024002

GIPPSLAND BASIN STUDY

FOR

HAEMATITE EXPLORATIONS PTY. LTD.

BY

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TEXT

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ABSTRACT:

The onshore non-marine greywackes, arkoses and mudstones of the Jurassic (in age including Lower Cretaceous) were deposited in a graben trending east-west across the grain of the Palaeozoic orogenic belt. These sediments are estimated to be about 11,000 feet thick. The south boundary fault of the graben has been determined; as to the north boundary fault, a relationship is inferred between its position and the north edge of two large horsts of main Tertiary faulting.

Structural movements believed to be basically normal faults and fault blocks are recognised in the Jurassic of both the onshore and offshore portions of the basin. However, the conspicuous block faulting in the western portion of the basin - great horsts of Jurassic and sinking blocks of Tertiary - does not extend into the offshore area.

During the hiatus prior to Tertiary, the Jurassic was considerably levelled by erosion. It was a land surface at the beginning of the Tertiary.

The Tertiary basin developed as a gentle sag over the well-defined area of the graben and spread beyond it, north and south. Subsidence was more or less continuous, with oscillations. In the western area, the first sediments were coal measures with basalt flow at the base. Along the innermost sheltered portion of the basin, continental environment (Latrobe Valley Coal Measures) persisted throughout the Tertiary, whereas a short distance outward marine conditions in relatively shallow water environment prevailed during the upper two-thirds of the Tertiary. This change from continental to marine appears to be along an abrupt front and is regarded as a lateral facies change rather than the result of erosion of the continental beds followed by transgression of the marine sediments, as formerly assumed.

The top, or near-top of the Latrobe Valley beds gives off strong seismic reflections from which a large portion of the offshore area was mapped. Pronounced variations in thickness are indicated both onshore (from well data) and offshore (from seismic data). These variations are attributed to lateral changes between non-marine and marine environments. The easternmost thickly developed portion terminates as an elongated barrier ridge with a steep side, as though facing open sea. The ridge is probably made up of mixed non-marine and marine facies.

The Tertiary thickens from 4,500 feet in the onshore area to 9,500 feet in the offshore eastern end of the surveyed area. Together with the Jurassic, the total estimated sedimentary thickness there is about 20,000 feet.

The Tertiary is believed to have good oil source potentialities, becoming better developed offshore with thickening and deeper water environment. As for the Jurassic, showings of oil and gas in bores indicate that the sediments were capable of generating hydrocarbons.

The search for oil in the Gippsland basin began with the discovery in 1924 of the non-commercial deposit in the basal Tertiary at Lakes Entrance. Since then some 135 wells explored the onshore portion of the basin and it appears as though the only prospect remaining to be tested is the pinchout of the Jurassic in the northern edge of the basin. Although both Tertiary and Jurassic are prospective, in the onshore area unfavourable factors are present in both, the Tertiary being completely flushed by fresh water and the Jurassic generally lacking in porosity. However, there is good reason to speculate that conditions change in the near-offshore area. There, interesting prospects in the Tertiary and Jurassic have come to light. They are mostly large features, representing nosing, elongated anticline-like structures, draping, sedimentary wedging, two types of pinchouts and a reef-like ridge.

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INTRODUCTION:

The Gippsland basin is the easternmost of the three sedimentary areas which resulted from the Jurassic* - Tertiary breakdown over the north-south trend of the Palaeozoic orogenic belt between mainland Australia and Tasmania. (See Index Map)

The Gippsland basin extends 200 miles eastward to the continental slope. It is filled with Jurassic and Tertiary sediments reaching a thickness of 20,000 feet in the offshore portion. The larger and thicker part of the basin lies in water depths of between 125 and 250 feet and offers prospects for commercial oil production from both the Tertiary and the Jurassic.

Haematite's tenements occupy this offshore portion of the Gippsland basin, commencing 8 miles seaward from the coast and covering about 9,000 square miles.

