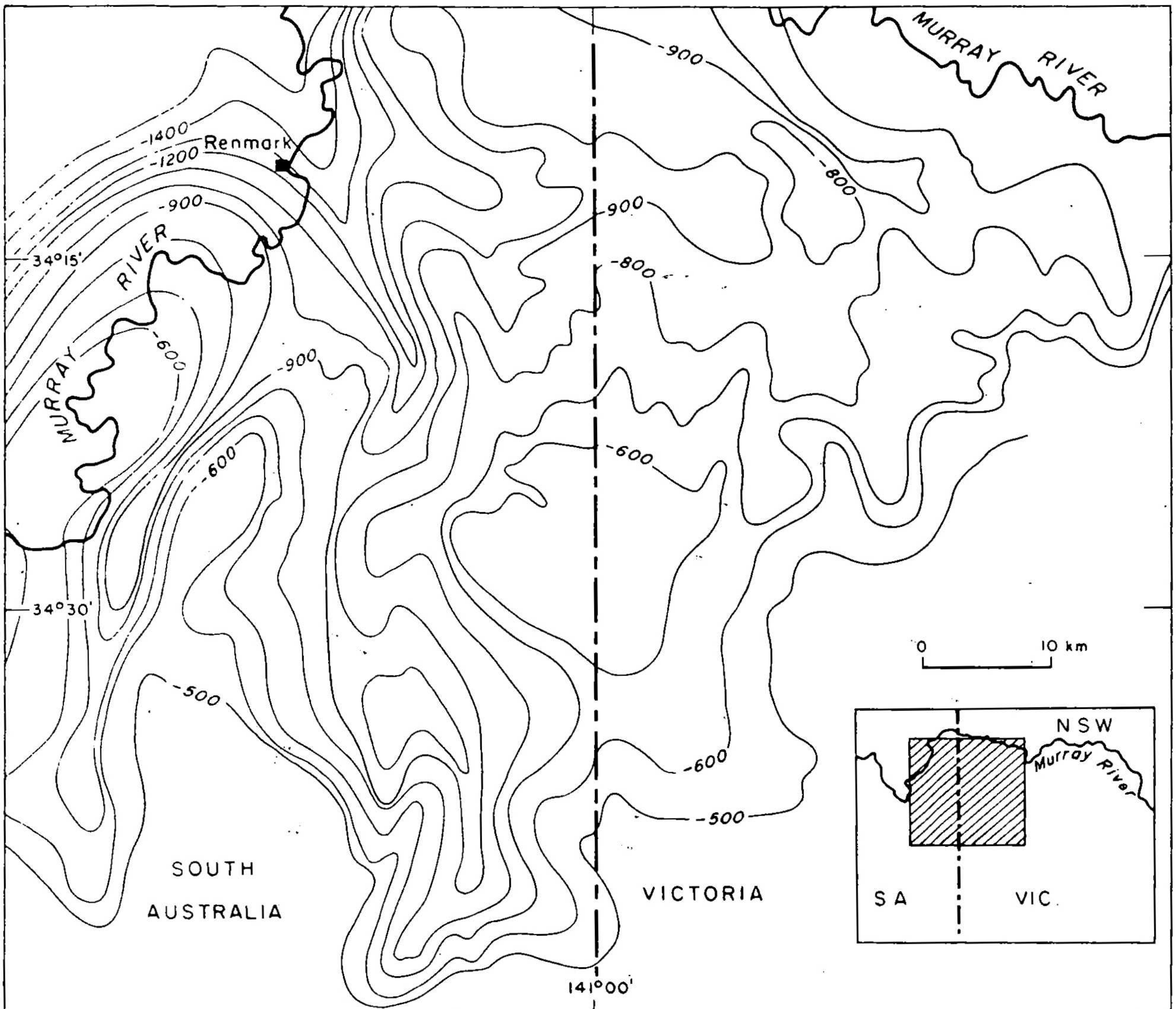
The sub-basins beneath the Murray Basin comprise a northeasterly trending group underlying the northern and western Murray Basin and a north-northwesterly trending group underlying the southern part of the basin. Table 2 lists known sub-basins with their stratigraphic sequences and the names of bores from which the sequences are taken. Sub-basin names are taken from Thornton (1976) except for the Numurkah Basin and the Netherby Basin which are named in this study.

The Renmark Trough is 30 km wide and 100 km long and has an estimated maximum sediment thickness of 3500 m (Thornton, 1974). Its western boundary is the northeasterly trending Hamley Fault which has a throw in the order of 1300 m. The Trough is a half-graben in the south and a full graben in the north where the north-trending Chowilla Fault forms the eastern margin and separates the northern end of the Renmark Trough from the Tararra Trough (Thornton, 1974). Though drilling has yet to penetrate the entire Renmark Trough sequence, geophysical evidence suggests that a significant thickness of pre-Permian sediments occupies the deepest part (Thornton, 1974).

The Canegrass Lobe is a poorly defined basement depression west of the Hamley Fault (Fig. 1; Derrington & Anderson, 1970). Thornton (1974) estimates that there is 1200 m of sediment in the deepest parts of the Canegrass Lobe and that the stratigraphy is similar to that of the Renmark Trough. The scant geophysical data available suggest that the northwestern and northern margins of the Canegrass Lobe are fault-controlled but that its southwestern margin is not (Thornton, 1974).

On the southeast side of the Renmark Trough is a complex system of basement highs and lows named the Paringa Embayment by Derrington & Anderson (1970). It consists of several sediment-filled valleys which slope north and northwest to join near Renmark, forming one large bedrock valley which joins the Renmark Trough about 1500 m below sea level (Fig. 2, Derrington & Anderson, 1970). The valleys were shaped by erosion, as shown by their complex form and the pinch-outs of Cretaceous sediments against the valley sides (Thornton, 1974). Flat-lying Permian sediments also occupy one of the deeper valleys (Derrington & Anderson, 1970), so that the first period of erosion must have preceded their deposition. There is no clear evidence for glacial erosion though a closed basement depression in one of the valleys may be explained by this mechanism. Faults detected in the basement (laws & Heisler, 1964) may also have played a part in the formation of the Paringa Embayment. It lies at the intersection of two major fault sets so that the bedrock was more easily eroded in this area than elsewhere beneath the Murray Basin. One set of faults trends northeasterly forming the Renmark, Wentworth and Tararra Troughs while the other trends north-northwesterly and is probably a set of faults bounding a Cambrian greenstone belt which has been reactivated occasionally since the Cambrian. Johns & Lawrence (1964) demonstrate the presence of such a greenstone belt with aeromagnetic data and suggest that its boundary faults were active during the Tertiary.

The other northeasterly trending structures beneath the Murray Basin are the Tararra, Merindee, Blantyre, Wentworth, Ivanhoe and Bundy Troughs (Fig. 1, Talbe 2). Sparse, mainly reconnaissance geophysical coverage and the little well control indicates that most of these features are fault-bounded. Seismic surveys have delineated faults along the margins of the Wentworth and Bundy Troughs (Watson, 1962; Keiez & Wiemer, 1963). The Ivanhoe, Tararra and Merindee Troughs are similar in shape and trend to the Renmark, Wentworth and Bundy Troughs for which fault control has been demonstrated (Thornton, 1974). Faulting commenced in the Devonian when thick sequences accumulated in these troughs. Following this phase of deposition, subsidence was relatively minor with only a few hundred metres of Permian sediments overlying several thousand metres of Devonian rocks (Evans, 1977). Permian sediments are probably absent from the Bundy Trough; the red conglomerate in Killendoo No. 1 previously logged as Permian closely resembles some Devonian and Lower Carboniferous rocks of southeastern Australia.



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Contours generalized from Thornton (1974). Contour interval 100m, Datum sea level

Fig. 2 Basement contours of the Paringa Embayment

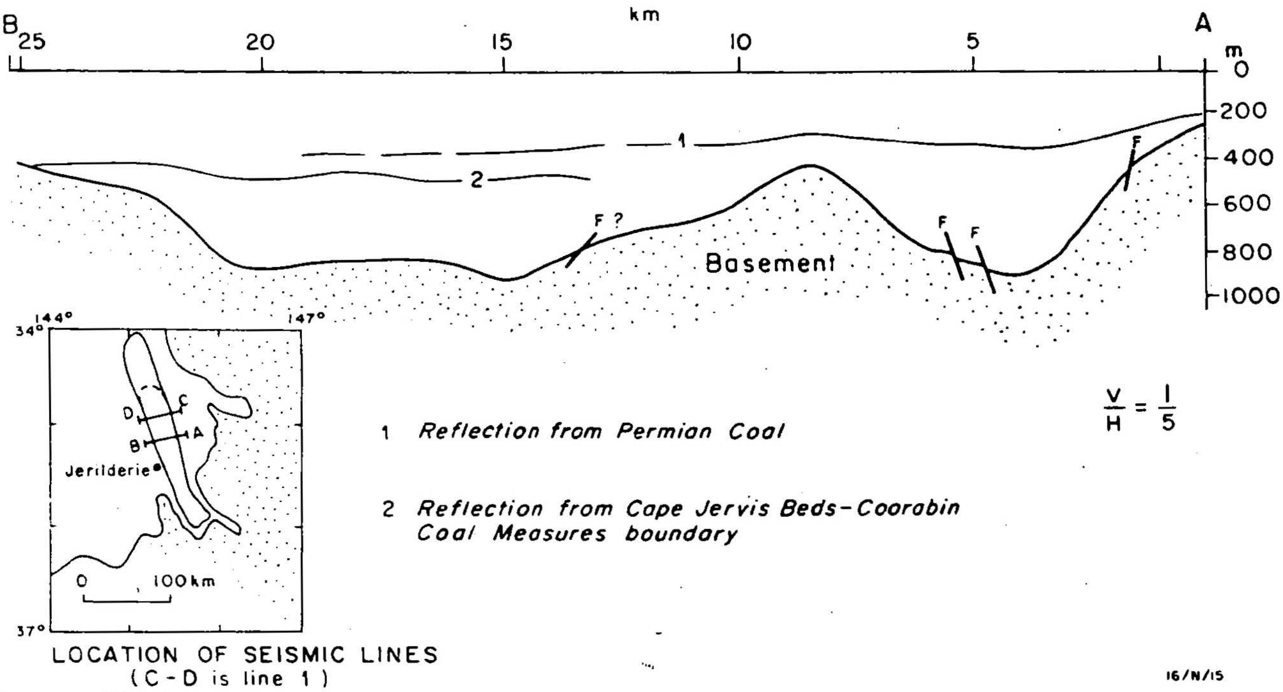

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Fig. 3. Interpretation of a seismic section across the northern Ovens Graben (Palmer, 1977) Datum 100m A.S.L.

Three sub-basins are present beneath the southern margin of the Murray Basin. Two are well defined by drilling, but the third is not. The Ovens Graben, the best known, is 25 km wide and extends north-northwest from Wangaratta in the south, approximately to the Murrumbidgee River. Permian sediments filling the graben thicken from 171 m in the south to 957 m in Jerilderie No.1 before thinning slightly to the north again (Krietz & Wiemer, 1963). Seismic traverses show that the Graben's western and eastern margins are faulted though both sets of faults have not been unequivocally detected on any one line (Kreitz & Wiemer, 1963; Palmer, 1977) Figure 3 is based on a seismic section from Palmer (1977) shot at right angles to the graben axis. It shows a set of faults along the eastern side of the Ovens Graben and a bedrock high in its centre. Armstrong (1970) uses gravity data to show that this feature is conical in plan.

The Numurkah Basin is an irregular sub-basin about 70 km across underlying an area between Shepparton and Deniliquin (Fig. 1). A narrow elongate extension underlies the present Goulburn River valley southeast of Shepparton. Numerous water bores have defined the southern edge of the basin in Victoria (Tickell, 1978; Tickell & Humphrys, 1979), but in New South Wales only one bore has intersected Permian sediments (Woolley & Williams, 1978). Therefore, interpretation of the northern edge depends on gravity data in Bluestone (1969) (Fig. 1).

The maximum thickness of sediments in the Numurkah Basin can only be estimated from geophysical data. Some bores do reach basement but these are shallower than others which have failed to reach the base of the Permian. Geophysical traverses by Pettifer and Polak (1980) between Shepparton and Numurkah suggest a maximum thickness of 650 m in that area and a gravity anomaly centred 16 km north of Echuca (Bluestone, 1969) suggests a range of thickness from 98 m to 690 m (Appendix I). The role of faulting in the formation of the Numurkah Basin is less clear than in other sub-basins. Tickell (1978) shows Permian rocks wedging out against bedrock along the southwestern margin, faults bounding the extension of the basin beneath the Goulburn River valley and basement horsts protruding into the basin.

