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A PRELIMINARY REVIEW OF THE OTWAY BASIN

By B.M.R.

CONTENTS

ILLUSTRATIONS

PLATES (in manilla wallet)

FIGURES

I. INTRODUCTION

The review of the Otway Basin began in October, 1963 and incorporates data obtained to the end of 1965. The aims of the review were:

1. To collate as much data as possible for this Basin before the amount of data became too voluminous to handle in a short-term review.

2. If results showed that good prospects for finding oil or gas existed, to stimulate the continued interest of exploration companies in the region.

3. If results showed little prospect for finding commercial oil, to make this fact known, but to outline other aspects of economic importance (such as other mineral accumulations, and good reservoirs which might be utilized for natural gas storage).

4. To provide facilities for State Mines Departments and exploration companies to assist them in their studies of the region, and if possible to obtain their active co-operation in the project.

The Otway Basin review has been made mainly by the Subsurface Section of the B.M.R. Petroleum Exploration Branch, but has been assisted by other Branches of the Bureau, and by the Institut Francais du Petrole (acting as consultants to the Bureau). The work was directed by M.A. Condon and L.W. Williams, and supervised initially by C.E.B. Conybeare and K.B. Lodwick, and since September 1964 by M.A. Reynolds. Other officers in the Subsurface Section who have contributed to the review have been J. Drummond, A. Bigg-Wither, R. Bryan, J.D.T. Scorer, P.J. Hawkins, K. Edworthy, D. Denham, R.P.B. Pitt, and V.F. Dent. Particular acknowledgement is made here of the assistance given in petrological studies by J. Dellenbach of the I.F.P., the contribution on palynological studies by P.R. Evans of Geological Branch, and the results of core analyses provided by P.G. Duff of the Petroleum Technology Laboratory. Technical staff of the Core and Cuttings Laboratory and of the I.F.P. worked in close co-operation with the Basins Study Group, and contributions to this report have been made by I.K. Kraitsowits and S. Ozimic. It will be most convenient to refer to authorship of this report as "B.M.R., 1966".

The authors gratefully acknowledge the assistance given to them by the various companies who hold unpublished data on the Otway Basin, and who have made most of their data available on request; visits from representatives of the companies for discussions on progress were also stimulating. The companies who have provided data or otherwise contributed to the review are the Frome-Broken Hill Co. Pty Ltd, Oil Search Ltd, W.D. Mott and Associates, Planet Exploration Co. Pty Ltd, Interstate Oil Ltd, and Haematite Explorations Pty Ltd.

Useful discussions were also held with some of the officers of the South Australian and Victorian Mines Departments, but the Departments were unable to offer the type of co-operation hoped for by the Bureau in their initial objectives; for this reason, the work has been terminated at this stage, and the report has been prepared as a preliminary review.

1. Methods used

Apart from the contribution on palynology, four main approaches were made to the review - petrology, literature review, geophysics, reservoir engineering.

(1) Petrological Studies: In order to provide a framework for the review, ten subsidized+ wells were chosen for detailed petrological studies, with thin-section examination of core and cuttings samples at every 50 feet (average) or at marked changes of formation, and examination of cuttings for each 10 feet. In all, 1700 thin sections were prepared. The results have been given in Bureau Records by Dellenbach (1964, 1965 a, b)*, Dellenbach and Hawkins (1964)*, Dellenbach, Kraitsowits, Ozimic and Hawkins (1965)*, Edworthy (1964, 1965 a, b)* Hawkins (1965)*, and Hawkins and Dellenbach (1964)*. Due to staff movements during the review, it has not been possible to do much specialized sedimentary petrology such as grain size analysis; however, the studies did yield new information on the sediments, and led to the recognition of a number of lithological units, and at least three unconformities of basin-wide extent. The naming of the lithological units was deferred during the studies because in previous geological surveys and in completion reports, different names had been applied to each individual unit depending on location; the problem was temporarily overcome by using an informal letter-number identification for each lithological unit. The division of units is shown in Chart 1 and some of the more important stratigraphic tables are compared in Chart 2 (fold-out at the end of text).

(2) Literature review: The number of references (published and unpublished) that relate to the Otway Basin exceeds 500. It was not possible to examine all of these, but most of them have been indexed. Two types of card were used; one showing the reference, and the other an edge punch card on which data to be easily recoverable was recorded (see Reynolds, 1964)*. In preparing the bibliography, two divisions have been made:

A. Published Reports: this is abridged and partly annotated, and contains the main references to the Otway Basin and references used in the text of the report; special mention is made of reports with comprehensive bibliographies which contain some older references omitted from this report because they are no longer applicable, or whose results are incorporated in more recent reports.

B. Unpublished Reports: these are differentiated in the text of the report with an asterisk; they are divided into three categories and prefixed in the bibliography as follows:

(A) other than company reports (B.M.R. Records, Mines Department reports, etc.);

(S) Company reports of subsidized oil search operations;

(C) Other company reports which were made available for the review of the Otway Basin.

(3) Geophysics: gravity data have been taken directly from Geophysical Branch compilations and from work done for Frome-Broken Hill by K.A. Richards (1956)*. The results of aeromagnetic surveys have been collated, but no attempt has been made to reinterpret the records. Most effort has been directed to combining all available seismic data into a number of cross-sections, and contour maps of unconformable horizons recognized in the petrological studies.

+ 'subsidized' refers to wells drilled and geophysical surveys conducted under the Commonwealth Government's Petroleum Search Subsidy Acts, and indicates that material and data from such operations have been available for the review.

* Unpublished.

(4) Reservoir engineering: Pressure and fluid data have been collated, but are insufficient for construction of pressure flow nets and hydrodynamic analysis. A Bureau Record by Scorer (1965)* summarizes the available data and gives some general comments on drillstem testing techniques.

When the independent studies were completed, the results were combined, and form the basis of this report. Palynological results were incorporated with the results of petrological studies and stratigraphic correlations were made. A general index map and a combined geological-surface structure map+ were prepared. Thickness variations were analysed and lithofacies studies were made of some of the units. Index maps of the geophysical surveys were prepared and the survey results were incorporated into a number of maps; the subsurface structure map includes both geophysical and some geological data. (Palaeotectonic and isopach maps were not drawn, as such, because the horizons contoured from seismic records coincided more or less with the major unconformities, and thus gave better basin coverage; isochron maps of two intervals provided the equivalent of isopachs for two of the major lithological units). Additional studies on the structure and provenance were made and the results have been included in an account of the geological history of the Basin. Finally the petroleum prospects were assessed using all of the available data, and some notes were prepared on other mineral occurrences.

2. History of exploration

Some of the first geological observations in the Otway Basin were made by Darwin in 1844 (Grayson and Mahony, 1910; Boutakoff, 1963). The establishment of the Victorian Geological Survey followed soon after the discovery of gold in 1851, and A.R.C. Selwyn was appointed Mineral Surveyor in May 1852, (see Baragwanath, 1953). Other pioneers of geological exploration in the Otway Basin include R.A.F. Murray, F.M. Krause, J. Stirling, A.E. Kitson, H.Y.L. Brown, E.J. Dunn, H. Herman, J. Dennant, T.S. Hall, G.B. Pritchard, R. Tate and J.E. Tennyson-Woods.

Easy access is available to most parts of the Otway Basin region, and a large amount of geological work has been done since the pioneering days, particularly on the Cainozoic rocks - sediments and volcanics - which cover most of the area. The Lower Cretaceous outcrops of the Casterton area, Barrabool Hills and Otway Ranges have also been surveyed, particularly in the search for coal. However, many of the available reports deal only with Tertiary stratigraphy and palaeontology and have become obsolete as geological work has progressed.

The more recent geological surveys of the Otway Basin region have been made by:-

Baker (1943-1963)	-	coastal geology from Peterborough to Moonlight Head;
Boutakoff (1963)	-	Portland area;
Bowler (1963)	-	Geelong and Maude areas, Victoria;
Coulson (1960)	-	Barrabool Hills and other reports mainly on the Geelong district, back to 1930;
Sprigg (1952)	-	the south-east of South Australia;
Thomas (1957,1960)	-	Corangamite and Glenelg Regions.

Early attempts to correlate Lower Cretaceous and some of the younger stratigraphic units (particularly the thick sedimentary units met in drilling) were unsuccessful, mainly because of the lack of suitable criteria for correlation. This problem has been overcome to some extent by palynological studies, and since 1953 useful contributions have been made by Isabel C. Cookson, Mary E. Dettmann, J.G. Douglas, A. Eisenack, P.R. Evans, W.K. Harris, and E.A. Hodgson.

The main contributions to Tertiary stratigraphy and palaeontology have been made by Carter (1958 to 1964), Chapman (1904 to 1935), Crespin (1926 to 1955), Glaessner (1947 to 1964), Ludbrook (1957 to 1963), McGowran (1959, 1965), Parr (1926 to 1950), Pritchard (1896 to 1940), and Singleton (1935 to 1943). Bock and Glenie (1965) and Taylor (1964,1965) have also recently interpreted the late Cretaceous and Tertiary geological history of parts of the Otway Basin in Victoria. Descriptions of the physiography, geomorphology and Quaternary geological history can be found in Boutakoff (1963), Cotton and Crocker (1946), Crocker (1941, 1946), Fenner (1918 to 1930), Gill (1943 to 1964), Hills (1946), Hossfeld (1950), Jutson (1927 to 1937), and Sprigg (1950 to 1959).

Reference is also made here to the work done in the areas marginal to the Otway Basin because of its importance when considering the problems of provenance. Papers have been written by Harris and Thomas (1949, Meredith area), Mawson et al (1943-45, Padthaway Ridge), Spencer-Jones (1956, Kadnook-Mooree area, western Victoria; 1958 to 1965, the Grampians), Summers (1923, Bacchus Marsh-Coimadai), Thomas (1937, Heathcote; 1959, Victoria general), Wells (1956, Casterton,) and Williams (1964, Kinglake district).

Studies designed to coordinate the geology of the South Australian and Victorian parts of the Otway Basin were undertaken in the early 1950's, and led to papers by Boutakoff (1952), Sprigg (1952), and their joint papers in 1953. The two most general publications covering the geology of the region are by David (1950), and Glaessner and Parkin (1958). A second joint study by the Geological Surveys of Victoria and South Australia began in 1964 (Bock and Glenie, 1965).

A number of general papers on petroleum exploration in Australia also cover the Otway Basin: Reeves (1951), B.M.R. (1960), Rudd (1962), Guillemot and Tissot (1965). Boutakoff (1951,1956) dealt with oil search in Victoria, and details of South Australian exploration are given in Wade (1951), and Ward (1916 to 1944). More specific studies on the Otway Basin have been made by Brown (1965), Glenie and Reed (1961), McQueen (1961), Sprigg (1961 to 1964 - nine papers, two with J.B. Woolley), Stach (1962), and Woolley and Laws (1964). The paper by Leslie (1965) covers the whole of the Basin and incorporates the results of most of the recent exploration.

Drilling in the Otway Basin has been mainly for water, oil, and coal. Bore data is available from hydrological reports: Gloe (1947), O'Driscoll (1960), Ward (1913, 1941, 1946), and several records by the Victorian Department of Mines (V.D.M., 1929 to 1960). The first well for oil in Australia was the Alfred Flat Bore, drilled in 1892 in the Coorong area (near the Padthaway Ridge, part of the northern margin of the Otway Basin); this was drilled in the search for oil thought to be associated with the surface occurrence of coorongite, a brown rubbery substance derived from algae, which on distillation yields petroleum-like products, and known from the Coorong area since 1852. Later wildcat drilling was based in some cases on outcrop indications of structure, and Mount McIntyre No. 1 was drilled to ascertain whether any oil had accumulated through distillation of organic matter in carbonaceous beds by volcanic intrusions, or by folding of the beds as a result of the intrusion. Table 1A lists some of the deeper wells and bores drilled in the Otway Basin.

The first use of geophysical methods in the Otway Basin (to ascertain the nature of a structure which was about to be drilled for oil) was in 1930 when J.M. Rayner conducted a magnetometer survey on Knight's Dome in south-eastern South Australia. (The subsequent drilling of the dome was unfortunately stopped before the whole of the Tertiary section had been penetrated, and results were inconclusive.) The next known geophysical work was not undertaken until 1948-49 when the Zinc Corporation flew some aeromagnetic lines in south-eastern South Australia and western Victoria. The B.M.R. then did some gravity and magnetometer surveying in 1949-50 in south-western Victoria (Wiebenga, 1957, 1960)*, and the South Australian Department of Mines ran gravity surveys in south-eastern South Australia from 1950 to 1954, (Grant, 1954; and some unpublished work); the results were co-ordinated by Richards (1956)* in a report for Frome-Broken Hill Co. Pty Ltd. Subsequent surveys, mainly geophysical, are summarized in Table 1B.

3. Definition of the Otway Basin

The Otway Basin is the western segment of a late Mesozoic (Jurassic or Lower Cretaceous) downwarp, now exposed partly on land, forming south-western Victoria and south-eastern South Australia, and partly off-shore. Its on-shore limits have been determined from outcrop and well data; the off-shore boundary has not yet been defined but apparently extends beyond the 100 fathom line.

The eastern margin is the Selwyn Fault and a strong aeromagnetic gradient off-shore to the south-south-west. In outcrop, Precambrian and Palaeozoic basement rocks occur to the east of this lineament, and geophysical evidence also suggests shallow submarine basement to the east, thus forming a narrow basement ridge between the Otway Basin and the Gippsland Basin to the east and the submarine Bass Basin to the south-east. The margin has been continued to the south-west, mainly following magnetic anomalies, to the western side of King Island.

From the north-western side of Mornington Peninsula, the margin turns to the west through Melbourne and runs irregularly westwards past Hamilton and to the north-west and west to Kingston in South Australia. The northern margin in Victoria is somewhat arbitrary except where the Lower Cretaceous sediments overlie basement north-west of Hamilton. Most of the region between Hamilton and Melbourne is obscured by Tertiary volcanics and sediments, and the margin has been drawn around the southern limits of Palaeozoic outcrops. However, some fault control may exist as suggested by the unusual east-west trend of faults north of the Barrabool Hills and the east-west lineament along the northern side of the Bellarine Peninsula east of Geelong.

From the north-western edge of Lower Cretaceous outcrop (north-north-west of Casterton), the margin follows the Kanawinka Escarpment where the Escarpment abuts against basement for a short distance, and swings northwards to Naracoorte. The Kanawinka Escarpment is a strong feature, partly fault-controlled at the surface, but is mainly an off-set expression of deep-seated faulting. The margin undulates from north of Naracoorte to Kingston, and embraces a small area of shallow basement with some Tertiary and possibly older sediments; doubtful hydrocarbon occurrences were reported from bores in this area. Geophysical and subsurface data show that a strongly faulted zone exists at depth just south of this margin and extends from south of Naracoorte to the west through Cape Jaffa; sudden thickening of Tertiary and particularly Mesozoic sediments occurs to the south of the faulting.

The area to the north of the margin between Naracoorte and Kingston is called the Padthaway Ridge; granite and other acid igneous

Table 1A : Some of the deeper wells and bores in the Otway Basin

Year	Operator	Name	Location	Elevation G.L. (Feet)	Total Depth (Feet)
1892	Salt Creek Petroleum Co.	Alfred Flat	Alfred Flat	20	922
1894	Victorian Dept. of Mines	Portland No.1	Portland Botanical Gardens		2265
1895	" " " "	Bolwarra No.1	7 miles north of Portland		1505
1910	" " " "	Sorrento	Sorrento	50	1658
1915	S.A. Oil Wells Co.	Robe No.1	Sect.714,Hd. Waterhouse	127.5	4504
1915)	" " " "	Tantanoola	Sect.195,Hd. Hindmarsh	95	1532
to	" " " "	Caroline No.1	Sect.598,Hd. Caroline	15	839
1928)	" " " "	Caroline No.2	Sect.337,Hd. Caroline	95	1226
	" " " "	Caroline No.3	Sect.336,Hd. Caroline	100	1824
	" " " "	Caroline No.4	Sect.543,Hd. Caroline	100	1561
1922	" " " "	Anglesea Bore No.1	4 mls. north of Pt. Castries	10	462
1922	" " " "	Anglesea Bore No.1	½ ml. west of Anglesea Bore No.1	260	742
?	Adelaide Oil Expl. Co.	Mt. McIntyre	Sect.9,Hd. Riddock	493	1045
1922	Coorong Oil Co.	Salt Creek	Salt Creek, Co. Cardwell	20	931
1923	Assoc. Oil Corp.	Mt. Gambier No.1	8 mls. north-west Mt. Gambier	135	2110
1923	Point Addis Co. (or	Jan Juc. No.1	near Torquay	40	1453
1923	Torquay Oil Wells Co.)	Jan Juc. No.2	near Torquay	34	894
1923	" " " "	Jan Juc. No.3	near Torquay	20	843
1923	" " " "	Jan Juc. No.4	near Torquay	114	715
1923	" " " "	Jan Juc. No.5	near Torquay	216	700
1924	" " " "	Jan Juc. No.6	Point Addis	50	842
1924	" " " "	Jan Juc. No.7	Point Addis	50	822
1924	Coorong Oil Co.	Santo No.1 (1)	Sect.B, Hd. Santo	5	650
		(2)	" " " "	5	656
		(3)	" " " "	5	701
?	Southern Ocean Oil Co.	Coorong No.1	Sect.42,Hd. Lacepede	35	1170
1925	" " " "	Coorong No.2	Sect.507," "	20	2660
?	Mersey Valley Oil Co.	Mumbannar No.1	C.A. 3A, Parish Malanganee	200	1100
1926		Palpara No.1	4½ mls. north of Nelson No.1	85	1170
1926	Point Addis Oil Wells N.L.	Comaum No.1	Lake Cooie		1171
1930	Oil Search Ltd.	Knight's Dome No.2	Sect.170,Hd. Blanche	170	2013
1932	Enterprise Oil Prospecting	Salt Creek No.1	Salt Creek,Co. Cardwell	20	606
1933	" " "	Salt Creek No.2	" " " "	25	450
?	" " "	Enterprise Oil	Sect.442 NE, Hd.Lacepede	35	466

Table 1A (Continued)

Year	Operator	Name	Location	Elevation G.L. (Feet)	Total Depth* (Feet)
?	Kingston Amalgamted Oil Wells	Blackford	Sect.10B,Hd.Murrabinna	144	1363
?	Producers Oil Wells	Mt. Gambier	Sect.150 or 153, Hd. Blanche	130	1220
1939-42	Producing Oilfields Ltd. and Western Petroleum N.L.	Portland North	North Portland	17	2835
1941		Springs Bore	Sect.150,Hd. Blanche	130	1160
1941-45	B.M.R. & V.D.M.	Nelson Bore (or Glenelg No.1	Nelson	10	7305
1949	Geelong Flow Oil Co.		3 mls. N. of Torquay	100	1595
1952	S.A.D.M.	Comaum Coal Bore	near Comaum	359	1122
1957-58	V.D.M.	Portland No.2	Portland	110	4719
1958-59	V.D.M.	Portland No.3	West Portland	16	5638
1959	V.D.M.	Belfast No.4	Port Fairy	20	5521
1959	V.D.M.	Timboon No.5	$\frac{1}{2}$ ml. S. of Timboon	315	3500
1959	Frome-Broken Hill	Pt.Campbell No.1	$3\frac{1}{2}$ mls.NW of Pt.Campbell	337	5965
1960	" " "	" " No.2	$1\frac{1}{2}$ mls.NW ofPt.Campbell	266	8846
1961	" " "	" " No.3	6 mls.NW of Pt.Campbell	195	5530
1961	O.D.N.L.	Penola No.1	Sect.100, Hd. Penola	204	4985
1961	Frome-Broken Hill	Flaxmans No.1	20 mls.SE of Warrnambool	206	11528
1962	South East Oil Synd.	Beachport No.1	Sect.20, Hd. Lake George	13	3963
1962	O.D.N.L.	Mount Salt No.1	12 mls.SW of Mt. Gambier	70	10044
1962	Frome-Broken Hill	Pretty Hill No.1	13 mls.NNW of Pt. Fairy	189	8124
1962	O.D.N.L.	Anglesea No.1	Anglesea	65	10065
1963	Frome-Broken Hill	Eumeralla No.1	8 mls. E. of Tyrendarra	154	10308
1963	Beach Petroleum	Geltwood Beach No.1	$7\frac{1}{2}$ mls SW of Millicent	15	12300
1963	V.D.M.	Latrobe No.1 Bore	Princetown	102(RT)	2054
1963	Frome-Broken Hill	Sherbrook No.1	5 mls. NW of Princetown	467	5434
1963-64	Frome-Broken Hill	Fergusons Hill No.1	5 mls. N of Princetown	651	11622
1964	Planet	Heathfield No.1	10 mls. WSW of Casterton	230	7500
1964	Frome-Broken Hill	Port Campbell No.4	6 mls. NNW of Pt.Campbell	427	8520
1964	Planet	Tullich No.1	17 mls. WNW of Casterton	258	5363
1965	Planet	Casterton No.1	4 mls. SW of Casterton	461	8183
1965	A.O.D.	Kalangadoo No.1	$\frac{3}{4}$ ml. SW of Kalangadoo	228	9040

** Depths measured from Datum Level (see Chart 1)

Table 1B: Other surveys associated with oil search in the Otway Basin from 1955 to 1965.

YEAR	SURVEY	OPERATOR
1955	Gambier-Otway. Aeromagnetic Survey, South Australia	S.A.D.M.
1956	Western Victoria, Gravity. Heywood, western Victoria, Experimental Seismic	B.M.R.
1957	Dartmoor-Heywood, Gravity	Frome-Broken Hill
	Mt. Salt-Mt. Schank, Summer Hill, Tantanoola, Gravity	Frome-Broken Hill
1957-58	Port Phillip Bay, Gravity	B.M.R.
1958	Adelaide-Cape Nelson, Aeromagnetic (long line)	B.M.R.
1959	Princetown-Warrnambool, Seismic	Frome-Broken Hill
	Portland and Port Campbell-Timboon, Seismic	Frome-Broken Hill
1960	Port Campbell-Peterborough, Seismic	Frome-Broken Hill
1960-61	Bass Strait-Encounter Bay, Aeromagnetic	Haematite
	Portland-Otway Area, Seismic	Frome-Broken Hill
1961	Gambier Sunklands, Seismic	General Exploration
	Warrnambool-Port Campbell Marine Seismic	Frome-Broken Hill
	Princetown-Warrnambool, Seismic	Frome-Broken Hill
1961-62	Area 3, southwest Victoria, Seismic	Frome-Broken Hill
	Dartmoor-Nelson, Seismic	Frome-Broken Hill
	Mayurra, or O.E.L. 22 Millicent-Beachport, Seismic	Beach Petroleum
1962	Mount Salt Structure Drilling	O.D.N.L.
	Geelong-Adelaide, Aeromagnetic (long line)	B.M.R.
	Geelong-Adelaide - Leigh Creek A/M " "	B.M.R.
	Casterton, Seismic	Planet
1962-63	Southwest Victoria, Regional Gravity	Frome-Broken Hill
	Murray Basin, Aeromagnetic	Planet
1963	Gippsland, Bass Strait-Anglesea and S.A. Marine Seismic	Haematite
	Geltwood Beach No. 1 Well Structure Drilling	Beach Petroleum
	Princetown, Seismic	Frome-Broken Hill
	Permit 22 Southwest Victoria, Marine Seismic	Frome-Broken Hill
	Branxholme-Koroit, Seismic	Frome-Broken Hill
	Murrayville-Casterton Seismic	Planet
1963-64	Cooriemungle, Seismic	Frome-Broken Hill
1964	Curdie Vale, Seismic	Frome-Broken Hill
	Timboon, Seismic	Frome-Broken Hill
	Penola, Seismic	A.O.D.
	Otway Basin, Experimental Vibroseis	B.M.R.
	Kalangadoo, Gravity	A.O.D.
	Branxholme-Koroit, Seismic (second)	Frome-Broken Hill
	Koroit, Seismic	Frome-Broken Hill
	Casterton, Supplementary Seismic	Planet
	O.E.L. 22, Seismic (refraction & reflection)	S.A.D.M.
1964-65	Merino, Seismic	A.O.D.
	Cape Grim to Cape Jaffa, Marine Seismic	Haematite
1965	Kalangadoo-Lucindale, Seismic	A.O.D.

NOTE: Full details of geophysical surveys to the end of 1965 can be found on Plates 9A, B and C.

rocks crop out along the Ridge, and drilling has shown that Precambrian or early Palaeozoic, partly metamorphosed, basement rocks also occupy the area at shallow depth. At its southern end, the Padthaway Ridge adjoins a south-easterly basement belt (along the Kanawinka lineament), and a narrow westerly arm continues off-shore to join an apparently shallow submarine basement shelf area. Tertiary sediments extend from the Otway Basin across the south-eastern part of the Ridge into the Murray Basin; the Padthaway Ridge, and its subsurface extension towards the Palaeozoic rocks north of Casterton, form the south-western margin of the Murray Basin.

The shallow off-shore shelf west of Kingston has a southern margin showing a steep magnetic gradient, and is apparently an extension to the west of the faulting through Cape Jaffa. This could also be regarded as the off-shore continuation of the northern margin of the Otway Basin. However, an off-shore graben-like embayment occurs across the shelf area, parallel to and west of the Padthaway Ridge; this is apparent in aeromagnetic results, and marine seismic also shows thickening of section in the embayment. The thickening may be due to extension of Cretaceous and Tertiary sediments over the shelf, and the Basin margin has been drawn to cover this possibility. It should also be pointed out that mapped seismic horizons to the south of the shelf area could not be traced, as such, into the embayment, and that the reflections shown to the north could well be Permian sediments - known to occur in valleys at the northern end of the Padthaway Ridge and other graben-like structures in this general region. Older Palaeozoic sediments, e.g. uppermost Kanmantoo Group, may be present, but these are more likely to have been distorted during Palaeozoic orogenies and probably would not give the regular and flat reflections shown in the seismic records.

Off-shore limits around the southern margin of the Basin cannot be defined on present evidence, but available marine seismic surveys show continuous section (mainly Cretaceous) extending well south of the 100 fathom limit of the continental shelf. One of the authors, Pitt, has pointed out that the continental slope concept is not readily applicable in this region. Although dips comparable with those of a continental slope exist to the south of the 100 fathom line, indications are also present of some flattening of the sea floor at a level well above the main oceanic deeps. (The structure map, Plate 11 of this report, shows the 100 and 500 fathom lines determined during the marine seismic survey, (H.E.P.L. 1965), and places at which there are slopes of more than 5°; the 1000 fathom contour line is taken from the Tectonic Map of Australia. The bathymetric contours on the Tectonic Map of Australia show that much greater depths are reached, and that some much steeper gradients exist further south of the 1000 fathom contour line. The morphology of the slope development in the area of the marine seismic survey actually suggests pinch-out of off-shore sedimentation rather than any structural control. A "marginal plateau" province, as defined by Heezen, Tharp and Ewing (1959) might be a better classification for the region.

The Otway Basin region has been incorporated in the Murray Basin in many references, some as recently as 1961. However, Sprigg (1952) recognized that the 'Gambier-Portland coastal plain area forms a distinct geological province essentially unrelated to the Murray Basin in pre-Tertiary times'. The name "Otway Basin" was apparently first applied to the western Victorian coastal area during the B.M.R. survey of 1949-50 (Wiebenga, 1957*, 1960*). Fairbridge (1950) also used the name, but for "southern Victoria", and applied it to the region of David's (1932) "Bassian Cross Warp". The "Otway Basin" was next used by B.M.R. (1960) to include south-eastern South Australia, and the coastal area of western Victoria, but treated Port Phillip Bay as a separate area. Sprigg in papers from 1961 to 1963 used the name in a similar sense, and also called it the "Gambier-Otway Basin", including the "Gambier Sub-basin" as a division. In his paper (1962c) he described the "Otway Basin" as part of the "Otway-Gippsland Trough" and as having formed in the Jurassic. Mc Queen (1961) referred to the "Otway Basin" in the same sense as B.M.R., but Stach (1962) separated the "Gambier Basin" from the "Otway Basin" (in which he included the "Portland and Port Phillip Basins").

The extension of the Selwyn Fault lineament off-shore towards King Island was recognized during an aeromagnetic survey in 1960-61 (see H.E.P.L., 1962*, 1965), and the next definition by the B.M.R., (Reynolds, and others, 1963*) extended the Otway Basin to this lineament as the eastern margin, thus incorporating the "Gambier Sub-basin", the western Victorian coastal area, and Port Phillip Bay. Leslie's (1965) outline of the Basin is similar to that of B.M.R., and apart from some minor alterations the same outline is used in this report.

II. GEOLOGY (by P.J. Hawkins and J. Dellenbach)

1. General Remarks

Petrographic studies of the rocks in the Otway Basin allowed the recognition of a number of lithological units, most of which are summarized hereunder in Table 2; stratigraphic terminology is considered in more detail later, and only the names which can be readily applied to these units of the Basins Study Group are shown. As the petrographic studies progressed, and subsequent to some of the reports on the studies, ideas on the scope and range of some of the units have changed, and some variations will be noted in the descriptions which follow to those given in the earlier reports. The lithological subdivision of the Otway Basin succession conforms closely with the palynological framework of Evans (1966*, and this report), and the subdivision of Leslie (1966).

The oldest unit, W, is used for all igneous or strongly metamorphosed basement rocks encountered during drilling. Low grade metamorphosed sediments (mudstone and some sandstone with sericite in Kalangadoo No. 1) are designated Unit V, and are thought to be pre-Mesozoic (possibly lower Palaeozoic) in age. The Mesozoic and Cainozoic sediments which form Units T to A constitute the main Otway Basin succession, and only these are shown in Table 2. The full succession of units and their occurrences in Wells and Bores are shown in Chart 1.

2. Stratigraphy

A. Pre-Mesozoic

Basement rocks have been recognised in only four of the wells which formed part of this study. Because not all the basement rocks examined in thin section showed the same degree of metamorphism, a subdivision has been made as follows:

Unit W - Ingeous rock and moderate to strong metamorphism

Unit V - Low grade metamorphism

Surface occurrences of basement.

To the north of the Otway Basin are a variety of rocks ranging in age from Precambrian through the Palaeozoic which could be expected as basement below the Basin. In South Australia, the metamorphosed sediments of the Lower Cambrian - marble, dark phosphatic phyllite, and the Kanmantoo Group (a thick monotonous alternation of greywacke, phyllite, and impure quartzite) could be expected to extend subsurface from the eastern side of the Mount Lofty Ranges to the Padthaway Ridge. Further east, in Victoria, the Cambrian lithologies change to black shale with chert associated with diabase extrusions; these are mainly along the Mt. [redacted] and Heathcote thrust-belts (Thomas, 1959), but isolated outcrops are known from west of the Grampians, and west of Geelong along the Bellarine faulted zone. However, the greatest area of basement outcrop north of the Otway Basin in western Victoria is occupied by thick Ordovician rocks - mudstone, greywacke, and sandstone, locally metamorphosed to schist and gneiss. Silurian rocks apparently could be expected only east of the Heathcote belt, (see Geological Map, Plate 2).

The Cambrian and Ordovician rocks were locally altered as a result of an early Palaeozoic orogeny during which acid plutonic rocks were emplaced. These rocks also crop out north of the Basin and could occur in the subsurface.

In the Grampians region, a thick succession of Upper Devonian - Lower Carboniferous rocks form prominent outcrops. At the base is an indeterminate thickness of porphyritic and well-banded rhyolite, rhyodacite,

Table 2: Summary of lithostratigraphic units of the Otway Basin.

FORMATION	BMR UNIT	LITHOLOGY
	Ab	Coarse-grained sandy calcarenite, biocalcarenite and sand limestone.
		unconformity
	Bb	Limestone (polyzoal, partly dolomitic), marly limestone, spicular marl, with chert in parts.
	Bc_1	Glauconitic marly limestone (sandy in part).
		unconformity
	Bc_2	Brown glauconitic and limonitic marl; limonitic sandstone and conglomerate.
		unconformity
Dilwyn Formation	Db	Fine-grained carbonaceous sandstone with with subordinate siltstone; coarse argillaceous sandstone to clean fine-grained quartz sandstone, siltstone and shale.
Pebble Point Formation	Dd	Pebbly sandstone, pelletal and oolitic chamositic sandstone, siderite.
		unconformity
Curdies Formation	Gb	Argillaceous coarse-grained sandstone with coal fragments and stringers.
Paaratte Formation	Gd	Mainly sandstone and siltstone, chloritic in part; chlorite pellets; carbonate (siderite, dolomite, and calcite) cement in lower part, kaolinite matrix in upper part.
Belfast Mudstone	Gf	Gf - massive glauconitic mudstone.
Mount Salt Formation	Gg	Gg - interbedded and interlaminated sandstone and shaly siltstone, (an interfingering of Gf and Gh lithologies).
Flaxmans Formation	Gh	Gh - sandstone and sandy mudstone; chamositic to sideritic oolites, minor phosphate; some volcanic detritus.
		unconformity
Waarre Formation	J-H	Upper orthoquartzite, lower chloritic protoquartzite, with carbonaceous mudstone and coaly horizons; calcite cement in lower part; significant absence of volcanic detritus.
		unconformity
Eumeralla Formation	M	Chloritic mustone and shale with coaly lenses; subordinate greywacke to subgreywacke and volcanic sandstone; diagenetic calcite, siderite and zeolite, and clay cement.
Geltwood Beach Formation	P-R	P - lithic sandstone interfingering with fine sediments of Unit M affinities; volcanic and metamorphic detritus;
"Pretty Hill sandstone"		R - a facies variation of P, lithic sandstone with kaolinite and siderite cement; both sandstones rich in garnets.
		unconformity
Unnamed	T	Conglomeratic lithic sandstone (phyllite fragments mainly) with thin interbeds of mudstone, sideritic in lower part, and shale.
		unconformity

OTWAY BASIN

LITHO-STRATIGRAPHIC UNITS & THEIR THICKNESSES

(From available drilling data)

AREA		MOUNT GAMBIER									
MAP SHEET & Nº		SJ 54-6 PENOLA						SJ 54-7 HAMILTON			SJ 54-11 PORTLAND
WELL CODE		1	4	8	17	7	3	3	4	6	2
WELL NAME		Robe No. 1	Beachport No. 1	Geltwood Beach No. 1	Mount Salt No. 1	Kalangadoo No. 1	Penola No. 1	Tullich No. 1	Heathfield No. 1	Casterton No. 1	Nelson Bore (Glenelg No. 1)
UNIT \ DATUM LEVEL		128'(G.L.)	18'(R.T.)	30'(R.T.K.B.)	86'(R.T.K.B.)	230'(R.T.K.B.)	209'(R.T.)	272'(R.T.K.B.)	244'(R.T.K.B.)	472'(R.T.K.B.)	10'(G.L.)
CAINOZOIC	Recent		5'-300' 295'	15'-60' 45'				14'-24' 10'	14'-70' 56'		
	Ab	0'-148' 148'				11'-30' 19'	5'-35' 30'	24'-70' 46'	70'-152' 82'	11'-60' 49'	
	Bb	148'-510' 362'	300'-775' 475'	60'-890' 830'	16'-480' 464'		35'-250' 215'				0'-812' 812'
	Bc: Bc_1		775'-900' 125'	890'-910' 20'	480'-510' 30'		250'-410' 160'				
	Bc: Bc_2			910'-960' 50'	510'-590' 80'			70'-140' 70'	152'-276' 124'		812'-992' 180'
	Db: Db_1	510'-1,400' 890'	900'-1,920' 1,020'	960'-1,480' 520'	590'-3,130' 2,540'	30'-1320' 1,290'	410'-1,040' 630'	140'-160' 20'	276'-675' 399'		992'-2,681' 1,689'
	Db: Db_2			1,480'-1,810' 330'		1,320'-1,760 440'		160'-250' 90'	675'-798 123'		2,681'-3,690' 1,009'
	Dd			1,810'-1,910' 100'	3,130-3,270 140'	1,760'-1,980' 220'		250'-418' 168'	798'-1,217' 419'		3,690'-3,746' 56'
MESOZOIC	Gb			1,910'-2,960' 1,050'	3,270'-4,230' 960'	1,980'-2,320' 340'			1,217'-1,600' 383'		3,746'-4,500' 754'
	Gd: Gd_1			2,960'-3,490' 530'	4,230'-5,230 1,000'	2,320'-2,494' 174'			1,600'-1,680' 80'		4,500'-5,708' 1,208'
	Gd: Gd_2				5,230'-6,520' 1,290'						5,708'-7,305' 1,597' +
	Gg: Gf			3,490'-3,670 180'	6,520'-10,044' 3,524' +	2,494'-2,560 66'					
	Gg: Gh										
	J=?H										
	M	1,400'-4,490' 3,090'	1,920'-3,963' 2,043' +	3,670'-8,955' 5,285'		2,560'-5,600' 3,040'	1,040'-4,400' 3,360'	418'-4,770' 4,352'	1,680'-7,408' 5,728'	60'-4,850' 4,790'	
	P	4,490'-4,504' 14' +	–	8,955'-12,300' 3,345' +		5,600'-6,755' 1,155'	4,400'-4,985' 585' +	4,770'-5,363' 593' +	7,408'-7,500' 92' +	4,850'-6,765' 1,915'	
	R										
	T									6,765'-8,022' 1,257'	
Pz & Pre-M	V					6,755'-9,040' 2,285' +					
	W									8,022'-8,183' 161' +	
Intrusion or Extrusion										7,800'-7,900' Jur. 100'	
Total Depth	Driller	4,504'	3,963'	12,300'	10,044'	9,040'	4,985'	5,363'	7,500'	8,183'	7,305'
	E-log		3,962'	12,300'	10,036'	9,049'	4,159' Bottom not reached	5,353' Bottom not reached	7,500'	8,185'	

AREA		TYRENDARRA				
MAP SHEET & Nº		SJ 54-11 PORTLAND				
WELL CODE		3	6	7	8	9
WELL NAME		Heywood No. 10	Portland No. 2 ⊕	Portland No. 3 ⊕	Eumeralla No. 1	Pretty Hill No. 1
UNIT \ DATUM LEVEL		100'(G.L.)	110'(G.L.)	16'(G.L.)	167'(R.T.)	202'(R.T.)
CAINOZOIC	Recent	0-12' 12'	0-2' 2'	0-28' 28'		13'-50' 37'
	Ab		51'-115' 64'	28'-42' 14'		
	Bb	12'-1288' 1276'	115'-2841' 2727'	42'-2770' 2728'	13'-1110' 1097'	50'-1160' 1110'
	Bc: Bc_1	1,288'-1,335' 47'	2,841'-2,964' 123'	2,770'-2,823' 53'	1,110'-1,200' 90'	1,160'-1,220' 60'
	Bc: Bc_2	1,335'-1,373' 38'	2,964'-2,974' 10'	2,823'-2,862' 39'	1,200'-1,270' 70'	1,220'-1,300' 80'
	Db: Db_1	1,373'-4,258' 2,885'	2,974'-4,719' 1,745' +	2,862'-5,050' 2,188'	1,270'-2,400' 1,130'	1,300-1,600 300'
	Db: Db_2				2,400'-2,530' 130'	1,600'-2,030' 430'
	Dd	4,258'-4,352' 94'		5,050'-5,250' 200'	2,530'-2,660' 130'	2,030'-2,160' 130'
MESOZOIC	Gb	4,352'-4,700' 348'		5,250'-5,574' 324' +	2,660'-2,760' 100'	2,160'-2,370' 210'
	Gd: Gd_1	4,700'-5,283' 583'			2,760'-2,960' 200'	2,370'-2,625' 255'
	Gd: Gd_2					
	Gg: Gf	5,283'-5,390' 107' +			2,960'-3,108' 148'	2,625'-2,830' 205'
	Gg: Gh					2,830'-2,929' 99'
	J=?H					
	M				3,108'-9,110' 6,002'	2,929'-5,964' 3,035'
	P				9,110'-10,308' 1,198' +	
	R					5,964'-7,874' 1,910'
	T					
Pz & Pre-M	V					
	W					7,874'-8,124' 250' +
Intrusion or Extrusion			2'-51' Plioc. 49'	5,574'-5,638' Mioc. 64'		
Total Depth	Driller	5,390'	4,719'	5,638'	10,308'	8,124'
	E-log			5,605' Bottom not reached	10,308'	8,129'

AREA		PORT CAMPBELL								TORQUAY
MAP SHEET & Nº		SJ 54-12 COLAC								SJ 55-9 QUEENSCLIFF
WELL CODE		5	8	9	11	10	15	16	17	14
WELL NAME		Flaxmans No. 1	Port Campbell No. 1	Port Campbell No. 2	Port Campbell No. 3	Port Campbell No. 4	Sherbrook No. 1	Fergusons Hill No. 1	Latrobe No. 1	Anglesea No. 1
UNIT \ DATUM LEVEL		221'(R.T.)	346'(R.T.)	282'(R.T.)	210'(R.T.)	440'(R.T.)	480'(R.T.)	651'(R.T.)	102'(R.T.)	78'(R.T.K.B.)
CAINOZOIC	Recent								0-160' 160'	
	Ab									
	Bb	15'-1920' 1905'	9'-1050' 1041'	16'-782' 766'	15'-1248' 1233'	13'-964' 951'	13'-210' 197'			
	Bc: Bc_1	1,920'-2,213' 293'	1,050'-1,150' 100'	782'-1,230' 448'	1,248'-1,280' 32'	964'-1,012 48'	210'-250' 40'		160'-200' 40'	
	Bc: Bc_2		1,150'-1,510' 360'		1,280'-1,534' 254'	1,012'-1,300 288'	250'-560' 310'			
	Db: Db_1	2,213'-3,320' 1,107'	1,510'-3,300' 1,790'	1,230'-3,650' 2,420'	1,534'-2,740' 1,206'	1,300'-2,390' 1,090'	560'-1,710' 1,150'	13'-670' 657'	200'-1,140' 940'	13'-370' 357'
	Db: Db_2									
	Dd	3,320'-3,480' 160'	3,300'-3,380' 80'	3,650'-3,750' 100'	2,740'-2,910' 170'	2,390'-2,550 160'	1,710'-1,930' 220'	670'-849' 179'	1,140'-1,430' 290'	
MESOZOIC	Gb	3,480'-4,240' 760'	3,380'-4,250' 870'	3,750'-5,000' 1,250'	2,910'-3,710' 800'	2,550'-4,020' 1,470'	1,930'-3,230' 1,300'	849'-1,495' 646'	1,430'-1,525' 95'	370'-1,816' 1,446'
	Gd: Gd_1	4,240'-5,570' 1,330'	4,250'-4,930' 680'	5,000'-5,810' 810'	3,710'-4,230' 520'	4,020'-4,390' 370'	3,230'-3590' 360'	1,495'-1,955' 460'	1,525'-1,625' 100'	
	Gd: Gd_2									
	Gg: Gf	5,570'-6,600' 1,030'	4,930'-5,570' 640'	5,810'-7,900' 2,090'	4,230'-4,608' 378'	4,390'-4,850' 460'	3,590'-3,620' 30'	1,955'-2,046' 91'	1,625'-1,750' 125'	
	Gg: Gh	6,600'-6,880' 280'	5,570'-5,650' 80'	7,900'-8,110' 210'		4,850'-4,970 120'	3,620'-3,780' 160'			
	J=?H	6,880'-7,430' 550'	5,650'-5,965' 315' +	8,110'-8,514' 404'	4,608'-4,810' 202'	4,970'-5,340 370'	3,780'-4,050' 270'	2,046'-2,514' 468'	1,750'-1,970' 220'	1,816'-1,921' 105'
	M	7,430'-11,528' 4,098' +		8,514'-8,846' 332' +	4,810'-5,530' 720' +	5,340'-8,520' 3,180' +	4,050'-5,434' 1,384' +	2,514'-11,490' 8,976	1,970-2,054' 84' +	1,921'-10,065' 8,144' +
	P									
	R									
	T							11,490'-11,513' 23'		
Pz & Pre-M	V									
	W							11,513'-11,622' 109' +		
Intrusion or Extrusion										
Total Depth	Driller	11,528'	5,965'	8,846'	5,530'	8,520'	5,434'	11,622'	2,054'	10,065'
	E-log	11,518' Bottom not reached	5,934' Bottom not reached	8,836' Bottom not reached	5,530'	8,500' Bottom not reached	5,414' Bottom not reached	11,633'		10,041' Bottom not reached

NOTE: All depths in feet from datum level + Units not completely penetrated in wells ⊕ Datum level figures taken from Report by Glenie and Reed (1961)

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agglomerate and tuff (Spencer-Jones, 1965). These are overlain by sediments of the Grampians Group, up to about 20,000 feet of predominantly quartzose sandstone with siltstone and some mudstone; the sediments are mainly of freshwater origin although minor marine transgressions occur in the middle of the sequence. Further acid plutonic intrusions occurred in this region and elsewhere in western Victoria during the Kanimblan Orogeny (Lower Carboniferous).

The only other occurrences of Upper Devonian rocks are the volcanics at Mount Macedon and north-east of Melbourne, and the 1000 feet of conglomerate and sandstone at Gisborne (near Mount Macedon) which have been invaded by granodiorite (David, 1950).

No evidence has been produced as yet that the Upper Devonian - Lower Carboniferous sediments extend subsurface below the Otway Basin. Bain (1957)* also noted that although some granite and older basement rocks occurred among the ejectamenta found in volcanic vents near Portland, no fragments of the Grampians Group occurred.

Permian outcrops - mainly deposits of glacial origin with some marine incursions** - occur as outliers in the Bacchus Marsh area north-west of Melbourne (together with some thin plant-bearing sandy sediments thought to be Triassic in age), and in the area north of Coleraine in western Victoria. Permian rocks are known to occur in the subsurface, and are recorded below the Tertiary in Yalimba Bore near Penshurst (Spencer-Jones, op.cit.). Further evidence of the influence of Permian and Triassic sources is the widespread occurrence of spores of those ages at various Tertiary and Cretaceous horizons both in outcrop and in wells, (Cookson, 1956b; Evans in F.-B. H., 1961a*; Dettman in A.O.D.A., 1966*).

Subsurface occurrences of basement

Of the wells examined in the present study, only four have reached basement rocks: Casterton No. 1, Kalangadoo No. 1, Pretty Hill No. 1, Fergusons Hill No. 1.

Unit W

(a) Occurrence of Unit W rocks from well data.

Both metamorphic and altered igneous rocks form Unit W and these have been recognised in three widely separated wells.

Table 3A : Subsurface occurrences of Unit W

Well Name	Datum (feet A.S.L.)	Depths below datum level (feet)	Depth from sea datum level (feet)	Thickness (feet)	Area
Casterton No. 1	472	8022 to 8183 (T.D.)	-7550 to -7711	161	Mount Gambier
Pretty Hill No. 1	202	7874 to 8124 (T.D.)	-7672 to -7922	250	Tyrendarra
Fergusons Hill No. 1	651	11513 to 11622(T.D.)	-10862 to -10971	109	Port Campbell

** G.A. Thomas reported the discovery of marine Permian from near Bacchus Marsh at the A.N.Z.A.A.S. Meetings in Hobart, 1965.

(b) Lithology

Unit W consists of argillaceous and arenaceous sediments that have suffered moderate regional metamorphism; in addition to these sediments a highly altered igneous rock was encountered which was also thought to be moderately metamorphosed and to form part of Unit W.

In Casterton No. 1 basement is a brittle, grey biotite-sericite schist with patches of calcite and minor pyrite. This schist is probably a metamorphosed silty sediment. In Fergusons Hill No. 1 a schist containing well developed sericite bands and strongly interlocked quartz grains and calcite was observed. The grain size suggests that this schist is an altered sandy sediment.

In Pretty Hill No. 1, a dark green, dense, holocrystalline very fine-grained igneous rock which is much fractured and altered is thought to be basement; veining by calcite and chlorite is pronounced towards the base.

The rock has chlorite pseudomorphs after euhedral ?pyroxene, set in a fine-grained basaltic groundmass of augite and sodic plagioclase, the plagioclase showing an ophitic relationship with the augite; very small subspherical grains of iron ore make up 5% of the rock on average. It can best be described as a much altered lamprophyre; its mode of emplacement and relationship to the overlying rocks could not be determined.

(c) Structure

Fracturing is common in the metamorphic rocks and has also been recorded in the igneous rock in Pretty Hill No. 1. In Casterton No. 1 dips of 55-60° have been recorded from bedding planes; fracture planes occur at 45° to these bedding planes.

(d) Age

The metamorphic rocks and the highly altered lamprophyre (which proved unsuitable for radioactive dating) have been tentatively regarded as Cambro-Ordovician although there is no direct evidence for this other than a similarity to rocks of that age described from outcrop.

(e) Relationship of Unit W to overlying units.

An unconformable relationship exists between Unit W and the sediments above. The basement rocks had been deformed (and metamorphosed) and eroded before sedimentation began in the Otway Basin, and angular unconformities occur between the basement and subsequent units. In the Casterton well, Unit W is overlain by Unit T; a thin sandy unit (possibly equivalent to Unit T) occurs above Unit W in Fergusons Hill No. 1. Unit T is missing in Pretty Hill No. 1 and Unit R rests directly on the lamprophyre.

<u>Unit V</u>

(a) Occurrence of Unit V from well data.

Unit V has only been recognized in Kalangadoo No. 1. The nature of the sediments indicates that metamorphism in Unit V is of a much lower grade than that which affected Unit W sediments.

Table 3B: Subsurface occurrence of Unit V

Well Name	Datum level (feet A.S.L.)	Depths below datum level (feet)	Depth from sea datum level (feet)	Thickness (feet)	Area
Kalangadoo No. 1	230	6755 to 9040 T.D.	-6525 to -8810	2285	Mount Gambier

(b) Lithology

Unit V comprises light grey to dark brown siltstones and claystones which have suffered low grade metamorphism.

The claystones are hard, dense, illitic and sideritic in places; layers containing shards and fragments of glass bubbles are present in Core No. 14, (7057 feet) and may be present elsewhere. Fissures occur and are mostly infilled with calcite, quartz and clay.

The siltstones are hard, commonly banded, and sandy in places. The detrital constituents are quartz and plagioclase feldspar. Carbonate cement and sericite are developed in many parts. In Core No. 15 dolomitic siltstone occurs which contains laminae rich in illite and sericite; the development of sericite flakes showing preferred orientation together with the presence of sheared laminae at 7377-7378 feet suggest that differential pressures caused the metamorphism.

(c) Structure

Fracturing is common in these sediments and on some fracture planes slickensiding is evident; inclination of the fracture planes ranges from 65° to 80°. The fractures are at right angles to the bedding planes in some places. Bedding dips range from 25° to 40°.

(d) Age

There is no direct evidence for the age of Unit V, but it is considered to be pre-Mesozoic.

(e) Stratigraphic relationships

On the basis of the consistent high dips recorded in Unit V an angular unconformity is considered to exist between these sediments and those of Unit P above.

(f) Hydrocarbon occurrences

No oil staining was observed during the petrographic study of Unit V sediments but gas was recovered from a drillstem test in Kalangadoo No. 1 over the interval 6890-7005 feet. Analyses of the gas (A.M.D.L. and B.M.R.) indicated that it was composed chiefly of carbon dioxide with only minor hydrocarbons (2-3%), see Appendix I.

B. Mesozoic

From petrological studies the Mesozoic sediments are divisible into five units: Units T, R-P, M, J-H, and G. Further subdivision of Unit G is shown later.

Discussion of these units is divided into the three main intervals of deposition:

Unit T (Jurassic)

Units R-P, M, J-H (Lower to Upper Cretaceous)

Unit G (Upper Cretaceous)

Unit T

The sedimentary sequence which occurs above the unconformity at the top of the basement and below Unit P has been called Unit T.

Unit T sediments were found in Casterton No. 1, and possibly in Fergusons Hill No. 1. These sediments have not been given any formal nomenclature.

(a) Distribution of Unit T

Surface Occurrences:

No surface type areas are known for Unit T sediments; however a basal conglomerate has been recorded by Kenley (1954) in the Casterton area and Coulson (1930) described a basal conglomerate in the Barrabool Hills which he regarded as the base of the Otway Group.

Subsurface occurrences:

Casterton No. 1 contained Unit T, and it is also possible that the 23 foot lithic sandstone sequence occurring immediately above basement in Fergusons Hill No.1 represents a thin development of this unit. Only two other subsidized wells reached basement and in these wells Unit T was absent.

Table 4: Subsurface occurrences of Unit T

Well Name	Datum level (feet A.S.L.)	Depths below datum level (feet)	Depth from sea datum level (feet)	Thickness (feet)	Area
Casterton No. 1	472	6765 to 8022	-6293 to -7550	1257	Mount Gambier
Fergusons Hill No. 1	651	11490 to 11513	-10839 to -10862	23	Port Campbell

(b) General lithology of Unit T

The upper part of the unit comprises poorly sorted lithic sandstones with thin interbeds of mudstone, and the lower part of the unit is predominantly sideritic mudstones and shales. The conglomerates which occur in the sequence are composed mainly of metamorphic rock fragments.

Detailed lithology

Basic criteria for the recognition of Unit T in the Casterton area are :

- presence of conglomeratic horizons containing abundant metamorphic rock fragments
- subangular, fine to very coarse detritus, poorly sorted
- relative abundance of quartz compared with rock fragments and feldspar in the subgreywackes.

These criteria apply to Unit T in Casterton No. 1 and the sequence in Fergusons Hill No. 1. Sandstone and mudstone are present in approximately the same proportion in Unit T in Casterton No. 1. The framework of the sandstone in this unit differs from that in Unit P; in Unit T there is more quartz relative to lithic material and feldspar, together with a low cement/matrix content.

Mudstone and shale:

Brown sideritic mudstones predominate in the lower half of the unit. The mudstones contain silt-size and fine sandy particles of quartz, feldspar, phyllite and schist fragments; abundant small micaceous flakes are present which may be diagenetic in origin, and re-worked material from phyllites. Carbonaceous flakes and lenses of reddish brown carbonaceous matter and pyrite occur.

The groundmass of the mudstones may consist of either finely crystalline siderite or an opaque clayey groundmass of ? chloritic composition. In Casterton No. 1 at 7385-86 feet, spots of chalcedony occur in the sideritic patches; what appear to be bivalve fossils (possibly ostracods, 0.2 mm long and 0.1 mm wide) which are infilled with chalcedony are also present. Towards the base of the unit, shales with carbonaceous and coaly laminations occur, interspersed with thin dolerite and basalt bands. Contact alteration is negligible and the vesicular texture of some samples suggest that they formed as flows rather than intrusions.

Sandstones:

Two types exist:-

(i) Sandstone of subgreywacke composition;

(ii) Conglomeratic sandstone and sandy conglomerate.

(i) Subgreywackes

Light grey, compact, subangular, fine to very coarse-grained, poorly sorted although occasionally bimodal, lithic sandstones occur.

The framework is composed of quartz (50-60%), lithics (15-20%), feldspar plagioclase (andesine and labradorite), and potash feldspar including microcline - (7-10%). Some quartz grains show strong interpenetration and overgrowths. The lithics comprise metaquartzite, chalcedony, squeezed phyllite, schist, and minor amounts of fresh volcanic rock fragments. Important accessories are squeezed biotite and chloritized biotite; some garnet and chlorite grains are present. Carbonaceous patches and lenses occur.

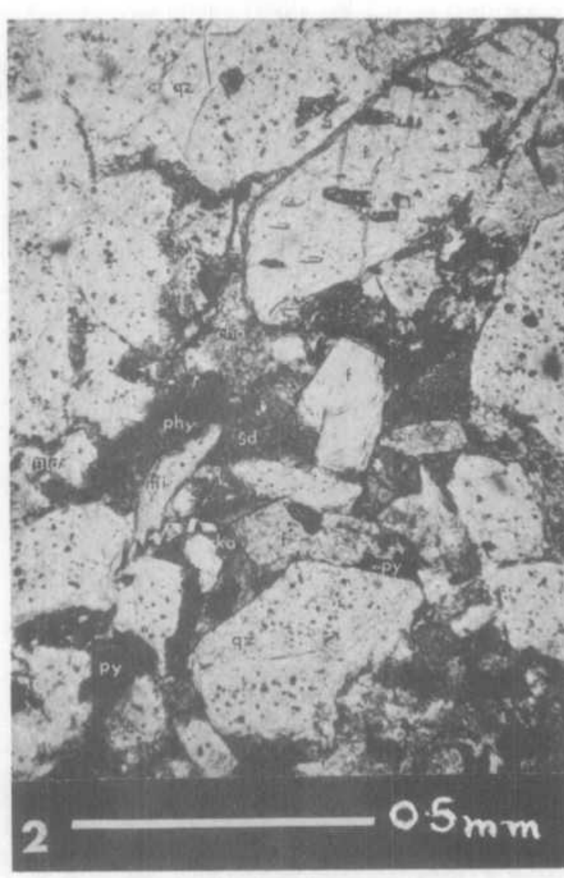
The matrix and cementing media (10-28%) consist of silt-size detritus of quartz, mica, squeezed grains of phyllite, kaolinite and chlorite; minor patches of diagenetic calcite cement (5%) and silica (10%) - as quartz overgrowths - are present.

Unit T.

Photomicrograph 1. Sandy conglomerate.
Casterton No. 1, Core No. 15, 6765'-66'.
Plane polarised light.
Subangular to subrounded, medium to coarse (0.27 - 0.54 mm) detrital grains, and well rounded pebbles (15 mm.); poorly sorted. Quartz (qz) 15%, feldspar (f) 2%, lithics - phyllite (phy), quartzite (qzt), metaquartzite (mtqz), basalt (bas), and chloritic (chl) fragments - 83%. Rare patches of siderite (sd) and chlorite (chl).
Note strong welding of phyllite fragments.

Photomicrograph 2. Sandstone.
Casterton No. 1, Core No. 16, 6857'-58'.
Plane polarised light.
Subangular, fine to coarse-grained (0.15 - 0.60 mm.); poorly sorted. Quartz (qz) 50%, feldspar (f) 10%, lithics - metaquartzite (mtqz), phyllite (phy), chalcedony (cha) - 20%; cement and matrix of squeezed phyllite, kaolinite (ka), silt-size detritus, and silica (sil) (quartz overgrowths), 20%.
Accessories, pyrite (py) and muscovite (mi). Chlorite inclusions occur in the feldspar.


qz
chl
qz
1
0·5 mm


qz
phy
sd
qz
py
2
0·5 mm

In Casterton No. 1 (Core No. 19) a fine-grained sandstone occurs which displays strong interpenetration of the grains - particularly lithics - and abundant sericite which might suggest contact metamorphism. However the sericite laths are not well developed and do not show preferred orientation; the presence of kaolinite in the matrix would preclude the possibility of the sericite having formed by metamorphism, as kaolinite is unstable and is transformed to sericite during metamorphism. The sericite is thought to result from a transformation of probably muscovite and hydromuscovite.

Porosity is poor (9%) and permeability negligible in these sediments, according to core analyses.

(ii) Conglomeratic sandstone and sandy conglomerate.

Three conglomeratic horizons have been recognized in Casterton No. 1; a sandy conglomerate is present at the top of Unit T and two conglomeratic sandstone horizons occur lower in the sequence.

The conglomeratic sandstones are fine to very coarse-grained, poorly sorted, with granules and pebbles (15 mm. in diameter); the sandy conglomerate at 6765 feet contains poorly sorted pebbles (10-30 mm.) and granules, with subordinate rounded, medium to coarse grains of quartz.

The composition of the conglomeratic sandstone is quartz (40%), lithic grains (25%) and feldspar-plagioclase and potash feldspar (15%). The rock fragments are soft phyllite, metaquartzite, chalcedony and rare volcanic rock fragments; penninite-bearing rock fragments also occur. Accessories include abundant chloritized biotite and muscovite. The matrix and cementing media (10-20%) consist of squeezed phyllite fragments, mica, kaolinite and illitic material; minor calcite (in patches) and silica (quartz overgrowths) are present. Porosity is fair (14-15%) and permeability low (1 - 2 md.).

In the sandy conglomerate the high lithic content (88%) is in the form of pebbles and granules of phyllite, metaquartzite and schist; rare basaltic rock fragments containing chlorite and magnetite - similar to the igneous rock in Core No. 20 - also occur. Other constituents include quartz (10%) and feldspar (2%). Strong interpenetration of phyllite fragments together with interstitial patches of calcite have reduced the porosity in this conglomerate.

(c) Structural features.

Sedimentary:

In Casterton No. 1, thin dark grey clay and carbonaceous clay laminations, carbonaceous lenses and wisps occur in sandstones. High angle (20°) cross-bedding is also present.

Tectonic:

Fracturing and slickensiding are present in cores in Casterton No. 1; in Core No. 15 near vertical (80°) open fractures with slickensides on the fracture planes occur. Similar fracturing (with 30° inclinations) accompanied by slickensiding, is apparent in sandstone of Core No. 16.

Bedding dips range from 10-20°. In Core No. 15, where preferred orientation of the pebbles exists, a dip of 25° has been recorded.

(d) Age

Palynological determinations carried out by Evans (1966) on Unit T sediments suggest they are of undifferentiated Jurassic age.

Other evidence to support a Jurassic age has been the radioactive dating of basic igneous rocks - either penecontemporaneous intrusions or lava flows - associated with these sediments. Geochron determined a total rock age by K-Ar dating of 153± 5 m.y. (in Harding, 1966*), which would place its age in the Upper Jurassic; the A.N.U. determination, however, was only 120± 10 m.y., a Lower Cretaceous age. The presence in the upper sandstones of Unit T of basaltic rock fragments of similar composition to the interspersed igneous bodies suggests that some lava flows occurred in the Otway Basin at about the same time as the sandstone was being deposited, or that intraformational erosion of the earlier flows took place. Mary White (in P.E.C., 1965b*) identified plants from this unit which range in age from Jurassic to Lower Cretaceous.

(e) Stratigraphic relationships.

In Casterton No. 1 a marked angular unconformity exists between Unit T and the underlying basement rocks, judging from the changes in dips recorded from cores (10-20° in Unit T, 55-60° in the basement).

A marked lithological change occurs at the boundary between units T and P; the sandy conglomerate containing abundant pebbles of phyllite is overlain by basal shales of Unit P. This marked change in lithology between Units T and P may represent an unconformity; no marked change in dip is indicated from the dipmeter survey.

(f) Environment of deposition

Unit T sediments are interpreted as having been deposited in a paralic (after Krumbein and Sloss, 1963) to alluvial environment, where both quiet water and high energy conditions existed.

The mudstones and shales which are laminated and contain carbonaceous material and plant remains, have been deposited in quiet shallow waters; some marine influence is suggested by the sideritic nature of these sediments and by the presence of possibly connate water of sea water composition. The sandstones, which are confined mainly to the upper part of the unit, indicate rapid deposition on account of their angularity, coarseness and poor sorting. The conglomeratic horizons contain mainly granules and pebbles of phyllite; however, rare pebbles of basalt do occur in the conglomerate at 6765 feet.

The presence of abundant soft phyllite pebbles in parts of Unit T suggests that Casterton No. 1 passed through sediments which had been deposited close to a metamorphic landmass. Indeed, metamorphosed Ordovician rocks do crop out some 10 miles north and north-east of Casterton No. 1.

(g) Hydrocarbon occurrences.

No oil staining was observed in Unit T sediments. A drillstem test in Casterton No. 1 over the interval 6939-6995 feet yielded 900 feet of muddy salt water, with a salinity of about 35,000 p.p.m. (as Na Cl) calculated from the S.P. log.

Units R-P, M and J-H

At an early stage in the petrological studies of selected wells in the Otway Basin, Unit M was used to cover the sections referred to as the "Otway Group" and "Merino Group", and the "Waarre Formation" became Unit J.

Studies of the samples from Pretty Hill No. 1 Well (Edworthy, 1964*) showed that another unit could be distinguished between the lamprophyre basement, Unit W, and Unit M. This is the characteristic "Basal Sandstone" referred to by Bain (in F-B.H., 1962b*) and was designated Unit R. Further petrological studies of well samples in the western part of the Otway Basin showed that Unit R lithology became interbedded with lithologies similar to those of Unit M above. It became apparent that Unit R was, in fact, a facies variant of a unit with mixed lithologies - Unit P - first described from both Eumeralla No. 1 (Edworthy, 1965a*) and Geltwood Beach No. 1 (Dellenbach, 1965a*). We have proposed the name Geltwood Beach Formation for Unit P; a separate name has not been raised for Unit R because of its limited known occurrence. In this text we refer to Unit R-P.

While Unit R-P appears to be restricted to that part of the Otway Basin west of the Koroit Divide, Unit M appears to be continuous throughout the Basin, on-shore and off-shore (based on seismic evidence). Different names have been applied to Unit M in the various areas of outcrop beginning with 'Otway beds' (Seward, 1904) and others which are detailed in a later section on stratigraphic nomenclature; the best known are "Merino Group" and "Otway Group". Because of the continuity of Unit M as a whole, and the possibility that further detailed studies of its petrology may lead to the recognition of individual formations within the unit, the name Otway Group appears to be the most convenient at this stage of our knowledge; the use of the name 'Korumburra Group' (first used for equivalent sediments in the Gippsland Basin - Stirling, 1899, and re-erected by Talent 1965) is not considered to be desirable (see later discussion).

Unit J is predominantly a quartz sandstone equivalent to the Waarre Formation, and is known only from the Port Campbell area. However a thin unnamed sandy bed in Anglesea No. 1 (Unit H of Dellenbach, 1965b*) is thought to be equivalent, and we have referred to Unit J-H in this text. It is a separate unit from Unit M below, and Unit G above.

Unit R-P

Unit P which was defined from both Eumeralla No. 1 (Edworthy, 1965a*) and Geltwood Beach No. 1 (Dellenbach, 1965a*) was partially penetrated in six subsidized wells studied in the western part of the Otway Basin. Since these wells were studied, the unit has been fully penetrated in two other wells in the western part of the Otway Basin, namely Casterton No. 1 and Kalangadoo No. 1. In the eastern part of the Otway Basin the only well- Fergusons Hill No. 1 - to intersect the full sequence of sediments to the Cambro-Ordovician basement, did not encounter Unit P.

(a) Distribution of Unit P

Surface Occurrences:

Unit P sediments have not been recognized in outcrop.

Subsurface Occurrences:

The detailed petrological studies carried out on eleven subsidized wells which penetrated Lower Cretaceous sediments indicate that eight wells reached Unit P sediments; only in Pretty Hill No. 1, Casterton No. 1, and Kalangadoo No. 1 was this sequence fully penetrated.

From the present well information the distribution of Unit P and Unit R (Pretty Hill No. 1) is confined to an area extending westwards from Pretty Hill No. 1.

(b) Lithology

The relationship contemplated between units P and R is one of lithofacies variation; R is represented by a sandstone facies deposited from a single source area whilst Unit P consists of a sandstone facies containing admixtures of volcanic and granitic and/or metamorphic lithics interdigitating with fine-grained sediments with Unit M affinities. Thus the sediments of P appear to have originated from two source areas.

Lithologically it has not been necessary to divide Unit P into sub-units.

General lithology of Unit P

The sequence consists predominantly of chloritic mudstone, with subordinate fine to coarse-grained sandstone mainly subgreywacke in composition; in Casterton No. 1 very coarse-grained to granule size sandstone is present. The characteristic feature of the sandstone is the abundance of pink and brown grains of garnet. The sandstone may contain either a chemical cement or a clay matrix.

Detailed petrological examinations have revealed the presence of Unit P in eight of the subsidized wells studied. Unit P may occur in other wells where sample material is unavailable.

Table 5: Subsurface occurrences of Unit P

Well Name	Datum level (feet A.S.L.)	Depths below datum level (feet)	Depth from sea datum level (feet)	Thickness (feet)	Area
Geltwood Beach No. 1	30	8955 to 12300 T.D.	-8925 to -12270	3345	
Kalangadoo No.1	230	5600 to 6755	-5370 to -6525	1155	MOUNT
Penola No.1	209	4400 to 4985 T.D.	-4191 to -4776	585	
Tullich No.1	272	4770 to 5363 T.D.	-4498 to -5091	593	GAMBIER
Heathfield No.1	244	7408 to 7500 T.D.	-7164 to -7256	92	
Casterton No.1	472	4850 to 6765	-4378 to -6293	1915	
Eumeralla No.1	167	9110 to 10308 T.D.	-8943 to -10141	1198	TYREN-
Pretty Hill No. 1 **	202	5964 to 7874	-5762 to -7672	1910	DARRA

** The sediments originally designated as Unit R have been regarded as a lithofacies variation of Unit P in this report.

Detailed Lithology.

Basic criteria for the recognition of the sandy fractions of Unit P are:

- presence of abundant grains of pink garnet
- admixture of fresh fragments of metamorphic rocks and volcanics
- angular to subrounded, fine to coarse-grained detritus of moderate sorting
- preponderance of subgreywacke (Pettijohn, 1957)
- recurrent high-energy features: ripples, strong cross-bedding (in foresets), moderate sorting.

These criteria apply to all wells studied which have intersected the unit. In Pretty Hill No. 1, a unit designated R presented similar characteristics except that it contained no lithics of volcanic origin and was not interbedded with mudstone.

In Unit P mudstone predominates over sandstone. These mudstones are very similar to mudstones of Unit M under microscopic examination.

The indurated chloritic mudstone.

The groundmass of the mudstone is clayey and chloritic. The chlorite is either in the form of crypto-crystalline newly formed chlorite, or chloritized micaceous material. Clay minerals are flaky illite, possible "illitized" kaolinite, montmorillonite and some kaolinite. Coaly matter is finely dispersed but plant fragments are also recurrently abundant. Pyrite and opaques are abundant. Cryptocrystalline silica and zeolite may be present, but their proportion is difficult to assess by microscopic methods.

Sandstones

The sandstones show either a carbonate cement (subgreywacke) or a detrital, clayey, and chloritic matrix. In both cases the framework is similar and consists of moderately sorted, angular, very fine to medium-grained lithic fragments (20-30%), untwinned feldspar, microcline and plagioclase (15-20%) and quartz (10-20%). Some horizons exist which contain up to 45% quartz and other horizons are very rich in lithic grains. However, these are apparently end-members of the normal range of Unit P sandstone which is an admixture of predominantly terrigenous material with volcanic material. The cementing media (15-45%) are either clay, chlorite and opaque material, or very clean calcite and minor chlorite, the latter forming grain-coatings in some cases. Carbonaceous matter is abundant in some horizons. The heavy minerals are very conspicuous pink garnet (up to 10%) and abundant apatite, with some chloritoid, epidote, leucoxene, monazite, tourmaline, sphene, zircon and opaques. Rock fragments of metamorphic origin containing epidote, garnet and apatite are also common.

Diagenetic changes have strongly affected the sandstones. These changes are :

- development of chlorites and zeolites
- transformation and genesis of clay minerals

Units P and R

Photomicrograph 3. Feldspathic Lithic Sandstone.

Geltwood Beach No. 1, cuttings sample 9000'-10'.
Plane polarised light.
Angular, very fine to fine-grained (0.09-0.15 mm); well-sorted.
Quartz (qz) 5%, feldspar (f) lithics (li) 40%, chloritic (chl) and illitic clay matrix 35%.
Accessories :- pyrite (py), sphene (sp), muscovite (mi). Much alteration and welding of the lithics.
Pellicules of illitic clay (ill) occur around grains.

Photomicrograph 4. Lithic Sandstone.

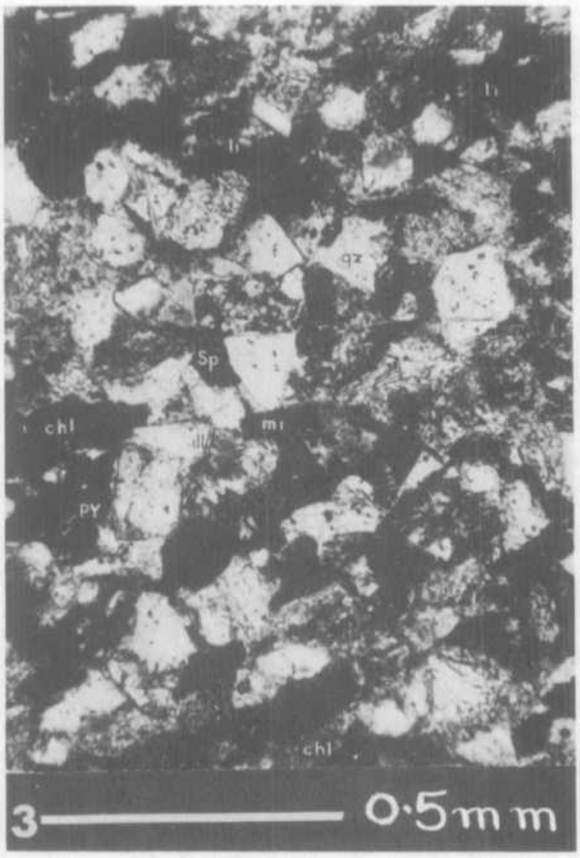
Tullich No. 1, cuttings sample 4910'.
Plane polarised light.
Angular, very fine to fine-grained (0.09-0.21 mm); moderately sorted.
Quartz (qz) 30%, feldspar (f) 20%, lithics-metamorphic (met) 20%, chloritic (chl) and kaolinitic (ka) matrix 30%.
Accessories :- muscovite (mi), pyrite (py), garnet (ga), zircon (zi), and carbonaceous (carb) matter.
Note corrosion of detrital grains by matrix and replacement of muscovite by siderite (sd).

Photomicrograph 5. Volcanic Sandstone.

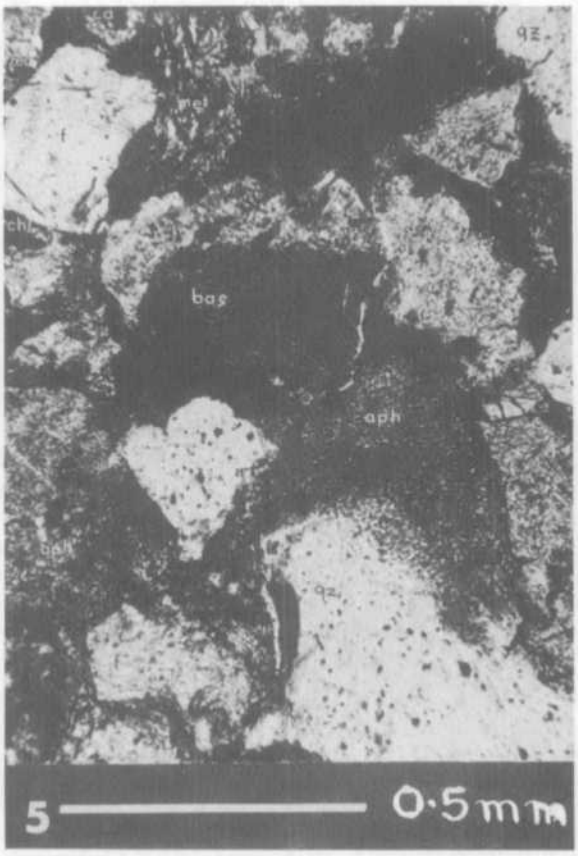
Eumeralla No. 1, cuttings sample 9620'-40'.
Plane polarised light.
Angular to subangular, fine to coarse-grained (0.15-0.54mm), main mode = medium-grained; poorly sorted.
Quartz (qz) 20%, feldspar (f) 15%, lithics - siliceous aphanitic rocks (aph), basalt (bas), metamorphics (met) - 50%, pellicular chlorite (chl), and zeolite (zeo) cement 15%.
Note welding of lithic grains; calcite replaces feldspar in places.

Photomicrograph 6. Quartz Sandstone.

Pretty Hill No. 1, cuttings sample 6500'-60'.
Plane polarised light.
Subangular, fine to medium-grained (0.18-0.48 mm), main mode = medium-grained, moderately sorted.
Quartz (qz) 65%, feldspar (f) 5%, siderite (sd) and kaolinite (ka) cement 20%. Porosity (por) 10%.
Note well developed siderite rhombs, and quartz welding.


3
0·5mm


4
0·5mm


5
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6
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penecontemporaneous deformation in the form of broken mudstone pellets occurs in Eumeralla No. 1. Worm burrows have been recorded in Kalangadoo No. 1.

In Heathfield No. 1 foreset bedding is thought to occur; at 7490 feet a dip of 45° is present in a well-laminated sandstone but at 7487 feet the dip becomes almost nil.

Tectonic:

Some vertical fractures have been recorded in cores from Eumeralla No. 1, and in Core No. 12 from Kalangadoo No. 1. Some slickensiding occurs on bedding planes in fracture zones in Kalangadoo No. 1.

True dips are difficult to assess due to the presence of cross-bedding and possible foreset bedding: however, dips are thought to range from 5 - 15°.

(d) Age

Palynological determinations carried out by Evans (1966) on Unit P indicate that this sequence is of Lower Cretaceous age. Using the terminology proposed by Evans, all the Unit P sediments so far encountered fall within his K1 division; zones K1a and K1b within K1 are represented.

(e) Stratigraphic Relationships

Relationship of Unit P to underlying units:

Only in Casterton No. 1 is Unit P underlain by a pebbly sequence - Unit T. The type of contact between Unit P and Unit T is difficult to assess but may be an unconformity, although dipmeter results do not indicate a marked change in dip. In Kalangadoo No. 1 and Pretty Hill No. 1, Unit P and Unit R respectively rest unconformably on basement rocks. In the other wells the sequence has not been fully intersected.

Relationships within Unit P:

There is no evidence of unconformable relationships within Unit P; lithological and palaeontological evidence supports continuous sedimentation in this unit.

Relationship of Unit P to overlying Unit M:

Unit P appears to be conformable with Unit M above it. Although the change of sediments of Unit M to the sediments of Unit P generally occurs over a short interval, and is well marked by the sudden influx of garnets, in some wells a more gradational relationship exists.

(f) Environment of deposition

Sediments of Unit P and Unit R are indicative of an inner paralic to alluvial environment. This view is supported by the general occurrence of high-energy features which alternate with quiet shallow water features. The occurrence of mudstone with coaly plant fragments and coal lenses together with sub-greywacke containing depositional calcite possibly indicates a transitional environment in which non-marine and marine influences recurred. The lithic constituents suggest that the sediments were derived partly from a regionally metamorphosed source area, and partly from an acid to intermediate igneous source area.

(g) Hydrocarbon occurrences

The only evidence of hydrocarbons in Unit P was obtained in Tullich No. 1, where gassy salt water was produced. The gas contained only 22.2% methane, the balance being oxygen, nitrogen and carbon dioxide.

Unit M

Sediments of this unit were first described in Port Campbell No. 2 (Dellenbach and Hawkins, 1964*). Eight petrographic studies including detailed descriptions of Unit M have been prepared by the Basins Study Group. An appraisal of the petrology of the sediments of Unit M based on thin sections of cores has also been made in seven other wells. Papers by Baker (1962), Baker and McAndrew (1961), Edwards and Baker (1943), and numerous company reports have been consulted.

(a) Distribution of Unit M.

Surface occurrences:

Lower Cretaceous sediments are exposed mainly in the Casterton area and the Otway Ranges. Coulson (1930) has described a section containing Lower Cretaceous sediments in the Barrabool Hills area. Small outcrops also occur along the northern side of the Bellarine Peninsula, and the eastern side of Port Phillip Bay.

Subsurface occurrences:

Unit M occurs in all subsidized wells that penetrated the Lower Cretaceous with the possible exception of Port Campbell No. 1. The literature shows that Lower Cretaceous sediments have been reached in many other wells and bores. Some of the occurrences are listed in Table 7A.

Table 7A : Subsurface occurrences of Unit M

Well Name	Datum - feet above sea level	Depths below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Beachport No. 1	18	1920 to 3962	-1902 to -3945	2043	
Geltwood Beach No. 1	30	3670 to 8955	-3640 to -8925	5285	MOUNT
Kalangadoo No. 1	230	2560 to 5600	-2330 to -5370	3040	
Penola No. 1	209	1040 to 4400	- 831 to -4191	3360	GAMBIER
Tullich No. 1	272	418 to 4770	- 146 to -4198	4352	
Heathfield No. 1	244	1680 to 7408	-1436 to -7164	5728	
Casterton No. 1	472	60 to 4850	+ 412 to -4378	4790	
Eumeralla No. 1	167	3108 to 9110	-2941 to -8943	6002	TYREN-
Pretty Hill No. 1	202	2929 to 5964	-2727 to -5762	3035	DARRA
Flaxmans No. 1	221	7430 to 11528	-7209 to 11307	4098	
Port Campbell No. 2	282	8514 to 8846	-8232 to -8564	332	
Port Campbell No. 3	210	4810 to 5530	-4600 to -8354	720	PORT
Port Campbell No. 4	440	5340 to 8520	-4900 to -8080	3180	
Sherbrook No. 1	480	4050 to 5434	-3570 to -4954	1384	CAMPBELL
Fergusons Hill No. 1	651	2514 to 11490	-1863 to -10839	8976	
Latrobe No. 1	102	1970 to 2054	-1868 to -1952	84	
Anglesea No. 1	78	1921 to 10065	-1843 to -9987	8144	TORQUAY

(b) General lithology of Unit M.

The task of producing a generalized description of rocks forming a sequence up to 9000 feet thick (Fergusons Hill No. 1) is greatly simplified by the striking uniformity of the sediments, and their clastic constituents in particular, over the whole basin. This observation has already been made by several authors including Edwards and Baker (op.cit.), and various oil company geologists.

The lithological sequence consists of chloritic mudstones and shales with subordinate thinly bedded lithic sandstones and coaly horizons. For convenience, the sediments are divided into two groups:

(i) Mudstones and shales - argillaceous sediments with admixtures of silt and sand-size constituents, ranging from mudstones without laminations or fissility, to shales which include fissile claystone and siltstone. The coaly lenses and beds occur in these sediments.

(ii) Sandstone - greywacke to subgreywacke and volcanic sandstone (Williams, Turner, and Gilbert, 1955) are angular, very fine-grained, and well sorted; diagenetic calcite, siderite, and zeolite occur as cementing media together with chloritic, illitic, and kaolinitic clay. Volcanic lithic fragments are important constituents in the sandstones.

(i) The mudstones and shales

Although evidence from cuttings is not fully conclusive, it is apparent from the examination of cores, the descriptions of surface sediments, and the electric log characteristics that most of the argillaceous rocks in Unit M are shales. They contain abundant chloritic material (some of which is diagenetic), mica, coaly matter, and finely divided pyrite. The clays include kaolinite, illite, chlorite and montmorillonite, and beds of bentonite are developed in some parts. Silt and sand size particles are mainly quartz, feldspar, and rock fragments of aphanitic texture - possibly chalcedony. Certain carbonates are present - mainly rhombs and spherulitic carbonate of the siderite-magnesite series.

Chemical analyses of two samples of Otway Basin mudstone, and of two equivalent Gippsland Basin samples are given in Table 7B.

Table 7B : Chemical analyses of some mudstone from the Lower Cretaceous of the Otway Basin (Unit M) and Gippsland Basin

	1.	2.	3.	4.
SiO_2	62.11	60.70	61.36	43.4
Al_2O_3	18.28	18.32	18.18	n.d.**
Fe_2O_3	1.98	1.18	4.26	8.7
FeO	4.18	3.18	-	16.2
MgO	1.97	2.02	1.26	5.8
CaO	0.85	2.00	1.68	3.0
Na_2O	2.10	1.25	1.94	n.d.**
K_2O	3.30	2.64	3.32	n.d.**
H_2O	4.05	7.48	7.33	4.4
CO_2	0.10	-	-	18.5
TiO_2	0.79	0.90	-	-
P_2O_5	0.13	tr	-	-
MnO	nil	-	-	-
SO_3	0.23	nil	-	-
Cl	-	-	-	-
Total	100.07	99.67	99.33	100.0
Na_2O/K_2O	0.6	0.47	0.58	-
Spec.Grav.	2.65	-	-	-
Free Carbon	3.68	analysis on carbon-free basis.		-

1. Mudstone 9123-9135', bottom of Core 36, Flaxmans No. 1 (Baker, 1963).

2. Shale from above coal seam, east adit near shore, Kilcunda, South Gippsland. Ann.Rept.Sec.Mines, 1906, in Baker (1963).

3. Shale from the roof of the Outtrim Colliery, South Gippsland, Ann.Rept.Sec.Mines, 1898, in Baker (1963).

4. Shale or sideritic mudstone from Core No. 12, 3158-3168', Anglesea No. 1 Well, O.D.N.L. (1963b*).
** Possibly included in H_2O figure.

Note: Analyses No. 2 and 3, although not made on rocks from the Otway Basin, provide a useful comparison with similar sediments from the Lower Cretaceous of the Gippsland Basin.

(ii) The sandstones

Visual percentage estimations of sandstone composition were made for thin sections of core and cuttings samples at approximately 65 foot intervals. These showed some vertical and lateral variations in the sediments of Unit M in different parts of the Otway Basin, but, apart from the important distinction between sandstones with cement and those with detrital matrix, there was no marked variation in composition throughout the Basin; Table 7C shows the average composition of Unit M sandstones at the western and eastern ends:

Table 7C: Estimation of the constituents of some Unit M Sandstones.

	Sandstone with matrix western end (Geltwood Beach area).	Sandstone with cement eastern end (Anglesea area).
	%	%
Rock fragments	25 - 40	30 - 40
Feldspar	15 - 25	10 - 20
Quartz	5 - 15	5 - 15
Matrix	15 - 45	minor
Cement	minor	25 - 40
Accessories (incl. carbonaceous mat.)	5 - 10	5 - 10**

** In very clean sands, accessories may be less than 5%.

The significance of distinguishing sandstones with matrix and those with cement is discussed later.

Wherever possible the origin of rock fragments has been deduced from the grainsize and alteration of the fragments. Metamorphic and volcanic (as opposed to plutonic) sources are the most prominent. Because rock fragments are the most common constituents in these sandstones, interpretation of the chemical analyses which have been made requires caution. For convenience, eight analyses made by Baker (1963), and Edwards and Baker (1943) are listed in Table 7D; one analysis of a rock of similar composition from the "Triassic" of Tasmania is added for comparison.

Table 7D:

Chemical analyses of some so-called arkoses from the Otway and Gippsland Basins, and a feldspathic sandstone from the Triassic of Tasmania

	1.	2.	3.	4.	5.	6.	7.	8.	9.
SiO_2	60.40	66.30	66.37	64.18	65.50	62.18	57.57	64.00	64.08
Al_2O_3	14.91	12.14	16.54	15.29	15.49	17.13	17.96	15.88	15.74
Fe_2O_3	3.01	1.65	2.53	1.62	0.36	0.87	) 4.27	1.90	2.00
FeO	2.90	3.43	4.33	4.25	4.24	4.05	)	3.86	2.13
MgO	3.35	1.26	2.11	1.75	1.92	2.60	1.51	1.81	1.00
CaO	2.24	3.14	1.41	3.34	3.50	2.19	1.38	2.02	3.50
Na_2O	4.40	2.30	1.70	3.30	2.60	2.15	2.64	3.42	3.09
K_2O	3.00	2.60	0.80	0.90	1.96	1.57	1.73	1.86	1.41
H_2O	4.24	2.16	2.76	3.81	2.43	4.27	11.94	4.96	3.54
CO_2	0.60	2.34	0.21	1.12	1.65	1.32	0.50	-	1.21
TiO_2	0.79	0.54	0.78	0.59	0.60	-	0.72	tr	0.66
P_2O_5	0.20	0.08	0.17	0.16	0.20	-	-	tr	0.13
MnO	nil	tr	tr	tr	0.06	-	-	tr	0.04
SO_3	nil	1.78	nil	nil	-	-	-	-	
Li_2O	nil	nil	nil	nil	-	-	-	-	
Total	100.04	99.72	99.71	100.31	100.51	98.33	100.22	99.63	99.53
Na_2O/K_2O	1.1	0.9	2.1	3.7	1.33	1.37	1.53	1.8	2.01
Spec.Grav.	2.72	2.72	2.73	2.69	-	-	-	-	-

1–7 "Arkose", Otway Basin in Baker (1963).

8 "Arkose", Gippsland Basin (Edwards and Baker, 1943).

9 "Feldspathic sandstone", Drill Hole 8524, Wayatinah, Spry and Banks (1962).

Vertical variation in lithology of Unit M.

In his petrographic examination of sediments from O.D.N.L.Anglesea No. 1, Dellenbach (1965b*) was able to divide Unit M into two subdivisions: M_1 (upper) and M_2. Subunit M_1 was marked by an increase in the volcanic detritus present, and it has been suggested by Dellenbach that a recrudescence of volcanic activity occurred at M_1 time. The lithologies in other wells were checked for this effect, and it did appear that a subdivision was possible elsewhere in the Otway Basin; Figure 1 shows the tentative subdivision. It will be seen that the M_1 - M_2 boundary in Fergusons Hill No. 1 is an unconformity. This pick is based on dipmeter results, (F.-B.H., 1964f*).

No such angular unconformity could be proved, however, either in Anglesea No. 1 (due to lack of dipmeter results) or in any of the other wells in the Basin.

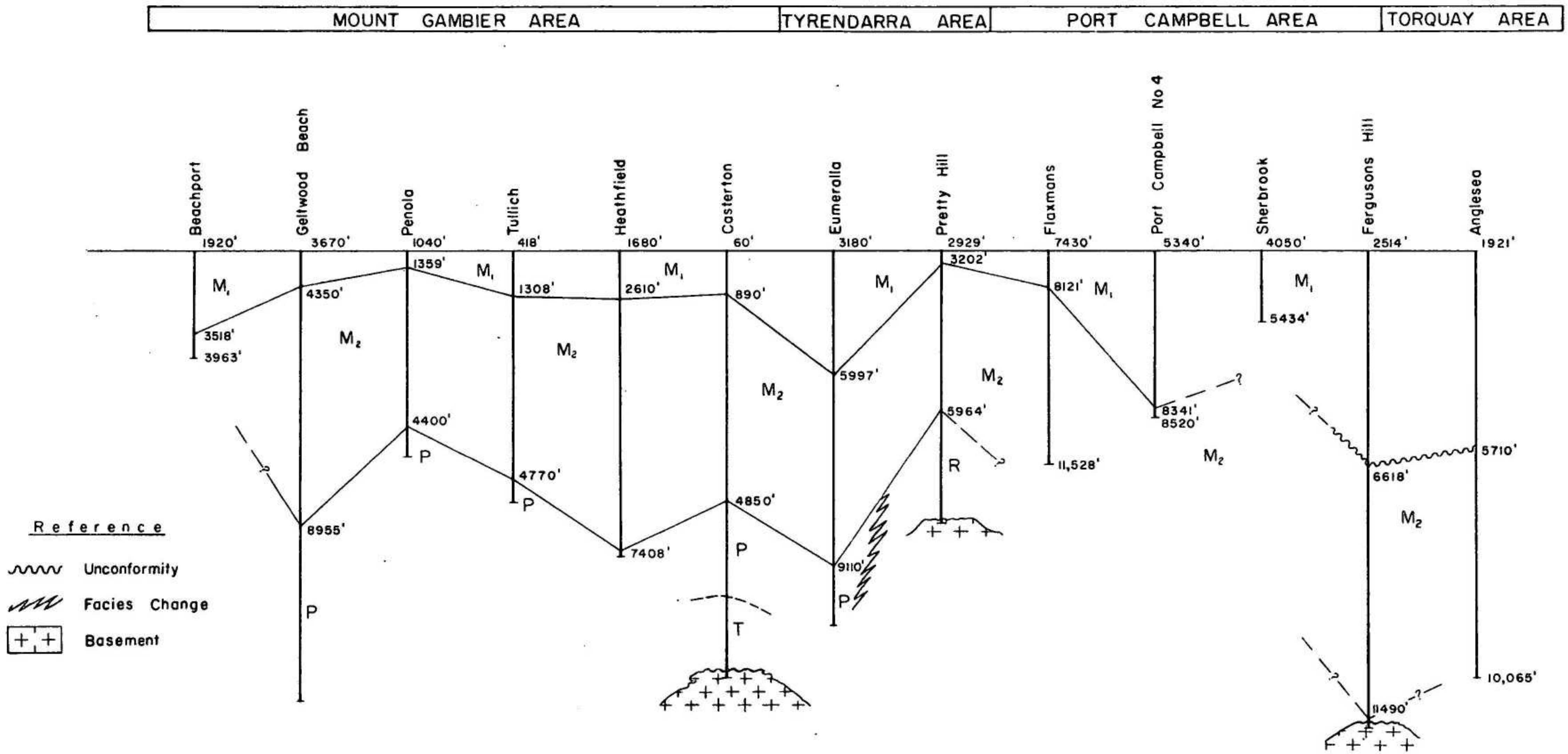
Furthermore, Evans (1966*) has shown from his palynological correlations that the tenative M_1 - M_2 boundary is markedly diachronic, an unlikely circumstance for a major volcanic event. Palynological correlations are shown on Plate 4A.

To check the degree to which lithologies changed between M_1 and M_2, Hawkins and Bryan prepared triangular plots of the sand-size fractions (Figure 2), and the overall composition (Figure 3) of the sandy parts of the subunits. The plots show little variation in composition.

These results do not necessarily invalidate the suggestion of volcanic recrudescence. The consistent appearance of volcanic detritus throughout the Unit M sequence probably indicates several episodes of vulcanism, one of which was centred to the east or southeast of the Basin and gave rise to subunit M_1 in Anglesea No. 1; penecontemporaneous sedimentation may have masked the effects of that particular episode to the west. The recent discovery of surface deposits of bentonite (Darragh and Bowen, 1965) suggests that a study of the volcanic history of the region as revealed by the sediments in wells might be economically important; some additional notes on vulcanism are given at the end of this discussion on lithology.

The study of vertical variations in Unit M sediments, did show some minor differences - not as marked as lateral changes, but nevertheless possibly quite important. In subunit M_2 the sandstones are predominantly greywackes with some subgreywackes, whereas in M_1 subgreywacke and volcanic sandstone predominate, with subordinate greywacke. There is also relatively more sandstone in subunit M_1. The following mineralogical differences were also noted:

- although the amount of volcanic lithics is greater in M_1 than in M_2, the proportion of well crystallized zeolite is greater in the lower (M_2) subunit;
- M_2 also shows more crystallized kaolinitic clay;
- M_1, on the other hand, has prominent zones of diagenetic calcite cement, and a zone of chlorite cement (in pellicular form) near the top.



CORRELATION OF MESOZOIC UNITS (INCLUDING 'M1' and 'M2')

AFTER J. DELLENBACH

Vertical Scale: 1cm = 1000 ft.