Onshore Exploration:

Onshore, the basin has been explored intermittently since the discovery of non-commercial oil at Lakes Entrance 40 years ago. Although 135 wells have since been drilled, no commercial deposits have been found.

The chart, Outline of Oil Exploration in Gippsland, (Fig. 18), gives a general picture of these activities and shows the phases of objectives through which exploration has progressed. In the present stage (1960-1963 of the chart), it is finally realised that all of the Tertiary of the onshore portion of the basin is flushed by fresh water, and that what further search is undertaken must be directed to the Jurassic.

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* "Jurassic" is used throughout this report to designate the group of Mesozoic rocks which is generally considered to be Jurassic through Lower Cretaceous in age.

ARCO - Woodside are presently drilling a group of three tests between Sale and the coast to further explore the upper several hundred feet of the Jurassic. Following this, a well is programmed for the Jurassic pinchout south of Lakes Entrance, which may be the last prospect of any interest in the onshore area.

Geophysical Surveys for Haematite:

Offshore, exploration so far consists of airborne magnetometer surveys and a marine reconnaissance seismic survey.

An airborne magnetic survey extending 50 miles offshore was flown by the Bureau of Mineral Resources in 1951-1952 and in 1956 (Record No. 1962/53). The southeast portion of the basin, which was not covered by this survey, was subsequently filled in by Aero Service Limited in 1961-1962 as part of their extensive survey for Haematite. (Report dated September 1962).

The seismic survey of Haematite's tenements in the off-shore Gippsland basin was shot in 1962-1963 by Western Geophysical Company, in a reconnaissance grid totalling 1,005 miles of line. (Final report dated August 1963).

Basin Study:

The geological study of the Gippsland basin was carried out from May 1963 to February 1964. The initial phase was devoted to the onshore area in order to obtain an understanding of the structure and stratigraphy based on outcrop and subsurface bore data, which is available for this portion of the basin. With this background, it was then possible to project offshore the geological picture, co-ordinating it with the results of the seismic survey.

Acknowledgements:

In his study of the Gippsland basin the writer was ably assisted by Mr. Brian Hopkins who contributed much toward development of the geological concepts and compilation of data. Thanks are due to Mr. George Hosking for the illustrations accompanying this report.

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CONCLUSIONS:

The main conclusion to be drawn from the study of the Gippsland basin is that the offshore portion of the basin, within the confines of Haematite's tenements, appears to have the pre-requisites - source beds, reservoirs, traps - of a major oil producing province. However, until this is borne out by drilling, the following possibilities should be kept in mind:

1. water flushing within the Tertiary may extend far out in the basin,
2. Tertiary source beds may be found inadequate for large accumulations, and
3. porosity of the Jurassic may fail to improve offshore.

The prospective areas add up to some 2,000 square miles, about equally divided between Jurassic and Tertiary. From two-thirds to all of the Tertiary is marine. It is expected that a good portion of it was capable of generating hydrocarbons. The Jurassic sediments, judging from the onshore portion of the basin, are not so attractive as those of the Tertiary. Nevertheless, they do give showings of hydrocarbons and possibly account for the seepage oil at Lakes Entrance. The Jurassic is expected to improve materially offshore by either admixture of marine facies or increase of porous beds.

At least fifteen individual features of oil trapping potentiality are recognised. They are of major size and comprise six types: porous ridge, wedge, drape, pinchout, nose and anticline.

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RECOMMENDATIONS:

In order to plan a forward programme and to explore to best advantage, stratigraphic drilling is recommended as the initial stage of exploration. It is considered essential to obtain at the very beginning certain basic information, such as:

1. Character of the Tertiary sediments and their reservoir properties;
2. Nature of formation fluid with relation to oil, and to flushing within the Tertiary;
3. Character of the pre-Tertiary sediments and their reservoir properties.

Apart from producing the above information, stratigraphic drilling would assist in re-interpreting existing seismic data and would clarify the objectives for additional seismic work.

Several of the prospective areas are sufficiently defined to be drilled for dual purpose without further seismic survey; this is, a stratigraphic test could also constitute a representative test of a particular prospect or structural feature.