Several small patches of Permian sediments underlie the southern margin of the Murray Basin. Two of these patches are thin and discontinuous, lying along the bottom of troughs beneath the Campaspe and Loddon River valleys (Tickell, 1978; Macumber, 1978). These troughs are probably similar to that beneath the Goulburn River valley. A poorly defined sub-basin which may be of greater size underlies the Murray Basin to the west of Lake Hindmarsh in western Victoria. A bore sited 5 km west of the town of Netherby intersected 371 m of Permian sediments whereas bores 15 km west and 5 km east of the first bore reached metamorphic rock and granite beneath Tertiary sediments. Unfortunately, no other deep holes have been drilled within 40 km of the area so the full extent of the Permian sediments is unknown; however, an elongate gravity low extends 50 km north-northwest of Netherby (Fig. 1). This negative anomaly fits within the width limits imposed by bore information and its elongate shape is unlike anomalies caused by granites in the subsurface (c.f. Bluestone, 1959). It is on the flank of a northwesterly trending belt of Cambrian greenstones, indicated by aeromagnetic data (Johns and Lawrence, 1964) and may be a trough containing Permian sediments formed by reactivation of faults bounding the greenstone belt. Such reactivation of faults has been demonstrated through the Tertiary (Johns and Lawrence, 1964) so movements during the Permian may have occurred.

Permian stratigraphy

Permian sediments beneath the Murray Basin are here subdivided into two major units. The upper unit is the Coorabin Coal Measures, defined and subdivided by Standing Committee on Coal Field Geology (1978), and the lower unit is here equated with the Cape Jervis Beds which crop out on the Fleurieu Peninsula and were defined by Ludbrook (1967). This correlation is made because the Murray Basin sediments have similar facies and faunas to the Cape Jervis Beds and the two sequences may have been continuous during sedimentation. The term Beds is retained because of its long standing usage (Hedberg, 1976).

The type section of the Cape Jervis Beds contains a fauna of arenaceous foraminifera typical of many Permian rocks in Australia (Ludbrook, 1967; Crespin, 1958; Scheibnerova, 1981). Similar assemblages occur in several bores in the Murray Basin, notably Jerilderie No. 1 (Terpstra, 1963). These sediments also contain acritarchs which are thought to have been marine organisms. However, the most important microfossils are palynomorphs, which provide correlations with other Permian sequences in Australia. Using the Permian palynozones defined by Kemp, Balme, Helby, Kyle, Playford and Price (1977), Stage 2 microfloras are present in the Cape Jervis Beds on Yorke Peninsula (Foster, 197~~8~~4), in the Renmark and Wentworth Troughs and the Paringa Embayment; Stage 2 and Stage 3 microfloras are present in the Numurkah Basin, and the Ovens Graben sediments contain a Stage 3 microflora only (Fig. 13).

The Coorabin Coal Measures contain a Stage 5 microflora and, in the upper-most unit, a mid-Triassic microflora (Standing Committee on Coal Geology, 1978).

Palynologists and palaeontologists working with marine invertebrates do not agree at present on the position of the Permian-Carboniferous boundary. Kemp and others (1977) place the boundary at the Stage2-Stage 3 boundary whereas invertebrate works place it significantly lower (Archbold; pers. comm., 1980). My personal preference is for the latter view because, in Central Victoria, a Stage 2 microflora overlies a Sakmarian invertebrate fauna (E.M. Truswell, pers. comm., 1981; Bowen & Thomas, 1976), so for the purpose of this study, the sediments are called Permian rather than Permo-Carboniferous. However, the relationship of the Cape Jervis Beds to the type Permo-Carboniferous boundary still requires much investigation, beyond the scope of this work.

THE CAPE JERVIS BEDS

Seven petroleum exploration wells have penetrated the Cape Jervis Beds beneath the Murray Basin. A few core samples from these subsidised wells are housed in the Core and Cutting Laboratory of the Bureau of Mineral Resources. In this study, cores and cuttings were examined in hand specimen and thin section to document their petrography and interpret their depositional environments. Geophysical logs were examined to determine the lithological sequence in each hole and several samples were examined by X-ray diffraction to determine the mineralogy of the clay fraction in the finer grained rocks.

Facies

1. Diamictites

In this study, the name diamictite is applied to muddy rocks with conspicuous coarse fractions visible in hand specimens (Flint, Sanders & Rogers, 1960a, b). The term therefore covers a range of rock types in the Cape Jervis Beds from sandy mudstones to till-like rocks. To compare these rock types with one another and with tillites of similar age and source area, representative samples were thin-sectioned and their size distribution measured by point counting. The results are plotted as cumulative frequency curves on Figure 4 along with an envelope representing the range of tillite textures found in central Victorian glacial deposits, as measured by the same technique. Three diamictite facies are recognised in drill cores from the Cape Jervis Beds.

Facies D1:- Diamictites of this facies have clayey silt matrix material with medium to coarse sand and scattered pebbles and form beds a few centimetres to over 20 cm thick. Beds are massive to faintly laminated. Facies D1 is depleted in fine sand and coarse silt relative to tillites in central Victoria (Fig. 4).

Facies D2:- Facies D2 has a sandy siltstone matrix and 3 to 10 percent granules and pebbles, similar to fine-grained tillites from central Victoria. Beds of Facies D2 range from 5 cm to over 20 cm thick and are massive. The contacts between successive beds of Facies D2 are sharp and irregular with small flame structures and rare, ripped-up clasts of the lower diamictite included in the upper bed.

Facies D3:- Diamictite Facies D3 is laminated claystone with abundant medium to coarse sand grains and granules in bands. Facies D3 beds are up to 5 cm thick and have gradational boundaries with overlying and underlying siltstones.

2. Siltstone Facies

Facies Z1 is massive to poorly laminated siltstone with minor fine sand and rare pebbles. Most cores are massive but a few from Jerilderie No. 1 show faint, discontinuous horizontal laminae and

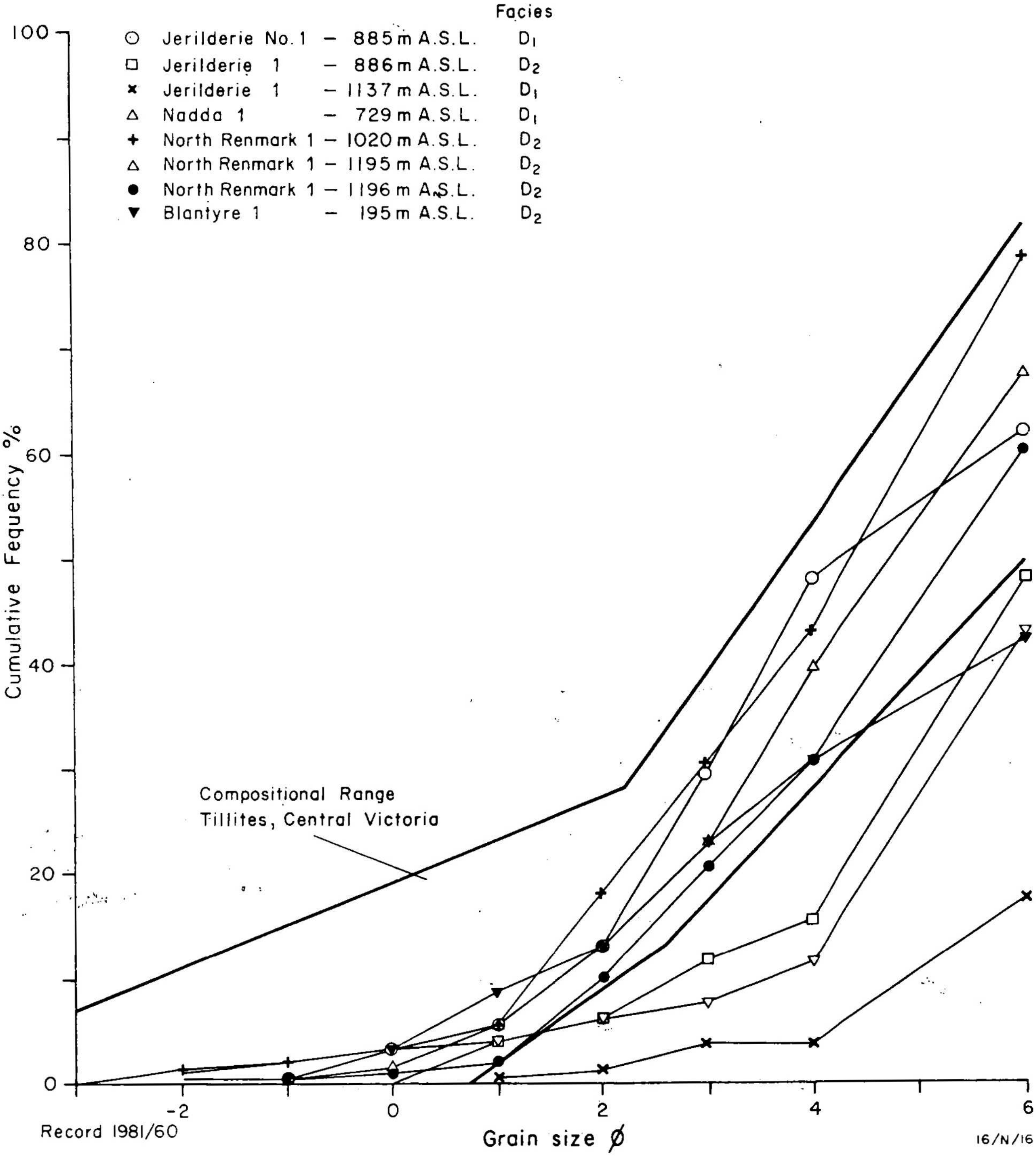

Fig. 4 Textures of diamictites from the Cape Jervis Beds. Grain size distributions were measured from −2 Ø (4 mm) to 6 Ø (0·156 mm) by point counting thin sections. The compositional range of tillites from central Victoria comes from unpublished work by the author

burrowed horizons. Foraminifera are present in some cores. Common features of this facies are red-brown ferruginous patches and concretions up to 2 cm across formed by the alteration of pyrite or siderite concretions. In some cores, joint surfaces are coated with a thin layer of white carbonate and scattered pyrite crystals.

Facies Z2 consists of light grey siltstone interbedded with dark grey claystone. Interbeds vary from 0.5 cm to 15 cm thick and some thin siltstones are graded. Some cores contain scattered coarse sand grains. This facies is commonly deformed, either by clay interbeds intruding the siltstone and breaking them into boudins or by mixing of interbeds accompanied by small recumbent folds. This mixing and folding may affect over 20 cm of sediment.

3. Sandstone Facies

Facies S1 is poorly sorted, silty medium sandstone with rare pebbles and mud clasts and is present in most bores. This facies is massive except for one faintly laminated core.

Facies S2 is massive, well sorted medium sandstone, commonly with a carbonate cement.

Facies S3 is yellow fine sandstone which has parallel laminae or ripple cross-bedding. Some cores have fine fragments of organic matter scattered along these laminae. Beds of this facies range from 1 cm to over 5 cm thick.

Facies S4 is fine-grained, yellow sandstone in graded beds 0.5 cm to 1.5 cm thick interbedded with Facies Z2.

Facies S5 consists of coarse, graded sandstone beds 2 cm to 5 cm thick interbedded with Facies Z2. These sandstones have sharp bases and tops and contain fragments of underlying siltstone.

4. Conglomerates

A few wells penetrate sandy, boulder conglomerate. This facies has up to 20 percent coarse sand matrix and framework clasts up to 15 cm in diameter. One core has interbeds of coarse sandstone up to 5 cm thick in the conglomerate.

Well sequences

From the geophysical logs, cores and cuttings, it is possible to draw tentative conclusions on the facies assemblages in each hole examined. These conclusions are tentative because of the small number of cores available, the limited number of geophysical logs run in the holes, and the ambiguous response of these logs to some of the facies present.

A.O.C North Renmark No.1

The 235 m of Cape Jervis Beds penetrated by North Renmark No. 1 (Fig. 5) is siltstone interbedded with claystones and sandstones (Facies Z2) overlain by 30 m of conglomerate which is in turn overlain by massive siltstone (Facies Z1). Ludbrook (1963) reports Permian Foraminifera in cuttings from North Renmark No. 1 and Harris (in Ludbrook, 1963) lists a Stage 2 microflora.

A.A.O Nadda No. 1

The section in Nadda No. 1 consists of 100 m of sandstones, (probably Facies S3 or S4) interbedded with diamictites (Facies D1) overlain by a siltstone plus minor sandstone and diamicite interval 112 m thick, followed by a sequence of diamictite beds (Facies D1) separated by thin sandstones and siltstone (Fig. 6). This interpretation relies heavily on the gamma log which, in this hole, distinguishes between the three main lithologies, giving a response intermediate between the extreme values registered for sandstones and siltstones when it is opposite diamictites (Fig. 5). The Cape Jervis Beds in Nadda No. 1 contain a Stage 2 microflora and rest unconformably on Lower Palaeozoic metasediments (Derrington and Anderson, 1970).