Datum: Top of Unit 'M1'

X AUS-1-30

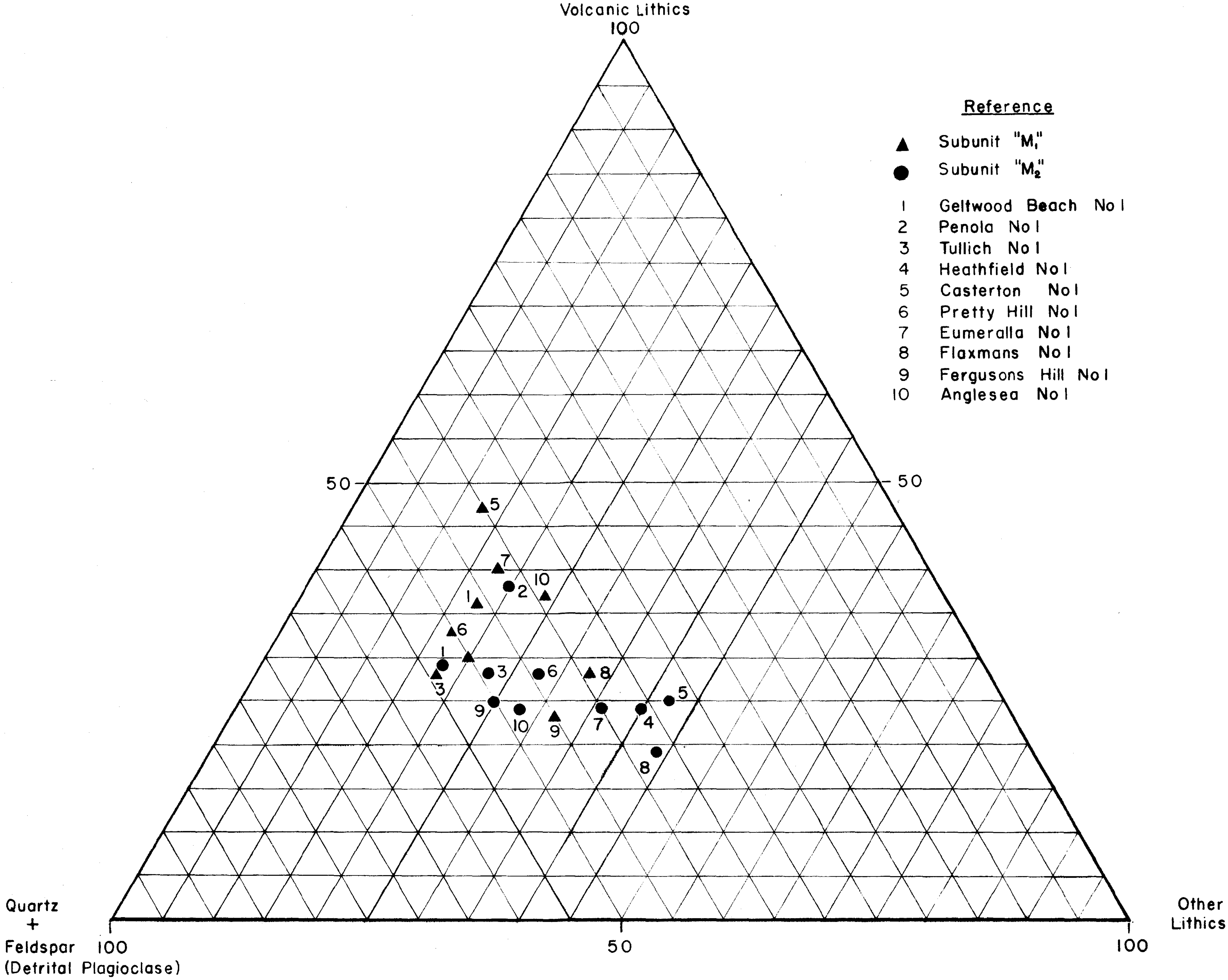
R.K.

Fig. 1

Bureau of Mineral Resources, Geology and Geophysics, July 1966 To accompany Record No

FIG. 2

COMPOSITION OF THE SAND-SIZED FRACTION OF ARENITES IN SUBUNITS "M_1" & "M_2"



Bureau of Mineral Resources, Geology and Geophysics. February 1966 *To accompany Record*

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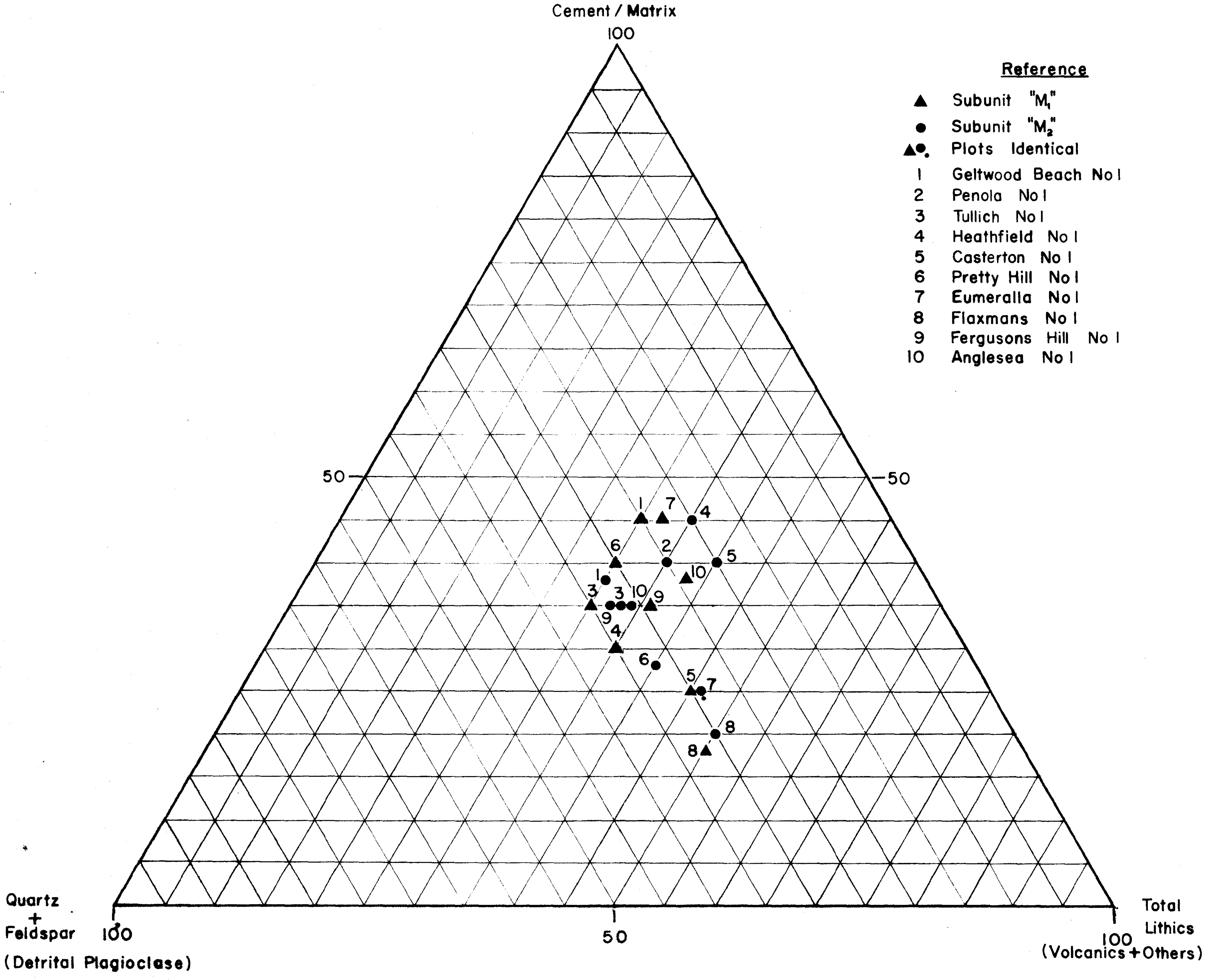
MINERAL COMPOSITION OF ARENITES

IN SUBUNITS "M1" & "M2"



Bureau of Mineral Resources Geology and Geophysics. February 1966. To accompany Record

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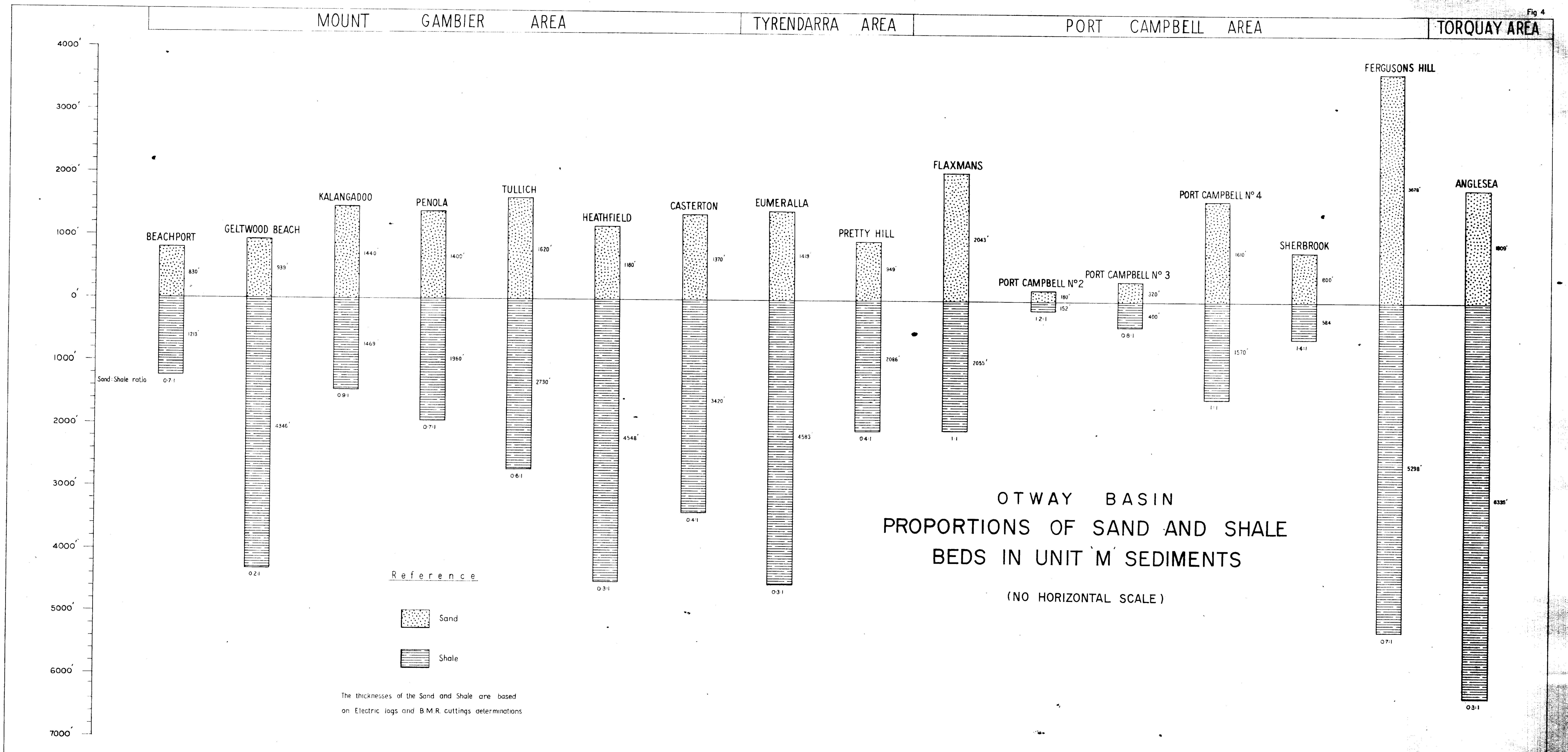


Bureau of Mineral Resources, Geology and Geophysics. May, 1966

To accompany record N° 1966/170

X AUS - 1 - 288

These differences may indicate greater marine influence in the upper (M_1) time. If so, and because the higher percentage of subgreywackes in M_1 has resulted in higher average porosities for its sandstones, the upper part of Unit M could be regarded as a more propective target for hydrocarbons than previously.

Lateral variations of Unit M.

Edwards and Baker (1943) noted the predominance of mudstones over sandstones in the sediments of the Otway Ranges (Unit M), and that mudstones constitute 75% of the sequence in the northern part of the Otway Ranges, and at least 60% in the north-western part of the Otway Basin. These results are confirmed by the sand:shale ratio study made by the Bureau. However, the study showed that lateral variations which might be important also occur, see Figure 4. Two areas are indicated in which the sand:shale ratios are almost 1 :

- the area from Kalangadoo towards the northern edge of the Basin;

- the Port Campbell area apparently extending off-shore.

The lateral variations in the nature and composition of sediments of the Unit M will be dealt with in two ways :

(1) Variations which occur within the ranges of composition of the sediments between the western and eastern ends, and as listed in Table 7C.

(2) The marked variations in the actual lithologies, i.e. the quartzose sandstone tongues in the Heathfield area.

(1) The variations which occur within the ranges of composition of the sediments are best described by examples taken from some of the wells studied :

(i) greywacke, subgreywacke, minor volcanic sandstone, and normal mudstone-shale suite for the lower part of Unit M - 4350 to 8955 feet, Geltwood Beach No. 1;

(ii) volcanic sandstone, subgreywacke, and minor greywacke suite of upper M in the same western area - 3670 to 4350 feet, Geltwood Beach No. 1; 3108 to 5997 feet, Eumeralla No. 1;

(iii) volcanic sandstone, subgreywacke suite of upper Unit M in the Tullich area - 418 to 1308 feet in Tullich No. 1;

(iv) subgreywacke, greywacke, and volcanic sandstone composition of Unit M towards the east - 1921 to 10,065 feet in Anglesea No. 1; 2514 to 11,490 feet, Fergusons Hill No. 1.

(i) In the Geltwood Beach area, mudstones predominate markedly over the sandstones, the majority of the sandstones in the lower part of Unit M are greywackes, and less than one third are subgreywackes. The mudstones and shales are rich in clay, chloritic material (some of which is of diagenetic origin), mica, coaly matter, and pyrite.

The sandstones consist of well-sorted, very fine grade, angular rock fragments (25-40%), feldspar (15-25%) and quartz (5-15%). The rock fragments are mostly of metamorphic origin, but volcanic rock fragments are recurrently abundant, and in some intervals amount to more than ⅓ of the lithic component (volcanic sandstones). The cementing media (15-45%) are either what can be termed a silty clayey chloritic to detrital matrix (greywackes), or carbonate cement - depositional and introduced/replacement - (subgreywacke type). Diagenesis has strongly affected most of the sediments, but is more conspicuous in the sandstones. The diagenetic processes were:-

- genesis of two types of chlorite: a clear finely crystalline low birefringent chlorite which coalesces in parts into scaly aggregates, vermicules and films, and brown, nearly amorphous flakes and colloform masses of chloritic material evolved from the chloritization of biotite and clayey material. Reworked chlorite and syngenetic chlorite, although present in the sediments are subordinate in this lower interval of Unit M.

- genesis of zeolites: the proportion of well crystallized poikilitic zeolite (s) is high (zeolite cement is present in approximately half of the sandstone fragments examined); even more cryptocrystalline zeolite is probably present in the matrix of sandstones and the groundmass of mudstones and shales (the significance of the occurrence of zeolite will be dealt with in the section on the volcanic nature of constituents of Unit M).

- genesis and/or transformation of clay minerals: there is a relation between the amount of clean finely crystalline to cryptocrystalline clay (possible illitized kaolinite) and depth, which has been observed in all wells intersecting Unit M; this clay mineral is interpreted as the result partly of adjustment of clay from the sediments to depositional conditions and partly of authigenesis; the phenomenom is distinct from the occurrence of mineralogically well-defined kaolinite and the kaolinitization observed in lateral variations of Unit M (e.g. Anglesea area).

- introduction of, and replacement by, carbonate minerals: replacement of some constituents (mostly feldspar by calcite) is common and extensive.

- development of quartz overgrowths and welding in some horizons.

(ii) The volcanic sandstones, subgreywackes and minor greywackes of the upper sequence of sediments of Unit M, e.g. Geltwood Beach No.1 3670-4350 ft. and Eumeralla No.1 3108-5997 ft. The sediments of this sequence are basically the same as those described for the lower part of Unit M. The main difference is the increased frequency of volcanic sandstone. The lithic fraction (25-60%) contains abundant fragments of devitrified glass of the groundmass of volcanic rocks (in parts red-stained by iron-oxide), fragments of possible acidic volcanic rock, and fragments of chloritic rock. The feldspars (5-15%) are mainly plagioclase and sanidine, some of which are zoned. Quartz is subordinate. The sandstones are porous in many instances. A thin chlorite or calcite coating around the grains is of syngenetic origin. The pores are partly infilled by early diagenetic (non-poikilitic) zeolites, also calcite, siderite and chlorite. The presence of horizons with conspicuous montmorillonitic clay matrix is also thought to be related to vulcanism.

(iii) The volcanic sandstones and subgreywackes of the upper sequence of sediments of Unit M e.g. Tullich No. 1 418-1308 ft. The framework of the sandstones of this sequence comprises abundant fragments of volcanic and low-grade metamorphic rocks. The volcanic rock fragments are mainly andesite and glass. The influence of a close active volcanic source is indicated by the occurrence of abundant fresh crystals of hornblende, apatite, magnetite, and altered mafic minerals (iddingsite?), together with big biotite flakes and zoned plagioclase. Crystals of zeolite framing reworked crystal tuff were observed. Montmorillonitic clay matrix is also present in several volcanic sandstone horizons.

(iv) The subgreywacke, greywackes and volcanic sandstones of Unit M in the east e.g. Anglesea No. 1, 1921 to 10,065 ft. and Fergusons Hill No. 1, 2514-11,490 ft. The framework of the sandstones, although very similar to those described in the lower sequence of Unit M in the Geltwood Beach area, appears to contain less feldspar. The basic differences lie in the general occurrence in the various rock types in the east of abundant siderite (and possibly other carbonates from the siderite - magnesite series), and clay. The clay matrix (mainly kaolinitic) is strongly recrystallized in part with possible introduction of supplementary clay. Fissures are infilled with recrystallized kaolinite and siderite. The introduction and replacement of the more labile constituents by clay and carbonates account for relatively lower percentages of feldspar as compared with sediments of the Geltwood Beach area. Carbonaceous matter is abundant both in a finely dispersed state and as coaly plant fragments. Zeolite and chlorite are subordinate in the sediments of Unit M in the Anglesea and Fergusons Hill areas.

2. Sandstones basically different to normal Unit M sediments have been found in the Mount Gambier area. These sandstone bodies occur in the northern and western parts as indicated in the Casterton, Heathfield, Tullich, Penola and Geltwood Beach wells.

They are mainly quartzose sandstones and may be divided into two groups:

- the "Heathfield Sand" which contains an abundance of metaquartzite fragments indicating a mainly metamorphic source.

- a lower sandstone unit containing and abundance of K-feldspars and fresh granitic fragments suggesting a mainly granitic source.

Occurrence of sands from subsurface evidence:

	"Heathfield Sand"	lower sandstone unit
Geltwood Beach No. 1	6050-6080'	-
Penola No. 1	-	3160-3180'
Tullich No. 1	2974-3094'	3769-3814'
Heathfield No. 1 **	4115-4144'	-
Casterton No. 1	1959-2025'	-

** The Heathfield Sand" was first recognized by J.R. Cundill (in P.E.C., 1964b*) and was also referred to informally by Brown (1965).

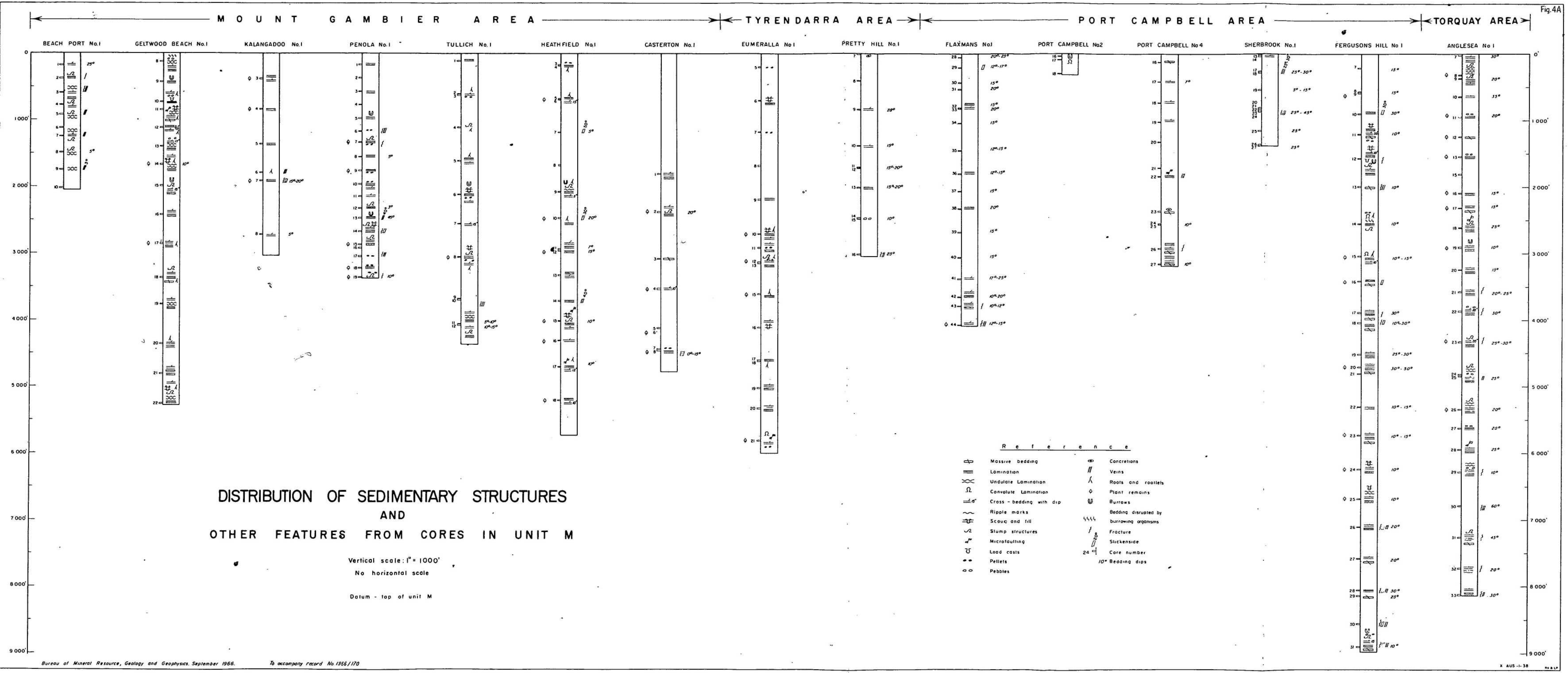
These sandstones comprise subangular to angular, medium to very coarse-grained (up to granule size), moderately to well-sorted quartz grains (40-50%), grains of plagioclase, microcline and untwinned feldspar (5-7%), and some rock fragments. Low-grade metamorphic fragments - sutured quartz, metaquartzite and quartzite - occur in the "Heathfield Sand" in variable amounts (from 10% up to 25% in the sand at 2980-3094 feet in Tullich No. 1) and distinguish it from the lower sandstone in which rock fragments are chiefly granitic fragments containing plagioclase and orthoclase feldspar, and minor amounts of metaquartzite (3769-3814 feet in Tullich No. 1). The cementing media (10-25%) are either clay (kaolinite) or calcite with kaolinite patches, or clay, chlorite and detritus wherever abundant lithic fragments are present. The cementing media are only patchily developed, and the porosity range is 20-25% with very good permeabilities. One characteristic common to all occurrences of these sandstones is the absence of volcanic rock-fragments. This points to solely metamorphic and granitic sources for the terrigenous constituents of the sandstones, whereas a combination of dominantly metamorphic source and influx of volcanic detritus is implied in the bulk of the sediments of Unit M throughout the Otway Basin.

As will be observed from the previous descriptions, the abundance of materials of volcanic origin is the most remarkable fact concerning the bulk of the sediments of the Unit M in the whole of the Otway Basin (and also the Gippsland Basin). The volcanic material comprises essentially rock fragments, which have been described by Edwards and Baker (1943) as:

- andesite and andesitic tuff
- dacite and rhyodacite.

Fragments of trachyte or andesite have been reported by Fander (in F.B.H., 1964f*). Other volcanic rock fragments observed in the wells studied were abundant glassy (more or less devitrified) material from the ground mass of acid to intermediate volcanic rocks. The typical reddish fragments are pieces of devitrified glass groundmass with released iron oxide. Fragments of lava with chlorite and quartz amygdales, opaque and chloritic material, are also abundant. Other evidence for strong volcanic influences:

- presence of crystals of mafic minerals (Tullich No. 1);
- presence of alteration products of mafic minerals in Geltwood Beach and other wells;
- presence of zoned feldspar and sanidine (also anorthoclase);
- presence of shards, glass bubbles (Tullich No. 1, Anglesea No. 1) and their devitrification products;
- presence of bentonitic beds (Darragh and Bowen, 1965); also mentioned by Whittle in the completion report of Geltwood Beach No. 1 (B.P.N.L., 1964*); Bell (1961) also refers to bentonite in equivalent sediments in the Gippsland Basin, and to volcanic agglomerate containing charred wood fragments in the Gellibrand area of the Otway Ranges);
- presence of chlorite; Carozzi (1960, p.70) states that primary argillaceous matrix derived from andesitic material contains chlorite as well as other minerals;



DISTRIBUTION OF SEDIMENTARY STRUCTURES AND OTHER FEATURES FROM CORES IN UNIT M

Vertical scale: 1" = 1000'

No horizontal scale

Datum - top of unit M

Bureau of Mineral Resources, Geology and Geophysics. September 1966.

To accompany record No 1966/170

- presence of syngenetic zeolite (diagenetic zeolite is a strong indirect evidence when extensively developed as in Geltwood Beach No.1, Eumeralla No.1, and to an even greater degree in the Gippsland Basin, e.g. Wellington Park No.1).

Previous studies have tended to link these volcanic materials to the erosion of volcanic terrain from the Upper Palaeozoic basement (Edwards and Baker, 1943); however, present evidence suggests contemporaneous volcanic activity during the Lower Cretaceous. The type of vulcanicity can be judged from the following features:

- predominance of flow-textured intermediate volcanic rock debris;

- scarcity of crystal and vitric tuffs (of direct pyroclastic origin);

- apparent absence of morphological features such as craters;

- absence (or non-recognition of centres or rifts with lava flows and associated rocks.

The loci of vulcanism may, of course, be submarine; on the other hand, another thick formation of reworked volcanic material up to 9,000 feet thick is known to one of the authors (Dellenbach*) as being derived from contemporaneous trachy-basaltic "feeder dykes" of limited extent as comparred with the volume of derived detritus (the Upper Eocene "Green Beds" of the Elbourz Mountains, Iran). It is apparent that not only contemporaneous activity must be envisaged during deposition of Unit M (and also to a lesser extent of Unit P), but that the volcanic activity was recrudescent at stages during the deposition.

(c) Structure

(i) Distribution and types of sedimentary structures:

The sedimentary structures observed in Unit M sediments may be mechanical, chemical and organic in origin. All these structures (Fig. 4A) have been recorded from sediments consisting of massive mudstones and siltstones with thin interbeds (5-20 feet thick) of fine-grained sandstones.

Structures indicative of both high and low energy influences occur throughout the sequence and are present across the entire basin suggesting that conditions of sedimentation were relatively uniform throughout. The random distribution of these structures would suggest that at any particular period in the sedimentary history of Unit M sediments no one set of conditions prevailed throughout the basin; there is no evidence to indicate that long periods of either high or low energy conditions - reflected by a zone of certain sedimentary structures - occurred in these sediments.

The most commonly found structures are thin laminations and undulations generally associated with mudstones, and cross-bedding in sandstones. From a study of the cores a general pattern is found to exist where certain structures occur in close association with one another. The following generalized sequence of sedimentary structures has been observed:

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* Ph.D. Thesis by Dellenbach, Strasbourg, 1964, unpublished.

Unit M

Photomicrograph 7. Volcanic Sandstone
Geltwood Beach No. 1, Core No. 12, depth 4771'.
Plane polarised light.
Angular, fine to medium-grained (0.15-0.30 mm). main mode = fine-grained; moderately sorted.
Quartz (qz) 10%, feldspar (f) 20%, lithics - volcanic rock (vol) siliceous aphanitic (aph), and chloritic (chl) fragments 55%, chloritic (chl) matrix 15%.
Note chlorite rims around detrital grains and welding of lithic grains.

Photomicrograph 8. Sandy Limestone - replacement.
Heathfield No. 1, cuttings sample 2080-2090'.
Plane polarised light.
Angular to subangular, very fine to fine-grained (0.12-0.21 mm.) detrital grains in limestone.
Quartz (qz) 2%, feldspar (f) 5%, lithics - siliceous aphanitic (aph), low grade metamorphic (met), and chloritic (chl) fragments - 20%, pyrite (py) + opaques 3%; coarsely recrystallized calcite (ca) cement 70%.
Note clay (cl) along crystal boundaries; also strong etching and replacement of detrital grains by calcite.
Relict (rel) structures of lithic grains are present.

Photomicrograph 9. Lithic Sandstone
Eumeralla No. 1, Core No. 12, depth 6242-6244'.
Plane polarised light.
Angular to subangular, fine to medium-grained (0.15-0.30 mm.); moderately sorted.
Quartz (qz) 15%, feldspar (f) 25%, lithics - siliceous aphanitic (aph), volcanics (vol), low-grade metamorphic (met), and chloritic (chl) fragments - 50%, zeolite cement (zeo) 10%.

Photomicrograph 10. Lithic Sandstone
Flaxmans No. 1, Core No. 29, depth 7652-7654'.
Plane polarised light.
Angular to subangular, fine to coarse-grained (0.21-0.51 mm.); poorly sorted.
Quartz (qz) 2%, feldspar (f) 15%, lithics - volcanics (vol), and chloritic siliceous (sil) rock fragments - 73%, chlorite (chl), and minor recrystallized silica (si) cement 10%.
Some detrital grains are rimmed with chlorite. Note feldspar being replaced by chlorite.


vol
vol
aph
chl
chl
qz
7
0·3 mm


rel
met
qz
aph
py
ca
ca
aph
rel
chl
8
0·3 mm


met
zeo
qz
met
aph
vol
chl
9
0·3 mm


zoned
chl
chl
chl
vol
10
0·3 mm

Top - Mudstone - slump structures and roots.

Sandstone - cross-bedding; pellets.

Base - Mudstone - laminations; scour-and-fill.

Mudstone immediately below a sandstone may show flat followed by undulate laminations; these laminations are thin (1-2 mm) and comprise clean, very fine-grained sand. Scoured surfaces which have been observed in some mudstones may occur at the boundary between mudstone and sandstone. The scoured surface is thought to represent periods when river channels eroded away surface sediments and filled the scour with sand. These scour-and-fill structures are found mainly in the upper section of Unit M sediments in the Mount Gambier and Fergusons Hill areas.

The sandstone above the mudstone may range in thickness from 5 to 20 feet but is generally about 10 feet; it is very fine to fine-grained and may contain either a clay matrix or a chemical cement - commonly carbonate. Low angle (10-15°) planar cross-bedding is common, and foreset bedding (dips up to 20°) has been recorded in Anglesea No. 1. Pebbles and pellets, observed in sandstone throughout the basin, occur more frequently in the Mount Gambier area. The pellets which consist of rounded fragments of chlorite and mudstone may be found at the base or within the sandstone. These pellets most probably represent fragments eroded from a nearby mudstone surface which had become hardened by exposure. It is often suggested that such pellets originate from the break-up of suncracked surfaces; there is no direct evidence here to support this view as no suncracks have been observed in any of the cores. Some of the sandstones contain abundant calcium carbonate. Chemical structures are rare but cone-in-cone structure was seen in carbonate-cemented sandstones in the upper part of Unit M in Heathfield No. 1.

The sediments above the sandstone are thin, clean, very fine-grained sandstone laminations and lenses which alternate with mudstone. Slump structures, ripple marks and convolute laminations, commonly in close association with one another, occur in the mudstone. Burrow markings are present in the mudstone particularly in the upper part of Unit M; the organisms responsible for the burrows seem to have confined their activities chiefly to the Mount Gambier area. Autochthonous roots and rootlets are present in the mudstones of Unit M; these features are also most common in the Mount Gambier area. Whether or not these roots represent the remains of mangrove swamps cannot be ascertained here.

(ii) Tectonic structure in Unit M sediments:

The occurrence of fracturing in Unit M sediments is most apparent in Fergusons Hill No. 1 and Anglesea No. 1; in these wells fracturing accompanied by slickensiding together with dips of 20-30° occur both above and below the unconformities suggested by Dellenbach (1965b)*. In Anglesea No. 1 some of the fractures are filled with siderite, calcite, kaolinite and quartz; brecciation was observed at 8607 feet. Elsewhere in the basin only isolated fracturing is present.

In the Mount Gambier area of the Otway Basin, unconformities are thought to be present at the base of the "Heathfield Sand", below which changes in dip and direction of the sediments occur. Some fracturing and slickensiding have been found in both Casterton No. 1 and Heathfield No. ; inclination of the fractures ranges from 15° to 50°. Bedding dips in Unit M sediments range from 10 to 20° although in Anglesea No. 1 and Fergusons Hill No. 1 dips of 20-30° are common.

Photomicrograph 11. Lithic Sandstone
Flaxmans No. 1, cuttings sample 7700-7710'.
Plane polarised light.
Subangular to subrounded, fine to medium-grained (0.15-0.45 mm.); moderately sorted.
Quartz (qz) 1%, feldspar (f) 10%, lithic - volcanic (vol), and siliceous aphanitic (aph) fragments - 69%, zeolite (zeo), and chlorite (chl) cement 20%. A bright orange coloured zeolite which fills pore spaces is heulandite.
Note euhedral crystals of zeolite and chlorite rims around detrital grains.

Photomicrograph 12. Volcanic Sandstone
Fergusons Hill No. 1, Core No. 7, depth 2747-2749'.
Plane polarised light.
Subangular to subrounded, fine to medium-grained (0.15-0.33 mm.); moderately sorted.
Quartz (qz) 1%, feldspar (f) 5%, lithics - abundant volcanic (vol), and rare low-grade metamorphic (met) fragments - 70%, chloritized mica (chl) 4%. Iron-rich (fe) rims and recrystallized calcite (ca) cement 20%.
Stages of development of the cement were:
(i) Formation of low birefringent unidentified (un) mineral coating detrital grains.
(ii) Development of iron-rich rim which in places has corroded the inner unidentified mineral rim.
(iii) Formation of calcite cement.

Photomicrograph 13. Lithic Sandstone
Fergusons Hill, No. 1, Core No. 11, depth 3744-3746'.
Plane polarised light.
Subangular to subrounded, fine to medium-grained (0.18-0.48 mm.); poorly sorted.
Quartz (qz) 5%, feldspar (f) 10%, lithics - volcanic (vol), and siliceous (sil) fragments - 25%, chloritized biotite (chl) 15%, recrystallized calcite (ca) and siderite (sd) cement 45%.

Photomicrograph 14. Lithic Sandstone
Anglesea No. 1, Core No. 7, depth 1947'.
Plane polarised light.
Angular to subangular, very fine-grained (0.09-0.12 mm.); well sorted.
Quartz (qz) 15%, feldspar (f) 15%, lithics - siliceous aphanitic (aph), and chloritic (chl) fragments - 30% illitic (ill) and kaolinitic clay matrix, and calcite (ca) and siderite (sd) cement 40%.
Patches of cryptocrystalline siderite and calcite; much welding of lithic grains making determination of matrix difficult.


aph
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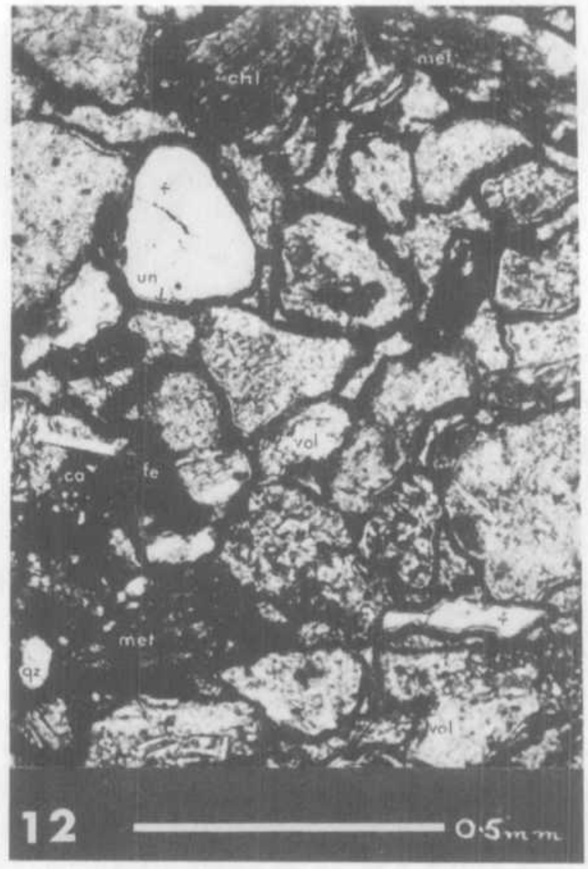
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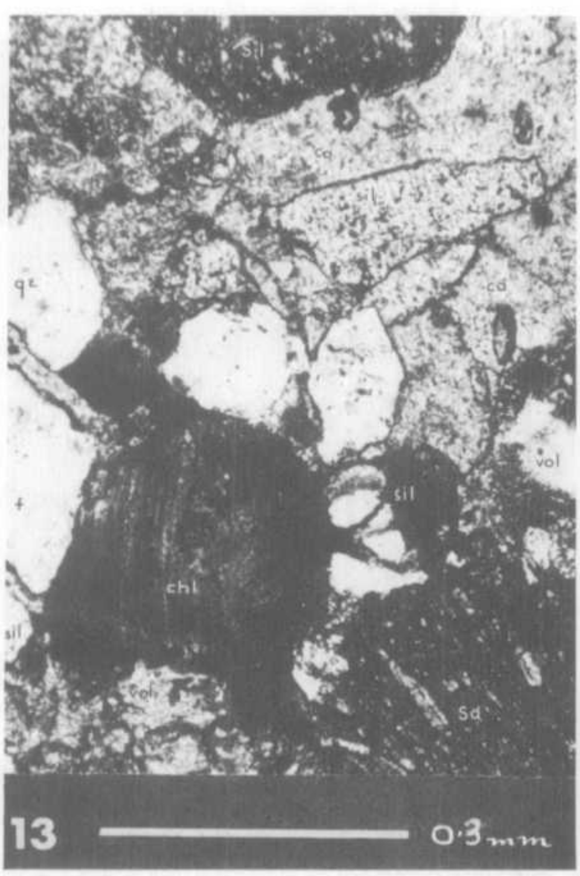
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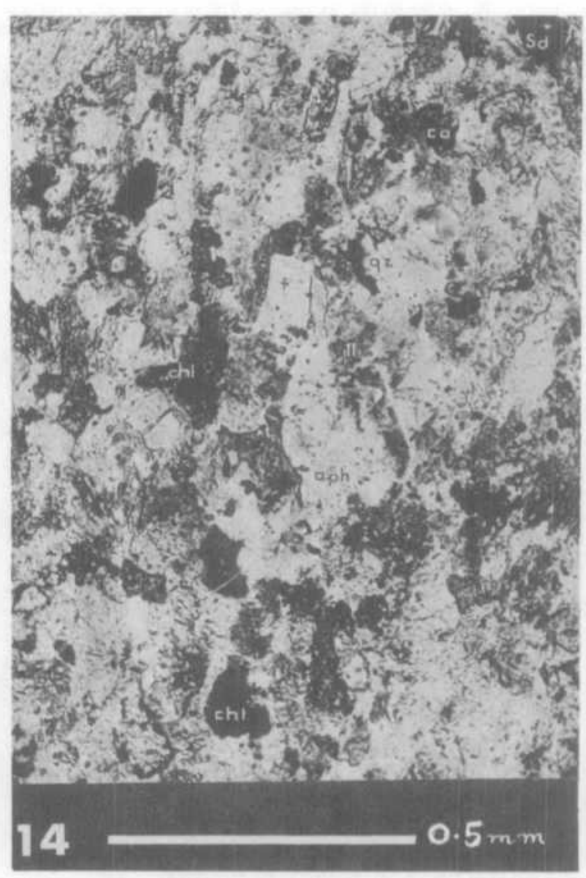
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(d) Age of sediments

The palynological study of Evans (1966)* has established that the entire Unit M sequence is Lower Cretaceous in age; in no well has Unit M been found to be older than Lower Cretaceous. In this study Evans has divided Unit M into six palynological units - K1a to d and K2a, b (see Plate 4). K1 broadly corresponds to Dettmann's (1963) "Speciosus" Zone, and K2 to her "Paradoxa" Zone. In the Otway Basin, there is an increase from east to west in the thickness of sediments contained in K1 at the at the expense of sediments in K2.

In Geltwood Beach No. 1, Unit M sediments extend up into the Ascodinium parvum zone of Upper Cretaceous age.

(e) Stratigraphic Relationships
Relationship of Unit M to underlying units:

The relationship between Unit M and units below is generally gradational except where it rests on basement. However, in Fergusons Hill No. 1 a clean lithic sandstone 20 feet thick (with Unit T affinities) occurs between Unit M and the metamorphic basement. It is possible, according to geophysical data, that Unit M rests on basement in the Anglesea area (O.D.N.L., 1963b*).

Relationship of Unit M to overlying units:

An unconformable relationship is thought to exist between Unit M and units above. This evolves from regional and petrological considerations. In the particular case of the Port Campbell area, the nature of the sediments above the unconformity and their relationship to sediments of Unit M will be studied in the section dealing with Unit J.

In the western part of the Basin, the top of Unit M is a carbonate-rich zone below the Upper Cretaceous or Tertiary sediments. This zone exists in Tullich No. 1 (418-440 feet), Heathfield No. 1 (2100-2200 feet), Kalangadoo No. 1 (2560-2760 feet), Geltwood Beach No. 1 (3670-3700 feet), Eumeralla No. 1 (3108-3130 feet), and Pretty Hill (2929-3010 feet). It could represent either a recrystallized product of sedimentation or a late diagenetic introduction of carbonate in the topmost layers of Unit M, below an unconformity. Also present near the top of Unit M is a pellicular chlorite zone.

(f) Environment of deposition for Unit M sediments

Two important features which characterize Unit M are the great homogeneity of the sediments and the widespread occurrence of carbonaceous plant fragments. The first characteristic is indicative of source areas of wide extent, similar composition, with the same response to erosion, and a similar amount of transportation. The general presence of dispersed carbonaceous matter, the occurrence of coaly plant fragments, coal stringers and beds, recurrent horizons (at various positions within the sequence) with roots in growth positions are significant.

The distribution and types of sedimentary structures encountered in Unit M sediments indicate that both high and low energy conditions prevailed across the basin, and also that conditions of sedimentation were relatively uniform throughout the basin. The presence of mudstone pellets in sandstones may indicate periods when there was a drying-out of mudflats followed by erosion and subsequent pellet formation. The mudflats in the western part of the basin seem to have been the centre of activity for burrowing organisms. The sediments and accompanying sedimentary structures indicate that shallow water conditions prevailed in a region where the rate of sedimentation was similar to the rate of subsidence.

Roots and rootlets in Unit M mudstones become less common eastwards; they are most plentiful in Geltwood Beach No.1. and Tullich No.1. In the west only two occurrences of roots have been recorded, both in Fergusons Hill No.1. Roots are present in situ in cores in the Mount Gambier area, whereas in Fergusons Hill No.1. roots have only been observed in a horizontal position (Core No.15) suggesting that they are of drift origin. Allen (1964) states that autochthonous roots associated with clay and silt-size sediments are characteristic of back-swamp deposits on a modern flood plain. Such backswamp conditions may have existed in the Mount Gambier area during deposition of Unit M sediments.

Plant fragments show an increase in occurrence eastwards with most plants being found in the Heathfield and Anglesea area. Their distribution is quite different to that of the roots. In Anglesea No.1. where no roots are to be found, remains of branching plants have been recorded at 7258 feet. Conditions in the basin may have been such that two types of flora developed during Unit M times; the plant fragments in the west may be related to stunted swamp-type vegetation whilst plant fragments in the east may be associated with luxuriant vegetation such as treelike ferns and lycopods. Edwards and Baker (1943) state that the flora in these sediments resemble the flora of the estuarine phase of the Yorkshire Oolite deposition.

Evidence that luxuriant vegetation did exist somewhere in the basin is borne out by the presence of coal which occurs in the form of beds and lenses 2 to 10 feet thick. The coal occurs as either soft black vitreous coal or as dull carbonaceous material. Edwards and Baker state that the coal is bituminous and is generally very finely banded; vitrain forms only a small proportion of these bands, the bulk consisting of dull coal. Siderite is also found in these sediments as finely crystalline siderite, and in sideritic sandstones.

Results of a recent study show that a sharp increase occurs in the amount of coal between Geltwood Beach No.1. where coal is absent and Heathfield No.1 (5.2%); this percentage remains more or less constant from Heathfield eastwards to Fergusons Hill No.1. (4.0%) but rises sharply to 11.6% in Anglesea No.1. A similar pattern exists for siderite distribution. The coal and siderite in Unit M is intimately associated particularly in Anglesea No.1. where siderite occurs above and below coal beds. In this well the siderite is regarded as syngenetic in origin and may contain carbonaceous material. Such a relationship between siderite and coal has been shown and discussed by Strahkov (1957).

The presence of coal and siderite in the Otway Basin, particularly in the east, would indicate that deposition took place in a humid zone under acid conditions; the presence of kaolinite in both the mudstones and sandstones in Anglesea No.1. would support this view. The marked increase of siderite and coal in approximately the same proportions (1.1:1) between the Fergusons Hill and Anglesea areas would suggest, according to Strahkov (op.cit.), that in this part of the basin, sedimentation took place in a gulf-like environment. In the west, however, particularly in Geltwood Beach No.1., coal is absent and siderite is rare which might indicate the influence of more marine conditions.

Evidence to support the suggestion of marine influence in the western part of the basin is two fold: the occurrence of calcite-cemented sandstone, and the presence of acritarchs in the sediments.

A study of the percentage of calcite-cemented sandstone in Unit M sediments has revealed that between Anglesea No. 1 and Eumeralla No. 1 the amount remains constant (5-6%) but on moving westwards to the Mount Gambier area there is a progressive increase which reaches 11% in Geltwood Beach No. 1. In both Eumeralla No. 1 and Geltwood Beach No. 1, calcite cementation is most apparent in the upper part of Unit M; in Heathfield No. 1, this property is shown in the middle and upper part of the sequence, but in Fergusons Hill No. 1 and Anglesea No. 1, it occurs mainly in the lower part of the unit. The formation of carbonate in association with soil pans, suncracks, interlayering of coarse and fine sediments and autochthonous plant remains such as roots could occur as a result of overbank flooding by tidal movements and would take place in the backswamp deposits away from river channels. The type of environment is described by Allen (1964).

Acritarchs were found in Unit M by Evans (1966)* during palynological studies of core material from wells in the Otway Basin. Of all the samples examined, only ten contained acritarchs and these were in illitic and chloritic mudstones. These pelagic forms show no pattern of stratigraphic significance but are most conspicuous in the western part of the basin; no acritarchs have been recorded east of Flaxmans No. 1. The mudstones in which the acritarchs have been found are closely associated with calcite-cemented sandstone. The acritarchs are thought to have been preserved in sediments where the oxygen content was low.

Sedimentary structures suggest that shallow water conditions prevailed throughout the basin during deposition of Unit M sediments. Features found in the sediments indicate that a paralic environment (Krumbein and Sloss, 1963) existed and that conditions were partly continental and partly transitional (Twenhofel, 1950); the environment which is envisaged includes alluvial, swamp (paludal), lagoonal and deltaic areas. Sedimentation is not thought to have taken place in a fresh-water lake environment because of the absence of limonitic material. The presence of mudstone pellets in sandstones, particularly in the western part of the basin may indicate that river channels flowed across an alluvial flood plain. Allen (op.cit.) considers that pellets represent erosion at the deepest part of a wandering river channel. According to Conybeare (1964) high-angle cross-bedding, such as that observed in cores of Unit M (15-20°) may be associated with currents in tidal channels. From evidence available such channels may have existed in the Geltwood Beach and Heathfield areas in the west, and Fergusons Hill and Anglesea areas in the east.

Away from river channels, mud flats are envisaged where burrowing organisms were active especially in the Mount Gambier area. Backswamp deposits are thought to have formed where autochthonous roots have been found in mudstones which are interbedded with calcite-cemented sandstones. The presence of acritarchs in the western area would suggest that periodic influxes of marine waters up tidal channels occurred, bringing acritarchs and carbonates. Although river channels probably existed in the east, marine tidal influence was presumably not great due to a more restricted environment. However, some marine influence is indicated in the Port Campbell area where microplankton and arenaceous foraminifera were recorded from Unit M in Port Campbell No. 2 Well by Evans (in F.-B.H., 1960c*).

Plant fragments become more abundant eastwards and show some relationship to the increase in coal. The presence of coal and siderite is also important for it reflects the Eh conditions during sedimentation.

In the Fergusons Hill and Anglesea areas, acidic and reducing conditions are thought to have prevailed in a gulf environment and allowed the formation of coal. At present there is not enough evidence to support an autochthonous origin for the coal as only two occurrences of roots have been recorded, and these were not in situ; nor have seat earths been recognized. It is suggested that the coal is of drift origin brought in by currents perhaps from the west but more probably from the east or south-east. This suggestion is based on the relative abundance of the associated plant material in the eastern part of the Basin. A drift origin for the coal has also been proposed by Edwards and Baker (1943). Siderite which is found in association with coal especially in Anglesea No. 1 further indicates that deposition took place under reducing conditions.

In summary, it may be stated that in the Mount Gambier area sedimentation took place on a slowly subsiding shelf where river-channels and swamps existed in a broad flood plain. Conditions did not permit the development of large deposits of peat and coal. Marine influences affected Unit M sediments indicating the nearness of the sea to the area of deposition. In the eastern part of the basin, sedimentation is thought to have taken place in a restricted environment but where alluvial, swampy and deltaic conditions also occurred in broad flood plains. Coal developed from drift material probably from areas around the eastern end of the basin, under reducing conditions and in deltaic areas where subsidence was very slow. Some marine inundation occurred in the Port Campbell area.

The mode of deposition of the "Heathfield Sand" and other coarse sandstone bodies of different composition to normal Unit M sediments raises an interesting problem. In some places they have formed not far above possible angular unconformities such as those suggested at approximately 100 feet below the base of the lower-sandstone unit in Tullich No. 1, and 150 feet below the "Heathfield Sand" in Heathfield No. No. 1 (P.E.C., 1964*). This suggested that some form of local tectonic event occurred where the dips change, and influenced sedimentation. However, the actual influence of coarse terrigenous material occurred later, and indicates another event. Palynological evidence (Evans 1966*, and this report) shows that a considerable amount of Unit M section could have been eroded from areas to the west of Casterton No. 1 in Kld time, before "Heathfield sand" sedimentation (see Plate 4B); this evidence supports the idea that the coarse sand deposition was a separate event. The dipmeter data available is unfortunately limited to two or three wells and cannot be correlated regionally, and some doubt exists as to its reliability. However, seismic records in the Casterton area do show that some faulting occurred during Unit M time, and could have resulted in the development of local angular unconformities.

On the available evidence, correlation between tectonic events and coarse sand deposition is not possible, but further attempts to make such a correlation may be worthwhile. Although the known sand bodies do not appear to be much more than thin near-shore wedges, they could be quite extensive, and if affected by penecontemporaneous movements, they could provide good reservoirs for hydrocarbon accumulation. Some of the faulting of Unit M time is shown in the structure map, Plate 11.

(g) Hydrocarbon occurrences

Flows of free gas and gas dissolved in salt water, have been obtained from Unit M, and Port Campbell Well No. 4 produced 36 barrels/day of emulsified crude oil. None of the gas flows was sustained, indicating that the reservoirs were small or restricted.

Unit J-H

The sediments which occur between the unconformity at the top of Unit M and the unconformity at the base of Unit G in the Port Campbell area are designated Unit J. In Anglesea No. 1, a thin sequence in a similar stratigraphic position and of similar lithology to Unit J has been called Unit H. The two units are thought to be equivalent although there is no palaeontological evidence to support the correlation.

Unit J was first described in the report on Port Campbell Nos. 1 and 2 (Dellenbach and Hawkins, 1964*). Detailed descriptions of Unit J also occur in a subsequent report by Edworthy (1965b)*. The unit is similar in composition and texture to sediments described as the Waarre Formation by Bain and McQueen in F.-B.H., (1960a)*.

Unit H was described by Dellenbach (1965b)*.

(a) Distribution of Unit J

There are no known outcrops of Unit J sediments in any part of the Otway Basin.

This unit has been intersected in six subsidized and other unsubsidized wells in the Port Campbell area. It is thought to occur in numerous water bores drilled by the Victorian Department of Mines. A 105 foot interval (1816-1921 ft) recorded as Unit H and consisting of sandstone with Unit J sandstone affinities was intersected in Anglesea No. 1 Well.

Table 8: Subsurface occurrences of Unit J-H

Well Name	Datum - feet above sea level	Depths below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Flaxmans No.1	221	6880 to 7430	-6659 to -7209	550	
Port Campbell No.1	346	5650 to 5965	-5304 to -5619	315**	PORT
Port Campbell No.2	282	8110 to 8514	-7828 to -8232	404	CAMPBELL
Port Campbell No.3	210	4608 to 4810	-4398 to -4600	202	
Port Campbell No.4	440	4970 to 5340	-4530 to -4900	370	
Sherbrook No. 1	480	3780 to 4050	-3300 to -3570	270	
Fergusons Hill No.1	651	2046 to 2514	-1395 to -1863	468	
Latrobe No.1	102	1750 to 1970	-1648 to -1868	220	
Anglesea No.1	78	1816 to 1921	-1738 to -1843	105	TORQUAY

** Unit J not fully penetrated.

Unit J-H sediments are apparently confined to the eastern part of the Otway Basin. Taylor (1964) has suggested on the basis of micropalaeontological evidence that the Waarre Formation may be considered as part of the "Otway Group" which we regard as equivalent to Unit M. Palynological studies and plant remains also suggest a close lateral relationship between sediments of Unit J and the uppermost sediments of Unit M in adjoining areas. An unconformable relationship between Units M and J-H is suggested as a result of petrological studies.

(b) General lithology of Unit J

The sediments may be divided into two parts, an upper sequence of orthoquartzitic sandstones and carbonaceous siltstones and mudstones, and a lower sequence of chloritic protoquartzites cemented by calcite, together with carbonaceous siltstones, mudstones and coals. In the sandstones, which range from fine-grained to conglomeratic in size, there is a significant absence of volcanic rock fragments.

Sandstone is the dominant rock type in this unit. The sand-shale ratio (Figure 5) ranges between 1.1 and 1.8 (average 1.5). However, in Latrobe No. 1 (south of Fergusons Hill No. 1, see Plate 1) the ratio is 6, and this marked increase in sand could indicate an important trend. The sandstones and mudstones are discussed separately in more detail below:

(1) The sandstones -

The sandstones of Unit J are differentiated from those of Unit Gh above firstly by their chemical constituents, and secondly by their framework. The differentiation of the sandstones of Unit J from those of Unit M is essentially on the basis of the framework.

The range of composition of the sandstones, estimated from thin sections of cores from the Port Campbell wells, Flaxmans No. 1 Well, and Sherbrook No. 1 Well, is as follows:-

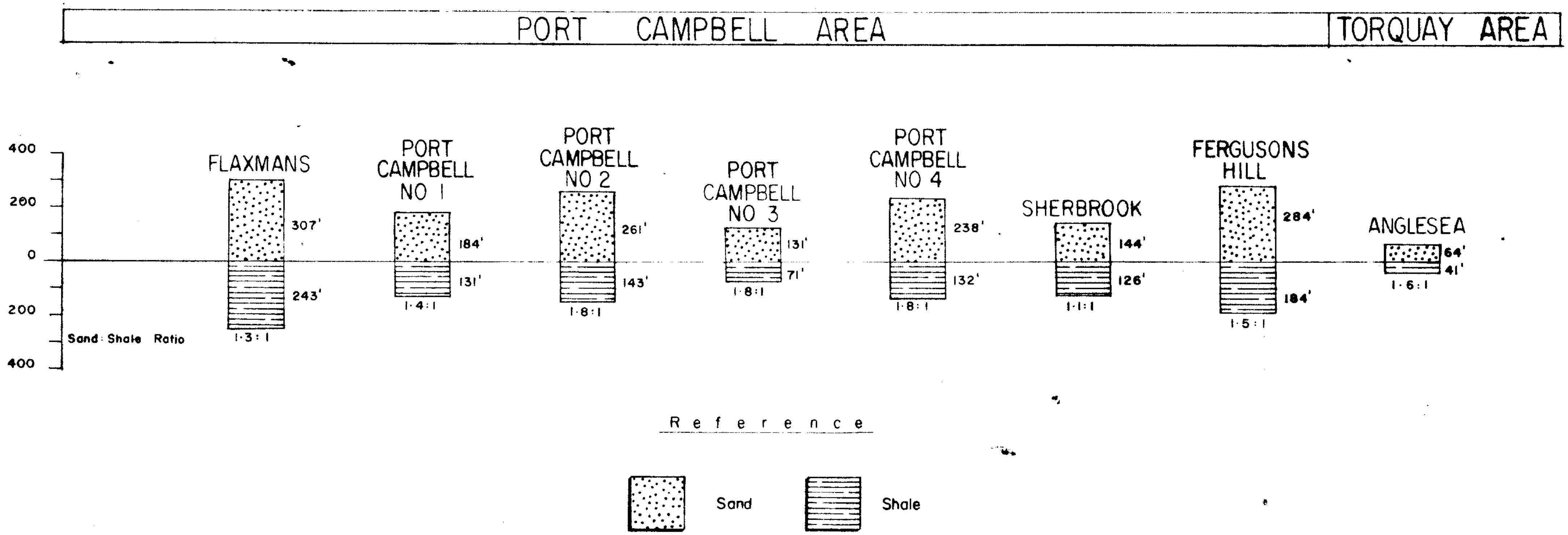
Quartz	55 - 85%
Feldspar	3 - 5%
Lithic fragments	3 - 10%
Accessories (Mica etc.)	0 - 4%
Cement: silica, calcite; <u>or</u> Matrix: detritus, clay, carbonaceous matter, pyrite.	0 - 35%

As can be seen from the above figures, there are wide variations particularly in the cementing media (nature and amount) and in the content of rock fragments. As previously reported by Weegar (1961a*), and Edworthy (1965b*), the sandstones could be termed quartzose sandstones or orthoquartzites to protoquartzites. The texture is also variable, the sediments varying in grain size from conglomeratic sandstone to fine-grained sandstone. The sorting ranges from good in some horizons to poor in most cases, and bimodal distribution is common. Very coarse grains, granules, and pebbles are well rounded whereas the coarse to fine constituents range from subrounded to angular. Sandstones in Sherbrook No. 1 and Fergusons Hill No. 1 are particularly angular. The lithic fragments comprise metaquartzite grains, phyllite, muscovite schist, aphanitic rocks rich in sericite flakes (metamorphic), chalcedonic rock of uncertain origin and minor chloritic rock fragments. Of particular interest is the occurrence in Flaxmans No. 1 (core 27 and cuttings from 7200 to 7430 ft.), and also in Port Campbell No. 4 (parts of cores 14 and 15), of aphanitic siliceous rock fragments of fine to very fine

OTWAY BASIN

PROPORTIONS OF SAND AND SHALE BEDS IN UNIT 'J' SEDIMENTS

(NO HORIZONTAL SCALE)



The thicknesses of the sand and shale are based on Electric Logs and B.M.R. cuttings determinations

In Anglesea well this interval has been designated Unit H However these sediments have affinities with Unit J.

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Bureau of Mineral Resources, Geology and Geophysics May 1966. *To accompany record Nº 1966/170* grade, some of which are chloritic. As suggested by Edworthy (op.cit.) these could represent reworked lithic grains from Unit M below. However it is emphasized here that none of these show the structure of andesite or basalt fragments so commonly seen in Unit M.

The nature and amounts of the cementing media are variable. In most of the wells, the top part of Unit J is either very porous (maximum recorded porosity 25%), or cemented by clear calcite with minor siderite and patches of recrystallized kaolinite. Quartz overgrowth also contributes significantly to the cementation processes. In some intervals, generally towards the bottom of the unit (i.e. Fergusons Hill No. 1, Flaxmans No. 1, Port Campbell No. 4, Sherbrook No. 1), the frequency of occurrence of matrix in the sandstones increases; also shale and coal horizons are present. The matrix is detrital (very angular quartz and some feldspar), and contains patchily distributed kaolinite (some of which is recrystallized as big flakes), abundant pyrite, opaque material and carbonaceous matter. In Flaxmans No. 1 (6905 ft, core 25), and Fergusons Hill No. 1 (2092 ft, core 4), chloritic coatings and pore infillings, chloritized mica, and bleached mica are present (5%). The occurrence of chlorite in Unit J is not a significant criterion for indicating a relationship with Unit M since chlorites of various types exist in most of the Mesozoic units.

A few accessory heavy minerals are represented: mainly zircon, tourmaline, sphene, rare epidote and opaques.

The sandstones of Unit J are on the whole very porous and permeable. The range of highest porosities measured on available cores is 20-25%, and the maximum measured permeability is 895 millidarcies (Flaxmans No. 1, core 24, 6882-6902 ft). It is probable from consideration of the type of cuttings, electric logs, and the failure to recover cores in some intervals, that even more porous and permeable sandstones and conglomerates may exist.

(2) The mudstones -

Mudstones and shales, with abundant pyrite and carbonaceous matter, and stringers of coal have been recorded at numerous depths within Unit J and particularly at the bottom of the unit in Fergusons Hill No. 1 and Port Campbell No. 4. The groundmass of the mudstone is illitic, carbonaceous and pyritic. Fragments of plant tissue are present. No chemical analyses are available for comparison with the mudstones of Unit M below.

Lateral variations

In view of the small areal extent of the Unit J and the limited amount of information available, it is not possible at present to envisage the nature of any lateral variations.

(c) Structure

(i) Sedimentary structures:

As few cores have been taken in sediments of Unit J, little can be said about sedimentary features. However, in Port Campbell Nos. 1 and 2, lenses of silty clays rich in organic matter are common in the sandstones. Thin white sandstone laminations occur in dark siltstone at the top of Port Campbell No. 2, and some convolute laminations are present in Port Campbell No. 1. Some sandstones show cross-bedding, and slump features and churned bedding are present in siltstone in Port Campbell No. 2. Burrow markings are recorded in mudstone in Port Campbell No. 1.

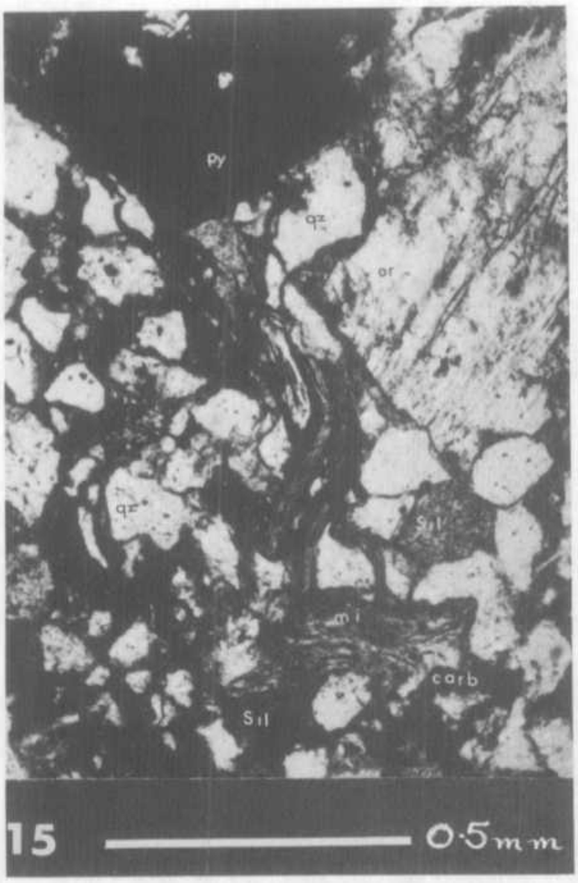
Unit J

Photomicrograph 15. Sandstone.
Flaxmans No. 1, Core No. 25, depth 6905'.
Plane polarised light.
Subangular to subrounded, very fine to coarse-grained (0.09–0.90 mm.); poorly sorted
Quartz (qz) 55%, orthoclase (or) 15%, lithics - siliceous (sil) rock fragments 5%, pyrite (py) 10%, muscovite (mi) 5%, carbonaceous clay (carb.) matrix 10%.

Photomicrograph 16. Sandstone.
Port Campbell No. 4, Core No. 14, depth 4995-97'.
Plane polarised light.
Subangular, silt-size to fine-grained (0.06–0.18 mm.); moderately sorted.
Quartz (qz) 60%, lithics-aphanitic siliceous (sil) fragments 5%, carbonaceous (carb) pyritic clay and siderite (sd) cement 35%.
Note carbonaceous clay lens.

Unit H.

Photomicrograph 17. Sandstone
Anglesea No. 1, cuttings sample 1890-1900'.
Plane polarised light.
Subangular, medium to coarse-grained (0.45–0.90 mm.); main mode coarse-grained; moderately sorted.
Quartz (qz) 65%, orthoclase (or) 5%, carbonate - dolomite (do), calcite (ca), and siderite (sd) - cement 30%.
Note corrosion of detrital grains by carbonate cement.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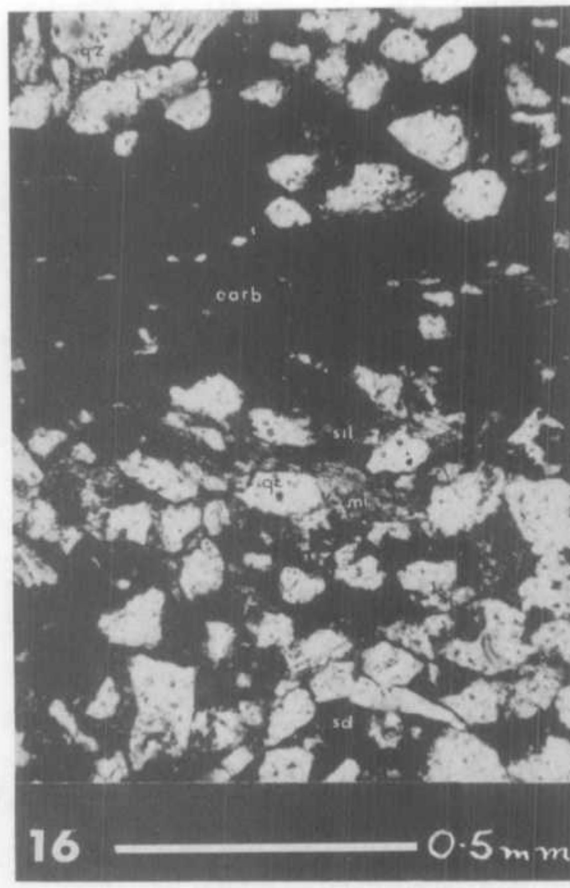
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(ii) Tectonic structures:

No dips have been recorded from cores taken within Unit J, and the sediments do not give any indication of structural movements.

(d) Age

Recent palynological studies have shown that Unit J extends in age from the uppermost part of the Lower Cretaceous to the lowermost part of the Upper Cretaceous.

Although Unit J sediments appear to be found mainly in Evans' K2b palynological unit (Lower Cretaceous), there is evidence for this unit extending up into the Ascodinium parvum Zone (Upper Cretaceous) in Flaxmans No. 1 and Port Campbell No. 2.

From these studies it is apparent that although no known Unit J sediments occur in the western part of the basin, sediments occur which are comparable in age to Unit J, e.g. the upper part of Unit M, and basal beds of Unit Gg.

(e) Stratigraphic relationships.

(i) Relationship of Unit J to underlying units:

The description of the sandstones of Unit J has shown that although some genetic relationship may exist between parts of the sediments of Unit J and the sediments of Unit M, the evidence points towards a different history for the two units. The texture and composition of the sandstones of Unit J imply the predominance of a granitic-metamorphic (rather than an older sedimentary) source, presumably situated on the present land area. The marked change in lithology is similar to that shown by sandstone bodies within Unit M in the Heathfield area. However, Unit J differs in that it is not overlain by sediments with close affinities to Unit M; in fact, a major basinwide unconformity occurs above Unit J. Unit J should therefore be considered as a sandstone unit with unconformable relationship to sediments of Unit M, and as an extensive wedge-shaped body similar to the porous sandstones intersected in Unit M in the Heathfield area.

(ii) Relationship of Unit J to overlying units:

There are indications of a marked unconformity at the top of Unit J. The fact that Units M and J are overlain by different units of Upper Cretaceous age starting with marine ones of restricted extent (Gh, Gf and Gg, see Plate 5), implies that structural events of basinwide significance increase in magnitude at the end of the deposition of Unit J.

Further evidence is based on the different nature of units above Unit J which show features of a typical marine transgression, whereas Unit J was apparently regressive.

The results of the dipmeter survey carried out in Port Campbell No. 4 are not conclusive enough to indicate an angular unconformity or disconformity.

(f) Environment of deposition.

The petrology and the setting of Unit J in the Otway

Basin suggest a regressive character. Mudstones and sandstones with evidence of marine conditions are interbedded low in the sequence with coaly horizons, and a paralic environment is indicated. Higher in the sequence, coarser terrigenous sands become more prominent and a conglomerate develops at the top.

The shape of the body of sediments of Unit J is difficult to determine in view of the almost linear arrangement of the wells available for study; it does appear to thicken however, towards the central part of the Port Campbell area, and so varies from sandstone bodies in Unit M (Heathfield area) which wedge out towards the central axis of the basin.

(g) Hydrocarbon occurrences

No oil staining was observed from thin section studies. The only indications of hydrocarbons in Unit J obtained so far have been in the Port Campbell wells. Port Campbell No. 1 initially produced a substantial flow of gas but this was not sustained. Port Campbell Nos. 2 and 3 produced gas and salt water. All other wells tested produced either salt or fresh water.

Unit G.

Unit G was established in the Nelson Bore (Hawkins & Dellenbach, 1963*) and Port Campbell No. 1 (Dellenbach & Hawkins, 1964*).

Unit G occurs between the unconformity at the top of Unit J-H or Unit M, and the unconformity at the base of Unit D. Five sub-divisions of Unit G have been recognized by their distinctive lithological and petrological characteristics:

Unit Gb (uppermost)

Unit Gd

Unit Gf

Unit Gg **

Unit Gh

(a) Distribution of Unit G.

Outcrops of Unit G sediments have not been recognized in any part of the basin.

Unit G sediments occur in most of the wells examined during the course of the study. Only in the Port Campbell area has the full section from Unit Gb to Unit Gh been intersected; in western areas the lower units, Gf and Gh, are not distinguishable as such, and a unit of mixed lithologies, Gg, occurs.

(b) General lithology of Unit G.

The sediments comprise oolitic sandstones, glauconitic mudstones, cemented sandstones, immature argillaceous sandstones, coal seams and mudstones.

The sandstones and sandy mudstones (Unit Gh) at the base of Unit G contain chlorite ooliths and pellets; the sandstones are siderite-cemented. Unit Gf is a sequence of massive mudstone containing abundant glauconite; minor sandy horizons occur. This sequence is followed by predominantly arenaceous sediments (Unit Gd) of siderite-cemented sandstones containing chlorite pellets and friable, kaolinitic sandstones. Unit Gd is succeeded by a sandy unit (Unit Gb) consisting of coarse-grained sandstones with detrital clay matrix and carbonaceous, pyritic mudstones and shales.

In the west, Unit Gg consists of predominantly silt-size sediments in the lower part of the unit, followed by a more sandy sequence towards the top.

Unit Gh

(a) Occurrences of Unit Gh sediments from well data.

Unit Gh or Flaxmans Formation (Bain, in F.-B.H., 1961a*; Bock and Glenie, 1965) is a localised body of sediments which has been recognized in certain subsidized wells.

** A mixture of Gf and Gh lithologies found in the Mount Gambier area.

Unit Gh.

Photomicrograph 18. Oolite.

Flaxmans No. 1, Core No. 19, depth 6616'-21'.
Plane polarised light with condenser.
Subangular detritus and rounded pellets and ooliths, very fine to medium-grained (0.09-0.45 mm), moderately sorted.
Quartz (qz) 5%, lithics (li) 5%, limonite ooliths and pellets (ool) 50%, ferriferous chlorite matrix (chl) 40%.
Note diagenetic siderite (sd) as rims around some ooliths.

Photomicrograph 19. Sandstone.

Port Campbell No. 2, Core No. 6, depth 7904'.
Plane polarised light.
Subangular to subrounded, very fine to medium-grained (0.09-0.39 mm), main mode=fine-grained; moderately sorted.
Quartz (qz) 20%, lithics-chloritic siliceous (sil) 20% and chlorite (chl) fragments 10%, glauconite (gl) 5%. Siderite cement (sd) and chlorite matrix 45%.

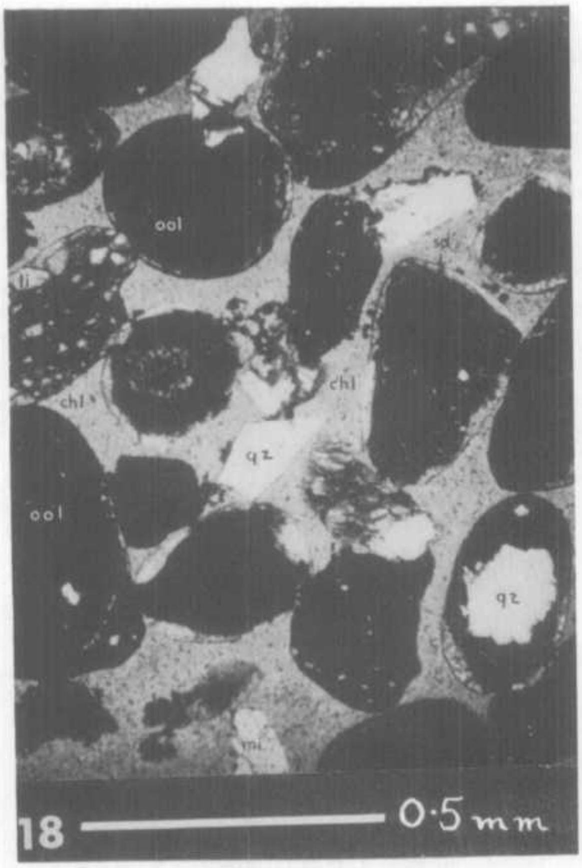
Unit Gf.

Photomicrograph 20. Glauconitic Mudstone.

Pretty Hill No. 1, Core No. 6, depth 2726'-28'.
Plane polarised light.
Angular, silt-size to very fine-grained detritus of quartz, and fine to medium-grained pellets of glauconite.
Glauconite (gl) pellets 30%, quartz (qz) detritus 5%, illitic clay (ill) with carbonaceous matter and pyrite specks 65%.

Photomicrograph 21. Glauconitic Mudstone.

Flaxmans No. 1, Core No. 17, depth 6380'-85'.
Plane polarised light.
Angular, silt-size detritus, and fine to coarse-grained pellets of glauconite.
Glauconite (gl) 35%, quartz (qz) 5%, illitic clay (ill) + opaque minerals 60%.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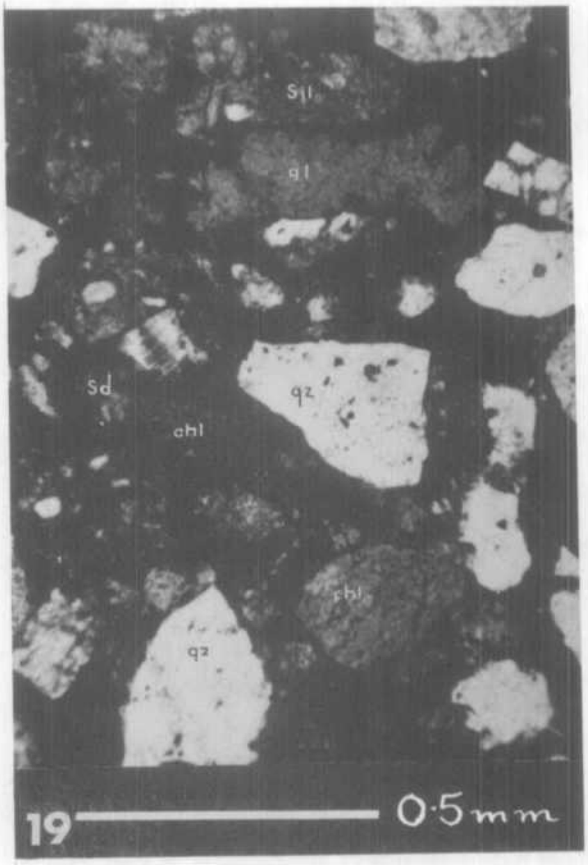
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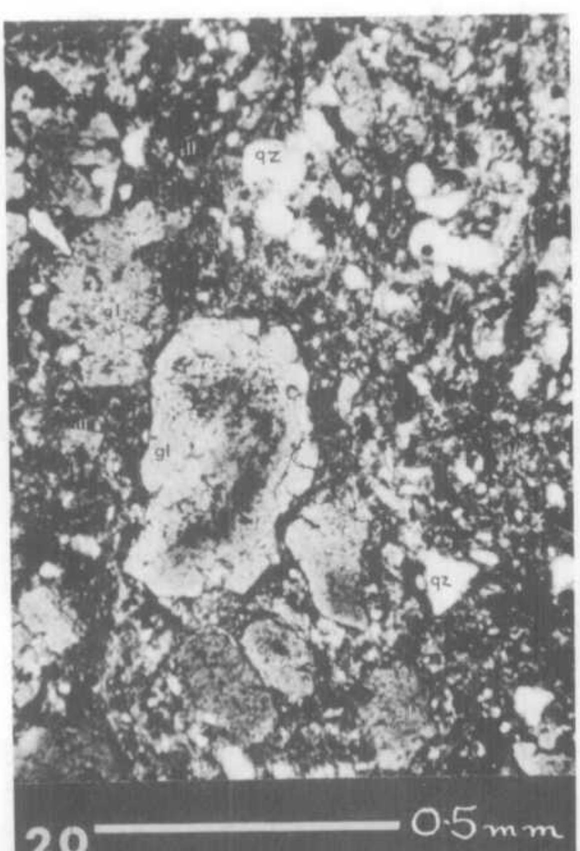
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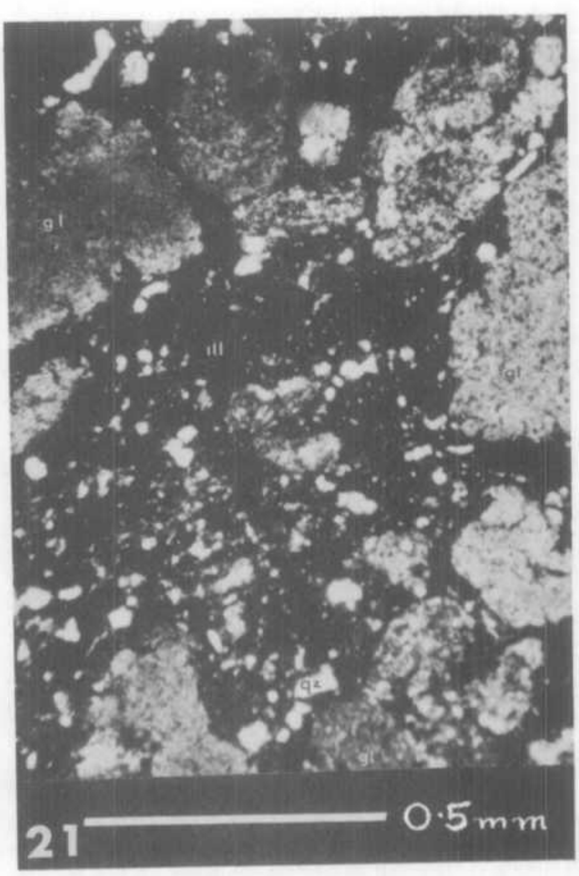
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The maximum intersected thickness of sediments of Unit Gh is in Flaxmans No. 1 Well, and these sediments constitute the type-section.

Table 9A: Subsurface occurrences of Unit Gh

Well Name	Datum - feet above sea level	Depths below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Pretty Hill No. 1	202	2830 to 2929	-2628 to -2727	99	Tyrendarra
Flaxmans No. 1	221	6600 to 6880	-6379 to -6659	280	Port Campbell
Port Campbell No. 1	346	5570 to 5650	-5224 to -5304	80	
Port Campbell No. 2	282	7900 to 8110	-7618 to -7828	210	
Port Campbell No. 4**	440	4850 to 4970	-4410 to -4530	120	
Sherbrook No. 1	480	3620 to 3780	-3140 to -3300	160	

** No cuttings or core samples were available for Port Campbell No. 3.

(b) Lithology

The sediments comprise sandstones and sandy mudstone. The sandy mudstone is very interesting because of its content of sedimentary ferriferous chlorite ooliths and pellets, with related siderite, and minor phosphate. The ferriferous chlorite is oxidized to limonite in varying degrees. Chemical analyses of the oolitic rock and a sideritic sandstone are given by Baker (1963). The sandy parts comprise quartz grains, feldspar grains (plagioclase and microcline), lithic grains (metaquartzite, aphanitic siliceous rocks), and some volcanic rock fragments (andesite, chalcedony).

Lateral variations exist only in terms of contents of detritus: the amounts of quartz, feldspar grains and lithic fragments are greatest in the Flaxmans No. 1 Well.

The presence of ferriferous chlorite in the form of ooliths, carbonate and some phosphate is diagnostic for Unit Gh.

(c) Structures

No sedimentary features were observed in the few cores cut in this unit, and no comments can be made concerning dips and structural features.

(d) Age

Palynological studies indicate that Unit Gh is Upper Cretaceous in age; the sediments occur in the Ascodinium parvum Zone defined by Evans (1966)*.

(e) Stratigraphic relationships

The pronounced difference between sediments of Unit J and the transgressive sediments of Unit Gh, and the regional relations between Unit J and younger units, imply an unconformity at the bottom of Unit Gh.

From our studies, Unit Gh appears to be more restricted laterally than the overlying unit, Gf, (see Plate 5), and the contact between the two is conformable, partly gradational. Taylor (1964b), however, suggests that in the Port Campbell area, the "Flaxmans Beds" (to which Gh is equivalent) extend beyond the limits of the Belfast Mudstone (Gf) to where they are overlapped by the marginal marine Paaratte Formation (Gd). Bock and Glenie (1965) interpose the "Nullawarre Greensand Member" between the Flaxmans Formation and the Paaratte Formation; this is a basal member of the Paaratte Formation and represents a landward facies of the Belfast Mudstone.

(f) Environment of deposition

The chemical and detrital constituents of Unit Gh suggest a transgressive near-shore shallow marine environment with recurrent high energy conditions. Both the nature of the detritus and the presence of abundant iron in the form of ferriferous chlorite imply a nearby continental source. The composition of the lithic constituent suggests that both metamorphic basement outcrops and Lower Cretaceous landmasses were sources for the terrigenous content. The fragments of volcanic detritus could also be derived from older deposits, or could represent the last manifestation of the vulcanism which began in the Upper Jurassic and continued spasmodically throughout the Lower Cretaceous; the volcanic source appears to be restricted to the Port Campbell area.

(g) No evidence of hydrocarbons has been noted in Unit Gh.

Unit Gf

Bain and McQueen (in F.-B.H., 1960*) introduced the name Belfast Mudstone, here termed Unit Gf, to designate a glauconitic mudstone which was intersected in Port Campbell Nos. 1 and 2 Wells.

(a) Distribution

Unit Gf has been recognized in Fergusons Hill No. 1 Well and the Latrobe Bore in the east, and is thought to extend to the west of the Heywood No. 10 Bore. In the Mount Gambier area, the character of Unit Gf is lost by interfingering with Unit Gg.

Table 9B: Subsurface occurrences of Unit Gf

Well Name	Datum - feet above sea level	Depths below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Heywood No. 10	100	5283 to 5390 T.D.	-5183 to -5290	107+	TYRENDARRA
Eumeralla No. 1	167	2960 to 3108	-2793 to -2941	148	
Pretty Hill No. 1	202	2625 to 2830	-2423 to -2628	205	
Flaxmans No. 1	221	5570 to 6600	-5349 to -6379	1030	
Port Campbell No. 1	346	4930 to 5570	-4584 to -5224	640	
Port Campbell No. 2	282	5810 to 7900	-5528 to -7618	2090	PORT CAMPBELL
Port Campbell No. 3	210	4230 to 4608	-4020 to -4398	378	
Port Campbell No. 4	440	4390 to 4850	-3950 to -4410	460	
Sherbrook No. 1	480	3590 to 3620	-3110 to -3140	30	
Fergusons Hill No. 1	651	1955 to 2046	-1304 to -1395	91	
Latrobe No. 1	102	1625 to 1750	-1523 to -1648	125	

(b) Lithology

The mudstone is massive, dark grey, with abundant glauconite (authigenic), finely divided pyrite and organic matter. Minor dolomitic-phosphatic lenses are present. Some ferriferous chlorite and siderite have also been recorded. Minor sandy or silty horizons may occur within the sequence. In addition to fragments of ammonites, small pelecypods, gastropods, foraminifera, ostracods, fish teeth and scales are present. Two chemical analyses were done by Baker (1963). They show that the contents of Fe_2O_3 and FeO vary. The free carbon percentages were 3.91 and 5.87%, and thin sections proved organic material to be finely dispersed. These figures are important because they only barely support any comparison with mudstones from an euxinic environment (23-35% carbon in the Black Sea, Pettijohn, 1957, p.622).

Lateral variations are insignificant and exist only in the form of minor sandy horizons, e.g. Pretty Hill No. 1, Port Campbell No. 2 (Core 13, 7687-7689 feet). The occurrence of fine to very coarse-grained chlorite (ferriferous chlorite cement) sandstone in Port Campbell No. 4 and Sherbrook No. 1 in the upper part of a sequence of similar age is not considered as a lateral variation. These horizons are included in the overlying Unit Gd (Paaratte Formation).

(c) Structures

Sedimentary:

Burrow markings are the only sedimentary features recorded in cores in Unit Gf.

Tectonic:

Slickensiding has been observed in cores from Port Campbell Nos. 3 and 4 and Sherbrook No. 1; this feature may indicate that faulting has affected these sediments.

(d) Age

Recent palynological studies have shown that Unit Gf is Upper Cretaceous in age; the sediments extend in age from the Ascodinium parvum Zone up to and including the Nelsoniella aceras Zone (Evans, 1966). However, the main portion of Unit Gf sediments occurs within the intermediate Deflandrea cretacea Zone.

(e) Stratigraphic relationships

(i) Relationship of Unit Gf to underlying units:

Where Unit Gh is not present Unit Gf is disconformable over Unit M, as in Eumeralla No. 1, or over Unit J, as in Fergusons Hill No. 1 and Latrobe No. 1. Elsewhere in the Port Campbell area, Units Gf and Gh are conformable.

(ii) Relationship of Unit Gf to overlying units:

In some wells the boundary between units Gf and Gd (Paaratte Formation) is gradational, and a gradual reduction in the amount of mudstone is accompanied by an influx of sandstone. Generally, however, the lithological change from

Unit Gf (cont'd.)

Photomicrograph 22. Sandy Mudstone.

Port Campbell No. 2, Core No. 5, depth 7885'-87'.
Plane polarised light.
Angular to subangular, very fine to medium-grained detrital grains.
Quartz (qz) 25%, glauconite (gl) 5%, pyrite lenses and specks (py) 5%, illitic clay (ill) with finely divided organic matter 65%.

Photomicrograph 23. Mudstone.

Fergusons Hill No. 1, Core No. 3, depth 2028'-31'.
Plane polarised light.
Angular silt-size detritus.
Quartz (qz) 30%, glauconite (gl) 5%, illitic (ill) and sideritic clay with disseminated organic matter 65%.

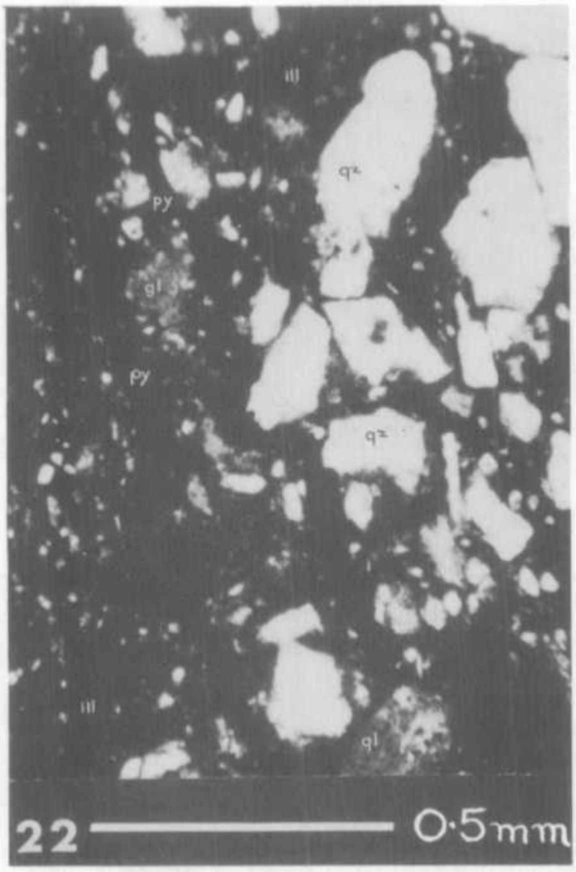
Unit Gg.

Photomicrograph 24. Sandstone

Mount Salt No. 1, Core No. 30, depth 8913'.
Plane polarised light.
Subangular to subrounded, fine to coarse-grained (0.15-0.75 mm); poorly sorted.
Quartz (qz) 65%, feldspar (f) 25%, chloritic (chl) and carbonaceous clay matrix 10%.
Note chlorite development on fractured feldspar.

Photomicrograph 25. Mudstone

Geltwood Beach No. 1, Core No. 7, depth 3632'-47'.
Plane polarised light.
Angular, silt-size detritus of quartz (qz); subangular, very fine to fine-grained fragments of quartz and subordinate orthoclase feldspar (f).
Groundmass is cryptocrystalline illitic (ill) and chloritic clay with finely divided pyrite and organic matter. Siderite occurs as dispersed microcrysts, and as cryptocrystalline aggregate (0.12 mm).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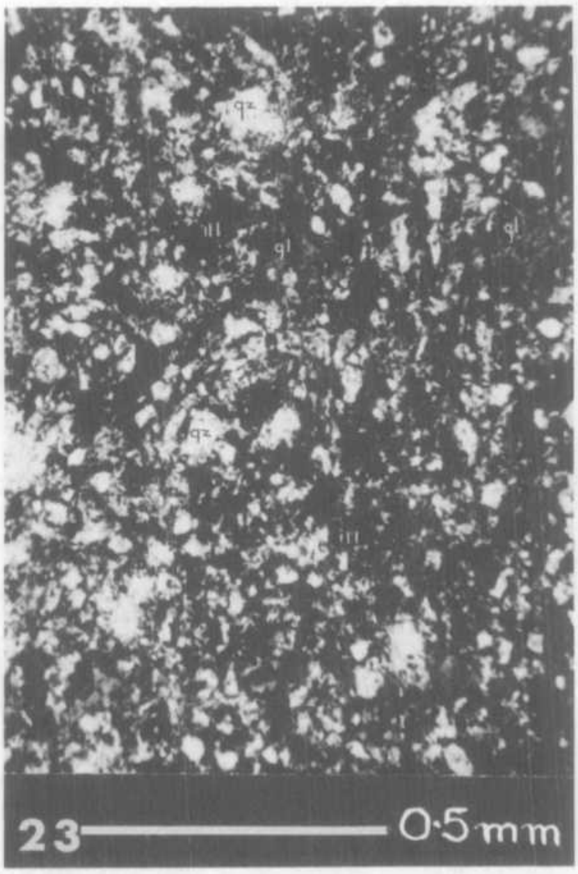
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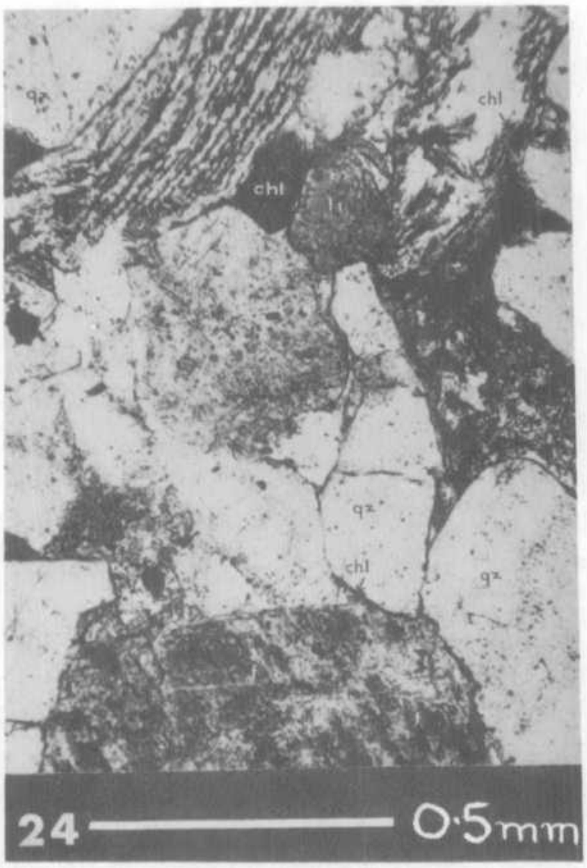
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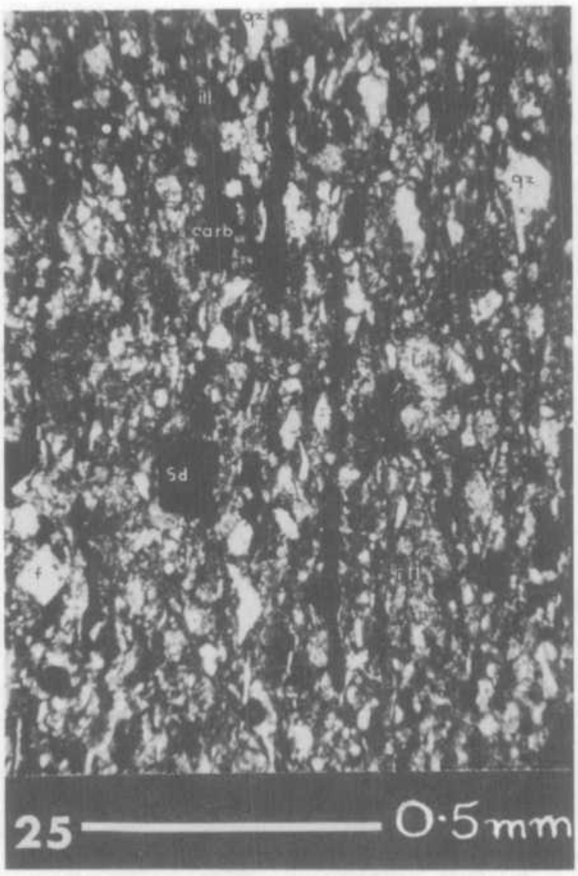
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Unit Gf to Unit Gd is sharper, as reflected in marked changes in the cuttings over short intervals.

The widespread deposition of coarse-grained sandstones of Unit Gd over Units Gf and Gg to the west heralds regressive conditions which continue into Gb time. Both Taylor (1964) and Bock and Glenie (1965) show interfingering of Belfast Mudstone (Gf) and Paaratte Formation (Gd) in the northern part of the Port Campbell area.

(f) Environmental criteria

The suspended loads which were brought to the area of deposition of Unit Gf were mainly clay and silt, with some coarser material. Chemical precipitation took place at the same time. This may be referred to as a "restricted basin" of deposition (Krumbein and Sloss, 1963). The deposition took place in calm restricted slightly alkaline waters, where reducing conditions prevailed, with the formation of glauconite and sulphides. The macro- and microfaunal associations are also characteristic of such an environment (Taylor, op. cit.).

(g) Hydrocarbon occurrence in Unit Gf

No oil staining has been observed in either the cores or cuttings of Unit Gf sediments.

Unit Gg

In the preceding section dealing with Unit Gf, restricted conditions have been described for the depositional environment. Unit Gg includes time-equivalent sediments to Unit J-H, Gf and Gh deposited outside the restricted basin area.

(a) Occurrences of Unit Gg sediments from well data

Occurrences of Unit Gg in wells drilled to date are restricted to the Mount Gambier area.

Table 9C: Subsurface occurrences of Unit Gg

Well Name	Datum (feet above sea level)	Depths below datum level (feet)	Depths from sea level (feet)	Thickness (feet)	Area
Geltwood Beach No. 1	30	3490 to 3670	-3460 to -3640	180	MOUNT
Mount Salt No. 1	86	6520 to 10044 T.D.	-6434 to -9958	3524+	GAMBIER
Kalangadoo No. 1	230	2494 to 2560	-2264 to -2330	66	

The wide variations in the thickness of Unit Gg sediments are probably due to the fact that Geltwood Beach No. 1 and Kalangadoo No. 1 were probably near the edge of the basin during this phase of deposition.