The recommended features are, in order of preference:

1. the facies or barrier ridge;
2. the elongated anticline-like structure "G-16-10-4", and
3. structure "G-1-2-12" situated downdip from Lakes Entrance.

The present basin study did not include a detailed examination of the seismic data pertaining to the uppermost portion of the Tertiary. It is recommended that this be undertaken in the near future by a geophysicist.

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STRATIGRAPHY:

General Statement:

The sedimentary fill of the Gippsland basin is made up of eastward sloping deposits of Jurassic (Jurassic to Lower Cretaceous) and Tertiary (including Quaternary), totalling about 15,000 feet (4,500 feet Tertiary, 11,000 feet (?) Jurassic) at the coast and about 20,000 feet (9,500 - 10,000 feet Tertiary, 11,000 (?) feet Jurassic) in the eastern off-shore area.

The Palaeozoic sediments are of little interest for oil and have therefore been classed on maps and sections as "basement". The Palaeozoics seen to the west and north of Gippsland are highly folded and metamorphosed to one degree or another except, however, for isolated areas of non-marine Upper Devonian and Carboniferous. Although indurated, these rocks are not highly deformed or metamorphosed. Several bores, notably Nos. 45 and 46, were drilled to explore the possibilities of these beds. The results offered little encouragement for further attempts. In this connection it is believed that the coastal and offshore area is underlain extensively by granites with only a relatively few remnants of Palaeozoics.

The sediments of the basin fall within two main groups, separated by an unconformity and deposited under quite different types of basin structure and sedimentary environment. The first group belongs to the Jurassic graben in which non-marine (at least in the onshore portion) sediments were deposited. The second group comprises the sediments of the Tertiary which may be further subdivided into non-marine beds in the lower portion and marine in the upper. In general the marine portion thickens eastward and northward.

The subdivisions of the Tertiary are based on rock units as proposed by A.N. Carter and which are now in general use.

The corresponding ages of these subdivisions are usually referred to as follows:

Eocene	Latrobe Valley Coal Measures
Oligocene	Lakes Entrance Formation
Miocene	Gippsland Limestone
Pliocene	Tambo River, Jemmy's Point, Haunted Hills Gravels.

It will be noted from the Stratigraphic Column that according to our interpretation only the lower portion of the Latrobe Valley can be Eocene.

Jurassic:

On the basis of spore and plant remains the age of this group is considered to be Jurassic in its lower portion and Lower Cretaceous in its middle and upper portions. It is similar in aspect and equivalent in age to the Otway Group of the Otway basin. The name "Strezlecki Group" has also been used, but as a matter of convenience the group is referred to here simply as "Jurassic".

In the onshore portion of the basin the sediments of the Jurassic as far as penetrated (8, 215 feet) in Wellington Park No. 1 are considered to be non-marine, based on the absence of marine fossils. On the other hand, salt water (15, 850 ppm NaCl) was found in a drill stem test in the upper part of the Jurassic (5, 774 - 6, 005 feet) in Merriman''s Creek No. 1, and in the three other deep wells of this group (Wellington Park, North Seaspray and Carr's Creek) salt water is indicated from analysis of the electric logs. (Chart Jurassic Water Salinity and Hydrocarbon, Fig. 19). It is therefore possible that either marine conditions were close by or that the sediments were actually deposited under marginal marine conditions which for some reason, such as extreme muddiness, did not favour growth of marine fauna.

The sediments as seen in the onshore area are made up mainly of arkoses, greywackes, feldspathic sands, mudstones, carbonaceous clays and some fragments of black coal. They are characteristic of a rapidly sinking trough in which the sediments are "dumped" without having opportunity to become sorted. (See Generalised Stratigraphic Column, Fig. 2).

It is considered that the arkoses were derived from igneous rocks, whereas the mudstones were chiefly from Palaeozoic sediments. Sources were apparently close at hand in extensive land areas to the north, west and south (Bass Ridge). No land areas are now in evidence eastward.