Reference for figures 5-11

- *Facies D1 (Diamictite)*
- *Facies D2 (Diamictite)*
- *Conglomerate*
- *Facies Z1 (Massive siltstone)*
- *Facies Z2 (Interbedded siltstone and claystone)*
- *Sandstone facies*
- *Coorabin Coal Measures*
- *Interbedded sandstone and siltstone*
- *Unconformity*
- *Depth in metres*
- *Datum - Sea level*

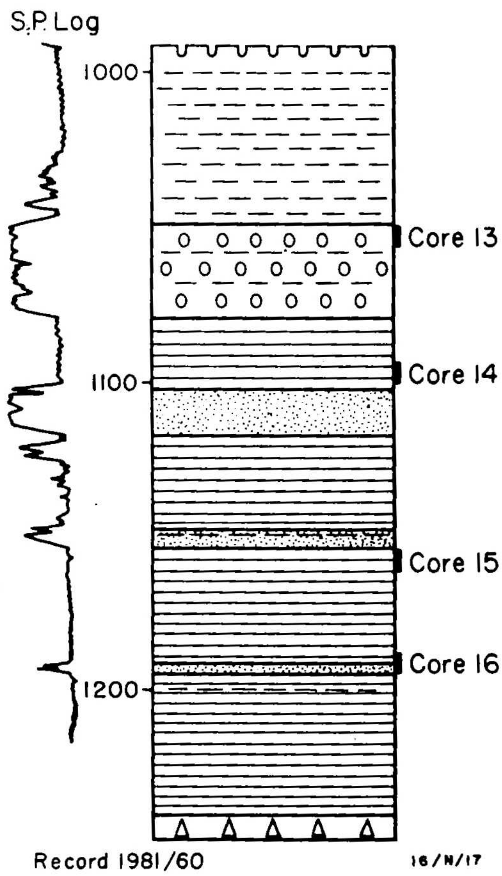

Fig. 5 A.O.C. North Renmark No 1

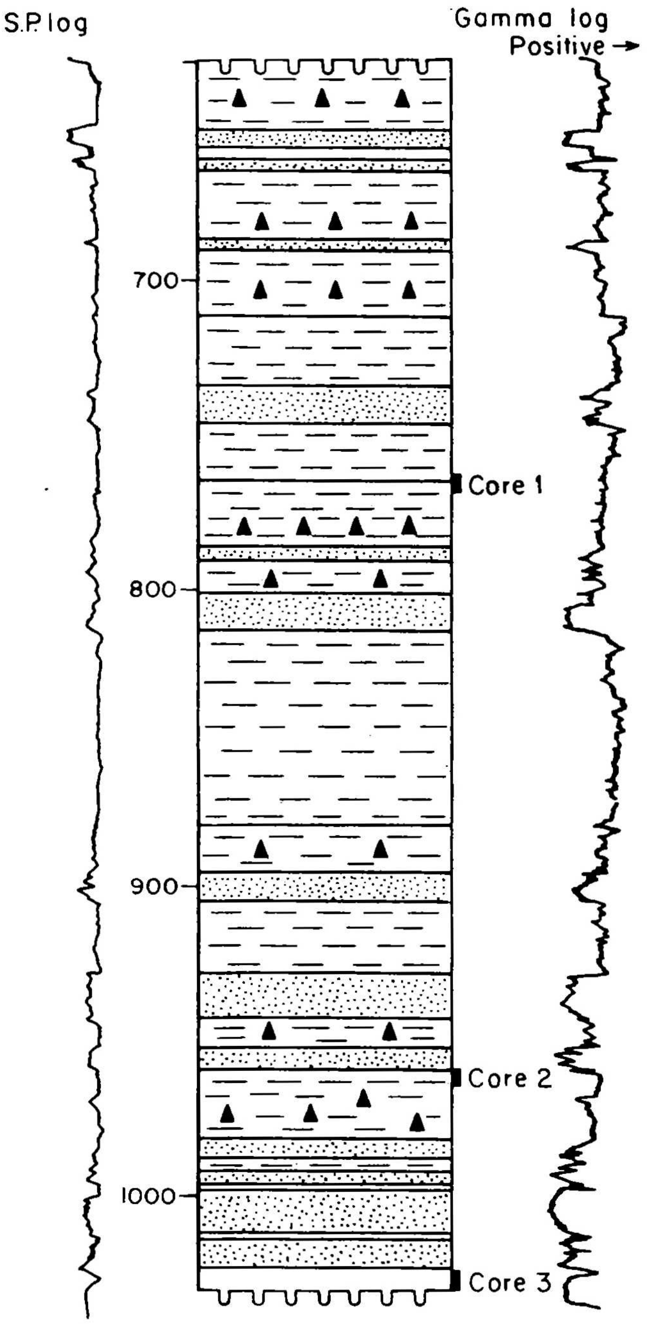

Fig. 6 A.A.O. Nadda No 1

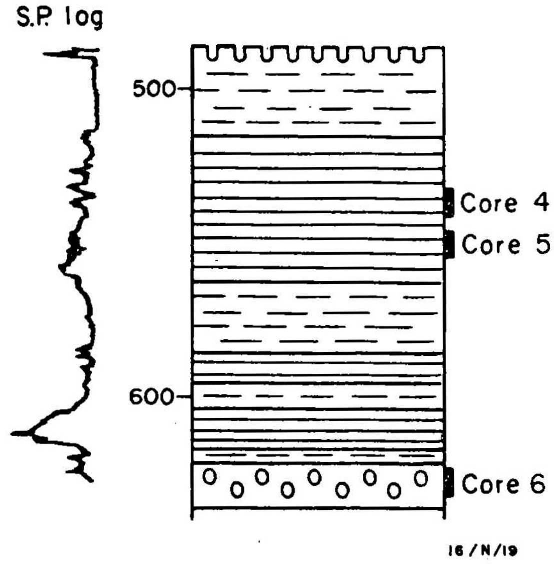

Fig 7 A.O.G. Wentworth No 1

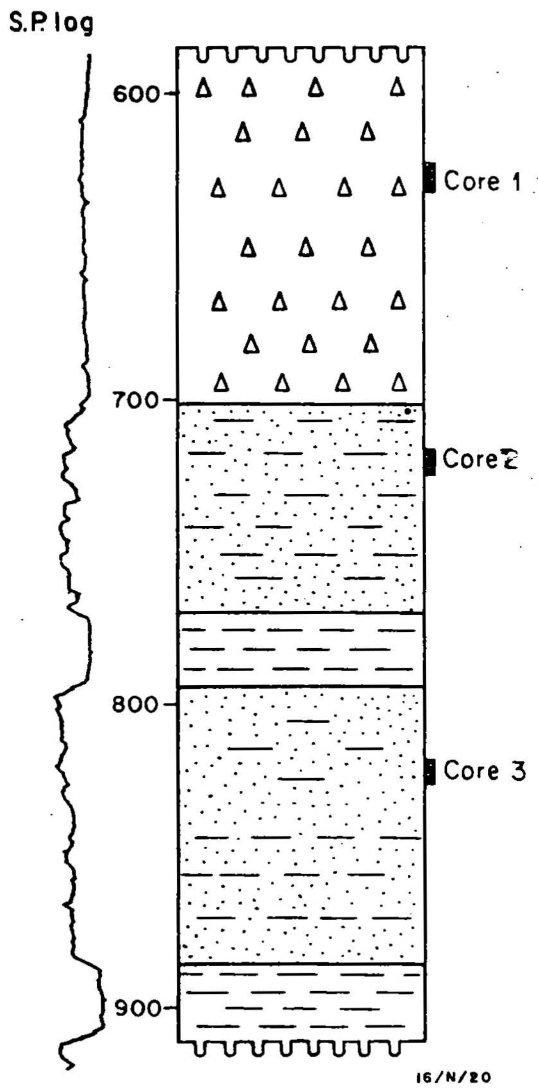

Fig. 8 A.O.G. Tararra No 1

A.O.G. Wentworth No. 1

Wentworth No. 1, like North Renmark No. 1, bottomed in Cape Jervis Beds. Drilling ceased in a sandy conglomerate at 639 m (Fig. 7). The rocks overlying this conglomerate are siltstones and claystones interpreted as Facies Z2 with thin beds of diamictite (Facies D3) and sandstone on the basis of the S.P. curve. The S.P. curve shows numerous small negative peaks opposite intervals from which cores containing siltstone, sandstone and diamictite (Facies Z2, S4, S5 and D3) while it does not deflect opposite other intervals. These small negative deflections are probably caused by the sandstone and coarse siltstone beds therefore the intervals which produce a quiet response probably lack such interbeds. Deformation involving folding and mixing of interbeds is common in Cores 4 and 5 but is less common in cores lower in the sequence.

A.O.G. Tararra No. 1 (Fig. 8).

The S.P. log of Tararra No. 1 shows five units in the Cape Jervis Beds, two with negative responses, three having a quiet response. Cores taken from the intervals with negative response are interbedded siltstone (Facies Z1) and sandstone (S3) while core from an interval with quiet response near the top of the Cape Jervis Beds was diamictite (Facies D2). The other quiet intervals are shown as siltstone but diamictites may also be present because the S.P. log cannot discriminate between the two lithologies and the examination of cuttings proved inconclusive. The section rests unconformably on Devonian sediments and contains a Stage 2 microflora (Boyd and Heibler, 1967; Evans, 1977).

Mid-East Oil Blantyre No. 1

The section revealed by Blantyre No. 1 is 100 m of conglomerate with one interbed of shale or diamictite followed by 67 m of diamictite (Facies D2) (Fig. 9). The conglomerate was previously logged as Carboniferous but its lithology and association with Permian sediments suggest it is probably Permian. The Blantyre No. 1 sequence rests unconformably on Devonian sediments.

North Star Oil Ivanhoe No. 1 (Fig. 10).

The lithologic and geophysical logs of Ivanhoe No. 1 are of poor quality for the Cape Jervis Beds, and core recovery was also poor so specific facies in the sequence cannot be identified. The sequence appears to consist of diamictites, siltstones and conglomerates, the upper 70 m being sandier than the rest. The Cape Jervis Beds again rest on Devonian sediments.

A.O.G. Jerilderie No. 1 (Fig. 11)

Jerilderie No. 1 penetrated the thickest sequence of Permian marine rocks found beneath the Murray Basin. The Cape Jervis Beds can be subdivided into three intervals on the basis of lithology and foraminiferal assemblages. Between the top of the Cape Jervis Beds at 425 m and 640 m the rocks are light grey siltstone (Facies Z1), sandstone (Facies S1) and some diamictite (Facies D2). The foraminifera are mostly arenaceous forms of the genera Ammodiscus and Hyperammina (Terpstra, 1963). Beneath this interval, the cuttings become less sandy and the main lithologies are siltstone (Facies Z1), sandstone facies S1, S3 and S4; calcareous foraminifera and ostracods are present in addition to the arenaceous foraminifera (Terpstra, 1963). This interval is 225 m thick. Beneath -800 A.S.L., poorly laminated diamictite facies D1 becomes the dominant lithology with smaller amounts of sandstone facies S1, S3 and S4. This lowest interval is 400 m thick and rests on Lower Palaeozoic slate. Morgan (1975b) lists a Stage 3 microflora from core taken from 1252 m, in the lowest interval.

Laceby No. 2

Laceby No. 2 was a Victorian Mines Department stratigraphic bore sited in the southern end of the Ovens Graben. From the remaining core samples and descriptions of material now missing in Bowen (1959) and Lawrence (1975), it seems that the Cape Jervis Beds in this area are 170 m thick and consist mostly of diamictite Facies D1, D2 and siltstone Facies Z1 with minor amounts of sandstones (Facies S1, S3) and conglomerate.

Warraquil No. 1

Warraquil No. 1 was sunk early this century near Netherby in western Victoria. It intersected 371 m of Permian sediments resting on Palaeozoic rhyolite. Fragmentary core samples are sandstone facies S1 and S3, diamictite facies D2 and D3 and siltstone facies Z2. Several intervals are red-brown which Lawrence (1975) interprets as staining caused by contemporaneous weathering.