(b) Lithology

The sediments comprise interbedded and interlaminated sandstone and mudstone (shaly in part). In the Mount Salt No. 1 well an estimate of the sand/shale ratio is :-

Upper part: subunit Gg_1 sand/shale ratio=4
Lower part: subunit Gg_2 sand/shale ratio=1

The sandstone comprises -

quartz -	35-45%
feldspar -	3-5%
lithics: metaquartzite, aphanitic rocks, chloritic rock fragments -	5-15%
accessories -	2-5%
matrix -	40-45%

The lithics were derived from metamorphic sources and are also present in units above Unit Gg. No volcanic rock fragments were observed in the framework of the sandstones of Unit Gg. Suitable terminology for the sandstones of Unit Gg is lithic greywacke (Pettijohn, 1957). The matrix (up to 45%) is a silt with abundant clayey material (mainly illitic, but with kaolinite patches), finely dispersed chlorite, pyrite, some organic matter, or cement may occur as minor siderite rhombs and patchily developed dolomite. In the latter case the porosity may be as high as 25%, with good permeability. However the great variability in the distribution of cementing media from layer to layer results in erratic permeabilities both laterally and vertically.

The silt-size particles in siltstones may constitute up to 70% of the rock, and comprise angular quartz, fragments of chloritic rocks, and feldspar grains; feldspars are less abundant than rock fragments. The groundmass is illitic, kaolinitic and chloritic. Opaque minerals, pyrite, carbonaceous matter and reddish plant (spore ?) fragments constitute an important part of the groundmass, together with micas.

Because Unit Gg was intersected in three wells only, little is known of lateral variations except that important changes in thickness occur in the area of deposition.

The difference between Unit Gg and the time equivalent units J-H, Gf, and Gh in the Port Campbell area results from the different structural history of these two areas. In both areas however, contemporaneous subsidence is envisaged.

In the Mount Salt area conditions inducing a broadly cyclic sedimentation existed during deposition of the lower part of Unit Gg (sub-unit Gg_2). These are cycles of bedded sandstone 50 to 100 feet thick followed by 30 to 50 feet of argillaceous siltstone and shale. This pattern of sedimentation is not apparent in the upper part of Unit Gg (sub-unit Gg_1) which becomes much sandier. The 180 feet interval corresponding to Unit Gg in Geltwood Beach No. 1 is very sandy, contains gravels, and presents no signs of cyclic sedimentation.

(c) Structures

(i) Sedimentary:

Small scale low-angle cross-bedding, churned bedding and burrows are common throughout the sequence. The churned bedding and burrow markings are generally associated with the argillaceous sandstones. Other features include laminations, convolutions and scour-and-fill structures.

It appears that in the coarser grained sediments, cross-bedding and scouring features frequently occur, whilst in the finer grained sediments, fine laminations, convolutions, burrows, churned bedding and load effects are common.

(ii) Tectonic:

No evidence of faulting has been recorded in cores of Unit Gg sediments. Variable dips ranging from flat to 25° have been recorded in cores from Mount Salt No. 1 (O.D.N.L., 1963a*) but high dips are attributed mainly to cross-bedding; a true dip of approximately 15° in Core No. 24 was noted by Dellenbach (1964*).

(d) Age

The age determination of Unit Gg is based mainly on foraminifera (Ludbrook, in O.D.N.L., 1963a), and on spores, pollens and microplankton (Evans, op. cit.); further discussion is given in Dellenbach (op. cit.*).

In Mount Salt No. 1 palynological evidence suggests that the age of Unit Gg sediments ranges from uppermost Lower Cretaceous up to and including Upper Cretaceous; these sediments fall within the palynological unit K2, the <u>Ascodinium parvum</u> Zone and part of the <u>Deflandrea cretacea</u> Zone. This would indicate that Unit Gg is in part time-equivalent to Unit J (Waarre Formation), Unit Gh (Flaxmans Formation) and Unit Gf (Belfast Mudstone).

(e) Stratigraphic relationships

Recent palynological studies (Evans pers.comm.) indicate that only a small time break exists between units M and Gg; however an unconformity is thought to extend from the east across the western area of the Basin, and this relationship is also suggested by seismic records.

A gradational relationship is envisaged between Unit Gg and Gd (Paaratte Formation). The frequency of mudstone interbeds or laminae decreases upwards as the marine influence regresses and influxes of coarser sediments occur.

(f) Environment of deposition

Shallow water sedimentary structures, features indicating intermittently turbulent conditions, and cyclic deposition in the lower part of Unit Gg, support the view that sedimentation took place in a shallow sea or outer paralic zone.

The evidence of regression in the upper part of Gg in the western area of the Otway Basin, whereas marine influences persisted in the east, suggests relative uplift of the western region at that time. However the marked thickening of sediments in the Mount Salt area indicates a fairly rapid subsidence. These facts, combined with the interpretation of seismic contouring (Plates 13, 14), show that as the western area was rising, a median graben with an E.S.E.-W.N.W. trend was subsiding and being infilled rapidly with detritus eroded from the marginal areas.

In Geltwood Beach No. 1 and Kalangadoo No. 1 the reduction of thickness and the granularity of sediments of Unit Gg suggest that these wells were drilled in the marginal areas of the graben.

(g) Only limited evidence of hydrocarbons has been noted in Unit Gg; fluorescence was noted in core analyses of Cores 28 and 33 of Mount Salt No. 1. A drillstem test in subunit Gg_2 in Mount Salt No. 1 yielded salt water.

Unit Gd

(a) Occurrences of Unit Gd sediments from well data

Unit Gd or Paaratte Formation (Bain and McQueen, in F.-B.H., 1960a*) is present in most of the subsidized wells of the Otway Basin. Although the original definition of this formation was in wells from the Port Campbell area, the petrological characteristics of this unit are such that the unit can be followed with certainty throughout the basin to the west of the Otway Ranges.

Table 9D: Subsurface occurrences of Unit Gd.

Well Name	Datum (feet above sea level)	Depths below datum level (level)	Depths from sea datum level (feet)	Thickness (feet)	Area
Geltwood Beach No. 1	30	2960 to 3490	-2930 to -3460	530	MOUNT GAMBIER
Mount Salt No. 1	86	4230 to 6520	-4144 to -6434	2290	
Kalangadoo No. 1	230	2320 to 2494	-2090 to -2264	174	
Heathfield No. 1	244	1600 to 1680	-1356 to -1436	80	
Nelson Bore No. 1	10	4500 to 7305 T.D.	-4490 to -7295	2805+	
Heywood No. 10	100	4700 to 5283	-4600 to -5183	583	TYREN-DARRA
Eumeralla No. 1	167	2760 to 2960	-2593 to -2793	200	
Pretty Hill No. 1	202	2370 to 2625	-2168 to -2423	255	
Flaxmans No. 1	221	4240 to 5570	-4019 to -5349	1330	PORT CAMPBELL
Port Campbell No. 1	346	4250 to 4930	-3904 to -4584	680	
Port Campbell No. 2	282	5000 to 5810	-4718 to -5528	810	
Port Campbell No. 3	210	3710 to 4230	-3500 to -4020	520	
Port Campbell No. 4	440	4020 to 4390	-3580 to -3950	370	
Sherbrook No. 1	480	3230 to 3590	-2750 to -3110	360	
Fergusons Hill No. 1	651	1495 to 1955	- 844 to -1304	460	
Latrobe No. 1	102	1525 to 1625	-1423 to -1523	100	

(b) Lithology

The sediments of Unit Gd are mainly sandstones and siltstones (or shales). The sand/shale ratio is variable, ranging from 0.3 in Port Campbell No. 2 to 3.4 in Port Campbell No. 3, see Figure 6. The sandstones are discussed in terms of the framework and the cement.

The framework consists of angular to subrounded, fine to very coarse-grained quartz (40-50%), lithics - metaquartzite and chalcedonic rock fragments (10-15%), with up to 25% of well rounded chloritic rock fragments or chloritic (greenalite ?) pellets in Port Campbell No. 4, Core 8. Feldspar (microcline and orthoclase) is present in minor amounts (5-10%). The sorting is variable with bimodal distribution occurring in many places.

The presence of rounded chloritic-rock fragments and chlorite pellets is typical of Unit Gd. These have been often confused with glauconite, which may also be present in minor amounts in the sediments. The chloritic constituents are generally of a coarser grade than the remainder of the detritus. Their shape is well-rounded to lobate. Some of the pellets have concentric coatings of chlorite and thus represent incipient ooliths. Many of the fragments represent reworked chloritic mudstone. Others are lithic fragments or single mineral grains (feldspar mainly) which may be coated or replaced by chlorite.

Although some of these chloritic constituents may be derived from the erosion of a chlorite-bearing metamorphic rock, the majority are thought to have been authigenic. This is supported by the type of chlorite - a cryptocrystalline ferriferous chlorite (probably geenalite), and the presence of chlorite coatings on grains. Fragments of reworked chloritic mudstone are obviously derived from a sedimentary rock source, either from older Cretaceous formations, or penecontemporaneously.

The chlorite detritus horizons are distinct from horizons cemented by chlorite which are known both from Unit Gd to the older units, Gf and Gg.

Chloritic sandstones of Gd have been referred to as the "Nullawarre Greensand Member" of the Paaratte Formation by Bock and Glenie (1965), who suggest that they represent a landward facies of part of the Belfast Mudstone. W.A. Esplan, at an underground water symposium in Melbourne (1966) noted that the "Nullawarre Greensand Member" is thickest (557 feet) at Ayrford, seven miles north-west of Timboon, and apparently formed in an east-west depression; low salinity waters are general in the unit, becoming brackish in the south-western part.

Other cementing media, where present, are mostly carbonates. The most typical occurrence of these carbonates is in the form of rhombs of siderite, which tend in many cases to form aggregates and spherules. In some instances a chamosite nucleus is surrounded by siderite. Calcite and dolomite constitute a megacrystalline cement. Lenses of cryptocrystalline siderite may also be present. Pockets

Unit Gg (cont'd)

Photomicrograph 26. Sandstone and Mudstone lamination

Kalangadoo No. 1, Core No. 2, 2505'-06'.
Plane polarised light.
Subangular to subrounded, very fine to fine-grained (0.12-0.24 mm); moderately sorted.
Quartz (qz) 35%, feldspar (f) 5%, lithics (li) 10%, muscovite (mi) 5%, chloritic (chl) and illitic clay matrix 45%.
Groundmass of the mudstone is illitic (ill) and chloritic with dispersed organic matter (carb) and pyrite.

Unit Gd

Photomicrograph 27. Sandstone

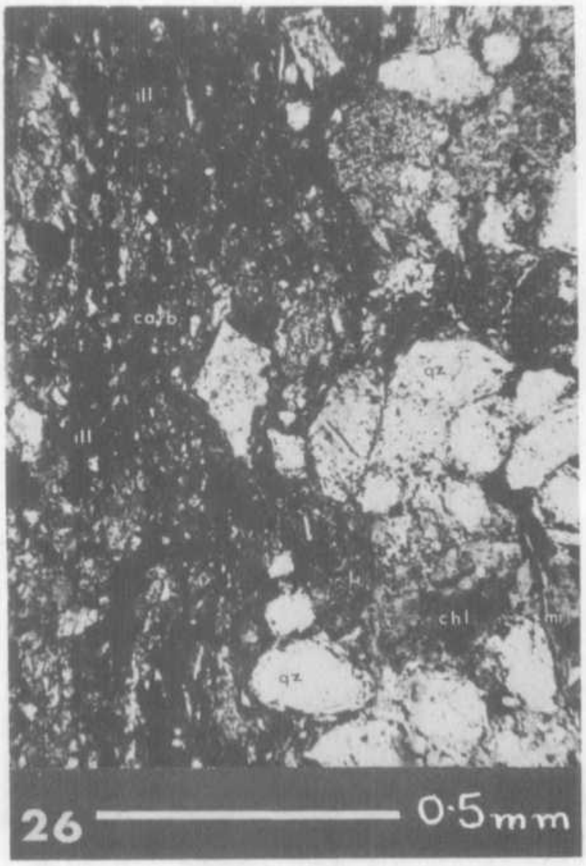
The Nelson Bore, core sample at 6298'.
Plane polarised light.
Compact, subangular, fine to coarse-grained (0.24-0.81 mm); moderately sorted.
Quartz (qz) 60%, chlorite fragments (chl) 10%, recrystallized siderite cement (sd) 30%.
Note corrosion of grains by siderite.

Photomicrograph 28. Sandstone

Eumeralla No. 1, Core No. 4, depth 2839½-41'.
Plane polarised light.
Compact, angular to subrounded very fine to medium-grained (0.12-0.27 mm); moderately sorted.
Quartz (qz) 70%, siderite cement (sd) 30%.

Photomicrograph 29. Sandstone

Sherbrook No. 1, Core No. 8, depth 3285-87'.
Plane polarised light.
Compact, subangular to subrounded, fine to medium-grained (0.15-0.48 mm); moderately sorted.
Quartz (qz) 40%, lithics (chlorite pellets (chl), metamorphics (met)) 20%, carbonaceous matter (carb) 20%, muscovite (mi) 5%, calcite (ca), and chlorite (chl) cement 15%.
Note shredded muscovite and chlorite rims around quartz grains.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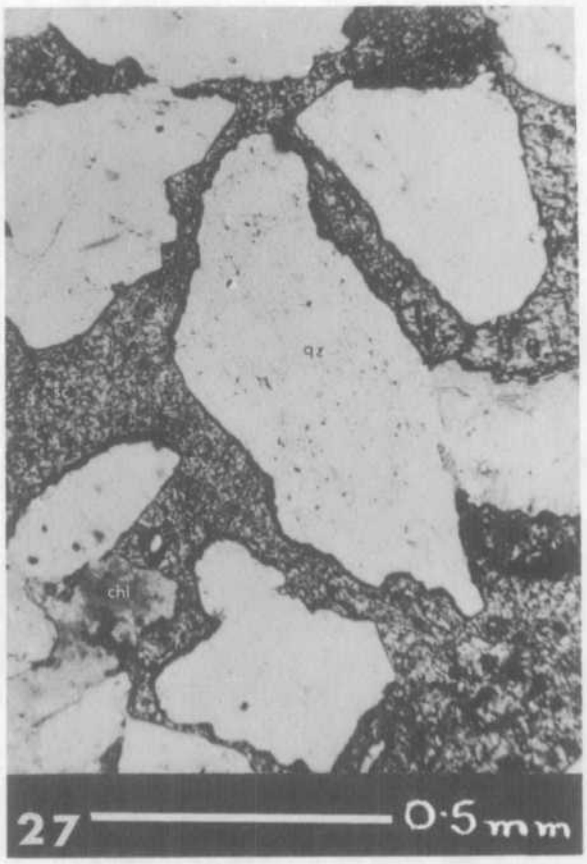
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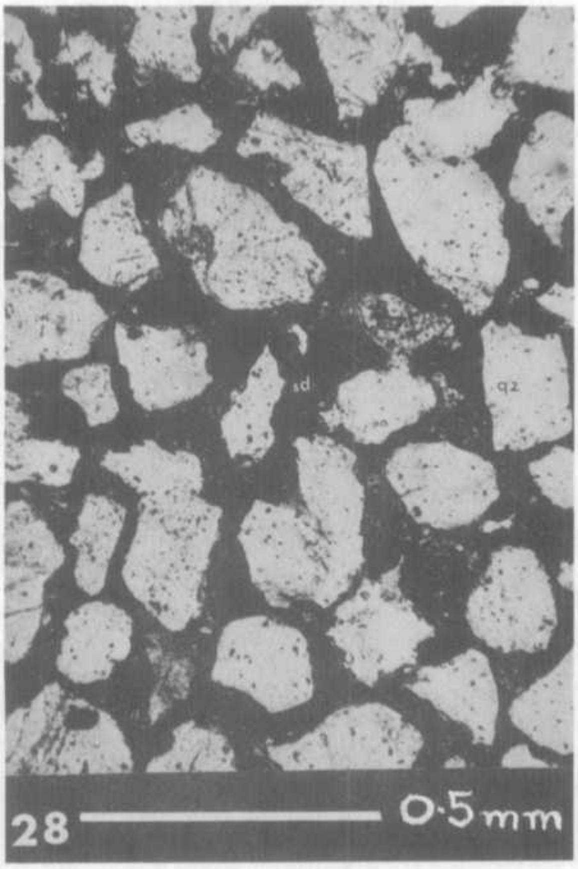
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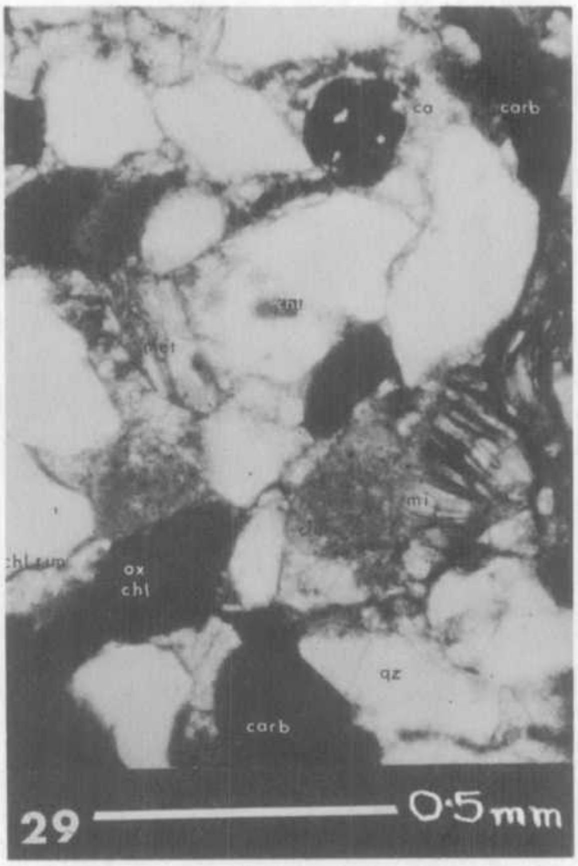
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of kaolinite occur and include recrystallized booklets of kaolinite. Limonite and haematite may be present in a finely divided state, and minute crystals of pyrite and marcasite are common. Small macerated coaly fragments of plants are typically associated with the siderite lenses in the sandstones.

The relationship between cement and framework is also characteristic for Unit Gd; the carbonate cement extensively corrodes the detrital grains and contributes to the rather loose packing of the sandstones. Siderite rhombs have generally formed around the quartz and feldspar grains and are best developed where the grains are in contact.

The only lithofacies variations in Unit Gd are in the relative amounts of the detrital constituents making up the sandstones. In both Geltwood Beach No. 1 and Mount Salt No. 1 there is an increase in the silt content of Unit Gd towards the base.

(c) Structures

(i) Sedimentary:

Sedimentary structures occur throughout Unit Gd, and have been studied mainly in Mount Salt No. 1 and the Nelson Bore, where considerable footages were cored.

In the upper section (sub-unit Gd_1) low angle (5-10°) planar cross-bedding is common together with fine laminations, scour-and-fill, churned bedding and burrows; current ripples and "sand nests" (Bouma, 1962) are rare.

In the lower part of Unit Gd (sub-unit Gd_2) high angle (up to 30°) cross-bedding occurs in fine to coarse-grained sandstone; other features include laminations, convolutions, current ripple marks, small scale scour-and-fill and collapse (slump) structures, churned bedding and burrows.

(ii) Tectonic:

No features suggesting tectonic movements have been observed in the cores. The dip of Unit Gd sediments is thought to be low.

(d) Age

Foraminiferal studies (Taylor, 1964) and palynological studies (Evans, 1966*) indicate that Unit Gd is Upper Cretaceous in age. Evans has shown that Unit Gd may occur within three palynological zones: <u>Deflandrea cretacea</u>, <u>Nelsoniella aceras</u> and <u>Xenikoon australis</u>. In most wells examined the bulk of Unit Gd sediments occurs in the <u>N. aceras</u> Zone.

(e) Stratigraphic relationships

(i) Relationship of Unit Gd to underlying units:

Some difficulty is experienced in placing the lower limit of Unit Gd, because a gradational relationship exists between it and Unit Gf. In some wells intertongueing of Unit Gd by a facies similar to the Belfast Mudstone (Unit Gf) occurs, which adds to the difficulty of separating the two units.

The relation between the facies and fossil content has been discussed by Taylor (1964) who contends that there is no evidence of an unconformity between the Paaratte Formation (Gd) and Belfast Mudstone (Gf), and that the upper horizons of the Belfast Mudstone are in part "synchronous" with basal Paaratte Formation. All petrological data available show that the sandstones of Unit Gd are well defined in terms of grain-size range, sorting, nature of the framework constituents, cements and relationship between cement and grains. Furthermore, a comparative study has been made of sandstones with chlorite cement from the 4013-4393 feet interval of Port Campbell No. 4 which had previously been correlated with the Belfast Mudstone (F.-B.H., 1964g*). The results show that the nature of the rock-fragments, as well as the sorting, angularity, and maturity are different to the sandy parts of the Belfast Mudstone, and similar to Unit Gd, and this interval is now correlated with Gd. The rock-unit status of Unit Gd or Paaratte Formation is considered to be well established, and its lower limit, although gradational with Unit Gf where the latter is present, is well-marked throughout the rest of the Basin.

(ii) Relationship of Unit Gd to overlying units:

The boundary between Unit Gd and Unit Gb is obscured by the gradational nature of the lithological change. The best criteria for recognizing the boundary are the occurrence of typical carbonate-cemented sandstone or siltstone of Unit Gd and the development of coal bearing horizons or coal stringers in Unit Gb. The Frome-Broken Hill Company considered that the upper part of the Paaratte Formation (Unit Gd) is at the change from sandstone below to silty sandstone above. However, the cementing media of the silty horizons are similar to those of Unit Gd, and the change in lithology which best supports the existence of two distinctive Units Gd and Gb (and a change in environment of deposition) is above the silty interval.

In the past, the presence of a formation with strongly regressive characters above the Unit Gd has not been recognized. Some more recent publications (Taylor, 1964; Bock and Glenie, 1965) still do not distinguish this upper unit and its significance with regard to the basinwide unconformity at the top of the Upper Cretaceous (or possibly within the Palaeocene). The evidence gained from the study of the subsidized wells shows that, where present, Unit Gd is always overlain by Unit Gb, and that the younger units of the Upper Cretaceous have a wider areal extent than the older ones. The change from Gd to Gb marks a phase in the evolution of the Otway Basin and an equilibrium is reached between terrigenous supply and rate of subsidence.

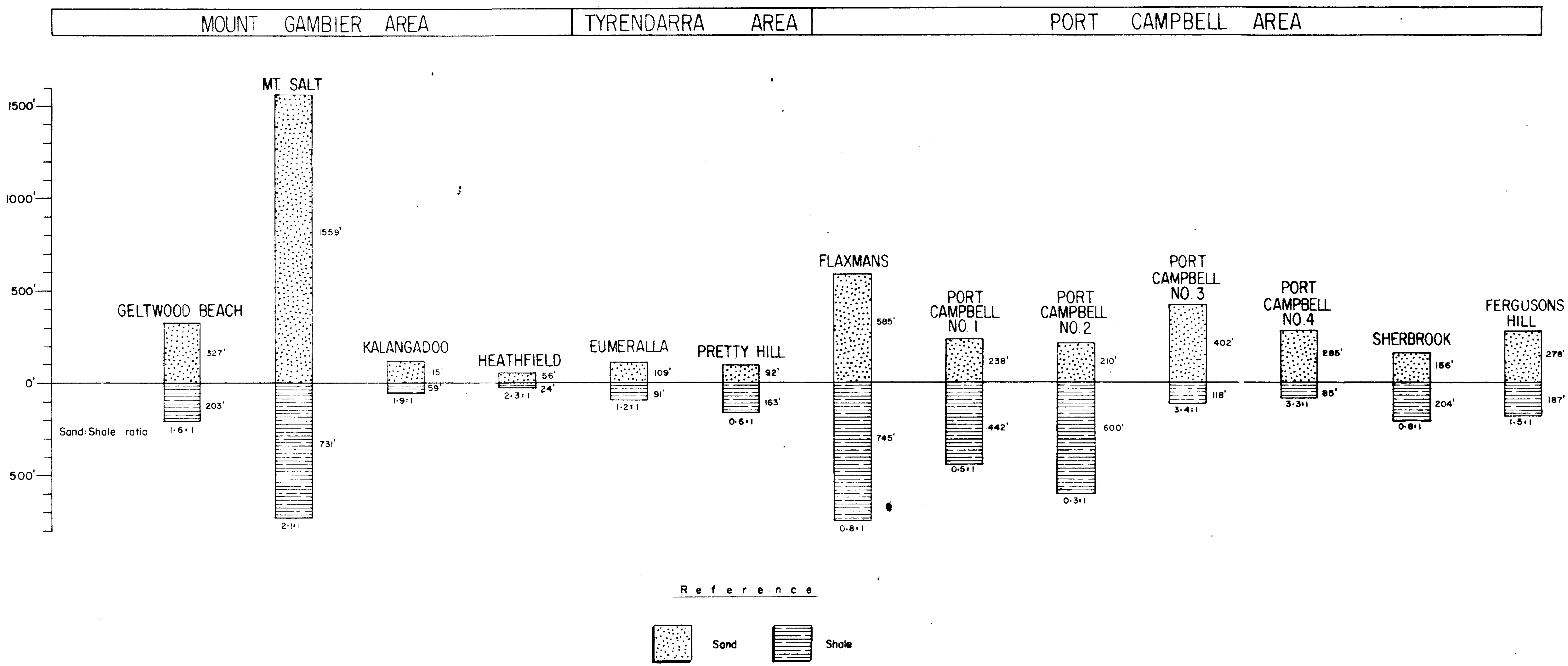
(f) Environment of deposition

The sediments of Unit Gd have been correctly termed 'marginal marine' (Taylor, 1965) or outer paralic. They correspond to deposition in outer deltaic lagoonal and shallow neritic areas. It is most interesting that the environment was propitious for the genesis of iron silicate producing ferriferous chlorite pellets, and in some parts an extensive ferriferous chlorite cement.

OTWAY BASIN

PROPORTIONS OF SAND AND SHALE BEDS IN UNIT 'Gd' SEDIMENTS

(NO HORIZONTAL SCALE)



The thicknesses of the sand and shale are based on Electric Logs and B.M.R. cuttings determinations.

The mineral constituents indicate that the sandstones were deposited in oxidizing to slightly reducing conditions with slightly alkaline water. There was little supply of organic matter, unlike in Unit Gb above.

Flocculation of iron gels evolving from climatic-pedogenic processes on a nearby landmass and erosion account for the supply of iron. Similar conditions probably recurred at different times during deposition of units Gb, Dd, and to a lesser extent, Unit Be.

(g) Hydrocarbon occurrence in Unit Gd

The only hydrocarbon occurrence recorded in Unit Gd was in Port Campbell No. 1 (Core 17, 4757 feet) where waxy oil was recorded (F.-B.H., 1960a*).

The porosities of the sandstones of Unit Gd are generally fair to good. Permeabilities although good on the average may vary strongly in relation to presence of silty material and chemical cements (including chlorites). Regressive conditions become more marked towards the top of Unit Gd, and so the amount of chemical cement decreases.

On the whole Unit Gd presents good reservoir potential. However, it is in most cases overlain by a porous permeable unit Gb, which in turn is separated by an unconformity from the lowermost Tertiary sediments.

Unit Gb

(a) Occurrences of Unit Gb sediments from well data

Unit Gb, tentatively named "Curdies Beds" by Leslie (1966), evolves from the recognition in 14 subsidized wells which intersected Upper Cretaceous sediments, of an interval with characteristic lithology between typical Unit Gd sediments and the unconformity at the base of Unit Dd. The main difficulties encountered in the study of Unit Gb were that the cuttings recovered were generally of loose sands, and that few cores were taken in this interval.

Table 9E: Subsurface occurrences of Unit Gb

Well Name	Datum - feet above sea level	Depths below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Geltwood Beach No. 1	30	1910 to 2960	-1880 to -2930	1050	MOUNT
Mount Salt No. 1	86	3270 to 4230	-3184 to -4144	960	
Kalangadoo No. 1	230	1980 to 2320	-1750 to -2090	340	GAMBIER
Heathfield No. 1	244	1217 to 1600	- 973 to -1356	383	
Nelson Bore No. 1	10	3746 to 4500	-3736 to -4490	754	
Heywood No. 10	100	4352 to 4700	-4252 to -4600	348	
Portland No. 3	16	5250 to 5574	-5234 to -5558	324	TYREN-
Eumeralla No. 1	167	2660 to 2760	-2493 to -2593	100	DARRA
Pretty Hill No. 1	202	2160 to 2370	-1958 to -2168	210	
Flaxmans No. 1	221	3480 to 4240	-3259 to -4019	760	
Port Campbell No. 1	346	3380 to 4250	-3034 to -3904	870	
Port Campbell No. 2	282	3750 to 5000	-3468 to -4718	1250	PORT
Port Campbell No. 3	210	2910 to 3710	-2700 to -3500	800	
Port Campbell No. 4	440	2550 to 4020	-2110 to -3580	1470	
Sherbrook No. 1	480	1930 to 3230	-1450 to -3750	1300	CAMPBELL
Fergusons Hill No. 1	651	849 to 1495	- 198 to - 844	646	
Latrobe No. 1	102	1430 to 1525	-1328 to -1423	95	
Anglesea No. 1	78	370 to 1816	- 299 to -1738	1446	TORQUAY

The widespread occurrence of the unconformity above Gb is confirmed in the present study from both petrological and seismic investigations. The inclusion (Baker and Cookson, 1955) in the Lower Eocene to Palaeocene of sediments between 4250 and 4500 feet in the Nelson Bore is different to our division of units; we include these sediments in Unit Gb which is at least partly Upper Cretaceous. Bock and Glenie (op.cit.) likewise do not recognize the marked unconformity near the base of the Tertiary and include all formations from the "WaarreSandstone" to their "Dilwyn Formation" in the Wangerrip Group; its age in their division is Upper Cretaceous-Palaeocene. Stratigraphic nomenclature is discussed in more detail later.

(b) Lithology

The chief characteristic of Unit Gb is the presence of coal fragments and seams in a sequence of argillaceous sandstones and subordinate mudstones.

The argillaceous sandstones

The sandstone is subangular to subrounded, coarse to very coarse-grained with some granules. Quartz (up to 50%), potash-feldspar (up to 15%) and varying amounts of lithic fragments (up to 20%) comprising metaquartzite, schist, and grey rounded siliceous rock fragments, constitute the framework of the sandstone. A detrital matrix comprising clay, mica (muscovite and biotite), opaque minerals including abundant pyrite, and carbonaceous matter is present. The clay material is mainly kaolinitic and occurrences of recrystallized kaolinite have been noted. The degree of cementation by a clayey matrix is variable and it appears that horizons with poorly consolidated sands occur. Coal fragments and stringers are particularly abundant towards the top of the unit in wells close to the Otway Ranges (Sherbrook No. 1, Anglesea No. 1). The apparent trend for the frequency of coal horizons is a general increase eastwards but with local increases in the main area of thick sedimentation (see Figure 7). The cumulative thickness of coal stringers is in excess of 150 feet in Anglesea No. 1, approximately 50 feet in Sherbrook No. 1 and thickness of 60 to 70 feet occur in the Port Campbell and Mount Salt areas. The tentative sand/shale ratio values calculated for Unit Gb show important variations with highest values in the wells nearest the areas of the main troughs of sedimentation, and a general predominance of sandstones over shale (Figure 7).

The mudstones

Dark pyritic silty mudstones are subordinate in Unit Gb. The groundmass is brown to grey-brown clay with finely dispersed carbonaceous matter, abundant pyrite, and concentrations of muscovite and biotite flakes.

In addition to the general trend of increasing thickness and increasing frequency of coal horizons to the east of the Otway Basin, some minor variations occur in the Mount Salt and Heathfield areas. In the Heathfield No. 1 well, Unit Gb is very sandy and a possible explanation is the proximity (closer than 10 miles) of a land source at the time of deposition.

In Eumeralla No. 1, Unit Bg, though containing coal stringers, also contains horizons cemented by siderite and some calcite. It is probable that these sediments were deposited in brackish water.

(c) Structures

(i) Sedimentary:

Fine sand and carbonaceous clay laminations are common in Unit Gb sediments. Other features include cross-bedding and rare scour-and-fill; burrows outlined by pyrites have been recorded in siltstone in Port Campbell No. 1.

(ii) Tectonic:

Structures have only been recorded in Sherbrook No. 1 (F.-B.H., 1964b*); these are in the form of slickensiding (Core No. 5) and microfaulting (Core No. 6). Apparent dips ranging from 5° to 20° occur in Sherbrook No. 1. In general, Unit Gb sediments are thought to dip at a low angle.

Unit Gb

Photomicrograph 30. Sandstone

Mount Salt No. 1, Core No. 13, depth 4221'.
Plane polarised light.
Angular to subangular, very fine to medium - grained (0.09-0.45 mm), main mode = fine-grained; moderately sorted.
Quartz (qz) 35%, lithics (li), chert (ch) and metamorphics 35%, coal (c) 20%, mica (mi) 5%, kaolinitic matrix (ka) 5%.
Note sideritization (sd) of muscovite.

Photomicrograph 31. Sandstone

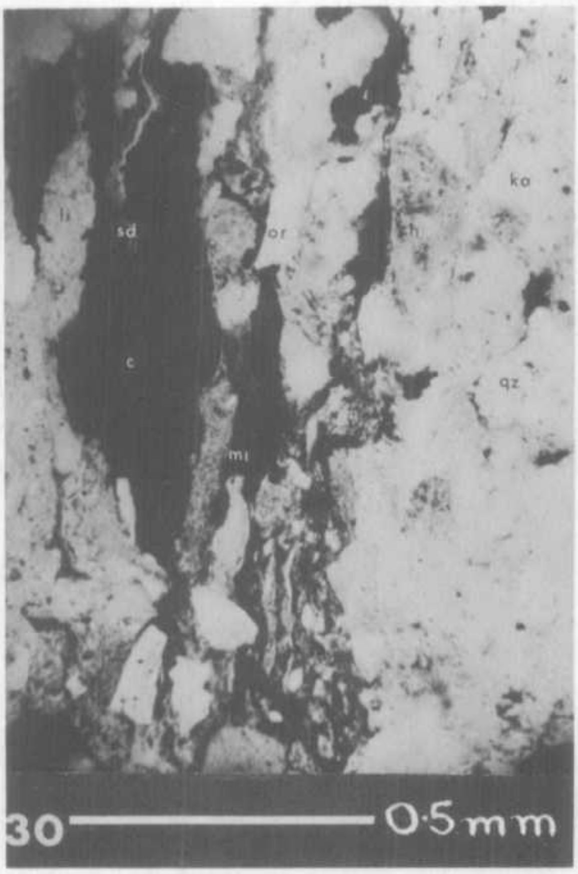
Eumeralla No. 1, cuttings sample 2680'.
Plane polarised light.
Angular to subangular, very fine to medium-grained (0.09-0.30 mm); main mode = fine-grained; moderately sorted.
Quartz (qz) 5%, opaques (op) 5%, siderite cement (sd) 45%.
Note corrosion of grains by microcrystalline siderite.

Photomicrograph 32. Sandy dolomite

Pretty Hill No. 1, cuttings ~~sample~~ 2300'.
Plane polarised light.
Angular to subangular, silt-size to fine-grained (0.09-0.15 mm) detrital fragments.
Quartz (qa) 25%, opaques-carbonaceous matter (c) + pyrite (py) 10%, chloritic matrix (chl) 5%, dolomite cement (do) 60%.
Carbonaceous matter (carb) and clay is present between crystal boundaries.

Photomicrograph 33. Sandstone

Sherbrook No. 1, Core No. 7, depth 3046'-66'.
Plane polarised light.
Angular to subangular, very fine to fine-grained (0.09-0.21 mm) with rare coarse-grained (0.60 mm) detritus; moderately sorted.
Quartz (qz) 70%, lithics-siliceous fragments (li) 5%, muscovite (mi) 5%, illitic carbonaceous clay matrix (ill) 20%.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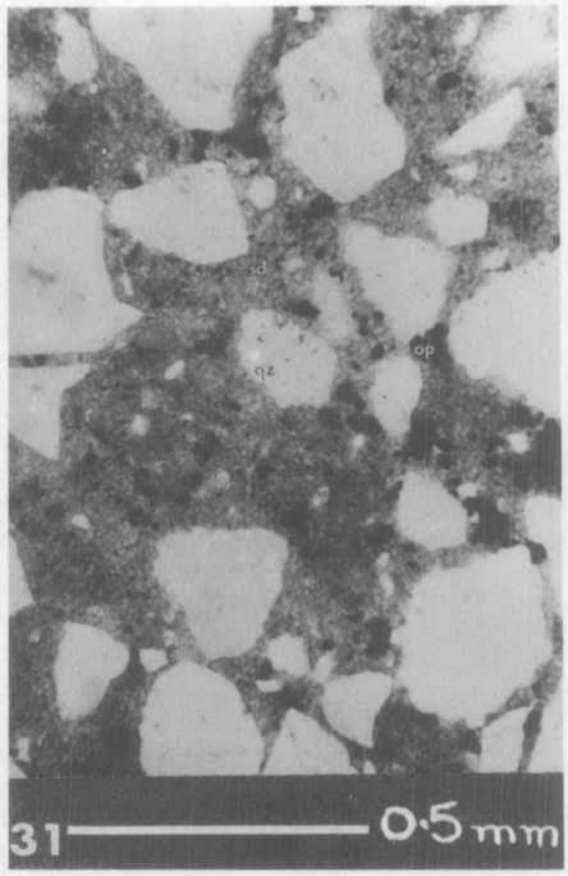
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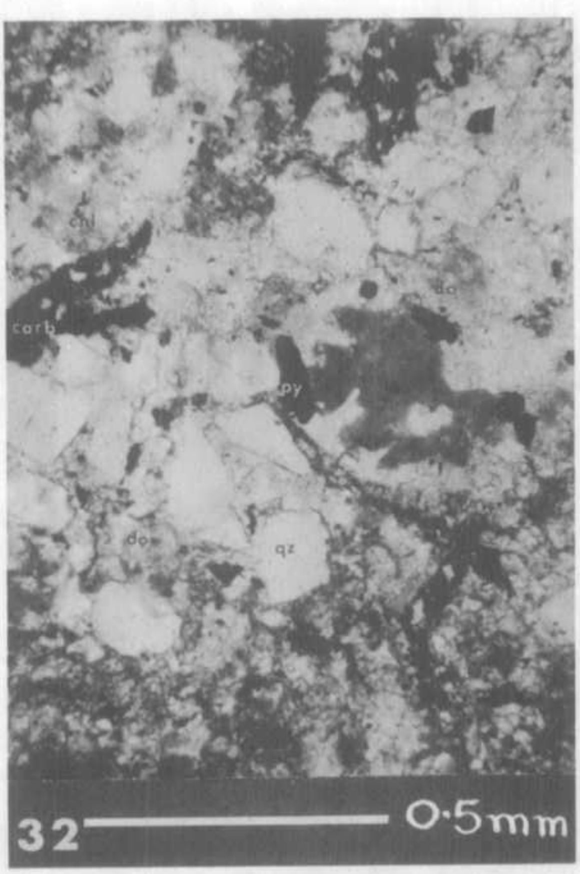
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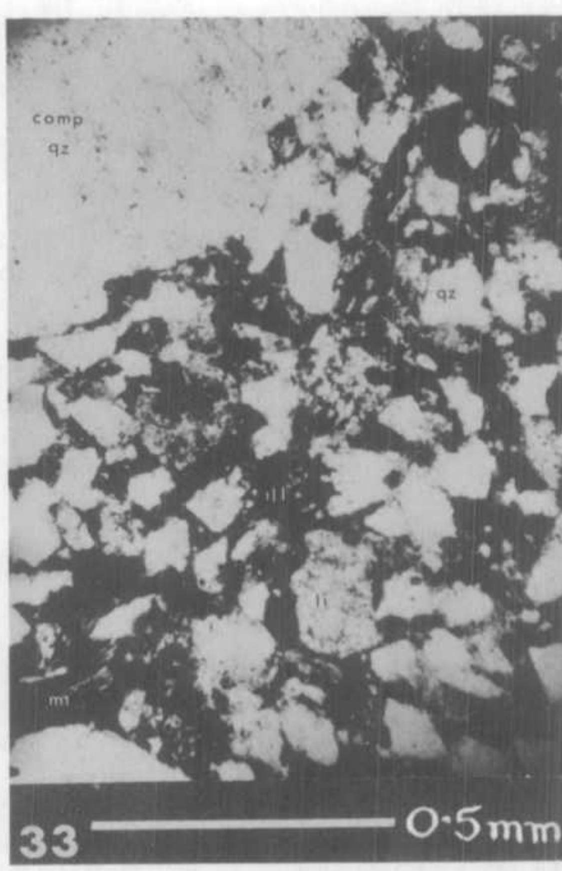
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(d) Age

The small number of cores taken in Unit Gb has resulted in uncertainties in the dating of the sediments. Since the sedi- contain few foraminifera, reliance must be placed mainly on palynological age determinations and these require core material. Where this is available, an Upper Cretaceous age has been found for the lower part of Unit Gb (Flaxmans No. 1, Port Campbell No. 2). In wells where no cores, or insufficient cores were taken, uncertainty is experienced in picking the Mesozoic-Tertiary boundary.

(e) Stratigraphic relationships

(i) Relationship of Unit Gb to underlying unit:

A gradational relationship is apparent with Unit Gd below. The boundary is set ideally where coal seams and stringers in Unit Gb sediments disappear and the first occurrence of carbonate cement marks the top of Unit G. The Frome-Broken Hill Company has picked the boundary between Unit Gb or "Curdies Beds" and the Paaratte Formation (Gd) at a granulometric change from sandstone above to siltstone below. Although this choice does not introduce an importance difference of interpretation in terms of depth, such a granulometric change becomes too tenuous outside the Port Campbell area to serve as a reliable basis for the placing of the boundary between Units Gb and Gd.

(ii) Relationship of Unit Gb to overlying unit:

An unconformable relationship is considered to exist at the top of Unit Gb. This is well supported by the occurrence in all wells studied of abundant iron in the form of oxides and silicates in the formation above Unit Gb, and signs of high energy marine conditions with fossils. It is probable that the iron in most cases evolved from a subaerial weathering surface and that the onset of the early Tertiary transgression brought about high energy conditions and a reworking of the old surface material. This unconformable relationship is a fundamental character of sedimentation in the Otway Basin and is supported by geophysical evidence.

(f) Environment of deposition

The lithology shows that the environment for Unit Gb was clearly inner paralic to alluvial in the on-shore part of the Otway Basin. The evidence of thicker sands in the trough areas of earlier thick sedimentation, suggests alluvial deposits (inner deltaic ?) and stronger energy conditions than in the intervening flats where coal has formed. In the Port Campbell area, both Units Gb and Dd contain fresh water (less than 1000 ppm) which has obviously been derived from the same intake into Unit Dd (i.e. the Pebble Point Formation) which crops out south-east of Princetown.

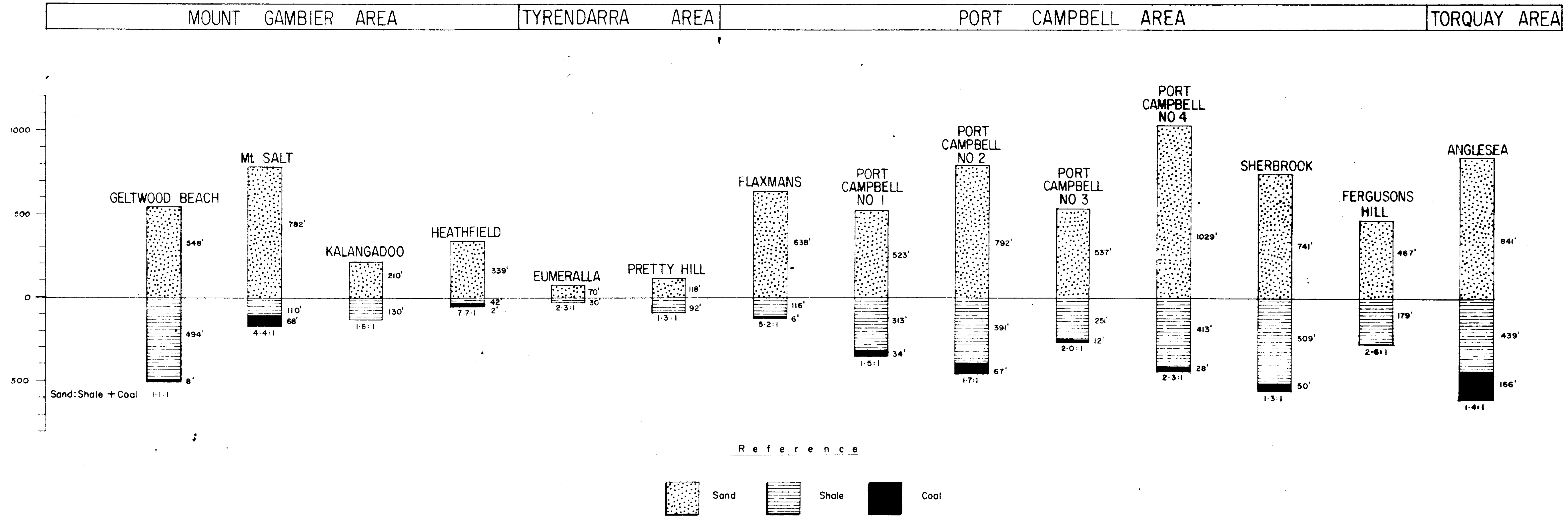
(g) Hydrocarbon occurrences

No indications of hydrocarbons have been reported in this unit. It is possible that some shows of gas may be found associated with the coal layers, particularly in the eastern part of the basin. Organic matter in sandstone at 3650 and 4221 feet in Mount Salt No. 1 has been called "dead oil", but Dellenbach (1964)* attributes its derivation to bituminous coal.

OTWAY BASIN

PROPORTIONS OF SAND, SHALE AND COAL BEDS IN UNIT 'Gb' SEDIMENTS

(NO HORIZONTAL SCALE)



The thicknesses of the sand, shale and coal are based on Electric Logs and B.M.R. cuttings determinations.

C. Cainozoic

During petrological studies, the Cainozoic sediments were divided into three units: D, B and A, which were further subdivided as shown in Table 1 and the text. The main units are thought to have been deposited in three intervals, and are discussed under these headings:-

(i) Unit D - Palaeocene to Middle Eocene.

(ii) Unit B - Upper Eocene to Miocene.

(iii) Unit A - Pliocene to Pleistocene.

Because the Cainozoic are the best exposed rocks of the Otway Basin, and access to them is easy, they have received most attention from geologists, in particular palaeontologists. Many papers have been written and only the most recent and comprehensive are considered here.

Unit D

This unit was first used and defined in the Nelson Bore (Hawkins and Dellenbach, 1963*); it is used to describe sediments similar in composition to the Knight and Wangerrip Groups referred to by other workers.

The subdivision of Unit D into Dd and Db was also first carried out in the study of the Nelson Bore sediments; Unit Db was further subdivided as follows:-

Db_1 - sandstones with interbedded carbonaceous siltstones

Db_2 - compact shales and claystones with friable sandstones.

(a) Distribution of Unit D.

(i) Surface Occurrences:

Sediments referred to as Unit Dd are restricted in outcrop. At Killara Bluff, Kenley (1951) describes an outcrop consisting of grits, silts and clays, mostly glauconitic, with Palaeocene or Eocene fossils such as Aturoidea, Lahillia, Cucullaca (Cucullona) etc. These sediments were called the Bahgallah Formation by Kenley and the name was first published in Boutakoff and Sprigg (1953). Kenley (1954) divides this formation into two horizons :-

Upper - 22 feet of clayey sediments,

Lower - 31 feet of sand and gravel.

In the eastern part of the basin at Pebble Point, near Princetown, Baker (1943, 1950) describes an outcrop of conglomerates and grits containing glauconite which he calls the "Pebble Point Beds".

Unit Db sediments occur as isolated outcrops across the basin; on the banks of the Glenelg River at Drajurk and Killara the succession consists of purple silts and black carbonaceous laminated silts with Cyclammina sp. These sediments are regarded as forming the base of the "Dartmoor Formation" (Boutakoff and Sprigg, 1953). In the bed of the Glenelg River at Dartmoor and Myaring is a thick sequence of quartz sands, grits and gravels with interbedded micaceous silts and carbonaceous clays containing plant remains. In the Knight's Quarry, sands and clays occur, which represent an upper level equivalent of the "Dartmoor Formation", according to Boutakoff and Sprigg.

In a coastal section between Moonlight Head and the Gellibrand River, northwest of Cape Otway, sediments consisting of clay, sandy clays, carbonaceous sandy shales and glauconitic clay are present; this sequence is referred to as the "Dilwyn Clay" by Baker (1953) and is assigned an Upper Palaeocene to Middle Eocene age by Glaessner (1959).

In the Torquay area, claystones, sandstones, sandy siltstones and lignitic siltstones are exposed in a coastal section at Demon's Bluff, Anglesea. The sequence is defined by Raggatt and Crespin (1955) as the "Demon's Bluff Formation", and this formation, together with the "Johanna River Sands" (Thomas, 1957) of the Aire District, are thought to be equivalent to the "Dilwyn Clay" at least in part.

(ii) Subsurface Occurrences:

In all the subsidized wells examined, both Unit Dd and Db sediments occur, with the exception of Casterton No. 1 and Anglesea No. 1 where Unit Dd was not recognized. In the unsubsidized wells referred to in this study, Unit D sediments have been recognized from lithological descriptions and by comparing the electrical logs with those in subsidized wells.

In all wells it was possible to identify and differentiate Unit Dd sediments from those of Unit Db above, and Unit Gb below; sediments in Unit Dd are of a much coarser nature and contain pellets and ooliths.

(b) General lithology of Unit D

This sequence consists of silty sandstones, carbonaceous siltstones, shales and sandy shales.

The sandstones are friable to compact, fine to very coarse-grained, conglomeratic in places, and oolitic and pellety at the base of the unit; sorting ranges from poor to good. The sediments are micaceous and contain carbonaceous material ranging from finely divided organic matter to lignitic fragments. The bonding media is generally a silty matrix although in some sandstones dolomite, siderite and pyrite occur as cementing media.

The siltstones are generally sandy, micaceous and contain abundant carbonaceous material; however, there is a decrease in the carbonaceous content of these sediments towards the base.

The shales are compact, exhibit all degrees of fissility, and often contain thin sand laminations and lenses; mica flakes occur parallel to bedding planes and some organic matter is present.

<u>Unit Dd</u>

(a) Occurrences of Unit Dd sediments from well data.

These sediments have been recognized in most of the subsidized wells studied. In the unsubsidized wells where Unit Dd

Table 10A: Subsurface occurrences of Unit Dd

Well Name	Datum (feet above sea level)	Depth below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Geltwood Beach No. 1	30	1810 to 1910	-1780 to -1880	100	
Kalangadoo No. 1	230	1760 to 1980	-1530 to -1750	220	MOUNT
Mount Salt No. 1	86	3130 to 3270	-3044 to -3184	140	
Nelson Bore	10	3690 to 3746	-3680 to -3736	56	GAMBIER
Tullich No. 1	272	250 to 418	+ 22 to - 146	168	
Heathfield No. 1	244	798 to 1217	- 554 to - 973	419	
Heywood No. 10	100	4258 to 4352	-4158 to -4252	94	
Portland No. 3	16 (1)	5050 to 5250	-5034 to -5234	200	TYREN-
Eumeralla No. 1	167	2530 to 2660	-2363 to -2493	130	DARRA
Pretty Hill No. 1	202	2030 to 2160	-1828 to -1958	130	
Flaxmans No. 1	221	3320 to 3480	-3099 to -3259	160	
Port Campbell No. 1	346	3300 to 3380	-2954 to -3034	80	
Port Campbell No. 2	282	3650 to 3750	-3368 to -3468	100	PORT
Port Campbell No. 3	210	2740 to 2910	-2530 to -2700	170	
Port Campbell No. 4	440	2390 to 2550	-1950 to -2110	160	
Sherbrook No. 1	480	1710 to 1930	-1230 to -1450	220	CAMPBELL
Fergusons Hill No. 1	651	670 to 849	- 19 to - 198	179	
Latrobe No. 1	102	1140 to 1430	-1038 to -1328	290	

(1) Figure taken from report by Glenie and Reed (1961).

Unit Dd

Photomicrograph 34. Oolite

Heathfield No. 1, Core No. 1, sample 969 - 969'4".
Plane polarised light.
Dark green, compact, subrounded to rounded, very fine to coarse-grained (0.12 - 0.75 mm), main mode = medium grained; poorly sorted.
Quartz (qz) 20%, chamosite ooliths (ch) 50%, chloritic matrix and recrystallized granular siderite (chl) 30%.
Note quartz nuclei in oxidized chamosite ooliths; also iron-coated (fe) quartz grains representing incipient oolith development.

Photomicrograph 35. Sandy oolite

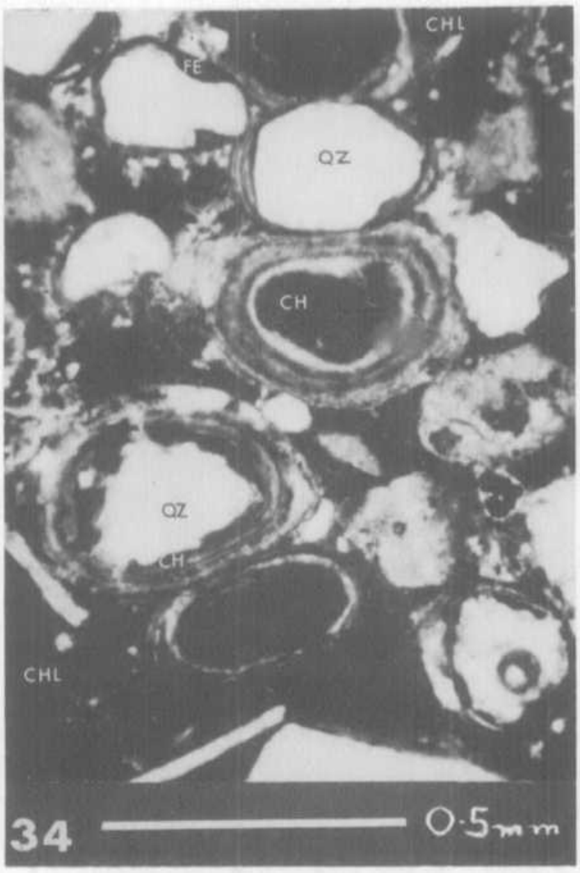
Tullich No. 1, cuttings sample 250 - 260'.
Plane polarised light.
Compact subrounded to rounded, fine to medium-grained (0.21 - 0.36 mm); moderately sorted.
Quartz (qz) 10%, oxidized chamosite pellets and ooliths (ch) 60%, recrystallized calcite (ca) 20% and microcrystalline siderite (sd) cement 10%.
Note ooliths now appear as pellets due to concentric layering being largely obliterated by oxidation; also iron-oxide (Fe)-coated quartz grains. The diagenetic siderite formed after the calcite.

Photomicrograph 36. Oolitic Sandstone

The Nelson Bore, core sample 3698'
Plane polarised light.
Compact, subangular to subrounded, fine to coarse-grained (0.24 - 0.60 mm), main mode = medium-grained; poorly sorted.
Quartz (qz) 20%, carbonate ooliths (ool) 40%, recrystallized calcite cement (ca) 40%.
Note pyrite (py) rimmed quartz nuclei and pyrite rims around ooliths; also recrystallization of carbonate ooliths leaving only pyrite rims and no nuclei.

Photomicrograph 37. Pellety, oolitic sandstone

Port Campbell No. 1, Core No. 10, sample 3337'.
Plane polarised light.
Compact, subangular to subrounded, silt-size to medium-grained (0.06 - 0.45 mm), main mode = medium-grained; poorly sorted.
Quartz (qz) 10%, chamosite pellets and ooliths (ch) 50%, siderite (sd) 25% and calcite cement (ca) 15%. Chamosite pellets form nuclei of ooliths. Microcrystalline siderite is replacing recrystallized calcite.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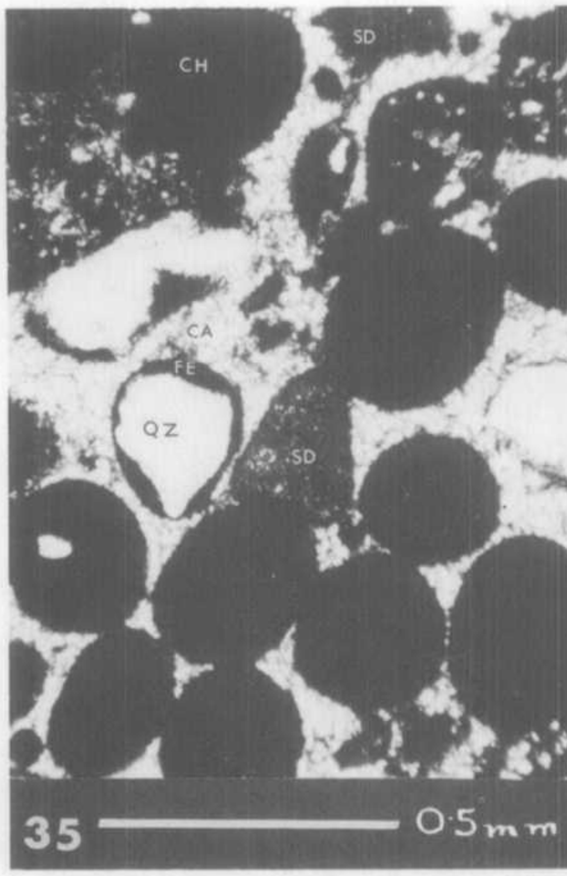
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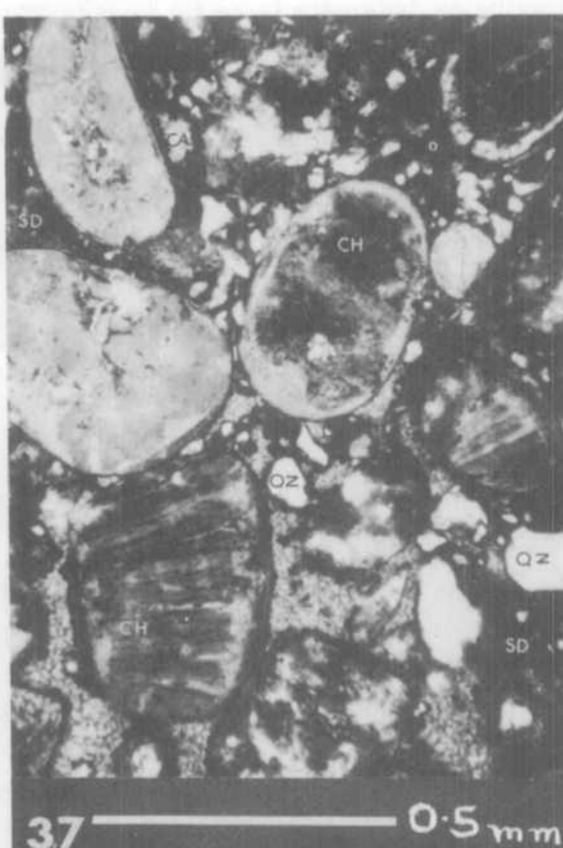
CA
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occurs, it has either been interpreted from the lithological log and descriptions, or the electric log, or both where possible.

(b) Lithology

The sediments comprise pebbly sandstone, pelletal oolitic sandstone, oolites, siderite rock and siltstone.

Pebbly Sandstone:

This lithology is found chiefly in the eastern part of the basin; it is a medium to dark grey, friable, subrounded to rounded, very fine to very coarse-grained, poorly sorted sandstone with rounded pebbles of quartz and quartzite and some glauconite. The sequence is generally devoid of pellets but may contain ooliths and minor dolomitic horizons; thin interbeds of siltstone and clay may occur.

Oolitic Sandstone:

The sandstone is dark grey to dark green, compact, oolitic, also pellety, subrounded to rounded, medium to coarse-grained and poorly sorted.

The constituents are quartz (including minor chalcedony) 15 to 50 per cent; orthoclase, microcline and acid plagioclase 5 to 8 per cent, chlorite, chamosite (including greenalite and brown oxidized pellets) and carbonate ooliths make up to 40 per cent of the rock. The nuclei of the ooliths are generally quartz but some are detrital limestone. In the Nelson Bore, phosphate and pyrite coated nuclei and pyrite-rimmed carbonate ooliths occur; in Heathfield No. 1 chamosite pellets and ooliths predominate.

The bonding media which range from 20 to 30 per cent of the rock comprise chloritic clay, calcite, dolomite, siderite, phosphate, limonite and pyrite. The recrystallized carbonates are diagenetic products and have a granular texture. The siderite commonly corrodes and replaces pellets, ooliths and quartz grains.

Porosity in these sandstones ranges from poor to fair, depending on diagenetic changes.

Oolites:

This lithology ranges from a gritty chamosite oolite to a limonite oolite rock.

The oolite bed is brown and in Mount Salt No. 1 (Dellenbach, 1964*) consists of 60 per cent groundmass of ferriferous chlorite of a chamositic nature and 40 per cent chamositic ooliths and coated detrital grains. The detrital constituents are angular to subangular, very fine to granule size grains of quartz, metaquartzite and minor (5%) orthoclase, microcline and plagioclase feldspar; these grains may be coated with chamosite or siderite.

The ooliths may be single to composite, with nuclei of angular detrital grains or of chlorite and limonite pellets; they show concentric layering of ferriferous chlorite (in parts chamosite), often displaying various stages of limonitization and sideritization as in Eumeralla No. 1 (Edworthy, 1965a*). In Eumeralla No. 1 siderite was the dominant cementing medium.

A similar oolith with the above petrographic characteristics was encountered in Port Campbell No. 1.

Unit Dd (Cont'd)

Photomicrograph 38. Sandstone

Sherbrook No. 1, Core No. 4, sample 1778' - 82'.
Plane polarised light.
Compact, angular to subangular, fine to medium-grained (0.15 - 0.45 mm); poorly sorted
Quartz (qz) 40%, feldspar (f) 2%, lithics-metaquartzite (mqz) and siliceous rock (sil) fragments 8%, pyrite (py) and opaque minerals 5%, chloritic clay matrix (chl) 45%.

Unit Dd
Subunit Dd_2

Photomicrograph 39. Sandstone

Mount Salt No. 1, Core No. 6, 2494 - 2504'.
Plane polarised light.
Angular to subrounded, very fine to very coarse-grained (0.09 - 1.35 mm), bimodal; moderately sorted.
Quartz (qz) 60%, cryptocrystalline siderite (sd), calcite (ca) and minor pyrite (py) cement 40%.
Note recrystallized fossil fragments. Also etching of quartz grains by carbonate cement.

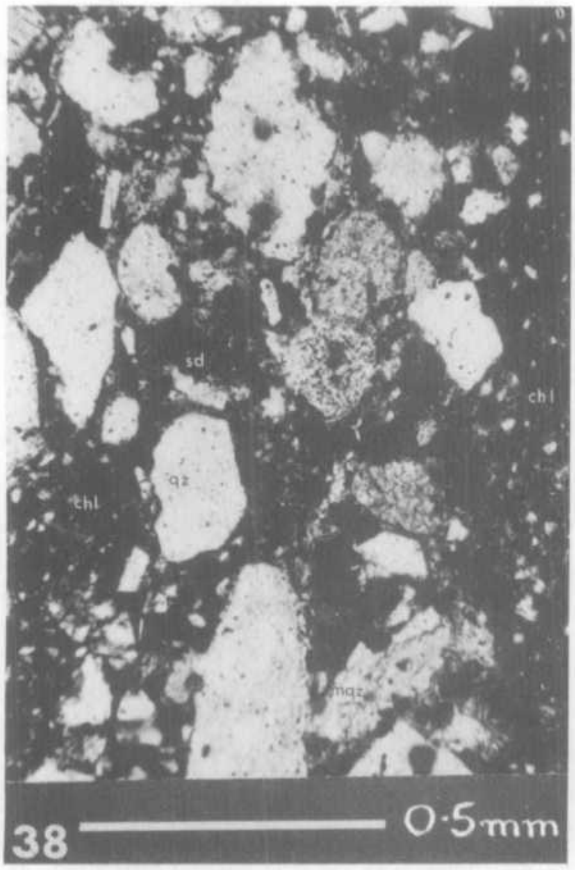
Photomicrograph 40. Sandstone

The Nelson Bore, core sample 2830'.
Plane polarised light.
Compact, angular to subangular, very fine to fine-grained (0.09 - 0.24 mm); moderately sorted.
Quartz (qz) 50%, microcline (micr) 5%, recrystallized calcite (ca) and siderite (sd) cement 45%.
Note strong corrosion of detrital grains by carbonate cement.

Subunit Dd_1

Photomicrograph 41. Sandstone

Tullich No. 1, cutting sample 140 - 150'.
Plane polarised light.
Compact, subangular to subrounded, fine to medium-grained (0.24 - 0.36 mm); moderately sorted.
Quartz (qz) 60%, metaquartzite (mqz) 10%, microcrystalline pyrite (py), cement 30%.
Note embayments in quartz grains due to corrosion by the pyrite cement.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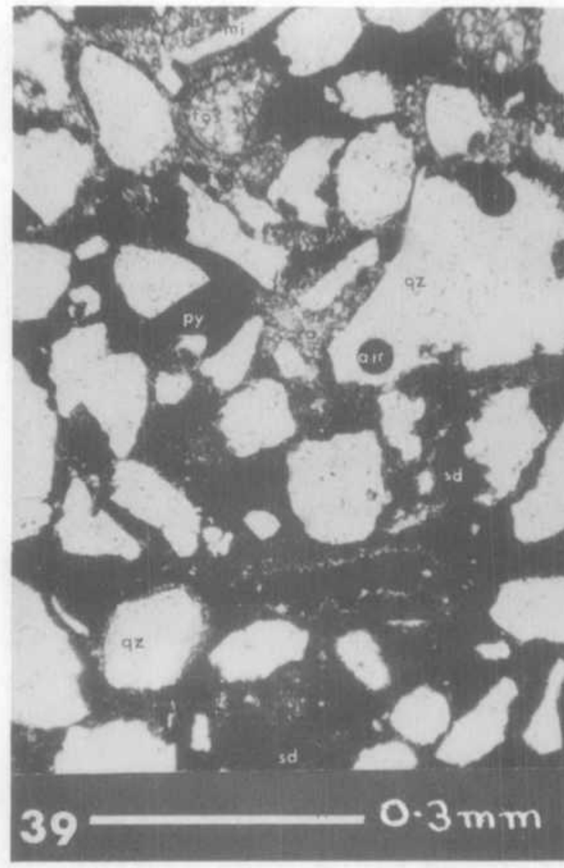
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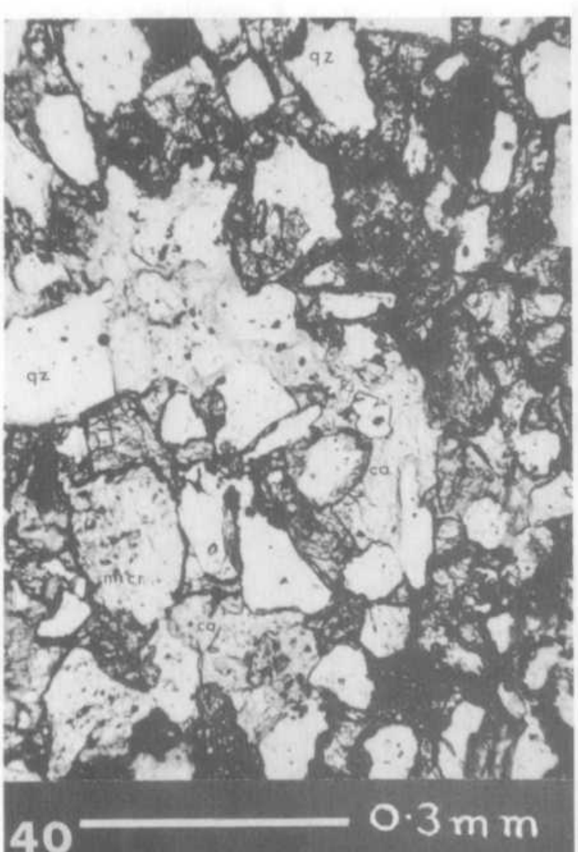
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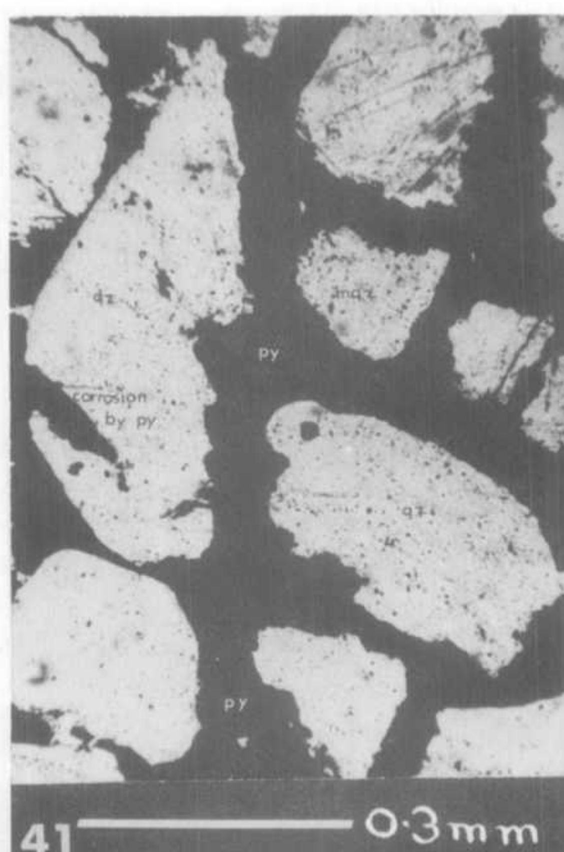
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These chemically cemented lithologies have low porosity.

Siderite Rock:

This type of rock occurs as thin beds in sandy and silty sequences; it is present in Geltwood Beach No. 1, Heathfield No. 1, Eumeralla No. 1 and Pretty Hill No. 1.

The lithology is a dark brown and grey, compact, pellety siderite; fine to medium-grained detrital quartz and metaquartzite occur. The detrital grains are coated with chamosite. The pellets are composed of green chamosite and brown oxidized chamosite and occasionally phosphate.

Siderite predominates either in a microcrystalline or a coarse recrystallized and spherulitic form; minor chloritic and phosphatic patches may be present. The siderite appears to be a primary deposit.

Siltstone:

The siltstone is dark brown and grey, sandy and carbonaceous, with interbedded clay.

The constituents of the siltstone are angular quartz, rare microcline, rare chamosite pellets and mica flakes. In the interbedded clay, minor quartz and chamosite pellets are set in a chloritic clay matrix with patches of globular siderite.

This lithology is present at the top of Unit Dd in Heathfield No. 1, Port Campbell Nos. 3 and 4.

The lithofacies variations which occur in Unit Dd are shown in Plate 6. The most consistent facies is the pelletal, oolitic sandstone and oolite lithology; this same facies is present in Mount Salt No. 1 and Port Campbell No. 1. However, in the Port Campbell area the oolitic facies passes laterally into a pebbly sandstone facies particularly in Port Campbell Nos. 3 and 4, Fergusons Hill No. 1 and Latrobe No. 1. In Sherbrook No. 1 there is evidence for both the oolitic chamositic facies and the pebbly sandstone facies being present.

In the Mount Gambier area, the oolitic facies and pebbly sandstone facies occur together in Tullich No. 1, Heathfield No. 1, and the Nelson Bore.

Other variations include the development of the silty facies in Port Campbell No. 3 and No. 4 and Heathfield No. 1; these variations are very localized.

Thickness variations are most marked in the Mount Gambier area between the Nelson Bore and Heathfield No. 1 well.

(c) Structures

Few structures occur in these sediments. In the Nelson Bore burrow markings occur in a carbonaceous silty sandstone at 3718 feet: elongated and bifurcating structures consisting of clean digested sand, are present on the bedding plane. Microstylolites are present in a carbonate-cemented sandstone at 3712 feet in the Nelson Bore.

No indication of dips could be obtained from cores taken within Unit Dd; it is assumed that the beds have low dips.

(d) Fossils and Age

The results of recent palaeontological studies over intervals which include or are part of Unit Dd are summarized below:

Ludbrook (in O.D.N.L., 1963a*) recognizes arenaceous foraminifera and some fish teeth over the interval 3130 to 3260 feet in Mount Salt No. 1, and although direct palaeontological evidence is lacking, the sediments of that interval are assigned to the "Bahgallah Formation (Paleocene)" based mainly on their petrology (Sweeney, in O.D.N.L., op.cit.). Similar fossils have been recorded by Ludbrook (in B.P.N.L., 1964*) from Unit Dd sediments, in Geltwood Beach No. 1, but here a ?Eocene age is given (although the interval is thought to be in part equivalent to the "Bahgallah Formation").

In the Nelson Bore, sediments between 3650 and 4025 feet yielded the pollen, Triorites edwardsii and the dinoflagellate Deflandrea bakeri (Baker and Cookson, 1955) and are similar in lithology and microfossil content to the Pebble Point Formation which is regarded as "Lower Eocene with Palaeocene affinities". Harris (1965) recognizes two assemblages containing T. edwardsii, and, on the basis of planktonic foraminiferal distribution in the Pebble Point Formation and the "Rivernook Member" of the overlying "Dilwyn Clay", gives an age range of Middle to Upper Palaeocene for the two assemblages; this age could therefore apply to Unit Dd in the Nelson Bore.

In Eumeralla No. 1, the presence of the Palaeocene species Globorotalia chapmani in drill cuttings at 2000 feet (Taylor, in F.-B.H., 1963a*) suggests that Unit Dd sediments which occur between 2530 and 2660 feet are probably Palaeocene in age.

In Sherbrook No. 1, Taylor (in F.-B.H., 1964b*) tentatively regards a side-wall core sample at 2100 feet as Palaeocene; it contained Anomalinoides sp. and "Globigerina triloculinoides". He also states that species which occur between 1290 and 2100 feet are typical of the Victorian Palaeocene although they are not diagnostic. Unit Dd (1710-1930 feet) is therefore considered to be Palaeocene, and the faunal evidence suggests that Unit Gb may also range in age from Upper Cretaceous to Palaeocene.

On the evidence available, Unit Dd is thought to be Palaeocene in age. McGowran (1965) would restrict the age of the Pebble Point Formation (equivalent to Dd) to the Middle Palaeocene on the basis of the occurrence of G. chapmani in the Port Campbell area and on the fact that in the Pebble Point Formation G. chapmani is a distinctive morphotype which can be compared with forms occurring in the G. pusilla-pusilla - G. angulata Zone of the Tethyan region. However, since the Pebble Point assemblage of G. chapmani specimens may be "a partly isolated marginal population" (McGowran, p.66), and because McGowran's study of this species in the Otway Basin has been confined more or less to the Port Campbell area, the age of Unit Dd is not restricted in this report. (The results of further studies on these foraminifera from subsurface samples to the west by D.J. Taylor of the Geological Survey of Victoria are not yet known).

(e) Stratigraphic Relationships

Relationship of Unit Dd to underlying unit:

The base of Unit Dd is represented by an unconformity which exists throughout the basin; the nature of the unconformity is not certain, but it is probably a disconformity in the form of a non-depositional or erosional break. No marked angular discordance has been observed between Unit Dd and the underlying sediments. In the wells studied Unit Dd rests on Unit Gb sediments except in Tullich No. 1 well where Unit Dd is underlain by Unit M sediments.

Relationship of Unit Dd to overlying unit:

The sediments of Unit Dd pass with no apparent break into the overlying siltstones and silty sandstones of Unit Db. The fossil evidence does not indicate any time break from Unit Dd to Unit Db. In all the wells studied, Unit Dd is overlain by sediments of sub-unit Db_2 or undifferentiated Unit Db.

(f) Environment of deposition.

The sediments of Unit Dd represent a transgressive marine facies deposited under shallow water conditions. The rounded nature of the detrital grains together with oolite formation indicate that these sediments were deposited in zones where high energy currents were active.

The presence of ferriferous chlorite and limonite in the form of ooliths and pellets in these sandstones indicates the availability of iron from erosion of a nearby landmass. During the deposition of these sediments the waters must have been sufficiently alkaline for the precipitation of carbonate cement and in some cases carbonate ooliths, but at times slightly reducing conditions prevailed for the formation of siderite and phosphate.

The pebbly sandstones which lack pellets but which contain some ooliths and minor dolomite cement suggest a shore-line facies equivalent of the oolitic sandstone.

(g) Hydrocarbon occurrences.

No hydrocarbon indications have been observed from sediments of Unit Dd either while drilling or in petrological studies.

Unit Db

(a) Occurrence of Unit Db sediments from well data.

Unit Db is represented by a thick sequence of sediments and has been found in all of the subsidized wells studied except Casterton No. 1, and has also been recognized in a number of unsubsidized wells. Table 10B lists the subsurface occurrences of the unit.

(b) Lithology

The sediments comprise sandstones, carbonaceous sandy siltstones and shales. On the basis of lithology and carbonaceous material content the sequence may be subdivided into:-

Sub-unit Db_1 (upper)

Sub-unit Db_2

Sub-unit Db_2

This is a succession of argillaceous sandstone, siltstone and shale and rare cemented sandstone.

Table 10B: Subsurface occurrences of Unit Db

Well Name	Datum (feet above sea level)	Depths below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Beachport No. 1	18	900 to 1920	- 882 to -1902	1020	MOUNT GAMBIER
Geltwood Beach No. 1	30	960 to 1810	- 930 to -1780	850	
Mount Salt No. 1	86	590 to 3130	- 504 to -3044	2540	
Nelson Bore	10	992 to 3690	- 982 to -3680	2698	
Kalangadoo No. 1	230	30 to 1760	+ 200 to -1530	1730	
Penola No. 1	209	410 to 1040	- 201 to - 831	630	
Tullich No. 1	272	140 to 250	+ 132 to + 22	110	
Heathfield No. 1	244	276 to 798	- 32 to - 554	522	
Heywood No. 10	100	1373 to 4258	-1273 to -4158	2885	TYREN-DARRA
Portland No. 2	110 (1)	2974 to 4719	-2864 to -4609	1745	
Portland No. 3	16 (1)	2862 to 5050	-2846 to -5034	2188	
Eumeralla No. 1	167	1270 to 2530	-1103 to -2363	1260	
Pretty Hill No. 1	202	1300 to 2030	-1098 to -1828	730	
Flaxmans No. 1	221	2213 to 3320	-1992 to -3099	1107	PORT CAMPBELL
Port Campbell No. 1	346	1510 to 3300	-1164 to -2954	1790	
Port Campbell No. 2	282	1230 to 3650	- 948 to -3368	2420	
Port Campbell No. 3	210	1534 to 2740	-1324 to -2530	1206	
Port Campbell No. 4	440	1300 to 2390	- 860 to -1950	1090	
Sherbrook No. 1	480	560 to 1710	- 80 to -1230	1150	
Fergusons Hill No. 1	651	13 to 670	+ 638 to - 19	657	
Latrobe No. 1	102	200 to 1140	- 98 to -1038	940	
Anglesea No. 1	78	13 to 370	+ 65 to - 292	357	TORQUAY

(1) Figures taken from report by Glenie and Reed (1961).

Sandstone:

The sandstone is dark brown and grey, and ranges from friable, subrounded, coarse-grained, poorly sorted, immature argillaceous sandstone to clean, subangular, fine-grained moderately to well-sorted, quartzose sandstone. Rare thin beds and lenses of compact, angular, fine-grained sandstone with carbonate cement (calcite, dolomite and siderite) are present. The constituents are quartz and metaquartzite, rare feldspar - orthoclase, microcline and acid plagioclase, and fragments of quartzite, chlorite, and chloritic schist; pyrite and muscovite are common together with small amounts of glauconite. Tourmaline and zircon are common accessories.

Siltstone and Shale:

The siltstone is brown, compact, sandy, micaceous and contains finely disseminated carbonaceous matter.

The shales are brown, compact, fissile and finely laminated, with mica flakes and carbonaceous matter.

<u>Sub-unit Db_1</u>

The major difference between this sub-unit and sub-unit Db_2 is in the increased content of finely divided carbonaceous matter and variation in grain size. The represented rock types are sandstones with subordinate siltstones.

Sandstones:

These sediments which are brown, friable or may be partly compacted near the base, range from dirty subangular to subrounded, coarse-grained, poorly sorted, to angular, fine-grained, well-sorted sandstones. Rare compact, fine-grained carbonate cemented sandstones occur. The constituents are quartz, rare feldspar--orthoclase and plagioclase, and rare chert and siliceous rock fragments. Muscovite and biotite are common and authigenic pyrite and glauconite and carbonaceous matter occur; accessories include zircon, tourmaline and opaques. The important bonding media are silt and clay with minor cement in the form of dolomite, anhydrite and siderite.

Siltstones:

The siltstones are brown, sandy with fine-grained quartz, micaceous, and rich in pyrite and carbonaceous matter. Rare haematitic clay may occur as in the Nelson Bore at 2681 feet. Coaly fragments are present in these siltstones.

In general it may be said that the sediments of Unit Db show four characteristics :-

(a) Decrease in clay content from bottom to top with a corresponding increase in grain size.

(b) Increase in carbonaceous material from bottom to top.

(c) Chemical cement in the sandstones is limited.

(d) Electric logs indicate cyclic alteration of siltstones and sandstones, observed also from cuttings.

The porosity and permeability are generally high and increase towards the top of the sequence.

Only minor variations are present in Unit Db sediments across the basin. In Eumeralla No. 1 and Pretty Hill No. 1 an increase in the amount of dolomite and siderite-cemented sandstones occurs in sub-unit Db_2.

Thickness variations are most marked in the Mount Gambier area, especially between the Nelson Bore where 2698 feet of Unit Db sediments were penetrated (the greatest intercepted thickness) - and Tullich No. 1 well, where only 110 feet of this unit was encountered. Other thickness variations are recorded in Table 10B.

(c) Structures

Laminations are common and consist of thin, clean, fine-grained sand in shales; thin clay and dark carbonaceous silt laminations are present in some sandstones. Low angle cross-bedding also occurs.

Load cast structures are rare and generally confined to sub-unit Db_2. Disturbed bedding, small scale slump (sediment slip) structures, convolutions and scour-and-fill structures are also more apparent in sub-unit Db_2.

The most characteristic featuresof sub-unit Db_1 sediments are burrow markings which occur in the fine-grained carbonaceous sandstones and carbonaceous sandy siltstones. They have irregular branching structures and are found along and normal to the bedding planes.

No dips could be detected from cores taken within Unit Db; the beds are thought to be generally flat-lying.

(d) Fossils and age

Recent interpretations suggest that Unit Db sediments may range in age from Palaeocene to Eocene; in some areas these sediments are thought to extend up into the Upper Eocene but are generally of Lower and Middle Eocene age.

In the Mount Gambier area, sediments equivalent to Unit Db in Mount Salt No. 1 are regarded by Ludbrook (in O.D.N.L., 1963a*) as being Lower to Middle Eocene age; they contain some characteristic arenaceous foraminifera ("Cyclammina" rotundata, Bathysiphon angleseaensis, Ammodiscus parri) and molluscan species, and are overlain in the Kingston area by sediments with definite Middle Eocene foraminifera. Similar fossils occur in Geltwood Beach No. 1 and Ludbrook (In B.P.N.L., 1964*) assigns a Lower to Middle Eocene age to the sediments which occur within our Unit Db. In addition to the normal microfauna, Globigerina linaperta is included by Ludbrook (in S.E.O.S., 1962*) in sediments equivalent to Db in Beachport No. 1; no reference to the species is made in the text, however, and the occurrence is shown only in the accompanying chart (1050-1070 feet) which also shows a Middle to Upper Eocene age (obviously based on this species). The specimens were found in cuttings and could easily be contamination from higher in the well where the species is more abundant.

In the Port Campbell area few specific age determinations have been possible on account of sparse fauna and lack of diagnostic fossils. In Fergusons Hill No. 1, for instance, Taylor (in F.-B.H., 1964*) does not record any diagnostic species in the Db interval. In Sherbrook No. 1 (F.-B.H., 1964b*), few fossils were observed by Taylor in the sediments equivalent to Db; Douglas, however, records the microfossil Wetzeliella homomorpha which is regarded by Deflandre and Cookson (1955) as Lower Eocene in age.

(e) Stratigraphic Relationships

(i) Relationship of Unit Db to underlying unit:

There are no indications of a sedimentary break between the base of Unit Db and the top of Dd; all petrological evidence points to continuous sedimentation throughout the basin. In all wells examined Unit Db rests conformably on Unit Dd, with the exception of certain unsubsidized wells, the logs of which do not show Dd lithology.

The age relationship suggests Palaeocene or Lower Eocene sediments of Unit Db resting on Palaeocene sediments of Unit Dd.

(ii) Relationship within Unit Db:

There is no lithological evidence to suggest a break within Unit Db; complete conformity exists between sub-units Db_2 and Db_1 where such subdivisions have been recognized. Palaeontological results confirm the view that sedimentation was continuous throughout Unit Db.

(iii) Relationship of Unit Db to overlying unit:

The top of Unit Db is marked by an unconformity which is present throughout the basin. The unconformity may be in the form of an erosional break, as observed in the Nelson Bore, or as a non-depositional break; no marked angular discordance was observed from well samples studied over this interval. In most of the wells, Unit Db sediments are overlain by Unit Bc sediments; however, in Tullich No. 1 Unit Ab rests unconformably on Unit Db, and both Sherbrook No. 1 and Anglesea No. 1 wells spudded into Unit Db sediments.

Palaeontological evidence suggests sediments of Lower to Middle Eocene age are overlain by Unit Bc sediments of Upper Eocene and in some places Oligocene age.

(f) Environment of Deposition

The sediments of Unit Db represent a regressive marine facies; deposition is thought to have taken place in a paralic environment where interfingering of marine and deltaic facies occurs.

The sediments in sub-unit Db_2 reflect a paralic environment with evidence for stronger marine influences corresponding to the occurrence of carbonate-cemented sandstones, glauconite and isolated marine organisms; small amounts of carbonaceous matter occur in these sediments.

In sub-unit Db_1, the sandstones and interbedded siltstones represent a regressive facies where deposition has taken place under predominantly deltaic conditions accompanied by minor marine influxes. These sediments contain abundant carbonaceous material, lignitic and coaly lenses, plant remains and burrows accompanied by pyrite, phosphatic fragments and glauconite; thus the waters of this paralic environment were of a reducing nature in which little primary carbonate cement was precipitated indicating neutral conditions during sedimentation (pH less than 7.8).

A form of cyclic sedimentation in Unit Db is suggested by the recurrence of coarse and fine carbonaceous sediments. The mechanism necessary for this type of sedimentation could be a migrating river across a sinking delta.

(g) Hydrocarbon occurrences

No petroleum indications have been observed in Unit Db sediments.

Unit B

Unit B was first defined in the Nelson Bore (Hawkins and Dellenbach, 1963*) and is used for sediments similar in lithology to the Glenelg and Heytesbury Groups referred to by other authors. Unit B was originally subdivided into Bc and Bb; as a result of more recent studies it has been necessary to revise Unit Bc on account of age and lithological differences within the unit. The subdivision of Unit Bc is as follows:-

Sub-unit Bc_1 - Glauconitic marly limestones

Sub-unit Bc_2 - Limonitic sandstones and marls

(a) Distribution of Unit B

(i) Surface Occurrences:

Type areas for Unit Bc sediments are isolated. The sandstones called the "Nelson Formation" by Boutakoff and Sprigg (1953) were recognized in the Nelson Bore. Also in the Mount Gambier area, Ludbrook (1961) recognizes a 1½ feet thick ferruginous conglomerate at Knight's Quarry which she defines as the "Compton Conglomerate". In wells in the Port Campbell area, the "Mepunga Formation" - glauconitic, ferruginous sandstones, and the "Narrawaturk Formation" - glauconitic marls, are described by Leslie (1965); no surface outcrops of these formations have been recorded. The "Clifton Formation" is described by Teichert (1947) and Baker (1950, 1953) from a coastal section to the northwest of Point Ronald. In the Torquay area Raggatt and Crespin (1955) name sediments occurring in surface section at Bird Rock Point and on the western side of Bell's Headland as the "Jan Juc Formation". The Bc interval is represented in the Aire District by the "Browns Creek Clays, Castle Cove Limestone, and Glen Aire Clays" (see Carter, 1958b).

Unit Bb sediments correspond to the "Mount Gambier Formation" which has been defined from surface limestone outcrops in the Mount Gambier area (Boutakoff and Sprigg, 1953); in the Port Campbell area similar limestones called the "Port Campbell Limestone" by Baker (1953) overlie the "Gellibrand Clay", which is present in a section to the northwest of Point Ronald. The "Heywood Marl" of Glenie and Reed (1961) is similar to the "Gellibrand Clay". In the Torquay area Crespin and Raggatt (1955) describe surface exposures of marl, siltstone and calcarenite which are referred to as the "Peubla Formation"; the type section is between Bird Rock and the mouth of Spring Creek. The "Calder River Limestone" and "Fishing Point Marl" (Carter, op.cit.) are equivalent to Bb in the Aire District.

(ii) Subsurface occurrences:

Both Bc and Bb are present in most of the subsidized wells studied. Casterton, Fergusons Hill and Anglesea Wells spudded into older rocks, and Unit B sediments could not be recognized in Kalangadoo No. 1. In both Tullich No. 1 and Heathfield No. 1 only Unit Bc was present.

In the past there has been much confusion over the stratigraphy of Unit Bc; this has been due to poor sample descriptions of type localities and lack of detailed petrological work on well samples. Little attempt has been made previously to correlate outcrop evidence with subsurface sections.

(b) General lithology of Unit B

The lower part of the sequence consists of coarse-grained, pellety, limonitic sandstones, dark brown limonitic and glauconitic marls, glauconitic marly limestones and sandy limestones containing glauconite pellets - Unit Bc.

Above these sediments is a carbonate sequence, which consists of argillaceous limestone, marl and minor dolomite, and polyzoal limestone and calcarenite with chert nodules. The argillaceous limestone contains abundant fossil debris together with abundant siliceous sponge spicules; in the polyzoal limestone is abundant fossil debris of polyzoa, foraminifera and shall fragments. This is Unit Bb.

Unit Bc

The general distribution of Unit Bc is shown in Table 11A.

Table 11A: Subsurface occurrences of Unit Bc

Well Name	Datum - feet above sea level	Depths below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Beachport No.1	18	775 to 900	- 757 to - 882	125	
Geltwood Beach No.1	30	890 to 960	- 860 to - 930	70	
Mount Salt No. 1	86	480 to 590	- 394 to 504	110	MOUNT
Nelson Bore	10	812 to 992	- 802 to - 982	180	GAMBIER
Penola No. 1	209	250 to 410	- 41 to - 201	160	
Tullich No. 1	272	70 to 140	+ 202 to + 132	70	
Heathfield No. 1	244	152 to 276	+ 92 to - 32	124	
Heywood No. 10	100	1288 to 1373	-1188 to -1273	85	
Portland No. 2	110	2841 to 2974	-2731 to -2864	133	
Portland No. 3	16	2770 to 2862	-2754 to -2846	92	TYREN-
Eumeralla No. 1	167	1110 to 1270	- 943 to -1103	160	DARRA
Pretty Hill No. 1	202	1160 to 1300	- 958 to -1098	140	
Flaxmans No. 1	221	1920 to 2213	-1699 to -1992	293	
Port Campbell No. 1	346	1050 to 1510	- 704 to -1164	460	
Port Campbell No. 2	282	782 to 1230	- 500 to - 948	448	
Port Campbell No. 3	210	1248 to 1534	-1038 to -1324	286	PORT
Port Campbell No. 4	440	964 to 1300	- 524 to - 860	336	CAMPBELL
Sherbrook No. 1	480	210 to 560	+ 270 to - 80	350	
Latrobe No. 1	102	160 to 200	- 58 to - 98	40	

(b) Lithology

The sequence is composed of coarse-grained, limonitic pellety sandstones, a basal conglomerate found only in the Nelson Bore and in outcrop at Knight's Quarry, marls with limonite and glauconite pellets, and glauconitic marly limestones and calcarenites. The sediments are characterized by the presence of pellets.

This succession can be divided into two sub-units on the basis of lithology :-

Sub-unit Bc_1 - Glauconitic marly limestone

Sub-unit Bc_2 - (Marl with limonite and glauconite
(Limonitic sandstone and conglomerate

Table 11B: Subsurface occurrences of Sub-unit Bc_2

Well Name	Datum - feet above sea level	Depths below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Geltwood Beach No. 1	30	910 to 960	- 880 to - 930	50	
Mount Salt No. 1	86	510 to 590	- 424 to - 504	80	MOUNT
Nelson Bore	10	812 to 992	- 802 to - 982	180	
Tullich No. 1	272	70 to 140	+ 202 to + 132	70	GAMBIER
Heathfield No. 1	244	152 to 276	+ 92 to - 32	124	
Heywood No. 10	100	1335 to 1373	-1235 to -1273	38	
Portland No. 2	110	2964 to 2974	-2854 to -2864	10	
Portland No. 3	16	2823 to 2862	-2807 to -2846	39	TYREN-
Eumeralla No. 1	167	1200 to 1270	-1033 to -1103	70	DARRA
Pretty Hill No. 1	202	1220 to 1300	-1018 to -1098	80	
Port Campbell No. 1	346	1150 to 1510	- 804 to -1164	360	
Port Campbell No. 3	210	1280 to 1534	-1070 to -1324	254	
Port Campbell No. 4	440	1012 to 1300	- 572 to - 860	288	PORT
Sherbrook No. 1	480	250 to 560	+ 230 to - 80	310	CAMPBELL

Sub-unit - Bc_2

Limonitic sandstone and conglomerate :

The sediments consist of finer-grained sandstones which grade up into very coarse-grained sandstones at the top; in the Nelson Bore a conglomerate (6feet thick) occurs at the base.

The conglomerate is compact, poorly sorted and consists of quartz pebbles, limonite, haematite and chamosite pellets; the cement is fine-grained siderite, iron oxide, minor calcite and a trace of phosphate. The finer-grained sandstones contain angular quartz, limonite-coated quartz, goethite and limonite pellets and laminae with abundant greenalite (Baker, 1961). The cement is dolomite, siderite and limonite. The coarse-grained sandstones are compact and contain subrounded grains; constituents are quartz pebbles, pellets of limonite, iron oxide and rare glauconite, and chamosite-coated quartz grains. The cement consists of calcite, dolomite and limonite.

The high percentage of dolomite cement is probably related to a primary carbonate cement which has been subject to diagenetic changes. The pellets are thought to have been formed by slight current action on a fine-grained precipitate.

Marl with limonite and glauconite.

This sequence has only been recognized in the Port Campbell area where purplish brown limonitic and glauconitic marls have been intersected. In Port Campbell No. 1 a purplish brown glauconitic marl, containing limonite and glauconite pellets and spots of gypsum associated with pyrite, was encountered; at 1375 feet a basal marl and sandy calcarenite was recognized. The purplish colour of the marl is due to the finely divided iron oxide or iron silicate content.

Only part of this sequence can be regarded as a true marl; tests have shown that the total carbonate content of these sediments ranges between 18.3% and 56.1%. The lithology of the upper section which contains 18.3 to 34.9% total carbonate should be termed a clayey marl (Pettijohn, 1957); the lower portion of these sediments which shows an increase in total carbonate (46 to 56.1%) should be called marl. Besides an increase in carbonate content towards the base of the unit there is evidence for an increase in the carbonate content from west to east.