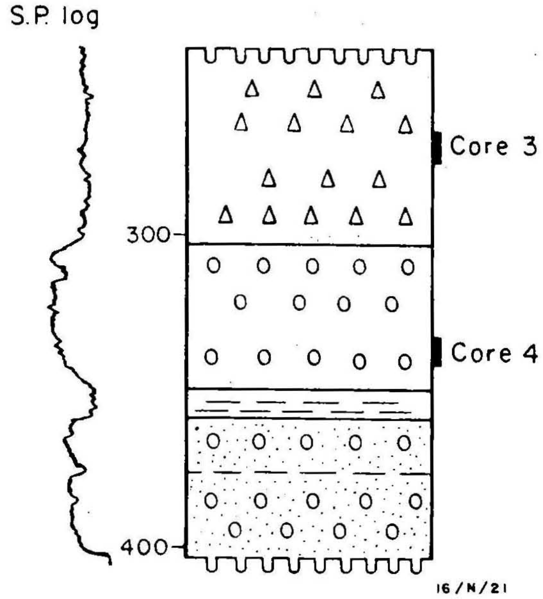

Fig.9 Mid-East Oil Blantyre No.1

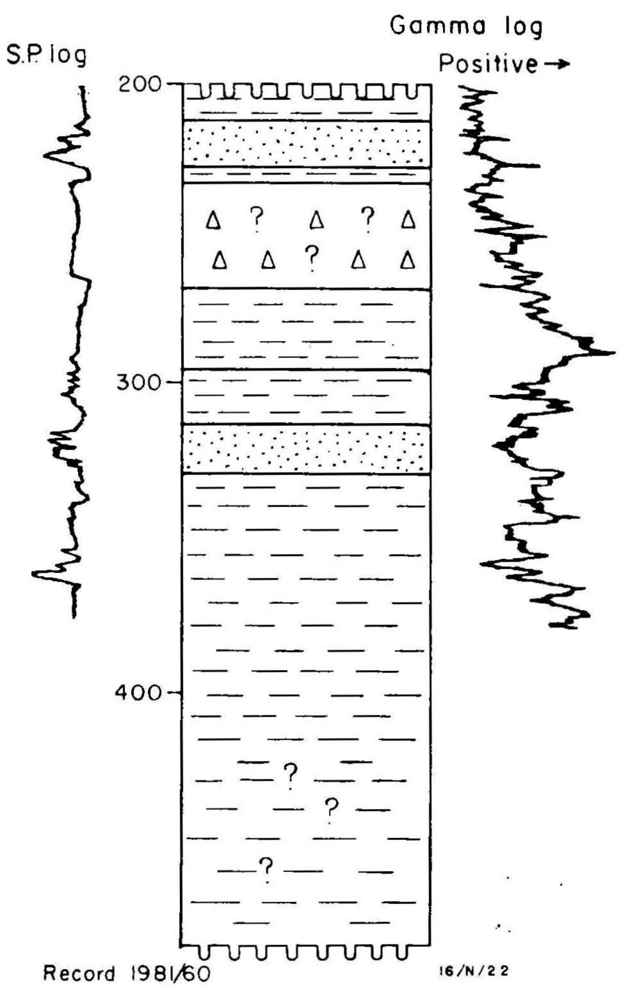

Fig.10 North Star Oil Ivanhoe No.1

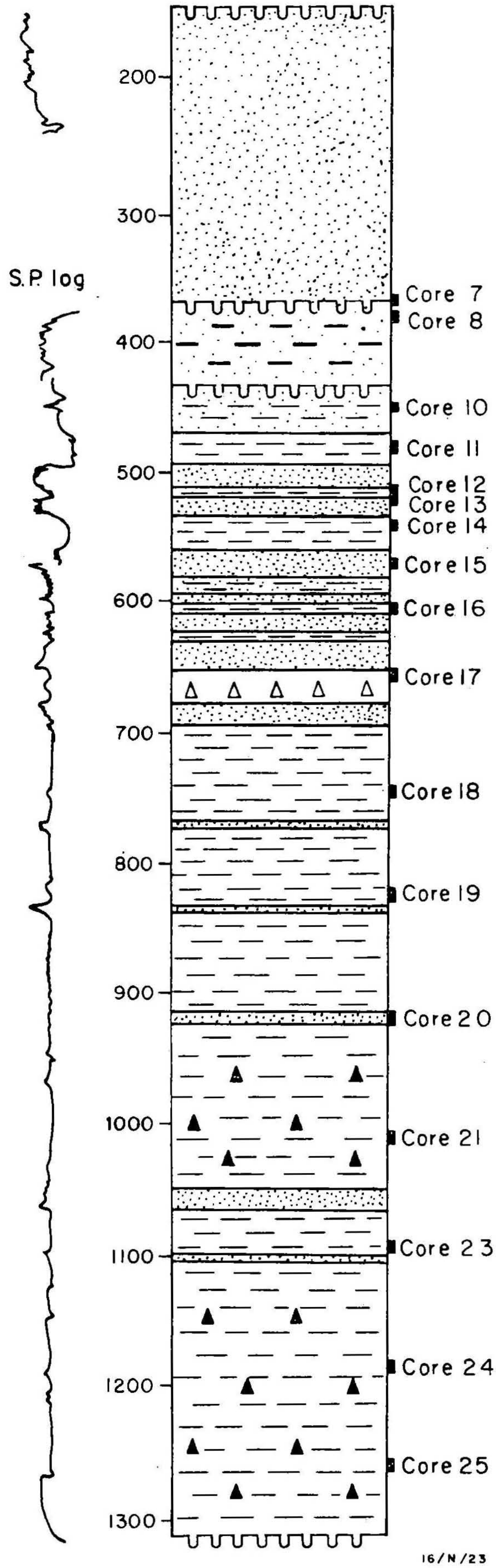

Fig. 11 A.O.G. Jerilderie No.1

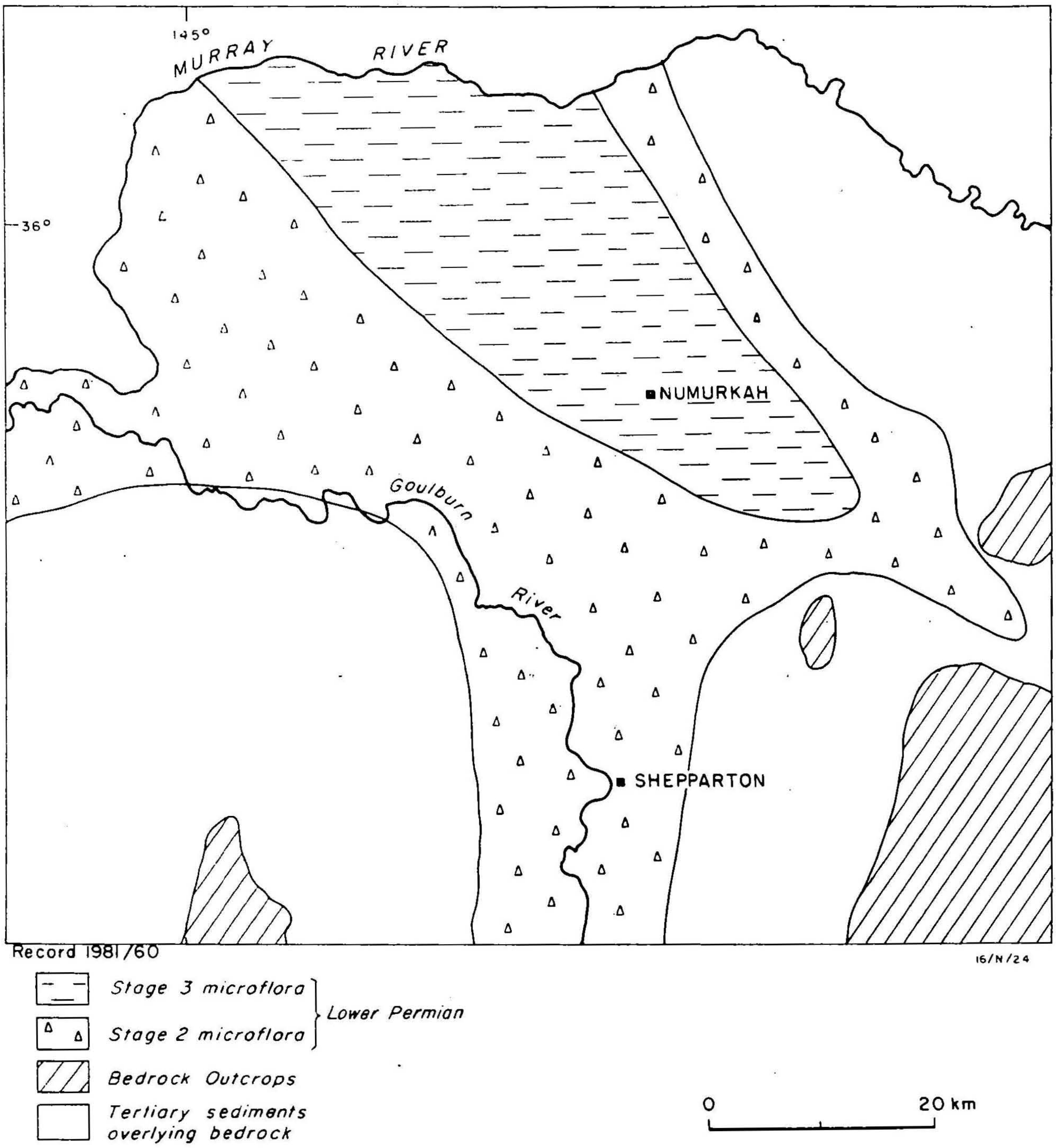

Fig. 12 Subcrop of Permian sediments in the Numurkah Basin

Bores intersectin the Numurkah Basin

Many water and coal exploration bores have penetrated the top of the Cape Jervis Beds in the Numurkah Basin. Most were sited on the south side of the Murray River, in Victoria (Tickell, 1978). Cuttings and the small amount of cores taken suggest that diamictite is the most common lithology around the southern margin of the Trough, and McLeod (1977, 1978, 1979) found microfloras equivalent to the Stage 2 microflora of Kemp and others (1977) around that edge (Fig. 12). Towards the centre of the Trough, sandy mudstones (Facies Z1) are the most common rock type contain and contains a Stage 3 microflora (McLeod, 1977; Fig. 12).

Petrography

Thin sections of the various rock types in the Cape Jervis Beds were examined to document the range of textures, types of clasts present and to investigate the hydrocarbon reservoir potential of the sandstones. Individual thin sections are described in Appendix III so only general descriptions are presented here.

Diamictites

Facies D1 and D2 consist of medium and coarse sand grains set in a matrix of silt, clay and fine sand, D1 having less sand than D2 (Fig. 4). The phenoclasts are angular to subrounded and show abundant evidence of grain breakage during transport (c.f. May, 1980). Seventy percent of the sand-sized grains are quartz, with quartzose metasedimentary grains the next most common grain type. Alkali feldspars, plagioclase, granitic rock fragments and slate fragments make up about 5% of the sand grains along with rare grains of detrital carbonate and highly altered basic volcanic rock fragments.

The diamictite matrices consist of four main components which are:-

1. Very fine quartz.
2. Relatively coarse phyllosilicate with high birefringence.
3. Low birefringent clay.
4. Fine carbonate which seems to coat other matrix grains.

Cuttings from Jerilderie No. 1 were treated to obtain the -2 micron grainsize fraction and subjected to qualitative analysis by X-ray diffraction using the techniques of Carroll (1970) (Appendix III). The minerals present are quartz, mica (probably muscovite), kaolinite, chlorite and some feldspar. The mica is probably the highly birefringent phyllosilicate seen in thin section while the low birefringent clay is probably kaolinite. In thin section, the proportions of these minerals vary from sample to sample, most being quartz-mica mixtures with minor kaolinite and carbonate. However, some samples, which are pale grey in hand specimen, have quartz-kaolinite matrices. Calcareous diamictites also occur with abundant fine carbonate coating matrix grains and filling the matrix pore spaces.

Matrix fabrics also vary. A diffuse, poorly developed preferred orientation of clays is common and domains of strongly oriented clays are present in some samples. Facies D3 has a clay matrix with very strong alignment parallel to bedding. The clays 'wrap around' the sand grains producing undulose extinction of the matrix when viewed under crossed nicols.

Siltstones

Siltstones in the Cape Jervis Beds are composed of angular quartz silt and fine clay. Graded laminae in Facies Z2 show symmictic grading; that is, there is no distinct separation between the fine upper part of the bed and the lower part (Sauramo, 1923). The only other sedimentary structures visible in some cores are fine burrows filled with clean silt.

Sandstones

The sandstones in the Cape Jervis Beds are of two petrographic types. Facies S1 is poorly sorted, and has a framework of subangular to rounded grains. Quartz is the most common grain type but lithic grains may constitute up to 40 percent of the framework. Feldspars are less than 5 percent. The lithic grains are mostly fine-grained, quartz-mica metasediments and granite with rare grains of chert, carbonate and basic to intermediate volcanics. The matrices are detrital clay with small amounts of secondary clay coating some grains and small patches of diagenetic carbonate. One sandstone from Warraquil No. 1 has red coatings, probably limonite, around the grains and sparry carbonate pore infillings coating the limonite. The red coatings may have formed during post-depositional weathering (Lawrence, 1975).

The well sorted sandstone facies (Facies S2, S3 and S4) have frameworks of quartz with low-birefringent clay and carbonate matrix material. The carbonate occurs as fine spar in pore spaces or as large poikiloblastic overgrowths up to 1 cm long incorporating many framework grains.

Conglomerates

Two thin sections of conglomerates were examined. The conglomerate from Wentworth No. 1 has framework pebbles of quartz, granite and fine-grained metasediments set in a matrix of fine sand-sized quartz, feldspar and low birefringent clay. The other sample, from North Renmark No.1, however, lacks granite pebbles in the framework and feldspar in the matrix. Pores are lined with a red coating, probably limonite, and filled with sparry carbonate. Some porosity is visible in both samples.

Facies interpretation

Diamictites: Clearly, ice was involved in the deposition of the Cape Jervis Beds diamictites because of their sorting and their association in time and space with glacial facies and erosion features in Victoria and South Australia (Crowell and Frakes, 1971a, b; Bowen and Thomas, 1976). Recent studies have found the following sediments in marine environments bordering glaciated areas.

1. Tills deposited by ice grounded on the continental shelf (Anderson, Kurtz, Dormack and Balshaw, 1980).
2. Mud flows derived from tills (Kurtz and Anderson, 1979).
3. Compound paratills composed of sediment deposited by normal marine processes plus an ice-rafted component (Anderson and others, 1980).
4. Residual paratills which are ice-rafted sediments which have been winnowed by current activity (Chriss and Frakes, 1972; Anderson and others, 1980).

Facies D3 in interpreted as a compound paratill formed by ice-rafting of coarse sand and pebbles into an environment in which clay was deposited. This interpretation is based on the bimodal size distribution of Facies D3 and its gradational bedding contacts with other fine-grained facies. Facies D1 is also regarded as a compound paratill resulting from rafting of sand and pebbles into silts. It probably represents higher rates of ice-rafted sediment deposition than D3 because the rafted coarse fraction is much more abundant than in D3. The massive Facies D2, however, has several possible origins. It may be a mudflow deposit, or tillite deposited by grounded ice. A mudflow origin is favoured for this facies because of the thin bedding seen in places, and the presence of intraclasts along the base of some examples. This evidence is not very strong so the possibility of tillites in the various sections cannot be ruled out.

Siltstone Facies: The settling of the fine particles from suspension produced the massive Facies Z1 and the claystone laminae of Z2 but some current activity may be indicated by the graded beds of Facies Z2. In thin section, the graded laminae are symmictic, that is, the silts and clays are not separated into discrete silt-clay couplets but form single, graded units. This sort of grading is typical of rhythmites deposited in marine environments where clay minerals flocculate (Duff, Hallam and Walton, 1967). Scattered coarse grains were probably ice-rafted into place. The different types of deformation affecting Facies Z2 result from loading of clay beds by rapid deposition of silts, causing the simple clay-into-silt intrusion structures, or from slumping of the seafloor which produced the complex mixing of the lithologies.

Sandstone Facies: The sandstone facies of the Cape Jervis Beds were deposited by currents of varying strength. The thin graded Facies S4 was deposited from weak, waning currents, possibly turbidity currents, though other currents may produce graded-bedding (e.g. Gilbert and Shaw, 1981). The coarse graded Facies S5 is also interpreted as turbidites deposited by currents powerful enough to erode the underlying silts. Facies S1 lacks grading but its very poor sorting suggests it too is the result of waning currents, in this case, rapidly waning and depositing most of the size fractions in transport at once (Stewart and La Marche, 1963). Facies S2 and S3 are well sorted and S3 displays sedimentary

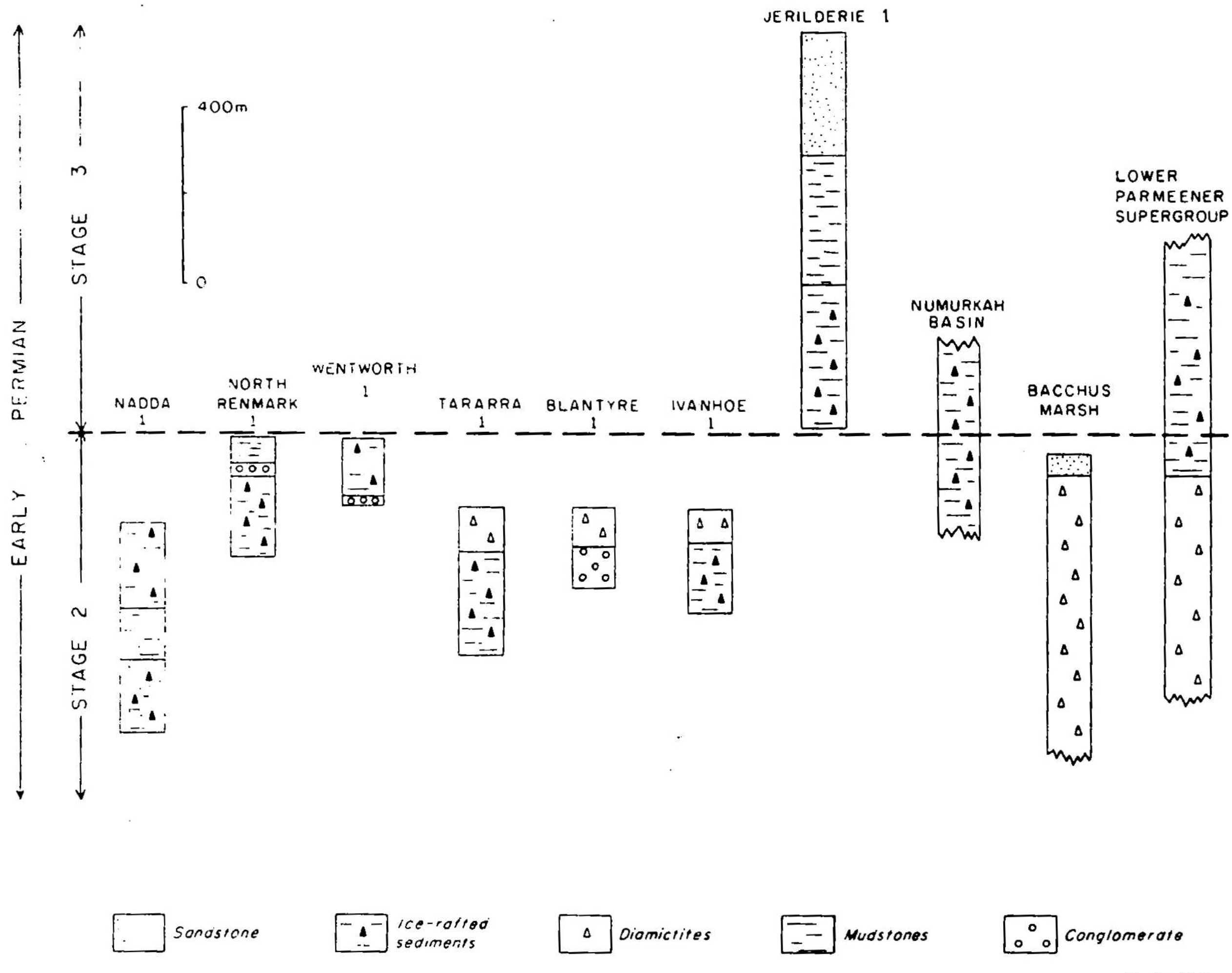

Fig. 13 Correlation of Cape Jervis Beds sections beneath the Murray Basin with the Bacchus Marsh Group (central Victoria) and the Lower Parmeener Supergroup (Tasmania)

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structures but, because of the fragmentary nature of cores of these facies little more can be said about them other than that they were deposited by currents capable of shifting fine and medium sand as bedload.

Conglomerates: The small size of the cores taken in the conglomeratic beds makes it impossible to draw any conclusions on the origin of the conglomerates other than that high energy conditions prevailed at the time.

Correlations of the Cape Jervis Beds beneath the Murray Basin

The microfloras in the Cape Jervis Beds suggest possible correlations between well sections (Fig. 13). Nadda No. 1, Wentworth No. 1 and North Renmark No. 1 contain Stage 2 microfloras (Derrington and Anderson, 1970; Ludbrook, 1962; Ludbrook, 1963). Paten and Price (in Derrington and Anderson, 1970) consider that the microfloras of Wentworth No. 1 and North Renmark No. 1 are more diverse and hence slightly younger than that of Nadda No. 1. Morgan (1975b) lists a Stage 3 microflora from low in the Jerilderie No. 1 section so that Nadda No. 1, North Renmark No. 1 and Wentworth No. 1, and Jerilderie No. 1 were deposited approximately consecutively. The palynological zones are too coarse to identify gaps or overlap between these sections (Fig. 13). The Numurkah Basin sequence ranges from Stage 2 to Stage 3 (McLeod, 1977, 1978, 1979). Of the other petroleum wells, Tararra No. 1 yielded an identifiable microflora but Blantyre No. 1 and Ivanhoe No. 1 did not. The Tararra No. 1 microflora is a Stage 2 assemblage (Boyd and Heibler, 1967; Evans, 1977). In Figure 13, Blantyre No. 1 and Ivanhoe No. 1 are tentatively correlated with holes containing Stage 2 microflora because the structural and lithostratigraphic positions of these two well sequences are broadly similar to the other wells drilled in the western part of the Murray Basin.

Palaeoenvironmental changes

The well sections through the Cape Jervis Beds beneath the Murray Basin suggest that they are mostly marine sediments with variable quantities of ice-rafted detritus in them. The factors which control the amount of ice-rafted detritus delivered to any particular place on the sea-floor are many and varied (Fillon, 1977) so that direct correlation of facies with palaeoclimatic change is not possible without data considerably more detailed than are presently available. However, the thick section in Jerilderie No. 1 exhibits facies changes which may reflect significant environmental changes.

The Jerilderie No. 1 section contains three different intervals (Fig. 11). The lowest 400 m is mostly diamictite (Facies D1), above it is 240 m mostly of siltstone (Facies Z1) and above that, the section is predominantly sandstone (Facies S1). The lower two intervals contain a restricted assemblage of calcareous and arenaceous foraminifera whereas the uppermost interval contains arenaceous foraminifera only (Terpstra, 1963). Ice-rafted pebbles are present in cores taken from the lower intervals and from cores near the bottom of the uppermost interval.

The difference between the lower two intervals in Jerilderie No. 1 is a difference in the coarse, ice-rafted component. The change from diamictite (Facies D1) to massive siltstones (Facies Z1) was caused by a reduction in the amount of ice-rafted detritus delivered to the area; a change with several possible causes:-

1. Reduction in the amount of floating ice due to a warmer climate.
2. Redirection of floating ice to other areas by wind or current changes.
3. Reduced sediment load in the ice.
4. Reduced melting of floating ice due to climatic cooling.

The climatic warming mechanism is the most likely cause of the facies change because work on other sections in southeast Australia suggests that the glaciation waned from late Stage 2 onwards (Foster, 1974; Kemp, 1978). The abundance of sandstones in the uppermost interval indicates a change to a higher energy environment. Similarly, the absence of calcareous foraminifera in the interval suggests a turbid or brackish environment (Harris and McGowran, 1971). The shape of the Self Potential curve (Fig. 11) may represent a regressive sequence (c.f. Davis, 1980) which, taken with the microfauna, suggests that the sequence may have been deposited by a prograding delta system. The plume of fresh, turbid water from a delta would cause the restricted microflora, and slumping of delta front sediments might have produced the beds of diamictite (Facies D2) present in the interval. However, this interpretation is speculative because the data are not very detailed.

It is much harder to identify major environmental changes in the other well sections. The Nadda No. 1 sequence includes a siltstone interval 67 m thick which may represent a period of reduced ice-rafted detritus deposition, but there are no vertical trends in facies apparent which might have been caused by warming of the climate.

THE COORABIN COAL MEASURES

Distribution and thickness

The Coorabin Coal Measures are continental, coal-bearing sediments overlying the Cape Jervis Beds in the northern part of the Ovens Graben. They are up to 70 m thick in the Oaklands-Coorbin area where exploration has been most intense and some mining has taken place. They form a broad syncline which follows the axis of the Ovens Graben and plunges gently north in the southern part of the basin (Fig. 14; Palese, 1974).

The northern part of the Ovens Graben and the areas east and west of the Graben are poorly known as there are only a few boreholes and little geophysical data. Palmer (1977) describes two seismic traverses north of Jerilderie which detected possible coal reflectors between depths of 150 m and 250 m below sea level in Line 2 (Fig. 3).

Reflectors which may correspond to the base of the Coorabin Coal Measures occur in both sections, rising from between 300 m and 500 m below sea level in the southern line to between 300 m and 400 m in the northern line. The lines are 25 km apart so the Coal Measures there may dip gently south. The northern edge of the basin has not been clearly delineated but a seismic line 16 km south of Murrumbidgee River detected the structure (Krietz and Wiemer, 1963) (Fig. 1). As yet, the extent of Coorabin Coal Measures in the northern end of the Graben is not known. If the shallow southerly dip detected by Palmer (1977) persists, the Coal Measures may be shallower than 289 m north of latitude 34°52'S (McIntyre, 1975).

The Coorabin Coal Measures extend beyond the eastern edge of the Ovens Graben. McIntyre (1975) suggests, on geophysical evidence, that Coorabin Coal Measures extend, with the Ovens Graben, as far north as the Murrumbidgee River (Fig. 1) and water bores show that the Coal Measures extend almost as far east as Urana (R.M. Williams, pers. comm., 1980). Figure 14 shows the known extent of the Coorabin Coal Measures in the Oaklands-Jerilderie area and the subcrop of the Cape Jervis Beds in the southern end of the Ovens Graben in New South Wales (R.M. Williams; pers. comm., 1980). Sediments equivalent to the Coorabin Coal Measures may occur to the west of the Ovens Graben, separated from the Graben by a shallow basement ridge. McIntyre (1975) suggests that Permian sediments beneath Tertiary cover may cause the poor definition of basement depths in gravity and aeromagnetic studies carried out to the west of the Ovens Graven. Also, at the western extremity of Line 2 of the reflection seismic study of Palmer (1977), he detected a reflector to the west of the known subcrop of the Coorabin Coal Measures which may be the top of equivalent sediments.

Stratigraphy

The Standing Committee on Coalfield Geology in New South Wales (1978) defined four formations within the Coorabin Coal Measures in the Oaklands-Coorabin and Jerilderie areas. Table 3 summarises the lithologies, thicknesses and ages of these units. The Coorabin Coal Measures contain Stage 5 microfloras (Morgan, 1977b) so the unconformity between the Coal Measures and the underlying Cape Jervis Beds represents a substantial time break.