Table 11C: Subsurface occurrences of Sub-unit Bc_1

Well Name	Datum (feet) above sea level	Depths below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Geltwood Beach No. 1	30	890 to 910	- 860 to - 880	20	MOUNT
Mount Salt No. 1	86	480 to 510	- 394 to - 424	30	GAMBIER
Heywood No. 10	100	1288 to 1335	-1188 to -1235	47	
Portland No. 2	110	2841 to 2964	-2731 to -2854	123	
Portland No. 3	16	2770 to 2823	-2754 to -2807	53	TYREN-
Eumeralla No. 1	167	1110 to 1200	- 943 to -1033	90	DARRA
Pretty Hill No. 1	202	1160 to 1220	- 958 to -1018	60	
Port Campbell No. 1	346	1050 to 1150	- 704 to - 804	100	
Port Campbell No. 3	210	1248 to 1280	-1038 to -1070	32	PORT
Port Campbell No. 4	440	964 to 1012	- 524 to - 572	48	CAMPBELL
Sherbrook No. 1	480	210 to 250	+ 270 to - 230	40	
Latrobe No. 1	102	160 to 200	- 58 to - 98	40	

Sub-unit Bc_1

Glauconitic marly limestone:

The sediments are glauconitic marly limestone, sandstone, and sandy limestone containing glauconitic pellets. The glauconite may occur as a green rock e.g. in Geltwood Beach No.1 where bright green slightly calcareous glauconite is present from 890 to 910 feet. In Eumeralla No.1 a fine to medium-grained dolomitie sandstone occurs and in Port Campbell No.1 a brown sandy, clayey calcarenite is present. In all these sediments oxidized glauconite, limonite, and iron oxide pellets and ooliths together with reworked limonitic rock fragments may occur.

Table 11D

Chemical composition of samples of Unit Bc from Portland No.3 and the Nelson Bore

	Limonitic rock sequence (Bc_2)		Glauconitic rock sequence (Bc_1)
	A.Nelson Bore (963')	B.Portland No.3 (2827')	C.Portland No.3 (2815')
	%weight	%weight	%weight
SiO_2	34.86	36.2	60.4
Al_2O_3	11.91	5.9	6.2
Fe_2O_3	26.24	28.1	10.2
FeO	0.01		1.9
MgO	3.79	4.9	3.0
CaO	3.99	1.8	2.9
Na_2O	0.04		
K_2O	0.05		
H_2O	8.49		
CO_2	8.00		
TiO_2	0.61		
P_2O_5	0.20		0.15
MnO	0.12		
SO_3	0.39		
C	0.85	5.9	
Cl_2+F_2	0.28		
Loss on ignition		(excluding Carbon) 16.2	(including Carbon) 11.1
Total	99.83	99.00	95.85

Key

A=Friable glauconitic oolitic rock. (Analysis by G.C.Carlos in Baker, 1961).

B=Ferruginous siltstone (Core AR; chemical analysis by Victorian Mines Department in Glenie and Reed, 1961).

C=Glauconitic siltstone. (Core AP; chemical analysis by Victorian Mines Department in Glenie and Reed, 1961).

These analyses show that :

(a) samples A and B have comparable chemical compositions, but C is markedly different;

(b) the SiO_2 content is higher in sample C; this would presumably be related to the glauconite and not detrital grains, although no K_2O analysis was made;

(c) the glauconitic oolitic sample A has a low K_2O content; this would indicate that the hydrous ferrous silicate is comparable to greenalite rather than glauconite (Baker, 1963);

(d) the Fe_2O_3 content in sample C is much lower.

Other variations in the mineral composition of Bc_1 and Bc_2 are shown in Table 11E.

Table 11E

Mineral composition of samples of Unit Bc from Geltwood Beach No.1 Well, the Nelson Bore, and Eumeralla No.1 Well.

	Limonitic Rock sequence (Bc_2)				Glauconitic Rock sequence (Bc_1)		
Well	Nelson Bore	Nelson Bore	Nelson Bore	Nelson Bore	Eumeralla No.1	Eumeralla No.1	Geltwood Beach No.1
Sample	A	B	C	D	E	F	G
depth							
Component	902'	902'6"	963'	976'	1100'-1150'	1168'-1170'	890'-910'
	%	%	%	%	%	%	%
Quartz	25.0	51.6	20.0	15.4	20.0	40.0	2.0
Rock fragments	25.0	11.0	15.0		7.0	2.0	
Feldspar	-	5.5		1.0	1.0	3.0	3.0
Mica	-	-					
Iron oxide pellets	5.0	1.1	15.0	31.3		2.0	5.0
Glauconite pellets	-				5.0		
Chamosite pellets	-						
Cement/Matrix							
Calcite	-						
Dolomite	45.0		50.0		67.0		
Siderite Pyrite	-			} 18.2		48.0	
Calcareous	-	30.8					
Greenish clay	-			34.1			
Glauconite	-						90.0
Fossils	-					5.0	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Key :

A,B,C,D = Sandstone (Bc_2).

E = Sandy dolomite or dolomitic sandstone (Bc_1).

F = Sideritic sandstone (Bc_1).

G = Glauconite rock (Bc_1).

B & D represent micrometric analyses by Baker (1961).

The lithofacies variations which occur in Unit Bc across the basin are shown in Plate 7. The limonitic sandstone facies (Bc_2) occurs throughout the basin, except in Latrobe No. 1. The Bc_2 marl facies which has been recognized in the Port Campbell area is absent in the Tyrendarra and Mount Gambier areas. The glauconitic marly limestone and calcarenite facies of Bc_1 is well developed in the Tyrendarra and Port Campbell areas. However, in the Mount Gambier area this glauconitic facies is found only in the Geltwood Beach and Mount Salt wells; in Tullich No. 1, Heathfield No. 1, and the Nelson Bore a limonitic sandstone facies is developed.

Thickness variations are most marked between Port Campbell No. 1 (460 feet) and Latrobe No. 1 (40 feet). The general trend is that Unit Bc sediments thicken or are less eroded towards the Port Campbell area.

(c) Structures

No sedimentary structures have been observed in either cores or cuttings studied in Unit Bc, and no evidence for dips or faulting were obtained from cores taken within the unit; generally the beds are thought to be dipping at a low angle.

(d) Fossils and age

At the commencement of these studies it was thought that Unit Bc was represented by sediments which may have been diachronic but which were mainly Oligocene in age. Recent palaeontological studies carried out on behalf of oil companies have shown that Unit Bc embraces two units and extends from Upper Eocene to Oligocene in age. An unconformity separates the two units, but is most apparent in the eastern part of the Basin.

In the Port Campbell area to the east, the basal limonitic sandstone facies (Bc_2) from 510 to 560 feet in Sherbrook No. 1 is thought by Taylor (in F.-B.H., 1964*) to be Upper Eocene in age on the evidence of "Globigeraspis index" which occurs between 350 and 605 feet. In this well the marl facies of Bc_2 is present from 250 to 510 feet; the interval 250 to 350 feet which contains Globigerina linaperta appears to belong to Faunal Unit 3 of Carter (1958b, 1964) and represents the Upper Eocene to Oligocene transition. The overlying glauconitic limestone (Bc_1) from 210 to 250 feet contains a fauna similar to Carter's Unit 5 (Upper Janjukian Stage - Oligocene in age).

Bock and Glenie (1965) indicate that the upper part of the marly facies (Bc_2) encountered in Mepunga No. 10 is a transgressive facies; in Port Campbell No. 1 there is no evidence of a lithological change in the marl sequence to support this view. The main transgression occurred above the marl and formed the "Clifton Formation" (equivalent to Bc_1). Bock and Glenie (1965) have not recognized the regional unconformities at the base of Unit Bc_2 (the "Mepunga Formation") or at the base of the "Clifton Formation", but they do show a similar range in ages - Upper Eocene to Oligocene - for the formations equivalent to Bc.

The original interpretation of Bc in Pretty Hill No. 1 (Edworthy, 1964*) to the west of the Port Campbell area has been changed, and we now show Bc_2 from 1220 to 1330 feet, and Bc_1 from 1160 to 1220 feet. Taylor (in F.-B.H., 1962b)* recognizes G.linaperta in Core No. 1 (1286-1288 feet) in this well; as this fossil is restricted to the Faunal Units 1 to 3 of Carter (op.cit.), the sequence 1220 to 1300 is regarded as Upper Eocene. Lithology varies from limonitic sandstone to dolomitic limestone. The slightly dolomitic calcarenite with limonite

Unit Bc

Subunit Bc_2

Photomicrograph 42. Limonitic Sandstone

Port Campbell No.1, Core No.5, depth 1476'.
Plane polarised light.
Subangular to subrounded, fine to coarse-grained (0.15 - 0.60 mm); poorly sorted.
Quartz (qz) 60%, limonite pellets (lim) 15%, recrystallized calcite (ca) cement 25%.
Note brown limonite (lim) coating around quartz grains and development of siderite (sd) rhombs around grains.

Photomicrograph 43. Dolomitic Sandstone

Pretty Hill No.1, Core No.1, depth 1282 - 1284'.
Plane polarised light.
Subangular to subrounded, medium to coarse-grained (0.36 - 0.90 mm); poorly sorted.
Quartz (qz) 30%, recrystallized dolomite cement (do) (70%).
Note development of siderite (sd) rhombs. Brown limonite (lim) in some interstices.

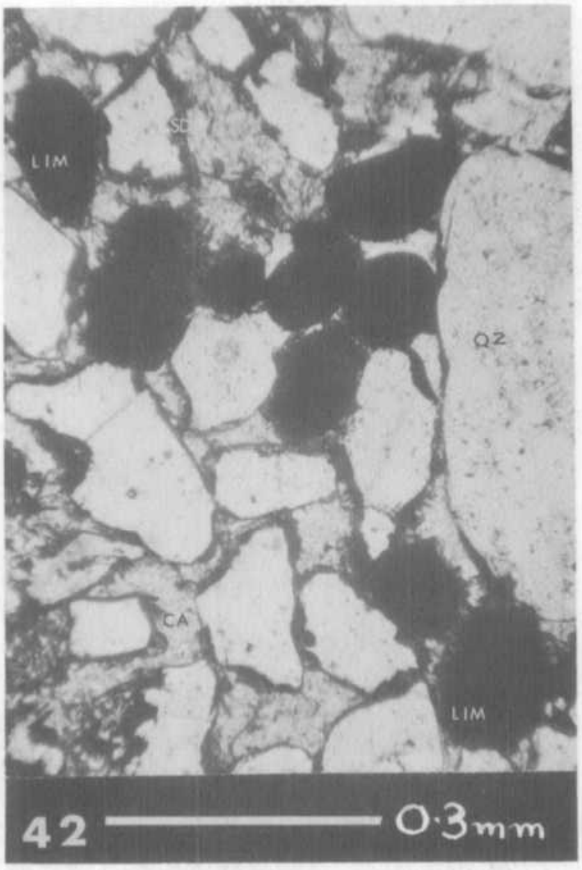
Photomicrograph 44. Conglomerate

The Nelson Bore, core sample 986'.
Plane polarised light.
Brown, compact, subrounded to rounded, medium to pebble size (0.33 - 7.0 mm) grains; poorly sorted.
Pebbles of quartz (qz) 60%, oxidized chamosite (ch) ooliths and pellets 25%, finely recrystallized calcite (ca) and siderite (sd) cement 15%.
Note iron oxide (Fe) coated quartz grain, squeezed oolith and pellet, and composite ooliths with quartz and pellet nuclei.

Subunit Bc_1

Photomicrograph 45. Glauconite Rock

Geltwood Beach No.1, cutting sample 890' - 910'.
Plane polarized light.
Green, compact, cryptocrystalline glauconite (gl) and slightly calcareous glauconite containing angular to subangular, very fine to fine-grained size quartz (qz), and fine to medium-grained size pellets of limonite (lim).
Abundant foraminifera (for) (globigerinids) occur in the rock.
Note limonite coating around quartz grain and outline of foraminifera in limonite pellet.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SD
QZ
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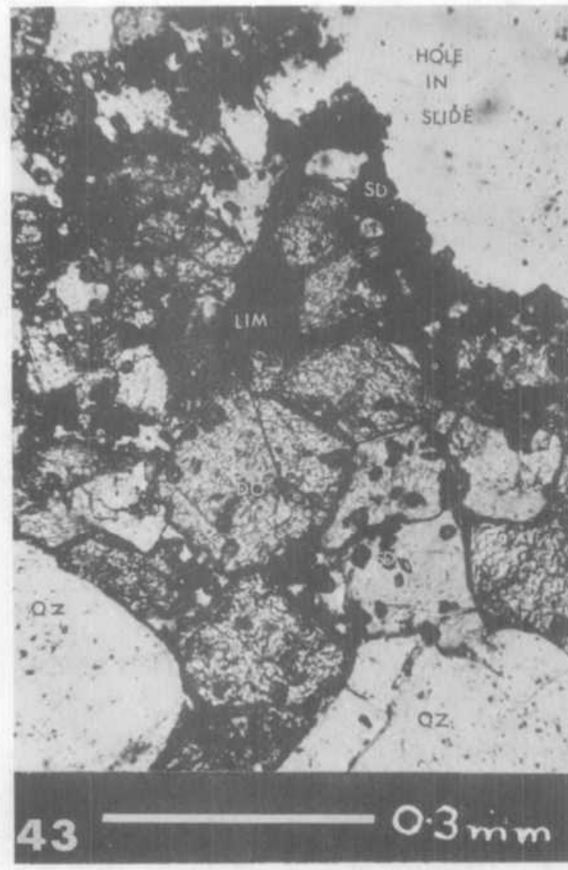
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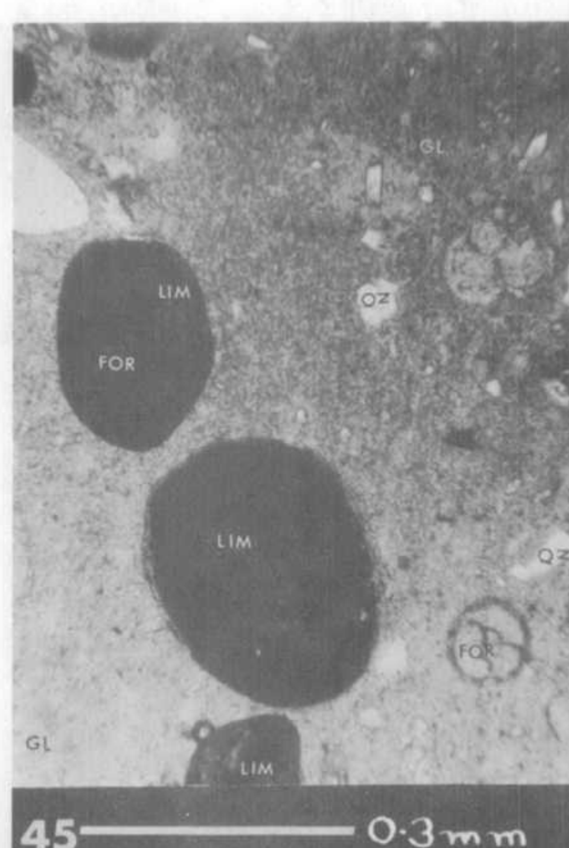
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FOR
QZ
LIM
QZ
FOR
GL
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45
0·3mm

and glauconite pellets occuring in the overlying interval is tentatively assigned to Unit Bc_1; identification of foraminifera was difficult and Taylor concluded that there is no evidence of any stage older than basal Longfordian (Upper Oligocene).

The Bc_1-Bc_2 division is more marked in Eumeralla No. 1. Taylor (in F.-B.H., 1963a)* recognizes G.linaperta in cuttings from below 1400 feet; higher sediments, including the limonitic sandstone interval of Bc_2 (1200 to 1270 feet), are therefore Upper Eocene or younger in age. In Core 2 (1160-1180 feet) is the Globigerina ouachitaensis - Globigerina bulloides group which probably represents the Janjukian (faunal units 4 or 5 of Carter). Because this core is within the glauconitic limestone facies (Bc_1), this sequence is considered as Oligocene.

Petrographic studies on the material available from the Nelson Bore suggest that only the limonitic sandstone facies (Bc_2) is present between Units Db and Bb. The presence at 877 feet of "Victoriella plecte" was identified by Crespin (1954), and this species (=V.conoidea) ranges from Carter's faunal unit 3 to unit 5; on this evidence, that horizon belongs to the Janjukian Stage. Crespin also records Eponides repandus at the same level, although this species is stated by Taylor (F.-B.H., 1962b)* to be diagnostic of the Longfordian Stage. Ludbrook (1961) also recognized both "V.plecte" and E.repandus at the same level in the Compton Conglomerate.

It is in this area and further west that age determination becomes complicated, not only by the general thinning of the Bc section, but also because the biostratigraphic arrangement of the foraminifera is slightly different (as above, and see also Ludbrook, 1963) to that given by Carter for Victoria.

In South Australia, no age determinations were possible in Mount Salt No.1 over the interval of Bc because of poor recoveries, but in the Mount Salt Structure Drilling Project, a sequence of up to 50 feet of glauconitic marl over glauconitic and limonitic sands yielded a microfauna of Upper Eocene age (Ludbrook, in O.D.N.L., 1962*) although the presence of Globoquadrina primitiva may indicate a Middle Eocene age (Ludbrook, 1963). The sequence is apparently equivalent to Unit Bc_2, and underlies glauconitic and marly limestone with no apparent diagnostic fossils except possibly Stomatorbina concentrica which is associated with the Unit 3 fauna of Carter (Ludbrook, op. cit.). The latter unit is thought to be equivalent to Bc_1.

In Geltwood Beach No. 1, Ludbrook (in B.P.N.L., 1964)* has assigned the interval 890-910 feet (i.e. her "910-930 feet") to the Upper Eocene on the presence of G.linaperta, which together with "Chiloguembelina rugosa" and the absence of G.index suggests correlation with Faunal Unit 3. Lithologically and petrologically this interval is also similar to the glauconitic marly limestone facies, Bc_1. The underlying limonitic sands apparently did not yield any diagnostic fossils.

In summary, the following sequence has been established within Unit Bc :

- a basal limonitic sandstone facies occurring throughout the basin, generally thought to be Upper Eocene (to possibly Middle Eocene in the west) except in the Nelson Bore area where an Oligocene fauna is present;

- a conformable marl facies (with glauconite and limonite) in the Port Campbell area, belonging to the Unit 3 (Upper Eocene - Oligocene transition) zone;

- an upper glauconitic limestone, unconformable over the marl in the

Port Campbell area, and over limonitic sandstone in most other parts of the basin (although it does not appear to be present in Nelson Bore, Tullich No. 1, or Heathfield No. 1); its age could range from Upper Eocene (Unit 3 zone) in the west to Oligocene - mainly Janjukian Stage.

Various possible interpretations of the lithofacies in terms of age using the available palaeontological data are shown in Figure 8 :

A. shows the limonitic sandstone as entirely Upper Eocene in age (possibly Middle Eocene in the west), and the glauconitic limestone ranging from possibly uppermost Upper Eocene in the west but mostly Oligocene; this would follow Taylor's results in the Port Campbell area.

B. limonitic sandstone is generally Upper Eocene but in the Nelson Bore area, it is the Oligocene lithofacies equivalent of the glauconitic limestone. This is based on Crespin's results in the Nelson Bore and Carter's reinterpretation of the age of the Janjukian.

C. limonitic sandstone is Oligocene in the Nelson Bore area; glauconitic limestone to the west is equivalent to the marl facies of the Port Campbell area, and is Upper Eocene in age, or in a transitional zone from Upper Eocene to Oligocene. This is postulated to agree with Ludbrook's interpretations.

D. limonitic sandstone is Upper Eocene but in the Nelson Bore is Oligocene also - representing two limonitic facies with an unconformity in between but not recognized. This was recently suggested by Hawkins and Dellenbach for the Nelson Bore sequence.

Interpretation (A) or (D) appears to be most acceptable from the petrological evidence available, but it is apparent that a closer petrological and palaeontological study of the Basin as a whole is required to resolve this problem.

The comparison between the profile of the base of Bc (drawn from seismic contouring) and the thickness variations in Bc is of interest in that an inverted relationship appears to exist: local thickening occurs opposite rises in the base; these features obviously reflect some minor epeirogeny of the Tertiary. Plate7 shows that sub-unit Bc_1 is, in fact, much more constant in thickness than Bc_2 which suggests the possibility of some adjustment between Bc_2 and Bc_1 times.

(e) Stratigraphic Relationships

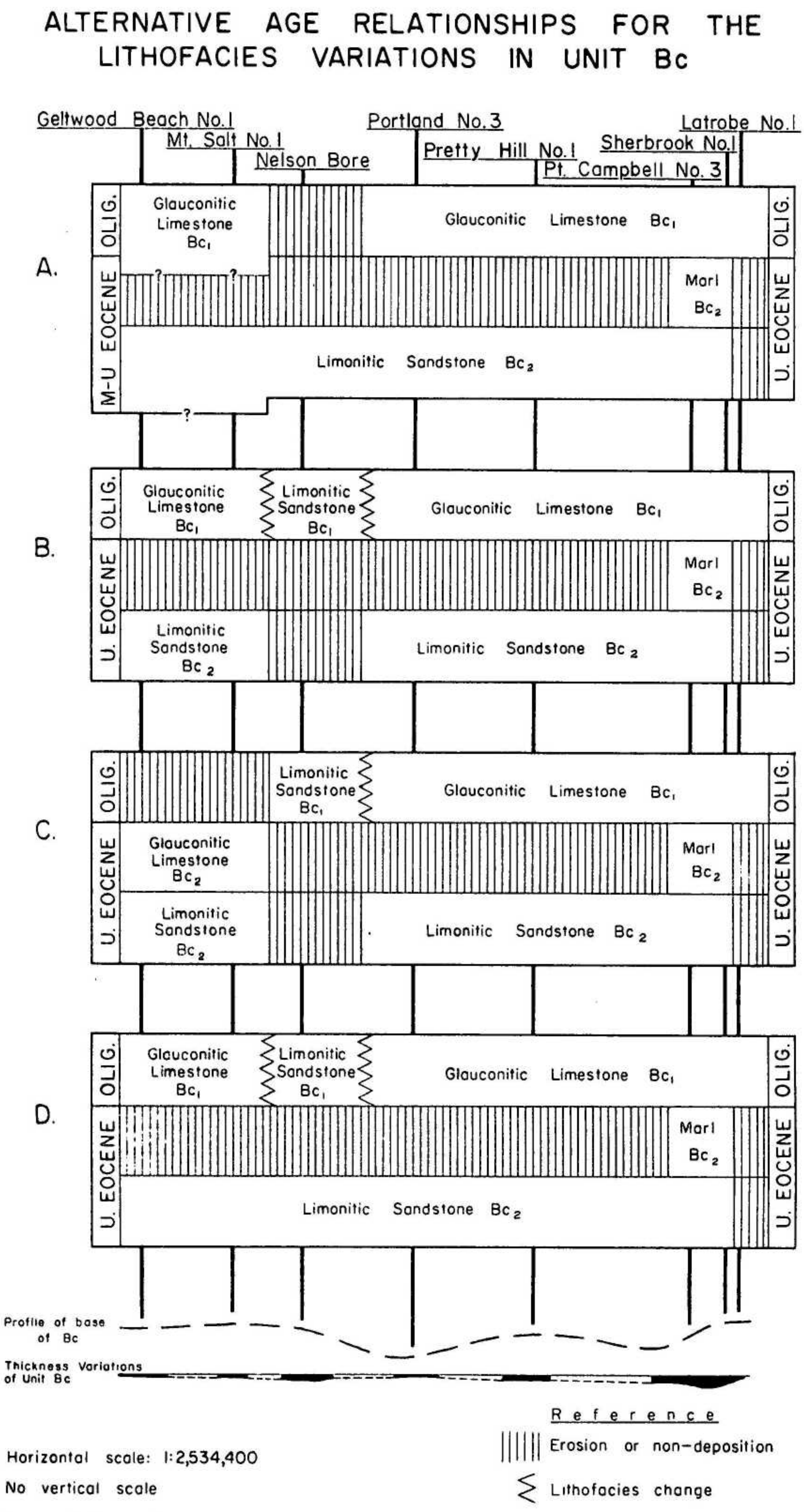
(i) Relationship of Unit Bc to underlying unit:

The base of Unit Bc is represented by an unconformity which exists throughout the basin; in some areas it may occur as an erosional break, as in the case of the Nelson Bore where a basal conglomerate is present, or it may be a non-depositional break.

The unconformity is marked by a change from a dirty immature sandstone facies with polished quartz grains (Unit Db) below, to a limonitic sandstone.

Although this unconformity does not represent a great hiatus, it must be considered important as it occurs also in other basins, at about the same time.

Fig. 8



Bureau of Mineral Resources Geology and Geophysics. August 1966 To accompany Record No

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(ii) Relationships within Unit Bc:

An unconformity occurs within Unit Bc, between Bc_1 and Bc_2; it is present throughout the basin and occurs as a minor break in the Port Campbell area and is represented by either a non-depositional break or erosional break in the Tyrendarra and Mount Gambier areas. Minor epeirogenic adjustments may have occurred during the break. In the Port Campbell area there is a much greater development of sub-unit Bc_2 indicating that from an age standpoint the unconformity is not great, as the marl facies which conformably overlies the limonitic sandstone facies represents a transition between Upper Eocene and Oligocene. However, it is assumed that the unconformity reaches greater magnitude in the west where the marl facies is generally absent.

(iii) Relationship of Unit Bc to overlying unit:

In the Port Campbell and Tyrendarra areas where sub-unit Bc_1 is present, Unit Bc passes gradually with no apparent break up into Unit Bb sediments. In parts of the Mount Gambier area an unconformable relationship exists between Unit Bc and the sediments above; this unconformity, found in the Nelson Bore (?), Tullich No. 1 and Heathfield No. 1, is probably related to non-deposition rather than erosion - there is no evidence for reworked Bc_1 fragments having occurred in Unit Bb sediments above.

(f) Environment of deposition

The sediments of Unit Bc represent a change to shallow marine conditions in sub-unit Bc_2 time and transgressive conditions in sub-unit Bc_1.

The limonitic sandstone facies reflects a period when the sea began to encroach upon a landmass which was still unstable. At the bottom of this sequence in the Nelson Bore a basal conglomerate is present; the very rounded nature of the pebbles suggests a reworking or erosion of a pre-existing conglomerate, possibly of Eocene age. In the sandstones the presence of iron oxide, limonite, haematite and goethite pellets and the rounded nature of the detrital grains suggest deposition under high energy conditions in shallow oxygenated waters. The level of the depositional interface appears to have been above the zero Eh surface for the precipitation of iron oxide, with some of the iron content possibly originating from the reworking of red beds representing the unconformity interface; increase in pH accompanied by quieter conditions occurred during the precipitation of the carbonate of the marl facies in the Port Campbell area.

The glauconitic marly limestone facies heralds the onset of a marine transgression over a shallow shelf area. Shallow water marine conditions prevailed and the temperature and salinity were suitable for supporting calcareous organisms. Although calcium and magnesium carbonates were precipitated, the pH and Eh must have been near neutral at times for glauconite to form.

In this glauconitic marly limestone facies the generally lower detrital content indicates that sedimentation was taking place on a stable shelf area where the adjoining landmass was low-lying.

(g) Hydrocarbon occurrences

There were no indications of hydrocarbons in Unit Bc sediments, either during drilling or in cuttings and thin section studies.

Unit Bb

(a) Occurrence of Unit Bb sediments from well data.

This predominantly carbonate sequence is widespreadin occurrence both in outcrop and subsurface; however, Unit Bb was not intersected in the Heathfield area or in Fergusons Hill No. 1, Latrobe No. 1 and Anglesea No. 1.

Table 12: Subsurface occurrences of Unit Bb.

Well Name	Datum -feet above sea level.	Depths below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Beachport No. 1	18	300 to 775	-282 to -757	475	MOUNT GAMBIER
Geltwood Beach No. 1	30	60 to 890	- 30 to -860	830	
Mount Salt No. 1	86	16 to 480	+ 70 to -394	464	
Nelson Bore	10	0 to 812	+ 10 to -802	812	
Penola No. 1	209	35 to 250	+174 to - 41	215	
Heywood No. 10	100	12 to 1288	+ 88 to -1188	1276	TYREN-DARRA
Portland No. 2	110	115 to 2841	- 5 to -2731	2726	
Portland No. 3	16	42 to 2770	- 26 to -2754	2728	
Eumeralla No. 1	167	13 to 1110	+154 to -943	1097	
Pretty Hill No. 1	202	50 to 1160	+152 to -958	1110	
Flaxmans No. 1	221	15 to 1920	+206 to -1699	1905	PORT CAMPBELL
Port Campbell No. 1	346	9 to 1050	+337 to -704	1041	
Port Campbell No. 2	282	16 to 782	+266 to -500	766	
Port Campbell No. 3	210	15 to 1248	+195 to -1038	1233	
Port Campbell No. 4	440	13 to 964	+427 to -523	951	
Sherbrook No. 1	480	13 to 210	+467 to +270	197	

(b) Lithology

The succession consists of marly limestones and marls containing spicules, thin dolomites and dolomitized limestones and polyzoal limestones with chert.

On the basis of lithology the sequence may be divided into the following intervals:-

Marly limestone and/or marl with spicules.

Polyzoal limestone with chert.

Marly limestone and/or marl with spicules:

This sequence contains pink to grey, marly and chalky limestones with abundant fossil debris and siliceous spicules; marly limestone containing glauconite may occur at the base. At the top of the interval pink, coarse-grained, sucrosic, vuggy dolomite and thin beds of dolomitized limestone may be present as in the Nelson Bore; the dolomite is diagenetic as shown by the palimpsest structures of former fossils.

In the Tyrendarra and Port Campbell areas this interval is represented by grey, soft, fossiliferous marls with thinly bedded marly limestones. The marls contain limonitic layers, pyritized burrows and casts, gypsum spots and glauconite pellets; siliceous sponge spicules and fossils are abundant.

Polyzoal limestone with chert:

The lithology comprises cream to grey chalky to crystalline limestones with rare argillaceous and dolomitized limestone stringers; silicified stringers are also present. Buff to brownish yellow, friable, coarse-grained calcarenites also occur especially in the Tyrendarra and Port Campbell areas. These sediments contain abundant fossil debris of polyzoa, foraminifera and shell fragments.

The silicification, which is secondary, occurs in the form of dark grey chert nodules and silicified fossiliferous limestone lenses. Rare authigenic quartz and scattered detrital quartx grains occur in the limestones. Granules and grains of authigenic glauconite, rare pyrite, biotite flakes and glaucophane are present in these sediments; occasionally fossil fragments are partially infilled by phosphatic material and glauconite.

In this carbonate sequence few localized lithofacies variations occur. The most obvious change is the increase in the marl facies in the Tyrendarra and Port Campbell areas which is accompanied by a corresponding decrease in the polyzoal limestone present. There is little evidence of chert in the limestone sequence in the eastern part of the basin; however, silicification is well developed in the Mount Gambier area.

Thickness variations are most marked in the Tyrendarra area between Portland No. 3 and Eumeralla No. 1 (Plate 8).

Unit Bb

Photomicrograph 46. Polyzoal Limestone

The Nelson Bore, core sample 578'.
Plane polarised light.
Compact, finely recrystallized limestone composed of bryozoa debris (bry); and some foraminifera (for). Shell fragments have undergone recrystallization (ca).

Photomicrograph 47. Dolomite

The Nelson Bore, core sample 536'.
Plane polarised light.
Compact, saccharoidal, recrystallized, very fine to medium-grained (0.12 - 0.33 mm) dolomite. Dark clay (cl) coats dolomite (do) crystals and occurs in interstices. Note well-developed dolomite (do) rhomb and also vug (v).

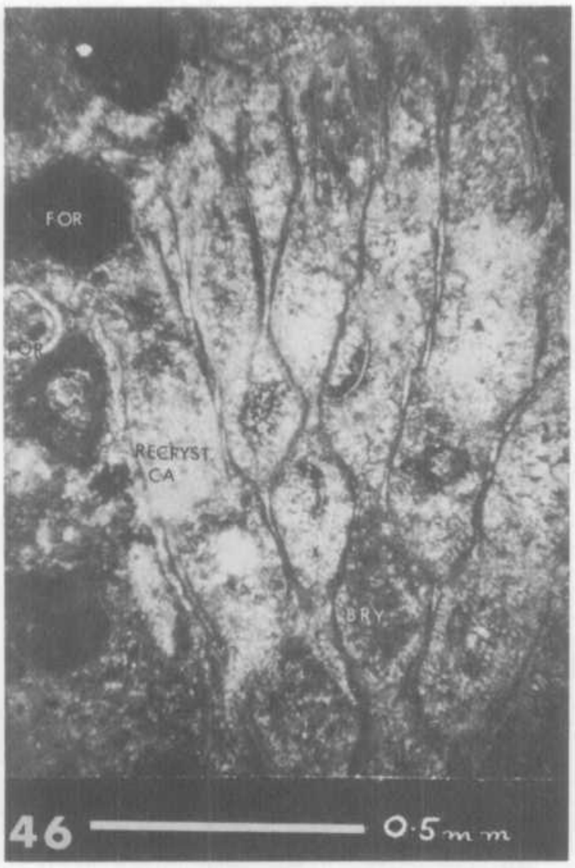
Photomicrograph 48. Spicular Marly Limestone

Geltwood Beach No. 1, cutting sample 810' - 820'.
Plane polarised light.
Dense, cryptocrystalline calcite (ca) with abundant siliceous sponge spicules (sp). Rare pyrite (py) specks. Some replacement of spicules by cryptocrystalline calcite.

Unit Ab

Photomicrograph 49. Calcarenite

Heathfield No. 1, cutting sample 100' - 110';
Plane polarised light.
Subrounded, fine to medium-grained (0.15 - 0.36 mm), main mode=medium-grained; moderately sorted.
Quartz (qz) 20%, bioclasts-bryozoa (bry), foraminifera (for) - 60%, recrystallized calcite (ca) 20%.
Iron oxide staining on some fragments.


FOR
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46
0.5 mm


CL
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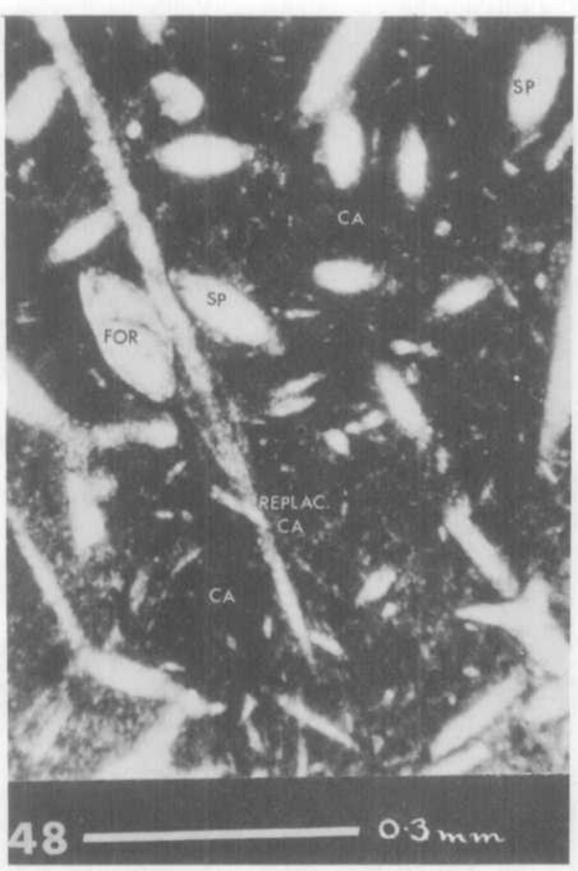
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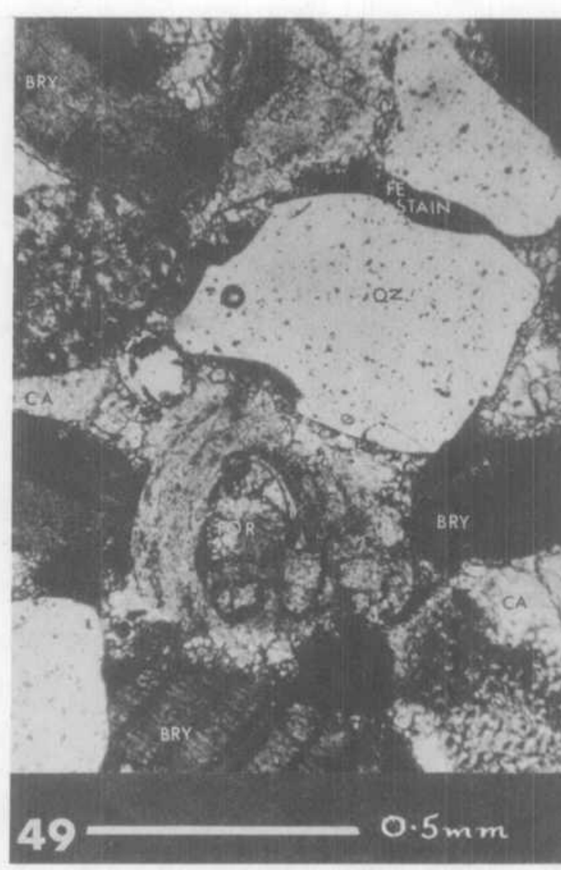
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(c) Structures

Chert nodules occur in the polyzoal limestone; pink dolomite and dolomitic limestone horizons may be present e.g. in the Nelson Bore. The dolomites are partly vugular.

No indication of dips could be obtained from cores taken within Unit Bb; it is assumed that the beds have a low dip, as in outcrop.

(d) Fossils and age

Palaeontological evidence shows that Unit Bb extends from the Oligocene to Miocene in age; however, faunal evidence for the Miocene sediments is not always conclusive.

(e) Stratigraphic relationships

(i) Relationship of Unit Bb to underlying unit:

Revision of the levels of the basal part of Unit Bb has been made since early petrographic studies as a result of more recent investigations and palaeontological evidence; in some wells sub-unit Bc_1, now includes sediments formerly assigned to Unit Bb.

In the Mount Gambier area, petrological evidence suggests the possible existence of an unconformity between Unit Bb and Unit Bc in the Nelson Bore. Elsewhere, as in Geltwood Beach No. 1 and Mount Salt No. 1, it appears that the glauconitic sediments of Bc_1 pass conformably into the Oligocene sediments of Unit Bb above.

In the Tyrendarra and Port Campbell areas Unit Bb rests conformably on sub-unit Bc_1.

(ii) Relationship within Unit Bb:

The marls and marly limestones present in the lower part of Unit Bb pass conformably into the polyzoal limestones above; there is no suggestion of a break from either lithological or palaeontological evidence.

(iii) Relationship of Unit Bb to overlying unit:

Where sediments are encountered above Unit Bb an unconformable relationship exists; the overlying sediments are either of Unit Ab - Pliocene age, or Recent. Most of the wells, especially in the Port Campbell area, enter Unit Bb at the surface.

(f) Environment of deposition

Unit Bb sediments represent deposition under open-shelf, near-shore conditions. The terrigenous material present at the base of the unit decreases upwards and must be a function of distance from the shore-line; the sandy limestones are replaced by marls and clean limestones towards the top of the sequence, and these appear to extend furthest inland.

The carbonate sediments formed in a neritic environment. The abundance of calcareous organisms throughout this sequence reflects the suitability of depth, temperature and salinity for faunal growth.

(g) Hydrocarbon occurrences

No indications of hydrocarbons have been observed in Unit Bb sediments. Any occurrences would have been flushed out of the sediments because of their high permeability.

Unit A

This unit was first described from Heathfield No. 1 (Hawkins, 1965*); it contains sediments similar in lithology to the Normanby Group (Boutakoff and Sprigg, 1953). To allow for subdivision, the unit was designated Ab.

(a) Distribution of Unit A

(i) Surface Occurrences:

Surface areas of Unit Ab sediments are isolated. The Whaler's Bluff Formation, which consists of fossiliferous marls, clays and calcarenites, was defined by Boutakoff and Sprigg (1953); these sediments were first recognized at Whaler's Bluff, Portland. Boutakoff and Sprigg record three members, the Maretime, Werrikee and Crawford (ascending order) within the Whaler's Bluff Formation. The type localities for the individual members are as follows : The Maretime Member occurs at Dutton Way, sections Nos. 1 and 2 below the Maretime homestead, Portland (Boutakoff, 1963); the Werrikoo Member is present at Caldwell Cliff on the Glenelg River (Singleton, 1941); the Crawford Member occurs in the Dartmoor Quarry on the Glenelg River, opposite the entrance to the Crawford River Valley.

Surface evidence shows the Maretime Member sediments filling solution channels, joints and cavities in the underlying Portland Limestone; this contact can be seen in the Portland Cliffs. The Maretime clays are thinly developed over the intervening ridges between depressions in the Portland Limestone. The overlying Werrikoo sediments are absent in the Dutton Way Sections; at points along the Portland Cliffs, however, sandy limestones, shelly limestones and calcareous sandstones belonging to the Werrikoo Member rest on Maretime clays and marly limestones. In a quarry in the Glenelg Valley the Crawford Member, consisting of calcarenites and calcareous silts, rests conformably on Werrikoo sediments. In the Portland area the Crawford Member is missing.

(ii) Subsurface Occurrences:

Of the subsidized wells studied in detail, only Casterton No. 1, Heathfield No. 1, Tullich No. 1 and Kalangadoo No. 1, contain Unit Ab sediments. Penola No. 1 is also thought to contain sediments belonging to Unit Ab and Glenie and Reed (1961) have recognized sediments equivalent to this unit in Portland No. 2 and No. 3 wells.

(b) General lithology of Unit A

The sequence consists of coarse-grained sandy calcarenites, biocalcarenites and sandy limestones. There is a gradual decrease of calcarenite and an increase in sandy limestone towards the base of the unit.

Unit A sediments found so far are placed in one subunit :- Unit Ab.

Unit Ab.

Table 13: Subsurface occurrences of Unit Ab

Well Name	Datum - feet above sea level	Depths below datum level (feet)	Depths from sea datum level (feet)	Thickness (feet)	Area
Kalangadoo No. 1	230	11 to 30	+219 to +200	19	
Penola No. 1	209	5 to 35	+204 to +174	30	MOUNT
Tullich No. 1	272	24 to 70	+248 to +202	46	GAMBIER
Heathfield No. 1	244	70 to 152	+174 to + 92	82	
Casterton No. 1	472	11 to 60	+461 to +412	49	
Portland No. 2	110**	51 to 115	+ 59 to - 5	64	TYREN-
Portland No. 3	16**	28 to 42	- 12 to - 26	14	DARRA

** Figures taken from report by Glenie and Reed (1961).

Unit Ab is composed of yellowish-orange and light to medium brown sandy calcarenites, biocalcarenites and sandy limestones.

The sandy calcarenite is friable, subangular to rounded, coarse to very coarse-grained and moderately sorted. The constituents are clear, milky, polished and frosted quartz, rare mica flakes, and sand-size, worn shell fragments. The shell fragments are of pelecypods, gastropods, bryozoa and foraminifera. Good porosity exists in these calcarenites.

Thinly bedded biocalcarenite occurs in the sequence; it is compact, with rounded, fine to coarse-grained and moderately sorted grains. The constituents comprise quartz and metaquartzite (5 to 20%) and fossil debris (40 to 60%) of algae, foraminifera and echinoid spines. The cementing media are finely recrystallized calcite, siderite and dolomite. In Heathfield No. 1 iron-coated dolomite rhombs occur in the calcite cement. Good intergranular porosity is present in these sediments.

Lithofacies variations are present between the Tyrendarra and Heathfield areas. In both Portland No. 2 and No. 3 wells (Glenie and Reed, 1961) clays and shelly marls are recorded at the base of the Whaler's Bluff Formation; these sediments represent the Maretime Member. In both Tullich No. 1 and Heathfield No. 1 these clays are absent; only calcarenites and sandy limestones are present which may be correlated with the calcarenites found in the upper half of the Portland No. 2 sequence (Werrikoo Member).

(c) Structures.

No sedimentary structures have been observed in the material available for study, nor could any evidence for dips be obtained from the petrological study of Unit Ab sediments.

(d) Fossils and Age.

Palaeontological studies have shown that Unit Ab extends from Pliocene to Pleistocene in age.

In Heathfield No. 1 the sediments are regarded as Pleistocene in age, whilst those in Tullich have been assigned to the Pliocene (P.E.C., 1964*, 1965*). In Portland No. 2 (Glenie and Reed, 1961), sediments comparable to Unit Ab are regarded as Upper Pliocene (Maretime and Werrikoo Members) in age. In Portland No. 3 only sediments assigned to the Maretime Member (Upper Pliocene) have been recorded.

From this evidence the Portland sequence appears to be older than that in the Heathfield area. No sediments of Lower Pliocene age have been recorded from these wells.

(e) Stratigraphic Relationships.

(i) Relationship of Unit Ab to underlying unit:

The base of Unit Ab is marked by an unconformity, the nature of which could not be fully determined from the wells studied. However, in both Portland Nos. 2 and 3 wells Glenie and Reed (1961) have reported the presence of a clay (Maretime Member) as the base of the Whaler's Bluff Formation (Unit Ab) which fills solution cavities and sinkholes in the underlying Portland Limestone (Unit Bb).

In both Heathfield No. 1 and Tullich No. 1 there is little evidence of an unconformity from petrological studies, but in both these wells Unit Ab rests on an arenaceous sequence interpreted as Unit Bc of Oligocene age. Erosion and nondeposition are envisaged, especially in the Heathfield area which is situated near the edge of the basin.

(ii) Relationship within Unit Ab:

The most complete succession of Unit Ab sediments occurs in Portland No. 2 well, where clays at the base pass into calcarenites above; there is no evidence to suggest a break from either lithological or palaeontological studies.

(iii) Relationship of Unit Ab to overlying sediments:

In wells where Unit Ab is overlain by sands and clays of Quaternary age a conformable relationship exists. In Portland No. 2, Unit Ab is overlain by basalt (Newer Volcanic Series).

(f) Environment of deposition.

From the rounded and very coarse nature of the quartz gains and bioclastics, the lack of clay matrix, and the presence of carbonate cement, the upper sediments of Ab appear to have been deposited under shallow marine conditions where current action was prevalent. Quieter marine conditions prevailed during earlier deposition in the Portland area.

(g) Hydrocarbon occurrences.

From petrological studies there is no evidence to suggest that hydrocarbons ever occurred in Unit Ab sediments.

3. The Unconformities

The term unconformity is used here to denote a surface of non-deposition or erosion at the base of or within a sedimentary section. The nature of unconformable surfaces in the Otway Basin has been difficult to determine; firstly, most of the unconformities have been recognized only in the subsurface, and secondly, only a limited number of cores have intersected unconformable surfaces. In most cases the unconformities have been determined by the nature of the sediments on either side.

Three types of unconformity occur: angular unconformity, disconformity, and nonconformity (as defined by Krumbein and Sloss, 1963). They are recognized by using structural, sedimentary, and palaeontologic criteria.

A limited amount of structural criteria was available from cores and dipmeter results; assessment of the dipmeter results, however, was difficult because of the presence of mineral veins and fractures - this was particularly so for Unit M. Structural criteria were only applicable for the Jurassic-Lower Cretaceous sediments (Units T, P-R, and M), and angular unconformities have been suggested between Units M_1 and M_2 in Fergusons Hill No. 1, and below some of the sand bodies in Unit M in the Mount Gambier area. An angular unconformity is thought to exist between Units W (basement) and T in Casterton No. 1.

In most cases an unconformable surface could not be recognized from subsurface samples so that the bulk of the evidence for a break in sedimentation has been determined from changes in environmental and energy conditions reflected in the sediments. The sedimentary criteria used include basal conglomerate, the formation of oolite and pelletal sandstone rich in iron and containing phosphate, and marked mineralogical changes, e.g. greywackes of Unit M to orthoquartzite and protoquartzite of Unit J.

Generally the palaeontologic criteria have been used to help substantiate the sedimentary criteria for unconformities. Palynological studies, particularly on Mesozoic sediments, showed changes in fossil assemblages and these proved to be of value in revealing possible time gaps; variations in assemblages could also indicate changes in environmental conditions. Foraminiferal studies for oil companies, particularly on Upper Cretaceous and Tertiary sediments, have proved useful in establishing unconformities especially at the base of and within Unit B.

Most of the unconformities established in the Otway Basin sequence - both Mesozoic and Cainozoic - have been regarded as disconformities (surfaces of unconformity separating essentially parallel strata). Their geographical extent has been determined from subsurface studies together with some information from the literature, and they have been described as either regional or local. The most important of the regional disconformities are those at the base of Unit B, at the base of Unit D, and one at the base of Unit G. The breaks at these horizons in each case represent changes from deposition in a marginal marine environment to sedimentation under entirely marine conditions; they occur between cycles of marine transgression and regression. Reflections from lithological units at these horizons are generally easy to follow in seismic records, with the exception that the prominent band of energy return shown at or near the base of Unit G tends to follow the base of Unit J-H in the area where this unit is known in the subsurface. Reflections in Unit M show some evidence of angular unconformity at the base of Units G, J-H.

Due to the poor distribution of the wells studied in the Otway Basin and lack of other reliable information, some of the disconformities considered as local may be more extensive than is presently known. Conversely, some of the local disconformities in the land area may simply be diastems, or become diastems, in the off-shore area.

Nonconformities (sediments covering an eroded basement surface) probably exist in Fergusons Hill No. 1 area, and to the west where wells show Units P and R resting on igneous and metamorphic rocks.

4. Stratigraphic nomenclature

At the start of the Otway Basin review, difficulties arose from the complexity of stratigraphic nomenclature within the Otway Basin. Very little of the existing nomenclature had been formalized.

Because of the proliferation of names, B. M. R. decided to use a set of informal units represented by symbols to designate the recognizable subsurface lithostratigraphic units. As noted earlier, the symbols are of three types (e.g. Db_2) and although they may approximate to Group, Formation and Member in some cases, no such formal status was intended for them.

When the review was near completion, the extent and character of B. M. R. units were carefully checked against the stratigraphic tables of others. Wherever possible, existing names were adopted for the informal units, although their status was changed in some cases because of additional evidence from the review. No names were available for some B. M. R. units, and some of these have subsequently been named (Reynolds, Evans, Bryan and Hawkins, 1966). They are all Cretaceous units.

In the case of Tertiary units, although a B. M. R. interpretation has been made on the basis of petrology, support from consistent palaeontological correlation is lacking. For this reason, no attempts have been made to name some of the informal units. However, correlation with existing nomenclature is attempted in Chart 2.

Because of the wide extent of the Basin and because it occurs in two States, much of the pre-existing nomenclature was only applied over restricted areas. The earlier tendency to regard the Otway Basin as a number of sub-basins or embayments also led to the setting up of new names for each new area investigated. For these reasons, it will be necessary to show the various nomenclatures in five groups according to areas in Chart 2. They are compared against the B. M. R. informal units and the names adopted as a result of the review.

Equivalents of pre-Cretaceous Units W, V and T.

The oldest of the informal units, W and V, are not shown on the Chart. Unit W applies to moderately metamorphosed rocks in Fergusons Hill, and Casterton No. 1 Wells, and to altered dolerite in Pretty Hill No. 1; these rocks are thought to represent part of the Cambrian-Ordovician succession of western Victoria. However, until more evidence is available, the rocks of this unit cannot be given stratigraphic names or correlated with existing stratigraphic units.

Unit V is a low grade metamorphosed sediment and appears to be similar to rocks of lower Palaeozoic age in western Victoria. No equivalent to Unit T is known. Neither of these units can be formally named because each is confined to a single well. However, Unit T is shown on Chart 2 because of its occurrence at the base of the Otway Basin succession.

Equivalents of Lower Cretaceous Units R, P, M and J-H.

New names have been proposed by B. M. R. for Units P and M because the existing nomenclature was not considered to be adequate. Unit R is only recognized in one well, and hence must retain the informal name "Pretty Hill sandstone". Unit P occurs in several wells in the western half of the Otway Basin; it is a distinctive unit composed of the interbedded lithologies of M and R. It has been called the Geltwood Beach Formation, and the "Pretty Hill sandstone" is regarded as a sandy facies of the Geltwood Beach Formation.

Unit M had no formation name, as such, but was generally referred to as 'Merino Group' or 'Otway Group'. Neither of these units should have been defined originally as a Group, because they were not constituted of a number of formally described and named formations. For this reason, B. M. R. has called Unit M the Eumeralla Formation. The lower part of the Eumeralla Formation in the eastern half of the Basin is equivalent to the Geltwood Beach Formation, and in the western half, the uppermost part is equivalent to the Waarre Formation. These correlations are based on palynological studies. The Geltwood Beach and Eumeralla Formations in the west, and the Eumeralla and Waarre Formations in the east have been described as constituting the Otway Group, thus formalizing the name 'Otway Group' and allowing its continued use, more or less as before. The name "Otway" has priority, and "Merino" and other synonyms for the same unit can be abandoned.

Difficulties have been encountered in correlating the 'Moonlight Head Beds' - the uppermost exposure of the 'Otway Group' as described by Baker (1950) from a coastal section near the Otway Ranges - with the more complete subsurface data from the Port Campbell and Torquay areas. All the deep drilling at Port Campbell has revealed Waarre Formation overlying Eumeralla Formation at the top of the Otway Group. For this reason, the 'Moonlight Head Beds' are shown lower than the Waarre Formation of the Port Campbell area. Similar sands to those of the Waarre Formation - designated Unit H - were found overlying the 'typical Otway Group' in Anglesea No. 1 Well (Dellenbach, 1965b*), and it is very likely that Unit H is also equivalent to the Waarre Formation. Unit H occurs subsurface in the Torquay area and hence was not recognized by earlier workers.

Equivalents of Unit G (Upper Cretaceous).

The recent contribution of Bock and Glenie (1965) dealing primarily with the cyclic sedimentation in the Otway Basin includes a composite stratigraphic column that has been reproduced in Chart 2; the only modification has been the addition of 'partial disconformities' - positioned and described by Bock and Glenie but not shown in their column. They have modified existing Upper Cretaceous and Tertiary nomenclature and have adopted a new role for the rock unit in stratigraphy. Their nomenclature is based on the idea of diachronic deposition of a number of units within a continuous phase of sedimentation through the Upper Cretaceous and Tertiary, and possibly unintentionally introduces a concept of time.

B. M. R. nomenclature for Unit G is designed to formalize the unnamed parts of the succession as distinct lithological units, and to ensure that existing names are used as intended. The name Sherbrook Group is introduced to give Unit G the status of a group which represents a single cycle of sedimentation and emphasizes the importance of the basin-wide unconformities above and below.

Unit G is known only as a subsurface unit and although seismic records show that at least the upper part extends to the east of the Port Campbell area, its comparison with possible equivalents in outcrop has not been possible. Unit Gb, the Curdies Formation, was recognized by Dellenbach in the Anglesea No. 1 Well, and has been correlated with the Eastern View Coal Measures on the basis of lithology. This is in the Torquay area. Although the correlation of the Eastern View Coal Measures appears to be straightforward, the position of the 'Boonah Sandstone' is problematical. It is described by Raggatt and Crespin (1955) as the unfossiliferous sandstone between the top of the Eastern View Coal Measures and the base of the Demon's Bluff Formation, but it is only loosely cemented and makes poor outcrops; it could not be distinguished in bores at Anglesea and Torquay. Stach (1962) suggested that the 'Boonah Sandstone' was merely a non-lignitic facies of the Eastern View Coal Measures, and Edwards (1962, p.109) recommends that the 'Boonah Sandstone' subdivision should be discarded because of the discovery of another coal seam in this subdivision.

In the Brown Creek area of the Aire District, the 'Rotten Point Sands' are unconformable on the Eumeralla Formation, and are composed of unfossiliferous sands that apparently wedge out in a short distance; they do not crop out further east in the Aire River area where the overlying Johanna River Sands and younger formations continue. The Rotten Point Sands are probably either a non-fossiliferous continuation of the Pebble Point Formation, or a part of the Curdies Formation (Gb). Seismic records show Unit G terminating to the south of the Aire District, but a thin wedge such as the Rotten Point Sands would probably not be recognized in the records at near surface level.

Equivalents of Tertiary units.

The sediments which compose Unit D have been called 'Wangerrip Group' (Baker, 1950, 1953) in the eastern, Port Campbell part of the Otway Basin, and 'Knight Group' in the west (Sprigg, 1952; Boutakoff and Sprigg, 1953). Petrological work and studies of seismic records have shown that Unit D extends across the Otway Basin from south-eastern South Australia into Victoria at least as far as the Port Campbell area, and also off-shore.

Baker (op.cit.) named the 'Wangerrip Group' to conform with the Stratigraphic Code (Raggatt, 1950) and in view of the priority of the name, and its formalization, the B. M. R. prefers the name Wangerrip Group for its Unit D. 'Knight Group' is to some extent an unsatisfactory name in that the name 'Knight' is taken from 'Knight Sands and Clays' - 20 feet of conglomerate, sand and clay cropping out in Knight's Quarry, near Mount Gambier in south-eastern South Australia (Spriggs, op.cit.), and yet the 'Group' is defined as being composed of the 'Bahgallah Formation' and 'Dartmoor Formation', both of which have their type areas in western Victoria.

Two divisions of Unit D have been recognized - Dd and Db - and these are equivalent to the Pebble Point Formation and 'Dilwyn Clay' respectively of Baker. The preference for the name 'Pebble Point Formation' instead of 'Bahgallah Formation' is its priority (Baker, 1943) and formalization (Baker, 1953). Kenley who first described the beds which were subsequently called 'Bahgallah Formation' (in Boutakoff and Sprigg, op.cit.) indicated their marked similarity (fossiliferous ferruginous pebbly grits and clays) to the Pebble Point Formation, and possibly for this reason did not name them.

Likewise, the 'Dartmoor Formation' is lithologically similar to the 'Dilwyn Clay' which name has priority. Also, the original description given by Boutakoff and Sprigg for the 'Dartmoor Formation' (976 to 7305 feet in the Nelson Bore) included an interval which was subsequently shown to be Upper Cretaceous in age and unconformable below the Tertiary, (Hawkins and Dellenbach, 1963*); the equivalent to the 'Dartmoor Formation' - Unit Db - occurs in the interval 992 to 3690 feet. Recent workers have used 'Dilwyn Formation' instead of 'Dilwyn Clay' (Bock and Glenie, 1965; Leslie, 1966) and in view of the diverse lithologies of Unit Db - argillaceous sandstone, mudstone, rare carbonate-cemented sandstone, and friable carbonaceous sandstone - the B. M. R. will also use the name Dilwyn Formation.

The 'distinctive interval of brown micaceous carbonaceous siltstone' recognized by Leslie (1966) above the Pebble Point Formation is the "Rivernook Member" (or 'Bed') of the Dilwyn Formation (Baker, 1943). This unit was not recognized, as such, by B. M. R. although we did make a division into Units Db2 (lower) - mudstone and clayey sandstone with rare carbonate-cemented sandstone and Db1 - mainly coarse quartz sandstone with carbonaceous beds. Bock and Glenie's 'Pember Mudstone Member' is at about the same level as the "Rivernook Member", but its lithology is not clearly described in their 1965 paper, nor is its relationship to the "Rivernook Member" shown. They also show another member, the 'Dartmoor Sand Member', at the top of the Dilwyn Formation; this is obviously similar in concept to the Db1 division of B. M. R., but it has been named after the 'Dartmoor Formation' - originally considered to be equivalent to the whole of the Dilwyn Formation; the change in concept of the name should be avoided because it could lead to confusion.

The Johanna River Sands in the Aire River area near Cape Otway, and the Demon's Bluff Formation near Anglesea both occur between unfossiliferous sandy formations below, and overlying calcareous formations with diagnostic fossils. They are lithologically similar, in parts, to the Dilwyn Formation, and the Demon's Bluff Formation is characteristically fine-grained near the base - 'Anglesea Siltstone Member' - and more sandy in the upper part - 'Addiscot Greywacke Member' (Raggatt and Crespin, 1955) although Edwards (1962) suggests that the two members are equivalent. Biostratigraphic correlations by Taylor (1965) suggest that the Johanna River Sands are equivalent to the Dilwyn Formation and may extend above the range of the exposed part of the Dilwyn Formation (whose uppermost outcrops are obscured by Recent deposits); some biostratigraphic correlation also exists between the Demon's Bluff Formation and the Dilwyn Formation. It is noted that freshwater beds and volcanics are shown in the uppermost part of the Demon's Bluff Formation by Raggatt and Crespin (op.cit.), in the top part of the 'Addiscot Member', and in the 'Angahook Member'.

In summary, Unit D is thought to be equivalent to the Wangerrip Group, and is composed of the Pebble Point Formation and Dilwyn Formation. The Johanna River Sands are correlated at least in part with the Dilwyn Formation, and the lower part of the Demon's Bluff Formation is probably also equivalent.

The youngest unit of basin-wide importance which has been separated in the review of the Otway Basin is Unit B which is marked by a distinctive lithological change above Unit D, and the break is also obvious in seismic records. It was originally divided by Hawkins and Dellenbach (op.cit.) into Unit Bc - conglomerate, sandstone with limonite and chamosite pellets, and Unit Bb - limestone, in their petrological study of the available Nelson Bore samples. Unit Bc was considered to be equivalent to the 'Nelson Formation' (Boutakoff and Sprigg) in western Victoria (and to the 'Compton Conglomerate' in south-eastern South Australia), and Unit Bb was related to the 'Mount Gambier Formation' extending from South Australia into Victoria; Unit B was thus equivalent to the 'Glenelg Group'.

Subsequent studies by Ludbrook (1963) and Leslie (1966) have shown, however, that B. M. R.'s original divisions of Unit B, particularly Bc, are inadequate for the Otway Basin. Ludbrook studied green sands from bores in south-eastern South Australia which would have been correlated on a lithostratigraphic basis with the 'Compton Conglomerate' and the Nelson Formation (or Unit Bc) but found foraminiferal assemblages with a different stratigraphic range to that envisaged for the Nelson Formation. Correlation of Unit Bc with the green sands in South Australia, and with other sediments of this general, Tertiary age in Victoria is further complicated by the fact that Ludbrook's biostratigraphic arrangement of the foraminifera in South Australia is different to that given by Carter (1964) for Victoria.

The sediments which were included by the Bureau in Unit Bc in the Port Campbell area to the east of the Nelson Bore, were subsequently split into three formations by Leslie :-

upper - limonitic sandy limestone, equivalent to the 'Clifton Formation';

- a glauconitic marl which he called the 'Narrawaturk Formation';

basal - glauconitic, ferruginous sandstone and silstone, named the 'Mepunga Formation'.

Leslie recognized a marked similarity between the lower two formations and the lower and upper parts of the 'Brown's Creek Beds' of the Aire District, and united the two formations into the ' "Browns Creek" Group '. His upper formation, the 'Clifton Formation', is unconformable above the 'Narrawaturk Formation', and forms the basal unit of the 'Heytesbury Group'. Bock and Glenie (1965), apparently considered that ' "Browns Creek" Group ' was invalid and changed the name to 'Nirranda Group' - composed of the Narrawaturk 'Marl' (a more suitable name than 'Formation'), and 'Mepunga Formation'.

B. M. R. subsequently altered their informal subdivision to conform with Leslie's scheme :

Bc_1 - a glauconitic limestone facies;

Unconformity;

Bc_2 - limonitic and glauconitic marl; limonitic sandstone.

The suggested distribution of these different facies is shown in Plate 7. However, it should be stressed that this is only a tentative suggestion; B. M. R. control in correlations of Unit B and younger sediments is limited :

(a) by the fact that few cores are available for this upper part of the subsurface section, and

(b) by the B. M. R.'s lack of up-to-date outcrop information and other unsubsidized subsurface data.

For these reasons, no attempt is made to provide a suitable nomenclature for the upper parts of the Otway Basin succession. The following notes explain our reasons for the correlation in Chart 2.

The western equivalent of the Clifton Formation (Baker 1953) now appears to be the Compton Conglomerate - both correlated with Unit Bc_1. Palaeontological evidence would indicate that the bulk of the Nelson Formation (Boutakoff and Sprigg, 1953) as recognized in the Nelson Bore and originally assigned an Eocene age (Crespin, 1954) belongs within the Oligocene and should be included within Unit Bc_1; but it is possible that a limonitic conglomerate recognised by Hawkins and Dellenbach (1963*) at 986 ft. in the Nelson Bore may be equivalent to the limonitic sandstones from Geltwood Beach No. 1 (910 - 960 ft.) and Mt. Salt No. 1 (510 - 590 ft.) - which are now regarded as the condensed sequence of Unit Bc_2.

Leslie (1966) considers that the Nelson Formation in the Nelson Bore may be equivalent to the "Mepunga Formation" and thus equivalent to our Unit Bc_2.

Glenie and Reed (1961) in describing sequences in the Portland Nos. 2 and 3 Bores state that 'correlation of sediments immediately overlying Dartmoor Formation with those in the type section of the Nelson Formation in Glenelg No. 1 (Nelson Bore) .... can be made on the basis of their lithology and sequential position'. For this reason Glenie and Reed's column in Chart 2 is matched precisely with that of Boutakoff and Sprigg over this interval. However we consider that only the lower "limonitic" portion of the Nelson Formation in the Portland Bores can be equated with any certainty with the Nelson Bore sequence and that the upper (glauconitic) interval has no real equivalent in the Nelson Bore.

In the Port Campbell area, a regression at the end of Nirranda Group time is suggested by the occurrence of freshwater sediments - the Point Ronald Clay - in outcrop below the Clifton Formation. The Point Ronald Clay is probably equivalent to freshwater sediments which occur with volcanics in the Angahook Member at the top of the Demon's Bluff Formation in a part of the Torquay area. A break at about this level is also suggested for the Aire District where [redacted] Unit 4 of Carter (1958) is missing.

Above the break, a brief period of limonitic sandy limestone deposition occurred - the Clifton Formation in the Port Campbell area, and possibly the Nelson Formation or part of the Nelson Formation, and the 'Compton Conglomerate' in the west. Dominantly carbonate and marl deposition followed and formed the Unit Bb. This is equivalent to the Gambier Limestone in south-eastern South Australia; the Gambier Limestone (or Mount Gambier Formation and Muddy Creek Formation) in western Victoria; and the Gellibrand Marl and Port Campbell Limestone in the Port Campbell area. The Calder River Limestone, Upper Glen Aire Clays, and Fishing Point Marl of the Aire District, and the Jan Juc and Puebla Formations and their equivalents of the Anglesea - Torquay area appear to represent only part of the Bc_1 - Bb sequence. The significant feature of the distribution of lithologies in Unit Bb is the development of marl rather than limestone in the Victorian part of the Basin where thickening has been postulated, (Plate 8).

The sediments of Unit A are confined mostly to westernmost Victoria and south-eastern South Australia and are of local significance only. The correlation of some of the equivalent stratigraphic units is shown in Chart 2, but no attempt is made to tie in the other local developments : Brighton Group near Melbourne (Gill, 1950), young clay and limestone deposits of the Port Campbell area (Baker, 1944 to 1953), sediments associated with the "Newer Volcanics" in western Victoria (Gill, 1964), younger formations of the Geelong area (Coulson, 1932 to 1935; Bowler, 1963), etc.

III PALYNOLOGY (By P.R. Evans)

1. Introduction

The palynology and stratigraphy of the Mesozoic of the Otway Basin have grown in unison during the past decade, promoted in particular by the search for hydrocarbons and water, and the consequent availability of material from deep drilling. Palynological studies by Baker & Cookson (1955), Cookson (1953c, 1954, 1956), Cookson & Dettmann (1958) and Cookson & Eisenack (1961a) showed that both Lower and Upper Cretaceous sediments exist in the basin. Evans (1961a*) indicated that most European stages of the Cretaceous were probably present; Douglas (1962) and Evans (1962*) introduced schemes for subdividing portions of the Upper Cretaceous; and Dettmann (1963), from a comprehensive systematic study of spores and pollens in several wells in Victoria and South Australia, including the Commonwealth subsidized ODNL Penola No. 1, indicated a way to subdivide the Lower Cretaceous. Apart from these more generalized accounts, a number of reports on the microfloras of specific wells have been compiled. Most of them are unpublished, but available as either BMR Records or appendices to subsidized well completion reports. These data are reviewed and summarized by Evans (1966*) into a tentative biostratigraphic framework from which the relative ages of sediments within the basin are assessed; this report is a contribution to the wider study of the Otway Basin by the B.M.R., and most of the discussion is reproduced below.

The positions of subsurface sections from which data are available and an expression of the palyno-stratigraphic divisions which may be derived from them, are illustrated in Plates 4a and 4b**. The subsurface and outcrop samples which have been examined are listed in Evans (1966*), together with a comprehensive bibliography of the palynology.

Data from the basin, the stratigraphic implications of which are not directly incorporated in the ensuing discussion or are of general interest are available from Cookson (1953a, b, 1965), Deflandre & Cookson (1955), Cookson & Eisenack (1961b, 1962), Eisenack & Cookson (1960), Cookson & Dettmann (1959a, b, c, 1961), Cookson & Manum (1964), Harris (1965), and Harris & Cookson (1965).

Although this section is only concerned with palynological aspects of the Mesozoic, notes on the foraminiferal content of many sections in the basin have been issued or published by Dr. N.H. Ludbrook (Department of Mines, South Australia), Mr. D.J. Taylor (Department of Mines, Victoria) and Prof. M.F. Glaessner (University of Adelaide).

2. Existing biostratigraphic schemes

Inevitably, few biostratigraphic divisions were recognized during early studies of the Otway Basin. Ages of samples and sections were expressed in terms of the accepted European nomenclature, derived in turn from similar usages in micropalaeontological studies of the Great Artesian, Carnarvon and Perth Basins.

** Plates 4a and 4b include sections encountered in Robe No. 1, Tullich No. 1, Portland No. 3, Port Campbell No. 4, and Anglesea No. 1 to which no reference is made below. A separate report on Anglesea No. 1 is in preparation. No data were available from Kalangadoo No. 1 when Plates 4a and 4b were constructed. However, relevant comments, based on work by Dettmann and Harris (in A.O.D.A., 1966*) and by the B.M.R. are incorporated in the ensuing text.

Douglas (1962) introduced concepts of three microplankton zones in Upper Cretaceous and Tertiary sediments across the Otway Basin, from the Nelson Bore in the west to Port Campbell No. 2 in the east. For the Upper Cretaceous he introduced an upper zone with Nelsoniella sp. and a lower zone "with specialized forms such as D.**pellucida, D. micracantha, D. tripartita and Amphidiadema sp., & c", numbering these zones 2 and 3 respectively. Evans (1962*) introduced four Cretaceous microplankton zones, Odontochitina operculata, Deflandrea cretacea, Nelsoniella aceras, and Xenikoon australis in ascending order. The zone of O. operculata in the Otway Basin is a Teil-zone, representing only an upper portion of the known range of the nominate species (Cookson & Eisenack, 1958; Evans in Vine & Jauncey, 1962*; cf. Edgell, 1964). The ranges of D. cretacea, N. aceras and X. australis overlap each other, but their relative stratigraphic positions permit recognition of the three nominated divisions of the Upper Cretaceous sequence. Both Evans' and Douglas' schemes suffer from a lack of adequate sampling in certain sections and the apparent absence of key fossils in critical samples. The base of zone 3 and the boundary (or interval) between the D. cretacea and O. operculata Zones in particular are unsatisfactorily defined for these reasons.

Dettmann (1963) proposed for the Lower Cretaceous three spore Assemblages, named Stylosus, Speciosus, and Paradoxa after the trivial names of three species, which occur in ascending sequence. Of the microfossils described by Dettmann, only the nominate species, Crybelosporites stylosus Dettmann is restricted to the Stylosus Assemblage, and in the absence of this type, the unit cannot be positively identified. Dettmann recognized the Stylosus Assemblage only in Penola No. 1 (basal core sample) in the Otway Basin, and in 25 feet of section at the base of Cootabarlow No. 2 in the Great Artesian Basin. She also found it in isolated samples from the Kirrack area of eastern Victoria and in the Warren District Bore No. 10528 in New South Wales. The position of the base of the Stylosus Assemblage is thus not determined and the zone has at present limited application as a stratigraphic concept. The bases of the succeeding Speciosus and Paradox Assemblages are marked by the appearance of a number of species; the nominate types (Dictyotosporites speciosus, Coptospora paradoxa) are relatively common within their ranges and form useful markers. Dettmann indicated that the Speciosus Assemblage could be subdivided into a lower unit with Murospora florida and an upper one with Crybelosporites striatus.

Dettmann (in F.-B.H., 1964g*) added two higher assemblages to the sequence: assemblage II, marked by the first appearance of tricolpate (angiospermous) pollens; assemblage III, characterized by a Gleicheniidites sp.

Dettmann related her Lower Cretaceous assemblages to stages as recognized in South Australia, and has continued to express results in this manner (e.g. in F.-B.H., 1964*). As this approach transposes to the palynological scheme inaccuracies of definition which may be inherent in the South Australian usage, it must be followed with caution.

Evans (1963) indicated four informally named divisions of the Lower Cretaceous and one of the Upper Cretaceous of the Great Artesian Basin. As the scheme was based on combined spore and microplankton data, it cannot be applied to the Otway Basin, where microplankton are generally scarce.

No other palyno-biostratigraphic divisions have been intentionally proposed for the Upper Cretaceous. Cookson (1954) introduced a scheme of three assemblages, which she thought were Lower Cretaceous (Microflora A) Paleocene or early Eocene (Microflora B), and Eocene or younger (Microflora C). Of these, Microflora B may in part cover some of the Upper Cretaceous.

** "D" = Deflandrea.

Glaessner (in F.-B.H., 1961a*) noted that foraminiferal evidence from the Belfast Mudstone (Unit Gf) of Flaxman's No. 1 and Port Campbell Nos 1 & 2 favours a Turonian age for most of the formation, although it is possible that more than Turonian may be represented. Taylor (1964a) recognized a sequence of two foraminiferal zonules, which he translated in terms of the European nomenclature (Turonian and Senonian), and for which he drew support from the microplankton studies by Cookson & Eisenack (1961a), and Cookson & Balme (1962) (cf. Harris, 1965). It should be noted that Taylor's deductions must stand on the foraminiferal evidence alone as the microplankton age determinations are based on evidence from sections also dated by foraminifera in Western Australia (Cookson & Eisenack, 1960). However, Taylor's stage identifications are of great value in indicating the approximate age of the associated microfloras, so that the time spans in which the over- and underlying microfloral sequences were flourishing may be judged.

3. Stratigraphy

From studies of the stratigraphic palynology of the Great Artesian Basin a scheme of informally named palynological divisions for much of the Upper Palaeozoic and Mesozoic is being developed (Evans, 1963, 1964*, 1965*). In order to extend this sequence, similar principles for recognition and definition and similar forms of nomenclature for the divisions identified in the Otway Basin are employed below. Palynological divisions in the Otway Basin differ from ones in the Great Artesian Basin in so far as the scales are restricted either to spores and pollen or to microplankton: the varying depositional and environmental facies of the Otway Basin make stratigraphic schemes based on combinations of the ranges of both terrestrial and aquatic microfloras useless as stratigraphic markers. Comparisons of these palynological units with other existing schemes for the basin are included as necessary.

Because this report is intended to be a review, the range of every species known to occur in the basin has not been checked, and, in consequence, discussion is restricted to the stratigraphic distribution of selected species (Table 14). Lists of associated species may be obtained from the references already cited. The relationships of the zones and formations discussed are summarized in Figure 6.

A. Pre-Mesozoic

Only four subsidized wells, Casterton No. 1, Kalangadoo No. 1, Pretty Hill No. 1 and Fergusons Hill No. 1 have penetrated the Mesozoic of the Otway Basin to enter ? Palaeozoic basement. Only one sample of this basement, from Kalangadoo No. 1, c.14, 7069 ft., (lithological unit V) has been examined in the BMR for a spore/microplankton content, but it yielded only highly carbonized residues.

B. Mesozoic

Casterton No. 1 probably penetrated the oldest Mesozoic sediments yet encountered in the basin, Unit T. The basal 80 feet (approx) of this section, which yielded Mesozoic plant remains, are overlain by two dolerite sills (7850-70 ft and 7895-947 ft) of Jurassic (153 m.y.) or Lower Cretaceous (120 m.y.) age (P.E.C., 1965b*); the plants were thought to be of Jurassic age (White in P.E.C., 1965b*). The sills were succeeded by medium grey, dense, hard, micaceous and carbonaceous shales and siltstone to a level of about 7265 feet below surface, from which c.18, 7385-95 ft, has yielded abundant carbonized plant tissue, a moderate number of carbonized and fragmented spores, among which *Baculatisporites* cf. *B. comaumensis* (Cookson), aff. *Laricoidites* sp. and *Lycopodiumsporites* sp, were found. The association of the long-ranging forms *B. comaumensis* and *Lycopodiumsporites* sp. indicates that c.18 is no older than the Jurassic, but there is insufficient evidence to indicate which part of the Upper Mesozoic is represented. J. Dellenbach and P.J. Jones (pers. comm.) noted undetermined ostracods in this core.

Casterton No. 1, c.14, 6396 ft, from the lower parts of Unit P, yielded a relatively abundant microflora, among which Lycopodiumsporites circolumenus Cookson & Dettmann, Foraminisporis wonthaggiensis (Cookson & Dettmann), Klukisporites scaberis (Cookson & Dettmann) and aff. Dictyotosporites complex Cookson & Dettmann, with rare acritarchs (Micrhystridium spp.) were found. L. circolumenus ranges from within the Jurassic palynological unit J5 into the Cretaceous (Cookson & Dettmann, 1958; Dettmann, 1963; Evans, 1965*), K. scaberis, D. complex and F. wonthaggiensis have been observed in unit J6 and younger in the Great Artesian Basin, and hence the age of this horizon may be somewhere in the Lower Cretaceous or upper-most Jurassic, no older than unit J6 (of about Tithonian age).

No equivalent to Casterton No. 1, c.14, has yet been recognized elsewhere in the Otway Basin. Although it appears to represent a portion of Unit P, all other samples from that formation have yielded typical K1 assemblages.

Lower Cretaceous

Definition of the Jurassic - Cretaceous boundary in Australia by palynolgical means is still vague, as there is no great microfloral change at about that level. Dettmann (1963) thought that beds with Cicatricosisporites australiensis and Dictyotosporites speciosus could be regarded as Cretaceous in age, but Evans (in Henderson et al., 1963) recorded both species in beds of possibly Upper Jurassic age in the Canning Basin. However, until the problem is examined further, Dettmann's criteria are maintained for the purposes of this report.

(1) Unit K1a:

The base of unit K1a, the oldest Cretaceous unit recognizable in the Otway Basin, is marked by the first appearance of Cicatricosisporites australiensis (Cookson), Cyclosporites hughesi (Cookson & Dettmann), and Dictyotosporites speciosus (Cookson & Dettmann). The top of the unit is marked by the last appearance of Murospora florida (Balme).

Beds falling within these limits are identified in Penola No. 1, c.19, 4390 ft to total depth, 4985 ft, and in Heathfield No. 1, c.16, 5990 ft to c.19, 7499 ft. Unit K1a commences within these sections in lithological Unit P and ends in Unit M.

Because of the presence of D. speciosus, horizons possibly of K1a age occur within Unit P of Casterton No. 1 (as low as c.12, 5609 ft), Unit P of Eumeralla No. 1 (c.25, 10, 302-05 ft), and Unit R of Pretty Hill No. 1 (c.20, 7200-14 ft); because of the presence of C. australiensis, Geltwood Beach No. 1, c.29, 12,222-32 ft, in Unit P, could also be of K1a age. The top of unit K1a cannot be determined in these sections, because M. florida is apparently missing. K1a incorporates Dettmann's Stylosus and the lower part of the Speciosus Assemblages. Crybelosporites stylosus, marker fossil of the Stylosus Assemblage, has been found in Penola No. 1 (Dettmann, 1963) at 4766 feet and in Kalangadoo No. 1 at 6632 feet.

(2) Unit K1b-c:

Unit K1b-c includes the continued appearance of Cictricosisporites australiensis and Dictyotosporites speciosus; its upper limit is marked by

TABLE 14: DISTRIBUTION OF PALYNOLOGICAL MARKER FOSSILS

NAME	PALYNOLOGICAL UNIT												
	TERTIARY	"D. pellucida"	X. australis	N. aceras	D. cretacea	A. parvum	K2b	K2a	K1d	K1c	K1b	K1a	J-K undiff.
Nothofagidites emarcida	—												
Nothofagidites cf. deminuta	- -	—											
Dacrydiumites florinii	—	—	—										
Triorites edwardsii	—	—	—	—									
Phyllocladidites mawsonii	—	—	—	—									
Tricolpate/triporate pollens	—	—	—	—	—	—							
Laevigatosporites ovatus	- -	—	—	—	—	—	—	—	—	- -	- -	-	
Trilobosporites trioreticulosus						—	—						
Coptospora paradoxa						—	—	—					
Crybelosporites striatus						—	—	—	—				
Dictyotosporites speciosus								—	—	—	—	—	
Cyclosporites hughesi											—	—	
Murospora florida												—	
Cicatricosisporites australiensis		-	-		-	—	—	—	—	—	—	—	
Dictyotosporites complex							—	—	—	—	—	—	
Lycopodiumsporites circolumenus									-	-	—	—	
Foraminisporis wonthaggiensis							—	—	—	—	—	—	
Klukisporites scaberis									—	—	—	—	
Lycopodiumsporites spp.	—	—	—	—	—	—	—	—	—	—	—	—	—
Baculatisporites comaumensis		-	-		-	—	—	—	—	—	—	—	—
Laricoidites sp.										-	-		—
Deflandrea pellucida	—	—											
Xenikoon australis			—										
Nelsoniella aceras			—	—									
Gymnodinium nelsonense				-									
Amphidiadema denticulata				-									
Deflandrea cretacea			—	—	—								
Hystrichosphaeridium heteracanthum		-	—	—	—	—							
Deflandrea acuminata						—							
Palaeohystrichophora infusorioides						—							
Hystrichodinium oligacanthum						—	—						
Odontochitina operculata						—	—						
Ascodinium parvum						—							
Acritarcha spp.		-	-		-	—	—	—	—	—	—	—	—

Bureau of Mineral Resources, Geology & Geophysics. November 1965.
To accompany Record 1966/69.

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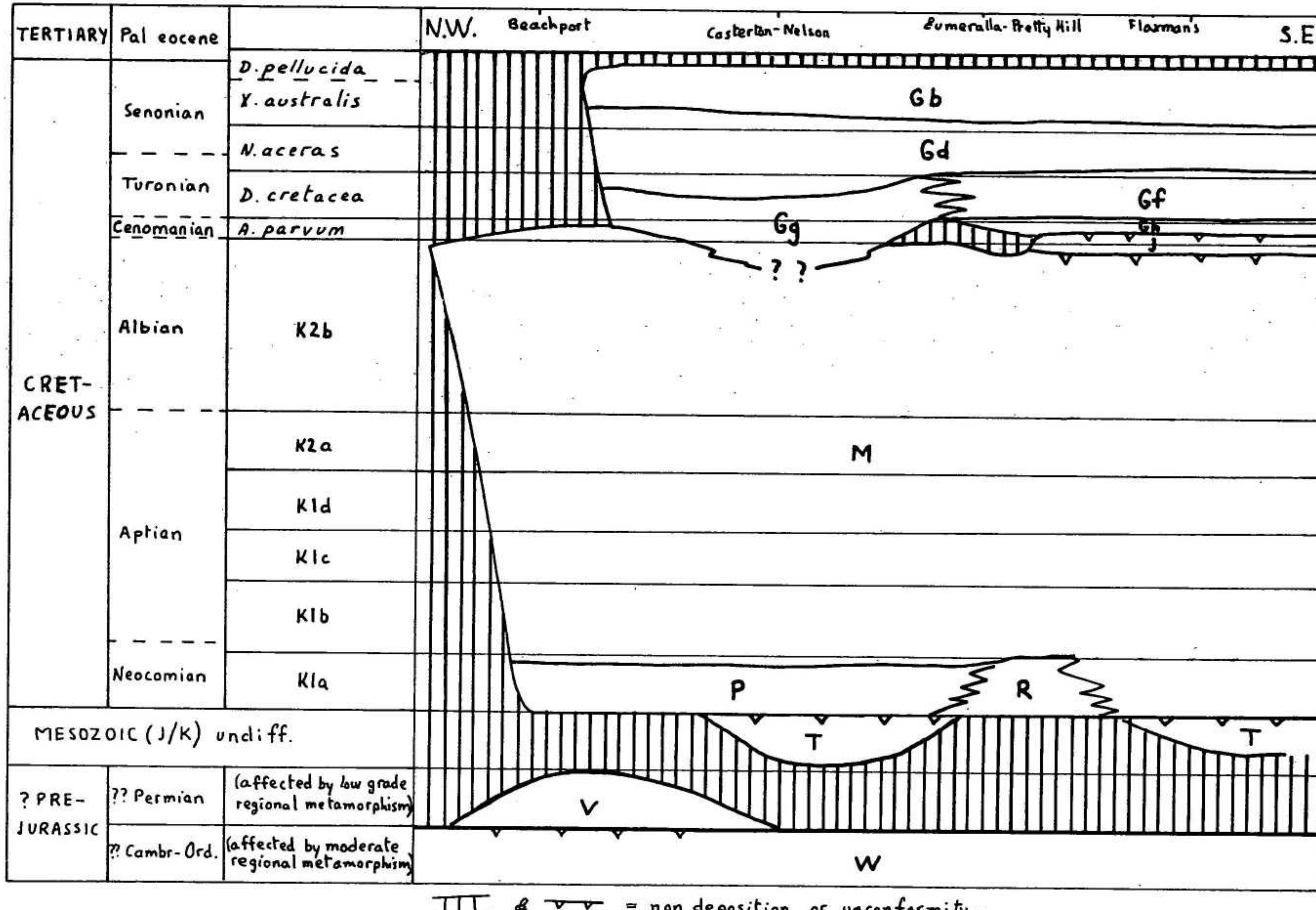
J54/A/3

FIGURE 9 : AGE & DISTRIBUTION OF MESOZOIC FORMATIONS - OTWAY BASIN



Bureau of Mineral Resources, Geology & Geophysics.
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J54/A/4

the first appearance of Crybelosporites striatus++. It forms a portion of Dettmann's Speciosus Assemblage, younger than that containing M. florida.

The unit is defined in Penola No. 1 between c.11, 3180 ft and c.15, 3928 ft, in Heathfield No. 1 between c.12, 4621 ft, and c.15, 5693 ft, and Kalangadoo No. 1 between c.9, 5288 ft and c.11, 6120 ft. it is confined in both these sections to a portion of lithological Unit M. Beds referable to Klb-c, because of their content of D. speciosus and C. hughesi also occur in Casterton No. 1, Geltwood Beach No. 1, Eumeralla No. 1, Pretty Hill No. 1 and Fergusons Hill No. 1.

The base of Klb-c is not always determinable (see above). Similarly the upper limit of the unit is not very satisfactorily defined except in Casterton No. 1 and Penola No. 1.

(3) Unit Kld:

Unit Kld is within the uppermost part of Dettmann's Speciosus Assemblage. Its base is marked by the first appearance of Crybelosporites striatus (Cookson and Dettmann), its top by the first appearance of Coptospora paradoxa (Cookson and Dettmann) (characterizing unit K 2). D. speciosus occurs throughout Kld.

Kld is represented by Penola No. 1, c.10, 2990-3000 ft and Heathfield No. 1, c.10., 4146 ft. However, a more expanded version of the zone is represented in Casterton No. 1 between c.1 2017 ft and c.3, 3142-52 ft. Although its lower limits have not been fixed, the zone is represented in Geltwood Beach No. 1 at least by c.15, 5655-63 ft. and c.16, 6081-96 ft. Eumeralla No. 1, c.13, 6254-57 ft, the basal section of Flaxmans No. 1, between c.41, 10,807-09 ft and c.44, 11,519-21 ft, and Fergusons Hill No. 1 c.19, 7037-47 ft to c.21, 7330-45 ft, also represent the zone. Kalangadoo No. 1, c.7, 4771 ft, may be of Kld age, but could also be of basal K2 age.

The "Heathfield Sand" (Brown, 1965) occurs in Heathfield No. 1 over the interval 4115 to 4144 feet and is just above, or within the Kld zone (known from c.10, 4146 ft). Based on electric log characteristics, the "Heathfield Sand" is suspected to be at the base of Kld (or in Klc) in Penola No. 1. However, it is developed towards the top of Kld in Casterton No. 1, where a marked expansion is noted in the thickness of Kld. This supports Brown's idea of an unconformity at the base of the "Heathfield Sand", and suggests that considerable erosion took place at that time in the Penola - Heathfield area.

(4) Unit K2a:

Dettmann (1963) took the point of first appearance of Coptospora paradoxa as the commencement of the Paradoxa Assemblage. This is chosen as the base of K2. Dettmann also noted that the ranges of D. speciosus and C. paradoxa overlap in some samples. This overlap is slight in terms of thickness of section and hence forms a useful marker horizon, which is denoted as unit K2a.

Only single samples in any one section have demonstrated this overlap: Penola No. 1, c.9, 2790-98 ft; Beachport No. 1, c.9, 3665-15 ft; Flaxmans No. 1, c.40, 10,492-502 ft; and Fergusons Hill No. 1, c.18, 6555-70 ft. The zone could be present in Kalangadoo No. 1, Casterton No. 1, Geltwood Beach No. 1, Eumeralla No. 1, and Pretty Hill No. 1, although the palynological evidence to prove it is unavailable.

++ Evans (1966*) divided Units Klb and Klc by the apparently different ranges of D. speciosus and Cyclosporites hughesi, a view which cannot be upheld. Hence unit Klb-c is now used. Plates 4a and 4b and Table 14, and Figure 9 should be considered in the same manner.

(5) Unit K2b:

The range of Coptospora paradoxa beyond its overlap with D. speciosus and prior to the introduction of tricolpate/triporate angiospermous pollens characterizes unit K2b. Dettmann recorded several species characteristic of the Paradoxa Assemblage, including Trilobosporites trioreticulosus Cookson and Dettmann, which may also be regarded as characteristic of K2b. Dettman (1963) and Evans (1963) noted the first appearance of angiosperm pollen grains in the Winton Formation of the Great Artesian Basin. In Innamincka No. 1 Well, angiosperm pollen grains are associated with the Paradoxa Assemblage, but it is better to regard the introduction of these pollen as another marker horizon and restrict K2b to below that level. The top of K2b in the Beachport-Casterton area is conveniently marked by an unconformity at the top of lithological Unit M. In the eastern portions of the basin, the first angiospermous pollen grains occur within the Waarre Formation in Port Campbell No. 1,c.23, 5700-08 ft, an horizon which could be thought of as close to the top of unit K2b. Thus K2b occurs within lithological Unit M in the western Otway Basin, and in Unit M and the lower but major portion of the Waarre Formation in the eastern areas.

K2b is represented by outcrop in the Merino area, three miles W.N.W. of Casterton (sample W-12), at Tahara Bridge (sample W-139), and possibly at Merino (sample W-37) Evans, (1961c*). Little may be judged of the stratigraphic significance of these determinations until a more systematic examination by mapping and perhaps shallow drilling of the outcrops around Merino is undertaken. They indicate that at least three points within the "Merino Group" are Lower Cretaceous unit K2b, by Dettmann's criteria of late Aptian or Albian age. Medwell (1954a, b) regarded most of the macrofloral localities in the Merino district as Jurassic age, but dated only one section (in the "Runnymede Formation" at Killara Bluff) as Cretaceous, based on the occurrence of a fossil angiosperm leaf. As much more of the Merino area Mesozoic appears to be Cretaceous in age than Medwell supposed, this angiosperm may be of Upper rather than Lower Cretaceous age, in accordance with the first general appearance of angiospermous pollen in post-K2b, approximately Cenomanian times. Kenley (1954) noted an erosional disconformity below the "Runnymede Formation" and above the "Mocamboro Member" at Killara Bluff. If it is in fact an unconformity of regional extent, it could be an expression of the post-M hiatus, rather than representative of a break in early Cretaceous times.

The validity of this argument rests on the presumption that angiospermous plants are post-Lower Cretaceous. However, Douglas (1965b) regarded the angiosperm leaf from 4320-30 feet in Yangery No. 1 Bore as Lower Cretaceous in accordance with his previous suggestion of a "pre-Upper Cretaceous" age. Taylor (1964a, Table 1 and Fig. 6) showed the leaf horizon to be below his Zonule A, and also in the Lower Cretaceous. Sprigg and Woolley (1963, Table 1) regarded the horizon as in the Paaratte Formation or Belfast Mudstone (i.e. Upper Cretaceous), However, Lower Cretaceous spores are now known to occur in this section.

It seems inadvisable under these circumstances to continue to use the terms "Runnymede" and "Mocamboro" for subsurface sections in the western Otway Basin (O.D.N.L., 1963).

Upper Cretaceous

Although angiosperm pollen grains have been recorded from the Upper Cretaceous sections, particularly in the eastern regions of the basin, few of them are described, and additional work is required before much stratigraphic use is made of them. The Upper Cretaceous microplankton are better documented and afford a means of biostratigraphic division of the containing beds. The first appearance of angiosperm pollen grains is taken as a marker for the base of the Upper Cretaceous. Microplankton, including dinoflagellates are well established where this takes place in the Waarre Formation (= Unit J). The incoming of angiospermous pollen seems to coincide with the introduction of the oldest recognizable microplankton Zone of Ascodinium parvum.** Edgell (1964) recognized a sequence of microplankton zones in the Cretaceous of the Perth Basin, Western Australia, but they are not applicable to the Otway Basin.

(1) Ascodinium parvum Zone+:

Ascodinium parvum Cookson and Eisenack occurs briefly in Port Campbell No. 2 between c.6, 7906-08 ft and c.8, 8100-02 ft (top of Waarre Formation and Flaxmans Formation in association with a varity of microplankton, including Odontochitina operculata Deflandre and Cookson, Hystrichodinium cf. oligacanthum Deflandre and Cookson, Palaeohystrichophora infusorioides Defl., an association which is about Cenomanian age (Cookson & Eisenack, 1958). A similar association lacking A. parvum, but including another Cenomanian species, Deflandrea acuminata Cookson and Eisenack, occurred in Port Campbell No. 1, c.22, 5660-65 ft to c.23, 5700-08 ft (Waarre Formation). An abundant microplankton assemblage, including Ascodinium parvum, A. serratum, O. operculata and rare tricolpate (angiosperm) pollen, and hence referred to the A. parvum Zone, occurred in Geltwood Beach No. 1, c.8, 3773-93 ft (particularly at 3774 ft), but in the top of lithological Unit M. A. parvum also appears, with Amosopollis cruciformis, Crybelosporites striatus, Coptospora paradoxa, Odontochitina striatoporifera and Hoegisporis sp. ? nov. in Kalangadoo No. 1, c.2, 2507 ft, in unit Gg. It would appear that, in spite of lithological evidence for an unconformity between the Waarre Formation and Unit M in the western part of the basin, the Waarre Formation and possibily the Flaxmans Formation were formed contemporaneously with at least the uppermost parts of Unit M and Gg in the western regions in A. parvum Zone times.

(2) Deflandrea cretacea Zone**:

The next recognizable unit is the Zone of Deflandrea cretacea Cookson, taken from the commencement of the range of D. cretacea to where it eventually overlaps with the range of the succeeding zone fossil Nelsoniella aceras. Thus defined, the zone occurs in the upper parts of the Belfast Mudstone (= Unit Gg), but the relationship of the A. parvum and D. cretacea Zones is not clear. Cuttings from the Flaxmans Formation in Port Campbell No. 1, 5600-10 ft, yielded D. cretacea, but the oldest record from a core sample is much higher in the sequence from c. 21, 5223-31 ft, and similarly in Flaxmans No. 1, from c.16, 5959-68 ft. It is possible that D. cretacea first appears sometime later than the last appearance of A. parvum, and that an unclassified gap occurs in the sequence. A similar problem occurs below the first appearance of D. cretacea in the western portion of the basin. D. cretacea was not found in Mount Salt No. 1 below c.20 5490 ft, in the N. aceras Zone; Deflandreidae spp. undiff. were found down to c.26, 7474 ft; and tricolpate (angiosperm) pollen to c.30, 8919 ft. The basal core, c.34, 10,037 ft, yielded Hystrichosphaeridium heteracanthum Deflandre and Cookson (common throughout the Upper Cretaceous of the Otway Basin) and Gonyaulacidae undiff., reminiscent of the Gonyaulacidae of the A. parvum Zone and below, with Aequitriradites tilchaensis (Cookson and

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** Chosen in preference to the Teil-zone of Odontochitina operculata, because of its restricted range.