The main lithologies in the Coorabin Coal Measures are conglomerates and sandstones with frameworks of milky or clear quartz and grey clay matrix material together with grey mudstones and coal. These lithologies are arranged in fining-upward cycles, grading from conglomerate at the base, through sandstones to mudstone and coal at the top. Morgan (1977b) interprets these cycles as point-bar sequences deposited by laterally migrating, meandering streams; the lower, coarse units were deposited in the stream channels, the sands on the point-bars and the mudstones and coals on floodplains (Allen, 1965). The petrography of the thickest coal seam, the Lane's Shaft Member, is consistent with peat accumulation in a raised bog environment during a long period of basin stability and low detrital input (Smyth, 1980).

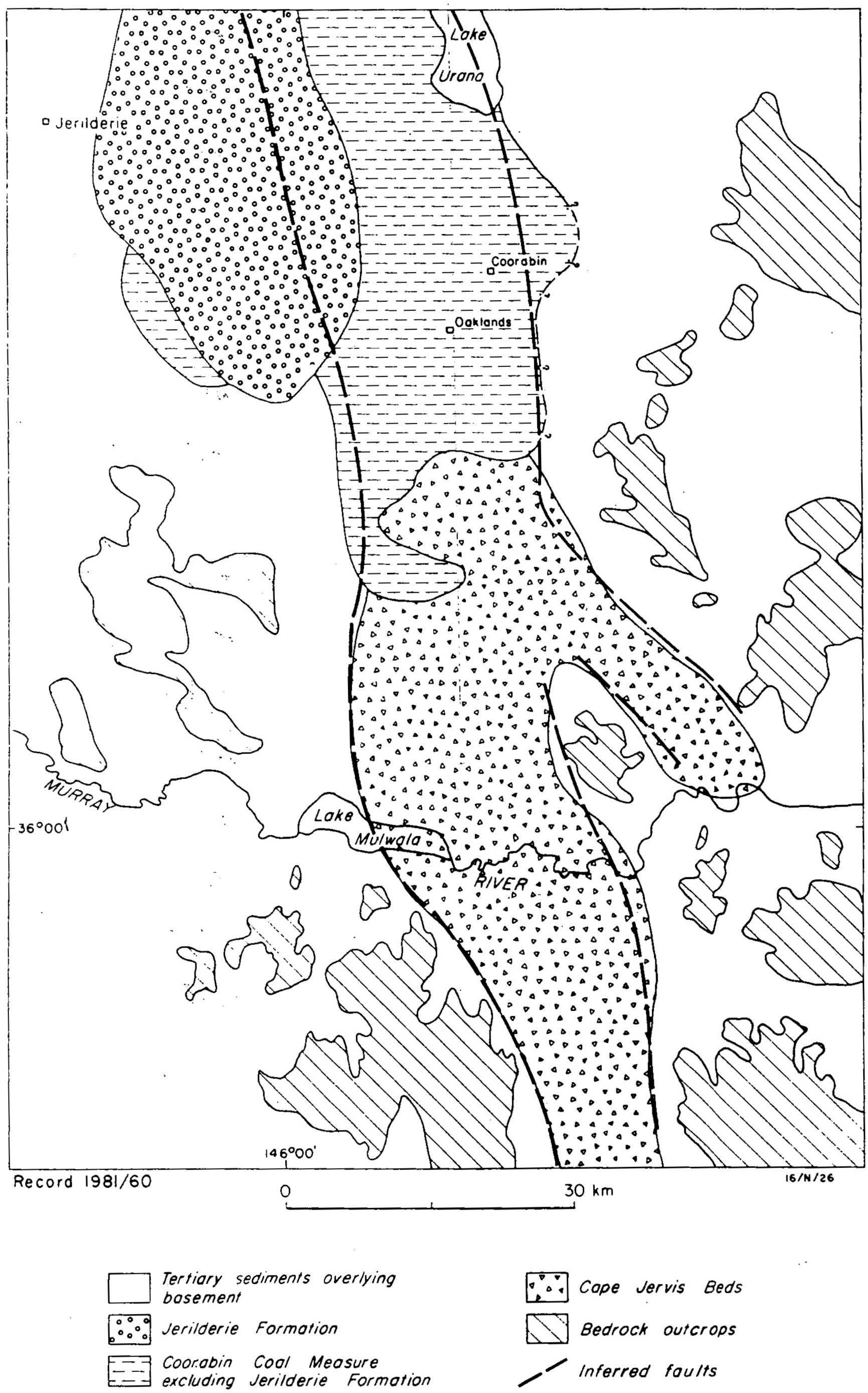

Fig 14 Subcrop of Cape Jervis Beds and Coorabin Coal Measures in the southern Ovens Graben (Williams, pers comm, 1980)

The uppermost pre-Tertiary unit is the Triassic Jerilderie Formation. It overlies Permian sediments along the western side of the Ovens Graben, overlapping the edges of the coal-bearing units (Fig. 14). It is up to 220 m thick and consists of quartzose sandstone and conglomerate with smaller amounts of grey to white mudstone. These sediments were regarded as part of the Tertiary Renmark Group until Morgan (1975b) recognised a Mesozoic microflora in material from Jerilderie No. 1. This flora is of mid-Triassic age; unit Tr 3B of Evans (1966) (Morgan, 1975b). This indicates a substantial time break between the uppermost Permian unit, the Nowranie Creek Formation, and the Jerilderie Formation. Because the lithologies of the Jerilderie Formation are similar to those of overlying Tertiary rocks, it may be more extensive than is presently recognised.

RESOURCE POTENTIAL OF THE PERMIAN BENEATH THE MURRAY BASIN

Hydrocarbon source potential

The Permian sediments beneath the Murray Basin have not been extensively examined as potential source rocks. Only eight source rock analyses from the Cape Jervis Beds were available for this study, two from Derrington and Anderson (1970) and six from the BMR organic Geochemistry Data Base. Those from the BMR Data Base are listed in Table 4, the others are not because they are based on different parameters. None of these samples are regarded as source rocks because of their low total organic matter contents though some approach maturity. Several minor hydrocarbon shows have been detected in the Cape Jervis Beds. In Jerilderie No. 1, a minor gas flow occurred at 518.7 m and gas bled from a core taken at 917.9 m (Wright and Stuntz, 1963). Also, thin sections cut for this study from Core 13 (518.7 m) revealed bituminous droplets up to 2 mm across occupying intergranular and fracture porosity (Appendix II). These shows, though minor, indicate that some hydrocarbons have been generated in the Ovens Graben.

Reservoir potential

Matrix clays and secondary minerals make most sediments in the Cape Jervis Beds poor reservoir rocks though some sandstones and conglomerates may have significant porosity and permeability. Wright and Stuntz (1963) present analyses of eight cores from Jerilderie No. 1 of which one has significant permeability (Table 5). Thin section examination of sandstones and conglomerates from other wells suggests that potential reservoirs exist elsewhere in the Cape Jervis Beds.

From the limited number of sections examined and the clay mineralogical data, it seems likely that any potential reservoirs would require careful stimulation to enhance production and avoid formation damage. Davies (1980) describes the behaviour of various minerals in sandstone reservoirs and notes that kaolinite may migrate during production, choking pore throats and reducing permeability. The potential reservoirs in the Cape Jervis Beds all contain kaolinite in varying amounts so stabilizing techniques may be necessary. Any method used to stabilize or dissolve the kaolinite should be designed with the possible effects of the stimulation fluids on the diagenetic carbonates and chlorite present in mind. These phases occur in variable amounts in the Cape Jervis Beds and might react unfavourably with acids introduced into the reservoir (Davies, 1980).

In conclusion, the hydrocarbon potential of the Cape Jervis Beds is low, on presently available evidence. However, most of the infrabasins are poorly understood so the possibility of economic hydrocarbon accumulations cannot be entirely ruled out. Gas shows in Jerilderie No. 1 suggest there is some possibility of small, locally significant gas discoveries in the Ovens Graben though the potential must be considered low.

Groundwater

Limited information is available on the groundwater resources of the Cape Jervis Beds and the Coorabin Coal Measures. Few analyses of water from the Cape Jervis Beds are recorded in well completion reports. The geophysical logs show that formation waters in the Cape Jervis Beds are brackish to saline, in some wells becoming more saline with depth. It seems unlikely that these formation waters are in contact with groundwater in the overlying Murray Basin sediments.

The Coorabin Coal Measures are probably more important aquifers in the regional groundwater system because they are permeable and may be in communication with overlying aquifers. Drilling and coal mining in the Oaklands area has revealed abundant groundwater, most of which is saline. Sturmfels (1950) reports salinites of 4200 ppm NaCl to 14 500 ppm NaCl. Groundwater flooded the small underground mines near Oaklands during the 1950's and any future mine will have to be designed to cope with it. New South Wales Water Resources Commission geologists are presently investigating the possible uses of groundwater from the Coorabin Coal Measures.

Coal

The Coorabin Coal Measures are being actively explored. Private companies are investigating the feasibility of mining in the Oaklands-Coorabin area where an estimated 200 million tonnes of coal is available for open-cut mining (Palese, 1974), the Lanes Shaft Coal Member being the only seam of interest. The seam is over 10 m thick over much of the area and consists of dull, low grade, bituminous coal. Recent analyses taken from the literature are shown in Table 6. The economic viability of a mine working the Coorabin Coal Measures depends on a suitable market for the coal and the ease with which the copious saline groundwater in and above the coal Measures can be controlled. Though the coal has limited value for its coking and steaming properties, a survey of the conversion potential of Australian coals (Joint Coal Board, Queensland Coal Board, 1978) lists the Coorabin Coal Measures coal as having good coal-to-oil conversion potential.

The northern extension of the Coorabin Coal Measures has lower resource potential because the coal lies at depths of 200 m to 300 m. To discover further potential coal fields, explorers will have to search for areas outside the Ovens Graben where Coorabin Coal Measures may lie in bedrock depressions beneath thin Tertiary cover around the edges of the Murray Basin.

REFERENCES

ALLCHURCH, P.D., WOPFNER, H., HARRIS, W.K., & McGOWRAN, B., 1973 - South Australian Department of Mines Cootanoorina No. 1 Well. Geological Survey of South Australia Report of Investigations, 40.

ALLEN, J.R.L., 1965 - A review of the origin and characteristics of recent alluvial sediments. Sedimentology, 5, 89-191.

ANDERSON, J.B., KURTZ, D.D., DOMACK, E.W., & BALSHAW, K.M., 1980 - Glacial and glacial-marine sediments of the Antarctic continental shelf. Journal of Geology, 88, 399-414.

ARMSTRONG, B., 1970 - Jerilderie detailed gravity survey No. 1, P.E.L. 160, New South Wales for New South Wales Oil and Gas Co. N.L. by Petty Geophysical Engineering Co. Bureau of Mineral Resources, Australia, File 69/3079 (unpublished).

BEMBRICK, C.S., 1974 - Murray Basin. In MARKHAM, N.L., & BASDEN, H. (Editors) 1974 - The Mineral Deposits of New South Wales. Geological Survey of New South Wales, 555-570.

BLUESTONE, A.E., 1969 - Murrumbidgee Gravity Survey, P.E.L.A. 233, P.E.L.A. 236 - N.S.W. by Planet Exploration Company Pty Ltd. Bureau of Mineral Resources, Australia, File 68/3022 (unpublished).

BOWEN, R.L., 1959 - Late Palaeozoic glaciation of eastern Australia. Ph.D. thesis, University of Melbourne (unpublished).

BOWEN, R.L., & THOMAS, G.A., 1976 - Permian. In DOUGLAS, J.G., & FERGUSON, J.A. (Editors) Geology of Victoria. Geological Society of Australia, Special Publication, 5, 125-142.

BOYD, B., & HEIBLER, H.H., 1967 - A.O.G. Tararra No. 1 well, New South Wales, well completion report. Bureau of Mineral Resources, Australia, File 66/4238 (unpublished).

CARROLL, D., 1970 - Clay minerals: a guide to their X-ray identification. Geological Society of America, Special Paper 126.

CHRISS, T., & FRAKES, L.A., 1972 - Glacial marine sedimentation in the Ross Sea. In ADIE, R.J., (Editor) Antarctic Geology and Geophysics. Oslo.

CRESPIN, I., 1958 - Permian Foraminifera of Australia. Bureau of Mineral Resources, Australia, Bulletin 48.

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

CROWELL, J.C., & FRAKES, L.A., 1971b - Late Paleozoic Glaciation Part IV. Bulletin of the Geological Society of America, 82, 2515-2540.

DAVIES, D.K., 1980 - Sandstone Reservoirs - their genesis, diagenesis and diagnosis for successful exploration and development. Petroleum Exploration Society of Australia Distinguished Lecturer Series, June 1980, Course Notes.

DERRINGTON, S.S., & ANDERSON, J.C., 1970 - A.A.O. Nadda No. 1 well completion report. Bureau of Mineral Resources, Australia, File 70/234 (unpublished).