+ Symbolized by "A.p." on Plates 4a and 4b.

** Symbolized by "D.c." on Plates 4a and 4b.

Dettmann), A. verrucosus (C. & D.) and Laevigatosporites ovatus Wilson & Webster, an assemblage comparable with high horizons in K2b. It is possible that beds with no equivalent in the eastern portion of the basin are present in the Mount Salt area, but additional study of the section is required to resolve the question.

(3) Nelsoniella aceras Zone**:

The Deflandrea cretacea Zone is succeeded by the Zone of Nelsoniella aceras Cookson & Eisenack, taken from the horizon of first appearance of N. aceras to the first appearance of Xenikoon australis.

The zone species first appears in Port Campbell No. 1, c.18, 4862-64 ft, but could be found no lower in Flaxmans No. 1 than c.8, 4974-83 ft. The Port Campbell horizon is close to the bottom of the Paaratte Formation (= Unit Gd), whereas the Flaxmans level is over one third up from the base of the same unit. However, associate species in Port Campbell No. 1, Gymnodinium nelsonense Cookson and Amphidiadema denticulata Cookson & Eisenack, occur in Flaxmans No. 1, c.13, 5458-63 ft and c.15, 5543-46 ft respectively, towards the base of the Paaratte Formation. Hexagonifera vermiculata Cookson & Eisenack occurs in the latter samples, and, with G. nelsonense and A. denticulata in Belfast No. 4 Bore at levels close to the base of the Paaratte Formation and the top of the Belfast Mudstone (Cookson & Eisenack, 1961a; Weegar, 1960a*) and at Port Campbell at least within or straddling the base of the N. aceras Zone. The base of the N. aceras Zone is extended down to c.15, 5543-46 ft in Flaxmans No. 1 accordingly. The pollen complex associated with the N. aceras Zone includes the first appearance of Triorites edwardsii Cookson & Pike (Port Campbell No. 1, c.17, 4758-60 ft) Phyllocladidites mawsonii Cookson. (Geltwood Beach No. 1, c.7, 3632 feet).

N. aceras has been recorded from the Paaratte Formation in Mount Salt No. 1 and the Nelson Bore. Its possible range in the Nelson Bore is extended downwards to at least 6233 ft, because of the presence of Gymnodinium nelsonense at that level (Cookson, 1956). However, in contrast to its distribution in the eastern wells, the N. aceras Zone does not extend down to or beyond the base of the Paaratte Formation in the Mount Salt-Nelson area.

(4) Xenikoon australis Zone++:

Xenikoon australis was first described by Cookson & Eisenack (1958) from Campanian sediments in the Carnarvon Basin, and it occurs in an appropriately high position in the Otway Basin. Its full range in the basin has not yet been determined, because of the lack of samples, but for the present, the base of a Zone of Xenikoon australis is taken at the point of first appearance of X. australis, and all points of occurrence of that fossil are included within the zone. Nothofagidites cf. deminuta (Couper) and Dacrydiumites florinii Cookson & Pike make their first appearance within or just before the X. australis Zone.

An upper portion of the Paaratte Formation and at least two thirds of the Curdies Formation (in Port Campbell No. 1) represent the X. australis Zone. The zone fossil has been detected as far west as Mount Salt No. 1, but could only be found in c.14, 4538 ft. A possible representative of the zone was sampled in Heathfield No. 1, c.2, 1378-93 ft, from the Curdies Formation, where a fragmentary specimen, possibly referable to X. australis was noted.

** Symbolized by "N.a." on Plates 4a and 4b.

++ Symbolized by "X.a." on Plates 4a and 4b.

Lack of information from above the X. australis Zone precludes determination of a satisfactory top to the zone and additional subdivision of the Curdies Formation. However, there are indications that these aims eventually may be realized. Douglas (1962) identified 'A post-Mesozoic, early Tertiary zone of large "D. bakeri" type micro-organisms'. Deflandrea bakeri was first described by Deflandre & Cookson (1955) from outcrops of the Pebble Point Formation. They recognized at the time a variety, D. bakeri f. pellucida, in the Nelson Bore, core at 3874 ft, and in the Pebble Point Formation outcrop. Cookson and Eisenack (1958) raised f. pellucida to specific rank after recognizing it in the Korojong Calcarenite of Campanian - Maestrichtian age in the Carnarvon Basin. Douglas apparently includes occurrences of both bakeri and pellucida in his '"D. bakeri" type' zone, but in fact records D. bakeri only from Heywood No. 10, 4300 ft+, which Leslie (1966) includes in the "Bahgallah Formation". Apart from Deflandre and Cookson's record of D. pellucida from Nelson, Douglas reported ?D. pellucida from Belfast No. 4, 4074-6 ft (Paaratte Formation acc. Weegar, 1960*) and Port Campbell No. 2. Douglas indicated in his section that his "D. bakeri" type zone was represented in the latter well at 4800 feet (low in the Curdies Formation), although in his text he records D. cf. pellucida from 5910-11 ft (top of the Belfast Mudstone), probably below the level of the N. aceras Zone. It appears that the '"D. bakeri" type zone' is not an effective stratigraphic marker. However, the one identification of the holotype of D. pellucida high in the Curdies Formation in the Nelson Bore, coupled with Cookson and Eisenack's determination of the species in the Carnarvon Basin in beds stratigraphically younger than those with Xenikoon australis (which is no younger than Campanian) suggests that an uppermost division of the Upper Cretaceous of the Otway Basin might be recognized by a Zone of Deflandrea pellucida, **represented by that part of the range of D. pellucida prior to the introduction of a more typical Tertiary assemblage. Such a zone would incorporate the upper part of the Curdies Formation.

Mesozoic - Tertiary Boundary

Few contributions to determinations of the base of the Tertiary in the Otway Basin have yet stemmed from palynology. The few observations available of microfloras at or near that horizon provide no independent evidence of the position of the boundary. Deflandre and Cookson (1955) and Cookson (1965) recorded microplankton from the Pebble Point Formation, which they regarded as Paleocene on the basis of evidence and reasoning offered by Singleton (1943), Teichert (1943) and Baker (1953). Singleton and Teichert in fact considered the age of the Pebble Point to be in the range Danian - Paleocene. Singleton compared his fossils with ones from the Wangaloan Stage in New Zealand. Hornibrook and Harrington (1957) and Wellmann (1959) considered that the Wangaloan was an invalid stage, and that its outcrops are part of the Teurian (Danian). The classificatory problem is resolved if Berggren's proposition (1965) is accepted that the Danian be included within the Paleocene.

Harris (1965) recognized a Triorites edwardsii Assemblage Zone in the outcrop of the Pebble Point Formation and in part of the overlying "Dilwyn Clay", which he refers to the middle Paleocene foraminiferal Zone of Globorotalia pusilla pusilla on opinions supplied by B. McGowran. McGowran has since outlined his reasoning for this determination (1965), implying that lowermost Paleocene is not represented in the Otway Basin. The T. edwardsii Assemblage Zone is based by the pre-Pebble Point Formation unconformity, and hence it is not yet known whether this zone commences within the Mesozoic or the Tertiary. Harris (op. cit.) regarded the T. edwardsii Assemblage Zone as equivalent in part to Microflora B of Cookson (1954). Cookson (op. cit.) recognized Microflora B. at 4025 feet in the Nelson Bore, i.e. in the Curdies Formation, so that the presence of the nominate species of the T. edwardsii Assemblage Zone may not be a suitable means of distinguishing basal Tertiary from uppermost Cretaceous sediments. Other species of the T. edwardsii Assemblage Zone

** Symbolized by "D.p." on Plate 4a. + Symbolized by "D.K." on Plate 4a.

must be checked for ranges more likely to be restricted to the base of the Tertiary.

For the present, however, McGowran's determination on the basis of foraminifera of a middle Paleocene (G. pusilla pusilla Zone) age for the Pebble Point Formation is accepted, and the boundary between the Mesozoic and Tertiary considered to be at the unconformity between the Curdies Formation and the Pebble Point Formation.**

4. The Palynological and International Geological Scales

Although division of the palynological sequence in terms of the international geological scale introduces a false sense of accuracy, demonstration of how the palynological and international scales may compare is desirable for a general understanding of the time sequence in the basin. As discussed in the preceding chapter, the first appearance of Cicatricosisporites is provisionally accepted as the base of the Cretaceous, and the unconformity above the Curdies Formation is thought to include the top of the Cretaceous. Palynological units between these markers are thought to be dated as in Figure 6. It is emphasized that none of these determinations are based on direct comparison of the ranges of the key species in Australia with those of the same species in Europe; they are all derived from determinations of the age of associated faunas, usually Foraminifera, in other Australian sections.

Unit K1a is regarded as Neocomian because of its association with a Neocomian macrofauna in Iehi No. 1 well, in the Papuan Basin (BMR unpubl. information), and because it is not known to occur higher than about the Kingull Member of the Blythesdale Formation (underlying beds with an Aptian fauna) in the Surat Basin (Day, 1964; BMR unpubl. information). It includes the Stylosus Assemblage, which Dettmann (1963) reasoned is post-Kimeridgian, and Valanginian or older in age.

The interval units K1b to K1d probably commences in the Neocomian and ends in the Aptian for reasons cited by Dettmann (1963) for the age of the Speciosus Assemblage. Dettmann obtained her ages from foraminiferal and molluscan evidence, which in turn is compared with Whitehouse's (1926) ammonite sequence in the Queensland portion of the Great Artesian Basin. It is now realized that the Queensland sequence, as understood by Whitehouse, was incomplete (Vine & Day, 1965) and it will be necessary to make a direct comparison with Day's faunal succession before the ranges of K1b-d may be adequately determined. Dictyotosporites speciosus does not extend above, but Crybelosporites striatus appears before the end of the range of Dingodinium cerviculum in the Eromanga Basin. Where the evidence is available, it appears that the microplankton Zone of D. cerviculum ends at about the top of the Aptian Doncaster Member of the Wilgunya Formation (Evans, in McPhee, 1963; Evans, in Vine & Jauncey, 1962*; Vine & Day, 1965).

Unit K2a is probably also of Aptian age, because of its content of D. speciosus. The fact that species of unit K2b range through the remainder of the Wilgunya Formation indicates that the zone is partly Aptian but mostly Albian in age.

The first appearance of triporate and tricolpate (angiosperm) pollen grains is probably close to the base of the Upper Cretaceous. Ascodinium parvum and its associate Deflandrea acuminata occur at about the same horizon as the triporate and tricolpate pollen. They are recorded from the Cenomanian section of the Gearle Siltstone of the Carnarvon Basin (Cookson & Eisenack, 1958), and hence the A. parvum

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** This relationship is not clear in Anglesea No. 1 as work subsequent to this study has shown, and should probably be only applied to the Port Campbell area and westwards, not to the Torquay area.

Zone is regarded as Cenomanian in age. Little may be said of the age of the Flaxmans Formation and the Lower Belfast Mudstone, but species of the Nelsoniella aceras Zone have been recorded from the Turonian, Santonian and ?Campanian in Western Australia (Cookson & Eisenack, 1960), although these ages must be accepted with caution (Belford, 1958; cf. Edgell, 1964). Taylor (1964a) regarded the Belfast Mudstone in the Port Campbell area as Turonian and the upper part of the Belfast Mudstone and the Paaratte Formation as Senonian, essentially in accordance with the palynological correlations. Glaessner (1964) reported the ammonite Hauericeras angustum Yabe of Coniacean - Maestrichtian age from the base of the Belfast Mudstone.

Cookson & Eisenack (1960) recorded Xenikoon australis from a Campanian and an upper Turonian or middle Senonian horizon, from which it could be deduced, when the Carnarvon and Otway Basin sequences are compared, that the presence of X. australis may represent a Campanian age. D. pellucida was recorded from Campanian to lower Maestrichtian sediments (Cookson & Eisenack, 1958) and its presence in the Otway Basin near the top of the Curdies Formation indicates that the upper limit of Mesozoic sedimentation is at least of Maestrichtian age.

5. Microplankton and depositional environment

This is a subject better suited to discussion in the wider context of occurrences of microplankton in eastern Australia and their environmental significance. However, Taylor (1964a,b) has already referred briefly to the relevance of microplankton to the environmental significance of Mesozoic foraminifera in the Otway Basin, and the following notes are offered to supplement Taylor's comments and to draw attention to the horizons of occurrence of microplankton and some of the limited deductions which may be drawn from them at this stage.

The term "microplankton" appears to have been first applied to fossil micro-organisms by Deflandre (1938). It has since gained general acceptance among palynologists as an all-embracing term, although proof that fossil organisms thus designated were of planktonic, rather than benthonic habitat, is usually lacking. The non-mineralized microplanktonic remains extracted by the palynological technique have been generally divided into dinoflagellates, hystrichospheres and incertae sedis, until reconsideration of these organisms' biological affinities (Evitt, 1961, 1963; Wall, 1962) led Downie, Evitt & Sarjeant (1963) to propose that "palaeo-microplankton" should be separated into dinoflagellates (including hystrichospheres s.s., thought to be encysted dinoflagellates) and acritarchs (hystrichosphere-like bodies which cannot be related to dinoflagellates). In an attempt to clarify the taxonomic position of these fossils, Downie, Evitt & Sarjeant proposed that the microplankton should be treated as Plantae under the International Botanical Code of Nomenclature, that the dinoflagellates be incorporated among the Dinophyceae, and that a new Group incertae sedis of Acritarcha should be created to accept the remainder.

In their remarks to the diagnosis of the Acritarcha, Downie, Evitt & Sarjeant commented, "In general, the group is marine, but this is not an essential attribute, for it includes some nonmarine forms (Churchill and Sarjeant, 1962, 1963)". The nonmarine forms referred to were found in Holocene deposits in southern Western Australia, but some valid doubts on the original environment of their growth were voiced by Varma (1964). Nevertheless, the record of microplankton in Mesozoic sediments in eastern Australia includes several instances where acritarchs occur in the absence of dinoflagellates, and where a marine origin for the sediments may be doubted. Generalizations on this problem would be premature, and must take note of other indications of depositional environment, such as associated lithology, sedimentary structures, shape of the containing rock body, distribution of the microflora in the rock body, and the associated fossils. It is also necessary to distinguish the type of acritarchs present at a given moment, as some may flourish in completely different environments to others.

Occurrences of microplankton in the Otway Basin show a clear stratigraphic separation in that dinoflagellates make their first appearance towards the end of K2b times (about the end of the Albian). Only acritarchs have been found in older rocks.

Rare occurrences (less than 1%) of the acritarchs Micrhystridium spp. and/or Veryhachium spp. have been noted in:

Well	Sample	Age
Casterton No. 1	c.14, 6396 ft	K1a
Beachport No. 1	c. 9, 3665-75 ft	K2a
Penola No. 1	c. 8, 2586-96 ft	K2b
Heathfield No. 1	c. 6, 2374 ft	K2b
Eumeralla No. 1	c. 5, 3313-15 ft	K2?b
	c. 8, 4812-14 ft	K2?b
Flaxmans No. 1	c.28, 7476-77 ft	K2b
	c.34, 8470-76 ft	K2b

Eumeralla No. 1, c.10, 5803-05 ft yielded specimens of Cymatiosphaera sp.

Casterton No. 1, c.12, 5609 ft, and Heathfield No. 1, c.19, 5590 ft, contained an abundance of a unicellular organism, described by Eisenack & Cookson (1960) as "Gen. et sp. indet. Forma A". Eisenack & Cookson found these problematica in a few samples from the Great Artesian Basin, but Evans & Hodgson (1964*) found them in great numbers in the Mesozoic of Woodside - Arco Duck Bay No. 1 in the Mesozoic of the Gippsland Basin. P. Hawkins (pers. comm.) reported that the lithologies associated with the swarms at Duck Bay, Casterton and Heathfield are similar in each section: illitic mudstones or shales with chlorite, sparse calcite, and disseminated carbonaceous debris. The occurrence of this microfossil in swarms implies that it is from an aquatic and not a terrestrial flora. Micrhystridium sp. and Veryhachium sp. were associated with the swarm at Duck Bay, but could not be found in Casterton or Heathfield.

Problematic microfossils, thought to be spores of vascular plants and identified by the name Schizosporis, but which might better be referred to the Acritarcha, occur at various horizons throughout the basin (Cookson & Dettmann, 1959c, Dettmann, 1963). Schizosporis may include a heterogenous group of fossils. S. reticulatus is prevalant in many horizons in the Otway Basin, and takes stain. However, S. spriggi and S. parvus, a notably abundant horizon of which occurred in Casterton No. 1, c.3, 3142 ft, take stain with difficulty in a manner similar to morphologically similar Inapertisporites de Jersey (Mesozoic), Pilasporites Balme & Hennelly (Permian), Circulisporites de Jersey (Permian - Triassic) and Leiosphaeridae (e.g. in the Permian of the Murray and Eromanga Basins), which are perhaps types of acritarchs or algae.

Dinoflagellates first appear in the Otway Basin towards the top of Unit M in Geltwood Beach No. 1 and Port Campbell No. 2. They are well established in the Waarre Formation of Flaxmans No. 1, Port Campbell Nos 1 and 2 and Fergusons Hill No. 1. This is in contrast to their appearance in the Great Artesian Basin as early as K1b times, at a level corresponding with the major influx of macrofossils and foraminifera in the Gilbert River Formation and its correlates. Taylor (1964a,b) noted that microplankton (dinoflagellates in particular) entered the Otway Basin towards the top of the "Merino Group", prior to the first appearance of foraminifera in the Belfast Mudstone, and concluded that the microplankton were tolerant of less saline conditions than the Foraminifera. However, other factors than salinity which might control the growth of foraminifera and microplankton, and evidence for a marine environment other than the abundance of foraminifera should be considered. Examples may be found, where sediments exist with acritarchs but no dinoflagellates; with acritarchs and dinoflagellates but no foraminifera; and with all three micro-organic types together. Acritarchs of the Micrhystridium, Veryhachium type in the Permian of the Bowen Basin, for example, vary in numbers from one horizon to another within sections dispersed with shelly faunas and foraminifera; similar acritarchs in the Lower Triassic Kockatea Shale of the Perth Basin are associated with ammonoids (Balme, 1963; Jansonius, 1962; Dickins & McTavish, 1963), although no foraminifera could be found in the same horizons (Belford, pers. comm.).

Of the sections discussed by Taylor, the petrological character of the top of the "Merino Group" was thought to be of marine origin, and at least part of the Waarre Formation contained the generally marine indicator, glauconite (Dellenbach & Hawkins, 1964*). Brown (1965) thought that sedimentary structures and lithological characters of the "Merino Group" in the western parts of the basin indicate deposition in shallow brackish water under conditions of rapid sedimentation and burial. Estimates of rapidity of sedimentation must only be relative, but Brown's contention is supported, if the thickness of K1b-d age sediments in the Otway Basin, in places probably in excess of 4000 ft, is compared with the similarly aged 250-300 ft of the Doncaster Member in the Eromanga Basin and a maximum of about 1300 ft in the Surat Basin.

Taylor (1964b) defined the term "marginal marine" to describe the Paaratte Formation with its sparse arenaceous microfauna, although with relatively abundant dinoflagellates and acritarchs. He included in this term sediments deposited in estuaries, deltas, lagoons and marshes, intending the term to imply the marginal depositional area between marine and nonmarine deposits, and not necessarily the margin between land and seas. The concept appears to differ from Schuchert's (1933) "paralic" conditions brought about in a swampy, coal producing environment, by lacking the oscillatory movements that periodically allowed general marine flooding to take place. It includes elements of both the continental and transitional facies of Krumbein & Sloss (1963). A major implication of Taylor's concept is that areas with such deposits have at least spasmodic access or connections with normal marine environments. The "marginal marine" environment would be affected by tides and would change as swamps were drained or flooded and estuaries altered their courses. The resultant local changes in salinity would in their turn control incursions and growth of marine-type micro-organisms. Where deposition is rapid, as in the Otway Basin, such changes would be expected and perhaps the spasmodic occurrences of microplankton are ephemeral evidence of such movements. If this is the case, most of the "Merino Group" could be regarded as "marginal marine" in character.

It would appear that the shoreline advanced northwards in late Albian times. Regression, followed by transgression occurred in A. parvum times, and a final reversion to "marginal marine" conditions took place at about the beginning of N. aceras times. Whereas the local picture may be of repeated development of "marginal marine" environments, the overall history of the Mesozoic of the landward portions of the Otway Basin is thus of paralic conditions, with a major marine encroachment during the first half of the Upper Cretaceous. The "Merino Group" of Lower Cretaceous age should not be excluded from any consideration of the cycles of development of the basin (cf. Taylor, 1964a, b; Glenie & Bock, 1965).

Note: The above section contains extracts from Evans' (1966)* Record; the detailed results of his subsequent work on Otway Basin samples will be incorporated in a later report by Evans.

IV GEOPHYSICS (By A.L. Bigg-Wither and R.P.B. Pitt)

1. General remarks

Because the officers who were to have assessed the geophysical data of the Otway Basin were committed to other work for much of the time, the scope of the geophysical contribution to the review has been limited. Early progress, in fact, indicated that little more than index maps (Plate 9 A to C), and seismic cross sections (Plate 12 A to C) could be prepared. However, concentrated work since December, 1965 has enabled other contributions to be made - particularly from the seismic data. All available records were picked and three horizons, which conform closely with basin-wide unconformities, have been contoured; isochron contour maps were prepared of the intervals between the horizons (Plates 13 to 17). Data from the seismic records have also been incorporated in a map which shows the subsurface structure of the Otway Basin (Plate 11).

Gravity contours covering the on-shore part of the Basin have been taken from B.M.R. Geophysical Branch compilations and from the work by Richards (1956)*. These are shown in a different colour to other data on the subsurface structure map. Aeromagnetic results are shown in the three Sheets of Plate 10: A and B are virtually the same as those in H.E.P.L., (1965), with the magnetic intensity contours of C.G.G., (1965)* for south-eastern South Australia added in Sheet A; Sheet C is a transparent overlay of the C.G.G., depth estimates and structure interpretation for south-eastern South Australia. (The H.E.P.L. and C.G.G. contours of depth to magnetic basement do no coincide, probably because of differences in the interpretation). Certain magnetic features have been shown for reference in the subsurface structure map (Plate 11).

2. Aeromagnetic Surveys

Aeromagnetic surveys carried out in the Otway Basin to the end of 1965 are shown on Plate 9A, along with an index of subsidized and unsubsidized surveys. For convenience, a total intensity map together with depth contours, and other information, has also been compiled at 1:500,000. The work in the Bass Strait and Encounter Bay Aeromagnetic Survey, 1960-61 (H.E.P.L., 1965), and the work done under contract to the Bureau for the South Australian Department of Mines in South Australia in 1955 (C.G.G., 1965*) were used for this compilation. The interpretations given by H.E.P.L. for the Bass Strait Survey, and by the C.G.G. for the South Australian Survey were also used.

Comparisons of thicknesses of sediments and attitudes of faults as indicated by the aeromagnetic, gravity and seismic surveys are made mainly in the discussions on gravity surveys; in some parts of the Basin there is remarkable agreement between the results. This discussion concerns only those aeromagnetic results off-shore and around the continental margin, which cannot be compared directly with gravity results.

In the area off-shore, opposite the Padthaway Ridge, aeromagnetic results suggest that a broad graben with sediments to more than 4000 feet extends north towards The Coorong; local anomalies due to basement variations are also shown (H.E.P.L., 1965). Deepening of sediments in this area is also indicated by seismic surveys (see Plate 12B), and a tentative loop to include the area has been made in the margin of the Otway Basin. One of the authors, Bigg-Wither, also points out the possibility that the thickening of sediments might be associated with a depression indicated by gravity and extending on-shore to the north of Kingston; a corresponding depression is also shown in the aeromagnetic interpretation. Alternatively, the gravity depression could be caused by granite known to intrude the Padthaway area, and deep-off-shore events in the seismic records could be multiple reverberations. However, it is of interest to speculate on the possibility of deepening section in this area because of the known occurrence further north of Permian sediments which include some marine section.

Some of the more important aeromagnetic anomalies that occur in the Otway Basin to the south of the off-shore extension of the Padthaway Ridge are shown on Plate 11. Anomaly 8 - 4 is a broad feature thought to be due to basic rock in basement which has been uplifted by faulting. Seismic records suggest that an anticlinal feature plunges west through the northern edge of Anomaly 8 -4; it could represent a basement nose over which pre-Unit G sediments thin.

The evidence associated with Anomaly 8 - 5 might mean that a basic volcanic event occurred in pre-Unit G time, possibly penecontemporaneous with the vulcanism in the Casterton area in the Upper Jurassic or Lower Cretaceous. Seismic evidence shows that Tertiary sediments are unaffected in the vicinity of this anomaly, except by faulting; magnetic evidence shows that the anomaly is due to sharp features common to basic intrusive bodies, and is at about 7000 feet, a depth consistent with the idea of an intrusion into pre-Unit G sediments or extrusion during pre-G sedimentation.

Apart from the above, no other anomalies are delineated as such, on Plate 11, except in the eastern part of the Basin; surface volcanic flows and areas of probable shallow volcanic bodies are indicated by symbols, and the axes of regional magnetic maxima and the central areas of broad minima are also shown.

One of the most prominent of the regional features shown by the total magnetic intensity contours is the broad minimum trending west-north-west off the southern coast of South Australia. On-shore, it passes to the south of Mount Gambier as a trough with more than 10,000 feet of sediments. The same trend persists across the border into Victoria towards Portland, and seismic surveys indicate that similar troughs occur also in this area. These troughs may have been continuous, but faulting along trends south-west from the "Dartmoor Ridge" (see Gravity Section) appears to have dislocated them. Seismic records suggest the presence of a prominent fault at the southern edge of the trough along the southern coast of South Australia, but this is reflected in the total magnetic intensity contours by only a very gradual rise to the south. Neither the trough nor the marginal fault is indicated by a gravity anomaly.

Another on-shore trough of thick sediments (more than 18,000 feet) is shown by aeromagnetics to occur to the north of the above, between Mount Gambier and Millicent (C.G.G., 1965*); the two troughs are apparently separated, at least in the north-western part, by a spur of shallower basement extending south-east in the north-western part, by a spur of shallower basement extending south-east from the Beachport area. This structural configuration is not shown by either the seismic or the gravity anomaly contours although there is a suggestion of a pre-Unit G depression south of Millicent in the available seismic records.

The problem of the contradictory results obtained by the geophysical surveys is discussed later in the section on Gravity Surveys.

Generally speaking, the results of the off-shore aeromagnetic surveys in the Otway Basin between south-eastern South Australia and the Otway Ranges in Victoria are featureless. Extensions of two lines over the edge of the continental shelf (H.E.P.L., op.cit.) show little except smooth regional changes. Also, the increase in the value of the total intensity contours south of the magnetic low anomaly in southern South Australia is only of the order of 60 gammas, whereas rises across other continental shelves may be more than 300 gammas (as in the Atlantic coast of North America, Heezen et al., 1959). The lack of feature off-shore from western Victoria may be entirely due to the poor aeromagnetic coverage in that area. However, a broad magnetic minimum is noted to the south-east of Portland - this has a south-westerly trend and may be linked with the previously mentioned on-shore troughs which extend west-north-west from Portland into south-eastern South Australia. Seismic records indicate that it was a depositional trough from pre-Unit G into Unit G time, and is possibly fault-controlled along its south-western side.

Further east, volcanic rocks at depth but probably above the main basement level are outlined by the Anomalies 14 - 1, 2 and 5, and 15 - 1 and 2. They could be pre-Unit G intrusions or extrusions, but they occur in the area of the " Older (Oligocene) Volcanics" and could well be associated with this phase of vulcanism. Anomaly 14 - 5 coincides with a strong positive gravity anomaly at Cape Otway, and shallow basement could have exerted some influence; however, its pattern is not like the magnetic basement pattern, as in the area immediately to the east, and the effects of a volcanic body or volcanic bodies at depth appear to be dominant.

Some of the anticlinal structures determined from the seismic records and shown on Plate 11 are seen to coincide with possible bodies of shallow volcanics determined by magnetic means; these structures may be due to the vulcanism, but other interpretations can be made. However, intrusion of basic rocks is probably responsible for the dome-like seismic structures south of Cape Bridgewater and south-west of Port Fairy, and possibly elsewhere; the doming is mainly in Tertiary sediments, whereas G and pre-G beds are unaffected, and it occurs in areas where shallow volcanics are known.

To the east of the Otway Ranges, negative features and strong positive axes are strongly contrasted, and shallow basement influence connected with a north-western extension of the King Island rocks is postulated for most of the area. Towards the central part of this off-shore region, some thickening of the sedimentary section is expected in a graben-like depression and its extension to the north into broad irregular magnetic low structures. The main trend of the strong magnetic features is meridional and similar to the regional basement trends. The eastern side of the area is marked by strong linear gradients which can be attributed to faulting; they are more or less aligned with the on-shore Selwyn Fault to the north, and constitute part of the eastern margin of the Otway Basin.

The Bureau has recently completed some 20 east-west high altitude traverses across Tasmania which were extended off-shore to the east and west over the continental shelf and slopes (Finney and Shelley, 1966*). The western off-shore area is similar to the southern parts of the Otway Basin in that it is, in general, magnetically flat, (although some troughs were delineated). The survey also showed that the magnetic basement is commonly close to the sea floor and in the north-western part is very shallow. The Precambrian block of north-western Tasmania extends off-shore to the north-north-west and is apparently bordered to the west by possible Cambrian rocks; these gave similar results to the on-shore Cambrian belt east of the Precambrian block.

Other recent aeromagnetic work by the Bureau includes surveys in small areas about 15 miles north-east of Hamilton, and immediately north of Creswick. These were planned to determine the thickness and state of decomposition of basalts by the magnetic method and to test the results against data known from drilling. If good predictions can be made by these means, the techniques will be used for other economic purposes. Results are not yet available.

3. Gravity Surveys

Gravity surveys carried out in the Otway Basin to the end of 1965 are shown on Plate 9B, together with an index of both subsidized and unsubsidized surveys. Many of the surveys listed were not carried out primarily in the search for oil, but could be useful for this purpose if integrated with the oil search surveys.

Due to the limited time available for the geophysical study of the Otway Basin it was not possible to compile a Bouguer anomaly map of the Basin using all available data. Contours on Plate 11 are from the B.M.R. regional gravity map G20-33 (1965) amended to incorporate some of the more detailed work by Richards (1963*). The gravity coverage of the basin is fair and, if a few additional traverses were to be run in areas of poor control, regional Bouguer anomaly maps could be compiled for the whole basin, the contour interval being selected according to degree of control. To undertake such a compilation, research into the files of the B.M.R. and private companies would be necessary as reports have not been written on many of the surveys. Gravity field sheets, elevation data, and Bouguer anomaly calculation sheets, for a large number of the surveys have been obtained by the Bureau and reference is made on Plate 9B to the B.M.R. files from which these data can be obtained. Any data that can be supplied to supplement these files would be appreciated for future compilations.

The first gravity survey in the Otway Basin was carried out in south-west Victoria by W.A. Wiebenga of the Bureau during 1950. A report on this survey showed that the gravity method could be useful, and several targets for further exploration were indicated (Wiebenga, 1957*).

A useful compilation, using data obtained by the South Australian and Victorian Departments of Mines, was made by K.A. Richards (1956*). Differences in the work of the two departments (resulting from the scale factors used, errors in assumed absolute gravity base values and elevation datums) were reconciled in the light of more recent information. No map of this work was obtained by the Bureau.

A later compilation by Richards (1963*) integrated the above work with the many surveys by Frome-Broken Hill Co. Pty. Ltd., and was the best Bouguer anomaly map of the Victorian part of the Otway Basin available for this review. This map together with the Bouguer anomaly maps of the Penola and Naracoorte sheet areas prepared by the South Australian Department of Mines, and the Bouguer anomaly map from the Kalangadoo Gravity Survey (A.O.D.A., 1965a*), give a good regional coverage of the Basin, and were used by the B.M.R. in their compilation.

The most recent gravity compilation was made by the South Australian and Victorian Departments of Mines. This work was undertaken in 1965 as part of a joint study of the Otway Basin and many gravity surveys were recomputed to a common datum.

Gravity surveys have supplied significant information on the regional configuration of the basin, particularly with regard to parts of the north-western, northern and eastern margins. The north-western and northern limits which extend across the South Australian-Victorian border are bounded by a prominent zone of steep gravity gradients; these are the expression of a faulted zone that extends north-east from Guichen Bay in the west, to a few miles north of Lucindale, and thence swings in a wide arc west of Naracoorte via Dergholm, to Casterton. South-east of Casterton, the fault zone possibly swings east-north-east through Merino and south-east past Hamilton. Some steep gradients that are roughly aligned in an east-west direction through Geelong follow west trending faults known to occur in that area. The eastern limit of the Basin is a zone of steep gradients co-incident with the Selwyn Fault.

In south-eastern South Australia where both aeromagnetic and gravity coverage is available, a general correspondence is noted in the zones of steep gradients and faulting. An apparent exception occurs south-east of Cape Jaffa where steep gravity gradients trend south-westerly across the east-west trend of the aeromagnetic fault interpretation; this is thought to be due to a misinterpretation of the on-shore aeromagnetic anomalies, and the gravity results appear to be more acceptable.

Within the area of the Otway Basin covered by gravity surveys, a number of prominent structural features have been recognized. These are outlined hereunder with an informal nomenclature to facilitate discussion of them elsewhere in the text.

In South Australia, the fault zone which is the expression of part of the north-western limit of the Basin is followed to the south by the "Cape Dombey Gravity Trough" which extends between Cape Dombey and Lucindale. The first indication of this trough and its faulted north-western margin was obtained from a gravity survey in the Cape Jaffa area (Grant, 1954). Calculations made on the assumption of a density contrast of 0.3gm/cc between basement and sediments gave a basement depth of approximately 10,000 feet. A review interpretation of refraction seismic traverse 'RG' across the north-eastern end of this trough shows a depth of sediments of about 6,000 feet (A.O.D.A., 1965b*). On marine seismic evidence the trough extends south-west past Cape Dombey for about 40 miles off-shore. Basement contours obtained from the interpretation of the total intensity magnetic map confirm the presence of a deep trough of sediments (10,000 feet) to the south-west of Cape Dombey. Good evidence of faulting along the north-west margin is also seen on the seismic cross-sections and confirmed by the off-shore aeromagnetic interpretation. On land there is little evidence for this trough from the aeromagnetic survey (C.G.G., 1965*), although the trend of the basement contours is north-east through Guichen Bay, and shows deepening to the south-east. On marine seismic evidence the south-western end of the trough is cut by a zone of parallel faults which trends east-south-easterly towards Beachport. The trends of the total intensity magnetic contours off Beachport are approximately parallel to this faulting. However, the control for the aeromagnetic contours further west is poor and the depths at the south-western end of the "Cape Dombey Gravity Trough" are indeterminate.

A marked change in structural trend occurs at the north-eastern end of the "Cape Dombey Gravity Trough"; conjugate and adjoining structures trend south-easterly. They occur along the north-eastern side of the Otway Basin in a "terrace" - the "Lucindale-Penola Gravity Terrace" - probably bounded on both northern and southern sides by faulting (on gravity and aeromagnetic evidence). Structure on the "terrace" is indicated by a succession of gravity high and low anomalies. Contours on magnetic basement follow the structural trends indicated by gravity in this area and depth estimates range from 3000 to 8000 feet.

Adjoining the "Lucindale-Penola Gravity Terrace" feature to the south-west is a south-east trending gravity low which appears to be the expression of a deep trough of sediments, the "Penola Trough". Depth estimates made on this anomaly, assuming it to be a trough of sediments, were in excess of 16,000 feet. Aeromagnetic interpretation shows a similar south-east trending trough of sediments with depths to magnetic basement in excess of 14,000 feet. On seismic refraction evidence depths to the 16,000 ft/sec. refractor are in excess of 12,500 feet. As an 18,000 ft/sec. refractor was shown to be present under Kalangadoo and Penola, depths of sediments in this trough are expected to be well in excess of 14,000 feet.

Refraction traverse 'RG' which crosses the north-eastern end of the "Cape Dombey Gravity Trough", also crosses the north-western end of the "Penola Trough". There is evidence of deep sediments in both troughs separated by shallow basement 2,500 feet deep. North of the basement high separating the two troughs, the traverse shows two refractors with volocities of 9,300 and 11,000 ft/sec., respectively. The 9,300 ft/sec. refractor is about 2000 feet deep and dipping south, and the 11,000 ft/sec. refractor is slightly deeper with steeper dips to the south. The Kalangadoo-Lucindale refraction survey (A.O.D.A., 1965b*) also showed an 11,550 ft/sec. refractor near the base of Unit G in the Kalangadoo No. 1 Well. Unit G sediments are therefore thought to be present in both the "Cape Dombey Trough" and the "Penola Trough" but appear to thin over the basement divide. The divide coincides with a circular gravity high anomaly.

The area to the south-east of the "Cape Dombey Trough" and west of the "Penola Trough" appears on gravity evidence to be one of relatively shallow sediments which become thinner to the south towards a semicircular high around Beachport. The C.G.G. (op.cit.) aeromagnetic interpretation, however, suggests that the gravity picture could be influenced by dense material intercalated in the sedimentary overburden and that, at least in the areas surrounding Beachport, sediments may extend to depths of more than 13,000 feet. The feature causing the Beachport gravity high of more than 40 milligals is also reflected by the total magnetic intensity of the area (H.E.P.L., 1965); the better control available from aeromagnetic surveys has allowed differentiation into three anomalies, 9-2, 3 and 4, which have been shown on Plate 11.

Anomalies 9-2 and 3 are thought to represent relatively the shallow magnetic influences; they are possibly affected by west-north-west faulting and are aligned with the off-shore aeromagnetic Anomaly 8-4. Anomaly 9-4 is similar to 9-2 but is deeper ; it appears to have a meridional trend similar to 9-3 but is less affected by cross faulting. Basic igneous intrusions into the sediments above basement or volcanic flows during sedimentation could cause these anomalies, particularly in the 9-2, 9-4 areas. The C.G.G. (op. cit) report on this area states (p.30): 'The quantitative interpretation of a prominent anomaly situated ..... north of .... Beachport indicates the occurrence of a magnetic contrast at a depth of about 5,000 feet. Since the average of the surrounding depth estimates (is) about 13,500 feet, the hypothesis of a magnetic horizon intercalated in the sedimentary overburden has been adopted.' They conclude that the main source of the Beachport anomalies is the 'buried core of a volcanic system' with other anomalies of lower intensity produced by buried volcanic flows, subsequently affected by faulting. Their hypothesis would account for the fact that Beachport No. 1 well was drilled to 4000 feet without encountering any evidence of volcanic flows or basic intrusions. The Beachport well ended in 2000 feet of Unit M (Lower Cretaceous) sediments, thus any basic rock body if present would occur in older Unit M or pre-Unit M sediments; the intrusion or extrusion could have been contemporaneous with the basic extrusions of Unit T time in the Casterton No. 1 area, and with the ? volcanic activity associated with the Anomaly 8-5.

To the south-west of the "Penola Trough" and south-east of Beachport, the gravity interpretation suggests a broad area of sediments somewhat shallower than those in the "Penola Trough"; a general south-easterly trend is maintained. However, the anomaly pattern does not reflect the zones of deep sediments indicated by aeromagnetic and seismic surveys; only isolated lows of small amplitude occur on a shallow gradient which rises towards the coast. As noted in the section on aeromagnetic surveys, two main troughs of sedimentation are thought to occur in this region. The probable reasons for the absence of any clear indication on the Bouguer Anomaly map of the depth and extent of sediments in the Mount Gambier area (and also to the east in the Tyrendarra area where a similar problem exists) are discussed below. First, however, the lack of control for the gravity surveys near the coast and off-shore, and the lack of seismic information in certain areas should be stressed; although the regional picture may remain essentially unaltered, more control could easily give the necessary detail to facilitate correlation of the various geophysical surveys.

Assuming that the interpretation of the available data is correct, and that a broad gradient rising in value towards the coast overlies an area in which two troughs of thick sediments occur, some explanation is necessary for the anomalous gravity pattern. The following factors have been considered:

(i) an isostatic anomaly;

(ii) a rise in the base of the Otway Basin sedimentary sequence from inland towards the coast;

(iii) a thinning of the sialic crust from inland towards the continental edge.

(i) The rise of the gravity values could possibly be attributed to an isostatic anomaly caused by continual sedimentation on the continental shelf, (A.O.D.A., 1965a*). This explanation does not appear to be valid for the following reasons:

(a) Continuous sedimentation on a continental shelf, originally in isostatic equilibrium (and with no adjustment taking place during sedimentation) would only give an isostatic anomaly of less than one milligal even if the sediments built up to sea level.

(b) Isostatic anomalies were computed for Mount Gambier by the Bureau (Dooley et al, 1961). The Hayford anomalies, computed for depths of compensation varying from 56.9 to 113.7 kilometers, range from -14.5 to -37.9 milligals. Isostatic anomalies calculated for thickness of the crust between 20 and 60 kilometers gave Airy anomalies varying from -1.7 to -41.6 milligals. In the computations of the above anomalies the density of the surface rocks was assumed to be 2.67 gm/cc. However, Mount Gambier is situated in a basin where depths of sediments are in excess of 10,000 feet (3050 meters). To find if the area is isostatically compenstated it is therefore necessary to apply a 'geological correction' (Heiskanen, 1950). Assuming a basin depth of 10,000 feet and a density contrast of 0.25 gm/cc the 'geological correction' is approximately +32 milligals. When this correction is applied to the isostatic it is seen that most isostatic anomalies are changed from predominantly negative values into anomalies ranging from -6 to +17.5 milligals on the Hayford hypothesis and -9.6 to +30.3 milligals on the Airy hypothesis. The mean isostatic anomaly on the Hayford and Airy hypotheses (for all ranges of depths of compensation and thicknesses of crust) is therefore +8 milligals**. The Bouguer anomaly calcuated for Mt. Gambier was +12 milligals. Some degree of isostatic compensation must therefore have taken place; no marked isostatic anomaly appears to exist.

(ii) Richards (1963*) discarded the idea of an isostatic anomaly because the results of marine seismic surveys showed the Otway Basin sediments thinning and rising seawards from the coast. He considered that the dominant density contrast occurs at the contact of the 'lower Cretaceous - Jurassic and the Palaeozoic' (presumably the older slightly metamorphosed Palaeozoic rocks), and that a rising contact would explain the increase in Bouguer values.

However, this explanation does not account for the lack of expression of the pile of sediments (? mainly pre-Unit G) which probably occupies the depression shown in the magnetic basement between Mount Gambier and Millicent, nor the Unit G depression extending from south-eastern South Australia into western Victoria. Likewise, the explanation does not account for some thickening of Tertiary sediments off-shore (compare Plate 16).

(iii) Much geophysical work has been carried out since the Wiebenga (op. cit.) gravity and magnetic reconnaissance survey in western Victoria in 1950, and some of his conclusions now need modification. However, he recognized the rising regional gravity effect that occurs towards the coast, and attributed it to thinning of the sialic crust towards the continental edge. The hypothesis cannot be fully tested because of the lack of gravity control off-shore, but it is suggested that the more marked increase in gravity values which could be expected on a regional basis from this influence has probably been offset by the great thicknesses of sediments towards the coast. Further effects could possibly also be expected from the changing of the axis of sedimentation which occurred from time to time. The result is a broad irregular Bouguer anomaly pattern of low regional gradient; areas of minor gravity depression roughly conform with some of the zones of sedimentation.

Some off-shore gravity surveys would be useful to ascertain whether the on-shore pattern persists seawards, and whether a sharp rise occurs to delineate the continental margin as in other parts of Australia. This would not only facilitate an understanding of the basic structure of the Otway Basin, but might also lead to the discovery of other troughs of sediments - mostly Unit M but probably a more marine lithofacies, and possibly older beds such as Permian sediments known to occur in the marginal on-shore parts of the Basin.

The south-easterly trend of gravity anomalies extending from South Australia into western Victoria is interrupted by a prominent trend which extends to the south-south-west from Merino - the "Dartmoor Gravity Ridge". It may reflect either a significant regional (basement) trend and/or thick shallow basalts (surface flows have occurred in this area). Seismic reflections down to intermediate depths at least, do not appear to be significantly influenced by any feature coincident with the trend, although some of the faulting near the coast and off-shore is aligned in a similar direction. The strong positive anomaly near Cape Bridgewater to the south of the "Dartmoor Gravity Ridge", is also reflected by a magnetic anomaly and is obviously associated with basalt intrusion and extrusion.

Bouguer anomalies to the east of the "Dartmoor Gravity Ridge" in the Tyrendarra area, are small and of large wave-length suggesting consistently thick sediments throughout, whereas seismic surveys and drilling have shown thick section locally and variation in basement

** Calculations after Wiebenga, (1957*).

relief. The problem is similar to that in the coastal area of south-eastern South Australia and has been discussed earlier.

Another prominent positive anomaly with a south-south-westerly trend occurs at the eastern edge of the Tyrendarra area; it passes between Koroit and Warrnambool and has previously been referred to as the 'Warrnambool High'. This term is unsatisfactory because it gives no indication of the type of 'high', and, because the feature can be recognized on some seismic horizons and is also prominent in cross-section (see Plates 4A and 5), the name Warrnambool Ridge has been adopted in this report.

The Warrnambool Ridge is similar to the "Dartmoor Gravity Ridge" in its trend. Some volcanic activity appears to be associated with it; aeromagnetic surveys suggest that vulcanism or basic intrusion occurred along the off-shore extension of the ridge. However, other evidence indicates that the Warrnambool Ridge is primarily a basement feature, and that it is part of a locus about which there is marked change in the regional structural trends of the Otway Basin, see Plate 11. To the west, the main trends are WNW-ESE, to the east they are NE-SW. Off-shore from the Warrnambool Ridge, trends appear to bend from south-west towards the west, and curve around the ridge.

On-shore gravity anomalies between the Warrnambool Ridge and the Otway Ranges show two areas of thick sediments, one in the Port Campbell area, and the other in a wedge-shaped depression east of Colac. The sediments in the Port Campbell area are obviously in a fairly deep localized basin structure thinning to the west on to the Warrnambool Ridge, to the north on to the edge of the Basin, and to the east on the Otway Range structure. They were previously considered to occur in an 'embayment' but sub-surface structure, partly reflected at the surface near Warrnambool, suggests that the south-western and southern sides of the Port Campbell area could be bounded by faulting. In fact the area is thought to have been a depression with restricted access to the sea, at least from Lower Cretaceous time; it will be referred to as the "Port Campbell Gravity Depression".

The wedge-shaped gravity low east of Colac may have been connected with the "Port Campbell Gravity Depression" but it now wedges out along (and possibly into) the western side of the Otway Range structure. The depression, in its present form, and the plunging of the Otway Range structure to the north-east, are attributed to movements associated with transcurrent faulting; the exact nature of the depression, however, is unknown and for the purposes of this report it will be called the "Colac Gravity Trough".

Adjacent to and south-east of the "Colac Gravity Trough", a prominent, elongate positive gravity anomaly exists in the Otway Range area. The shape and intensity of the gradients on the flanks of the feature suggest that it is a horst, (the "Otway Range Horst"), plunging to the north-east (Richards, 1963*). The highest Bouguer anomaly value (30 milligals), occurs at the southernmost end near Cape Otway. Aeromagnetic surveys suggest that the fault along the south-eastern side of this anomaly extends off-shore to the south-west, but that downthrow to deep basement is on the north-western side of this fault (see H.E.P.L., 1965, p.19), i.e. apparently contrary to the horst concept of the gravity interpretation. The off-shore aeromagnetic records show the strong magnetic contrasts typical of shallow basement south-east of the fault; however the patterns south-west of Cape Otway are typical of deep basement. Ground magnetic surveys along the coast in the Otway Range area were unsuccessful because of near surface influences, possibly ferruginous sandstones. A possible explanation for this apparent contradiction of results is given later; the idea of the horst is supported, particularly in view of the evidence given by the Anglesea No. 1 Well which was drilled east of the fault to more than 10,000 feet and did not reach basement.

To the north-east of the "Otway Range Horst" are two small bifurcating areas of gravity minima surrounded to west, north, and east by areas of possible basement high anomaly; they may be linked off-shore to the south, and appear to be areas of deeper sediments. The western area trends north-west from the coast near Anglesea towards Geelong with a possible re-entrant to the west of the nose of the "Otway Range Horst" linking with the "Colac Gravity Trough". It is separated from the eastern area by a small gravity high over the Bellarine Peninsula where Lower Cretaceous Unit M sediments crop out. Stach (1962) divided the western area into the "Anglesea Trough" adjoining the north-eastern end of the "Otway Uplift", the "Torquay Horst" plunging south-east from the Barrabool Hills, and the "Barwon Trough"; the high area to the east was called the "Bellarine Horst". This subdivision was based on a limited number of seismic traverses, and does not take account of the gravity results. Stach's subdivisions are not entirely acceptable because of the lack of control.

The eastern area of sedimentation is a slightly deeper trough coincident with Port Phillip Bay. The steep gravity gradient on its eastern side is probably associated with the Selwyn Fault which forms the northern part of the eastern margin of the Otway Basin. Neither the aeromagnetic nor the off-shore seismic surveys extended into this region of gravity anomalies. However, it is interesting to note that directly south of where the two gravity minima areas might join aeromagnetic contours indicate a broad depression with magnetic basement more than 5,000 feet deep, (H.E.P.L., op. cit.).

4. Seismic Surveys

A locality map of seismic surveys in the Otway Basin to the end of 1965 is given on Plate 9~~0~~5. No information has been obtained on the surveys carried out by the South Australian Department of Mines, apart from their locations.

Seismic reflection records of all marine surveys, except the Warrnambool-Princetown Survey which used the Seismic Underwater Explorer (S.U.E.) equipment, were re-interpreted by the Basins Study Group. Except for the S.A.D.M. surveys, the greater part of the land surveys was also re-interpreted. Previous interpretations of the various seismic surveys were not referred to during the work as it was felt that a complete re-assessment of all available data, using the latest bore hole information would be useful.

Marine Surveys

The quality of records varied from very poor to good, depending on the area and the techniques used. The results of the Gippsland, Bass Strait - Anglesea and South Australia (1963), and Permit 22 Southwest Victoria (1963) surveys were generally poor at deeper levels; 3-fold C.D.P. stacking was not used. The integration of these surveys with the Cape Grim to Cape Jaffa (1964-65) Survey, where 3-fold C.D.P. stacking was used, enabled reliable time contours to be drawn.

Land Surveys

The quality of the land seismic survey results varied from very poor to fair, again depending on the particular area and the techniques used. In general, they were not as good as the off-shore seismic results. A summary of the techniques used and the results obtained will be given later. The results were generally better from the shallower levels than from deeper horizons because of multiple interference at depth.

However, the horizons contoured on-shore are considered to be fairly reliable because they are shallow and can be tied to wells; interference to reflections was greatest in areas of sand dunes, basalt and limestone cover.

(a) Reassessment by Basins Study Group

Contour maps in time of three reflection horizons and isochron maps of the intervals between them are given (Plates 13 - 17).

The stratigraphic units mapped were identified by ties or near-ties to wells, and seismic profiles in two-way time showing the information at the wells used for control are given on Plates 12A, 12B, and 12C. Where no seismic ties exist, stratigraphic information from bores at Kingston and Robe and many shallow bores, especially in South Australia, was used as control for the contours. Trends of faults in areas of limited seismic control were also based to some extent on the gravity and aeromagnetic data.

The units mapped are:

(a) Base of Unit B - an horizon within the Tertiary

(b) Base of Unit D - the unconformity at the base of the Tertiary

(c) Base of Unit G or J - H - the unconformity at the base of the Upper Cretaceous or near the top of the Lower Cretaceous.

Where reflections on Units B, D and G (J - H) were not continuous numerous reflections above and below the horizons mapped served as control for phantom horizons which were drawn parallel to the nearest dip segments.

Recurring evidence that Units D and G (J - H) overlie unconformities helped in the identification of the horizons and the location of probable faults. Off-shore on lines where 3-fold C.D.P. stacking was not used, the steeper dips below the unconformity made the primary events evident despite interference from multiples.

A number of faults have been mapped. Their presence was commonly accepted where distinct displacements occurred across zones disturbed by diffraction interference, or was inferred in some places by loop misclosures. Only those faults believed to be of regional significance by their persistence across two or more traverses are shown, unless the evidence from a single traverse was considered reliable.

Wave guide (ringing) common to some water covered areas was not a major problem and was noted only in very few profiles in the southern off-shore areas of South Australia. These sea bottom multiples, along with other complex multiples recognised by their variable move out curvatures, made the identification of primary reflections very difficult in some places.

In areas far removed from well control, the data are not always sufficiently good to ensure that the contoured unit has been at the same stratigraphic level. Also, for areas of deeper water beyond the continental slope, only approximate corrections were made for water depth. These areas of poor control are indicated accordingly on Plates 13-17.

(b) Velocity information and time-depth conversion.

The contours have been presented in two-way time to facilitate correlation by time ties from area to area.

To convert the time values to depth, velocity information obtained from continuous velocity (sonic) logs and well-velocity surveys of the nearest well should be used.**

In the Mount Gambier area velocity information derived from t - Δt analysis computed from fair relfection information gave the functions:

V_a = 5300 + 0.65 Z for the northern part, and,

V_a = 6300 + 0.3 Z for the Beachport area,

(where V_a = Average Velocity, Z = depth)

Dynamic corrections applied during the "Vibroseis" survey (see later) which used the latter function, were found to slightly over-correct the reflections and consequently the function.

V_a = 6934 + 0.25 Z derived from Geltwood Beach No. 1 was adopted (Raitt and Schwing, 1965*).

An average Otway Basin time-depth curve was based on the data obtained by H.E.P.L. (1965*) from ten wells located along the South Australian and Victorian coastline. This curve supports several t - Δ t analyses made by the contractor in the off-shore areas of South Australia and Victoria.

The velocity function is V_i = 6075 + 0.84Z (i)

Where V_i = instantaneous velocity,

0.84 = acceleration factor (d)

Z = depth, and

6075 = datum velocity (V_o)

Well velocity data indicate that this function can be applied down to a depth of 9000 feet below sea level, below which a flattening of the time-depth curve suggests a constant velocity of 13,630 ft/sec.

H.E.P.L. (op.cit.) used the above velocity in the preparation of their structural maps for the Cape Grim to Cape Jaffa Marine Seismic Survey. It is suggested that this velocity function should be used until better control can be obtained from future well velocity surveys.

The instantaneous velocity, V_i (or $\frac{dz}{dt}$) = $V_o + \alpha Z$

can be integrated to give:

$$Z = \frac{V_o}{\alpha}\left(e^{\alpha t/2} - 1\right)$$

and when the velocity function (i) above is applied,

$Z = 7235\,(e^{0.42t} - 1)$ where t = two-way time.

** Subsequent to the preparation of this section of the report, a velocity study has been made on all information obtained from continuous velocity (sonic) logs, well velocity surveys t - Δt analyses, and from expanded spreads; a summary of results is included in Appendix II.

(c) Notes on techniques used in the marine surveys

(i) Flinders Island - Kingston Survey - part of the Haematite (1963) marine survey:

Short (approximately 600 meters) and long (1200 meters) spreads were used throughout the survey, and give 100% and 200% subsurface coverage respectively with a shot point interval of 600 meters. Variable area record sections were made from each short spread and alternate long spread tapes giving 100% subsurface coverage for both short and long spreads.

Fair to good quality reflections were recorded to the base of the Tertiary, but reflections below this depth were generally poor due to interference from multiples.

Although all the long spreads were recorded with 200% subsurface coverage, only a few stacked 2-fold C.D.P. sections were prepared. Some improvement in cancellation of multiples resulted but the recording of primary energy return was little better.

The results, however, indicated the possibility that further improvement could be expected by using 300% or more, continuous subsurface coverage.

(ii) Southwest Victoria Survey (1963):

In the western half of this survey and immediately off-shore between Lady Julia Percy Island and west of Flaxmans No. 1 well, only the long (1200m) cable was used with shot point interval of 1200 meters, giving 100% subsurface coverage. Reflection quality was patchy - good over several shot points and very poor over others. No wide-spread reflection continuity was found.

In the area off-shore from Flaxmans No. 1 well, two simultaneous 24-trace recordings with short and long spreads were made at each shotpoint giving 100% and 200% subsurface coverage with 600 meter shotpoint intervals. Variable area record sections were made from playbacks of each shot point and alternate long spread tapes giving 100% subsurface coverage for both long and short spreads. Later, 120 miles of line were shot using the long cable only and a shot point interval of 400 meters, giving 300% subsurface coverage.

At shallower levels, reflection quality on both the short (with 100% subsurface coverage) and long spreads (with 300% subsurface coverage) gave very good and continuous reflections. At deeper levels, however, considerable multiple energy and weak primary energy returns were present and the deeper reflections could only be followed on the 3-fold C.D.P. stacked sections. The cancellation of the multiple reflections and reinforcement of the primary reflection energy enabled reliable reflections to be followed down to at least 2.0 seconds.

In the immediate off-shore area between Port Campbell and Princetown, multiple interference was slight due to the shallower Mesozoic section, and the short and long spread sections with 600 meter shot point spacing could be used with confidence. However, south of line F-18 and over the rest of the survey area not covered by triple subsurface coverage, the intensity of multiple reflections is severe and the horizons below about 1 second are unreliable.

(iii) Cape Grim - Cape Jaffa Survey (1964-65):

During this survey, over 1800 miles of traverses were shot in the Otway Basin in the off-shore ares of South Australia and Victoria, extending from Cape Jaffa in the west to the King Island area in the east.

300 miles were shot with a special dual-purpose cable which recorded simultaneously with short (600m) and long (1200m) cables at the same shot point. Variable area sections were prepared for each short and long spread tape giving 100% subsurface coverage for both long and short spreads. This technique was used on the reconnaissance lines west of King Island and appears to have been adequate for the purpose.

About 1500 miles were shot using 3-fold C.D.P. coverage with long spreads and shot point spacing of 400 meters. 3-fold C.D.P. stacked sections were prepared from the tapes and a considerable improvement in record quality was noted. In general, reflections were continuous, showing good character, large amplitude and high frequency down to approximately the base of the Upper Cretaceous. Below this horizon, the amplitude and continuity of the reflections decreased, but phantom horizons might still be drawn with reasonable accuracy, in some areas, to levels almost twice the times recorded to the base of Unit G. However, it is doubtful if reliable regional contours could be drawn for horizons greater than about 0.5 sec. below the base of Unit G. Stratigraphic information available at present is insufficient to provide control for a horizon deeper than the base of Unit G or Unit J - H.

(d) Discussion of ties for marine surveys

Contoured horizon ties between the marine and land seismic surveys are considered to be reliable except in South Australia where on-shore seismic control is lacking.

The contours immediately off-shore from South Australia are tied to the Beachport, Geltwood Beach and Nelson wells. Further west and south-west, the marine traverses yield reliable contours which are tied to the reliable off-shore marine contours in western Victoria by a series of closed loops.

Correlation to the north is not certain and seismic control consists of only a few widely spaced traverses. Horizons at the base of Units B and D correlated (in time) with shallow horizons further north (Plate 12B) and hence are probably continuous across this area of shallow basement; the horizon at the base of Unit G is seen to pinch out against the ridge and no correlation is possible with the deeper horizons to the north on present evidence. Beyond the Padthaway Ridge sediments may deepen to more than 7000 feet.

In western Victoria, extensive on-shore and marine surveys together with the availability of ties through the several coastal wells, have allowed reliable correlation between the contours at various levels. The three horizons contoured were carried in closed loops to the South Australian-Victorian border from the Port Campbell area, and from the Port Campbell area off-shore to the Anglesea area.

In the latter area, there is little on-shore control but both Units B and D can be tied with Anglesea No. 1 Well. The horizon at the base of Unit B rises towards the Anglesea well but becomes too shallow to map above 0.3 second. However as this unit crops out near the well, the interpretation appears to be fairly reliable. The basal D horizon could be followed on the traverse to the Anglesea Well to 0.1 second and shows a close tie to the base of Tertiary. Diffractions interfere with reflections at the base of Units G - H just east of the Anglesea Well and faulting is suggested. However it is possible to correlate on character across the zone of interference, and the horizon at two-way time of 0.8 second east of the fault is found at 0.5 second to the west. This two-way time ties with the depth of the base of Unit H in Anglesea No. 1.

(e) Notes on techniques for land surveys (After Moss, 1965*)

On land, seismic work has yielded good results in many areas, although no single technique has given good results throughout the Otway Basin. Large areas with volcanic, sand dune or Tertiary limestone cover where only poor, or no reflection data could be obtained, have generally been avoided.

In areas with no basalt cover in the Tyrendarra area, fair quality seismic results have been obtained, with 3 shot-holes in line, 75ft apart, drilled to a maximum depth of 150 ft, with 5-15 lb. charges in each hole. Recordings have been made with 12 geophones per trace, with up to 27½ ft between geophones.

In some areas, mainly bordering the basalt, reflection quality deteriorated and considerable standard testing was carried out to improve reflection quality.

Testing showed that reflection quality generally could be improved by increasing the number of geophones per trace, the number and depth of shot-holes, and the charge sizes. However, shooting with 10 holes each 30 feet deep per shot point, with a total charge of 250 pounds, and recording with 24 geophones spaced 12½ feet apart per trace in an area of weathered basalt east of the Glenelg River gave only slightly improved results despite the large increase in effort (F.-B.H., 1962a*).

Noise spreads have also been shot in the course of the various surveys, on surfaces varying from tuff and weathered basalt to hard basalt. As these noise spreads were not continuously recorded out from the shot-point, they are extremely difficult to analyse. The main conclusion from noise shooting is that the type of noise present varies widely over a small area.

Exploration in the Tyrendarra area is now being directed to areas covered by volcanics. The common depth point (C.D.P.) method has been used, generally with 6-fold coverage. (F.-B.H., 1963 d and c*). Despite the difficulties experienced in obtaining good static and dynamic corrections to allow efficient compositing, significant improvements in reflection quality in the basalt areas have been achieved. The C.D.P. recording method, however, is generally slow and drilling difficult and costly.

Techniques used in the Mount Gambier area have generally been simple and little experimental work was conducted in "no record" and poor reflection areas, other than normal testing with different hole depths and charge sizes. In ordinary surveys, single holes 30 to 60 feet deep, with a normal charge of 5 to 10 lbs. have been shot in conventional split spreads, with normally 4 geophones spaced 10 to 15 feet apart per trace. Seismic results are fair in most areas which have been surveyed. Results on Gambier Limestone, or on sand dunes were poor and areas with these covers have generally been avoided in the reconnaissance surveys.

The problems associated with seismic surveys in parts of the Otway Basin have been analysed by the Geophysical Branch of the Bureau, and some experimental work has been done in an attempt to improve record quality. Moss (op.cit.) outlined the problems:

A. For volcanic provinces -

(1) surface problems

(i) the difficulty of transmitting energy through volcanic rocks (eroded basalt and tuff are the worst);

(ii) variations in the weathered layer make it difficult to calculate static corrections;

(iii) drilling is difficult and expensive (the rate may fall as low as one inch per hour);

(2) subsurface

(i) lateral changes in vertical velocities due to the varying extent and thickness of basalt (and in some cases due to limestone occurring below the basalt) become a major problem when C.D.P. stacking is used;

(ii) multiples are evident on most recordings made on or near basaltic areas; another type, similar to the reverberation (or ringing) type of marine surveys, may be due to a combined effect of basalt over limestone.

B. For Tertiary limestone areas -

(1) energy transmission is difficult due to the cavernous nature of the limestone;

(2) drilling problems are caused by loss of circulation and slow penetration rate through flint layers.

C. For dune country -

energy is lost due to high energy transmission of the surface sand, and circulation losses add to drilling difficulties. Another problem of unknown source caused poor results in an interdune area east of Beachport.

Seismograph Service Limited was employed by the Bureau between May and October 1964 to demonstrate the "Vibroseis" techniques in the problem areas (see S.S.L., 1965*). Results showed that:

A. For volcanic provinces -

(1) (i) sufficient energy penetrates the near surface layers to provide adequate returns from the deeper formations;

(ii) when long source and detector patterns were used, weathering depth variations were not critical;

(iii) no drilling problems applied;

(iv) noise testing showed that surface noise with velocities from 4000 to 7000 ft/sec. was present but was attenuated by the vibrator and geophone patterns used;

(2) (i) the "Vibroseis" survey showed that lateral velocity variations were less of a problem than previously thought;

(ii) interpretation problems due to multiples still existed;

(iii) noise testing showed noise with a frequence of 30 cycles per second and a velocity of 13,000 ft/sec. (believed to be a refraction from the basalt layer); the energy was not at an observable level beyond 1400 feet.

B. Tertiary limestone areas -

(i) good results were obtained in the Mount Gambier area down to about 1 second; failure to get better deep events is not considered to result from a lack of energy penetration;

(ii) three discrete high amplitude noise events were eventually attenuated using 10 fold C.D.P. stacking.

C. In sand dune country -

Improvements in results were obtained in some of the areas near sandy country and over thick sand after some experimentation. However, only poor reflections were obtained over a typical fossil sand dune, and testing in the interdune areas, where problems were previously encountered, yielded no conclusive results.

To obtain a better comparison between shot hole and "Vibroseis" methods, the Bureau then conducted shot hole surveys from April to August, 1965; they experimented with techniques other than the generally conventional methods used previously. The programmes and results are given by Raitt (1966*) and Jones (in prep.).

The final technique adopted in volcanic areas was; shot pattern - 7 holes in line, 50 feet apart with 7 x 20 lb. charges at 80 to 90 feet;

geophone pattern - 48 trace in two rows of 24, 15 feet apart, the rows being 30 feet apart;

spread - split spread of 2400 feet total length.

The quality of the section was fair and considered to be slightly superior to that obtained by "Vibroseis" over the same traverse. Events were recorded to 2.3 seconds; the continuity of shallow reflections between 0.75 and 1.05 seconds is good but deeper events were poorer. A short section shot with larger patterns and shorter spread showed a significant increase in quality (but surveys using short spreads involve much greater costs).

In limestone areas, the following programme was adopted:

shot pattern - 7 holes in line, 50 feet apart with 7 x 20 lb. charges at 50 to 55 feet;

geophone pattern - 48 per trace in two rows of 24, 15 feet apart, the rows being 30 feet apart;

spread - split spread of 2640 feet total length.

The quality of the section is fair, several strong and continuous events being present to about 1.5 seconds. Strong events persist to about 2.8 seconds but their continuity is poor; they could be multiples. The overall quality is considered to be superior to that of the "Vibroseis".

Patterns were also designed for the limestone covered areas to give greater energy transmission and to reduce transverse noise; these gave improved results and were more economical that other methods previously used.

V. STRUCTURE OF THE OTWAY BASIN (By R. Bryan and M.A. Reynolds)

Before considering in detail the structure of the Otway Basin it is essential to establish the validity of the concept that a single broad basin was developed south of the Murray Basin in western Victoria and south-east of South Australia, during Cretaceous and Tertiary times.

Elsewhere in this report (see Plate 12) geophysical data are presented that show convincingly that known Cretaceous sediments in this broad area do occur in a single structural depression though details of the shape, and also the form of the offshore extension are open to question. Petrological studies - also set out in this report - have established clear correlations of rock units across the landward portion of the basin.

The limits of Tertiary deposition closely match those of the Cretaceous units and the regional lithological correlations appear to be reliable. There is no evidence of large scale diastrophism in south-eastern Australia at the end of the Cretaceous, and Tertiary sedimentation probably developed in a slightly modified version of the Cretaceous basin.

Thus it would seem that a single term such as Otway Basin can be applied to include all the areas of Cretaceous and Tertiary deposits in south-eastern South Australia and south-western Victoria. There has been some argument as to whether this feature is a trough - see Bock and Glenie (1965) - or a basin, but at this stage of our knowledge the existing term "basin" is more appropriate.

1. Structure in pre-Mesozoic rocks

The eastern margin of the Basin is established at the Selwyn Fault to the east of Port Phillip Bay and has been extended partly by following a line of steep magnetic gradient with a south-south-west trend across part of Bass Strait. This steep gradient has been interpreted as faulting and extends from about 20 miles off-shore from the Selwyn Fault, to the eastern side of King Island. (It will be noted, however, that the assumed Basin margin follows only part of this fault, and that it is shown with an arbitrary curve to the west around a prominent submarine magnetic high and a southerly extension to the west of King Island). Faulting along the line of steep magnetic gradients is also suggested by seismic surveys, although it may not be as continuous (see Plate 11). A number of shorter faults with some off-setting could be interpreted, and their age appears to be late Lower Cretaceous or extending into the Upper Cretaceous. Evidence to the north along the Selwyn Fault indicates that movement here was late Tertiary or Quarternary, and displacement of more than 1400 feet is suggested by the Wannaeue Bore No. 13.

The Selwyn Fault and other parellel structures in the Palaeozoic rocks along Mornington Peninsula continue the trend to the north-north-east to north-east of Melbourne where a meridional trend is assumed (Plate 2). Structure further north maintains the meridional trend although some bending or off-setting to the north-west is noted. This apparent curving in the regional lineaments is also common to some of the major structural features of the Palaeozoic rocks north of the Otway Basin in western Victoria. Both the Mount Stavely and Heathcote 'thrust Belts' of Thomas (1959), which show a north-westerly trend in their northernmost exposure, also extend southwards, and appear to continue below the Basin with south-south-westerly trends. They both show evidence of overthrusting from the east. Williams (1964) concluded that folding along the Heathcote axis took place in the Middle Devonian and that sinistral movement in basement blocks subsequently caused the arcuate deflection and re-faulting, along the axis.

Elsewhere regional structural lineaments are meridional (see Plate 2), e.g. east of Ballarat, and along the western side of the Grampians (Spencer-Jones, 1965), or north-westerly as in the Black Ranges and Dundas Range. Further west towards the Victoria-South Australia border, the regional structures have a north-westerly orientation which is perhaps most evident in the Kanawinka lineament, a feature thought to be basically a fault in the basement, but reflected by scarps formed in the Tertiary limestone cover. Although the only direct evidence of movement along this lineament is from the Tertiary (downthrow to the south-west), it is probable that the South Australian portion of the lineament was a major tectonic feature - though not necessarily a fault - during the Lower Cretaceous, and marked the northern limit of Otway Basin sedimentation at that time.

Boutakoff and Sprigg (1953) indicated that the Kanawinka Fault was one of the controlling factors in the development of the "Gambier sunklands" and had a throw (to the south-west) of 2000-3000 feet. This view was compatible with those contained in the earlier paper of Sprigg (1952), in which he postulated the existence of a 'buried escarpment of the Padthaway - Dundas Horst ....(which) probably came into existence in pre-Mesozoic times......'. This 'horst' was regarded by Sprigg (op.cit.) as the major north-west to south-west high separating the Otway and Murray Basin sedimentation. In a more recent publication Boutakoff (1963) re-affirms his own earlier (1949) contention and Sprigg's view that the Kanawinka Fault is a major feature, and has a total throw of 3000 feet. He also states that it is a high-angle overthrust (based on information from the Bureau of Mineral Resources - see Wiebenga, 1957*, 1960*).

Brown (1965) thought that the length of the Kanawinka Fault, as such, was limited, that the escarpment to the south-east was erosional (as shown in our Plate 2), and that the main line of basement faulting is offset to the east. This suggestion conforms with the gravity results which show a parallel NW - SE trend of steep gradient through Casterton (Plate 11); seismic surveys, however, do show that some early Tertiary faulting occurred to the south-east along the Kanawinka lineament. As noted under the discussion of gravity results, the Casterton line of steep gravity gradient turns abruptly to the north-east through Merino, and thence south-east again through Hamilton.

Although the margin of the Otway Basin in South Australia more or less follows the limits of Tertiary deposition, the main boundary of sedimentation appears to be the fault suggested by steep gravity gradient extending north-east from Guichen Bay to north of Lucindale. This fault is parellel to the Cape Jaffa Fault of Grant (1954), and marks the northern edge of the "Cape Dombey Gravity Trough".

The preceding discussion shows that a set of parallel but offset basement lineaments extends to the south-east from the north-eastern end of the Guichen Bay - Lucindale fault trend. This set includes the Kanawinka Fault and the NW-SE gravity trend through Casterton and Hamilton, and appears to terminate at or near the prominent basement feature which we have called the Warrnambool Ridge (see Chapter IV, under 3 - Gravity Surveys, and later under V, 2 - Cretaceous Structure).

The regional trend shown by the Padthaway Ridge at the north-western on-shore end of the Otway Basin (and to the north of the Guichen Bay-Lucindale fault) is NW-SE, similar to the Kanawinka lineament. The Ridge has commonly been referred to as a "Horst". However, no evidence has been found for faulting with a similar north-westerly trend along the western side of the feature, and the name "Padthaway Ridge" suggested by O'Driscoll (1960) is preferred. The main structural trends of the older Palaeozoic rocks within the feature vary from sub-meridional in the south, to north-westerly, and resume a sub-meridional trend in the north. These trends are shown by aeromagnetic surveys, (C.G.G., 1965*, and the Murray Basin Oil Syndicate Survey included in O'Driscoll, 1960).

Faulting and other structures immediately off-shore to the west from the Padthaway Ridge also have sub-meridional trends (H.E.P.L., 1965) and a graben-like feature extends from the off-shore extension of the Otway Basin margin towards The Coorong. Further west, the total magnetic intensity contours suggest a change in the regional structure trends, towards east-west.

This change in trend of the magnetic basement from meridional to east-west in the off-shore area is similar to the swing shown in Precambrian to Cambrian rocks from meridional in the Mount Lofty Ranges to east-west on Kangaroo Island. The westernmost beds of the Kanmantoo Group occur in this curved belt, but to the east the Group continues to the south and apparently extends at shallow depth within the Padthaway Ridge towards the northern edge of the Otway Basin.

The southern limit to the Otway Basin is located off-shore. In the absence of drilling, the interpretaton is based entirely on geophysical data. Weeks and Hopkins (1966 b) claim that at the margin of the continental shelf there is a basement ridge whose outer edge forms a 'structural discordance, downthrown seaward'. However, the re-interpretation and integration of the various seismic records covering the off-shore area has not indicated any such feature. Instead it was found that due to the absence of reliable reflectors within or at the base of the Lower Cretaceous units, it was impossible to plot the basement off-shore - or the natural limits of Lower Cretaceous deposition - with any degree of certainty.

Metamorphic basement has been encountered at 11513 feet in the east (Fergusons Hill No. 1), and at 8022 and 6755 feet in the north and north-west (Casterton No. 1 and Kalangadoo No. 1 respectively). In the central area, basic volcanic basement occurred at 7874 feet (Pretty Hill No. 1). The latter is probably part of the Warrnambool Ridge, a basement high which existed in the Pretty-Hill-Warrnambool area throughout most of the Cretaceous and lower Tertiary.

Weegar (1960 b*) suspected the presence of 'a meridional Palaeozoic high or highs ...... between the Grampians-Mt. Stavely area and the Warrnambool district'. He felt that this feature could form 'the basis of inherited topography in younger rocks or provide a locus for rejuvenation of strudtural movements in a later time'. The present study has certainly shown a marked thinning of both Cretaceous and Tertiary sediments in the Warrnambool area. This area does not appear to have undergone any greater period of erosion than the remainder of the basin; this, together with the fact that most of the sedimentary units can be traced across the high, are strong evidence to support the single (Otway) basin concept rather than the sub-basin concept.

2. Cretaceous structure

Cretaceous outcrops are recorded from the Otway Ranges and Geelong area (Barrabool Hills and Bellarine Peninsula), a small inlier on the eastern side of Port Phillip Bay, and in the Merino-Casterton area. These sediments are now thought to be mainly Lower Cretaceous - though they have previously been reported as Jurassic - and they can be equated with our Unit M. Other Lower Cretaceous units, R-P and J-H, and the Upper Cretaceous succession in the Otway Basin have only been reported from the subsurface.

Some reference to conglomerates in outcrop have been made (Edwards and Baker, 1943; Benedek, 1960*; Weegar, 1960 a*; Leslie, Some references to conglomerates in outcrop have been made (Edwards and Baker, 1943; Benedek, 1960*; Weegar, 1960 a*; Leslie, 1966; etc.). Basal conglomerates occur in the Barrabool Hills and Casterton areas near the margins of Lower Cretaceous sedimentation. These are due to onlap and are possibly of no tectonic significance. The extent and significance of intraformational conglomerates is difficult to gauge due to the lack of marker horizons within the Lower Cretaceous. Weegar suggests that they are probably caused by local or even regional shoreline oscillations, and do not signify diastrophism. However, some diastrophic movement may have been associated with the recurrent vulcanism thought to have occurred during the Lower Cretaceous.

The incoming of sands such as the "Heathfield sand" at various levels in Unit M and at various places, and dipmeter changes such as those in Fergusons Hill No. 1, are evidence of tectonic events during the Lower Cretaceous. Structure confined to pre-Unit G beds (mainly pre-Upper Cretaceous) and indicated in seismic records is shown in Plate 11 by those features designated with short dashed lines. These are probably mostly in the Lower Cretaceous sediments. The fold-like features generally plunge towards the central axis of the Basin, particularly in the off-shore areas, and give the impression of a series of structural noses.

The north-westerly plunges of fold-like structures at the eastern end of the Basin clearly indicate the presence of a high feature along the eastern margin, and Line OS16 in Plate 12A shows apparent thinning of section towards King Island.

The folding and faulting shown in the pre-Unit G beds can be attributed mainly to regional adjustments at or near the end of the Lower Cretaceous. Many of the trends of subsequent activity are parallel to or coincident with the pre-Unit G trends (see Plate 11).

Some of the pre-Unit G trends probably reflect the influence of downwarping and faulting associated with the initiation of the Otway Basin (which in turn are partly controlled by old basement trends). These are WNW-ESE to NW-SE and are shown mainly by parallel sets of normal faults along the margins of horsts and grabens. They are most prominent in the western half of the basin.

The predominant trends developed in Palaeozoic structures along the northern margin of the Basin are north-north-west to north-north-easterly (the Grampians and the Heathcote Belt). The structurally controlled eastern margin also has a north-north-easterly trend. To the south within the Otway Basin, these trends appear as extensive fold-like features and swing more to the south-west, particularly in the eastern half of the Otway Basin, and as the fault-controlled Otway Range Structure.

Although the WNW-ESE lineation extends into the eastern half, and vestiges of submeridional to north-easterly aligned structures are seen in the western half, the Basin appears to be clearly divided into two tectonic provinces along a line extending south-west from the Warrnambool Ridge. The nature of the Warrnambool Ridge is difficult to define; drilling and seismic results suggest that it is a basement feature, which in Upper Cretaceous and early Tertiary time developed into a buried peninsula with a hinge-line along its south-eastern side. The disposition of Lower Cretaceous structure along the off-shore prolongation of the Ridge is quite irregular and suggests some form of rotation.

The influence of the Warrnambool Ridge is well-marked also by the history of sedimentation in the Basin. Although not many wells have been drilled to basement, results to date have shown that the oldest Lower Cretaceous sediments - the Geltwood Formation and its sandy equivalent (the "Pretty Hill sandstone") - have not been met east of the Ridge. The occurrence of the sandy lithofacies adjacent to the Ridge is probably also significant.

Towards the close of the Lower Cretaceous this feature became stabilized, and as a result the eastern and western portions of the basin tended to respond independently to tectonic activity. One of the earliest indications of this was the development of Unit J sands (Waarre Formation) in the east while Unit M (Eumeralla Formation) was still being deposited in the west. At the end of the Lower Cretaceous, a major change occurred in the west leading to the rapid accumulation of a thick sequence of "greywacke type" sediments - Unit Gg - derived from a quite different source to the underlying Unit M. This change was not nearly as sudden or as pronounced in the eastern part of the basin but a local uplift along the northern margin has been recorded by Weegar (1961b*).

According to Leslie (1966) 'Throughout the history .... (of the basin) faulting has been the dominant expression of tectonics ...... an important period of faulting commenced at the close of Lower Cretaceous time, and continued throughout Uper Cretaceous deposition ....'. Two dominant structural trends, NW-SE and NE-SW, were recognised by Leslie (op.cit.), and also by McQueen (1961), Benedek (1960*), Weegar 1960a*), and others; most faulting has paralleled one or other of these trends. Leslie also noted that the NE-SW trend is dominant in the east, and the NW-SE trend is dominant in the west; however the regional stress system at the close of the Lower Cretaceous was certainly more complex than that envisaged either by Leslie or by Weegar (op.cit.).

Both the mechanism and the timing of the Otway Range uplift have been widely discussed. Weegar postulated a series of epeirogenic movements at the close of the Lower Cretaceous, resulting in the non-deposition of Upper Cretaceous or Tertiary in the Otway Ranges and Casterton areas. Coulson (1939) regarded the Otway Ranges as an island in Tertiary times - at least above the present day 900 feet level. On the other hand the Australian Tectonic Map Commitee (G.S.A., 1962) reported that 'the Otway Ranges exhibit pre-Pliocene faulting and post-Pliocene updoming'. This is essentially the same view as expressed by Hills (1946). Edwards (1962) attributes the uplift of the Otway Ranges to Cainozoic faulting and folding, and suggests that early Tertiary deposits in the area were almost wholly stripped off by erosion. He based this belief principally on the occurrence of a relatively high range coal at Benwerrin (in the Otway Ranges), that had been determined by Cookson (1954) as Palaeocene to early Eocene. In the absence of any signs of metamorphism, Edwards concluded that a depth of burial of 'not less than 2500 feet of Tertiary sediments, and possibly as much as 3500 feet' would have been required to produce this rank of coal. The submerging of the Benwerrin area below the sea subsequent to deposition of the coal is indicated by the presence of fossils in overlying sediments.

The Lower Cretaceous hills of the Casterton area were possibly produced as a result of faulting at the close of the Lower Cretaceous, along the general alignment of the Kanawinka Escarpment (see Plate 2).

All structural interpretations of the Upper Cretaceous must be based on sub-surface data, as no surface occurrences have been recognized to date. During the Upper Cretaceous the areal extent of the basin was initially more restricted tha in the Lower Cretaceous (see Plates 13 to 15) but at the same time the marine influence was very strong. The Warrnambool Ridge remained a positive feature throughout; the western downwarp initiated towards the close of the Lower Cretaceous continued to be the major locus of deposition throughout the Upper Cretaceous and early Tertiary. A less pronounced downwarp also developed east of the Ridge - probably as a result of the intense faulting that caused such marked variations in the thickness of the Upper Cretaceous sequence in the Port Campbell area. These features are shown in Plate 5 which has been drawn on the results of drilling and with reference to the seismic contour maps. Plate 5 and other maps (Plates 13 to 17) also emphasise the degree to which the main axes of troughs of sedimentation varied during the Upper Cretaceous and Tertiary.

No major tectonic disturbance occurred at the close of the Mesozoic; the seas had gradually retreated in the Upper Cretaceous and no water-lain deposits are recorded from the Otway Basin until the next major transgression in the Middle Palaeocene.

3. Tertiary Structure

The Tertiary deposits were very widespread and in the main, marine; they were noteworthy as marking the first development of thick limestone and marl sequences in the Otway Basin. Three separate transgressions have been recognized, separated by unconformities; the unconformities mark intervals of only limited erosion, and structural changes to the basin at this time were confined to possible epeirogenic adjustments.

The first transgression - in the Middle-Upper Palaeocene - produced a very thick sequence (Unit D) in the west of the basin, and a less impressive pile in the east; clearly the Warrnambool Ridge was still a major influence, and the pattern of sedimentation was similar to that existing during the Upper Cretaceous. However, during the second (Upper Eocene) and third (Oligocene-Miocene) transgressions the Ridge was much less of an influence of sedimentation, and the distribution of the sediments was related to an enlarged continental shelf that included most of western Victoria and south-eastern South Australia. This situation appears to have continued until the close of the Miocene when differential uplift brought about the emergence of much of the shelf (G.S.A., 1962).

McQueen (1961) has stated that a regional dip of 10^{o} commonly occurs at the margins of Tertiary outcrops, and he regards this attitude as 'an initial dip imposed by the original sloping surface of the eroded Mesozoic rocks ....'. Woolley and Laws (1964) wrote that 'the regional structure consists of a gentle basinwards dip ....'. Leslie (1966) noted that 'relatively little faulting took place during the period of Tertiary deposition.......'.

Sprigg (1952), Boutakoff (1963) and the Australian Tectonic Map Committee (G.S.A., 1962) all suggest that intermittent movement took place throughout the Tertiary. The Committee stated that 'in the south-east of the state (South Australia) movements took place along the north-west fault-lines which had been active intermittently since the Mesozoic. Localized folding of the Tertiary strata along the north-west axes occurred to the south and south-west of Mount Gambier and was accompanied by volcanic activity........'. Coulson (1939) postulated a pattern of north-south and east-west normal faults in the Tertiary of the Geelong area; Thomas (1959) also noted an east-west trend in the Tertiary deposits. However, the displacements involved were of a low order.

On the other hand Reeves (1951) envisaged the possibility of earth movements in addition to the obvious epeirogenic adjustments affecting the Tertiary. Reeves wrote that 'contrary to general opinion Tertiary formations show pronounced folding in coastal areas of south-western Victoria'. Much of this folding was probably monoclinal drag associated with faulting (Boutakoff, 1963). Thus, the consensus of opinion is that although some movement occurred, very little deformation of regional significance affected the Tertiary of the Otway Basin.

Epeirogenic movements in the Tertiary culminated towards the close of the Miocene in the uplift and emergence of the onshore portion of the Otway Basin more or less as we know it today. Boutakoff (op.cit.) wrote that in the Portland area 'structure is expressed in vertical displacement leading to the development of pronounced high escarpments and consists essentially of monoclinal drag occasionally passing into true faulting'. It seems quite likely that this 'relay system of scarps' was produced as a result of renewed movement along Mesozoic lines of weakness. The same argument can be applied to the Kanawinka lineament, where the present day surface expression of the movement may be only 5-30 feet; however in this case caution must be exercised, as there is evidence to suggest that much of the actual scarp is an erosion feature.

The close of the Miocene was marked by a general regression of the sea and was followed in the Pliocene by very extensive basaltic vulcanicity. The basalt outpourings persisted into the Quaternary and the lavas now cover a great deal of the Tertiary Otway Basin deposits of western Victoria.

4. Quaternary Structure

The Otway Basin area has been stable since the major uplift at the close of the Miocene, most of the subsequent movements being related to the widespread vulcanism. Sprigg (1952) wrote that the Mount Gambier area during the Quaternary was a 'crestal locus of upwarping'. The Australian Tectonic Map Commiteee (G.S.A., 1962) also referred to a broad north-east trending regional upwarp north-west of Mount Gambier during the Quaternary. The seismic contours on the base of Unit B (Plate 17) show the same type of feature. This unusual trend could reflect an old basement trend reactivated by the regional stresses associated with the Kosciuskan Orogeny, and uplift in the northern marginal areas of the Otway Basin.

These same stresses could also be responsible for the small displacements and minor folds seen in outcrop, mainly in coastal scarps, but also in some of those areas not masked by volcanic deposits and unconsolidated sediments. Their development, and the formation of other subsurface structures known from geophysical surveys, are discussed under GEOLOGICAL HISTORY. Their development, and the formation of other subsurface targets for hydrocarbons is mentioned under the Section on ECONOMIC GEOLOGY; Otway Basin structures which could be considered important include closed anticlines and some fold-like structures in the subsurface, anticlines associated with faulting, doming and upwarp features, and stratigraphic and sedimentary traps associated with terraces and grabens.

VI. THE GEOLOGICAL HISTORY, AND PROVENANCE OF SEDIMENTATION (By M.A.R. & R.B.)

Because of the influence of basement trends on subsequent events in the Basin, a review of the general tectonic development of the region is essential to an understanding of the geological history of the Otway Basin.

1. Precambrian - Palaeozoic

A lower Palaeozoic sequence is thought to extend under the western part of the Otway Basin from the Padthaway Ridge. It may contain some equivalents of the Kanmantoo Group and older rocks which trend towards the Ridge to the north. Alternatively, or in addition, rocks of lower Palaeozoic age from western Victoria may continue at depth below the north-western part of the Basin. Bell (in A.O.D.A., 1966*) implies that basement rock in Kalangadoo No. 1 (Unit V) might be similar to the lower Palaeozoic argillaceous dolomites described by Wells (1956) from the Casterton area.

To the south-east of the Otway Basin is the Precambrian belt of western Tasmania with a north-north-west trend to King Island, bordered on the east by Cambrian-Ordovician rocks (and on aeromagnetic evidence, possibly off-shore to the west). The Precambrian rocks occur in two main groups: metamorphics- schists, quartzites, phyllites and slates with amphibolites, and sedimentary rocks - sandstones, lutites, dolomites and minor rudites (mainly unaltered). Siltstone and greywacke with some conglomerate are the main rock types of the Cambrian succession, and the Ordovician is composed mainly of conglomerate, sandstone, mudstone and limestone.

These Precambrian to early Palaeozoic provinces may have been originally linked, and an archipelago may have extended from southern South Australia to western Tasmania. Such a belt seems to be required as a margin to the shallow sea and slowly subsiding Middle Cambrian - Ordovician basin which represented the first phase in the development of the Tasman Geosyncline (Öpik, 1957). Basic volcanics are prominent across the part of this basin in western Victoria, and the sediments are predominantly lutites, up to 11,500 feet thick. These rocks were subsequently intruded by granite and partly metamorphosed.

In central to eastern Victoria, sedimentation continued in the Tasman Geosyncline from the Silurian to Lower Devonian. The final phase of deposition occurred during the Upper Devonian to Lower Carboniferous (in the Grampians region, and in eastern Victoria). A number of important orogenies had occurred during the history of the Tasman Geosyncline, mainly with NW-SE to submeridional trends. Granitic emplacement, and periods of acid vulcanism took place at various intervals.

However, at the end of the Lower Carboniferous, presumably associated with the Kanimblan Orogeny, the development of a strong north-easterly lineament occurred throughout eastern Australia. This prominent trend has been noted by Hills (1956), and Spence (1958*), and others, and subsequent exploration in eastern Australia continues to produce surface and subsurface evidence of extensively north-easterly lineations:

(a) the Broken River area in northern Queensland;

(b) across the northern end of the Drummond Basin;

(c) the south-eastern end of the Boulia Shelf (southern end of Georgina Basin) could be linked with either (a) or (b);

(d) across the Springsure Shelf and possibly influencing the Adavale Basin;

(e) the north-eastern end of the Flinders Ranges in South Australia and trends in the Cooper Basin;

(f) the Redan Fault along the north-western side of the Murray Basin and the Darling Lineament;

(g) the Lachlan Lineament and parallel lines near Cobar, etc.

The full import and nature of the stresses involved in the Kanimblan Orogeny are not fully understood, but pre-Lower Carboniferous rocks in many parts of Australia were affected. Transverse movements have been common along faults with this orientation.

The importance of the trend to the framework of the Otway Basin lies in the fact that it probably controlled the formation of the dividing ridge of Palaeozoic rocks between the Murray and Otway Basins in western Victoria, and some other major tectonic features which developed within the Otway Basin.

Sedimentation in the Permian in the Otway Basin region was fluvioglacial and partly marine. Here, as elsewhere in Australia, the sediments are preserved in old topographic hollows (glacial troughs) or, more commonly, in down-faulted graben and half-graben areas. The orogeny, or orogenies that deformed and down-faulted the Permian sediments occurred in the late Permian or during the Triassic (for in some areas Lower Triassic sediments are also preserved in the structures - Bowen and Sydney Basins, at Bacchus Marsh north-west of Melbourne, Tasmania Basin, etc.). The movements were due to strong thrust forces from the east to north-east. Whether these forces deformed, or partly deformed Palaeozoic rocks, and caused overthrusting across the Heathcote, Mount Stavely, and possibly the Kanawinka belts, or not, is unknown, but such an explanation seems possible.

To summarise, by Triassic or early Jurassic time, the Otway Basin region was a land mass bounded on the southern side probably by Precambrian and lower Palaeozoic rocks incorporating King Island and Tasmania. Regional structural trends were south-easterly to meridional, following those of the Tasman Geosyncline. Diagonal NE - SW trends resulting from the Kanimblan Orogeny were superimposed on the region. Some effects may have resulted from thrust movements from the east to north-east at the end of the Palaeozoic or early Triassic.

2. Mesozoic

A number of significant events in the tectonic evolution of the earth's crust are assigned to the Jurassic and Cretaceous:

(1) Creer (1964), writing on du Toit's reconstruction of Gondwanaland, suggests that continental drift began in the Triassic and continued into the Jurassic.

(2) Menard (1964) dates a paroxysm of vulcanism along the Darwin Rise in the western central Pacific from 100 to 60 million years ago, and this was preceded by the development of the rise earlier in the Mesozoic.

(3) van Bemmelen (1965) describes a north-eastward movement of Australia in mid- and upper Mesozoic time accompanied by dextral transcurrent movement along its 'starboard' (south-eastern) side (and refers also to the Alpine Fault of New Zealand which has been active since the Jurassic).

(4) Tuzo Wilson (1965) suggests that the latest period of drift due to convection currents in the earth began in the Upper Jurassic.

The age of vulcanism in the Otway Basin as determined from flows in the section of Casterton No. 1 Well was Upper Jurassic or Lower Cretaceous (Harding, 1966*) and an age determination for Tasmanian dolerite gave an Upper Jurassic age (Spry and Banks, 1962). The stratigraphic relationships of basalt outcrop at Kawarren north of the Otway Ranges is uncertain, but it is thought to be the same as the basalt between Lower Cretaceous and Palaeocene sediments in the Birregurra Bore, some 15 miles to the north-east (Benedek, 1960*; Weegar, 1961b*); this basalt could well be Lower Cretaceous in age and equivalent to other older basalts along the north-western flanks of the Otway Ranges, and to the dolerite intrusions referred to by Weegar.

On available evidence, the subsidence which led to the formation of the Otway Basin can be dated to the Upper Jurassic or earlier Jurassic, probably at a time of great crustal movements. The downwarps which originated sedimentation in the Great Artesian Basin had already begun, and early movements in the development of the Murray Basin had probably commenced. These downwarps show evident control by the Tasman Geosyncline lineaments, and also by the NE - SW system of trends, (in particular, see Hills, 1956, Fig. 1 for the Murray Basin). The nature of the movements, essentially controlled by older lineaments more or less at right angles to each other, suggests that they may have developed as a result of some form of crustal expansion.

Structural considerations have already shown how the old basement lineaments have influenced the Otway Basin, particularly in the western part. Parallel NW - SE trends occur along the Padthaway Ridge, the Kanawinka Fault, and as linear and close parrallel gravity contours through Casterton and Hamilton. They appear to be offset along NE - SW features such as the Guichen Bay - Lucindale fault and the short line of steep gravity gradient through Merino. The western part ends against the NE - SW Warrnambool Ridge; the off-shore bow to the WSW in this lineament may be due to subsequent rotation.

In the eastern part, a subordinate NW - SE trend appears along the coastal stretch from Warrnambool to Cape Otway, but regional trends in this region, particularly off-shore and in the Otway Range structure, are NE - SW. The eastern margin of the Otway Basin is along a strong NNE trend - the Selwyn Fault lineament.