DRIVER, R.C., 1975 - Oaklands-Coorabin Coal field, N.S.W. In TRAVES, D.M., & KIND, D., (Editors) Economic Geology of Australia and Papua New Guinea, 2, Coal, Australasian Institute of Mining and Metallurgy Monograph Series 6, 260-263.

DUFF, P.McL.D., HALLAM, A., & WALTON, E.K., 1967 - Cyclic Sedimentation. Developments in Sedimentology, 10, Elsevier, Amsterdam.

EVANS, P.R., 1962 - A palynological report on A.O.G. Wentworth No. 1, N.S.W. with observations on the Permian of the Oaklands-Coorabin Area of the Murray Basin. Bureau of Mineral Resources, Australia, Record 1962/4 (unpublished).

EVANS, P.R., 1966 - Palynological comparison of the Calilee and Cooper Basins. Bureau of Mineral Resources, Australia, Record 1966/222 (unpublished).

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

FILLON, R.H., 1977 - Ice-rafted detritus and palaeotemperatures: Late Cenozoic relationships in the Rose Sea region. Marine Geology, 25, 73-93.

FLINT, R.F., SANDERS, J.E., & RODGERS, J., 1960a - Symmictite: a name for unsorted terrigerous sedimentary rocks that contain a wide range of particle sizes. Bulletin of the Geological Society of America, 71, 507-510.

FLINT, R.F., SANDERS, J.E., & RODGERS, J., 1960b - Diamictite: a substitute term for symmictite. Bulletin of the Geological Society of America, 71, 1809-1810.

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

GILBERT, R., & SHAW, J., 1981 - Sedimentation in proglacial Sunwapta Lake, Alberta. Canadian Journal of Earth Sciences, 18, 81-93.

HARRIS, W.K., & McGOWRAN, B., 1971 - Permian and reworked Devonian microfossils from the Troubridge Basin. Geological Survey of South Australia, Quarterly Geological Notes, 40, 5-11.

HEDBERG, H.D., 1976 - International Stratigraphic Guide. Wiley, New York.

INGALL, L.N., 1966 - Ivanhoe gravity survey for Texam Oil Corp. by Wongela Geophysics. Bureau of Mineral Resources, Australia, File 64/4809 (unpublished).

JOHNS, M.W., & LAWRENCE, C.R., 1964 - Underground water resources of the northern plains of Victoria. Geological Survey of Victoria, Underground Water Investigation Report 1.

JOINT COAL BOARD, QUEENSLAND COAL BOARD, 1978 - Survey of Australian black coals of conversion potential. Pamphlet.

KEMP, E.M., 1978 - Palynology of the Permo-Carboniferous in Tasmania: an interim report. Geological Survey of Tasmania Bulletin 56.

KEMP, E.M., BALME, B.E., HELBY, R.J., KYLE, R.A., PLAYFORD, C., & PRICE, P.L., 1977 - Carboniferous and Permian palynostratigraphy in Australia and Antarctica: a review. BMR Journal of Australian Geology and Geophysics, 2, 177-208.

KRIETZ, E., & WIEMER, S., 1963 - Report on the Griffith Seismic Survey, P.E.L.s 49 and 50, N.S.W. for Amalgamated Petroleum Exploration by Prakala (Australia). Bureau of Mineral Resources, Australia, File 62/1653.

KURTZ, D.D., & ANDERSON, J.B., 1979 - Recognition and sedimentologic description of recent debris flow deposits from the Ross and Weddell Seas, Antarctica. Journal of Sedimentary Petrology, 49, 1159-1170.

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

LAWS, R.A., & HEISLER, H.H., 1967 - Beach Petroleum N.L., Berri North No. 1 well completion report. Bureau of Mineral Resources, Australia, File 67/4257 (unpublished).

LUDBROOK. N.H., 1962 - Australian Oil and Gas Corporation Wentworth No. 1 well, subsurface stratigraphy and micropalaeontological study. Geological Survey of South Australia, Palaeontological Report No. 14/61, Bureau of Mineral Resources, Australia, File 62/1212 (unpublished).

LUDBROOK, N.H., 1963 - A.O.C. North Renmark No. 1 subsurface stratigraphy and micropalaeontology study. Geological Survey of South Australia Palaeontological Report No. 6/63. Bureau of Mineral Resources, Australia, File 62/1223 (unpublished).

LUDBROOK, N.H., 1967 - Permian deposits of South Australia and their fauna. Transactions of the Royal Society of South Australia, 91, 65-92.

MACUMBER, P., 1978 - Permian glacial deposits, tectonism and the evolution of the Loddon valley. Mining, Geology and Energy Journal of Victoria, 7, 34-36.

MAY, R.W., 1980 - The formation and significance of irregularly shaped quartz grains in till. Sedimentology, 27, 325-333.

MOFFITT, W.H., 1961 - Final report on the reflection seismograph survey of the Jerilderie area, New South Wales, Australia for Australian Oil and Gas Corp. Ltd by Petty Geophysical Engineering Co. Bureau of Mineral Resources, Australia, File 62/1571.

MORGAN, R., 1975a - Microfloras from the Oaklands area, southeastern Murray Basin, New South Wales. Geological Survey of New South Wales Palynological Report No. 1974/4. Departmental File No. M73/7611 (unpublished).

MORGAN, R., 1975b - Palynoligcal examination of samples from A.O.G. Jerilderie R.D.H. 1 and A.P.E. Urana R.D.H. 1, eastern Murray Basin, New South Wales. Geological Survey of New South Wales Report No. GS 1975/148 (unpublished).

MORGAN, R., 1976a - palynology of Permian samples from Petromin Urana R.D.H. 2 and R.D.H. 3, eastern Murray Basin. Geological Survey of New South Wales Report No. GS 1976/076.

MORGAN, R., 1976b - Palynology of W.C. and I.C. hole 30323, eastern Murray Basin. Geological Survey of New South Wales Report No. GS 1976/072 (unpublished).

MORGAN,R., 1977a - Permo-Carboniferous palynology of W.R.C. Nos. 36201 and 36211, Murray Basin. Geological Survey of New South Wales Report No. GS 1977/106.

MORGAN, R., 1977b - Stratigraphy and palynology of the Oaklands Basin, New South Wales. Quarterly Notes of the Geological Survey of New South Wales, 29, 1-16.

McINTYRE, J.I., 1975 - Summary report of an assessment of previous geophysics Oaklands-Coorabin Coal basin. Geological Survey of New South Wales Report No. GS 1976/447.

McLEOD, M., 1977 - Palynology of Permian samples from the southeastern Murray Basin, Victoria for Western Mining Corporation Ltd, Exploration Division - Coal. Report by Palaeoservices, Australia (unpublished).

McLEOD, D.M., 1978 - Palynology of samples for Western Mining Corporation Ltd, Exploration Division - Coal. Report by Palaeoservices, Australia (unpublished).

McLEOD, M., 1979 - Report of palynological investigations on twenty-two samples for Western Mining Corporation Ltd, Exploration Division - Coal. Report by Palaeoservices, Australia (unpublished).

McMINN, A., 1981 - Palynological results from the Murray valley drilling project. Geological Survey of New South Wales Report No. GS 1981/082 (unpublished).

NETTLETON, L.L., 1940 - Geophysical Prospecting for Oil. McGraw-Hill.

PALESE, G.W., 1974 - Oaklands basin coal drilling program. Basin results of twenty-two bores drilled by the New South Wales Department of Mines from August 1973 to February 1974. Geological Survey of New South Wales Report No. GS 1974/090 (unpublished).

PALMER, D., 1977 - Interpretation of two seismic reflection traverses in the Oaklands Basin north of Jerilderie. Geological Survey of New South Wales Report No. GS 1977/142 (unpublished).

PETTIGER, G.R., & POLAK, E.J., 1980 - Experimental geophysical surveys in the Victorian part of the Murray Basin. Hydrology and Water Resources Symposium 1980, 4-6 November, 1980. Preprints of Papers. Institution of Engineers, Australia.

PRICE, P.L., 1976 - Report for Western Mining Corporation Ltd. Mines Administration Pty Ltd., Palynological Laboratory Report No. 135/2 (unpublished.

SAURAMO, M., 1923 - Studies on the Quaternary varve sediments in southern Finland. Bulletin Commission Geologique Finlande, 60.

SCHEIBNEROVA, V., 1980 - A review of the Permian foraminifera in the Sydney Basin. In HERBERT, C., & HELBY, R. (Editors), A Guide to the Sydney Basin. Geological Survey of New South Wales Bulletin, 26, 432-445.

SMYTH, M., 1980 - Thick coal members: products of an inflationary environment? Journal of the Coal Geology Group of the Geological Society of Australia, 2, 53-76.

STANDING COMMITTEE ON COALFIELD GEOLOGY IN NEW SOUTH WALES, 1978 - Stratigraphy of the Coorabin Coal Measures. Geological Survey of New South Wales. Record, 18. 141-146.

STEWART, J.H., & La MARCHE, V.C. Jr., 1967 - Erosion and Deposition produced by the flood of December 1964 on Coffee Creek, Trinity County, California. U.S. Geological Survey Professional Paper 422-K.

STRAUSS, P.G., ATKINSON, C.M., & RUSSELL, N.J., 1974 - Lithological description, petrographic analysis and chemical analysis of coal cores from boreholes RDH/2, RDH/3 and RDH/4, Oaklands-Coorabin area, Murray Basin, New South Wales. Robertson Research (Australia) Pty Ltd. Project No. 734/8771/6A Report No. 365. Geological Survey of New South Wales File No. GS 1974/275 (unpublished).

STURMFELS, E.K., 1950 - Preliminary report on geology and coal resources of Oaklands-Coorabin coalfield. Bureau of Mineral Resources, Australia, Report 3.

TERPSTRA, G.R.J., 1963 - Report on core samples from Jerilderie No. 1 well, Murray Basin, New South Wales. Bureau of Mineral Resources, Australia, Record 1963/50 (unpublished).

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

THORNTON, R.C.N., 1976 - Murray Basin and associated infrabasin. In LESLIE, R.B., EVANS, H.J., & KNIGHT, C.J. (Editors) - Economic Geology of Australia and Papua New Guinea, 3. Petroleum. Australasian Institute of Mining and Metallurgy Monograph Series, 7, 91-94.

THYER, R.F., & VALE, K.R., 1952 - Geophysical surveys, Oaklands-Coorabin Coalfield, New South Wales. Bureau of Mineral Resources, Australia, Bulletin, 19.

TICKELL, S.J., 1978 - Geology and hydrogeology of the eastern part of the Riverine Plain in Victoria. Geological Survey of Victoria, Report 1977/8.

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

WATSON, S.J., 1962 - Murray Basin seismic survey, 1960. Bureau of Mineral Resources, Australia, Record 1962/164 (unpublished).

WOOLEY, 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., & KELLEY, I.D., (Editors) - Symposium on the hydrogeology of the Riverine Plain of southeastern Australia. Australian Society of Soil Science.

WRIGHT, A.J., & STUNTZ, J., 1963 - A.O.G. Jerilderie No. 1 well completion report. Bureau of Mineral Resources, Australia, File 62/1216.

APPENDIX I

ESTIMATE OF THE THICKNESS OF CAPE JERVIS BEDS IN THE NUMURKAH TROUGH

This estimate uses the simple two-layer formula from Nettleton (1940).

$$h = \frac{ge}{0.042\ t}$$

Where h is the thickness of the upper layer in meters,

ge is the gravity effect of the upper layer in milligal.

t is the density contrast of the two layers in g/cm^3.

The gravity effect on the northern edge of the Numurkah Trough given by Bluestone (1969) is -29 mgal.

Density contrasts for the Cape Jervis Beds and various types of basements are taken from McIntyre (1975).

Contrast between Cape Jervis Beds and metasediment bedrock:- 1 gm^{-3} to 7 gm^{-3}.

Contrast between Cape Jervis Beds and granite:- 1 gm^{-3} to 6 gm^{-3}.

a) Taking the lowest contrast, $h = \frac{-29}{0.042} = 690$ m

b) Taking the maximum contrast, $h = \frac{-29}{0.042 \times 7} = 98.6$ m.

APPENDIX II

THIN SECTION DESCRIPTIONS

Twenty-three thin sections were examined to document the petrography of the various facies in the Cape Jervis Beds, particularly the diamictites and sandstones. The grainsize distributions of the diamictites were measured by point-counting with a stage micrometer to aid the interpretation of these facies and the sandstones were examined to assess their potential as hydrocarbon reservoir rocks. Nine thin sections were examined from Jerilderie No. 1, two from Nadda No. 1, Wentworth No. 1 and Tararra No. 1, five from North Renmark No. 1 and one from Blantyre No. 1.

Section 80302001. Jerilderie No. 1, Core 21, 1005.5 m.

Very silty fine sandstone (diamictite) with a framework of fine sand to coarse silt-sized quartz in matrix of very fine quartz, coarse birefringent clay and fine carbonate. Clay minerals show a moderate degree of preferred orientation parallel to bedding. Also, there are thin,contorted silt laminae cemented by blocky carbonate.