The influence of NE - SW and NW - SE trends in the eastern part of the Otway Basin was recognized by Jennings (1959). He shows (in his Fig. 4) a north-east trending "Otway Depression" between the Otway Ranges and the "Tail Bank", a bathymetric feature trending north-easterly from King Island (but in no way connected with the Basin margin). The "King Island Rise" adjoins the south-western end of the "Tail Bank" but extends SSE from it, as does the "Bassian Depression". The "Bassian Rise" along the eastern side of the "Depression" also bears south-south-east. Although the bathymetric features described by Jennings are recent, they could reflect the situation during the Jurassic and early Cretaceous. If his "Otway Depression" is extended into the western part of the Gippsland Basin, the avenue for continuous sedimentation between the Otway and Gippsland Basins becomes apparent. It was not a simple connection, however, and an off-shore ridge did exist (or formed) along the Selwyn Fault lineament during the Lower Cretaceous. The trough of Upper Jurassic - Lower Cretaceous sedimentation was not a simple east-west graben, but a set of connected depressions oriented NW - SE and NE - SW. Crustal expansion to the south-west across the Murray Basin and associated with the formation of the Otway Basin would have caused differential movement of blocks on either side of the Kanawinka lineament and parallel trends to the south-east. Subsidence resulted along the lineament and a system of grabens and a central horst gradually developed within the old land mass to the south. At the same time stresses due to expansion from the Murray Basin region to the south-east possibly uplifted a central Victorian plateau, and the King Island - Tasmania area (as part of the old southern land mass) drifted to the south-east. The region between the plateau and the southern land mass became a half-graben with deepest side to the north. Hence two sets of tensional stresses must have acted across the breadth of the old southern land mass: one to the south-west (in the west), and the other to the south-east (in the east).

With these two stresses acting at right angles to each other on a presumably continuous mass, some other stresses must have developed to relieve tension along the mass itself. There is little evidence of the results of such stresses in the western part, but at the eastern end rifts developed along NW - SE axes through the Tasmania Basin and into the Bass Strait area, and basic rocks were extruded in large volumes. Some flows of lava occurred elsewhere at about this time, but the major activity was at the eastern end.

The above hypothetical explanation of the development of the Otway Basin is based mainly on the nature and trends of structures observed within and around the Basin. The predominantly lutitic nature and homogeneity of the Upper Jurassic - Lower Cretaceous sedimentation, and widespread intermixing of the volcanic detritus which followed, suggest that the process was gradual. Only minor orogenic phases disturbed the early history of the Otway Basin. The provenance of sedimentation and geological history are now studied in more detail.

Upper Jurassic - Lower Cretaceous

The oldest known sediments of the Otway Basin sequence are the Upper Jurassic(?) sideritic mudstone with interbedded basin volcanics, and overlying sandstone and conglomerate beds of Unit T. They occur in the north-west of the Basin in Casterton No. 1 where they overlie metamorphic basement, but a possible equivalent occurs in Fergusons Hill No. 1 in a very thin sandy horizon, also above metamorphic basement. The environment in the north-western part is thought to have been paralic with low energy conditions initially, becoming high energy later due to some uplift of adjacent metamorphic and granitic terrain. The presence of potash feldspar and unstable rock fragments in the sandstone indicates that mechanical weathering was predominant and transportation rapid. As the rock fragments contain phyllite as well as granitic material, a low grade metamorphic rock and granite source (similar to the Padthaway Ridge where granite intrudes the Kanmantoo Group) could be suggested. The presence of basaltic flows and similar volcanic detritus in the sediment suggests contemporaneous vulcanism and possibly some form of associated diastrophism.

On the limited evidence of the absence of Unit T above Unit V (low grade metamorphics) in Kalangadoo No. 1, and on the basis of refraction seismic results and the pattern of the residual Bouguer anomaly profile (see Plate 12c), a narrow graben is predicted at that time; it was parallel to and near the north-eastern margin of the western part of the Basin. The structure is attributed to tensional drift. In this case, the thin sand in Fergusons Hill No. 1 in the eastern part of the Basin could be at the outer limit of a wedge of Jurassic sediments thickening to the north below the Port Campbell - Colac area. There is no Unit T equivalent between basement and Unit R in Pretty Hill No. 1 so that the Warrnambool Ridge was apparently an influence on sedimentation from the beginning of the Basin.

Units P and R (Geltwood Formation and "Pretty Hill sandstone") have only been recognized so far in wells west of the Warrnambool Ridge. Unit R is a garnet-bearing lithic sandstone in Pretty Hill No. 1 and is thought to be a sandy facies of Unit P, developed along the flank of the Ridge. Unit P is composed of the garnet-bearing lithic sands interbedded with mudstone, greywacke and sub-greywacke sediments, similar to those in the overlying Unit M (Eumeralla Formation).

Unit R and similar sandstone in Unit P contains quartz (10–45%), potash feldspar and some plagioclase (10–20%), metamorphic rock fragments, and heavy minerals with garnet notably abundant. Unit R differs from the sands of Unit P in that garnet appears to be the only heavy mineral, whereas P also contains apatite, chloritoid, epidote, leucoxene, monazite, tourmaline, sphene, zircon, and some opaques, and Unit R contains no volcanic detritus as in P. The provenance of the Unit R type of sand is obviously unrelated to that of the Unit M – type of sediment occuring in Unit P. Basement granitic and high grade metamorphic sources are suggested for R.

The thickest sequence of Unit P (in Geltwood Beach No. 1) contains about the same thickness of R-type sandstone as Unit R in Pretty Hill No.1. However the thickness elsewhere is not constant, and R-type sandstone is not so marked in Unit P in wells to the north. The overall thickness of Unit P varies across the Basin, and thinning occurs below Kalangadoo No. 1, and probably below Mount Salt No. 1 (on geophysical evidence, see Plate 12c). The thickness variations suggest that south-westerly expansion continued in the western part of the Basin in Unit P-R time and that another NW – SE graben developed, with adjoining horsts on the north-eastern side through Kalangadoo, and on the southern side below or just south of Mount Salt. The maximum known thicknesses of Unit P and Unit R occur in the Geltwood Beach and Pretty Hill areas respectively and the following relationships are suggested:-

(a) Precambrian rocks occur in the off-shore shelf at the north-western end of the Basin – possibly a continuation of Archaean rocks from the Mount Lofty Ranges to the south of Kangaroo Island along the bowed trends described under Structure;

(b) Granite and high-grade metamorphics occur in the Warrnambool Ridge – possibly a buried inlier of Precambrian rocks which once formed a link with the Precambrian of South Australia or north-western Tasmania. Garnets are known to occur in both the Archaean rocks of South Australia and the Precambrian of Tasmania, and both of the suggested source areas of R-type sediments could be similarly composed.

Unit M is the thickest, most homogeneous and laterally continuous stratigraphic unit in the Otway Basin. Apart from some lenticular sands in the western part, the bulk of Unit M is chloritic mudstone with subordinate greywacke, subgreywacke, and volcanic sandstone. Clasts are of sub-angular fine-grained volcanic, phyllite and schist fragments together with feldspar and quartz. Diagenetic alteration has led to irregular development of zeolite and carbonate cement.

Uncertainty exists about the provenance of the bulk sediment of Unit M, and several authors (Edwards and Baker, 1943; Weegar, 1960*; McQueen 1961; Sprigg, 1964; and Leslie, 1966) have expressed the idea of a land mass to the south. McQueen considered that the Palaeozoic sediments and associated metamorphic rocks, granites, acid and basic volcanics and tuffs to the north of the Basin were also a likely source. Weegar regarded a Bass Strait land mass as responsible for the Otway Range sediments (Unit M), and a northern source as more prominently represented in equivalent sediments to the west. The idea of a multiple source, however, does not appear to be compatible with the essential homogeneity of Unit M. Edwards and Baker were unable to relate the sediments with any Palaeozoic exposures to the north, except that the andesite fragments may have been derived from Upper Devonian dacites. They noted the close similarity in lithological composition with Triassic sediments of north-eastern Tasmania (a similarity subsequently extended to chemical composition; Hale, in Spry and Banks, 1962), and suggested that the Bass Strait was a common source that shed to the north and to the south in the Mesozoic.

After detailed petrological studies of Unit M, Dellenbach (1965* and see also earlier discussion under Geology) considered that the volcanics - particularly the glassy lithics - were from contemporaneous vulcanism with centres located with the Otway Basin and concentrated towards the Bass Strait end. He explained the comparative absence of flows to the rapid breakdown and removal of extruded material in this sub-aqueous environment - characteristic of present day vulcanism in this type of setting.

In view of the general dips to the north of the pre-Unit G (presumably mostly Unit M) sediments as shown in the corrected off-shore seismic records, and the nature of the sediments, an off-shore land mass which contributed the silts and low grade metamorphics, and contemporaneous vulcanism are suggested as the main source of Unit M sediments. This type of sedimentation was ubiquitous in the Otway Basin in Lower Cretaceous time, and the southern land mass could have been composed of the greywacke and low grade metamorphics of the Kanmantoo Group, and/or lower Palaeozoic sediments similar to the Cambrian-Ordovician sequence of the western Tasman Geosyncline.

Although the northern land mass between the Otway Basin and Murray Basin contains large areas of the material which could have contributed detritus to the Unit M sediments, a greater variety in facies could have been expected in the event of a consistently active northern provenance. As pointed out by Edwards and Baker (1943) marginal conglomerates are known along the northern edge, but they are locally derived and limited in extent. Little Unit M - type sediment is thought to have been derived from the north.

The thin sands which occur within Unit M (such as the "Heathfield sand") in the western part of the Basin, range in lithology from arkoses to lithic sandstone containing clasts of metaquartzite and schist. Occasional isolated lenses of grit and fine conglomerate have also been recorded from the Otway Ranges (Edwards, 1962). Local unconformities are associated with at least some of these sandy lenses. It is suggested that they were derived from different source areas to the bulk of Unit M, and because of their different individual compositions, from a provenance showing a variety of lithologies. The northern land mass appears to be a more logical suggestion for the source of these beds, particularly as they appear to thin away from the northern margin.

As well as the sources suggested for the Unit M-type sediments, a contribution from Permian and Triassic deposits also seems likely. The fine matrix of the fluvioglacials, and the marine mudstones would contribute to the mudstone facies, and Permian sediments are known to contain garnets in the Bacchus Marsh area (Edwards and Baker, op.cit.). The similar composition of Triassic rocks in the region (particularly in north-eastern Tasmania)has already been mentioned. The occurrence of both Permian and Triassic spores in Unit M sediments is evidence of some reworking of material of those ages.

Plate 4A shows that, on palynological evidence, the lower part of Unit M in the eastern part of the Basin is of the same age as Unit P-R in the west. This suggests some difference in the geological history of the Basin in Unit P-R time between the eastern and western parts. The western half, between the Warrnambool Ridge and the Guichen Bay-Lucindale fault, was probably bounded by fault-controlled margins with prominent regional NW-SE and NE-SW trends; it was initially a separate land-locked depositional basin. Although a continually rising southern land mass provided the bulk of Unit M-type sediments, the north-western and south-eastern marginal belts were also actively contributing detritus of the Unit R-type. Some faulting occurred concurrently with sedimentation and, as noted earlier, NW-SE horst-graben structures formed.

The Warrnambool Ridge and the western end of the Basin became more stabilized during the later part of the Lower Cretaceous, and sedimentation of the Unit M-type predominated throughout. Although the Ridge was covered by Unit M, and by most subsequent units, it retained its influence on sedimentation as a "synchronous high" until the early Tertiary.

During the later phase of Unit M sedimentation, minor local uplifts at various places along the northern margin have been suggested to account for the formation of sandy lenses, such as the "Heathfield sand". Faulting during Unit M time is certainly suggested by seismic evidence (Plate 12c; Sprigg 1962a, Fig. 2) but, although overthrusting could be interpreted at depth near Penola, it is not nearly as persistent across the Basin as shown by Dennison (in Sprigg, op. cit.). Palynological evidence shows that a considerable amount of Unit M section is missing below the "Heathfield sand" in areas west of Casterton No. 1, (see earlier under Unit M, Geology); erosion or non-deposition over a prominent feature is suggested. This in turn implies that some form of movement took place within the Basin also: either as uplift along a horst below or near Heathfield No. 1, or as subsidence in a Casterton graben.

Minor marine influence is noted during this period both in the west and in the Port Campbell area. Broad flood plains covered the Basin and alluvial, swampy, and deltaic conditions prevailed. Perhaps the main difference in sedimentation between the two halves of the

Basin is that, in the west there is evidence of roots in situ in muddy flats where burrowing organisms existed (but no large deposits of peat or coal were formed), whereas the eastern part was an embayment or more of a lacustrine environment into which plant matter drifted and in which coal deposits formed.

Towards the end of the Lower Cretaceous, changes occurred in the conditions and pattern of sedimentation. A thick sandstone unit, H-J (Waarre Formation), formed to the east of the Warrnambool Ridge, and while a marine littoral environment existed during early sedimentation, later sediments are coarse terrigenous sands and conglomerate and suggest a regression. The unit is composed mostly of quartz sandstone and siltstone, and is unconformable over Unit M. The unconformity is of local significance only, and in many ways this formation resembles the thin sandstone lenses in Unit M in the western part of the Basin. There is little evidence to support Weegar's (1961*) contention that Unit J is reworked "Otway Group" (Unit M) derived from an uplifted area such as the Otway Ranges. Nor could Unit J be described as a mature lithology - textures and grain sizes are variable and many samples are bimodal.

To the west of the Ridge, Unit M sedimentation continued and here, microfossil evidence indicates that the marine influence persisted; access was possibly through tidal channels. The same micropalaeontological evidence also shows that Unit M continued into the Upper Cretaceous.

At the end of the Lower Cretaceous and probably extending into the early Upper Cretaceous, a short period of marked tectonic activity occurred, but it has not been possible to closely date the events. The following features are noted:

(1) the ridge along the Selwyn Fault lineament (between King Island and Mornington Peninsula) has become established;

(2) the Otway Range structure formed as a horst plunging to the north, and faulting uplifted the Casterton area of Unit M sediments - presumably along the Kanawinka lineament because the Casterton No. 1 area would appear to have been uplifted at this time.

(3) some rotation of pre-Unit G trends along or around the Warrnambool Ridge took place (see Plate 11);

(4) the influence of the southern land mass became less evident, and the Unit M sediments formed the southern margin of sedimentation in the Upper Cretaceous;

(5) vulcanism declined.

Some type of stress reversal to the north-west after the early Cretaceous expansion is suggested at this time. Regional dextral transcurrent movement is envisaged.

This would explain the apparent "squeezing up" of a wedge of Unit M sediments to form the Otway Range structure, rotation along the Warrnambool Ridge, and the foundering of the old land mass north-west of Tasmania.

Upper Cretaceous

Although part of Unit M may be Upper Cretaceous, this discussion deals with the formation of Unit G (Sherbrook Group) which is predominantly Upper Cretaceous. In part, it may be as old as uppermost Lower Cretaceous, and it may extend up into the lowermost Palaeocene.

The influence of the Warrnambool Ridge persisted, and, as suggested by the section drawn using the top of Unit G as datum in Plate 5, it had become a much broader feature (possibly as a result of the late Lower Cretaceous rotational movements?). Early sedimentation was divided by the Ridge into an eastern province in the Port Campbell area where Units Gh (Flaxmans Formation) and Gf (Belfast Mudstone) were formed, and a western province where Unit Gg (Mount Salt Formation) was deposited. None of the units has been found in outcrop.

Unit Gh is a localized sand body intersected in wells in the Port Campbell area and extending westwards as far as Pretty Hill No. 1. It unconformably overlies Unit J and Unit M and is conformably overlain by Gf. Unit Gh is generally less than 200 feet thick, and consists of sandstone and mudstone. Both volcanic and metamorphic detritus are represented in the sandstone; the mudstone contains ferruginous chlorite ooliths and pellets, siderite, and minor phosphate. Deposition of Unit Gh, together with the basal part of Gg, marked the beginning of the Upper Cretaceous marine transgression, and occurred under near-shore high energy conditions. A northern source is suggested for the metamorphic material, and high areas such as the Otway Ranges (an island or peninsula at this time) for reworked Unit M detritus including volcanic fragments.

From this time onwards, the Palaeozoic land masses to the north, and the areas of uplifted Lower Cretaceous provided the main provenance of detrital sedimentation.

Unit Gf is thicker and more widespread than Gh, extending westwards to Eumeralla No. 1 and possibly to Heywood No. 10 Bore.

In places it is conformable over Unit Gh, but elsewhere unconformably overlies Units J and M. Massive dark mudstone containing abundant glauconite, pyrite, and minor phosphatic and dolomitic lenses, makes up the bulk of Unit Gf. The dark colour is due to finely dispersed organic material, but the free carbon percentages are much lower than might be expected from an euxinic environment. Deposition took place in a restricted environment where low energy conditions prevailed.

Although we show Unit Gh laterally more restricted than Gf, Taylor (1964b) extends the "Flaxmans Beds" (Gh) to the north in the Port Campbell area beyond the limits of the Belfast Mudstone (Gf). Bock and Glenie (1965) interpose the "Nullawarre Greensand Member" between the Flaxmans Formation and Paaratte Formation (our Unit Gd) in the northern area as a landward facies of the Belfast Mudstone. Although we do not entirely accept the terminology of these authors, we agree with their ideas of cyclic sedimentation in the Port Campbell area, and admit to some diachronism in parts of the succession.

Unit Gg is formed west of the Warrnambool Ridge in a major trough (now disturbed by faulting) from south-eastern South Australia to western Victoria. This trough occupies the axial part of the Basin, approximately in the same position on the graben formed south of the Kalangadoo horst in the Lower Cretaceous. The occurrence of Unit Gg is only known from three wells and shows marked variations in thickness from 66 and 180 feet in wells at the edge of the trough to more than 3500 feet in the centre (Mount Salt No. 1). Cycles of sedimentation from sandstone to siltstone to shale occur in the lower part of the succession, but are not apparent in the upper sandier part. Unit Gg is the time equivalent of Units J, Gh and Gf, according to microfossil evidence. Lithologically Unit Gg is a mixture of Units Gh and Gf except that it contains no volcanic rock fragments.

The apparent evidence of regression in the upper part of Gg in the western half of the Otway Basin - whereas marine influences persisted in the Port Campbell area - is explained on the basis of rapid infilling of a subsiding graben with detritus from rising marginal areas, both north and south of the graben (see Geology, Unit Gg). As the graben filled, marine influence waned, alluvial sources became more important, and rivers supplied sand and subordinate silt from the land masses to the north. Sprigg (1964) suggests that the 'steep foresets, slumping, wedging, and rapid interplay of marine and non-marine depositional conditions' indicate a major delta derived from the ancestral River Murray drainage system. This is a similar explanation although the deltaic environment probably began further north-west than Sprigg's 'Nelson Embayment', and developed in a trough which was open to marine incursion at its south-eastern end near Portland.

Subsequent sedimentation in the Otway Basin in the Upper Cretaceous shows a change from transgressive facies. Unit Gd (Paaratte Formation) extends throughout the on-shore part of the Basin and probably off-shore, conformably above Gf in the east (although overlapping Gh in part), and above Gg in the west. It is conformably overlain by Unit Gb throughout. Thicknesses range from more than 2000 feet in the Mount Salt Well and Nelson Bore to less than 800 feet in most other areas. Hence greatest thickness again appears to be west of the Warrnambool Ridge (although the locus of the main axis appears to have shifted eastwards - see Plate 5). The sediments are mainly poorly sorted sub-angular sandstone, and siltstones, although the relative abundances of each differ sharply over short distances. Clasts are principally quartz grains, with some metaquartzite, chalcedony, and chloritic rock fragments; chlorite pellets and ooliths are present, and carbonate cement (mainly siderite) is common.

Except for the greater sand content of Unit Gd, its composition is similar to that of Unit Gg and both reached their maximum known development west of the Warrnambool Ridge. A similar provenance is therefore suggested, and the effects of flood-outs from the old river system became more widespread as the sea gradually regressed, and the courses of the river channels meandered more widely across the region. The deposits have been termed 'marginal marine' by Taylor (1964a). This is a better term than 'paralic' because of its inference that marine inundation is less important, and brackish water and alluvial influences predominate.

Unit Gb (Curdies Formation) is principally a sandstone sequence with subordinate mudstone and coal (which becomes more abundant towards the top). Thicknesses of the unit vary considerably, and the greatest development appears to be in the eastern part of the Basin. Unit Gb conformably overlies Unit Gd but the upper limit is a basin-wide unconformity.

The sandstone is composed mainly of quartz, with feldspar and metamorphic rock fragments; the matrix is clayey - mainly kaolinite - with mica, pyrite, and carbonaceous matter. A similar provenance to the underlying unit, Gd, is envisaged but in Gb the sand-shale ratios are higher, and reflect the more alluvial nature of the deposits. The regressive character of Unit Gb is further emphasized by the development of coal deposits in the upper beds as the environment changed from marginal marine to paludal.

Early sedimentation in the Upper Cretaceous appears, on available evidence, to be limited to the western half of the Otway Basin, and to the Port Campbell area where a restricted marine embayment has been suggested. Later sedimentation became more widespread and Unit Gb, at least, is thought to extend to the east beyond the Port Campbell area into the Bass Strait area towards Port Phillip Bay, and across the eastern Basin margin into the Gippsland and Bass Basin regions. The Port Campbell and Port Phillip Bay areas may have been linked at this time, also by a strait in which deposition occurred across the northern end of the Otway Ranges, thus isolating the Ranges as an island during the late Upper Cretaceous. It is not known to what extent sedimentation earlier than Gb occurred in the eastern off-shore parts of the Otway Basin, but there may have been some sedimentation in depressions west of King Island, and in the area to the east of the Otway Ranges (see Plate 14).

In summary, the Upper Cretaceous was initially a time of some instability, and tectonic activity (mainly faulting) exerted considerable influence over sedimentation, particularly in the western part. A post - or late Lower Cretaceous deformation appears to have exerted more influence on Upper Cretaceous sedimentation in the Port Campbell area (as shown in Plate 5) than the later activity, although some contemporaneous movements are envisaged. Deposition was mainly in the central to northern axial part of the Basin, with a northern provenance exerting most influence on the composition of the sediments. The environment changed from marine (neritic to paralic with a restricted marine embayment in the Port Campbell area) to marginal marine and non-marine, at least in the on-shore part of the Basin, thus completing a cycle of transgression and regression.

3. Cainozoic

The unconformity which divides Unit G (Sherbrook Group) and Unit D (Wangerrip Group) is older than Middle Palaeocene on micropalaeontological evidence, but its lower limit cannot be closely defined - it could be late Upper Cretaceous, or early Palaeocene. For the purposes of this review, the unconformity is thought to mark the break between the Mesozoic and the Cainozoic.

Palaeocene - Middle Eocene

After a short hiatus in the Lower Palaeocene, a marine transgression occurred which was more widespread than the early Upper Cretaceous invasion. The Warrnambool Ridge was still an important influence and in the western half a broad downwarp developed similar to that in the early Upper Cretaceous, though its central axis was shorter and further to the north. Sedimentation continued in the Port Campbell area with the thickest deposits in a restricted basin, much more limited than that in the Upper Cretaceous (see Plates 5 and 16). Seismic records suggest that thick sediments of this age formed in a number of depressions along what is now regarded as the continental slope (beyond the 100 fathom line).

The cycle of sedimentation during this time is represented in the Otway Basin by Unit D (Wangerrip Group). The initial transgression is shown by Unit Dd (Pebble Point Formation). This unit is unconformable over Unit Gb and varies in thickness from 100 feet to 300 feet. The thickness variations are apparent in Plates 5 and 6, and these suggest that in some parts the thicker section is over high features and thin parts are in depressions. This apparent anomaly could be due to -

(a) thick foresetting along shelf areas and thinning away from the source areas; or

(b) reversal in profile due to subsequent movements.

Foresetting in Unit D has been recognized in the seismic records (Plates 12 and 16), mainly in the off-shore areas beyong the continental shelf. However a prominent belt occurs from Port Fairy to south of Eumeralla No. 1 in the Tyrendarra area within the on-shore part of the Basin; seismic records show the foreset beds to be low in Unit D, possibly in Dd. On the other hand, Plate 11 shows that some of the major faults extend from pre-Unit G into Unit D time, and may have affected the ultimate disposition of Unit Dd. Both possibilities could therefore have contributed to the anomaly.

The sediments of Unit Dd are ferruginous and consist of pebbly quartz sandstone, pelletal and oolitic sandstone, oolite, siltstone and siderite rock. Pellets and ooliths are chloritic, chamosite, iron oxide and carbonate. Pebbly fractions are polymict and include blocks of Unit M near Moonlight Head (Baker, 1950). The pebbly sandstones are thought to be a near-shore facies, locally derived, and reworked in part from older sedimentary rocks in a high energy marine environment. Deeper in the neritic environment, pelletal-oolitic facies formed but still under shallow water conditions; siltstone facies are apparently confined to ?channels or depressions in the region, and formed towards the end of Unit Dd time.

There is no evidence that Unit Dd extended east beyond Cape Otway, and based on the seismic records (see Plate 16), the geological history, and the aeromagnetic results, the present off-shore area east and south-west of Cape Otway could possibly have been a low land-mass in Dd time, and a source of sediment. The origin of the iron which is common in various forms in Unit Dd may have been ground water solutions from a provenance undergoing chemical weathering. The late Cretaceous or early Tertiary was a time of deep weathering - similar to lateritization - in many parts of the Australian continent.

Unit Db (Dilwyn Formation) is more widespread than Dd and shows the change from transgressive to regressive conditions. It is composed of sandstones which range from coarse and poorly sorted to fine-grained and clean; clasts are mainly of sub-angular quartz, metaquartzite, and chloritic rock fragments. The siltstones and shales are micaceous and carbonaceous, with clay content decreasing and carbonaceous content increasing towards the top. Unit Db is conformably above Dd, but its upper limit is marked by a basin-wide unconformity.

Deposition was in a paralic environment. An interfingering of marine sediments with the more common deltaic types has been recognized in a number of wells; the various sequences show a number of brief marine incursions in a succession becoming more regressive in character. The overall environment and pattern of sedimentation was probably not unlike that existing during the deposition of the upper part of Unit Gd.

The provenance may be indicated by the presence of metamorphic lithics and granite-type heavy minerals (tourmaline and zircon are the most common) in the sandstone. The main source was probably to the north. Carbonaceous material was derived from an apparently well-drained, and well-wooded terrain (Baker, 1950).

There is some evidence from seismic surveys that the Otway Ranges were downfaulted to the east along their western side during Unit D time, and that the Ranges again formed an island in Db time.

Upper Eocene - Oligocene

Towards the end or at the end of Unit D time (early Eocene?), uplift began along the divide between the Otway and Murray Basins, and led to the deposition of the basal Tertiary sands of the Murray Basin. The earliest movements of this uplift may have been responsible for the regression at the end of Unit D. Some of the movements during or after Unit D time and extending into Unit B, as shown in Plate 11, were probably also associated with continued uplift along the divide. In the western half of the Basin, the trends of structures were still predominantly NW - SE, but a prominent NE - SW trend of faulting is noted to the east of the Nelson Bore; this is similar to the trend of the "Dartmoor Gravity Ridge" although it is offset to the west. To the west of the faulted zone, in the on-shore part of the Otway Basin in south-eastern South Australia, another prominent feature with NE - SW trend is shown by O'Driscoll (1960) in his contours on the upper surface of the Knight Group. This is the "Mount Gambier Upwarp" first referred to by Sprigg (1952, see Fig. 8) and believed by O'Driscoll to have been active from Upper Eocene to Recent.

The structural trends in the eastern half of the Basin during the early Eocene (?) uplift were also dominantly NE - SW. This indicates that the Warrnambool Ridge was still an important controlling feature. It is shown in Plate 5 as a prominent rise in Unit B time, but the main axes of the rise and of the adjoining troughs of sedimentation are different to those of preceding units. This apparent migration of the axes is thought to have occurred later, at the end of Unit Bc_2 time.

The geological history of Unit B can be considered in two main transgressive phases: the first which occurred during Upper Eocene - Oligocene time and in which sub-unit Bc_2 was formed (this is synonymous with the Nirranda Group of the Port Campbell area); and the second which began in the Oligocene and extended into the Miocene. The latter includes Bc, and Bb. (As explained earlier, our initial subdivision of Unit Bc had to be modified as the review progressed and more petrological evidence became available).

By the end of Unit D time, the Otway Basin was more like a shelf region across which sediments were transported, than a major depositional depression. Initial Bc_2 sedimentation across the shelf was sandy - limonitic pelletal sandstone, in parts calcareous and silty. The thickest known sandstone development is in the Nelson Bore area (see Plate 7) - possibly due to the NE - SW downfaulting referred to above. The influence of the Warrnambool Ridge is apparent in that these sands are generally much thinner to the east and are overlain by limonitic glauconitic marl. The sandstone in the west, and sandstone plus marl in the Port Campbell area in the east form subunit Bc_2. Unit Bc_2 is generally thin in the west: it averages 100 feet thinning to 40 feet at Portland No. 3 Bore, but it becomes thicker in the Port Campbell area - particularly the eastern side where over

400 feet occurs in Port Campbell No. 2 Well. The continuation of Unit Bc_2 to the east of the Port Campbell area is known from the limited outcrops of the equivalent sequences - Browns Creek Clays, Castle Cove Limestone, Glen Aire Clays in the Aire District, and upper part of Demon's Bluff Formation in the Torquay area.

Sub-unit Bc_2 is similar to Unit Dd in terms of lithologies and the environment of deposition. However, some variation in the distribution of facies and thicknesses is noted in Bc_2 time. The near-shore facies with high energy environment was restricted more to the west of the Warrnambool Ridge over a shelf region with some local grabens, while low energy conditions in a deeper marine environment applied in the eastern half. At least part, if not all, of the island of the Otway Ranges was submerged at this time. The evidence suggests a stable shelf in the west with a slowly subsiding area to the east.

The end of Bc_2 deposition is marked in wells by an unconformity and there is some evidence of at least a local regression in the Port Campbell area where the unfossiliferous Point Ronald Clay was deposited, and in the Torquay area where freshwater sediments and volcanics occur at the top of the Demon's Bluff Formation in the Angahook Member. (The nature of the unconformity at the base of the Point Ronald Clay and its relationship to the regional unconformity of about that time is uncertain). A period of erosion is also suggested in the western half of the Basin by the fact that the equivalent of Bc_1 apparently rests directly on sediments of Unit Dd in the Knight Quarry, near the southern edge of the Kalangadoo horst block.

The volcanics which occur at about the end of Unit Bc_2 time have been referred to as the "Older Volcanics". They are only knownfrom the areas north-east from the Port Campbell area, but geophysical evidence suggests that they may occur subsurface in the Port Campbell area, and off-shore to the south-west of Cape Otway. In the Otway Basin, the "Older Volcanics" are apparently restricted to the eastern end.

The vulcanism is thought to have been associated with a pulse of tensional stress and rifting developed by a dextral rotational movement to the north-west, similar to that at the end of Lower Cretaceous time. The bending of regional basement trends, and some faulting probably accompanied this movement; the shift of the axes of the Warrnambool Ridge and associated depressions of sedimentation may also have been involved.

Oligocene - Miocene

The transgression that followed events at the end of Bc_2 was initially more localized than earlier transgressions, and thin deposits of glauconitic marly limestone and calcarenite were formed. The best known development is across the Port Campbell area and over the Warrnambool Ridge, although maximum thickness is only 100 feet. This is subunit Bc_1.

The conformable deposition of Unit Bb which followed Bc, was the most widespread marine transgression in the history of the on-shore portion of the Basin. The limestone and marl facies are variable in thickness, with greatest development in the Portland area (more than 2500 feet) and in Flaxmans No. 1 (at least 1900 feet) in depressions marginal to the modified Warrnambool Ridge. A change in facies is still shown on either side of this old feature in lower Bb time, with spicular marly limestone with chert to the west and non-cherty spicular marls to the east. However, the influence is finally lost in the upper Bb deposition of the widespread polyzoal limestone facies. This latter part of the transgression, at least, extended across the Padthaway Ridge into the Murray Basin (Hills, 1946, p.273), although the Ridge may have acted as an archipelago and partially restricted the access (Ludbrook, 1961).

The thin glauconitic beds (Bc) and limestone deposits (Bb) constitute the Glenelg and Heytesbury Groups in the western and Port Campbell areas, and other formations as shown in Chart 2 in the Aire District and Torquay area.

A sharp regression at the end of Unit Bb time probably accompanied one of the early phases of orogenic development which affected south-eastern Australia from the Miocene into the Quaternary. The exact age of this phase is difficult to define, but the intrusion of the basalt into Unit Cb of Portland No. 3 Bore in late Middle Miocene** time, and possibly a penecontemporaneous intrusion into the top of the Db succession of Heywood No. 10, may have been the fore-runners of the extrusions which accompanied the regional tensional stress system which developed later.

D. Pliocene - Recent

One more short transgression which occurred after the Miocene appears to have been restricted mainly to the western part of the Basin; this was in the Pliocene to Pleistocene. Unit Ab was deposited and has maximum known subsurface thickness of 210 feet in a structure hole drilled in the Casterton area (Brown, 1965). It consists of coarse calcareous sandstone, sandy limestone with abundant shell debris, and some clay. The unit rests unconformably on a number of older units, but mainly overlies Bb, and is in turn overlain in parts by Recent sand and clay. Aeolian dunes and other sediments deposited during eustatic changes of sea level at the times of the Pleistocene glaciation are equivalent to the sediments of Unit Ab. Possibly the brief Pliocene-Pleistocene marine transgression recorded by Bowler (1963) in the Moorabool Viaduct area northwest of Geelong could also be correlated with Ab.

** 17.1 million years, as determined by the Australian National University (Harding, 1966*).

Minor tectonic movements at the end of the Miocene and continuing into the Quarternary have been documented for the Murray Basin by Spence (1958*) and others. The movements culminated during the spread of stress throughout eastern Australia at the time of the Kosciuskan Orogeny. The Mount Lofty Ranges were uplifted, and the Padthaway Ridge tilted downwards to the north.

The effects in the Otway Basin were similar to earlier events in that dextral translation occurred, and Tasmania and King Island moved westwards with respect to the mainland. The effect is shown in Plate 11 by the en echelon faults (interpreted from aeromagnetic results) north-east of King Island. Bending to the west of the old basement lineaments which extend off-shore is also shown. Further irregular deformation of the structure in the Port Campbell area could have occurred at this time, (possibly due to some form of rotational movement produced by a buffering effect against the Warrnambool Ridge). The initial trends, however, could have been created earlier in the Tertiary and reactivated later by the Kosciuskan movements. The small thrust faults shown in outcrop near Port Campbell (Baker, 1944) could be manifestations of these movements.

Likewise, the late uplift of the Otway Ranges could have occurred at any time from the Oligocene to Recent. Whether it was produced directly by dextral transcurrent movement or indirectly by a rotational movement is hard to ascertain. The folding described by Edwards (1962) along the south-eastern side of the Ranges might suggest direct compressive movement from the east, except that the south-eastern limbs generally have the steepest dips. In either case the Otway Ranges were uplifted as a block, but at the same time tilted downwards to the north-east by the northern component of the thrust. Uplift of the Barrabool Hills accompanied by steep faulting with downthrow to the north is thought to have resulted from the Otway Ranges uplift. Coulson (1960) dates the Barrabool Hills faulting as 'post-Janjukian, pre-Balcombian' which would be equivalent to about middle or late Miocene (end of Bc_2 time), and pre-Kosciuskan. Nevertheless, some later movements are envisaged in the Otway Ranges to account for the marked effect which the structures have on the present day coastline. A similar effect to that of the Otway Ranges - Barrabool Hills structure is seen in the western side of the Gippsland Basin, with a horst-like block elongated NE - SW with steep, down-to-the north faulting at the north-eastern end.

The Pliocene to Quaternary volcanics of western Victoria and south-eastern South Australia appear to have erupted generally north and west of the "Older (Oligocene) Volcanics", probably following along a region of tensional or shearing effects associated with the Kosciuskan Orogeny, and adjacent to the uplifted central western Victoria highlands. The duration and history of phases of Tertiary vulcanism are not yet fully understood, although Gill (1964) gives a history for western Victoria from the mid-Tertiary to Pleistocene time based on the nature of the interfaces between flows and sediments. However, it does appear that some of the youngest vulcanism occurs to the west in South Australia, and it could well be that the eruptions were in response to a late pulse of Kosciuskan stress directed along the axis of the Mount Gambier upwarp. This would explain :-

(a) why the main eruptive centres appear to be along tensional fractures or faults at right angles to the axis of upwarp; and

(b) the reason for the en echelon arrangement of faults and folds as shown in outcrop to the south at Mount Gambier (see Sprigg, 1962a).

Surprisingly little surface evidence of the late Cainozoic movements is seen in outcrop; however, small displacements and minor folds have been described by Sprigg (1952, 1962) Boutakoff (1963), Coulson (1940, 1960), Baker (1943, 1944, 1950), Edwards (1962), and Raggatt and Crespin (1955). The structures occur mainly in coastal areas, and in those areas not masked by Quaternary volcanics and unconsolidated sediments. Possibly the most marked surface indications of the nature and trends of structural control in the Otway Basin are parts of the present day coastline which still apparently follow the old fault and structure lines which have persisted throughout the history of the Basin.

The important conclusions that can be derived from this study of the geological history and provenance of sedimentation, apart from ideas on the patterns of sedimentation during the various depositional cycles, are that -

(1) two main tectonic provinces existed and these were divided by the Warrnambool Ridge;

(2) structural trends in each province are different;

(3) "down-to-basin" faulting, as described by Weegar (1960a*), probably occurred throughout the Mesozoic and lower Tertiary time in various parts of the Basin, and some of the faulting, at least, was contemporaneous with sedimentation;

(4) the main axes of troughs and depressions of sedimentation have migrated at various times;

(5) several minor epeirogenic events (with transcurrent movement) have affected the Basin, and there have been at least three volcanic episodes.

VII RESERVOIR ENGINEERING (By J.D.T. Scorer)

Although several wells have had substantial shows of gas, a commercial reservoir has not yet been found in the Otway Basin. Good initial flows of gas were obtained in Flaxmans No. 1 (250 Mcf/day from Unit M), Port Campbell No. 1 (4.3 MMcf/day from Unit J) and Port Campbell No. 4 (220 Mcf/day from Unit M). None of these flows was sustained, and in each case the reservoir pressure fell rapidly, indicating that the zones tested were of very limited extent.

The summary of testing which follows gives details of significant fluid recoveries,** together with indications of reservoir conditions for each well, and details of fluid occurrences for some of the litho-stratigraphic units are shown in Table 15.

Eumeralla No. 1

Two tests in Unit M recovered small quantities of mud and salt water (average salinity 10,000 ppm chlorides). There was strong fluorescence over most of the cored section, but gas detector readings while drilling were thought to come mainly from coal. Core samples from Unit M had permeabilities ranging from 3md to nil. Eumeralla No. 1 was drilled on the downthrown side of a prominent subsurface fault.

Fergusons Hill No. 1

Unit J produced fresh water, and only gas-cut mud was recovered from Unit M; this well was drilled to test pinchout possibilities against a subsurface structure.

Flaxmans No. 1

Flaxman's No. 1 was drilled on a closed seismic structure, part of an extensive line of fold-like structures (see Plate 11). The particular area is extensively faulted.

Gas-cut water was produced from the Paaratte Formation (Unit Gd), which had some intervals of good porosity and moderate permeability. The Waarre Formation (J) was porous and permeable, although it appeared slightly dirtier than in the Port Campbell area. This formation produced salt water with small quantities of gas.

Core analyses of Unit M all showed nil permeability and the production of gas was thought to come from fractures. The initial flow-rate was 250 Mcf/day with some condensate, but in an extended flow period the rate dropped to zero.

NOTE : Flaxmans No. 1 is shown on Plate 2 as having both an oil and gas show; the only indication of oil is some staining in cuttings from 10,928 feet and in core 43 (11,225-11,235 feet).

Geltwood Beach No. 1

Signs of hydrocarbons in this well were negligible, apart from a small amount of gas in one test in Unit M. Total dissolved solids in Unit M waters ranged from 20,000 to 28,000 ppm. Core samples showed permeabilities up to 212 md above 5000 feet, but below this depth the maximum measured permeability was 8 md, and most samples showed nil permeability. This well was also incorrectly shown on Plate 2 as having both an oil and gas show; only a small gas show was obtained. The

** Gas and oil analyses are given in Appendix I.

TABLE 15. FLUID OCCURRENCES IN SOME OF THE LITHOSTRATIGRAPHIC UNITS

Well Name	Units P, R, T & V	Unit M	Unit J	Unit G	Unit D	Remarks
Anglesea No. 1		Traces of HC gas in mud				
Casterton No. 1	P and T: Salt water. DST No. 9 (T) est NaCl 35,000 ppm from logs					No water analyses supplied.
Eumeralla No. 1		DST No. 1 Salt water Cl 11,170 ppm T.D.S. 19,170 ppm				Water analyses in Scorer (1965*)
Fergusons Hill No. 1		Gas, g.c.m. & g.c.w.	DST No. 11 Fresh water Cl 240 ppm T.D.S. 1367 ppm		'Fresh water' (no analysis supplied)	Gas analysis in Appendix I. Water analysis in Scorer (1965*)
Flaxmans No. 1		Gas at initial rate 250 Mcf/day. Flow not sustained.	D.S.T. No. 16 - gas cut salt water Cl 13,240 ppm T.D.S. 22,700 ppm	DST No. 2 (Gd) G.c.w. Cl 11,610 ppm T.D.S. 21,260 ppm		Unit M - gas analysis in Table 18. Water analyses in Scorer (1965*)
Geltwood Beach No. 1		DST No. 3 Gas cut salt water Cl 15,880 ppm T.D.S. 26,060 ppm				Unit M - gas analysis in Appendix I. Water analyses in Scorer (1965*)
Heathfield No. 1		DST No. 2 Gassy salt water Cl 15,340 ppm T.D.S. 26,840 ppm				D.S.T. No. 2 CH_4 72.00% O_2 2.30 C_2H_6 0.51 CO_2 0.80 C_3 + 0.15 N_2 to 100%
Kalangadoo No. 1	DST No. 7 (V) 1.55 MMcf/day gas	DST No. 1 Muddy salt water T.D.S. 24,467 ppm				DST No. 7 (V) Gas analysis in Appendix I
Mount Salt No. 1				DST No. 1 (Gg_2) Salt water Cl 22,150 ppm T.D.S. 39,450 ppm		Water analysis in Scorer (1965*)
Penola No. 1	Gas bubbles in core at 4600'.	Gas shows in mud				
Port Campbell No. 1			Prod. Test 1a 4.2MMcf/d gas and salt water Cl 8,000 ppm T.D.S. 18,000 ppm	Gas and oil indications. DST No. 8 (Gd) Brackish water Cl 1,065 ppm T.D.S. 4,592 ppm		Gas analyses in Appendix I. Water analyses in Scorer (1965*)
Port Campbell No. 2			DST No. 12 G.c water Cl 7,500-8,000 ppm			
Port Campbell No. 3		DST No. 1 G.c. salt water Cl 17,300 ppm	DST No. 2. G.c. salt water Cl 14,600 ppm	DST No. 4 (Gd) Gas cut water Cl 4,400 ppm		Non-subsidised well. Gas and water analyses not available.
Port Campbell No. 4		DST No. 9. Crude oil emulsion, gas and salt water Cl 12,000 ppm	DST No. 23 Salt water Cl 14,300 ppm	DST No. 24 (Gd) Brackish water Cl 1,750 ppm		Gas analyses in Appendix I. Full water analyses not supplied.
Pretty Hill No. 1	DST No. 1a (R) Salt water Cl 13,500 ppm					No water analysis supplied.
Sherbrook No. 1			DST No. 6 Fresh water Cl 263 ppm T.D.S.1,733 ppm	Gd Salt water DST No. 1 No water analysis		DST No. 6 (J) Water analysis in Scorer (1965*)
Tullich No. 1	Gassy salt water (P)	Fresh to brackish water to 2000'. Gassy salt water below 3000'				Gas analyses in Appendix I. No water analyses supplied.

Geltwood Beach structure is a small fold with a limited amount of closure, and is possibly associated with transverse faulting in basement.

Heathfield No. 1

A test of Unit M interval 4078-4144 feet produced a strong flow of gassy salt water (total solids 26,840 ppm). Most core samples below 2879 feet exhibited fluorescence. This well tested a seismic structure south-west of the Kanawinka lineament; the site appears to be in an area of complex faulting.

Mount Salt No. 1

Considerable sections in this well showed very good porosity and permeability on the Microlog. A test of Unit Gg gave a strong flow of salt water. The Mount Salt structure was suggested by a photo-geological study and confirmed by structure drilling; its development may be similar to that of the Geltwood Beach structure and associated with transverse faulting in basement.

Port Campbell No. 1

The Waarre Formation was very permeable and initially produced gas at a rate of 4.3 million cu.ft/day. The well then started to produce salt water, and attempts to shut this off were unsuccessful. Formation pressure dropped rapidly indicating that production came from a lenticular sand of limited extent. The target was in a subsurface high feature delineated by seismic surveys, and is apparently adjacent to faulting.

Port Campbell No. 2

The Waarre Formation produced gas-cut mud and gas-cut salt water from a sand of only moderate porosity and permeability. Port Campbell No. 2 is in a similar structural environment, but is between two faults with downthrow to the east, and was located to drill increased section to that in No. 1.

Port Campbell No. 3

Although core porosities and permeabilities from the Waarre Formation were very good, the intervals tested gave only small flows of gas and salt water. A small gas flow was obtained from the Paaratte Formation, (Unit Gd) and Unit M produced a small flow of gas and salt water. This well appears to have been drilled on an anticline.

Port Campbell No. 4

The Waarre Formation had good porosity and permeability but produced salt water on test. An initial flow of 220 Mcf/day gas together with small quantities of oil emulsion, was obtained from Unit M. Pressure declined sharply with flow, indicating that the zone tested was of limited extent. The seismic structure drilled was a small anticline.

Pretty Hill No. 1

A well developed sandstone Unit R found at the base of Unit M produced a strong flow of salt water. No indications of hydrocarbons were obtained. Pretty Hill No. 1 was on a small seismic structure north of a prominent fault which has downthrow to the south.

Sherbrook No. 1

Permeability over the Unit J - Unit M section was only fair. Fresh water was produced from the Waarre Formation (J). This well was located to test pinchout possibilities against a subsurface structure.

Tullich No. 1

Core analysis and the Microlog indicated that porosity and permeability were rather low over most of Unit M. Fresh to brackish water was produced from the top part of the section, and gassy salt water from the bottom part. Tullich No. 1 is located in a somewhat similar structural environment to Heathfield No. 1, and is near the extension of the Kanawinka lineament.

1. Reservoir Prospects

Substantial initial flows of gas have been obtained from two tests of Unit M and one test of the Waarre Formation (Unit J). The only recovery of oil to date has been a few barrels of oil emulsion from reservoirs of very limited extent, as was shown by the rapid decline of pressure which followed a small amount of production.

Permeabilities of up to 4840 md have been measured in the Waarre Formation, which so far has been found only in the Port Campbell area. Thicknesses have ranged from 202 to 468 feet, so that this formation must be considered to have good reservoir prospects. The potential productivity is evidenced by the results of Port Campbell No. 1, in which an initial gas flow-rate of 4.3 million cu.ft/day was obtained. However, the zone under test appeared to be a small lenticular type reservoir. Lithological studies of the Waarre Formation indicate that it was deposited under mixed fresh water and salt water conditions. Formation waters produced on test also include both fresh and salt waters. The fresh formation waters produced in Fergusons Hill No. 1 and Sherbrook No. 1 could conceivably be the original deposition waters, although the high proportions of bicarbonate suggest a meteoric origin is more likely. If this is so, then at least parts of the reservoir must be continuous over considerable distances.

The exceptional thickness of Unit M sediments, thought to be up to 9000 feet in the deepest part of the basin, makes any general comment on reservoir properties very difficult. In Pretty Hill No. 1, a well developed sandstone (Unit R) was found at the base of Unit M. This sand, which produced a strong flow of salt water, has not so far been found in any other wells. In several places in the western half of the Basin, Unit M sediments have good permeability, whereas the evidence from logs, core analysis and drillstem testing indicates that there are very few well developed and permeable sands in the eastern half. An initial flow of 250 Mcf/day from Unit M in Flaxmans No. 1 is thought to have come from fractures. Several wells have had small shows of gas in Unit M, but no other measurable flow has been recorded.

Gas shows have also been obtained in the Paaratte Formation (Gd), and Belfast Mudstone (Gf). The equivalent formation in Mount Salt No. 1, Unit Gg, appeared as a porous and permable sandstone which produced a strong flow of salt water.

2. Reservoir Pressures

Details of the results of drillstem tests in which a value for the static formation pressure was either measured directly or calculated from a build-up analysis are given in Table 16. Obviously not all the pressures are of similar accuracy, since many were obtained with now obsolete equipment, or by extrapolation. With allowance made for possible errors, most of the pressures are close to normal hydrostatic for the depth of measurement.

The Waarre Formation has not been found in outcrop, and therefore it is doubtful if a hydrodynamic gradient presently exists in this formation. This remark applies to a conventional gradient set up by the gravity effect of high intake areas and low outlet areas. It is possible, of course, that entry to, and exit from the Waarre Formation can occur via other beds. The presence of what appear to be fresh meteoric waters in Sherbrook No. 1 and Fergusons Hill No. 1 suggest that flushing has occurred in parts of the formation at some stage in its history. There are not enough reliable pressure readings in this formation to draw any valid conclusions regarding the existence of hydrodynamic gradients. The abnormally low potentiometric levels in Port Campbell No. 1 (-515 and -497 feet) may be a result of faulting, or may simply be incorrect values. The level measured in Port Campbell No. 2 was +428 feet, representing a difference in head of 934 feet between these wells.

Pressures in Unit M throughout the Basin are close to normal hydrostatic. As values are only available for four wells, any attempt to deduce a gradient from these measurements alone would be unrealistic. However, assuming that these beds are in communication with an intake area 200 miles away at an elevation of 1000 feet A.S.L., then the probable average gradient is roughly 4 feet/mile. This is very hypothetical, as the nature of these beds is strongly against extensive lateral continuity.

The anticipated direction of hydrodynamic gradients is approximately southerly from elevated areas inland towards the coast. There is also a gentle dip of the beds in the same general direction and any down-dip flow of water would be favourable to the trapping of hydrocarbons.

A more detailed account of reservoir engineering and pressure data in the Otway Basin is to be found in Scorer (1965*).

3. Porosity and Permeability

Five main methods are available for investigating the porosity and permeability of sediments:

(a) Core Analysis

(b) Examination of cuttings

(c) Formation testing

(d) Log interpretation

(e) Rate of penetration log

Each of the above methods has its own merits and demerits e.g. although core analysis provides a direct measurement of these parameters, the sample is extremely small relative to the total bulk of the sediments; in the subsidised wells, there is an average of one plug per 200 feet drilled. Again, although cuttings cover the whole well section, only a qualitative idea of porosity and permeability is obtainable from them.

By combining the indications obtained by the various methods, a reasonable idea of the flow properties may be obtained. It should be remembered that only a prolonged flow test will give a true indication of the producing potential of a formation. In many cases a sand penetrated by a well will be highly porous and permeable but lenticular in nature, so that the flow will rapidly fall off after the initial flush production. A very porous and unconsolidated sand may wash out so that on a caliper log it has the same appearance as a shale, and would probably not be recovered when coring. Thus the most permeable formations may easily be missed unless due consideration is given to all the criteria for detecting permeability.

Details of particular units are given in Table 17 and a brief summary of these details is given below:

Unit Bb

The sediments in this unit are partly unconsolidated and consist of marls, limestones, biocalcarenites etc. Porosity and particularly permeability will obviously vary widely with the different facies.

Unit Bc

With the exception of an 80 foot sand in Flaxmans No. 1, this unit does not appear to have any well developed reservoirs.

Unit Db

This unit contained thick, well developed sands in all of the wells examined except Kalangadoo No. 1 and Port Campbell No. 4.

Unit Dd

Exceptionally good sands are found in Mount Salt No. 1 and Flaxmans No. 1. Sands in other wells appear to be of low permeability.

Unit Gb

In this unit also, Mount Salt No. 1 and Flaxmans No. 1 showed very good sands. Kalangadoo No. 1, Port Campbell No. 1 and Port Campbell No. 4 showed some permeability.

Unit Gd

Very good sands are present in Mount Salt No. 1, Flaxmans No. 1 and Port Campbell No. 4. Other wells show some permeability in parts, probably up to 100 md.

Unit Gf

Very little porous section exists in any of the wells.

Unit Gg

Only Mount Salt No. 1 shows appreciable good sand development.

Unit Gh

Very little porous section occurs in any of the wells.

Unit J

There is good permeability in the six Port Campbell area wells in which this unit occurs.

Unit M

The proportion of good sand is very small in all of the wells.

Unit P

None of the wells shows good sand development in this unit.

Table 16. Summary of Static Reservoir Pressures in the Otway Basin

Well Name	D.S.T. No.	Interval (ft below datum)	Depth of Measurement (ft below datum) 'D'	Formation Pressure (psig) P_r	Potentiometric level F_t above+ below- sea level	P_r/P_h*
			Paaratte Formation (Gd)			
Port Campbell No. 1	5	4815 - 4840	4850	1850	-230	0.881
"	7	4498 - 4515	4520	1750	-131	0.894
"	8	4463 - 4475	4480	1735	-126	0.894
Port Campbell No. 4	24	4020 - 4040	4000	1620	+181	0.935
			Mount Salt Formation (Gg)			
Mount Salt No.1	1	9813 - 9892	9850	4310	+290	1.011
			Waarre Formation (J)			
Flaxmans No.1	16	6875 - 6881	6890	2900	+28	0.972
Port Campbell No. 1	3	5756 - 5766	5770	2125	-515	0.851
"	4	5695 - 5701	5705	2105	-497	0.852
Port Campbell No. 2	12	8338 - 8350	8330	3670	+428	1.017
Port Campbell No. 4	2	4963 - 4985	4950	2004	+118	0.935
"	3	5005 - 5062	5000	2035	+140	0.940
"	23	5263 - 5307	5250	2140	+132	0.941
			Unit M			
Geltwood Beach No. 1	1	3859 - 3901	3875	1708	+100	1.018
"	2	4708 - 4780	4740	2070	+ 71	1.008
"	3	4983 - 5055	5000	2197	+104	1.015
"	4	6039 - 6081	6050	2634	+ 63	1.005
Heathfield No.1	1	3660 - 3754	3643	1597	+289	1.012
Port Campbell No. 4	11	6404 - 6444	6400	2665	+195	0.962
"	12	5874 - 5903	5850	2380	+ 87	0.940
"	13	5672 - 5702	5650	2253	- 7	0.921
"	14	6900 - 6929	6850	2866	+209	0.966
"	15	6691 - 6765	6650	2730	+ 95	0.948
"	17	6555 - 6601	6525	2726	+211	0.965
Tullich No.1	1	1596 - 1631	1600	674	+229	0.973
"	2	2075 - 2110	2080	889	+245	0.987
"	3	2947 - 2982	2932	1237	+197	0.974
"	4	3721 - 3786	3750	1634	+296	1.006
			Unit P			
Tullich No.1	6	4815 - 4880	4840	2118	+323	1.011
"	7	4980 - 5045	5000	2163	+267	0.999

* P_h = Calculated hydrostatic pressure at depth 'D'.

Unit R

Occurs only in Pretty Hill No. 1; has high porosity and permeability throughout.

Unit T

Occurs only in Casterton No. 1; shows good sands over the top 450 feet.

Summary

The most interesting examples of porosity and permeability are as follows:

(1) Unit Db which is permeable in all wells examined.

(2) The Waarre Formation (J) which only occurs in the Port Campbell area, is permeable in each well examined.

(3) Unit R ("Pretty Hill sandstone") only occurs in one well, but is an exceptionally thick and permeable sand.

(4) Almost continuous sands are present in Mount Salt No. 1 from 590-10,044 feet (T.D.).

(5) Flaxmans No. 1 has considerable sections of good sand from 2000-7100 feet.

Table 17. Indications of porosity and permeability in lithostratigraphic units

	Beachport No. 1	Geltwood Beach No. 1	Mount Salt No. 1	Kalangadoo No. 1	Penola No. 1	Tullich No. 1	Heathfield No. 1	Casterton No. 1	Eumeralla No. 1	Pretty Hill No. 1	Flaxmans No. 1	Port Campbell No. 1	Port Campbell No. 2	Port Campbell No. 4	Sherbrook No. 1	Fergusons Hill No. 1	Anglesea No. 1
Bb	Micro-caliper shows sand	Very porous and permeable (Final Report)	?	X	?	X	X	X	?	Unconsolidated	Nothing on M Log or M Cal	?	?	?	?	X	X
Bc	Very little sand	?	Probably porous	X	?	?	Unconsolidated	X	A few poor sands Plug 100 md	Unconsolidated	A good sand from 2014-2098'	Plugs 0-29md.	?	?	?	X	X
Db	Thick sands on M Cal	Porous and permeable. Continuous sand on M Log. Little on M Cal.	Almost continuous very permeable sand on M Log and M cal. Plug 670md.	Poor sands on M Cal. Little on M Log.	?	?	Unconsolidated	X	Continuous good sand	Good sand especially at base	Continuous very good sand	Plug 398md.	?	Bottom 100' might be slightly permeable	Very permeable at top. Bottom moderate. Plug 1505md.	?	?
Dd	X	Probably sandy. Nothing on M Cal	As above for 3150-3210'	Mostly sandy	X	M Log fair M Cal poor	Nothing on logs Plugs tight.	X	Nothing on M Log. Hole below gauge.	Fair porosity and permeability.	As above	Plug 108md.	?	Very little porosity	Little permeability	?	X
Gb	X	Unconsolidated? Very little sand? Nothing on M Cal.	Continuous permeable sand	Nothing on M Log. M Cal good. Plug 65md.	X	X	M Log doubtful. No SP deflection	X	As above	M Log fair. Hole below gauge	Good porosity and permeability	Plug 231md.	?	Some permeability over most of section. Plug 3100md	Sand streaks	?	Some sands
Gd	X	Sand at top. Nothing on M Log or SP. Hole under gauge.	Continuous permeable sand. Plug 2390md	As above	X	X	Nothing on M Log. Little SP deflection	X	Reasonable M Log and M Cal. Plug 100md	Nothing on M Log. Hole below gauge Plug 33md.	Mainly porous and permeable. Plug 18md.	Plugs tight.	?	Some good permeability. Plug 22md	Fair M Log. Nothing on M Cal. Plug 25md	Plug 73md	
Gf	X	?	Gg Porous and permeable Plug 955md.	Gg As above	X	X	X	X	M Log and M Cal doubtful	As above. Plug 39md	Little porosity except at base. Fair M Log. Nothing on M Cal	?	? Plugs 0-5md	No porosity	No porosity	Very little porosity	
Gh	X	?	X	X	X	X	X	X	X	No porosity.	Sep. on M Log. Nothing on M Cal. Plugs tight.	?	?	Very little porosity.	Very little. One fair test.	X	
J	X	X			X	X	X	X	X	X	Very good porosity and permeability. Plug 909 md.	Plug 2985md	Two good tests. Plug 80md	Mainly permeable. Good test. Plug.426md	Some permeability	Very porous clean sand	?
M	Few thin sands. Plug 27md.	Two good tests. Cores tight. Plug 212md		Streaky sands. Plug 65md	Plug 522md	Two good tests. Little on logs. Plug 95md.	Scattered small sands. Only imp't 4115-4144'. Good test.	Almost no porosity	Almost nil on M Log. Some hole below gauge. Plug 20md.	Fair porosity. and permeability. Plug 70md.	Slightly permeable in parts.		Plugs tight	Two good sands	Almost nothing. Plug 38md.	Almost nothing on M Log. Plug 108md	Tight throughout.
P		Plugs tight.		Almost no porosity	Plugs tight	Reasonable M Log and M Cal. Tight on test. Plug 15md	No porosity	Some very good sands Two good tests. Plug 44md	No porosity	X							
R				X						Continuous high porosity and permeability. Plug 2756md.							
T & V				130 feet of low porosity				Some good sands									

Abbreviations and symbols

X Unit not present ? Evidence lacking or inconclusive
M Cal Microcaliper M Log Micrólog
SP Self potential log

VIII ECONOMIC GEOLOGY

The initial aim when undertaking this review of the Otway Basin was to stimulate interest in oil search in the region. During the course of the review, however, commercial gas deposits were discovered in the Gippsland Basin, an adjoining basin with somewhat similar geological history. This discovery has created new interest in the Otway Basin and the following notes are designed to point out the prospects of finding hydrocarbons, and possible difficulties that might be experienced in the search.

During the course of the literature survey and other work done during the review, references to other economic aspects were found and these are noted later in this section.

1. Petroleum prospects

Although the following discussion is based mainly on the results of on-shore exploration, the possibilities of hydrocarbon accumulations both in the on-shore and off-shore regions are considered. The off-shore data available for study during this review were from regional aeromagnetic coverage and marine seismic surveys; no off-shore drilling has been done. However, the ideas developed from the on-shore results could be extended to the off-shore region by using the geophysical data, and an interpretation of the history of the Basin as a whole has been possible. The limitations of this interpretation were carefully considered when assessing the petroleum possibilities.

A. Hydrocarbon occurrences

One of the significant facts regarding the prospects of finding oil and gas in the Otway Basin, is that both oil and gas have already been found in non-commercial quantities. The quantities and quality of the hydrocarbon occurrences in the more recent deep wells have been discussed above under RESERVOIR ENGINEERING. Apart from the small quantities of oil recovered from Port Campbell No.4, the hydrocarbon accumulations have been mainly gaseous. The amount of data available on these gas occurrences is small and only limited interpretation can be made on variations in the quality.

In the Port Campbell area, gas occurs mainly in Units M and J, and is generally wet with up to 20% and more of ethane and higher hydrocarbons. In the western half of the Basin, Unit J is absent but Unit M yields some gas, mainly methane (with a maximum of 3% of higher hydrocarbons); however, these occurrences are much more limited. Boutakoff (1951) also refers to the occurrence of hot water and inflammable gas (63% hydrogen, 20% methane, 13.5% nitrogen and traces of other gases) in the Geelong Oil Flow Well in the Torquay area (in sediments equivalent to Unit M).

The percentage of carbon dioxide in analyses of gas from Port Campbell Wells 1 and 2 is relatively high (5 to 23%). The reason for this is uncertain, but volcanic intrusion ("Older Volcanics") is suggested on aeromagnetic evidence in this region, and could be responsible for the oxidation of some of the hydrocarbons. The question of carbon dioxide accumulation leads to the interesting occurrence in Unit V in Kalangadoo No.1 of gas which analyses show may contain 80 or even up to 96% CO_2. Unit V is a sediment which has undergone low grade metamorphism, and would normally be regarded as economic basement. However, it has been fractured, and as it forms part of a horst block, gases from younger sediments in the adjoining graben to the north could have migrated into it. Here also the gases may be oxidized hydrocarbons produced by basic igneous intrusion (such as the intrusion into Unit T in Casterton No.1).

A similar explanation could be made for the escaping carbon dioxide gas at Clifton Springs (Coulson, 1933) along the Bellarine Peninsula, an area underlain by Unit M - type sediments which have been intruded by the "Older (Oligocene) Volcanics". The seepage is probably along faulting in that area. In yet another area affected by vulcanism, Sprigg (1961) refers to a 'big flow' of carbon dioxide gas from Yangery No.1 Bore at Koroit.

Other units which contain small gas accumulations are Units P and Gd. Unit P flowed salt water containing dissolved gas which was unusually high in nitrogen (32-62%) in Tullich No.1. Gas from Unit M in the same well also contains nitrogen possibly up to 18½%. The only other well to record more than 10% of nitrogen is Fergusons Hill No.1 in gas from Unit M (12%). A trace of gas of unknown composition is also recorded from Unit P in a core from Penola No.1

Unit Gd contains mainly methane in the gas show from Flaxmans No.1 and coal or carbonaceous sources might normally be expected; however, these are not characteristic of Unit Gd even though it does contain patches of macerated carbonaceous material, and some other source is suggested. Drilling records of the Nelson Bore also refer to a "fair show of gas" (derived from the Unit Gd level) in the mud ditch.

A trace of gas and some residual crude oil in cores, were recorded from sediments of Unit Gg in Mount Salt No.1, and cores from Db also contained traces of crude oil.

Many reports were made of hydrocarbons in some of the early wells drilled for oil, particularly in south-eastern South Australia, but these have been mostly discredited for various reasons (Gray and Croll, 1938). However, the significance of hydrocarbons in the well drilled on Knight's Dome was never successfully resolved (Woolnough, 1933) and it is unfortunate that drilling was abandoned before the well had been properly tested.

Off-shore seepages have been suggested for the numerous strandings of dominantly asphaltic material along the shores of South Australia and western Victoria. Many reports have been made of these strandings (Wade, 1915) and other on-shore seepages (Pritchard, 1924). Most of these have been referred to by Sprigg (1952 to 1964) who supports older suggestions of off-shore seepages for the strandings, even though another 'plankton bloom' concept for their origin was suggested by Ludbrook (1961)*. Analyses of the material are given in Sprigg and Woolley (1936). Woolley and Laws (1964) suggest 'pitch dome' diapirism for the off-shore seepages.

Evidence that faulting has been the dominating structual influence throughout the history of the Basin, together with the evidence of tensional stresses at various times, would support the idea of hydrocarbons seepages in the off-shore areas.

In addition to possible loci within the framework of the Basin, the continental slope in the region of the foundering of the hypothetical southern land mass, might also be considered. Here the Lower Cretaceous and older (?) sediments dip landwards and would have been cut by faulting as the old land mass foundered thus providing an ideal escape for any hydrocarbons which migrated up-dip from within the Basin.

The most convincing report of an on-shore oil seepage is that given for the Haines Landing area, about fifteen miles upstream along the Glenelg River from the Nelson Bore. However, it was never fully substantiated and its meaning is inconclusive (Boutakoff, 1951).

B. The properties of the sediments

Unit T

The sediments are mudstones and sandstones with porous sand bodies in the upper 450 feet; they are thought to have been deposited in a paralic to alluvial environment. Marine conditions are indicated by connate water with a salinity of about 35,000 ppm obtained from the unit in a drillstem test in Casterton No.1 Fracture porosity may also be present in parts of the unit. Unit T has been found only in the north-western part of the Basin, but a similar development may occur in the eastern half.

Units R - P

Good sands with high porosity and permeability occur in the "Pretty Hill sandstone" (Unit R) but generally do not extend to Unit P. Diagenetic cementation has diminished the reservoir potential of sandy intervals in Unit P. However, in Casterton No.1, Unit P contains some conglomerate horizons and is more sandy (protoquartzite) towards the base; the change is reflected in the electric logs which indicate some porosity. This suggests that improved reservoir conditions can be expected towards the margins of the Basin. Fractures have been noted from cores. Unit R is 1910 feet thick in Pretty Hill No.1; Unit P varies but is up to at least 3300 feet. The depositional environment is thought to have been paralic to alluvial. Units R - P are only known from west of the Warrnambool Ridge.

Unit M

Mainly mudstone with minor coal lenses in parts of the Basin, and subordinate greywacke to volcanic sandstone from the bulk of Unit M. The overall thickness may exceed 9000 feet. Thin sandy wedges, from 20 to 120 feet thick, are known from the north-western part. The proportion of porous and permeable zones is very small for the wells studied. Fracturing is most prominent in Fergusons Hill No.1 and Anglesea No.1 (wells adjacent to the Otway Ranges structure). The sediments and accompanying sedimentary structures indicate that shallow water conditions, mainly lacustrine, prevailed in the region. A great amount of material was provided by penecontemporaneous vulcanism. There is evidence of marine incursions, mainly towards the top of the sequence.

The known occurrences of oil and gas in Unit M do not appear to be at any particular level, and the main gas flow from Flaxmans No.1 came from 4000 feet below the top of the unit, probably from a fractured zone.

Unit J

The sands of Unit J are porous and permeable in the Port Campbell area and the thickness of the unit varies from 200 to 550 feet. Unit J may extend into the eastern part of the Basin, with a possible equivalent, Unit H, of 105 feet in Anglesea No.1 However, it does not extend west of the Warrnambool Ridge in the on-shore area. A paralic environment of deposition is indicated in the lower part where marine mudstones and sandstones interfinger with coaly horizons, but a more regressive facies - coarse sands and conglomerate - develops towards the top. The overall more sandy facies of Unit J (sand/shale ratio = 6) in the Latrobe Bore area may represent a significant near-shore sand development.

Unit G

A cycle of sedimentation through marine transgression and regression occurs in Unit G. The tight sandstone and sandy mudstone of Unit Gh and dark glauconitic mudstone of Gf in the eastern part of the basin are represented in the west by a composite unit, Gg, of interbedded sandstone and siltstone; sands in Gg show some porosity, particularly in Mount Salt No.1. These units represent the transgressive phase. Regression is shown by Unit Gd and the basin-wide unit Gb, both of which have some porosity and show good to fair permeability depending on the distribution of silt and cement. The variations in thickness of the units in cross-sections across the on-shore part of the Basin are shown in Plates 4 and 5; Gh and Gf exceed 2000 feet in the Port Campbell area, and Gg is more than 3500 feet thick in Mount Salt No.1. Units Gd and Gb exceed 3000 feet in the west, and are up to 2000 feet thick in the eastern part of the Basin. The only one of these units known to continue east of the Port Campbell area is Gb, although it seems likely that some of the older units are represented in the depressions east of the Otway Ranges and west of King Island. In the southern off-shore part of the Port Campbell area of "restricted basin" sedimentation, the more marine facies of Gb and Gf are expected to thicken, whereas the regressive facies will probably thin.

Unit G contains possible source rocks, and good reservoir and cap rocks, and it is surprising that so few shows of hydrocarbons have been located within this unit.

Unit D

This unit also represents a cycle of sedimentation. The basal part, Dd, is a pebbly, pelletal and oolitic sandstone, 50 to 400 feet thick. A belt of foreset sands is predicted from seismic evidence to occur underneath the coastal area west of Port Fairy, adjacent to an area of calcarenite rich in ooliths (Eumeralla No.1), and another more extensive belt of foreset sands is thought to occur along the edge of the continental shelf (Plate 16). This southern belt is widest south of Port Fairy and appears to have spread out around the south-eastern side of an off-shore projection of the Warrnambool Ridge. Good porosity and permeability occur in parts of Unit Dd sediments (see Table 17) but other parts have low permeability. The bottom of Unit Db shows evidence of being deposited in a deeper marine environment, with conditions becoming regressive higher in the sequence. The unit contains thick porous and permeable sands over most of the Basin, and is over 2800 feet thick in Heywood No.1 Bore.

Unit B

Two transgressions occur in this final main phase of sedimentation in the Otway Basin, the first represented by Unit Bc_2 - limonitic sandstone and conglomerate overlain in the eastern half of the Basin by a glauconitic and limonitic marl, and, after a sharp regression, the second and widest landward transgression represented by Bc, and Bb. The latter are not important for this section of the report; formations represented by Bc, crop out over wide areas and are generally porous, so that there would be little possibility of hydrocarbons being trapped. Units older than Bc, in the western half of the Basin, Bc_2 and most of Unit D also do not offer much prospects for hydrocarbon accumulation because they show little evidence of overlying impermeable horizons of wide extent.

In the eastern half of the Basin, however, the sandy horizon at the base of Bc_2, ranging from 20 to 150 feet thick, is conformably overlain by more than 200 feet of marine marl in the Port Campbell area (see Plate 7). The marl may not be important on-shore, but equivalent sediments occur in outcrop along the Aire and Anglesea coastal areas east of the Port Campbell area, and an off-shore extension of the Unit seems likely. Its importance is not so much as a possible source rock, but because it could form a cap to some of the older more permeable units, and it has been folded during late Tertiary movements.

C. Petroleum traps

The majority of deep wells drilled in the search for oil since 1959 have been located on closed structures (anticlines or higher features produced by faulting) defined by seismic exploration, although both Fergusons Hill No.1 and Sherbrook No.1 were located to test possible pinch out of sediments against an uplift. Anglesea No.1 was an off-structure stratigraphic well.

The most prominent structural features in the Otway Basin, as shown by subsurface data, are faults, and these have been produced both by tension, giving horsts and grabens or half-grabens, and by shear, producing transcurrent faults and short en echelon fractures. It is suggested that some faults have also been produced or influenced by "buffering" effects against prominent shallow basement features. Although a lot of faulting of the different units has been post-depositional, faulting contemporaneous with sedimentation has also occurred at various times. These are the "down - to - basin" faults of Weegar (1960 a) and they may be expected in such basins as the Otway Basin which has a history of rapid clastic sedimentation, particularly in the western half in the Cretaceous and lower Tertiary. In the later Tertiary, more stable shelf conditions existed and deposition of limestones and marls predominated.

The types of reservoir traps that might be expected from faulting are the purely fault traps where confined permeable strata have been positioned against impermeable beds, or pinch outs which have formed as a result of "down - to - basin" faulting. Another type of reservoir which may develop as an indirect result of the faulting is the stratigraphic trap formed in areas of rapid clastic sedimentation where floods of coarse detritus produce localized, or blanket - type sand lenses.

Although faulting is more common in the Basin, folds and fold-like features are present both in outcrop and in the subsurface. They are more common in the eastern half of the Basin than in the west, as shown in Plate 11. The nature of many of the fold-like features is difficult to determine because of limited seismic control, particularly in the off-shore area, but at least some are probably compressional. These, and other types of folds which may be present, are discussed hereunder :

(1) The subsurface fold-like forms, which have been interpreted from seismic records follow the extensions of regional basement trends for long distances. Some of these would probably be folds by compression, and could be associated directly with thrusting from the south-east to east intermittently during the history of the Basin. Others may have developed indirectly by thrust derived from transcurrent movement. Examples of the compressional type of fold are not common in outcrop, but the folds along the south-eastern part of the Otway Ranges (Edwards, 1962) could have formed by compression, either directly or indirectly.

Plate 11 shows that some of the subsurface features are confined to pre-Unit G sediments, others persist into the times of deposition of Units G and D, and the most persistent affected Unit B. Some of the anticlinal types appear to plunge towards the long axis of the Basin. Others that are more elongated may show closure at one or more places along their axes; the extensive feature through Flaxmans No.1 is typical.

(2) Some of the folds seen in outcrop in south-eastern South Australia have been attributed by Sprigg (1962a) to basement shearing at depth; these are small en echelon folds with low dips on the limbs. Transcurrent movements are believed to have been common throughout the Otway Basin, particularly in the later geological history, and many of the folds seen in outcrop and in the seismic records could be similar to those described by Sprigg. The mode of deformation would mean that although the structures are small at the surface with only a small amount of closure, they may increase in size with depth. These structures could form traps.

(3) "Down-to-basin" faulting (Weegar, op.cit.) is believed to have formed anticlines or monoclines at the edges of troughs where the strata adjacent to the down-faulting would be bent downwards. This type of displacement therefore, is important in that it may produce two types of reservoir: folds at the sides and pinch-outs within the troughs. The folds would not be expected to have much closure, but in view of the extensive tensional faulting in the Basin, they could occur over long distances. The Geltwood Beach 'anticline' and the buried structure at Kalangadoo No.1, may have been of the type of fold which is confined to areas of graben development.

(4) A fourth type of fold is shown in seismic records as dome-like structures which appear mainly in certain younger sediments but not in older units; these are more common in the areas where vulcanism is known, and may be due to basaltic intrusion or extrusion. Their potential as traps for hydrocarbons could vary considerably. Intrusions through sediments containing hydrocarbons could cause oxidation, and it has been suggested that some gas accumulations rich in carbon dioxide may have formed in this way. However, traps could possibly be created by an updoming of strata by the intrusions, or the intrusions and extrusions could have formed rises over which draping has occurred. The latter might be expected in earlier sediments associated with the Upper Jurassic-Lower Cretaceous (?) vulcanism, or in the eastern part of the Basin where the "Older (Oligocene) Volcanics" occur.

Reservoir traps are possible in areas where sediments form angular contacts with younger sediments at uncomformities around the southern and eastern margins of the Basin. However, throughout much of the Otway Basin sequence, most uncomformities are followed by marine transgressions, and the deposition of course-grained generally porous sediments which would not provide a seal. This would be so particularly in the marginal areas where the angularity is due to depositional rather than structural causes. It is possible that in the off-shore areas, where some units thin or pinch out along the edges of shallow basement features such as the Warrnambool Ridge and south of Cape Otway, they might be unconformably overlain by impermeable strata, and excellent reservoir traps could be developed.

D. Prospects

The discussion of petroleum prospects has shown that hydrocarbons occur in the Otway Basin, that possible source rocks occur interbedded in parts of the sequence with porous, permeable rocks, and that reservoir traps could be present.

Hydrocarbons have been found in small amounts in the on-shore part of the Basin, and occur mainly in Upper Jurassic to Lower Cretaceous sediments which appear to have been affected in some parts of the Basin by volcanic intrusion. The best porosity and permeability in the thick Upper Jurassic-Lower Cretaceous section are in sands such as in Unit T, Unit R, Unit J, and other sandy wedges along the northern margin in the western part of the Basin. Apart from Unit J, the other units are near the basement edge, or are along the flanks of shallow subsurface basement features such as the Warrnambool Ridge. Drilling in marginal areas has been unsuccessful, but only Casterton No.1 and Pretty Hill No. 1 were drilled to basement. It might be useful to ascertain whether a wedge of sand equivalent to Unit T extends along the northern edge in the eastern half of the Basin. The only evidence of such a possibility is the thin sand above basement and below Unit M in Fergusons Hill No.1. Some prospects may still exist along the northern marginal areas generally, or in regions of shallow basement where porous and permeable sand wedges may be present in an otherwise tight section.

Other prospects in areas of possible fracture porosity should also be considered and the tectonic style of the Basin formation would indicate that fracture porosity could be quite common. It has already provided at least one good show of gas in Flaxmans No.1.

Units J and H are prospective sands at the top of the Lower Cretaceous in the Port Campbell and Anglesea areas respectively. Shows of gas have been recorded in Unit J and both sands may be worth following off-shore, although they will not be easily identified in seismic surveys.

Restricted marine influence is best known from the lower and uppermost parts of the Upper Jurassic-Lower Cretaceous sequence. More marine conditions may have existed in the present day off-shore region, although seismic has shown that the outer margin of sedimentation at those times was probably well beyond the present edge of the continental shelf in many parts of the Basin.

The most prospective part of the Otway Basin sequence appears to be in the Upper Cretaceous sediments (Unit G), but results so far have been disappointing. These sediments are more marine in the Port Campbell area than elsewhere, although the environment was not entirely open marine, and possible source rocks are overlain by porous and permeable sands. West of the Warrnambool Ridge, the marine influence is not as noticeable, but the rate of sedimentation here was greater and good permeable sands occur interbedded with the finer clastics to give more opportunity for reservoir traps. Possibly the best marine conditions are in the area off-shore from Portland where marine incursions occurred along the south-western side of the Warrnambool Ridge and into the extensive graben structures stretching north-west into South Australia. In this area also, the oceans probably spread across the Ridge into the Port Campbell area, and interfingering of Units Gb and Gf with the more mixed facies of Unit Gg can be expected.

The extent to which the formations of Unit G spread eastwards from the Port Campbell area is not known except for the upper unit, Gb (Curdies Formation), which is thought to be present as the Eastern View coal measures in the Torquay area. The coal measures could have been a source for hydrocarbons which, if in sufficient quantity, would be well-situated for exploitation. Areas of thicker Unit G sedimentation shown in marine seismic records east of the Otway Ranges and west of King Island should also be investigated.

After the hiatus at the end of the Cretaceous a thick clastic section - Unit D - was deposited in the Palaeocene, in an environment which changed from shallow shelf to slightly deeper marine. This was an extensive transgression which gave some good porous clastics in the lower part, with some foreset development. The transgression was followed by regression in a similar sedimentary cycle to that of Unit G. Unit D has shown little evidence of hydrocarbons (except for traces of oil in Mount Salt No.1) possibly because reservoir traps are rare in the on-shore part of the Basin, and because the beds have probably been well flushed by underground water. The absence of impermeable strata in sediments above Unit D in the western part of the Basin does not enhance its prospects there as a possible reservoir for hydrocarbons.

However, in the eastern part, a well developed marl in Unit Bc_2 extends across the Port Campbell area and it could continue over the off-shore shelf area to the south-east. In a high structual feature, it could provide a good reservoir seal, and has the added advantage of being a possible source rock. It extends north to near the Anglesea area where it appears to be more of a near-shore facies (Demon's Bluff Formation); deeper marine characteristics are shown in the equivalent formations (Browns Creek Clays, Castle Cove Limestone, Glen Aire Clays) near Cape Otway.

A hydrodynamic gradient may exist in the direction of the off-shore part of the Otway Basin and its possible influence on trapping conditions should not be ignored.

However, a lot more pressure data are required before reliable isopotentials can be drawn and before the hydrodynamics can be interpreted.

The prospects of finding hydrocarbon accumulations in Palaeozoic rocks have not been analysed to the same extent as those in Mesozoic and Cainozoic sediments. Of the older Palaeozoic rocks, only the Cambrian and Ordovician are known to extend as continuous basement below the Otway Basin. Dark marine mudstone is common in the succession in outcrop, but in many parts it has undergone medium to low grade metamorphism, and rocks of this age encountered in wells have been altered. The rocks are generally not considered to be likely sources of hydrocarbons in the Otway Basin, but the possibility that unaltered sediments of the type occurring in the Cambrian-Ordovician succession could have generated hydrocarbons should not be disregarded completely.

Permian sediments have been preserved in grabens or glacial troughs around the margin of the Basin, and occur at shallow depth within the Basin in a bore near Penshurst in western Victoria. The presence of reworked Permian and Triassic spores in sediments of the Otway Basin sequence has been recorded. Thick deposits of Permian sediments may be preserved in troughs in the basement below the Otway Basin succession but would be hard to detect. The most likely area to suggest for exploration of subsurface Permian sediments on available evidence is in the northern lobe of the Basin off-shore from the Padthaway Ridge in the graben which Sprigg (1964) has included in his "Encounter Bay trough". Although mostly of glacial origin, Permian sediments commonly overlie or are associated with marine sediments which are potential source rocks for hydrocarbons. Little structure, other than in the basement, is indicated on geophysical evidence for the "Encounter Bay trough", and reservoir traps might be restricted to the stratigraphic type.

E. Conclusions

Although prospects of finding further hydrocarbon accumulations appear to exist in the Otway Basin, one of the main difficulties associated with the search will be locating suitable targets for drilling. The following problems will be particular to the Otway Basin:

(1) folds associated with faulting will be hard to locate because they may be buried and have little, if any, surface expression;

(2) pinch outs and stratigraphic traps are not obvious in seismic records and will also be difficult to find because of the shifting of the depositional axes from time to time;

(3) faulting may have created problems by lateral dislocation of possible traps and by causing fracturing;

(4) the possible effects of intrusions have to be carefully considered;

(5) the hydrocarbon accumulations formed in on-shore drilling have been small or have quickly declined in flow, from both the clastic and fracture-type reservoirs; this suggests that either the reservoirs are small, or, in the case of clastic sediments, that permeability is extremely variable.

The search on-shore has offered hope but so far no substantial accumulations. Further testing on-shore might be warranted in the marginal areas, with Unit T or its possible equivalent in the east, and permeable sands in Unit M as targets. Structure associated with faulting, and possible pinch out and stratigraphic traps within the grabens could also yield hydrocarbons. Locating off-shore targets will present more difficulties because of the particular problems associated with the Otway Basin. Further, because the overall cost of off-shore exploration is greater than for similar on-shore operations, structure must be more carefully defined before drilling commences.

In spite of the difficulties associated with exploration in the Otway Basin, many reasonable prospects remain to be tested both on-shore and off-shore, although present company interest is centred mostly on the off-shore area. This interest is probably guided by the off-shore discoveries in the Gippsland Basin and by the apparently similar conditions in the off-shore Otway Basin area. However, this review has shown that the Otway Basin should not be assessed so much by its prospects on-shore compared with off-shore, as by the differences which exist in the western and eastern halves on either side of the Warrnambool Ridge.

In the western half, Unit T, Units R - P and M (Otway Group), and Unit G (Sherbrook Group) offer the best prospects. Reservoirs could be provided by foreset beds in Unit D except that no evidence has been found of a possible cap rock. Structural features are mainly NW-SE tensional and shear faulting, with subordinate folding. The folding appears to be generally small and associated with the faulting. Some doming may be due to basic intrusions in the Beachpost area (Upper Jurassic - Lower Cretaceous in age) and south of Cape Bridgewater and elsewhere the "Newer Volcanics" are suggested. Late Cainozoic upwarp, and possibly associated down-faulting, have affected south-eastern South Australia and south-western Victoria, and produced some NE-SW trending structure.

Areas of interest lie along the northern margin, on-shore and off-shore, and along the flanks of the various grabens. Because the off-shore sediments of the Otway Group are possibly more marine than those to the north, and the greatest known marine influence in Unit G appears to be centred around the Warrnambool Ridge area, the graben opening off-shore to the south-east from Portland might have been one of the most favourable areas for hydrocarbon formation and accumulation.

In the eastern part, all units to the top of Bc_2 can be regarded as possibly prospective for hydrocarbons, at least in the Port Campbell area, and elsewhere if the marl at the top of Bc_2 is as widespread as earlier suggested. However, some thinning of the Upper Cretaceous section occurs to the east of the Port Campbell area. Fold-like features with NE-SW axes that continue for long distances are predominaut in the structure of the area, but faulting is common in the Port Campbell area. Some of the features are probably anticlines, but in the off-shore area more detailed seismic is needed in many parts to prove folding and closure.

Doming due to basic intrusions is also suspected in some parts; in the eastern half of the Basin however, the second phase of intrusion is due to the "Older (Oligocene) Volcanics" and not to the "Newer Volcanics" as in the west.

The influence of faulting in the eastern half appears to be least in the off-shore area, and the anticline - like features appear to offer the best targets. Good fracture porosity may occur in the faulted areas; and pinch outs appear to offer some prospects along some of the basement features such as the Warrnambool Ridge, and the edge of the shelf thoughtto extend south-west from Cape Otway. The marginal belt north of the Port Campbell area and extending eastwards from about Lake Corangamite, offer reservoir prospects if sands similar to Unit T are developed in the eastern half. If permeable sands do exist here or further east in the Port Phillip Bay area, the possibility of the existence of suitable reservoirs for gas storage, as well as the hydrocarbon prospects, could be considered an added incentive for exploration.

The South Australian part of the Otway Basin covers the same area as the 'Gambier Sunklands' hydrological province of the Murray Basin, as defined by O'Driscoll (1960). O'Driscoll states that the upper ground water flows in the limestone of the 'Glenelg Group' (Unit B) or in limestone of Recent - late Tertiary origin. The whole system appears to act as a single aquifer in which a large volume of high quality water of local origin moves to the south and south-west and escapes through springs. The underlying 'Knight Group' (Unit D) aquifer carries pressure water which appears to be fed from more distant Victorian intakes.

The hydrology of the Victorian part of the Otway Basin was reviewed by Esplan (1966)*. Shallow groundwater, when it is of suitable quality, is used for stock watering over most of the area. Esplan states that the Otway Basin has a high potential for supply from moderate to deep aquifers, but there is little or no development or information on these at present.

In the Port Campbell area the 'Dartmoor Sand Member' and the 'Port Campbell Limestone' offer good possibilities. A lot more drilling throughout the basin will be necessary before the production and recharge capacities of the various aquifers can be determined.

2. Notes on other mineral occurrences

Little information on the economic importance of other mineral occurrences has been derived from the subsurface study of the Otway

Basin. This section of the report, therefore, deals mainly with the various reports of mineral occurrences noted in the course of the literature review.

Water

Valuable research on hydrology has been and is being conducted by both the Victorian and South Australian Mines Departments in their respective parts of the Otway Basin, (Bain, 1959; Ward, 1941, 1946; O'Driscoll, 1960; and the numerous boring reports). The outlines of the mineral resources of the Corangamite and Glenelg Regions by Thomas (1957, 1960) refer to the hydrology of those regions, and Boutakoff (1963) also discusses water in his memoir on the geology of the Portland area.

Coal

Coal seams of some economic importance occur in both Cretaceous and Tertiary sediments. The many references to coal include the following: Daintree (1862), Stirling (1899c), Dunn (1912), Edwards and Baker (1943), Thomas and Baragwanath (1949) Kenley (1954), Edwards (1962), and we have referred to various occurrences revealed by drilling in the descriptions of our informal stratigraphic units.** The most comprehensive of recent reports are those by Edwards (1953) and Thomas (1953); McLeod (1965) lists minor black coal occurrences in the Otway-Bellarine and Casterton - Merino areas among Australian mineral deposits.

The common development of the marginal marine, paralic, and alluvial types of environment during the geological history of the Otway Basin would suggest the possibility of further deposits below the Tertiary marine and volcanic rocks along the marginal areas between the Port Campbell area and Geelong.

Footnote ** The thickest development known is in Anglesea No.1 where Dellenbach (1965*) has interpreted several seams, some more than ten feet thick, in Unit Gb (equivalent to the Eastern View Coal Measures); small lenses and stringers were also found in Unit M.

Phosphate

Because of the current need to discover phosphate deposits in Australia, references are listed with a note on locality:

Baker (1961) - phosphate in Nelson Bore sediments;

Baker (1962) - accretions in sediments in coastal regions south-west of the Otway Ranges;

Bowler (1963)- Geelong to Maude area;

Coulson (1932)-concretions and pebbles, Geelong District;

Crespin (1926)-derived phosphatic nodules in sediments of Keilor area;

Dennant (1889)-pebble bed at Muddy Creek;

Gill (1957) -nodules in "Grange Burn Coquina";

Teichert (1947)- fossils from phosphatic nodule bed near Princetown.

Detrital phosphate has been referred to in the descriptions of many of the informal lithostratigraphic units of this report, and phosphatic cement has been recognised in small amounts in some of the sediments. Although many reports of occurrences have been made, little research appears to have been done on the source of the material.

Probably the most important source of detrital material would be the older Palaeozoic black shale facies which occur in the outcrops to the north of the Otway Basin, and probably extended within the basement to the old land mass thought to have existed to the south in Mesozoic time.

Sheldon (pers. comm.) has indicated that concentrated indigenous deposits of phosphate are unlikely in clastic sections that have been rapidly formed, and this fact would considerably reduce the potential of most parts of the Otway Basin succession. The best environment appears to be in an area of current upwelling where deposition is slow and allows time for the precipitation or formation and concentration of the phosphatic material. To derive phosphatic material from decaying organic matter also requires a reducing environment, hence the common association with black shales. The only unit which might be considered to occur in this category is Unit Gf (Belfast Mudstone) in which some phosphatic material has been identified. However, it is only known subsurface, and as Taylor (1964a) suggests that the Belfast Mudstone wedges out in the northern part of the Port Campbell area, it is not likely to be found at a shallow enough depth to be worth mining. The only other unit which might be considered as a potential indigenous phosphatic source is Unit Bc_2; clays in this unit are marine and obviously of quiet water deposition, and further studies might suggest areas where reducing conditions applied during sedimentation.

Detrital phosphate is recorded from Units Dd, basal Bc_2, and Bc_1 in sediments that mark the initiation of marine transgressive phases. However, detrital deposits of phosphatic material are not commonly good economic prospects because of the lack of concentration of the material, the impurities, and the thinness of the deposits.

It is interesting to note that the gamma ray count of Unit Dd is higher than that in the beds above and below in several of the wells drilled in the Otway Basin. Although phosphatic beds commonly show a higher radioactive background than enclosing sediments, the effects are probably secondary, particularly in the case of Dd. Lahoud, Miller, and Friedman (1966) have shown the relationship between depositional environments and the uranium content of molluscan shells, and the association of urano-phosphatic material in fish remains has provided the means of tracing the Toolebuc Member throughout the Eromanga Basin. Both fossil shells and fish remains occur in Unit Dd and may provide the radioactivity. However, high readings in some wells appear to be opposite shaly or silty beds and are a normal response from such lithologies.

Lime and dolomite

Numerous good limestone deposits have been reported as sources for cement manufacture and for lime for various purposes, and limestones have been mined as building material. References to Victorian deposits have been made by Bain (1950), Boutakoff (1963), Keble (1925), and Kenny (1939).

Dolomitization of limestones in south-eastern South Australia has accompanied late Cainozoic tectonic activity, and reports on both the limestone and dolomite have been made by Cochrane (1952), Johns (1963, 1965a, b), and Sprigg (1952).

Clay

Hosking (1951) refers to clay at Colac in his account of the clay resources of Australia; Keble and Watson (1952), and Boutakoff (1963) also refer to clay deposits in Victoria. Reference to South Australian occurrences are made by Hiern (1965), and Kingsbury (1957).

Sand

Good commercial sand deposits occur in various parts of the Otway Basin region; they have been mentioned by Boutakoff (op.cit.), and Thomas (1947) describes sands near Melbourne.

Building stone

Building stone in the Portland area is also referred to by Boutakoff, and a more comprehensive account of building stones in Victoria is given in McInerney (1929).

Bentonite

The bentonite of the Otway Ranges area is associated with the sediments of Unit M in which considerable amonts of volcanic detritus have been found. One deposit has been described by Darragh and Bowen (1965), and is listed by McLeod (1965). In view of the wide extent of Unit M, and the similarity of its composition throughout the Basin, other bentonitic beds of economic importance could be located in Victoria.

Fuller's earth and diatomite

McLeod (op.cit.) mentions a Fuller's earth deposit near Colac. Reference to diatomites associated with the "Newer Volcanics" was made by Mahony (1912), and another reference is made by Kitson (1906); diatomite occurrences in Victoria are summarized by Cröhn (1952).

Gold

Small amounts of alluvial gold have been found in Tertiary gravels of the lower Gellibrand River, (Stirling, 1898, 1899).

Minor occurrences of pyrite of no economic significance have been reported by Easton (1936), and Edwards and Baker (1951) describe the formation of supergene iron sulphides. Another mineral of interest but no economic importance, is the "humicite" found in veins and to a limited extent in beds in sandstone of the Grampians Group; it is a bituminous material which Spencer-Jones (1958) considers to have been derived from Tertiary coal, and to have migrated as a gel into the old Devonian sandstone. Mott (1959*) considers the "humicite" to be a 'distillation product from carbonaceous shale in the underlying Ordovician rocks'.

IX. PROBLEMS

A number of interpretational problems developed during the course of the Otway Basin review, and attempts have been made to resolve them using all available data. Some of these problems are reiterated here to suggest topics that need further study, and projects for further work.

1. One of the first problems to arise was that of establishing basin-wide correlations using the existing stratigraphic nomenclature. This was impossible, and a set of informal lithostratigraphic units was used instead. The approach was generally successful and basin-wide correlations became possible; there was good agreement between the results of the petrological and palynological studies of the Cretaceous units, and early Tertiary units were confidently tied across the Basin. However, a problem remains in the case of Units Bc_2 and Bc_1 - we had difficulty in making correlations based on petrology alone, particularly in the western part of the Basin, and reports that were available on the palaeontology were of only limited assistance because of some inconsistence between interpretations in South Australia and in Victoria.

Although we have made a tentative interpretation for this review, the Tertiary still needs further study with a re-appraisal of the palaeontology and stratigraphy of some of the outcrop areas.

2. The suggested geological history for the Upper Jurassic and Lower Cretaceous is based on our conclusion that vulcanism was penecontemporaneous with sedimentation, and that, although there was vulcanism at various places within the Basin, the bulk of volcanic detritus was derived from the Tasmania - Bass Basin region. Two problems remain:

(1) the age of the volcanics - the ages of only two samples are available, one from the intrusion near the base of the section in Casterton No.1 (Upper Jurassic or Lower Cretaceous), and the other from an outcrop in the Tasmania Basin (Upper Jurassic). A lot more age determinations are required to test the hypothesis of this report that this early vulcanism occurred between the Upper Jurassic and Lower Cretaceous.

(2) the history of sedimentation during Unit M time - Dellenbach suggested two main phases of vulcanism based on his studies in the eastern part of the Basin; although further work by Bryan and Hawkins did not substantiate this suggestion for the rest of the Basin, additional detailed petrological studies in this thick unit would probably help in making further interpretation of the depositional history. Such studies could well incorporate the work done by Hawkins on the sedimentary structures (Figure 4A).