Section 80302002. Jerilderie No. 1, Core 21, 1006 m

Diamictite with medium to coarse sand-sized phenoclasts mostly of quartz but with K-feldspar, quartzite, shale, biotite and detrital carbonate grains. The matrix is coarse, birefringent clay, quartz and carbonate. Clays have moderate to strong preferred orientation with some patches, poor in quartz, showing very strong orientation. The matrix also includes thin, flamate, irregular clay laminae.

Section 80302003. Jerilderie No. 1, Core 13, 518.7 m.

Quartzose siltstone (approximately 60 percent quartz, 40 percent clay) with a few sand-sized grains of weathered K-feldspar, detrital carbonate and chloritic sandstone. The rock is notable for its scattered, fine fragments of organic matter and bituminous droplets. The bituminous material forms subangular patches up to 2 mm across which envelope the clastic grains. The bitumen also forms thin crack infillings. Some fine carbonate seems to have grown around the edges of some of the bituminous patches.

Section 80302004. Jerilderie No. 1, Core 20, 609.9 m.

Medium sandstone. Framework of 65 percent quartz, 30 percent rock fragments and 5 percent feldspar. These grains are accompanied by rare biotite flakes and chert and carbonate grains. The lithic grains are mostly fine, quartzose metasediments with a few grains of fine micaceous schist. The matrix is mostly fine, birefringent clay with minor fine carbonate. Primary and secondary porosity were not observed.

Section 80302005. Jerilderie No. 1, Core 20, 915.3 m

Medium-grained sandstone. Framework is 50 percent quartz, 45 percent rock fragments and 5 percent feldspar Most of the rock fragments are quartzose metasediments and slates with rare grains of highly altered volcanic rock. A few grains of unknown composition have been replaced by a fine, radiating fibrous mineral thought to be kaolinite. Some chlorite is visible in the altered volcanic grains. Pore spaces are filled with fine clay matrix and some secondary clay rims on framework grains. Porosity is very low because of the matrix and the squashing together of rock fragments.

Section 80302006. Jerilderie No. 1, Core 20, 915.9 m

Similar to Section 80302005 only with less clay matrix and hence greater porosity.

Section 80302007. Jerilderie No. 1, Core 19, 821.4 m

Massive siltstone which is about 80 percent quartz, 20 percent clay minerals. It contains thin burrows filled with dark brown silt and patches of clean silt-sized quartz grains 1 mm in diameter which may also be burrows. Some secondary chlorite is visible and flecks of organic matter are common.

Section 80302008. Jerilderie No. 1, Core 23, 1097.3 m

Cross-bedded very fine sandstone and coarse siltstone. The rock is quartzose with the grains closely packed so no porosity or matrix is visible though some patches are calcareous and carbonaceous fragments occur along the cross-bedding.

Section 80302009. Jerilderie No. 1, Core 25, 1257.9 m.

Sandy mudstone (fine diamictite) consisting of about 20 percent medium and fine-grained sand in a clayey siltstone matrix. The sand-sized

Section 80302009 (contd.)
grains are mostly quartz with only rare metasediment and carbonate grains. The matrix is fine quartz and detrital micas with some fine carbonate.

Section 80302011. Nadda No. 1, Core 1, 763.5 m

Sandy mudstone (fine diamictite) with 10 percent framework of subrounded to angular sand grains. They are mostly quartz grains but rare feldspar, slate and carbonate grains are present. Some grains, strongly altered to chlorite, may be volcanic rock fragments or altered feldspars. Rare muscovite flakes are partly replaced by carbonate which splits the flakes along basal cleavage planes. The matrix is quartz and fine micas with traces of carbonate and chlorite.

Section 80302012. Nadda No. 1, Core 2, 957 m

Poorly sorted siltstone consisting of subangular quartz silt with sparse detrital micas irregularly interlaminated with clayey siltstone. Carbonate cements the quartz siltstone laminae.

Section 80302013. Wentworth No. 1, Core 4, 616 m

Laminated claystone with scattered granules and coarse sand grains. Coarse grains are quartz, granitic rock fragments, microcline and gneissic fragments. The matrix clays are strongly oriented parallel to bedding except where the matrix bends around the larger grains in response to differential compaction.

Section 80302014. Wentworth No. 1, Core 6, 631.2 m

Conglomerate with a framework of granite, fine-grained metasediment and quartz pebbles. The conglomerate has a matrix of fine-sand sized quartz grains and detrital clay. No porosity was observed.

Section 80302015. North Renmark No. 1, Core 13, 1045.7 m

Conglomerate with a framework of quartz and granite pebbles and matrix of quartz silt and clay. Pores are visible and have linings of red iron oxide overlain by carbonate.

Section 80302016. North Renmark No. 1, Core 13, 1043.6 m

Very poorly sorted sandstone (sandy diamictite). It has a framework of angular to subrounded quartz and K-feldspar grains set in a matrix of fine quartz and clay. The rock also contains a few granules of fine metasediments and rare granite fragments.

Section 80302017. North Renmark No. 1, Core 15, 1154.6 m

Well sorted medium-grained quartz sandstone with rare plagioclase and chert grains. The rock is cemented by large carbonate crystals up to 1 cm long which grow poikiloblastically over the detrital grains. No porosity was observed.

Section 80302018. North Renmark No. 1, Core 19, 1223 m

Very poorly sorted sandstone (sandy diamictite) with a framework of angular, medium-grained sand in a matrix of low-birefringent clay, fine quartz and small amounts of carbonate. Carbonate has also extensively replaced granite framework grains.

Section 80302019. North Renmark No. 1, Core 19, 1223.7 m

Very poorly sorted sandstone (sandy diamictite) with a framework of coarse to medium-grained sandstone in a matrix of fine quartz and detrital mica. The framework grains are 90 percent quartz accompanied by muscovite, biotite, K-feldspar, metasediment grains and chert. The feldspars are partly replaced by blocky and needle-like carbonate.

Section 80302020. Blantyre No. 1, Core 4, 275.8 m

Diamictite consisting of 40 percent medium to coarse-grained sand set in a clay matrix. The sand grains are mostly quartz with rare granite and quartzite fragments and some chloritic, heavily altered grains. The matrix is a mixture of high and low birefringent clays which show patchy, weak preferred orientation which wraps around the coarse grains.

Section 80302022. Tararra No. 1, Core 2, 715.9 m

Fine-grained, quartz sandstone with a matrix of fine, low-birefringent clay. Carbonate forms as small patches growing poikiloblastically around sand grains or as the infilling of single pores.

Section 80302023. Tararra No. 1, Core 3, 816.9 m

Fine quartz sandstone with graded laminae 1 to 3 mm thick. There is no matrix material and only patchy development of secondary carbonate and clay rims.

APPENDIX III

DETERMINATION OF CLAY MINERALOGY

Five samples of cuttings from Jerilderie No. 1 were disaggregated in distilled water using an ultrasonic disaggregator and passed through 63 micron nylon sieve cloth. The -2 micron fraction was removed from the filtrate by settling in a graduated cylinder. The dispersed clay was then placed on glass slides by dropping pipette and air-dried.

The resulting oriented mount was then run on the University of Melbourne School of Earth Sciences Phillips Diffractometer on the following settings:

Radiation Cu $K\alpha$ with Ni filter

Scan speed - 1 degree per minute from 3 to 30 degrees

Voltage - 35 kV

Current - 15 milliamp.

After the initial run, the mounts exposed to ethylene glycol vapour at $60^{o}C$ for 1 hour and re-run to detect expandable clays.

Finally, fresh mounts were heated in a muffle furnace to $600^{o}C$ for 1 hour to observe the collapse of the kaolinite peaks and some of the chlorite peaks.

Table 1. Petroleum Exploration Wells which intersected Permian sediments beneath the Murray Basin.

Well	Year	Licensee
Wentworth No. 1	1961	Australian Oil and Gas Corp.
North Renmark No. 1	1962	Australian Oil Corporation
Jerilderie No. 1	1962	Australian Oil and Gas Corp.
Urana No. 1	1962	Amalgamated Petroleum Exploration
Ivanhoe No. 1	1963	Exploration Drilling Australia
Blantyre No. 1	1965	Planet Exploration Co.
Tararra No. 1	1967	Australian Oil and Gas Corp.
Nadda No. 1	1970	Australian Associated Oilfields

Table 2. Stratigraphy of sub-basins beneath the Murray Basin

Infrabasin	Reference Bore	Cainozoic	System Thickness (metres) Mesozoic	Permian	Devonian	Depth to Basement (metres A.S.L.)
Renmark Trough	North Renmark No. 1.	548	440	+235	-	-
Paringa Embayment	Nadda No. 1	449	179.5	395	0	-992
Tararra Trough	Tararra No. 1	440	90	323	+1022	-
Blantyre Trough	Blantyre No. 1	184	0	169	+1883	-
Wentworth Trough	Wentworth No. 1	329	101	+145	-	-
Ivanhoe Trough	Ivanhoe No. 1	107	39	285	+178	-
Bundy Trough	Killendo No. 1	357	0	0	+398	
Ovens Graben	Jerilderie No. 1	362	202	957	0	-1210
Numurkah Trough	Katunga No. 1	158	0	+63.7	-	-
Netherby Trough	Warraquil No. 1	350	0	371	0	-548

Table 3. Stratigraphy of the Coorabin Coal Measures

Age	Palynological Zone/ Stage	Stratigraphic Unit	Thickness	Lithologies
Mid-Triassic	Unit Tr 3B	Jerilderie Formation	0-219 m	White to grey quartzose sandstone, conglomerate & mudstone
		UNCONFORMITY		
Upper Permian	Protohaploxypinus reticulatus assemblage	Nowranie Creek Formation	0-7 m	Grey to pink claystone
		UNCONFORMITY		
Upper Permian	Upper Stage 5	Coreen Creek Coal Member	0.5 m - 1.5 m	Coal and carbonaceous mudstone
"	"	Loughmore Formation	7 m - 18 m	Conglomerate grading up into sandstone and coal
		UNCONFORMITY		
Upper Permian	Lower Stage 5	Lanes Shaft Coal Member	3.5 m - 19 m	Dull, uniform coal with fusain lenses and several mudstone bands
"	"	Narrow Plains Formation	15 m - 35 m	Conglomerate and sandstone grading up into mudstone and coal
		UNCONFORMITY		

Table 4. Source Rock Data from the Cape Jervis beds, Murray Basin

Well	Depth m	TOC %	VTREF %	EOM ppm	SATD ppm	AROM ppm	POLAR ppm	ASPH ppm	EPOC	HPE
Blantyre No. 1	275.8	0.01	0.71	97	9	45	44	-	9.7	55.7
Jerilderie No. 1	741.4	0.65	-	131	23	19	56	-	2.02	32.0
Nth Renmark No. 1	1096.0	0.19	0.73	-	-	-	-	-	-	-
Nth Renmark No. 1	1184.0	0.09	0.74	-	-	-	-	-	-	-
Wentworth No. 1	550.8	0.15	-	126	35	21	37	-	8.4	44.4
Wentworth No. 1	614.5	0.2	-	173	22	7	39	-	8.65	16.7

TOC - Total Organic Carbon (%)
VTREF - Vitrinite reflectance
EOM - Extractable organic material (ppm)
SATD - Saturated hydrocarbons (ppm)
AROM - Aromatic hydrocarbons (ppm)
POLAR - Polar, Nitrogen - Sulphur - Oxygen Compounds (ppm).
ASPH - Asphaltenes (ppm)
EPOC - Total extract (EOM) as % organic carbon
HPE - Total hydrocarbon as percentage of extract.

(Data from BMR Petroleum Exploration Branch Data Base)

Table 5. Porosity and Permeability Data, Jerilderie No. 1

Well	Core Number	Depth below Sea Level	Effective Porosity % by volume		Absolute Permeability millidarcies	
			Vertical	Horizontal	Vertical	Horizontal
Jerilderie No. 1	18	-622 m	20	20	0	0
"	19	-715 m	14	N.D.	0	N.D.
"	20	-797 m	26	25	53	62
"	21	-887 m	N.D.	N.D.	0	N.D.
"	22	-888 m	11	N.D.	0	N.D.
"	23	-979 m	11	9	0	0
"	24	-1062 m	4	N.D.	0	N.D.
"	25	-1140 m	6	N.D.	0	N.D.

Porosities and permeabilities determined on plugs cut at right angles and parallel to cores.

N.D. means Not Determined (Data from Wright & Stuntz, 1963).

Table 6. Analyses of the Lane's Shaft Coal Member

Bore	Thickness m	Moisture %	Ash %	Volatile Matter %	Fixed Carbon %	Specific Energy Mj/kg	S	Source
-	17.1	13.0	14.1	25.4	-	21.69	0.27	Driver (1975)
-	16.2	12.5	17.4	24.8	-	20.85	0.45	"
-	4.0	12.8	18.7	23.5	-	19.85	0.36	"
-	-	-	18.0	29.4	52.6	23.66	0.34	Joint Coal Board (1978)
Coorabin RDH/2	14.2	13.7	13.7	24.1	48.5	20.94	0.21	Strauss, Atkinson & Russell (1974)
Coorabin RDH/4	14.89	13.3	16.3	24.2	46.2	20.17	0.32	" " " "
Coorabin RDH/3	17.47	14.2	12.7	24.4	48.7	21.13	0.20	" " " "