3. Problems of geophysical interpretation have been raised in the discussion of the results:

(1) the absence of marked negative gravity anomalies over the suggested deep grabens in south-eastern South Australia and south-western Victoria;

(2) the variations in the interpretation of aeromagnetic results where these overlap in the coastal areas of south-eastern South Australia (compare Sheets A and C of Plate 10);

(3) whereas down-faulting of basement below the Otway Ranges has been suggested on limited aeromagnetic results (H.E.P.L., 1965) gravity surveys show a strong positive anomaly;

(4) discrepancies in the alignment of the north-western margin of the Basin east from Cape Jaffa as shown in the aeromagnetic and gravity interpretations;

(5) an unusual depression shown by both gravity and magnetic contours trending north-east across the Padthaway Ridge to the north of Kingston.

4. Problems with economic implications have already been enumerated, and will not be repeated here.

X. BIBLIOGRAPHY

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A. Published reports.

B. Unpublished reports; these are listed in alphabetical order but are prefixed (A), (S), or (C) according to their category, as follows:

(A) - other than company reports (B.M.R. Records, State Survey reports, etc.);

(S) - company reports of subsidized oil search operations;

(C) - other company reports which were made available for the review of the Otway Basin.

In the case of reports of subsidized operations and some other company reports, the initials of the distinctive names of the operator are listed as author; where known, the actual author is indicated towards the end of the reference.

The bibliography contains references to most reports of stratigraphic importance, and all other references used in the text (some of which are not directly related to the Otway Basin). However, it excludes some early papers, (particularly those on Tertiary stratigraphy and palaeontology), which are included in the comprehensive bibliographies of

Boutakoff (1963, 111-113, Portland area);

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For the inspection of unpublished reports, the reader is referred to the company or to the organization which produced the report; however, copies of all of the listed reports on subsidized operations are available for inspection at the Bureau of Mineral Resources, Canberra. Lists of many of the reports on petroleum exploration which are on open file in the South Australian Department of Mines have been published - (S.A.D.M., 1962, 1963).

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COOKSON, Isabel C. & EISENACK, A., 1961b - Tertiary microplankton from the Rottnest Island Bore, Western Australia. J.Roy.Soc.W.A., 44, 39-47.

COOKSON, Isabel C. & EISENACK, A., 1962 - Additional microplankton from Australian Cretaceous sediments. Micropalaeontology, 8 (4), 485-507.

COOKSON, Isabel C. & MANUM, S., 1964 - On Defl.victoriensis n.sp., D.tripartita C. & E. and related species. Proc.Roy.Soc.Vic., 77 (2), 521-524.

(The 20 references given above are mainly for the section on Palynology.)

COTTON, B.C. and CROCKER, B.C., 1946 - Some raised beaches of the lower south-east of South Australia and their significance. Trans.Roy.Soc.S.Aust., 70 (1), 64-82.

COTTON, C.A., 1949 - A review of tectonic relief in Australia. J.Geol., 57 (3), 280-296.
A brief review with numerous references to the physiography and geomorphology of Australia.

COULSON, A., 1930 - Notes on the Jurassic rocks of the Barrabool Hills, near Geelong, Victoria. Proc.Roy.Soc.Vic., 43 (1), 36-41.
The notes describe a section of 131 feet of conglomerate, sandstone and grit, with mudstone beds containing plant fossils. The basal conglomerate contains Ordovician slate fragments with graptolites. Structural trends are east-west, and the Barwon Fault has a 400 foot throw. A geological map and cross-section is included.

COULSON, A., 1932 - Phosphatic nodules in the Geelong district. Ibid, 44 (2), 118-127.
Concretionary phosphate occurs in Miocene limestone and marl, and in rolled pebbles at the "Miocene - Pliocene" disconformity; considered to be too thin to be economic at that time.

COULSON, A., 1933 - The Older Volcanic and Tertiary marine beds at Curlewis, near Geelong. Ibid., 45 (2), 140-149.
Local folding and faulting is thought to be due to tectonic movements associated with extrusion of the Newer Volcanics. Reference to gas seepage (95% CO_2) at Clifton Springs.

COULSON, A., 1935 - Geological notes on Lake Connewarre, near Geelong. Ibid., 48 (1), 1-7. Notes on sediments ranging in age from "Lower Miocene" to Recent and incorporates data from shallow drilling (all bores less than 100 feet except one to 339 feet).

COULSON, A., 1938 - The basalts of the Geelong District. Ibid., 50 (2), 251-257.

COULSON, A., 1939 - Notes on the physiography of the Geelong district. Ibid., 51 (1), 61-72.
He discusses the local structures as well as the physiography of the district.

COULSON, A., 1940 - The sand dunes of the Portland District and their relation to post-Pliocene uplift. Ibid., 52 (2), 315-335.

COULSON, A., 1941 - The volcanoes of the Portland district. Ibid., 53 (2), 394-402.
Description of the various volcanoes with some petrography.

COULSON, A., 1960 - Some structural features of the Barrabool Hills. Ibid., 72, 45-52.
East-west faults of small displacement mark the northern and southern limits of the Barrabool Hills; their age is "post-Janjukian-pre-Balcombian". Minor north-south faulting is "probably Upper Pliocene or Pleistocene" in age.

CREER, K.M., 1964 - Palaeomagnetic data and du Toit's reconstruction of Gondwanaland. Nature, 204 (4956), 369-370.

CRESPIN, Irene, 1926 - The geology of Green Gully, Keilor, with special reference to the fossiliferous beds. Proc.Roy.Soc.Vic., 38, 100-124. Older Basalt, foraminiferal limestone, fossiliferous ironstone (with derived phosphatic nodules), current-bedded sands, Newer Basalt, and younger sediments (including 5 feet of carbonaceous deposits containing diatoms).

CRESPIN, Irene, 1936 - The larger foraminifera of the Lower Miocene of Victoria. Palaeont.Bull.,Canberra 2.
Descriptions and illustrations of the larger foraminifera, mainly from the Gippsland Basin, but some from localities and bores in western Victoria.

CRESPIN, Irene, 1952 - Occurrence of Hantkenina at Torquay, Australia, and the age of the "Janjukian" and "Anglesean" Stages. Contr. Cushman Fdn., 1 (3,4), 70-75.

CRESPIN, Irene, 1954 - The Nelson Bore, south-western Victoria, micropalaeontology and stratigraphical succession. Bur.Min.Resour.Aust.Rep. 11
Gives lithological descriptions and fossil description of 427 samples; ?Miocene to 108 feet, Janjukian (limestone and glauconitic sandstone) to 976 feet, and unnamed lignitic sandstone to 7299 feet (T.D.)

CROCKER, R.L., 1941 - Notes on the geology and physiography of south-east South Australia with reference to late climatic history. Trans.Roy.Soc.S.Aust., 65 (1), 103-107.

CROCKER, R.L., 1946 - Post-Miocene climatic and geologic history and its significance in relation to the genesis of major soil types of South Australia. Bull.Coun.Sci.ind.Res.Aust. 193.

CROHN, P.W., 1952 - Victorian diatomite deposits. Bull.geol.Surv.Vic. 53.
Reference to small deposits near Melbourne and Allestine (Portland) in the Otway Basin.

DAINTREE, R., 1862 - Report on geology of Bellarine and Paywit with special reference to probable existence of workable coal seams in those parishes. Rep.geol.Surv.Vic. 1861-1862. (Not seen).

DALLWITZ, W.B., 1952 - A note on glauconitic minerals of low refractive index from Lower Tertiary beds in South Australia and Victoria. Sir Douglas Mawson Anniversary Volume, Univ. Adel., 55-62.
He compares samples from the Saint Vincent Basin with a sample from near the top of the Jan Juc Formation at Bird Rock, Victoria; "... the predominance ... of low-index, presumably aluminous, glauconites in certain Early Tertiary rocks of Australia" would supply information on the environment of deposition (possibly paralic).

DALLWITZ, W.B., 1955 - Petrography of sedimentary rocks from the Torquay - Eastern View area, Victoria. Proc.Roy.Soc.Vic., 67 (1), 143-148.
Descriptions of six samples collected by Raggatt and Crespin (1954) from the Tertiary sedimentary succession; an "acid ashstone" is described from just west of Airey's Inlet (from the Eastern View Coal Measures?).

DARRAGH, P.J., and BOWEN, K.G., 1965 - The occurrence of bentonite at Gellibrand. Min.geol.J., 6 (5), 32-36.
The bentonite occurs in the Mesozoic Otway Group of sediments - it provides evidence of contemporaneous vulcanism.

DAVID, T.W.E., 1914 - The geology of the Commonwealth.Brit.Ass.Adv.Sci., 84th Meeting: Australia 1914, Federal Handbook on Australia.

DAVID, T.W.E., 1932 - Explanatory notes to accompany a new geological map of the Commonwealth of Australia.Sydney: Commonwealth Coun.Sci.ind.Res.

DAVID, T.W.E., (ed.Browne, W.R.), 1950 - The geology of the Commonwealth of Australia.London,Arnold.

DAY, R.W., 1964 - Stratigraphy of the Roma - Wallumbilla area. Publ.geol.Surv.Qld, 318, 23pp.

DEFLANDRE, G., 1938 - Sur le microplancton des mers jurassiques conserve a l'etat de matiere organique dans les marnes de Villers-sur-Mer. C.R.Acad.Sci.Paris, 206, 687-689.

DEFLANDRE, G. & COOKSON, Isabel C., 1955 - Fossil microplankton from Australian late Mesozoic and Tertiary sediments. Aust.J.Mar.Freshw.Res., 6, 242-313.

DENNANT, J., 1889 - Notes on the Muddy Creek beds, with brief remarks on other Tertiary strata of south western Victoria. Trans.Roy.Soc.S.Aust., 11, 30-59.
A description of the geology with lists of fossils; two formations were recognized and these are separated by a phosphatic pebble bed at Muddy Creek.

DENNANT, J., 1890 - Observations on the Tertiary and post-Tertiary geology of south-western Victoria. Rep.Aust.Ass.Adv.Sci. 2, 441-452.
Additions to Dennant (1889); divides the sediments into Lower, Middle, and Upper Tertiary, and Pleistocene and Recent.

DENNANT, J., 1895 - Notes on a trip to Cape Otway. Geelong Naturalist, 5, 4-7. (not seen).

DENNANT, J., 1902 - Report on fossiliferous ironstone conglomerate from Cape Patton.Rec.geol.Surv.Vic., 1 (1), 36.
A note on the conglomerate which occurs at 500 feet above sea level and its fossils; (basal Unit Dd?).

DENNANT, J., and KITSON, A.E., 1903 - Catalogue of the described species of fossils (except bryozoa and foraminifera) in the Cainozoic fauna of Victoria, South Australia, and Tasmania. Rec.geol.Surv.Vic. 1 (2), 89-147.

DENNANT, J., and MULDER, J.F., 1897 - Probable Miocene age of a conglomerate at Shelford.Proc.Roy.Soc.Vic. 9, 174-182.
A fossiliferous ironstone conglomerate, named "Shelford Conglomerate" (basal Unit Bc?).

DENTON, E., and DENNISON, R., 1962 - Geophysical profiles through South Australian coastal basins.Aust.Oil Gas J., 8 (5), 24-28.
Describe and illustrate continuous reflection traverses from the Kanawinka Fault, through Penola into the zone of vulcanism north-west of Mount Gambier, and at Beachport, and compare these with observed gravity and vertical magnetic (where available) profiles; they conclude that seismic gives the more conclusive results.

DETTMAN, Mary E., 1963 - Upper Mesozoic microfloras from south-eastern Australia. Proc.Roy.Soc.Vic. 77 (1), 7.
The samples described are from the South Australian part of the Great Artesian Basin, the Otway Basin and the Gippsland Basin. Systematic descriptions of spores are given, and three successive microfloral assemblages are distinguished: "Stylosus" (lowermost Cretaceous); "Speciosus" (Valanginian-Aptian); "Paradoxa" (Aptian-Albian).

DICKINS, J.M., and McTAVISH, R.A., 1963 - Lower Triassic marine fossils from the Beagle Ridge (B.M.R.10) Bore, Perth Basin, Western Australia. J.geol.Soc.Aust., 10 (1), 123-140. (A reference used in palynological discussion).

DOOLEY, J.C., McCARTHY, E., KEATING, W.D., MADDERN, C.A., and WILLIAMS, L.W., 1961 - Pendulum measurements of gravity in Australia (1950-1952). Bur.Min.Resour.Aust.Bull. 46.

DOUGLAS, J.G., 1962 - Microplankton of the Deflandreidae Group in Western District sediments. Min.geol.J., 6 (4), 17-32. Defines a post-Mesozoic, early Tertiary zone of D.bakeri, a zone in the upper Mesozoic with Nelsoniella sp., and a third, older Deflandreidae zone with specialized forms such as D.pellucida, etc.
A correlation of part of bore and well sections is shown in Figure 1.

DOUGLAS, J.G., 1965a - The Mesozoic leaves Ginkgoites australis (McCoy) Florin, and Ginkgoites waarrensis n.sp.
Ibid., 6 (5), 20-24.

DOUGLAS, J.G., 1965b - A Mesozoic dicotyledenous leaf from the Yangery No. 1 Bore, Koroit, Victoria.
Ibid., 6 (5), 64-67.

DOWNIE, C., EVITT, W.R. & SARJEANT, W.A.S., 1963 - Dinoflagellates, hystrichospheres and the classification of the acritarchs. Stanford Univ.Publ.Geol.Sci., 7 (3), 1-16.

DUNN, E.J., 1912 - Geological notes on the Casterton and Coleraine Districts. Rec.geol.Surv.Vic., 3 (2), 113-117.
Reference to coal seams in two bores drilled at Merino; the beds have shallow south-westerly dip.

DUNN, E.J., 1917 - Alleged occurrence of mineral oil at Anglesea. Ibid., 4 (1) 45-6. Reference to brief gas discharge from bore to 90 feet at beach half-mile west of the mouth of the Anglesea River, on the flank of a small fold; no evidence of oil.

EASTON, J.G., 1936 - Pyritic lodes at Wyelangta, Cape Otway.
Ibid., 5, 659.
Thin seams located by a party looking for the source of alluvial gold reported from the area.

EDGELL, H.S., 1964 - The correlative value of microplankton in the Cretaceous of the Perth Basin, W.A. Rep.Dept.Mines W.A. (1963), 100-105.

EDWARDS, A.B., 1938 - The Tertiary volcanic rocks of central Victoria. Quart.J.geol.Soc.Lond., 94 (2), 243-320.
The description includes the north-eastern end of the Otway Basin; mostly petrological, but some discussion on physiography with several illustrations and a geological sketch map that shows structure.

EDWARDS, A.B., 1939 - Petrology of the Tertiary Older Volcanic Rocks of Victoria. Proc.Roy.Soc.Vic., 51 (1), 73-98.
The Older Volcanics are distinct from the Newer Volcanics both in their petrology and in the probable composition of the parent magma. Edwards prefers the division into 'Older (pre-Miocene to Miocene) and Newer (Pliocene to Recent) Volcanic Series'.

EDWARDS, A.B., 1953 - The composition of Victorian brown coals. In Coal in Australia. 5th.Emp.Min.metall.Cong., 6, 727-753. General descriptions of the properties of the various types of coals; the geology and distribution is given in Thomas (1953).

EDWARDS, A.B., 1962 - Notes on the geology of the Lorne District, Victoria. Proc.Roy.Soc.Vic., 75 (1), 101-119. Refers to the Benwerrin Coal Measures; these are Paleocene to Eocene in age and, because of their relatively high rank, Edwards estimates that they were originally buried below not less than 2500 feet of sediments. Uplifted in late Tertiary.

EDWARDS, A.B., and BAKER, G., 1943 - Jurassic arkose in southern Victoria. Proc.Roy.Soc.Vic., 55 (2), 195-228. The arkose beds are up to 433 feet thick and tend to be lenticular, with current bedding, mud pellets, and wood fragments. They are interbedded with mudstones, and minor grit, conglomerate, and black coal. Edwards and Baker suggest a Palaeozoic sedimentary and igneous rock source for the sediments; deposition in shallow water in a slowly subsiding basin is suggested, and a land mass in Bass Strait is regarded as the source of some of the material. Freshness of the feldspars is attributed to rapid erosion of the hinterland.

EDWARDS, A.B., and BAKER, G., 1951 - Some occurrences of supergene iron sulphides in relation to their environments of deposition. J.sediment.Petrol., 21, 34-46. The form of ferrous sulphide found in supergene deposits is an indication of the acidity of conditions at the time of deposition. The formation of marcasite in the acid environment of brown coal beds contrasts with the development of pyrite in marine clays (as in the Otway Basin) in a neutral or alkaline environment; these developments were paralleled in laboratory tests.

EISENACK, A. & COOKSON, Isabel C., 1960 - Microplankton from Australian Lower Cretaceous sediments. Proc.Roy.Soc.Vic. 72 (1), 1-10.

ETHERIDGE, R., 1873 - Note on the lignite deposit at Lal-Lal, Victoria, Australia. Quart.J.geol.Soc.Lond., 29, 565-568.

EVANS, P.R., 1963 - The application of palynology to stratigraphy in Australia. Proc. 2nd.Symp.Dev.Petr.Resour.Asia & Far East. Min.Dev.Ser., 18 (1), 285-290.

EVANS, P.R., 1966 - Mesozoic stratigraphic palynology in Australia. Aust.Oil Gas J., 12 (6), 58-63. Eleven subdivisions of the Cretaceous are recognized, most of which have been found in the Otway Basin. Lower Cretaceous sediments in the northern Murray Basin, which contain abundant microplankton, are linked with the Great Artesian Basin rather than the Otway Basin where acritarchs and only rare microplankton have been found.

EVITT, W.R., 1961 - Observation on the morphology of fossil dinoflagellates. Micropaleontology, 7 (4), 385-420.

EVITT, W.R., 1963 - A discussion and proposals concerning fossil dinoflagellates, hystrichospheres and acritarchs. Nat.Acad. Sci.Proc., 49, 158-164.

FAIRBRIDGE, R.W., 1950 - Problems of Australian geotectonics. Scope 1 (5), 22-28. A discussion of the geomorphological structure and geotectonic evolution of Australia (with accompanying figures); little mention of the Otway Basin region other than the occurrence of grabens filled with Tertiary sediments.

F.-B.H., 1964 - Port Campbell No. 1 and No. 2 Wells Victoria of Frome-Broken Hill Company Proprietary Limited. Bur.Min.Resour.Aust. Petrol.Search Subs. Acts Publ. 18.

FENNER, C., 1918a - The physiography of the Glenelg River. Proc.Roy. Soc.Vic., 30 (2), 99-120.

FENNER, C., 1918b - Physiography of the Werribee River area, Victoria. Ibid., 31 (1), 176-313.

FENNER, C., 1921 - The craters and lakes of Mount Gambier, South Australia. Trans.Roy.Soc. S.Aust., 45, 189-205.

FENNER, C., 1930 - The major structural and physiographic features of South Australia. Ibid., 54, 1-36. The above four papers deal mainly with physiography, geomorphology, and recent geological history.

GILL , E.D., 1943 - The geology of Warrnambool. Proc.Roy.Soc.Vic., 55 (2), 133-155.
Discusses the surface geology along a coastal strip two miles wide at Warrnambool. Miocene limestone is regarded as 'basement'. Dunes are thought to extend out to sea, hence sea-level originally lower; most recent movement is an elevation of 15 feet.

GILL, E.D., 1950 - Nomenclature of certain Tertiary sediments near Melbourne, Victoria. Proc.Roy.Soc.Vic., 62, 165-171.
Proposes the name 'Sandringham Sands' for sediments in the cliffs and coastal region between Melbourne and Mordialloc; they form part of the 'Brighton Group' (a name adopted from the 'Brighton beds' used in early geological maps, 1858 to 1893.)

GILL, E.D., 1957 - The stratigraphical occurrence and palaeoecology of some Australian Tertiary marsupials. Mem.nat.Mus.Vic., 21, 135-203.
Describes a section in the Hamilton district with Grange Burn Coquina containing phosphatic nodules, disconformably over Muddy Creek Marl (75 feet), conformably over Bochara Limestone (17 feet plus) - a new name for Lower Miocene limestone. In the eastern part of the basin, the Sandringham Sands are divided into the Pliocene 'Red Bluff Member' disconformably over the Upper Miocene 'Black Rock Member'.

GILL, E.D., 1964 - Rocks contiguous with the basaltic cuirass of western Victoria. Proc.Roy.Soc.Vic., 77 (2), 331-355.
Descriptions of terrains associated with the two main periods of vulcanism; these are useful for dating where fossils absent. The basaltic extrusions were associated with two major episodes of earth movement: the "Bass Strait Epoch" (older) and "Kosciusko Epoch". Some new formations are named.

GLAESSNER, M.F., 1947 - Decapod Crustacea (Callianassidae) from the Eocene of Victoria. Proc.Roy.Soc.Vic., 59, 1-7.

GLAESSNER, M.F., 1951 - Three foraminiferal zones in the Tertiary of Australia. Geol.Mag., 87, 273-283.
Notes the existence of three distinctive though not consecutive foraminiferal zones in the Tertiary of Australia.

GLAESSNER, M.F., 1953a - Conditions of Tertiary sedimentation in southern Australia. Trans.Roy.Soc.S.Aust., 76, 141-146. 'Tertiary sedimentation in southern Australia begins generally with paralic deposits (brackish, lignitiferous, intermittently marine), followed in some areas by an Upper Eocene marine ingression'. Also evidence of second paralic phase of late Eocene and early Oligocene age followed by an Upper Oligocene to Lower Miocene transgression. 'The Upper Miocene was a period of regression and faulting. The Lower Pliocene transgression which followed was more extensive in Western Victoria than in South Australia.'

GLAESSNER, M.F., 1953b - Clarke Memorial Lecture. Some problems of Tertiary geology in southern Australia. J.Roy.Soc. N.S.W., 87, 31-45.
Deals mainly with South Australia; his Figure 2 shows stratigraphic relations of the Tertiary formations, including those at Princetown and Anglesea, with ten stages.

GLAESSNER, M.F., 1959 - Tertiary stratigraphic correlation in the Indo-Pacific region and Australia. J.geol.Soc.India, 1, 53-67. The correlation of the Tertiary sequences from India to the islands of the western Pacific and to Australia is attempted.

GLAESSNER, M.F., 1964 - An Ammonite from the Upper Cretaceous of Victoria. Proc.Roy.Soc.Vic., 77 (2), 517-519.
The ammonite is from the lower part of the Belfast Mudstone in Flaxmans No. 1 Well, and is identified as Hauericeras angustum; a Lower Senonian age, (which is consistent with microfaunal and other macrofaunal evidence), is suggested.

GLAESSNER, M.F., and PARKIN, L.W., (Ed.), 1959 - The geology of South Australia. J.geol.Soc.Aust. 5 (2). The geology of south-eastern South Australia (western part of the Otway Basin) is described under the Murray Basin by N.H. Ludbrook; under a short section on Structure the south-east is separated as the "Gambier Sunklands" from the Murray Basin proper.

GLENIE, R.C., and REED, K.J., 1961 - Bores 2 and 3, Portland, Victoria - subsurface geology and engineering data.
Min.geol.J., 6 (4), 37-43.
Both bores drilled for water, No. 2 to 4719' 6" and No. 3 to 5638' 0". E - logs, gamma-ray and temperature logs were run except for the interval 3300 to 5600 feet in No. 3 for which no gamma ray log is available. They show a thick development of Tertiary sediments; No. 3 bottomed in ? lamprophyre of Miocene age.

GLOE, C.S., 1947 - The underground water resources of Victoria. Victoria State Rivers and Water Supply Commission, 1.
Details of some bores in the Mallee, Wimmera and Glenelg regions of western Victoria, with brief logs, and water analyses; the Tertiary is the main source of water.

GLOVER, J.E., 1955 - Petrographical study of rock samples from the coastal section between Torquay and Airey's Inlet, Victoria. Proc.Roy.Soc.Vic. 67 (1), 149-164.
Description of twenty-five specimens of sedimentary rocks, volcanic breccia and agglomerate, jarosite ?, and gypsum.

GRANT, C.Kerr, 1954 - Gravity survey Cape Jaffa area. Min.Rev.Adelaide, 96, 72-74. A major basement fault (throw 8600 feet) is shown south of Cape Jaffa, and two minor faults across the Cape; a small gravity high occurs south of Kingston.

GRANT, F.E., 1901 - Notes on the Royal Park (Melbourne) railway cutting. Rep.Aust.Ass.Adv.Sci., 8, 226 (Abstract).
Reference to a fossiliferous ironstone band which extends through the cutting, 'indicating the northern limit of the eocene'.

GRAYSON, H.J., and MAHONY, D.J., 1910 - The geology of the Camperdown and Mount Elephant districts. Descriptive of Geological Quarter - Sheet Maps Nos. 8 N.E. and 17 S.E. (New Series). Mem.geol.Surv.Vic. 9.
The area occurs in the volcanic plains of western Victoria, and most of the paper deals with the volcanics; marine Cainozoic sediments are briefly described and accompanied by fossil lists. Many references to early reports (earliest by Charles Darwin, 1844).

GRIFFITHS, G.S., 1887 - The geology of the Portland promontory, western Victoria. Trans.Roy.Soc.Vic., 24 (1), 61-80.

G.S.A., 1962 - Geological notes in explanation of the Tectonic Map of Australia. Bur.Min.Resour.Aust., 1962.
Generalized notes on the tectonics of the major time divisions.

GUILLEMOT, J., and TISSOT, B., 1965 - La géologie des principaux bassins sédimentaires Australiens. Rev.Inst.Franc.Pétrole et Ann. des combustibles Liquides, 20 (3), 451-462.
Brief descriptions of the Otway and Gippsland Basins (which are similar) and a probable basin under Bass Strait; references to oil and gas indications in Gippsland Basin, and gas in the Otway Basin.

HALL, T.S., and PRITCHARD, G.B., 1897a - A contribution to our knowledge of the Tertiaries in the neighbourhood of Melbourne. Proc.Roy. Soc.Vic., 9, 187-229.
A summary of investigations and outcrops of the Tertiary rocks around Melbourne; some bore data and fossil lists.

HALL, T.S., and PRITCHARD, G.B., 1897b - The geology of the Lower Moorabool. Ibid., 10 (1), 43-56.
Description of outcrop geology; fossil lists.

HALL, T.S., and PRITCHARD, G.B., 1899 - The Tertiary deposits of the Aire and Cape Otway. Ibid., 12 (1), 36-58.
Outcrops are described and fossils listed; suggest that Tertiary-Mesozoic boundary is faulted.

HALL, T.S., and PRITCHARD, G.B., 1901 - Some sections illustrating the geological structure of the country about Mornington. Ibid., 14 (1), 32-54.
Description of some sections, local structure and general succession (no map).

HALL, T.S., and PRITCHARD, G.B., 1902 - A suggested nomenclature for the marine Tertiary deposits of southern Australia. Ibid., 14 (2), 75-81.
Localities assigned to the Werrikooian, Kalimnan, Balcombian, and Jan Jucian, and the sequence and ages of these divisions are discussed. (Later revised by Pritchard, 1924).

HARE, R., & Associates, 1963 - See O.D.N.L., 1963.

HARRIS, W.J., and THOMAS, D.E., 1949 - Geology of the Meredith area. Min.geol.J., 3 (5), 43-51.
The geology and structure north of Maude - mainly Ordovician, but some Permian glacials, and Tertiary volcanics and sediments. (See also Thomas, 1959).

HARRIS, W.K., 1965 - Basal Tertiary microfloras from the Princetown area, Victoria, Australia. Palaeontographica 115B, 75-106.
Descriptions of new genera and species of spores and pollen. The microfloral succession indicates the climate changed from cool to warm temperate or sub-tropical during deposition of the basal Tertiary sediments.

HARRIS, W.K., and COOKSON, Isabel C., 1965 - The stratigraphy of the Comaum No. 2 Bore - a reinterpretation. Aust.J.Sci., 28 (1), 25-26.
A reinterpretation following Dettmann (1963).

HEEZEN, B.C., THARP, M., and EWING, M., 1959 - The floors of the oceans.1. The North Atlantic. Spec.Pap.geol.Soc.Amer. 65.

HEISKANEN, W., 1950 - On the isostatic structure of the earth's crust. Isostatic Institute, Helsinki.

HENDERSON, S.D., CONDON, M.A., & BASTIAN, L.V., 1963 - Stratigraphic drilling, Canning Basin, Western Australia. Bur.Min.Resour.Aust. Rep. 60.

H.E.P.L., 1965 - Bass Strait and Encounter Bay Aeromagnetic Survey, 1960-1961. Bur.Min.Resour.Aust.Petrol.Search Subs.Acts Publ.60.

HILLS, E.S., 1939 - The age and physiographic relationships of the Cainozoic volcanic rocks of Victoria. Proc.Roy.Soc.Vic., 51. 112-139.
Concludes that Older Volcanics are Oligocene to Lower Miocene, and Newer Volcanics are Middle Pliocene to Recent. Some petrological descriptions are given.

HILLS, E.S., 1946 - The physiography of Victoria. Whitcombe & Tombs Pty. Ltd., Melbourne.
A text book on physiography and geomorphology, illustrated by features mainly in Victoria. Physiographic divisions in Victoria are described (pp.238-270). He notes that the F2 (Kanawinka) Fault in South Australia passes into an escarpment in Victoria which is a former marine cliff. The coast exposed in the eastern part of the Otway Basin was formed by the drowning of a block-faulted land mass.

HILLS, E.S., 1956 - A contribution to the morphotectonics of Australia. J.geol.Soc.Aust., 3, 1-15.
The lineament patterns on which he bases his arguments occur in the Otway Basin region. He concludes that the Australian block is everywhere underlain by Precambrian basement (as against the idea of the addition of successive fold belts), and that the continental mass has fractured both marginally and internally.

HILLS, E.S., 1963 - Elements of structual geology. Methuen, London.
Another general text following his earlier work of 1940: Outlines of structual geology (revised 1953). The Otway Basin is included in the "Bassian Trough" in his Figure XI. - 2: Simplified tectonic map of Australia, (p.316); figures on pages 334-5, and 435 are also relevant to the structure of the Otway Basin.

HORNIBROOK, N.de B. & HARRINGTON, H.J., 1957 - The status of the Wangaloan Stage. N.Z.J. Sci.Tech., 38, 655-670. (See Palynology).

HOSKING, J.S., 1951 - Clay resources of Australia. Rep.Aust.Ass.Adv. Sci., 1951.
In places such as Colac, weathered 'Jurassic' arkose and shale provide an important source of raw material for brick manufacture. (See also Keble and Watson, 1952).

HOSSFELD, P.S., 1950 - The late Cainozoic history of the south-east of South Australia. Trans.Roy.Soc.S.Aust., 73 (2), 232-279.
A provisional chronology is presented for the late Cainozoic shoreline movements which are correlated with sea-level changes in the 'Pleistocene Ice Age'.

JACK, R.L., 1930 - Geological structure and other factors in relation to underground water supply in portions of South Australia. Bull.geol.Surv.S.Aust. 14.
See papers by Ward (1941, 1946) and O'Driscoll (1960) for later information.

JANSONIUS, J., 1962 - Palynology of Permian and Triassic sediments, Peace River area, Western Canada. Palaeontographica, 110B, 35-98. (A reference for palynological contribution).

JENNINGS, J.N., 1959 - The submarine topography of Bass Strait. Proc.Roy.Soc.Vic., 71 (1), 49-72.

JOHNS, R.K., 1963 - Limestone, dolomite and magnesite resources of South Australia. Bull.geol.Surv.S.Aust. 38.

JOHNS, R.K., 1965 a - Tantanoola dolomite deposit - Up and Down Rocks. S.Aust.Min.Rev., 118, 5-15.

JOHNS, R.K., 1965b - Diamond drilling operations - Section 333, Hundred of Caroline. Ibid., 118, 87-90.
On the economic possibilities of carbonate deposits of the south-east of South Australia.

JUTSON, J.T., 1927 - Notes on the coastal physiography of Port Campbell, Victoria. Proc.Roy.Soc.Vic., 40 (1), 45-57.

JUTSON, J.T., 1931 - Erosion and sedimentation in Port Phillip Bay. Ibid., 43 (2), 130-153.

JUTSON, J.T., and COULSON, A., 1937 - On the age of certain marine deposits at Portarlington, Victoria, with a proposed subdivision of the post-Tertiary rocks of the Port Phillip Bay District. Ibid., 49 (2), 314-326.
Papers on the post-Tertiary sedimentation and physiography of parts of the eastern end of the Otway Basin.

KEBLE, R.A., 1925 - Tertiary magnesium limestone at Coimadai. Rec.geol.Surv.Vic., 4 (4), 441-443.
Source of lime and building stone.

KEBLE, R.A., 1950 - The Mornington Peninsula. Mem.geol.Surv.Vic., 17, 84 pp.
A description of the geology with two maps and numerous text figures. The Selwyn Fault along the western side of Mornington Peninsula, and across the Nepean Peninsula to the south, has a throw of over 1300 feet - based on correlation between outcrop east of the fault, and the Sorrento Bore section to the west. (The Selwyn Fault forms part of the eastern boundary of the Otway Basin).

KEBLE, R.A., and WATSON, J.C., 1952 - Clay and shale deposits of Victoria. Mem.geol.Surv.Vic. 18.
A description of clay occurrences and their properties.

KENLEY, P.R., 1951 - Marine Eocene sediments near Casterton, Victoria. Aust.J.Sci., 14 (3), 91-92.
These beds occur in Glenelg River, seven miles south of Casterton; they underlie bryozoal limestone and overlie Mesozoic claystones; the fauna is similar to the Pebble Point Beds, and the beds were subsequently (Kenley, 1954) referred to the Bahgallah Formation.

KENLEY, P.R., 1954 - The occurrence of Cretaceous sediments in south-western Victoria. Proc.Roy.Soc.Vic., 66, 1-16.
Describes the Merino Group comprising the Lower Cretaceous Runnymede Formation (65 feet thick) disconformably over the Mocamboro Member (Upper Jurassic, 24 feet plus). The lithology includes sandstone (commonly lenticular), polymict conglomerate, mudstone, intraformational breccias, and coal; a deltaic environment is suggested. The Kanawinka Fault is extended south of Killara as the Weecurra Fault.

KENLEY, P.R., 1959 - The occurrence of marine Cretaceous sediments in the Belfast No. 4 Bore, Port Fairy. Min.geol.J., 6 (3), 55-56.
The marine Cretaceous contains ammonites and is possibly Upper Cretaceous in age; it occurs between 4649 and 4655 feet.

KENNY, J.P.L., 1938 - Geology of the Kawarren - Gellibrand District. Min.geol.J., 1 (3), 76-79.
Area lies on north side of Otway Ranges; descriptions of sporadic outcrops. Suggests that Tertiary, with dips up to 30°, is faulted.

KENNY, J.P.L., 1939 - Limestone at Heywood. Min.geol.J., 2 (1), 52-54.
Important economic source of lime.

KINGSBURY, C.J.R., 1957 - Eocene clays of the Knight Formation - South east province. S.Aust.Min.Rev., 103, 93-97.
No shallow clays of economic significance; geological map of Mount Gambier area.

KITSON, A.E., 1900 - Report on the coast line and adjacent country between Frankston, Mornington, and Dromana. Monthly Progress Rep.geol.Surv.Vic., 12, 2-13.
Recognized 'Jurassic' similar to that in Cape Otway district. Geological map.

KITSON, A.E., 1906 - Report on the diatomite deposits and general geology of the Portland District, with plan (Plate XXX). Rec.geol.Surv.Vic., 1 (4), 254-5. (Not seen; see Crohn, 1952).

KRAUSE, F.M., 1874 - Report, Cape Otway District. Progress Rep.geol.Surv.Vic., 1, 99-117.
Recognized 'pliocene' Tertiary from 300 to 1200 feet above sea-level, over Mesozoic rocks. Several sketches of sections.

KRUMBEIN, W.C., and SLOSS, L.L., 1963 - Stratigraphy and sedimentation. 2nd.Ed. Freeman, San Francisco.

LAHOUD, J.A., MILLER, D.S., and FRIEDMAN, G.M., 1966 - Relationship between depositional environment and uranium concentrations of molluskan shells. J.sediment.Petrol., 36 (2), 541-547.

LESLIE, R.B., 1966 - Petroleum exploration in the Otway Basin. 8th.Comm.Min.metall.Cong., 34th.Sess., Queensland, 1965, Paper 109, 203-216.
A comprehensive review of the Otway Basin, its stratigraphy, structure, and the exploration for petroleum; he concludes that conditions suitable for the occurrence of petroleum are present.

LUDBROOK, N.H., 1957 - A reference column for the Tertiary sediments of the South Australian portion of the Murray Basin. J.Roy.Soc.N.S.W., 90, 174-180.
The Gambier Sunklands are included in the Murray Basin for the purpose of this paper. Seventeen rock units are named according to the Australian Code of Stratigraphic Nomenclature.

LUDBROOK, N.H., 1961 - Stratigraphy of the Murray Basin in South Australia. Bull.geolSurv.S.Aust. 36.
'The Murray Basin is an area of Mesozoic and Tertiary sedimentation divided into two main units, the Murray Basin proper separated by structural highs - the Padthaway "Horst" - from the Gambier Sunklands'. The stratigraphy deals mainly with the Murray Basin proper, incorporating bore data and palaeontological information; the rock units are after Ludbrook (1957).

LUDBROOK, N.H., 1963 - Correlation of the Tertiary rocks of South Australia. Trans.Roy.Soc.S.Aust., 87, 5-15.
A correlation based mainly on microfossils with some notes on environment of deposition.

MAHONY, D.J., 1912 - Diatomaceous earth and its occurrence in Victoria. Bull.geol.Surv.Vic., 26.
Impure deposits at Portland and near Melbourne; generally associated with the 'Newer' basalts. (see also Crohn, 1952).

MAWSON, D., and DALLWITZ, W.B., 1944 - Palaeozoic igneous rocks of lower south-eastern South Australia. Trans.Roy.Soc.S.Aust., 68 (2), 191-209.
Descriptions of Middle Cambrian quartz-keratophyres and pre-Ordovician potash-soda granite, microgranite, and quartz porphry from the "Padthaway Horst" area.

MAWSON, D., and PARKIN, L.W., 1943 - The granitic rocks of soth-eastern South Australia.
Ibid., 67 (2).

MAWSON, D., and SEGNIT, E.R., 1945 - Granites of the Tintinara District. Ibid., 69 (2), 263-276.
The above three papers form a study of the granites of the "Padthaway Horst" area.

Mc GOWRAN, B., 1959 - Tertiary nautiloids (Eutrephoceras and Cimomia) from South Australia. J.Paleont., 33 (3), 435-448.
Some specimens from the Otway Basin.

McGOWRAN, B., 1965 - Two Paleocene foraminiferal faunas from the Wangerrip Group, Pebble Point coastal section, Western Victoria. Proc.Roy.Soc.Vic., 79 (1), 9-74.

McINERNY, K., 1929 - The building stones of Victoria, Part II. The igneous rocks. Proc.Roy.Soc.Vic., 41 (2), 121-159. (see also Victorian Department of Mines Pamphlet - Victorian building stones, 1937).

McLEOD, I.R., 1965 - Australian Mineral Industry: the mineral deposits. Bur.Min.Resour.Aust.Bull. 72.
Mentions the minor black coal deposits in the Otway-Bellarine and Casterton-Merino areas, and bentonite and Fuller's Earth near Colac.

McPHEE, I., 1963 - Conorada Ooroonoo No. 1, Queensland, of Conorada Petroleum Corporation. Bur.Min.Resour.Aust.PetrolSearch Subs. Acts Publ. 23.

McQUEEN, A.F., 1961 - The geology of the Otway Basin. Aust.Oil Gas J., 8 (2), 8-12.
A summary of the stratigraphic and structural knowledge of the Otway Basin presented at the Australian Petroleum Exploration Association meetings of 1961. Suggests Bass Strait region as source of Mesozoic clastics because arkose predominant in Otway area, and minor near Merino. No evidence of compressional folding.

MEDWELL, Lorna M., 1954a - A review and revision of the flora of the Victorian Lower Jurassic. Proc.Roy.Soc.Vic., 65 (2), 63-111. There is a large section on previous investigations - a review of literature concerning Victorian Mesozoic plants and strata, and a comprehensive bibliography. Reference is made to the Merino Group, Otway Group, Barrabool Sandstone (and also the Strzelecki and Ovens Groups).

MEDWELL, Lorna M. 1954b - Fossil plants from Killara, near Casterton, Victoria. Ibid., 66, 17-24. These were used to differentiate the Runnymede Formation from the underlying Mocamboro Member in the landslip scar in the bluff near Killara; on the basis of Medwell's work, (and because of the disconformity between the units) the Runnymede Formation was given a Lower Cretaceous age, and Mocamboro Member was regarded as probably Upper Jurassic (Kenley, 1954).

MENARD, H.W., 1964 - Marine geology of the Pacific. McGraw-Hill, New York, 271 pp.

MITCHELL, Caroline, and TOWNSEND, Florence I., Lexicon of Victorian stratigraphy. Lex.strat.Int., 6 (5c), in press.

MURRAY, R.A.F., 1877 - Report on the geology of the Cape Otway district. Progress Rep.geol.Surv.Vic., 4, 127-135. Geology of the coastal area between Princetown and Joanna Bay and 25 miles inland.

O.D.N.L., 1963 - O.D.N.L. Penola No. 1 Well, South Australia of Oil Development N.L. Bur.Min.Resour.Aust.Petrol.Search Subs. Acts Publ. 42. Drilled on the subsurface Coonawarra structure. Tertiary drilled to 1040 feet. Lower Cretaceous sediments occurred from 1040 to 4985 feet (total depth). Minor gas shows occurred in the Lower Cretaceous sediments.

O'DRISCOLL, E.P.D., 1960 - The hydrology of the Murray Basin province in South Australia. Bull.geol.Surv.S.Aust. 35. The Gambier Sunklands are included in the Murray Basin. Refers to 'Padthaway Ridge' instead of 'Horst' and disagrees with Sprigg's (1952) structural interpretation. As well as structure, he discusses the stratigraphy, general hydrology, and detailed hydrology of each county. Numerous plates and figures are included - surface contours, contours of Tertiary floor, aeromagnetic contours, Bouguer anomaly contours, structural lineaments, sections, contours of upper surface of Knight Group, and many drawings showing hydrological aspects, and also a lot of bore data.

OLLIER, C.D., and JOYCE, E.B., 1964 - Volcanic physiography of the western plains of Victoria. Proc.Roy.Soc.Vic., 77 (2), 357-376. 94 named points of volcanic eruption are described. There are few lineaments in the pattern of eruption, and since many flows can be related to particular vents, it is suggested that central eruption was prevalent. The main lineaments are compared with gravity anomalies.

ÖPIK, A.A., and others, 1957 - The Cambrian geology of Australia. Bur.Min.Resour.Aust.Bull. 49. This bulletin includes the paper by Thomas and Singleton (1956), and Öpik's account of the Cambrian palaeogeography of Australia.

PARR, W.J., - (Several references listed in Singleton, 1941, and Carter, 1958b, 1964).

PETTIJOHN, F.J., 1957 - Sedimentary rocks. Harper, New York. (Main reference for sedimentary petrological work).

PHILIP, G.M., 1958 - The Jurassic sediments of the Tyers Group, Gippsland, Victoria. Proc.Roy.Soc.Vic., 70 (2), 181-199. The Tyers Group is a basal Jurassic conglomerate with greywacke sandstone, mudstone, etc., up to 2000 feet thick.

PRITCHARD, G.B., 1896 - On the present state of our knowledge of the older Tertiaries of South Australia. Rep.Aust.Ass.Adv.Sci., 6, 348-361.

PRITCHARD, G.B., 1924 - The character and sequence of the Victorian Tertiaries. Proc.Pan-Pacif.Sci.Cong.,Australia, 1923, 1, 934-939. The history of Tertiary nomenclature from 1900 to 1920, with a discussion of the sediments and depositional environments at different localities for each unit.

PRITCHARD, G.B., 1940 - The Tertiaries of Australia. Proc.Pan-Pacif. Sci.Cong.California, 1939, 2, 523-526.

RAGGATT, H.G., and CRESPIN, Irene, 1952 - Geology of the Tertiary rocks between Torquay and Eastern View, Victoria. Aust.J.Sci., 14 (4), 143-147.
A preliminary paper which defines a number of stratigraphic units.

RAGGATT, H.G., and CRESPIN, Irene, 1955 - Stratigraphy of Tertiary rocks between Torquay and Eastern View, Victoria. Proc.Roy.Soc.Vic., 67, 75-142. Detailed mapping and stratigraphy along 20 miles of coastline, with descriptions and illustrations of many sections.

REED, K.J., 1965 - Mid-Tertiary smaller foraminifera from a bore at Heywood, Victoria, Australia.
Bull.Amer.Paleont., 49 (220), 43-100.

REEVES, F., 1951 - Australian oil possibilities. Bull.Amer.Ass.Petrol.Geol., 35 (12), 2479-2525.
He includes the Otway Basin in the "Murray River Basin" and in the group of basins with slight prospects for oil (favouring the off-shore, rather than on-shore areas). His Table IV gives a summary of exploratory wells deeper than 1000 feet.

REYNOLDS, M.A., EVANS, P.R., BRYAN, R., and HAWKINS, P.J., -
The stratigraphic nomenclature of Cretaceous rocks in the Otway Basin. Aust.Oil Gas J., 13, (3), 26-33.

RICHARDS, H.C., 1921 - Post Cretaceous rocks of Australia. Proc.Pan-Pacif. Sci.Cong.,Honolulu, 1920 3, 753. (not seen).

RUDD, E.A., 1962 - Oil in Australasia. Aust. Oil Gas J., 8 (12), 8-14.
Rudd refers only south-western Victoria to the Otway Basin, and also to the thick section of marine Cretaceous with promising signs of gas and condensate which occurs there. In south-eastern South Australia, the more attractive environments for hydrocarbon occurrence may be off-shore in the continental shelf area.

S.A.D.M., 1954 - Exploratory drilling for coal at Comaum. S.Aust.Min.Rev., 97, 20-21.
Brief description accompanied by radiometric and geological logs.

S.A.D.M., 1962 - Department of Mines, South Australia. Schedule of petroleum exploration reports on open file. Aust. Oil Gas J, 8 (10), 34-39.

S.A.D.M., 1963 - Idem, Ibid., 9 (9), 40-41.
The schedules include reports from 1954 to 1961. Only a few of these have been listed in the bibliography, mainly those which were available at the Bureau of Mineral Resources for the Otway Basin review.

SCHUCHERT, C., 1929 - Review of the later Paleozoic formations and faunas, with special reference to the ice-age of middle Permian time. Bull.geol.Soc.Amer., 39, 784.

SEWARD, A.C., 1904 - On a collection of Jurassic plants from Victoria. Rec.geol.Surv.Vic., 1 (3), 155-211.

SINGLETON, F.A., 1935 - Werrikooian deposits of western Victoria. Rep.Aust. Ass.Adv.Sci., 22, 146 (abstract).
The limestone with Ostrea in south-western Victoria is Werrikooian or younger; the steep-sided valley of the lower Glenelg River was cut as a result of post-Werrikooian (Pleistocene) uplift; the "Newer Basalt" of Portland Cliffs is probably not older than Pleistocene.

SINGLETON, F.A., 1938 - The Tertiary sequence in south-east Australia. Rep.Aust.Ass.Adv.Sci. 23, 442. (see below).

SINGLETON, F.A., 1941 - The Tertiary geology of Australia. Proc.Roy.Soc. Vic., 53, 1-125.
Gives an historical account of the work done since 1861, with a comprehensive bibliography.
He reviews the stratigraphic nomenclature, the regional distribution of the units and the Tertiary geological history, and presents a correlation table of the units in Australia.

SINGLETON, F.A., 1943 - An Eocene molluscan fauna from Victoria. Ibid., 55 (2), 267-281.
The Lahillia - Cucullaea fauna from the Pebble Point Formation shows relationships to the Wangaloan fauna of New Zealand (and also to the late Cretaceous - early Tertiary of South America and Antarctica). Singleton states that it is different to known Australian faunas, and refers it to the Lower Eocene or Paleocene. Some new species are described.

SINGLETON, O.P., 1954 - The Tertiary stratigraphy of Western Australia - a review. Proc.Pan-Indian Ocean Sci.Cong.,Sect. C, 59-65.
Mainly on Western Australia, but briefly describes south-eastern Australia and shows the similarity between the western and eastern Australian sequences. He suggests three environmental facies below the Miocene: a lower, widespread non-marine lignitiferous facies, a euxenic facies of carbonaceous sands and silts, and an upper normal marine facies.

SKEATS, E.W., 1909 - The volcanic rocks of Victoria. Address by the President. Rep.Aust.Ass.Adv.Sci., 12, 173-235.
He deals with the Cainozoic volcanics from page 199 to 211. A map showing distribution of volcanic rocks, and several cross-sections are presented. Papers by Edwards (1938, 1939) follow Skeats's work.

SKEATS, E.W., (Ed.), 1935 - Outline of the physiography and geology of Victoria. Handbook for Victoria. Aust.Ass.Adv.Sci., Melbourne, 78-135.

SOLOMON, M., and SPRIGG, R.C., 1951 - Geological atlas of South Australia sheet Kingston. 1 inch/1 mile (1:63,360). Geol.surv.S.Aust. Military survey map ref. 883, Zone 6.

SPENCER-JONES, D., 1956 - Permo - Carboniferous and Jurassic sediments in the Kadnook - Mooree area, Western Victoria. Min.geol.J., 6 (1), 36-38. Unfossiliferous Permo - Carboniferous sediments, more than 300 feet thick, occur over post-Ordovician granite and Cambro-Ordovician rocks; they are tillite, sand, silt and clay (some varved). Their contact with the Jurassic was not seen. The Jurassic sediments include sandstone and mudstones, with basal gravels in places, and some plant fossils. Map at 1 inch = 2 miles. (This area is north of the limits of the Otway Basin).

SPENCER-JONES, D., 1958 - Humicite in the Grampians sandstone, McKenzie Creek, western Victoria. Min.geol.J., 6 (2), 42-45. Blackish-brown material filling veins and pores in sandstone; it is too high in oxygen to be asphaltic pyrobitumen and its mode of occurrence does not suggest that it is a cannel coal or lignite. He suggests a derivation from Tertiary coal, and its movement into veins etc., as humic acid gel, hence the name "Humicite".

SPENCER-JONES, D., 1963 - Joint patterns and their relationship to regional trends. J.geol.Soc.Aust., 10 (2), 279-297. An analysis of joint patterns in the Grampians using photogeology and some field observations. The joints conform to fault trends, and probably formed during the Kanimblan Orogeny (epi - Lower to Middle Carboniferous). Later movements of less intensity may have accentuated the joint system. Includes a map showing distribution of Grampian Group rocks, and several figures and photographs.

SPENCER-JONES, D., 1965 - The geology and structure of the Grampians area, western Victoria. Mem.geol.Surv.Vic. 25. The integration of Spencer-Jones' work in the Grampians. It is presented in four main parts: regional geology, structure, the sediments of the Grampians Group, and geomorphology, with a bibliography for each part. The petrography is included in appendices.

SPRIGG, R.C., 1950 - Stranded Pleistocene sea beaches of the south-east of South Australia and aspects of the theories of Milankovitch and Zeuner. Rep.Int.geolCong., 18th Sess. London, 1948, 8, 226-237. (see Sprigg, 1952).

SPRIGG, R.C., 1952 - The geology of the South-East Province, South Australia, with special reference to Quaternary coast-line migrations and modern beach development. Bull.geol.Surv.S.Aust. 29. Divides the Province into the Padthaway "buried horst" and "Gambier sunklands" with over 7,000 feet of Tertiary sediments and an unknown thickness of 'Jurassic non-marine sandstones'. Bedrock crops out in places on the Padthaway horst, and Permian glacigenes occupy hollows in the horst and 'may also occur at depth in the sunklands'. The important structural elements are faults; folding is subordinate and mainly associated with faulting. The Mount Gambier region, however, was on a north-north-east trending crest of upwarping in the Quaternary (more or less parallel to the Mt. Lofty - Kangaroo Island horst). Late Tertiary and Quaternary vulcanism is described, and the concluding chapters deal with Quaternary coast-line migrations, beach studies and geochronology of the Quaternary. He regarded the region's petroleum possibilities as incompletely tested. Introduces new formations: 'Knight sands and clays' and 'Gambier limestone'.

SPRIGG, R.C., 1959a - Stranded sea beaches and associated sand accumulations of the upper South-East. Trans. Roy. Soc. S. Aust., 82, 183-193. This paper covers the area north of Cape Jaffa; granite outcrops of the Padthaway ridge as shown. The Kanawinka Fault escarpment is traced to the north.

SPRIGG, R.C., 1959b - Presumed submarine volcanic activity near Beachport, south-east South Australia. Ibid. 82, 195-203. Interprets submarine ridges normal to the coast-line as old lava flows with marginal valleys.

SPRIGG, R.C. 1961 - Petroleum prospects of the Mesozoic - Tertiary basins of south-eastern Australia. Aust. Oil Gas J., 7 (10), 8-18. He gives a brief stratigraphic outline, illustrated by composite logs of strata in the various basins; the chapter on structure deals mainly with faulting for the Otway Basin, with reference to 'lines of gentle fold structures' indicating shear faulting in depth. Although Sprigg earlier (1952) expressed disappointment that oil seepages were not known from the region, he tends in this paper to regard occurrences of coastal bitumen as derived from local offshore sources, and to accept the suggestions of A. McIntosh Reid, (1931 - The oilfields of south-western Victoria and south-eastern South Australia. Bull. and Supp. by Western Petroleum N.L. - a private report?).

SPRIGG, R.C, 1962a - Oil and gas possibilities of the Gambier Portland Basin. Aust. Petrol. Expl. Ass. Ltd. Conference, Melbourne, 196~~1, 57-70. Reference to the "Penola and Kingston troughs";~~ basin terminology is, however, inconsistent and unreliable. He regards the possibilities of locating economic accumulations of hydrocarbons as more promising than he did in earlier papers, mainly as a result of additional exploration in the region. The Kanawinka escarpment is now regarded as an old coastal cliff and separated from faulting.

SPRIGG, R.C. 1962b - Progress exploration in southern Australain Tertiary Basins. J. Aust. Petrol. Expl. Ass. 1962, 43-44; also, Aust. Oil Gas J., 8 (10), 30-31. Reference to exploration activity in preceding twelve months; recognizes a trough or half-graben south of a hinge-line through Beachport, north of Mount Gambier, towards the base of the 'Otway highlands'.

SPRIGG, R.C., 1962c - Petroleum prospects of the Gambier sub-basin in relation to the evolution of the continental terrace. Aust. Inst. Min. Metall. Tech. Papers: Oil in Australasia, Annual Conference, Queensland, 1962. Refers to the "Otway - Gippsland Trough", formed in the Jurassic and possibly tectonically related to Tasmanian dolerite extensions. This is separated from the Gambier Sub-basin by the Dartmoor ridge. The paper is more or less a summary of previous papers.

SPRIGG, R.C., 1963a - Chairman's Inaugural Address. Progress in oil exploration in eastern and central Australia in 1962. J. Aust. Petrol. Expl. Ass., 1963, 6-9. Significant contributions made in 1962 to knowledge of the Otway Basin were that the Upper Mesozoic sediments of the Port Campbell embayment extend westerly beneath the sea (and not to the north-west as expected); that the Mount Salt structure did not persist at depth and that a thick marine Upper Cretaceous section occurred in that region; and that the potential importance of the continental shelf was indicated by geophysical surveys.

SPRIGG, R.C., 1963b - New structural discoveries off Australia's southern coast. Aust. Oil Gas J., 9 (12), 32-42. An oceanographic survey was conducted at the western end of the Otway Basin, south of Kangaroo Island. It showed large, 'canyon-like' furrows down the continental slope, and evidence of submarine sliding (which is advanced as further evidence of bitumen strandings being of local significance).

SPRIGG, R.C., 1964 - The South Australian continental shelf as a habitat for petroleum. J. Aust. Petrol Explr. Ass., 1964, 53-63. Refers to Permian, Cretaceous and Tertiary sediments extending into the shelf region, and a "Permian trough" or glacial valley offshore from the Padthaway ridge, interpreted on aeromagnetic data to extend to 4,000 feet. This concept requires a land mass to the south. An east-west graben filled with Cretaceous sediments projects across the continental shelf in the south-east; landward dip at depth may suggest a land mass to the south which formed the southern margin to the Otway Basin. A major structural break is postulated for the end of the Lower Cretaceous when development of the modern continental shelf began. The Murray River had its principal outlets in the extreme south-east (Mount Salt area) in the 'mid-Cretaceous' (Upper Cretaceous) to early Tertiary but shifted to its present position during the late Cainozoic. Thick sediments in the Mount Salt area, and opposite the present Murray River mouth have provided promising environments for petroleum generation, and there are areas of coastal bitumen recordings. Best prospects for hydrocarbons are in the 'Middle Cretaceous' to Tertiary sediments, but older Cretaceous and Permian Deposits are also prospective. Data is repeated from SPRIGG (1963b) and a table of 'crude oil strandings', March 1961 to April 1964, is presented.

SPRIGG, R.C., and BOUTAKOFF, N., 1953 - Summary report on the petroleum possibilities of the Gambier Sunklands. S. Aust. Min. Rev., 95, 41-62. The results of a combined review of the western part of the Otway Basin by the South Australian and Victorian Departments of Mines. The prospects for petroleum were considered to be unpromising on the information available. More geophysical surveys, to be followed possibly by one or more trial bores, were recommended. The report includes a correlation chart, and a bore summary table (the data given varies from that in O'Driscoll 1960).

SPRIGG, R.C., and WOOLLEY, J.B., 1963a - Oil and gas prospects of the Geltwood Beach Anticline, Millicent, South Australia. J. Aust. Petrol. Expl. Ass. 1963, 69-79. The conclusion is reached that the anticline is on the 'inner continental shelf' margin; it is south of the Beachport - Kalangadoo "hinge-line", and within a zone of submarine oil seepage; it was considered to be favourably situated for accumulation of hydrocarbons. (However, see G.E.A.L., 1964 unpublished).

SPRIGG, R.C., and WOOLLEY, J.B., 1963b - Coastal bitumen in South Australia, with special references to observations at Geltwood Beach, south-east South Australia. Trans. Roy. Soc. S. Aust., 86, 67-103. The authors continue the argument in favour of the local origin of the bitumen, and give examples of seepage elsewhere in the world. Analyses of oil and bitumen are given in appendices.

SPRY, A., and BANKS, M.R., (Ed.), 1962 - The geology of Tasmania. J. geol. Soc. Aust. 9 (2).

STACH, L.W., 1962 - Surface geology of the Torquay Embayment, Port Phillip Basin, Victoria. Aust. Oil Gas J., 8 (5), 30-35. The embayment existed in the western side of the Port Phillip Basin during most of Tertiary time and possibly in the late Mesozoic. The paper outlines the subsurface geology using all available data. The stratigraphy follows Raggatt and Crespin (1955) with some amendments due to later work. Five subsurface topographic features are recognized: "Bellarine horst, Barwon trough, Torquay horst, Angelsea trough, Otway uplift." He suggests that a wedge of possibly marine Cretaceous exists between the '"Jurassic" basement floor and the overlying Eastern View Coal measures' in the Anglesea trough'. Prospects of hydrocarbon occurrences would be limited on land to the Anglesea trough, and stratigraphic traps offered the best targets; greater thicknesses of potential source rocks could be expected offshore.

STIRLING, J., 1898 - Report on geological and mining features of the Lower Gellibrand River. Progress Rep. geol. Surv. Vic., 9, 91-92. Deals with small findings of alluvial gold in Tertiary gravels, quartz (feldspar) 'reefs' in the Mesozoic sediments - thought to be apophyses from deeper porphyry intrusions, and describes the section at Moonlight Heads.

STIRLING, J., 1899a - Report on gold discoveries, Wangerrip, Gellibrand River.
- Examination of Mt. Sabine and district.
- Report on alleged gold discoveries, Beech Forest, Cape Otway District. Monthly Prog.rep.geol.Surv.Vic., 8-9, 3-6.
As above, Stirling (1898).

STIRLING, J., 1899b - Progress report on survey of quarter-sheet No. 2 - Gippsland carbonaceous area. Ibid., 8-9, 54-56.

STIRLING, J., 1899c - Report on the brown coals and lignites of Victoria. Progress Rep.geol.Surv.Vic., 10, 73-83. Descriptions of bore and outcrop sections (with sketches).

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TAYLOR, D.J., 1964a - Foraminifera and the stratigraphy of the western Victorian Cretaceous sediments. Proc.Roy.Soc.Vic., 77 (2), 535-603. Mainly a taxonomic study, (53 species are described and illustrated). Marine Cretaceous sedimentation began in the Cenomanian or Turonian (Upper Cretaceous). The earliest foraminifera occur in dark mudstone, and deposition in barred basin conditions is suggested. Higher mudstone contains planktonic and benthonic faunas, and indicated unrestricted water circulation; contemporaneous marginal sands and silts interdigitate with the mudstone. 'Marginal marine' sedimentation followed, and continued from Middle Senonian time into the Lower Tertiary. The structural configuration of the Otway Group surface controlled the transgressive Upper Cretaceous sedimentation. 'Faulting and warping initiated Upper Cretaceous sedimentation and continued contemporaneously with it and Lower Tertiary sedimentation.'

TAYLOR, D.J., 1964b - The depositional environment of the marine Cretaceous sediments of the Otway Basin. J.Aust.Petrol.Expl.Ass., 1964, 140-144.
He concludes that on the available evidence, the Upper Cretaceous sediments of the Otway Basin were deposited in close proximity to the shoreline, and are mostly paralic. In discussing the "Port Campbell Embayment" he makes two important observations:

(i) the Flaxmans Beds are transgressive and diachronous;

(ii) Belfast Mudstone lithologies recur in the overlying Paaratte Formation.

TAYLOR, D.J., 1965 - Preservation, composition, and significance of Victorian lower Tertiary "Cyclammina faunas". Proc.Roy.Soc.Vic., 78 (2), 143-160.
A detailed taxonomic study has shown that the foraminiferal genus Cyclammina is not present in the lower Tertiary of western Victoria; Haplophragmoides had been misinterpreted previously because of changes which are apparently due to decay of the agglutinating cement, possibly associated with weathering processes. Haplophragmoides assemblages and their distribution are described. It is also pointed out that species of Haplophragmoides would tolerate the paralic environment envisaged for lower Tertiary time.

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TEICHERT, C., 1943 - Eocene nautiloids from Victoria. Proc.Roy.Soc.Vic., 55 (2), 257-264.
Aturoidea distans, n. sp., indicates an Eocene age for the Pebble Point Beds, but the formation could be as old as Upper Cretaceous.

TEICHERT, C., 1947 - New nautiloids from the older Tertiary of Victoria. Min.geol.J., 3 (2), 48-51.
These are from the phosphate nodule layer in the Clifton Beds near Princetown; they are estimated to be 1300 feet stratigraphically above the Pebble Point Beds.

THOMAS, D.E., 1937 - Some notes on the Silurian rocks of the Heathcote area. Min.geol.J., 1 (1), 64-67.
Descriptions of folded, fossiliferous mudstone, and sandstone with conglomerate lenses which crop out north of the Otway Basin (but may extend below the Basin).

THOMAS, D.E., 1939 - Geological section - The structure of Victoria with respect to the Lower Palaeozoic rocks. Ibid., 1 (4), 59-64.
This paper deals mainly with central Victoria, north of the eastern end of the Otway Basin.

THOMAS, D.E., 1947 - Sand deposits of the Melbourne district. Ibid., 3 (2), 41-47. Sand from near Bacchus Marsh may be pure enough, after washing, for industrial purposes.

THOMAS, D.E., 1953 - Geology of the brown coals of Victoria. In Coal in Australia. 5th Emp.Min.metall.Cong., 6, 694-726.
Distribution (Bacchus Marsh, Newport - Altona, and Anglesea) and geology of the deposits. (See also Edwards, 1953).

THOMAS, D.E., 1955 - Underground water. Min.geol.J., 5 (4-5), 5-12.
The Otway Basin in Victoria is divided into artesian basins whose boundaries are imprecisely known.

THOMAS, D.E., 1957 - Physiography, geology and mineral resources. In Resources Survey, Corangamite Region, Central Planning Authority, Victoria, 26-35. The physiography and stratigraphy are given. Devonian granite and Upper Devonian sandstone occur near the northern edge of the Otway Basin. The Mesozoic rocks of the Otway Ranges are considered to be folded along a north-east to south-west trend. Tertiary sediments in the Aire and Moonlight Head areas are compared in Table 1. (2 maps - one of geology and mineral occurrences, the second shows topography and water resources).

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Three major belts of folding and thrust-faulting are recognized, all with roughly meridional trends, and all characterized by inliers of Cambrian thrust over Ordovician, Silurian and Lower Devonian rocks. The "Stavely Belt" (including the Grampians) and "Heathcote Belt" are north of the Otway Basin.

THOMAS, D.E., 1960 - Physiography, geology and mineral resources. In Resources Survey, Glenelg Region, Central Planning Authority, Victoria, 24-32. Similar to the Corangamite study (Thomas, 1957). Cambrian, Ordovician, and Upper Devonian Lower Carboniferous rocks crop out north of the Otway Basin, and glacial deposits ('Permo-Carboniferous') are described from near Coleraine. (Geological, and topographic water resources maps).

THOMAS, D.E., and BARAGWANATH, W., 1949 - Geology of the brown coals of Victoria. Part I. Min.geol.J., 3 (6), 28-55.
The authors give an historical account of the search for coal (with a selected bibliography); the report deals mainly with the Gippsland Basin, but briefly refers to western Victoria and gives some bore data.

THOMAS, D.E., and SINGLETON, O.P., 1956 - The Cambrian stratigraphy of Victoria. El Sistema Cambrico, su paleogeografia y el problema de su base. Int.geol.Cong., 20th Sess., Mexico, Pt. 2, 149-163. Descriptions of Cambrian outcrops in the Glenelg River area near Casterton, in the belt extending north from Hopkins River (Mt. Stavely - Mt. Drummond Belt), the Ceres - Dog Rocks area near Geelong, and the Mt. William - Heathcote - Colbinabbin Belt north of Melbourne, as well as other areas in eastern Victoria.

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VINE, R.R., and DAY, R.W., 1965 - Nomenclature of the Rolling Downs Group, northern Eromanga Basin, Queensland. Qld.Govt.Min.J., 66 (767), 417-421.

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(In connection with the drilling of Knight's Dome No. 1 - See O.S.L. unpublished reports).

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This bulletin deals with the history of oil search and gives a list of wells drilled.

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WOODS, J.E.T., 1860 - On some Tertiary rocks at Portland Bay. Trans. Phil. Inst. Vic., 4, 169-172. Descriptions of Tertiary outcrops along the coast.

WOODS, J.E.T., 1862 - Geological observations in South Australia. Longman, Green, London. (not seen). Tate's (1879) observations on the south-east of South Australia are mainly from this publication.

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J. Aust. Petrol Expl. Ass., 1964, 14-20.
They give a brief description of the regional geology and the geophysical discovery of the Geltwood Beach anticline. Geltwood Beach No. 1 Well is also described; the well did not find any strong shows of hydrocarbons, nor did it encounter any obvious oil source rock. However, some small gas occurrences and fluorescence are noted. 'Pitch dome' diapiric structures are suggested as more likely sources of the off-shore seepages, than shallow outcropping oil sands.

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Appendix I

Gas and oil analyses of wells in the Otway Basin

The following section lists the occurrences of oil and gas only in cases where an analysis is available. For a more complete survey of oil and gas occurrences, reference may be made to Scorer (1965*). This reference also contains a fairly comprehensive collection of water analyses from drilling operations.

Fergusons Hill No.1

Production Test No.9 — Slight gas flow at rate too small to measure

5436-5464'

Unit M

Analyses

	Vol. % *	Vol. % **
Methane	74.1	76.6
Ethane	6.0	8.51
Propane	2.2	2.07
Isobutane	0.74	0.65
n-Butane	0.51	0.35
Neopentane	0.015	-
Isopentane	0.32	0.13
n-Petane	0.19	0.06
C_{6+}	0.73	0.07
Oxygen	2.8	11.56
Nitrogen	12.4	

* Analysis by State Laboratories, Melbourne

** Analysis by Petroleum Refineries (Aust.) Pty. Ltd.

Flaxmans No. 1

D.S.T. No.2 5356-5396' Paaratte Formation (Gd)	Recovered gas-cut water. (For gas analysis see Table 18)
D.S.T. No.3 6891-6913' Waarre Formation (J)	Recovered gas, gas-cut mud and water. (For gas analyses see Table 18)
D.S.T. No.6 10,842-11,528' Unit M	Flowed gas (see Table 18)
D.S.T. No.14 ~~8518-8528'~~ 8462-8480'	Recovered gas-cut water and small amount of wax in tailpipe. (For gas analysis see Table 18).
D.S.T. No.16 6875-6881' Waarre Formation (J)	Recovered gas-cut water. (For gas analysis see Table 18).
Prod. Test No. 1 10,842-11,528' Unit M	Flowed gas at initial rate of 250 Mcf/day falling to zero in extended flow. Small amount of 51.2° API condensate produced. (Analysis of condensate, see Table 19).

Table 18

Flaxmans No. 1

Gas Analyses

	D.S.T. No.2 5356-5396 ft. Paaratte Formation	D.S.T. No. 3 6891-6913 ft. Waarre Formation	Gas from Mudstream Bottom Hole depth 11,388 ft. Otway Group	D.S.T. No. 6 10842-11528 ft. Otway Group	D.S.T. No. 14 8518-8528 ft. 8462-8480 ft. Otway Group	D.S.T. No. 16 6875-6881 ft. Waarre Formation
	%	%	%	%	%	%
Air	3.9	-	-	-	-	-
Carbon Dioxide	1.7	1.7	-	-	-	-
Hydrogen	0.5	-	-	-	-	-
Nitrogen and oxygen	3.9	2.5	-	-	-	-
Methane	91.3	88.7	88.1	76.9	95.9	83.7
Ethane	2.3	3.4	6.3	13.2	3.3	10.4
Propane	0.3	0.8	4.0	6.9	0.8	4.5
Propylene	0.1	-	-	-	-	-
Isobutane	-	-	0.4	1.5	-	0.7
Normal butane	-	-	0.8	0.7	-	0.7
Isopentane	-	-	0.2	-	-	-
Water vapour	-	-	-	0.8	-	-
Analysis by:	State Laboratories Melbourne	State Laboratories Melbourne	Standard Vacuum Refinery, Altona	Standard Vacuum Refinery, Altona S.G. of gas 0.729 (Air = 1.0) Site determination	Standard Vacuum Refinery, Altona.	Standard Vacuum Refinery, Altona.

Table 19

Flaxmans No. 1

CONDENSATE ANALYSIS

by

Standard Vacuum Refinery

Production Test No. 1 — 10,842 to 11,528 feet — Otway Group

Initial Boiling Point:		176°F
Cuts:	10%	224 "
	20%	236 "
	30%	246"
	40%	256 "
	50%	271 "
	60%	292 "
	70%	316 "
	80%	358 "
	90%	444 "
	Final	577 "

Residue: 3% wax

Loss: 2% (Methane-Ethane)

Liquid is aromatic (Toluol) rather than paraffinic base

Geltwood Beach No. 1

D.S.T. No.3 Recovered gas-cut mud and salt water 4983-5055'

Unit M

Gas Analysis

Air	5.0%
Methane	92.0%
Ethane	1.6%
Propane	1.4%
iso-Butane	45 ppm
n-Butane	40 ppm

No higher hydrocarbons detected.

Analysis by A.M.D.L.

Kalangadoo No.1

D.S.T. No. 7 Flowed gas at rate of 1.55 MMcf/day until packer failed.

6890-7005'

Unit V

Gas Analysis

	% vol.
Nitrogen	1.33
Carbon Dioxide	96.25
Methane	2.40
Higher hydrocarbons	Not detected (less than 0.02%)

Sample as received contained 2.55% air. Analysis calculated on air-free basis.

Above analysis by Australian Mineral Development Laboratories.

	Sample 1 % vol.	Sample 2 % vol.
H_2	0.012	0.044
He	0.029	0.019
O_2 + Ar	3.1	2.9
N_2	12.6	11.9
CO	0.33	0.5
CO_2	81.8	81.2
CH_4	2.07	3.34
C_2H_6	0.052	0.097
C_3	Trace	Trace
C_4	"	"
C_5	"	"
C_{6+}	n.d.	n.d.

Above analyses by B.M.R. Petroleum Technology Laboratory.

Port Campbell No.1

D.S.T. No.1 — Strong blow of gas. Recovered 900 feet of gas cut mud.

5653-5718'

Waarre Formation (J)

Gas Analysis

	Vol. %	Vol.% **
Hydrogen	-	0.022
Oxygen	-	1.14
Nitrogen	3.3	8.13
Carbon Dioxide	23.0	10.00
Methane	63.2	68.7
Ethane	5.4	6.1
Propane	2.7	3.0
iso-Butane	0.7	0.67
n-Butane	0.7	0.76
iso-Pentane	0.1	0.26
n-Pentane	0.1	0.21
C_{6+}	-	0.21
Water Vapour	0.8	-

* Analysis by Standard Vacuum Refining Co. (Aust.) Pty Ltd.

** Analysis by Gas and Fuel Corporation, Melbourne.

D.S.T. No.4 — Slight flow of gas. Recovered 270 feet of g.c.m. and 5050 feet of gas-cut salt water.

5695-5701'

Waarre Formation (J)

The sample of gas collected in a cylinder contained a liquid. The gas and liquid fractions were analysed separately.

(i) Gas Sample

Density 1.390 gram per litre at 25°C	
Air	- 2.8% by volume
Carbon dioxide	- 9.6%
Methane	-58.0%
Ethane	- 4.8%
Propane	- 6.2%
Iso-Butane	- 3.5%
n-Butane	- 4.6%
Pentanes	- 6.3%
Hexanes	- 3.0%
Higher hydrocarbons	- trace

No helium could be detected.

(ii) Liquid in Gas Sample

Approximately 140 grams of liquid were run from the cylinder and yielded on analysis:

Density	- 0.709 at 25°C
Propane	- 0.6% by volume
Butanes	- 3.3%
Pentanes	-11.1%
Hexanes	-20.0%
Heptanes	-27.5%
Octanes	-28.8%
Nonanes	- 5.5%

This liquid represents approximately three quarters of the original sample by weight.

Production Test No. 1a
5656-5666'
Waarre Formation (J)

Flowed gas at initial rate of 4.2 MMcf/day

Production Test No. 1b
5657-5663'
Waarre Formation (J)

Flowed gas at initial rate of 2.51 MMcf/day. Condensate of 65° API gravity was produced at the rate of 0.224 gallons/Mcf.

For analyses of gas and condensate see Tables 20 and 21.

Production Test No. 1a

Sample "ex tank" collected at 10.00 am on 3rd January, 1960

Sample consisted entirely of hydrocarbons with no water present.

Density	- 0.744 at 25°C
Pentanes	- 0.8% by volume
Hexanes	- 3.0%
Heptanes	- 16.0%
Octanes	- 30.4%
Nonanes	- 20.4%
Decanes	- 12.8%
Undecanes	- 7.4%
Duodecanes	- 3.4%
Tridecanes	- 2.2%
Tetradecanes	- 1.6%
Pentadecanes	- 1.15%

Sample "ex tank" collected at 6.00 pm on 3rd January, 1960.

The sample consisted largely of water of s.g. 1.013 at 25°C with a layer of organic liquid floating on top.

(i) Analysis of water as under:-

Radicles	
Chloride	- 621.0
Sulphate	- 7.8
Carbonate	- 159.0
Sodium	[illegible]
Calcium	- 2.5
Magnesium	- 5.8
Iron	- 0.6
Total Salts	1311.0

Assumed Composition	
Ferrous Carbonate	- 1.2
Calcium Carbonate	- 6.2
Magnesium Carbonate	- 20.1
Sodium Carbonate	- 248.0
Sodium Sulphate	- 11.5
Sodium Chloride	- 1024.0

(ii) Analysis of organic liquid floating on water:-

Density	- Insufficient sample to measure
Pentanes	- Nil
Hexanes	- 1.0% by volume
Heptanes	- 8.3%
Octanes	- 14.5%
Nonanes	- 21.2%
Decanes	- 18.2%
Undecanes	- 15.6%
Duodecanes	- 7.7%
Tridecanes	- 5.4%
Tetradecanes	- 4.2%
Pentadecanes	- 2.6%

Table 20 Production Tests 1a and 1b 5656 to 5668 feet

Recovered gas condensate oil and salt water

a Gas Analysis

Analysis by	Standard Vacuum Refinery	Gas & Fuel Corporation *	Standard Vacuum Refinery	Standard Vacuum Refinery	Gas & Fuel Corporation	Standard Vacuum Refinery	Standard Vacuum Refinery	Gas & Fuel Corporation
Date Collected	Jan. 2	Jan. 2	Jan. 3	Jan. 4	Jan. 4	Jan. 5	Jan. 6	Jan. 21
	%	%	%	Vapour Phase %	%	%	Gas chromatograph Method %	%
Helium		0.02			0.02			0.02
Hydrogen								0.18
Oxygen		1.1			0.02			) 3.5
Nitrogen	3.5	6.8	3.4	3.5	3.7	3.4	3.4	)
Carbon Dioxide	15.6	12.5	14.9	15.6	16.1	16.2	16.2	14.2
Methane	71.6	51.8	70.5	71.6	71.2	70.1	70.1	72.5
Ethane	4.8	5.4	4.7	4.8	4.9	5.1	5.1	5.5
Propane	2.6	5.1	2.8	2.6	2.1	2.8	2.8	1.8
Isobutane	) 1.7	) 6.3	0.8	0.7	) 1.2	0.7	) 1.4	0.5
n - Butane	)	)	1.1	1.0	)	0.7	)	0.5
Isopentane	) 0.2		0.7	0.2		0.2	) 0.2	) 0.5
n - Pentane	)		0.3				)	)
Hexane		11.0	0.3					Trace
Water Vapour						0.8	0.8	

* Container had leaked

Table 21. Condensate and oil analysis.

	Collected Jan.2, 1960 Gas Sample Vessel	Collected Jan.2	Collected Jan.3	Collected Jan.6	Collected Jan.7 Oil	Collected Jan.22	Collected Jan.22	Collected Jan.23	Collected Jan.29
Analysis by:	Standard Vacuum Refinery	Vacuum Oil Coy.	Vacuum Oil Coy.	Vacuum Oil Coy.	Vacuum Oil Coy.	Vacuum Oil Coy.	Vacuum Oil Coy.	Vacuum Oil Coy.	Vacuum Oil Coy.
Specific Gravity		.704	.749	.752	.772	.726	.731	.722	.728
Color		White	Yellow	Yellow	Brown-black				Water white
Refractive Index		1.398	1.432	1.426	1.428	1.410	1.413	1.407	1.406
Odour		Sweet	Sweet	Sweet	Sweet				
Doctor Test		Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative
Copper Strip Test		-	-		1a				
Sulphur %		Below 0.1	-	Below 0.02	-				
Distillation	°F	°F	°F	°F	°F	°F	°F	°F	°F
IBP	180	90	208	235	257	147	172	129	145
10% Recovered	246	134	235	253	306	183	196	173	190
20%	256	158	246	266	316	196	205	189	205
30%	264	176	257	279	331	205	214	199	247
40%	272	192	270	293	349	217	223	212	228
50%	280	208	286	307	369	228	237	223	234
60%	290	226	304	324	390	243	248	235	253
70%	300	246	329	345	421	257	262	252	270
80%	314	293	365	385	464	282	291	273	291
90%	333	342	428	444	536	320	325	315	333
FBP	388	381	545	460	592	444	455	426	439
Recovery %	99	94	98.0	92.0	96.0				
Residue %	1	5.6	2.0	8.0	4.0				
Loss		0.4	Nil	Nil	Nil				
Nature of Residue		Wax free at 20°F	Waxy with MP 45-50°F	Waxy with MP 34-37°F	Waxy with MP 64°F				

Port Campbell No. 2

D.S.T. No.11 8395–8405' Waarre Formation (J)	Recovered 1320 feet gas-cut mud and 7050 feet gas-cut water. For gas analysis see Table 22.
D.S.T. No.12 8338–8350' Waarre Formation (J)	Recovered 1020 feet gas-cut mud and 7308 feet gas-cut water. For gas analysis see Table 22.

The remaining gas analyses noted in Table 22 were obtained from small recoveries of liquid containing solution gas.

TABLE 22

PORT CAMPBELL NO. 2

Gas Analyses

	DST No. 9 8586–8594 ft. Unit M %	DST No. 11 8395–8405 ft. Waarre Form. %	DST No. 12 8338–8350 ft. Waarre Form. %	DST No.14 8338–8350 ft. Waarre Form. %	DST No. 16 8294–8299 ft. Waarre Form. %	DST No. 18 8294–8299 ft. Waarre Form. %	DST No. 22 8188–8196 ft. Waarre Form. %
Air	8.0	0.4	0.3	11.2	5.9	21.0	2.0
Methane	76.6	93.1	94.6	72.4	81.8	63.4	93.2
Ethane	3.2	2.9	2.5	2.8	3.4	2.1	2.2
Propane	0.4	0.4	0.2	0.4	0.8	0.2	0.2
Isobutane	-	-	-	-	0.2	-	-
Butane	-	-	-	-	0.2	-	-
CO_2	9.4	0.8	Nil	10.8	5.3	10.9	Nil
Water Vapour	2.4	2.4	2.4	2.4	2.8	2.4	2.4

ANALYSIS BY STANDARD VACUUM REFINING COMPANY

Port Campbell No. 4

D.S.T. No.9
5947-5970'
Unit M

Flowed gas at rates from 160 to 219 Mcf/day. Liquid produced at rates between 215 and 240 bpd, consisting of 85% salt water and 15% emulsified crude oil of 38.2° API gravity.

Gas Analysis

	% *	% **
Methane	82.2	75.77
Ethane	6.6	5.66
Propane	3.6	3.58
iso-Butane	1.07	1.87
n-Butane	1.22	1.10
Neopentane	0.018	-
iso-Pentane	0.49	0.43
n-Pentane	0.40	0.36
C_{6+}	1.47	0.53
Oxygen	0.7	air
Nitrogen	2.2	

* Analysis by Gas and Fuel Corporation

** Analysis by Petroleum Refineries (Aust.) Pty Ltd.

D.S.T. No. 12
5874-5903'
Unit M

Flowed gas 160 Mcf/day and 57 barrels liquid/day. Liquid consisted of 45 barrels/day water and 12 barrels/day oil emulsion. On pulling tester 35-40 gallons of fluid were recovered containing 10% crude oil 46° API gravity.

Gas Analysis

	% *	% **
Nitrogen	2.5	11.9 } air
Oxygen	0.5	
Hydrogen	0.4	-
Methane	83.8	74.39
Ethane	4.8	7.30
Propane	3.4	3.80
iso-Butane)	2.1	0.90
n-Butane)		0.86
iso-Pentane	-	0.29
n-Pentane	-	0.19
Hexane and Higher	-	0.29

* Analysis by State Laboratories, Melbourne.

** Analysis by Petroleum Refineries (Aust.) Pty Ltd.

D.S.T. No. 21
5870-5878'
Unit M

Flowed gas at rate of 84.5 Mcf/day. Liquid recovered from separator in last 6 hours of flow was $\frac{3}{4}$ barrel, consisting of 5% solids, 60% water and 35% of 34.7° API gravity oil. On pulling out, 270 feet of oil and 450 feet of oil-water emulsion were recovered from the tubing.

Gas Analysis

	%
Nitrogen	2.4
Oxygen	0.6
Methane	84.4
Ethane	5.7
Propane	3.4
Butane	2.3

Analysis by State Laboratories, Melbourne. Instrument used was the Janak Gas Chromatograph. Hydrocarbons higher than butanes may be present, but cannot be determined by this instrument.

Tullich No. 1

D.S.T. No. 3 2947-2982' Unit M	Recovered 1500 feet of gassy salt water.
D.S.T. No. 4 3721-3786' Unit M	Recovered 500 feet of very gassy salt water-mud and 3160 feet of very gassy salt water.
D.S.T. No. 6 4815-4880' Unit P	Recovered 450 feet of gassy, muddy salt water.
D.S.T. No. 7 4980-5045' Unit P	Recovered 400 feet of muddy, gassy water.

Analyses of gas from these tests are given below:-

	D.S.T. No.3	D.S.T. No.4	D.S.T. No.6	D.S.T. No.7
	%	%	%	%
Carbon Dioxide	-	0.1	1.2	0.7
Hydrogen	0.4	-	-	-
Nitrogen	18.7	6.5	32.3	62.0
Oxygen	1.1	0.5	8.2	14.8
Methane	79.3	91.0	56.6	22.2
Ethane	-	0.4	0.4	0.1
Propane	-	-	-	-
Butane	-	-	-	-

Analyses by State Laboratories, Melbourne.
The instrument used does not detect hydrocarbons above butane and the limit of detection of any one gas is 0.1%.

APPENDIX II (VELOCITY INFORMATION)

	WELL	VELOCITY FUNCTION Ft/sec.	DATUM	METHOD
1.	Geltwood Beach No. 1	$v_i = 6900 + 0.62Z^+$	+ 30' A.M.S.L.	Sonic and W.V.S.*
2.	Port Campbell No. 4	$v_i = 5500 + 1.00Z$	+441' A.M.S.L.	Sonic
3.	Kalangadoo No. 1	$v_i = 6200 + 0.60Z$	+175' A.M.S.L.	Sonic and W.V.S.
4.	Heathfield No. 1	$v_i = 6000 + 1.00Z$	+130' A.M.S.L.	Sonic and W.V.S.
5.	Fergusons Hill No. 1	$v_i = 6150 + 1.06Z$	+651' A.M.S.L.	Sonic and W.V.S.
6.	Sherbrook No. 1	$v_i = 6000 + 1.00Z$	+480' A.M.S.L.	Sonic and W.V.S.
7.	Port Campbell No. 2	$v_i = 5700 + 1.00Z$	+282' A.M.S.L.	W.V.S.
8.	Pretty Hill No. 1	$v_i = 5700 + 1.00Z$	+202' A.M.S.L.	Sonic and W.V.S.
9.	Eumeralla No. 1	$v_i = 6000 + 0.80Z$	+167' A.M.S.L.	Sonic and W.V.S.
10.	Flaxmans No. 1	$v_i = 5721 + 0.989Z$	+222' A.M.S.L.	Sonic (below 7000' and W.V.S.
11.	Tullich No. 1	$v_i = 5800 + 1.07Z$	+272' A.M.S.L.	Sonic
12.	Latrobe No. 1	$v_i = 5100 + 2.10Z$	+160' A.M.S.L.	Sonic (to 2000' only)
13.	Casterton No. 1	$v_i = 6500 + 1.00Z$	+300' A.M.S.L.	Sonic and W.V.S.
14.	Penola No. 1	$v_i = 6200 + 0.73Z$	+183' A.M.S.L.	W.V.S.
15.	Wangoom No. 2	$v_i = 6200 + 0.80Z$ (approximate only)	Sea Level	W.V.S.

	SURVEY (AREA)	VELOCITY FUNCTION	DATUM	METHOD
1.	Curdie Vale (Line S-5, Location 92)	$v_i = 5200 + 1.55Z$	+300' A.M.S.L.	$X^2 - T^2$ Plot (Expanded Spread)
2.	Curdie Vale (Line S-6, S.P. 60.5)	$v_i = 5939 + 1.28Z$	+300' A.M.S.L.	$X^2 - T^2$ Plot (Expanded Spread)
3.	Curdie Vale (Line 47, near Port Campbell No. 2)	$v_i = 6400 + 1.00Z$	+140' A.M.S.L.	$X^2 - T^2$ Plot (Expanded Spread)
4.	Curdie Vale (Line 53, near Port Campbell No. 3)	$v_i = 6400 + 1.0Z$	+160' A.M.S.L.	$X^2 - T^2$ Plot (Expanded Spread)
5.	Curdie Vale (Line S-1 Survey 1-SP22.5)	$v_i = 6000 + 0.8Z$	+140' A.M.S.L.	$X^2 - T^2$ Plot (Expanded Spread)
1.	Timboon (Line 49, SP3, near Flaxmans No. 1)	$v_i = 5721 + 0.989Z$	+120' A.M.S.L.	$X^2 - T^2$ Plot (Expanded Spread)
2.	Timboon (Line 187, SP.4345)	$v_i = 6000 + 0.8Z$	+140' A.M.S.L.	$Z^2 - T^2$ Plot (Expanded Spread)
3.	Timboon (Line 183, SP.4140)	$v_i = 5900 + 1.0Z$ to 7000' only	+330' A.M.S.L.	$X^2 - T^2$ Plot (Expanded Spread)
4.	Timboon (Line 184, SP.4158)	$v_i = 6000 + 0.8Z$	+200' A.M.S.L.	$X^2 - T^2$ Plot (Expanded Spread)

* W.V.S. = Well Velocity Survey

\+ Equation given in the form

$$v_i = V_o + \alpha Z$$

v_i = Instantaneous Velocity (ft/sec.)

v_o = Datum Velocity (ft/sec.)

α = Acceleration Factor

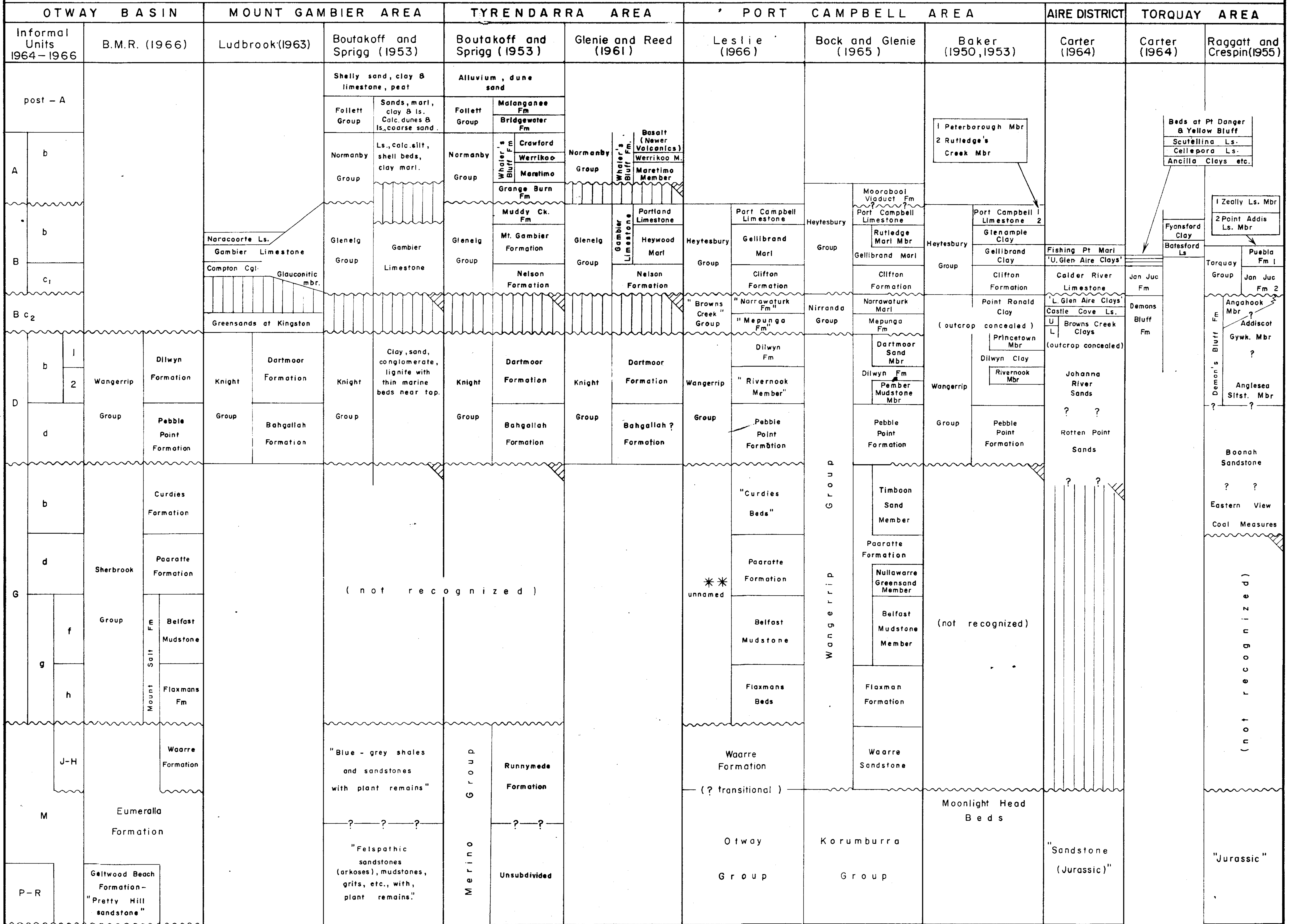
Z = Depth in ft.

The above formula gives a depth-time relationship of $Z = \frac{V_o}{\alpha}(e^{\alpha t/2} - 1)$ where t = two way time.

SURVEY (AREA)	VELOCITY FUNCTION Ft/sec.	DATUM	METHOD
1. Branxholme-Koroit (Line 105, S.Ps 3496-98) near Pretty Hill No. 1	v_i = 6000 + 0.Z	Sea Level	$X^2 - T^2$ Plot (Expanded Spread)
2. Branxholme-Koroit (Line 155, SPs1927-1931) - near Heywood)	v_i = 6000 + 0.8Z to time t = 0.65 sec. below t = 0.65 sec. add 450'	Sea Level	$X^2 - T^2$ Plot (Expanded Spread)
3. Branxholme-Koroit (Line 195, SP4403)	v_i = 7342 + 0.56Z	+ 35' A.M.S.L.	$X^2 - T^2$ Plot (Expanded Spread)
1. Corriemungle (Line 167, S.P.s 4088-4092)	v_i = 5900 + 1.0Z to 10,000' Below Z=10,000' Z=10,000' + 12987 (t-1.0) sec.	Sea Level	$X^2 - T^2$ Plot (Expanded Spread)
2. Corriemungle (Line 174, S.P. 3903-3905)	v_i = 5280 + 1.0Z	Sea Level	$X^2 - T^2$ Plot (Expanded Spread)
3. Corriemungle (Line 175, SP's3944, 3951-3954)	V_i = 7015 (0-1950') V_i = 7188 (1950-3510') V_i = 10784 (3510-5160')	Sea Level	$X^2 - T^2$ Plot (Expanded Spread)
4. Corriemungle (Line 178, SP's4022-4026).	V_i = 5900 + 1.0Z	Sea Level	$X^2 - T^2$ Plot (Expanded Spread)
Mayurra (Millicent)	v_i = 6000 + 0.8Z to t = 0.8 sec.	?Sea Level	t-Δt analysis
Penola	v_i = 6000 + 1.4Z	?Sea Level	t-Δt analysis
Koroit	v_i = 5900 + 0.95Z) or = 5200 + 1.20Z)	?Sea Level	t-Δt analysis
Casterton	v_i - 6160 + 0.6Z to time t=0.6 sec.only	?Sea Level	t-Δt analysis
Bass Strait Lines B-9, B-10, B-11	v_i = 6160 + 0.6Z	Sea Level	t-Δt analysis
1. Princetown (S.P.s 3491-3495 Near Port Campbell No.1)	v_i = 6700 + 0.8Z	Sea Level	$X^2 - T^2$ (Expanded Spread)
2. Princetown (Line 158, S.P.s 3399-3401)	v_i = 6400 + 1.0Z	Sea Level	$X^2 - T^2$ (Expanded Spread)
3. Princetown (Line 170, SPs3393-97)	v_i = 6400 + 1.0Z to time t=0.454 sec. depth Z=3591 ft. below t=0.454 sec. Z=3591 + 24800(t-0.454)	Sea Level	$X^2 - T^2$ (Expanded Spread)

Chart 2

COMPARISON OF STRATIGRAPHIC NOMENCLATURE FROM THE OTWAY BASIN



unconformity — non-deposition or erosion — transitional and/or disconformity — ? ? relative position of break uncertain — breaks inserted by B.M.R. — * * Named "Sherbrook Group" in an earlier unpublished chart by Leslie.

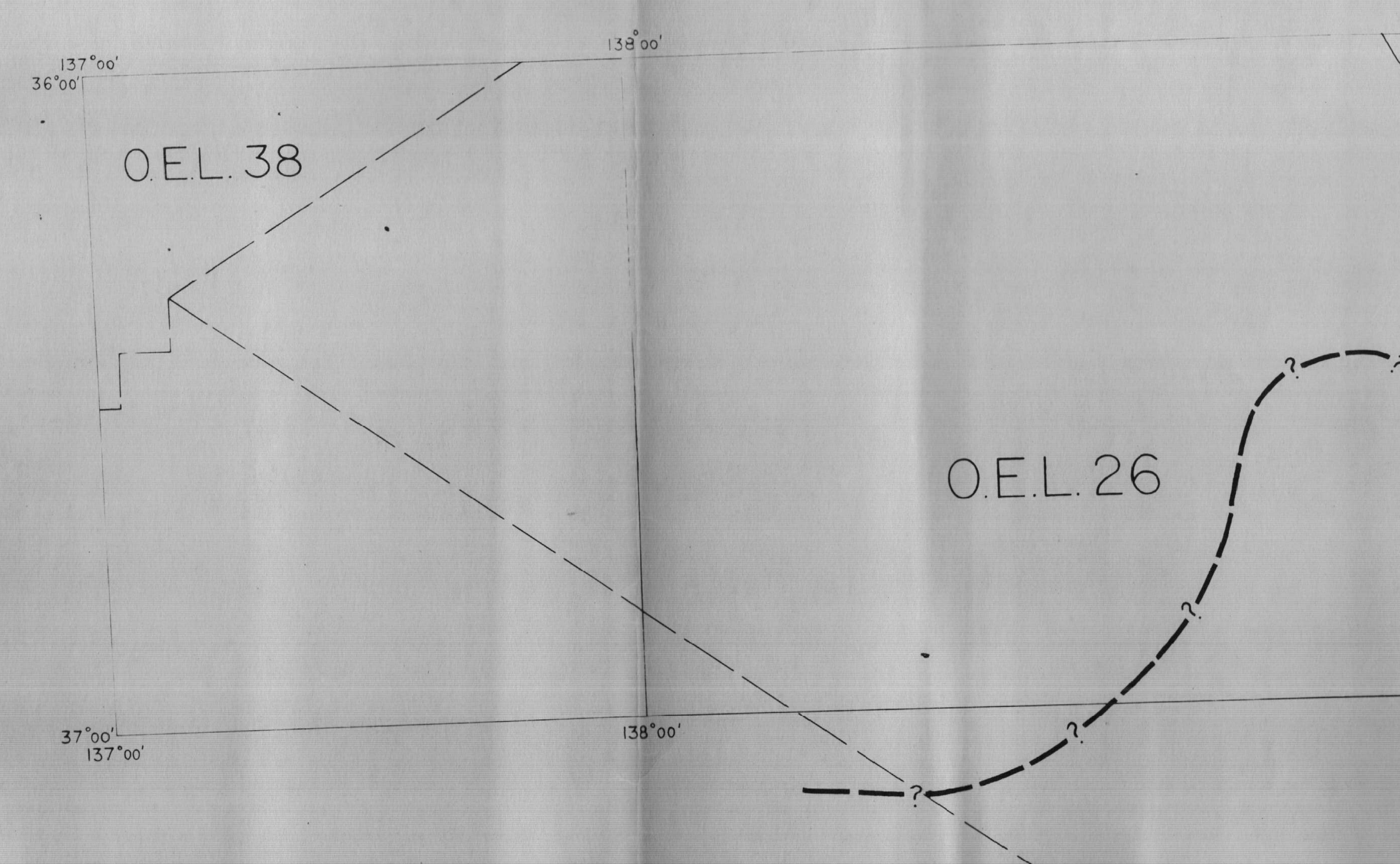
Bureau of Mineral Resources, Geology and Geophysics. December 1966.

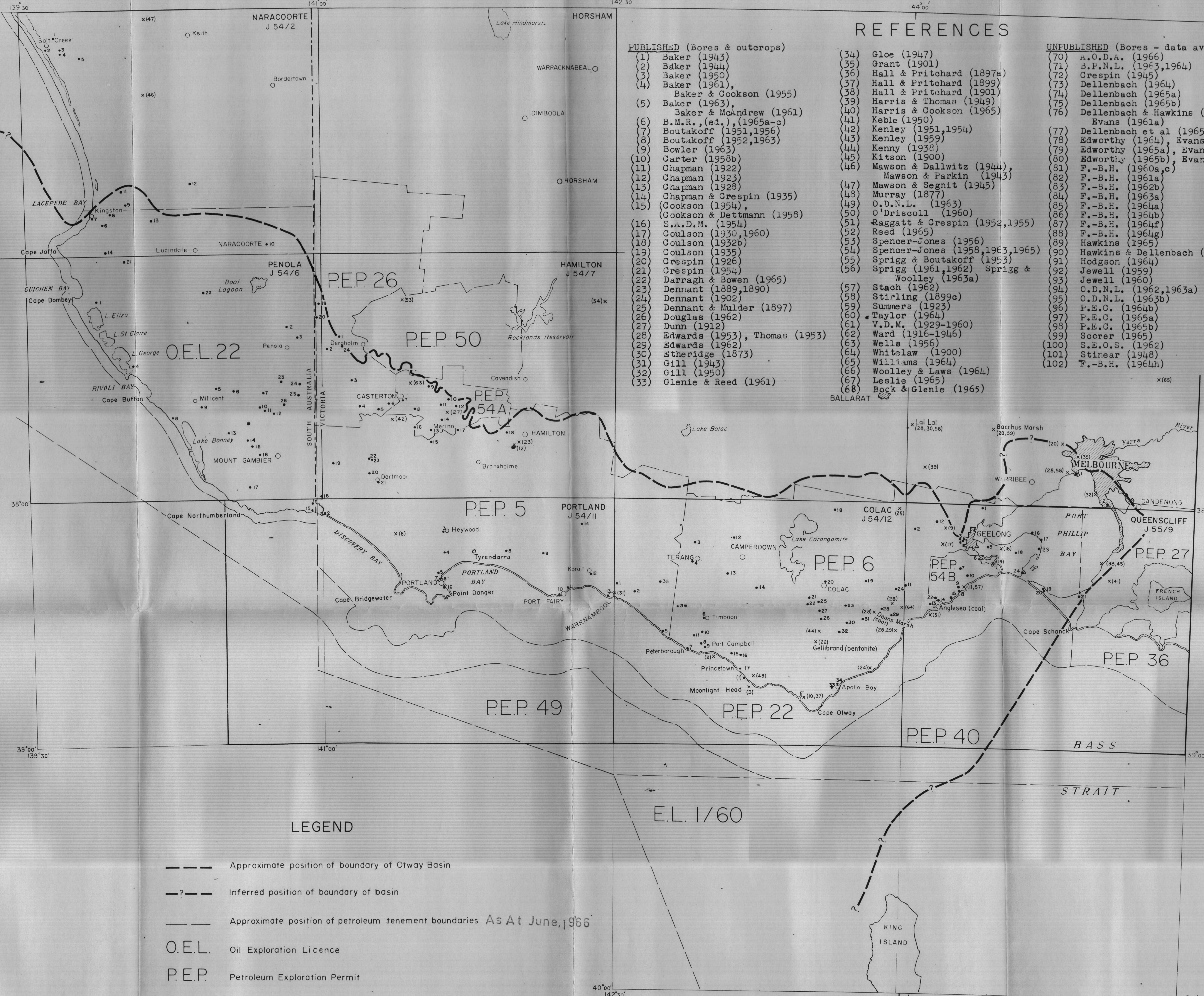
X AUS -1-44 JM,LP

PLATES TO ACCOMPANY
RECORD 1966/170
A PRELIMINARY REVIEW OF
THE OTWAY BASIN

PART 2
of 2

OTWAY BASIN LOCATION MAP





BORE AND WELL INDEX

SOUTH AUSTRALIA

NARACOORTE SHEET (J54/2)
1. Salt Creek
2. Santo 1
3. Alfred Flat
4. Salt Creek 1
5. Salt Creek 2
6. Coorong 1 (Lacepede 42)*
7. Coorong 2 (Lacepede 507)*
8. Enterprise Oil (Lacepede 442 NE)*
9. Blackford (Murrabinna 10B)*
10. Naracoorte (Government Bore)
11. (Murrabinna 23)*
12. (Woolumbool 40)*
13. (Minecrow 106)*
14. (Bowaka 95)*

PENOLA SHEET (J54/6)
1. Robe No. 1 (15)
2. S.E. Drainage Works Bore
3. Penola No. 1 (49)
4. Beachport No. 1 (100)
5. Mount Burr (72)
6. Mount McIntyre
7. Kalangadoo No. 1 (70)
8. Geltwood Beach No. 1 (6,66,71,74)
9. Cheese Factory No. 1
10. Dismal Swamp 2
11. Dismal Swamp 1
12. Dismal Swamp 3
13. Tantanoola (S.A. Oil Wells)
14. (Springs (56,62,101)
(Mount Gambier (Producers' Oil Well)
15. Mount Gambier (A.O.C.) No. 1
16. Knights Dome No. 2 (62)
17. Mount Salt No. 1 (6,73,94)
18. Palpara No. 1
19. Comaum No. 1 (56)
20. Comaum Coal Bore (No. 1A or 2)(15,16,40)
21. (Bowaka 167)*
22. (Joyce 395)*
23. (Nangwarry 143)*
24. (Nangwarry 130)*
25. (Nangwarry 113)*
26. Tarpeena (56)

*Refers to Hundred & Section in (Reference 50)

VICTORIA

HAMILTON SHEET (J54/7)
1. Kanawinka No. 1
2. Kanawinka No. 6
3. Tullich No. 1 (77,97)
4. Heathfield No. 1 (89,91,96)
5. Bahgallah No. 2
6. Casterton No. 1 (Planet)(98)
7. Casterton No. 1 (Water Bore)
8. Sandford
9. Carapock No. 2
10. Muntham No. 1
11. Muntham No. 2
12. Coleraine
13. Merino No. 2 (27)
14. Merino No. 3
15. Merino No. 5
16. Mocamboro No. 1
17. Tahara No. 1
18. Yulecart No. 1
19. Mumbannar No. 1
20. Dartmoor No. 1
21. Dartmoor No. 14
22. Dartmoor No. 19
23. Dartmoor No. 20
24. Dergholm No. 1 (15)

PORTLAND SHEET (J54/11)
1. Caroline Nos. 2,3,4 (S.A. Oil Wells)
2. Nelson No. 1 (Glenelg No.1)(4,8,21,90)
3. Heywood No. 10 (52)
4. Bolwarra No. 1 (8,33)
5. Borthwicks (Portland North) (8,33)
6. Portland No. 2 (8,33)
7. Portland No. 3 (8,33)
8. Eumeralla No. 1 (79,84)
9. Pretty Hill No. 1 (78,83)
10. Belfast No. 4 (43,92,102)
11. Glaxco
12. Yangery No. 1 (102)
13. Wangoom No. 6 (102)
14. Kangertong No. 5 (102)
15. Caroline No. 1 (S.A. Oil Wells)
16. Portland No. 1 (33)

COLAC SHEET (J54/12)
1. Wangoom No. 2 (102)
2. Mepunga No. 2
3. Glenormiston No. 2
4. Terang No. 1
5. Flaxmans No. 1 (5,6,80,82)
6. Timboon No. 5 (93)
7. Narrawaturk No. 2
8. Port Campbell No. 1 (5,76,81)
9. Port Campbell No. 2 (5,76,81)
10. Port Campbell No. 4 (88)
11. Port Campbell No. 3 (5)
12. Koort-Koort-Nong No. 2
13. Tandarook No. 1
14. Carpendeit No. 1
15. Sherbrook No. 1 (86)
16. Fergusons Hill No. 1 (87)
17. Latrobe Bore (85)
18. Cressy No. 1
19. Birregurra No. 1 (15)
20. Colac No. 1
21. Colac No. 2
22. Colac No. 3
23. Yeo No. 5
24. Yan Yan Gurt
25. Barongarook No. 1
26. Barongarook No. 2
27. Kawarren Nos. 1-7
28. Bambra No. 1
29. Boonah No. 1
30. Gerangamete No. 3
31. Murroon No. 5
32. Yaugher No. 1
33. Krambruk No. 1
34. Krambruk No. 3
35. Panmure No. 2 (102)
36. Nullawarre No. 3 (68)

MELBOURNE SHEET (J55/5)
1. Newport (36)(58)
2. Mentone (36)

QUEENSCLIFF SHEET (J55/9)
1. Woornyalook No. 1
2. Derog No. 1
3. Barrabool No. 30
4. Gherineghap No. 1
5. Moolap No. 1
6. Connewarre
7. Duneed No. 2
8. Jan Juc No. 1-4 (51)
9. Jan Juc No. 5
10. Geelong Flow Oil (57)
11. Wensleydale No. 1
12. Wabdallah No. 1 (Bannockburn)
13. West Mineral Corp.
14. Anglesea No. 1 (75,95)
15. Point Addis Bores (51)
16. Portarlington No. 1
17. Paywit No. 3
18. Bellarine No. 1
19. Sorrento (13)
20. Nepean No. 29
21. Wannaeue No. 13
22. Angahook No. 23 (57)
23. Paywit No. 2
24. Queenscliff No. 7

Bores generally -
References (7), (9), (14), (26), (34), (50), (55), (56), (60), (61), (62), (67), (99), (101)

REFERENCES

PUBLISHED (Bores & outcrops)
(1) Baker (1943)
(2) Baker (1944)
(3) Baker (1950)
(4) Baker (1961), Baker & Cookson (1955)
(5) Baker (1963), Baker & McAndrew (1961)
(6) B.M.R.,(ed.),(1965a-c)
(7) Boutakoff (1951,1956)
(8) Boutakoff (1952,1963)
(9) Bowler (1963)
(10) Carter (1958b)
(11) Chapman (1922)
(12) Chapman (1923)
(13) Chapman (1928)
(14) Chapman & Crespin (1935)
(15) (Cookson (1954), (Cookson & Dettmann (1958)
(16) S.A.D.M. (1954)
(17) Coulson (1930,1960)
(18) Coulson (1932b)
(19) Coulson (1935)
(20) Crespin (1926)
(21) Crespin (1954)
(22) Darragh & Bowen (1965)
(23) Dennant (1889,1890)
(24) Dennant (1902)
(25) Dennant & Mulder (1897)
(26) Douglas (1962)
(27) Dunn (1912)
(28) Edwards (1953), Thomas (1953)
(29) Edwards (1962)
(30) Etheridge (1873)
(31) Gill (1943)
(32) Gill (1950)
(33) Glenie & Reed (1961)
(34) Gloe (1947)
(35) Grant (1901)
(36) Hall & Pritchard (1897a)
(37) Hall & Pritchard (1899)
(38) Hall & Pritchard (1901)
(39) Harris & Thomas (1949)
(40) Harris & Cookson (1965)
(41) Keble (1950)
(42) Kenley (1951,1954)
(43) Kenley (1959)
(44) Kenny (1938)
(45) Kitson (1900)
(46) Mawson & Dallwitz (1944), Mawson & Parkin (1943)
(47) Mawson & Segnit (1945)
(48) Murray (1877)
(49) O.D.N.L. (1963)
(50) O'Driscoll (1960)
(51) Raggatt & Crespin (1952,1955)
(52) Reed (1965)
(53) Spencer-Jones (1956)
(54) Spencer-Jones (1958,1963,1965)
(55) Sprigg & Boutakoff (1953)
(56) Sprigg (1961,1962) Sprigg & Woolley (1963a)
(57) Stach (1962)
(58) Stirling (1899c)
(59) Summers (1923)
(60) Taylor (1964)
(61) V.D.M. (1929-1960)
(62) Ward (1916-1946)
(63) Wells (1956)
(64) Whitelaw (1900)
(65) Williams (1964)
(66) Woolley & Laws (1964)
(67) Leslie (1965)
(68) Bock & Glenie (1965)

UNPUBLISHED (Bores - data available at B.M.R.)
(70) A.O.D.A. (1966)
(71) B.P.N.L. (1963,1964)
(72) Crespin (1945)
(73) Dellenbach (1964)
(74) Dellenbach (1965a)
(75) Dellenbach (1965b)
(76) Dellenbach & Hawkins (1964), Evans (1961a)
(77) Dellenbach et al (1965)
(78) Edworthy (1964), Evans (1963)
(79) Edworthy (1965a), Evans (1963)
(80) Edworthy (1965b), Evans (1962)
(81) F.-B.H. (1960a,c)
(82) F.-B.H. (1961a)
(83) F.-B.H. (1962b)
(84) F.-B.H. (1963a)
(85) F.-B.H. (1964a)
(86) F.-B.H. (1964b)
(87) F.-B.H. (1964f)
(88) F.-B.H. (1964g)
(89) Hawkins (1965)
(90) Hawkins & Dellenbach (1964)
(91) Hodgson (1964)
(92) Jewell (1959)
(93) Jewell (1960)
(94) O.D.N.L. (1962,1963a)
(95) O.D.N.L. (1963b)
(96) P.E.C. (1964b)
(97) P.E.C. (1965a)
(98) P.E.C. (1965b)
(99) Scorer (1965)
(100) S.E.O.S. (1962)
(101) Stinear (1948)
(102) F.-B.H. (1964h)

LEGEND

- Approximate position of boundary of Otway Basin
- Inferred position of boundary of basin
- Approximate position of petroleum tenement boundaries As At June, 1966
- O.E.L. Oil Exploration Licence
- P.E.P. Petroleum Exploration Permit
- •11 Bore or Well with Index Number
- (3) Reference Number (used in Bore & Well Index)
- x(5) Outcrop or regional geological description with Reference Number

10 0 10 20 30 40 MILES

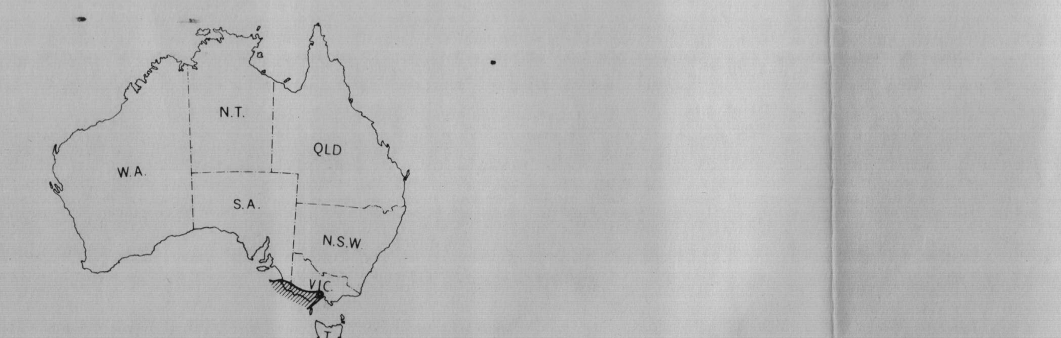
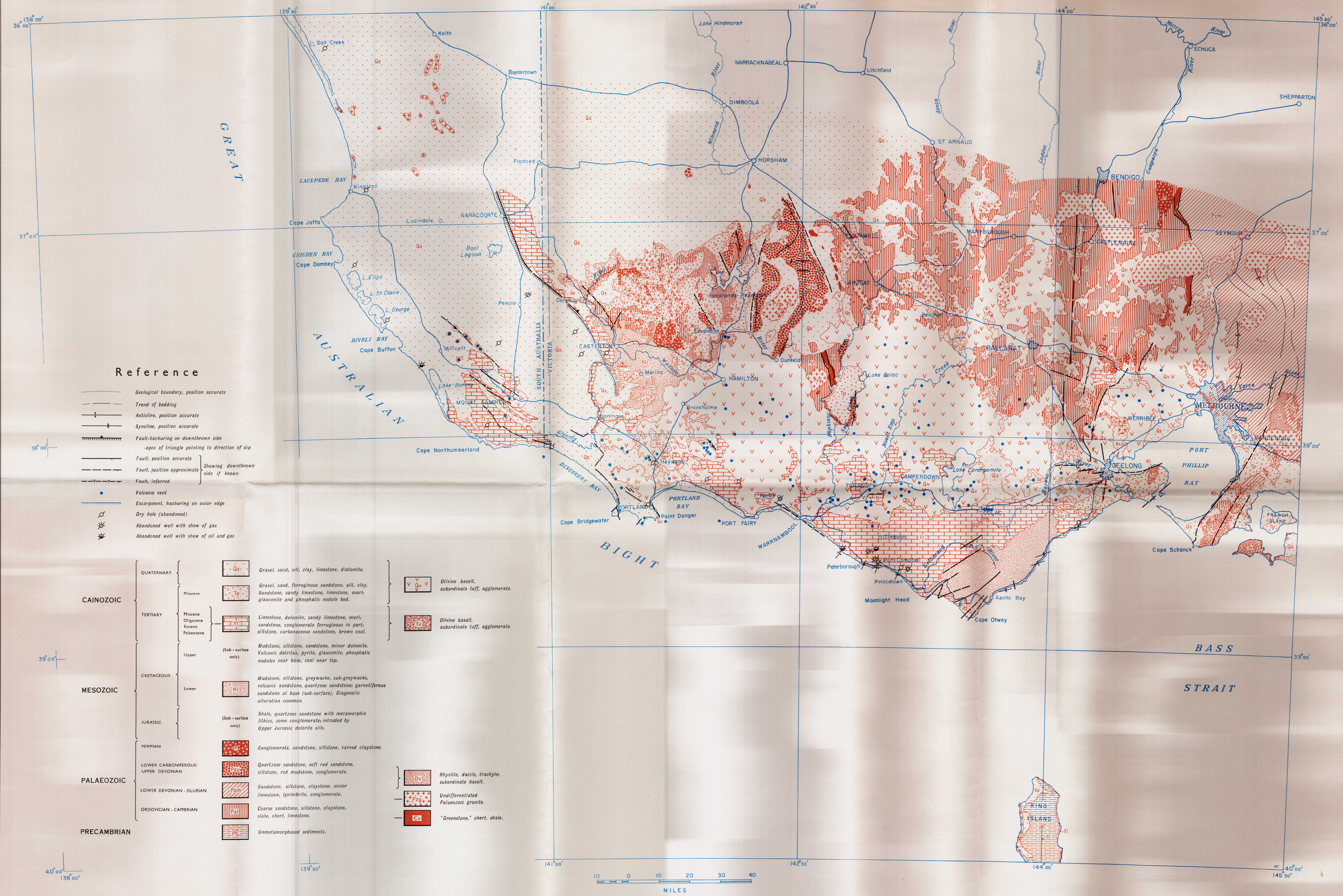


Plate 2

GEOLOGICAL MAP

OTWAY BASIN AND ADJACENT AREAS

VICTORIA AND SOUTH AUSTRALIA



Bureau of Mineral Resources, Geology and Geophysics. August 1966

X-AUS-I-29
H.Z

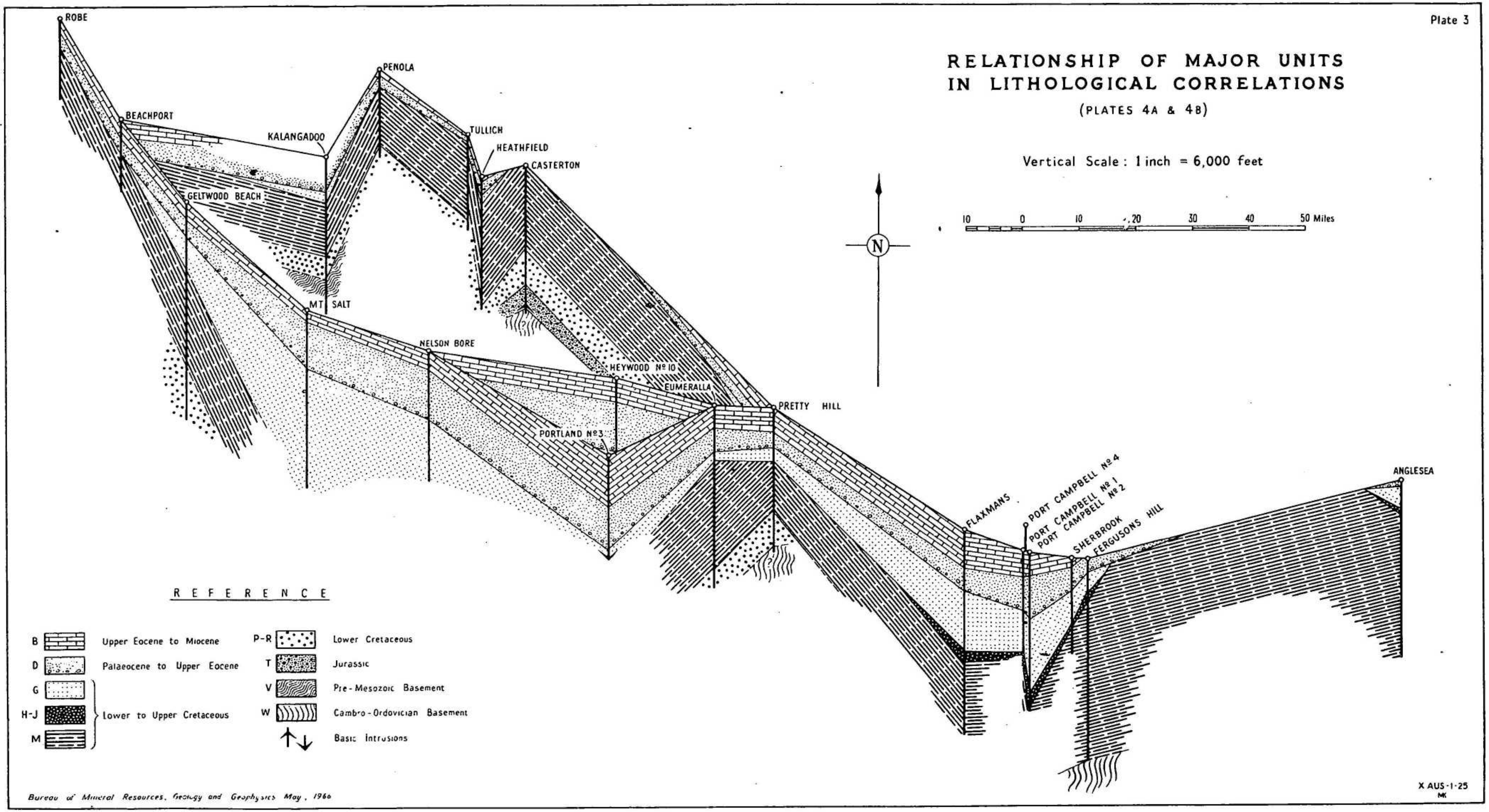


Plate 3
RELATIONSHIP OF MAJOR UNITS IN LITHOLOGICAL CORRELATIONS
(PLATES 4A & 4B)
Vertical Scale: 1 inch = 6,000 feet
10 0 10 20 30 40 50 Miles
N
ROBE
BEACHPORT
KALANGADOO
PENOLA
TULLICH
HEATHFIELD
CASTERTON
GELTWOOD BEACH
MT SALT
NELSON BORE
HEYWOOD Nº 10
EUMERALLA
PRETTY HILL
PORTLAND Nº 3
FLAXMANS
PORT CAMPBELL Nº 4
PORT CAMPBELL Nº 1
PORT CAMPBELL Nº 2
SHERBROOK
FERGUSONS HILL
ANGLESEA
REFERENCE
B Upper Eocene to Miocene
D Palaeocene to Upper Eocene
G
H-J
M
Lower to Upper Cretaceous
P-R Lower Cretaceous
T Jurassic
V Pre-Mesozoic Basement
W Cambro-Ordovician Basement
Basic Intrusions
Bureau of Mineral Resources, Geology and Geophysics May, 1966
X AUS-1-25
MK

Plates 4A & 4B

LITHOLOGICAL AND PALYNOLOGICAL CORRELATIONS OF OTWAY BASIN - COASTAL SECTION

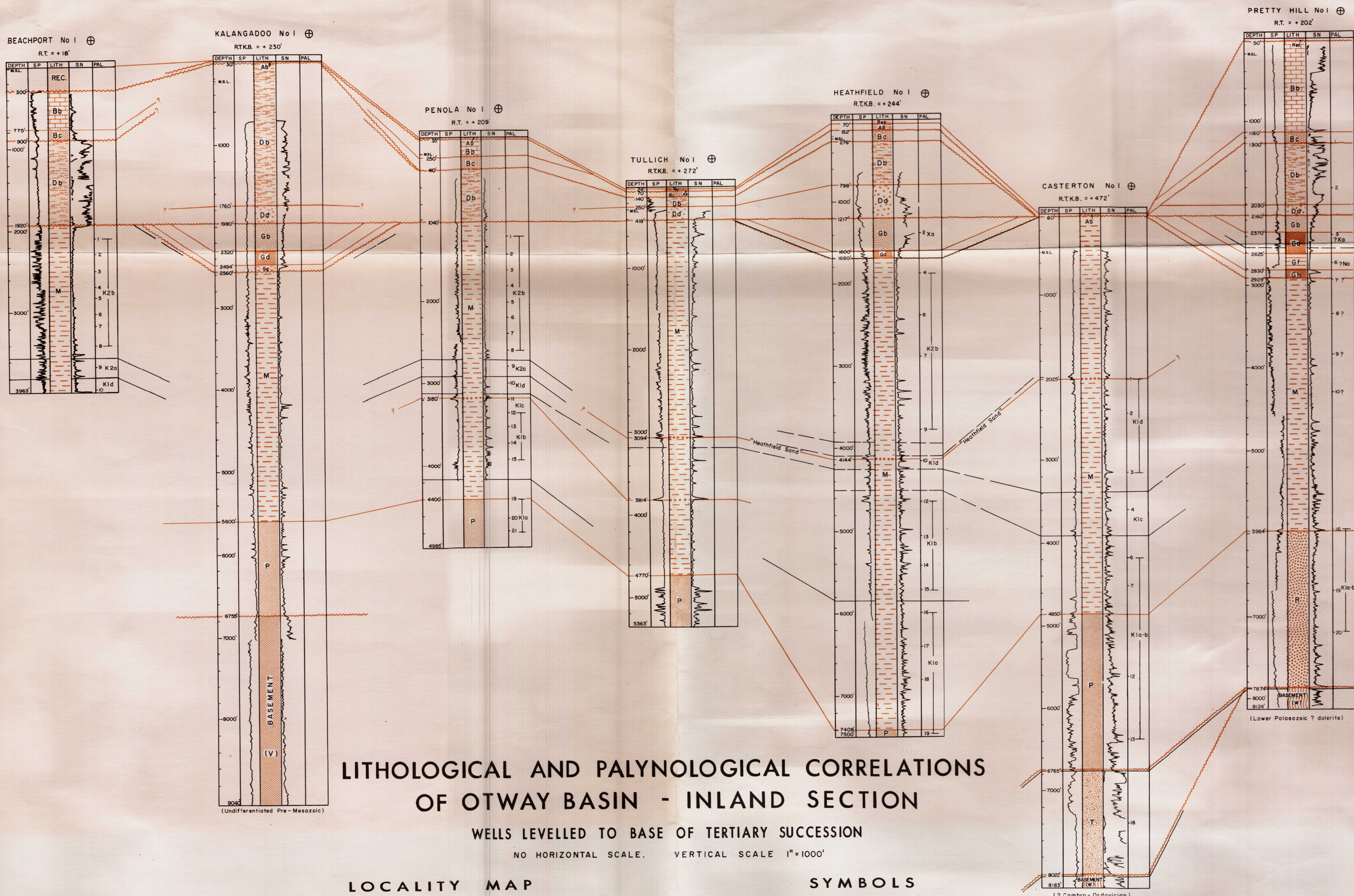
WELLS LEVELLED TO BASE OF TERTIARY

NO HORIZONTAL SCALE. VERTICAL SCALE : 1" = 1000'

SYMBOLS

- ⊕ *Well interpretation based on study of samples, E - logs and literature*
- ⊖ *Well interpretation based on study of E - logs and literature*
- ⦶ *Well interpretation based on study of literature*
- 2 *Core numbers important for palynological correlation*
- 17 *Represents core from deviated hole in Port Campbell No 2*
- JB *Junk basket core in Port Campbell No 1*
- *Unconformity*
- *Unconformity inferred*
- *Lithological boundary established*
- *Lithological boundary inferred*
- *Palynological boundary interpolated*
- *Palynological boundary inferred*

PLATE 4B

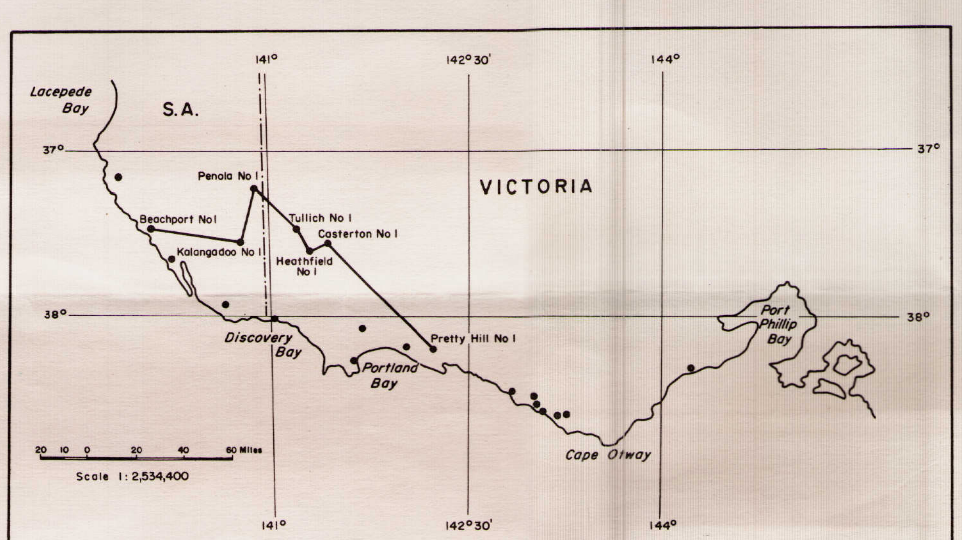


LITHOLOGICAL AND PALYNOLOGICAL CORRELATIONS OF OTWAY BASIN - INLAND SECTION

WELLS LEVELLED TO BASE OF TERTIARY SUCCESSION

NO HORIZONTAL SCALE. VERTICAL SCALE 1" = 1000'

LOCALITY MAP



SYMBOLS

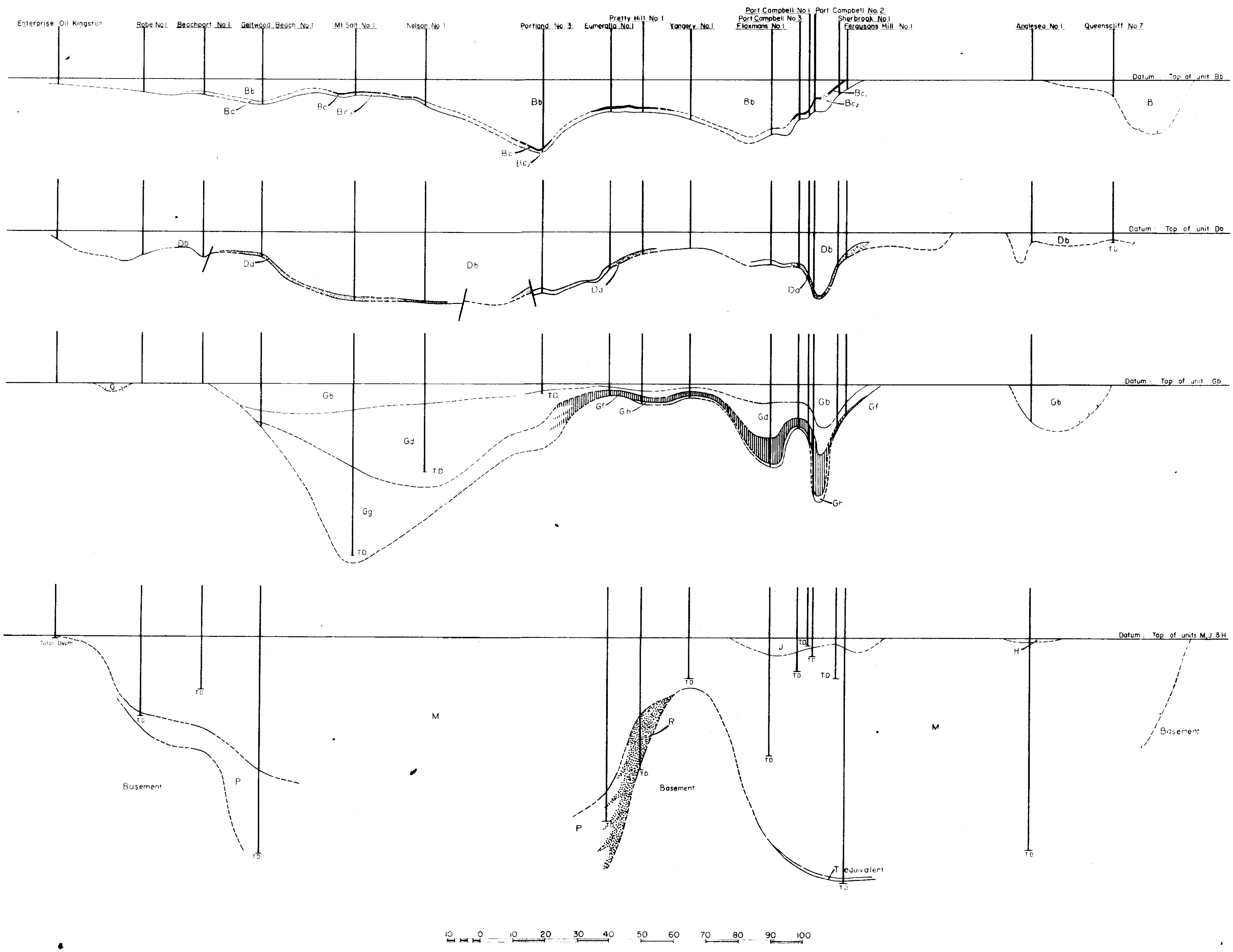
- ⊕ *Interpretation based on study of samples, E - logs and literature*
- ⊖ *Interpretation based on study of E - logs and literature*
- ⦶ *Interpretation based on study of literature*
- ⊢12 *Core numbers important for palynological correlation*
- *Unconformity*
- *Unconformity inferred*
- *Lithological boundary established*
- *Lithological boundary inferred*
- *Palynological boundary interpolated*
- *Palynological boundary inferred*

DISTRIBUTION & THICKNESS VARIATIONS OF LITHOLOGICAL UNITS

IN THE COASTAL ONSHORE PART OF

OTWAY BASIN

(Major unconformities used as Datums)



Scale in miles

Vertical scale 1 inch = 4,000 ft

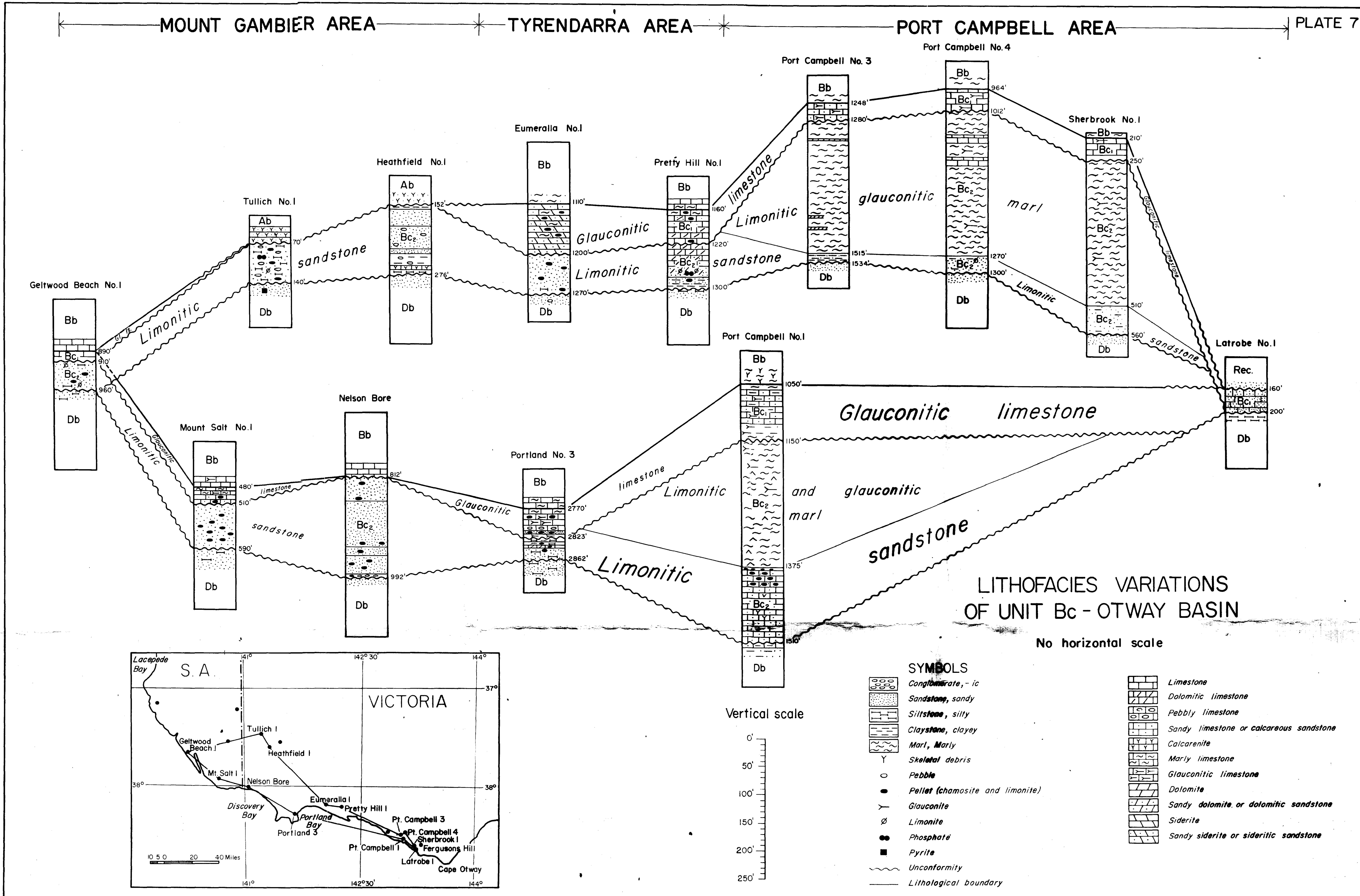
Bureau of Mineral Resources, Geology and Geophysics August 1966

To accompany Record No 1966/170

x AUS-1-35

PLATE 6

LITHOFACIES VARIATIONS OF UNIT Dd - OTWAY BASIN



LITHOFACIES VARIATIONS OF UNIT Bc - OTWAY BASIN

No horizontal scale

PLATE 8

LITHOFACIES VARIATIONS OF UNIT Bb - OTWAY BASIN

AEROMAGNETIC INDEX MAP – OTWAY BASIN

(UP TO END 1965)

10 0 10 20 30 40

MILES

YEAR	SYMBOL	FLOWN FOR	FLOWN BY	NAME OF SURVEY	REFERENCE
1948	C1	The Zinc Corporation Ltd.	Oscar Weiss (Geophysical Consultant)		Sprigg, R.C. (1952)
1954	20	B.M.R.	B.M.R.	Melbourne-Adelaide	Bureau Maps J54/81-1 and J55/B1-1
1954	15	B.M.R.	B.M.R.	Broken Hill-Melbourne L.L.T.*	Bureau Maps J54/B1-1 and J55/B1-1
1955	M1	South Australian Department of Mines	Adastra Hunting Geophysics Ltd.	Gambier-Otway	C.G.G. (1965)
1955	C2	Murray Basin Oil Syndicate	Adastra Hunting Geophysics Ltd.	Murray Basin	O'Driscoll, E.P.D. (1960)
1955	C3	Frome-Broken Hill Co. Pty. Ltd.	World Wide Aerial Surveys (Aust.) Pty. Ltd.	Murray River Basin	F.-B.H. (1955) (Map only)
1956	3	B.M.R.	B.M.R.	Cranbourne	Thyer, R.F. (1957)
1956	22	B.M.R.	B.M.R.	Kalgoorlie-Melbourne. L.L.T.*	Bureau Maps J54/B1-1 and J55/B1-1
1956	29	B.M.R.	B.M.R.	Alice Springs-Melbourne L.L.T.*	Bureau Maps J54/B1-1 and J55/B1-1
1958	19	B.M.R.	B.M.R.	Adelaide-Cape Nelson L.L.T.*	Bureau Map J54/B1-1
1960	9	B.M.R.	B.M.R.	Melbourne-Parkes L.L.T.*	Bureau Map J55/B1-1
1960	S1	Haematite Explorations Pty. Ltd.	Aero Service Ltd.	Bass Strait	H.E.P.L. (1965) (Reconnaissance for S3)
1961	6	B.M.R.	B.M.R.	Melbourne-Rockhampton	Bureau Map J55/B1-1
1961	26	B.M.R.	B.M.R.	Melbourne-Renmark	Bureau Maps J54/B1-1 and J55/B1-1
1961	S2	Haematite Explorations Pty. Ltd.	Aero Service Ltd.	Encounter Bay	H.E.P.L. (1965) (Reconnaissance Lines for survey S3).
1961	S3	Haematite Explorations Pty. Ltd.	Aero Service Ltd.	Bass Strait-Encounter Bay	H.E.P.L. (1965) (Subsidized Survey)
1962	S4	Oil Development N.L.	Aero Service Ltd.	Andersons Inlet	Incorporated in H.E.P.L. (1965) Bureau Reference 62/1713 (Subsidized)
1962	8	B.M.R.	B.M.R.	Sydney-Canberra-Melbourne.L.L.T.*	Bureau Map J55/B1-1
1962	17	B.M.R.	B.M.R.	Broken Hill-Melbourne L.L.T.*	Bureau Maps J54/B1-1 and J55/B1-1
1962	24	B.M.R.	B.M.R.	Geelong-Adelaide L.L.T.*	Bureau Maps J54/B1-1 and J55/B1-1
1962	25	B.M.R.	B.M.R.	Geelong-Adelaide-Leigh Creek.L.L.T.*	Bureau Maps J54/B1-1 and J55/B1-1
1962	S5	Planet Oil Company N.L.	Aero Service Ltd.	Murray Basin	P.O.C. N.L. (1963) Bureau Reference 62/1732 (Subsidized)
1963	S6	Seismic Analysis Incorporated	Adastra Hunting Geophysics Pty. Ltd.	Echuca	Final Report by Adastra Hunting Geophysics Pty. Ltd. Bureau Reference 62/1723 (Subsidized)

* Long Line Traverse flown at an altitude of 1,500 feet above general ground level.

LEGEND

—C1— Traverse

C2 Area

(Symbols indicate authority of surveys)

Prefix C = Unsubsidized Prefix S = Subsidized

Prefix M = South Australian Mines Department

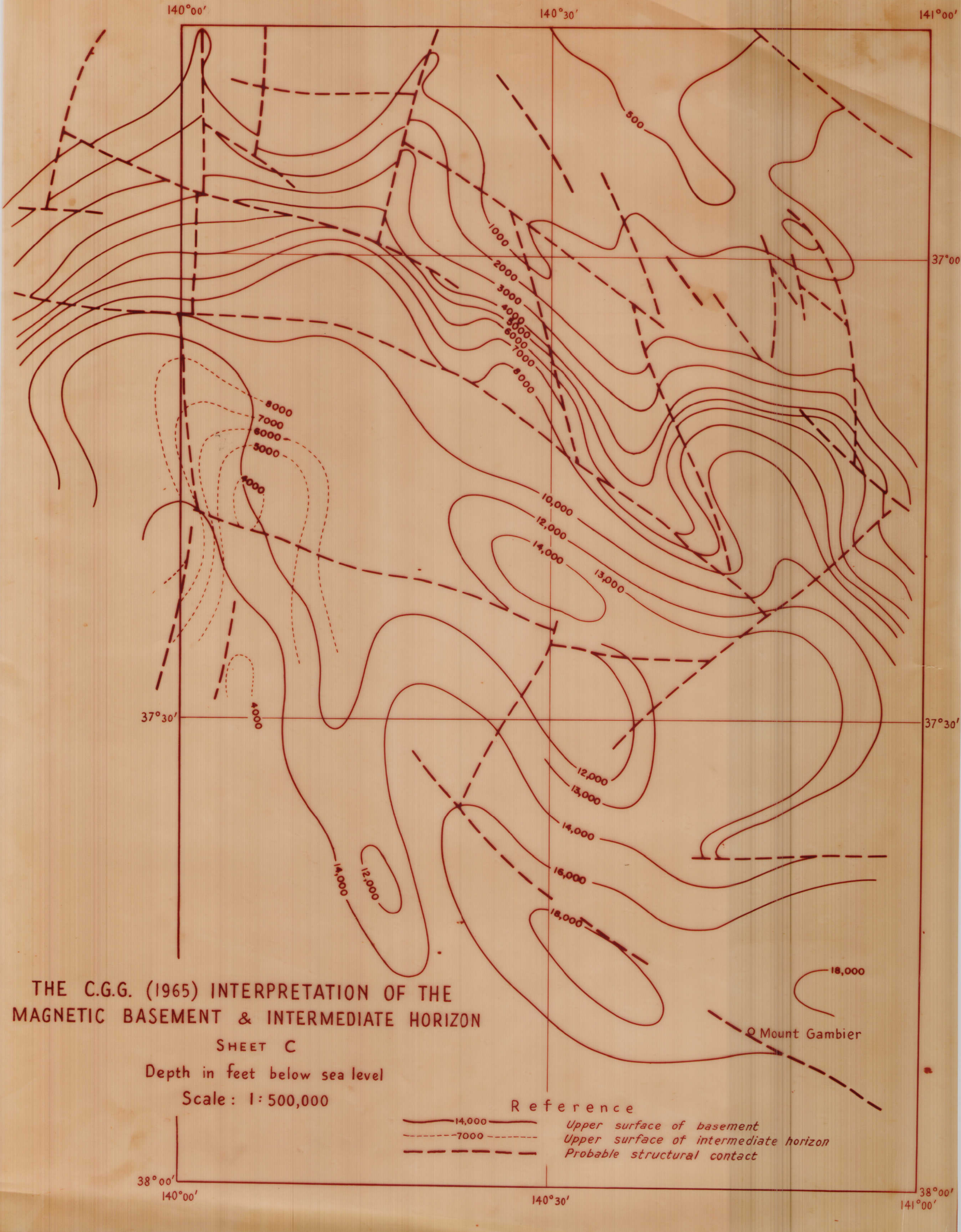
B.M.R. surveys have numerals only

YEAR	SYMBOL	SURVEY BY	AREA	REFERENCE
1893-1905	-	Wright, Bernachi et al	Melbourne	Jeffreys, H., 1941 - Mon. Not. Roy. Astron. Soc. 5(1), 10-11
1949	6	B.M.R.	Adelaide-Melbourne	Oldham (1963)* B.M.R. Files 4905-1, -2A and -2B
1949/50	7	B.M.R.	SW Victoria	Wiebenga (1957)* B.M.R. Files 4906-1 to -3. Also Richards (1956)
1950/52	M1	S.A.D.M.	Cape Jaffa	Grant (1954). Approximately 150 stations.
1950/52	5	B.M.R.	National	Dooley et al (1961). B.M.R. Files 5099, 6491 and 6591.
1950/54	M2	S.A.D.M.	Naracoorte-Penola	Sprigg (1962a). B.M.R. Files 57682-4. Also Richards (1956)
1951	17	B.M.R.	Melbourne-Bendigo	B.M.R. Files 5103-1 to -3 (Regional gravity survey).
1956	8	B.M.R.	St. Arnaud-Bendigo	B.M.R. Files 5608-1 and -2.
1956	11	B.M.R.	W Victoria	B.M.R. Files 5609-1 and -2.
1956	4	B.M.R.	Hamilton-Colac	B.M.R. Files 56-504, -505 and -506.
1957	C4	F.-B.H.	Portland	Richards (1958)* B.M.R. File 61-675.
1957	C5	F.-B.H.	Mount Salt	Richards (1957)*.
1957/58	19 19A	B.M.R. B.M.R.	Port Phillip Bay Mornington Peninsula	Gunson, Williams & Dooley (1959)* and Gunson & Williams (1965)* B.M.R. Files 57508-D, 57509 and 57510 (Port Phillip Bay) 58501-D and 58502 (Mornington Peninsula).
1958	1	B.M.R.	Horsham	Neumann and Van Son (1958)* B.M.R. Files 58-020D & 58-021 to -024.
1959	10	B.M.R.	Horsham	Neumann and Van Son (1959)* B.M.R. Files 59-010D, 59-011 and 59-012.
1959	12	B.M.R.	Melbourne-Bendigo	Regional gravity survey. B.M.R. Files 5903-1 to -4.
1959	16	B.M.R.	Melbourne	" " " B.M.R. Files 5902-1 to -3.
1959	37	B.M.R.	Bendigo	" " " B.M.R. Files 58513D and 58513.
1959	18	B.M.R.	Echuca	" " " B.M.R. Files 5904-1 to -3.
1960	36	B.M.R.	Melbourne - Tasmania	Airstrip occupation. Calibration File 6091.
1960	C7	F.-B.H.	Port Campbell	B.M.R. File 61-665.
1961	C8	Adastra for P.E.C.	Casterton	Basins Study Group. File No. 6
1960/61	46	B.M.R.	National	Barlow (1965)*. B.M.R. File 6091 (Calibration File).
1961/62	C9	F.-B.H.	Warrnambool	B.M.R. File 61-670. Stations W1-W242.
1961	15	B.M.R.	Seymour	Regional gravity survey. B.M.R. Files 6104-1 to -3.
1962/63	C10	F.-B.H.	Hamilton	B.M.R. File 61-660. Stations W243-W652.
1962	50	B.M.R.	National	Dooley (1962).
1962/63	C11	F.-B.H.	Colac	Richards (1963)*. B.M.R. File 62-720. Stations W652-W1341.
1963	3	B.M.R.	Stawell	Smith and Daly (1964)*.
1963	C2	Geosurveys for B.P.N.L.	Geltwood Beach	Geltwood Beach No. 1. Application for subsidy, B.M.R. File 63/1323.
1964	C12	Namco for A.O.D.A.	Kalangadoo	A.O.D.A. (1965a)*. B.M.R. File 64/4805.
1964/65	13	B.M.R.	National	Isogal survey of Australia by B. Barlow. B.M.R. Files 6491 & 6591.
1965	41	B.M.R.	Footscray-Toolangi	Gravity tie. B.M.R. Files 6592-1 and -2.

Bureau of Mineral Resources, Geology and Geophysics, December 1966.

X AUS-1-45


PLATE 9C
SEISMIC INDEX MAP — OTWAY BASIN
(To end of 1965)
SCALE 1:500,000
10 0 10 20 30 40
MILES
Reference
8 Survey index number
RA Traverse identification (Lettered and/or numbered)
Shot point numbers (Letter prefixed or otherwise)
Boundary between surveys or groups of surveys
Approximate boundary of Otway Basin
GEELONG
ANGLESEA
COLAC
HAMILTON
CASTERTON
NARACOORTE
KINGSTON
WARRNAMBOOL
PORTLAND
MOUNT GAMBIER
Bureau of Mineral Resources, Geology and Geophysics
October
X AUS-1-37A



THE C.G.G. (1965) INTERPRETATION OF THE MAGNETIC BASEMENT & INTERMEDIATE HORIZON

SHEET C

Depth in feet below sea level

Scale: 1:500,000

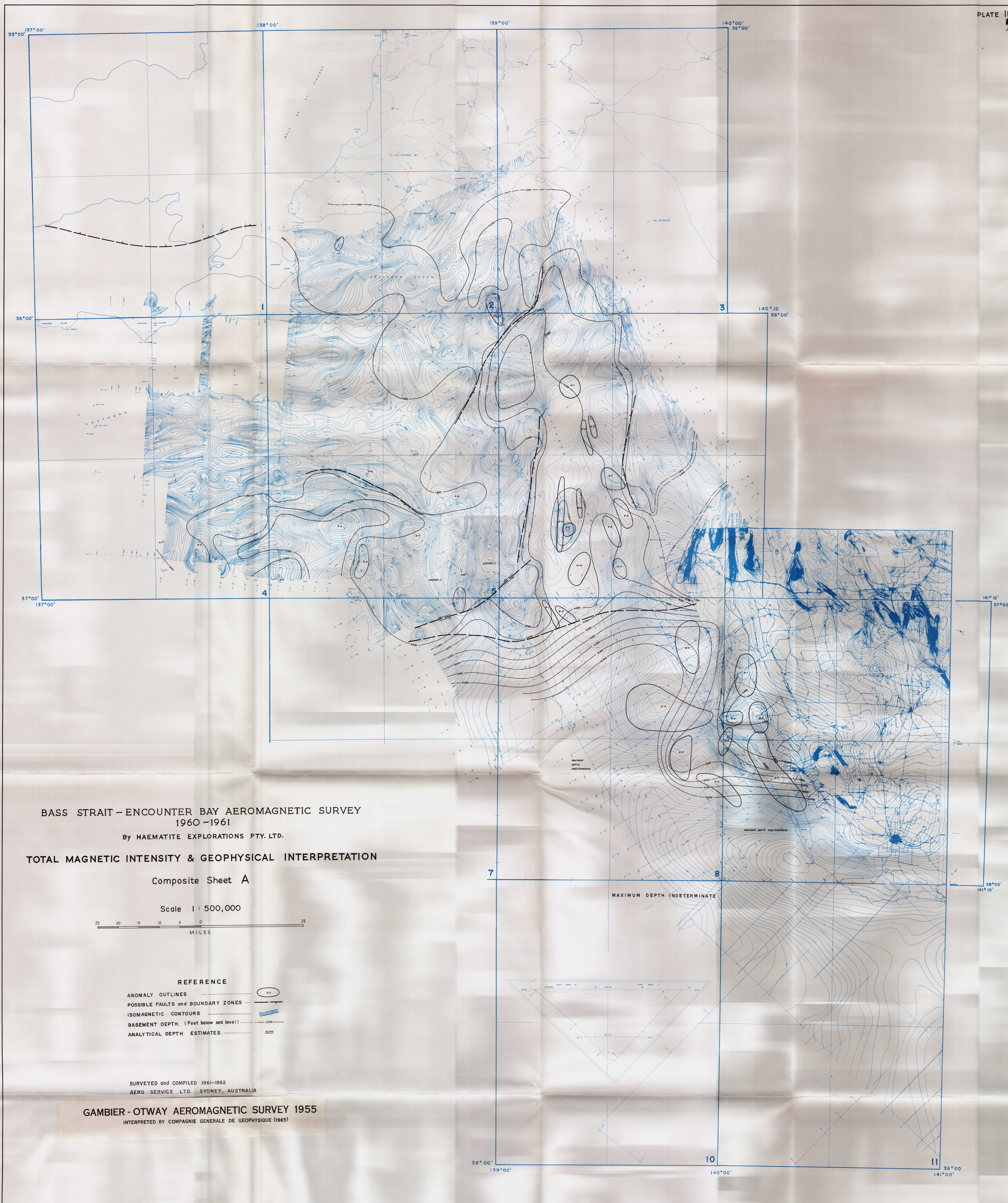
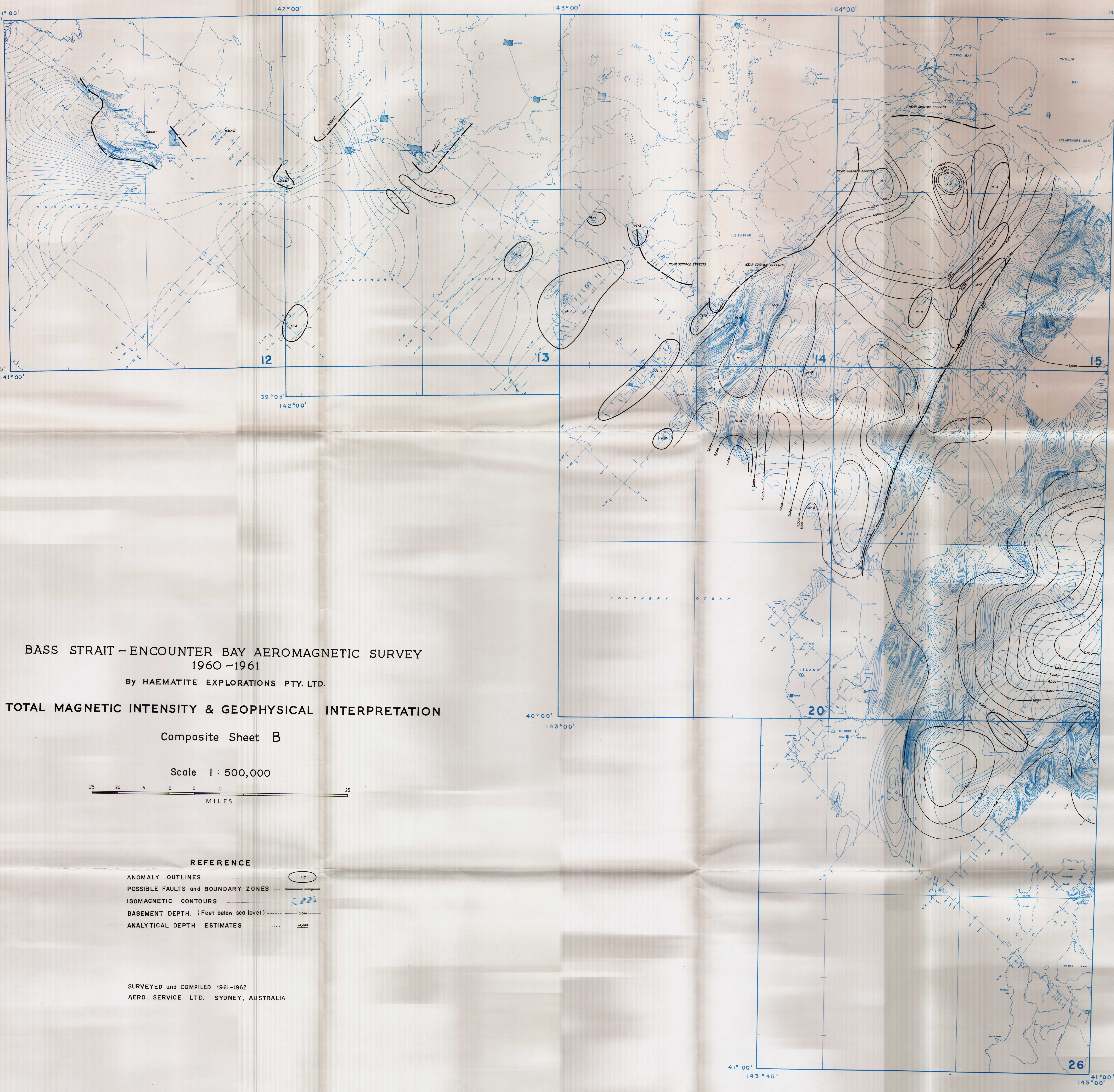


PLATE 10 A
BASS STRAIT – ENCOUNTER BAY AEROMAGNETIC SURVEY
1960 – 1961
By HAEMATITE EXPLORATIONS PTY. LTD.
TOTAL MAGNETIC INTENSITY & GEOPHYSICAL INTERPRETATION
Composite Sheet A
Scale 1 : 500,000
MILES
REFERENCE
ANOMALY OUTLINES
POSSIBLE FAULTS and BOUNDARY ZONES
ISOMAGNETIC CONTOURS
BASEMENT DEPTH. (Feet below sea level)
ANALYTICAL DEPTH ESTIMATES
SURVEYED and COMPILED 1961–1962
AERO SERVICE LTD. SYDNEY, AUSTRALIA
GAMBIER - OTWAY AEROMAGNETIC SURVEY 1955
INTERPRETED BY COMPAGNIE GENERALE DE GEOPHYSIQUE (1965)
MAXIMUM DEPTH INDETERMINATE
137°00'
138°00'
139°00'
140°00'
141°00'
35°00'
36°00'
37°00'
38°00'
39°00'

PLATE 10 A



BASS STRAIT – ENCOUNTER BAY AEROMAGNETIC SURVEY 1960 – 1961

By HAEMATITE EXPLORATIONS PTY. LTD.

TOTAL MAGNETIC INTENSITY & GEOPHYSICAL INTERPRETATION

Composite Sheet B

Scale 1 : 500,000

25 20 15 10 5 0 25

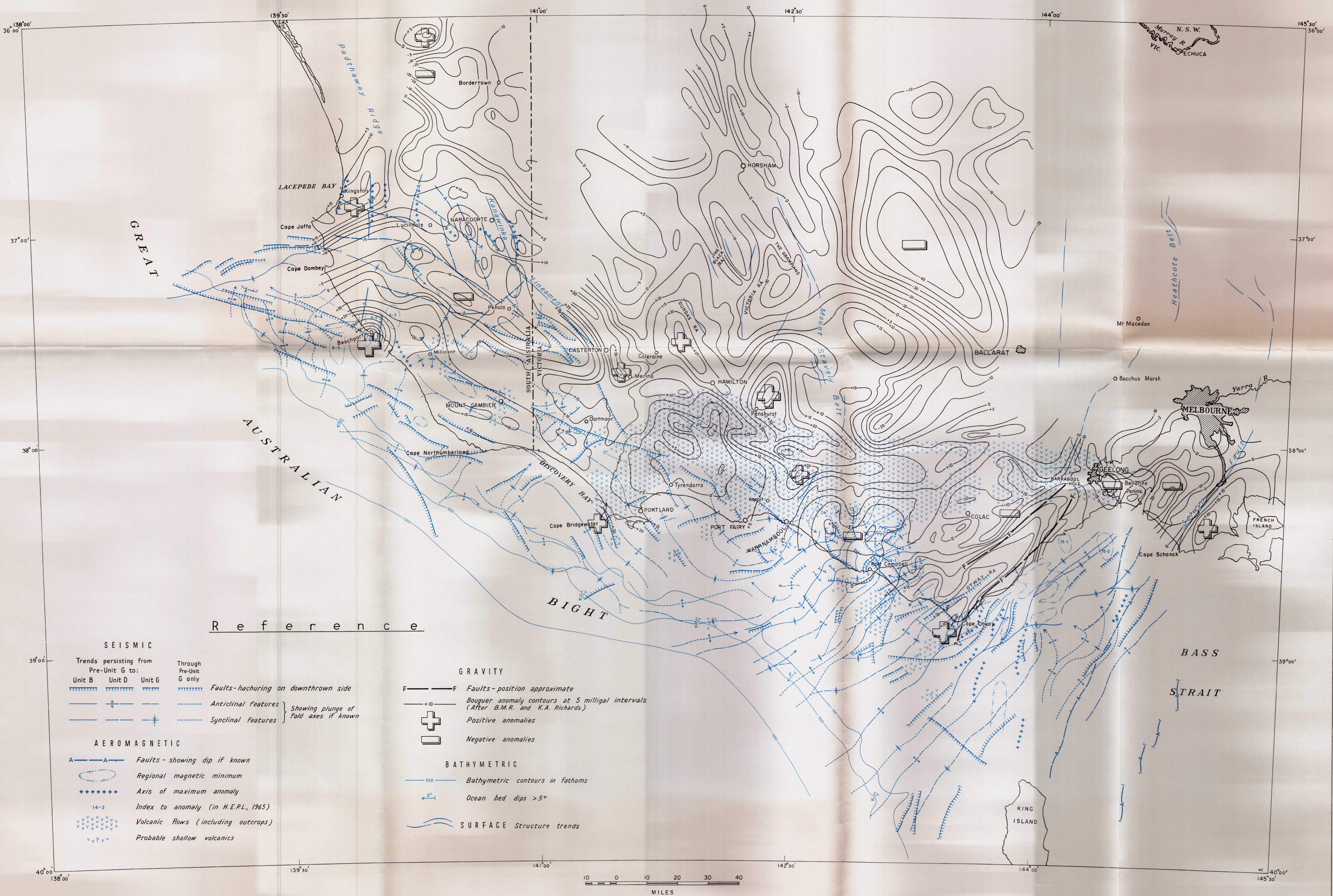
MILES

REFERENCE

- ANOMALY OUTLINES
- POSSIBLE FAULTS and BOUNDARY ZONES
- ISOMAGNETIC CONTOURS
- BASEMENT DEPTH. (Feet below sea level) 2,000
- ANALYTICAL DEPTH ESTIMATES 10,000

SURVEYED and COMPILED 1961-1962
AERO SERVICE LTD. SYDNEY, AUSTRALIA

SUBSURFACE STRUCTURE - OTWAY BASIN



10 0 10 20 30 40
MILES
Scale: 1 : 1,000,000

Bureau of Mineral Resources, Geology and Geophysics. November, 1966.

X AUS-1-37 B
PJB & MK

SEISMIC SECTIONS - OTWAY BASIN

REFERENCES

THE SECTIONS HAVE BEEN COMPILED FROM RECORDS SHOT BY -

1. Western Geophysical Co. for Haematite Explorations Pty. Ltd., (1963, 1965)
2. Ray Geophysics (Aust.) Pty. Ltd. for Frome - Broken Hill Co. Pty. Ltd., (1961 to 1963)
3. United Geophysical Corp. for " " " " (1960 to 1964)
4. Western Geophysical Co. for " " " " (1963)
5. Geoseismic (Aust.) Ltd. for General Exploration (Aust.) Ltd., (1961)
6. Namco International Inc. for Alliance Oil Development (Aust) N.L., (1964, 1965)

Interpretations by Sedimentary Basins Study Group, Bureau of Mineral Resources, unless otherwise indicated on sections

Wells shown have been used for phantom control

HORIZONS PHANTOMED

Approx. Base of Unit 'B'
" Base of Unit 'D'
" Base of Unit 'G'
(N.B.: Unit 'J' included in Unit 'G')
} B.M.R. informal nomenclature

70 — Record lines showing shot points - datum : sea level

Phantomed horizons in regions of good well control or good reflection continuity

Phantomed horizons in regions of poor control or poor reflection continuity

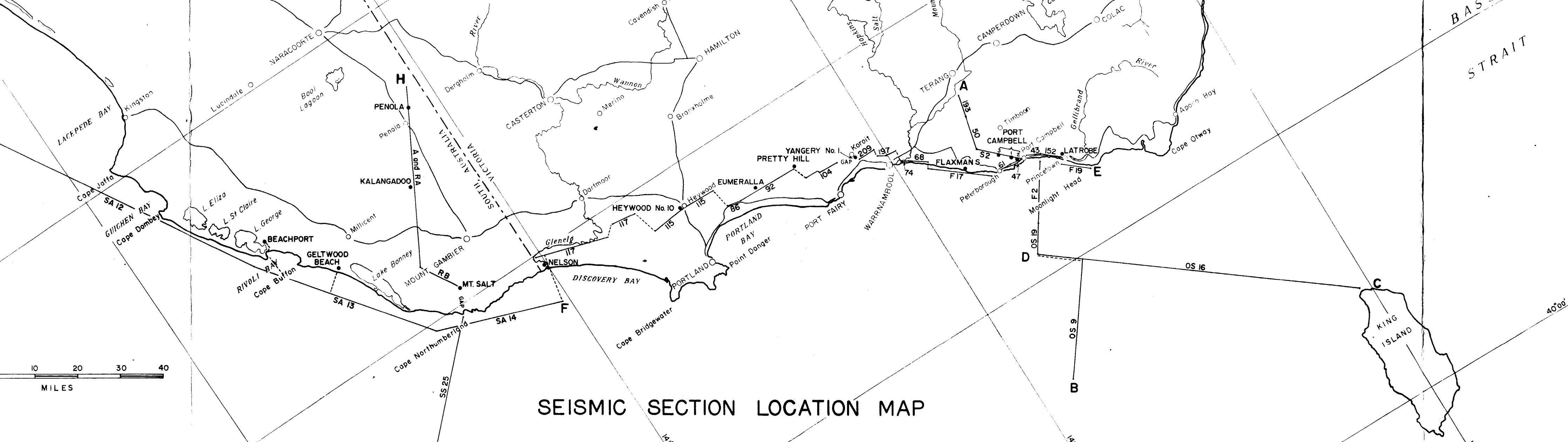
Other prominent reflections on Variable Area and Variable Density records

Prominent reflections on wiggle - trace records (section H1 only)

Vh= 8,500 — Refractors (Vh = velocity of refractor in feet/second) (section H1 only)

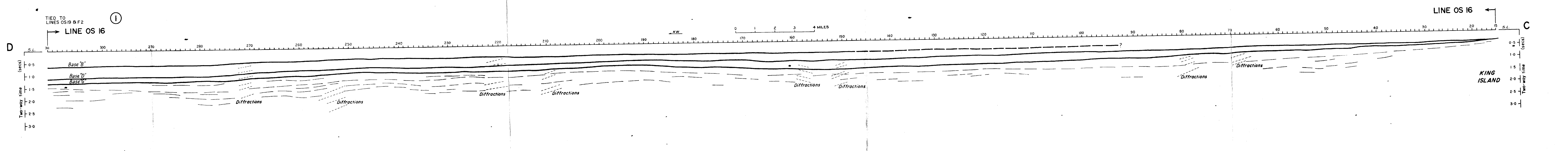
Inferred faults

Equivalent reflections across fault



SEISMIC SECTION LOCATION MAP

PLATE 12 A

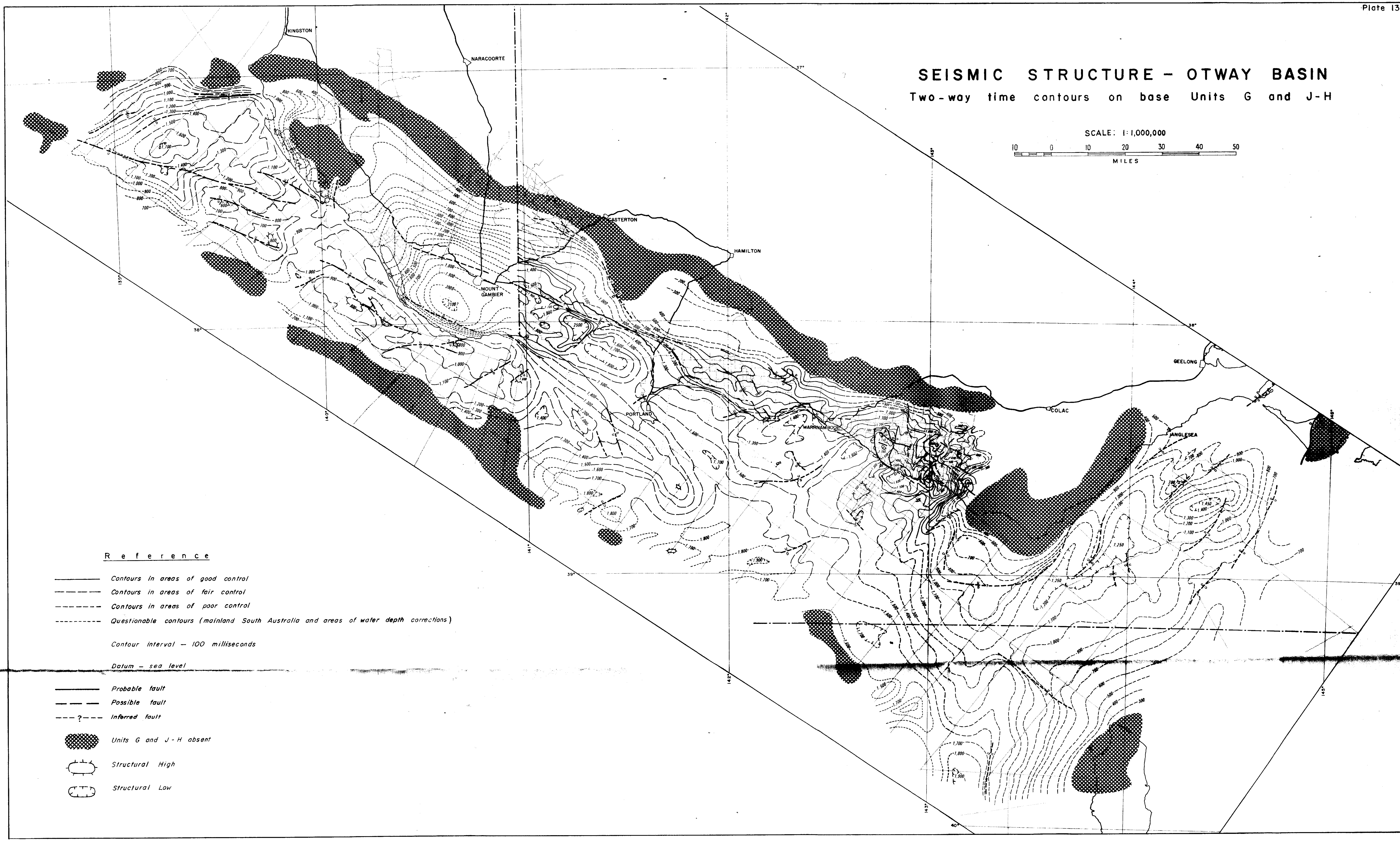


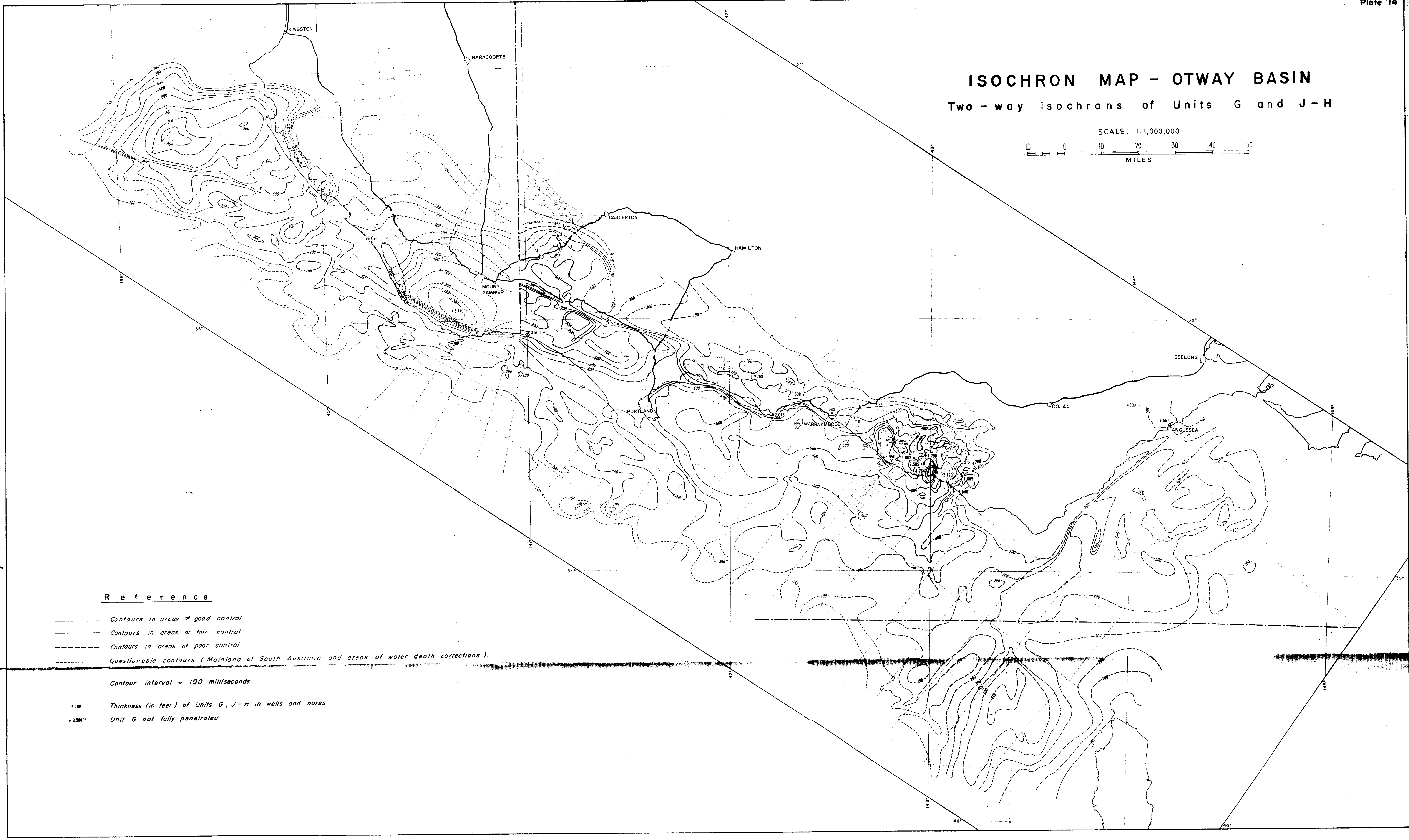
LONGITUDINAL SEISMIC REFLECTION PROFILE C-D — OTWAY BASIN

LONGITUDINAL SEISMIC REFLECTION PROFILE E-F-G — OTWAY BASIN

TRANSVERSE SEISMIC PROFILES A-B & H-I — OTWAY BASIN

Plate 13


SEISMIC STRUCTURE - OTWAY BASIN
Two-way time contours on base Units G and J-H
SCALE: 1:1,000,000
10 0 10 20 30 40 50
MILES
KINGSTON
NARACOORTE
CASTERTON
HAMILTON
MOUNT GAMBIER
PORTLAND
WARRNAMBOOL
COLAC
GEELONG
ANGLESEA
Reference
Contours in areas of good control
Contours in areas of fair control
Contours in areas of poor control
Questionable contours (mainland South Australia and areas of water depth corrections)
Contour interval - 100 milliseconds
Datum - sea level
Probable fault
Possible fault
Inferred fault
Units G and J-H absent
Structural High
Structural Low


ISOCHRON MAP - OTWAY BASIN
Two - way isochrons of Units G and J - H
SCALE: 1:1,000,000
MILES
KINGSTON
NARACOORTE
CASTERTON
HAMILTON
MOUNT GAMBIER
PORTLAND
WARRNAMBOOL
COLAC
GEELONG
ANGLESEA
Reference
Contours in areas of good control
Contours in areas of fair control
Contours in areas of poor control
Questionable contours (Mainland of South Australia and areas of water depth corrections).
Contour interval - 100 milliseconds
Thickness (in feet) of Units G, J - H in wells and bores
Unit G not fully penetrated

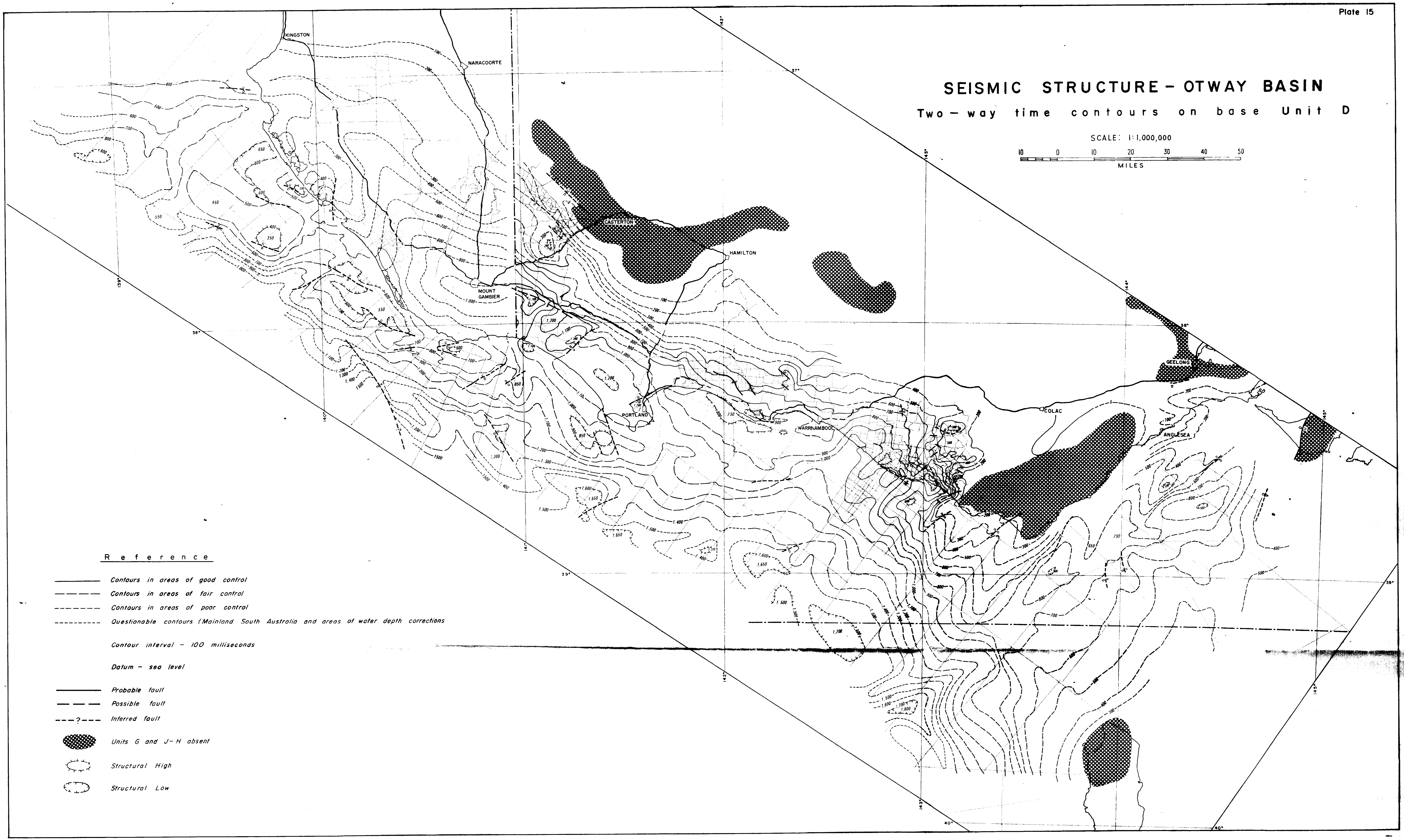

SEISMIC STRUCTURE - OTWAY BASIN
Two - way time contours on base Unit D
SCALE: 1:1,000,000
10 0 10 20 30 40 50
MILES
KINGSTON
NARACOORTE
CASTERTON
HAMILTON
MOUNT GAMBIER
PORTLAND
WARRNAMBOOL
COLAC
GEELONG
ANGLESEA
Reference
Contours in areas of good control
Contours in areas of fair control
Contours in areas of poor control
Questionable contours (Mainland South Australia and areas of water depth corrections
Contour interval - 100 milliseconds
Datum - sea level
Probable fault
Possible fault
Inferred fault
Units G and J-H absent
Structural High
Structural Low

Plate 16

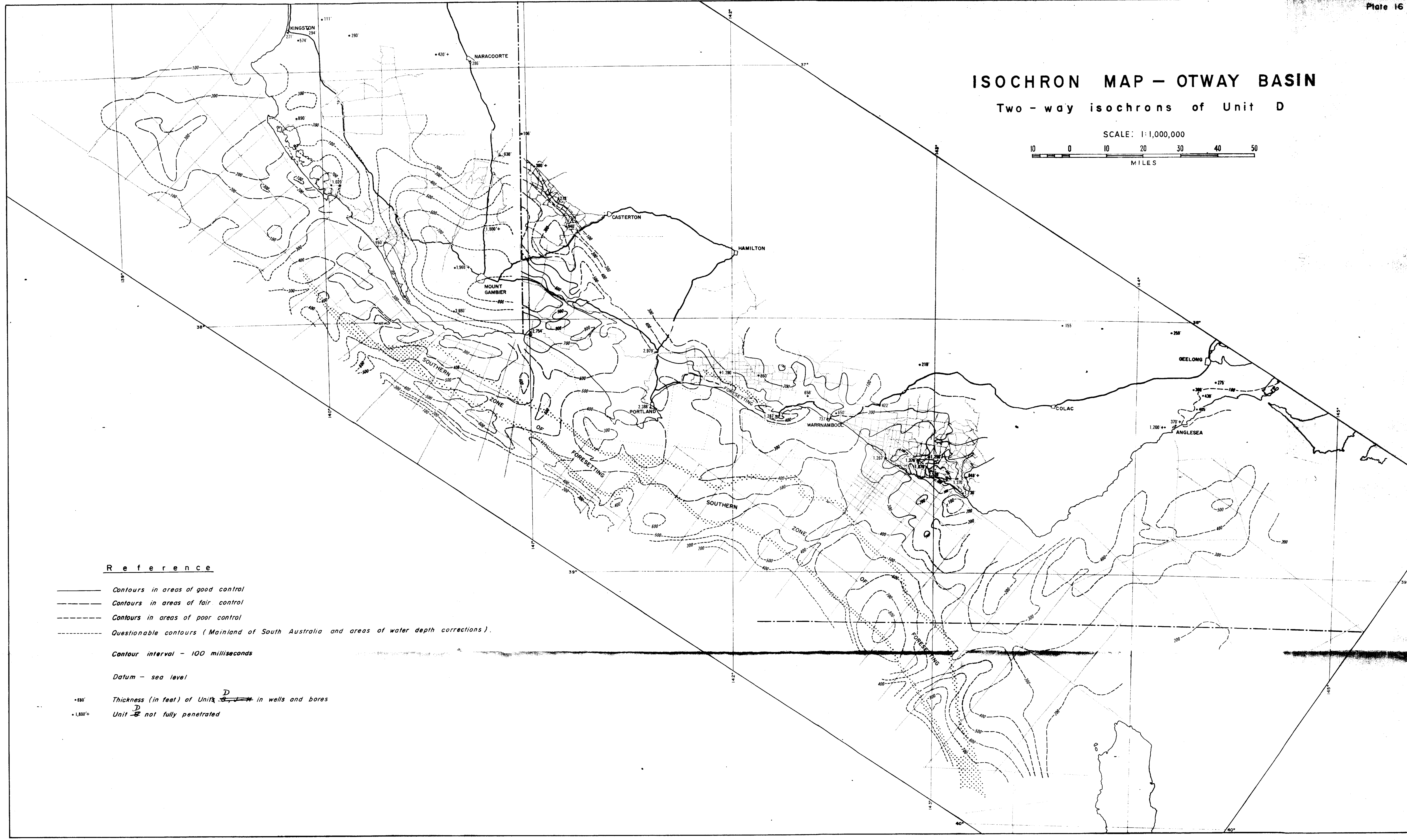
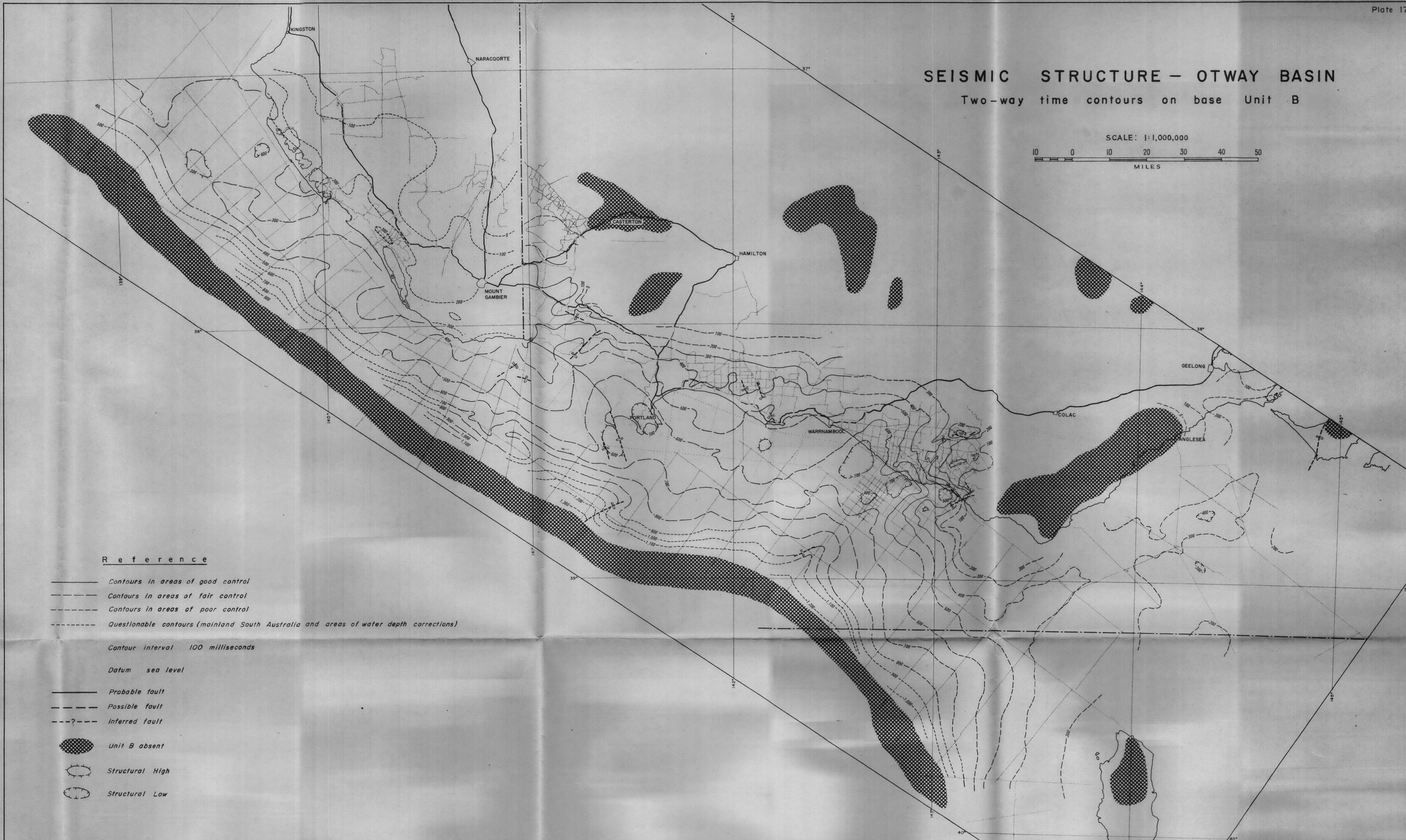

ISOCHRON MAP — OTWAY BASIN
Two - way isochrons of Unit D
SCALE: 1:1,000,000
10 0 10 20 30 40 50
MILES
KINGSTON
NARACOORTE
CASTERTON
HAMILTON
MOUNT GAMBIER
PORTLAND
WARRNAMBOOL
COLAC
GEELONG
ANGLESEA
SOUTHERN ZONE OF FORESETTING
Reference
Contours in areas of good control
Contours in areas of fair control
Contours in areas of poor control
Questionable contours (Mainland of South Australia and areas of water depth corrections).
Contour interval - 100 milliseconds
Datum - sea level
Thickness (in feet) of Unit D in wells and bores
Unit D not fully penetrated

Plate 17


SEISMIC STRUCTURE – OTWAY BASIN
Two-way time contours on base Unit B
SCALE: 1:1,000,000
10 0 10 20 30 40 50
MILES
KINGSTON
NARACOORTE
CASTERTON
HAMILTON
MOUNT GAMBIER
PORTLAND
WARRNAMBOOL
COLAC
GEELONG
ANGLESEA
Reference
Contours in areas of good control
Contours in areas of fair control
Contours in areas of poor control
Questionable contours (mainland South Australia and areas of water depth corrections)
Contour interval 100 milliseconds
Datum sea level
Probable fault
Possible fault
Inferred fault
Unit B absent
Structural High
Structural Low