It has not been possible to zone the group or even to distinguish the base from the top. Even in the thinly developed westernmost part of the basin there is no noticeable difference in the aspect of the sediments except for black coal in commercial quantities. Here these beds may represent the basal, upper or even the entire time span of the Jurassic.

Latrobe Valley Coal Measures:

It may be seen from the Stratigraphic Column that the Latrobe Valley is mapped as a continental facies of the Tertiary, best developed in the secluded inward portion of the basin.

The age of the Latrobe Valley as determined from spores and pollen was stated by Crespin (1943) to be Miocene and by Carter (1960) ? to be Eocene. It is believed that these determinations were based on well cores from the lower portion of the section underlying the marine Tertiary. However, both Crespin and Carter considered the entire Latrobe Valley to have been overlapped by the marine Tertiary (and therefore older) rather than the upper half of the Latrobe Valley being the time equivalent of the marine Tertiary as shown on our Stratigraphic Column.

The early Tertiary basalt is included here as the basal portion of the Latrobe Valley. It attains a maximum thickness, mixed with sands and siliceous conglomerates, of about 465 feet.

Basalt outcrops extensively in the western onshore area and is also found on top of the uplifted Jurassic blocks, showing that it spread over the surface before (perhaps immediately before) the block fault movements began. In the subsurface it is found to be weathered.

From the tectonic viewpoint the basalt is a product of the first movement of the early Tertiary breakdown. It is significant, as discussed elsewhere, that it is present westward beyond the confines of the basin and that it is not known in the subsurface of the onshore area east of Darriman No. 1.

The Latrobe Valley Coal Measures are made up of sands, fine to coarse grained, mainly quartz, but often argillaceous. It has good porosity and permeability. Brown coal (lignite) is well developed in part of the onshore basin and is variable in thickness and extent (80% of section at Yallourn-Morwell, 20% of the section at Wellington Park No. 1 and 9% in Holland's Landing No. 1). In general the percentage of coal decreases northward, along with decrease in overall thickness. Minor amounts of siltstone (in places calcareous and dolomitic) and brown carbonaceous clays are present. The brown coal is mined commercially in open pits in the Yallourn-Morwell area and was formerly mined in the Yarram-Welshpool area to the south. The offshore continuation of the Latrobe Valley is shown on map Latrobe Valley Thickness. It is discussed further under Facies-Tertiary.

Lakes Entrance Formation:

This is the basal unit of the marine portion of the Tertiary. It is composed of foraminiferal marls, siltstones and glauconitic sands.

In the northeastern onshore area it has a well developed basal glauconitic sand that attains a maximum thickness of 75 feet. The oil occurrance at Lakes Entrance is within this sand.

The Lakes Entrance Formation varies considerably in thickness, with a maximum of 786 feet at Hollands Landing No. 1 (Cross Section No. 1). It is somewhat difficult to distinguish in wells from the overlying limestone series and it is believed that there is considerable gradation from one to the other.

The offshore continuation of the Lakes Entrance Formation cannot be delineated from the seismic data.

Gippsland Limestone:

This group is composed of shallow water limestones and marls rich in foraminifera and shell remains. Part of it is seen at the outcrop in the Bairnsdale - Lakes Entrance area. A maximum thickness of 1, 657 feet was found in Hollands Landing No. 1. A fair degree of porosity is present in portions of the limestone, as determined from water bores.

The Gippsland Limestone is made up of limestone, sandy, impure, generally unconsolidated but contains thin dense bands, tan-cream, fine grained fossiliferous with some porosity. Marls, shades of grey and brown, very fossiliferous. Glauconitic - becomes more argillaceous at base. It is often difficult to place the dividing line with the underlying Lakes Entrance Formation.

The offshore equivalent of the Gippsland Limestone may continue in somewhat similar facies for some distance, if it is assumed that relatively shallow water prevailed seaward during that interval of the Tertiary. The cross sections are illustrated in this manner. Although the general interval is seen to thicken along with the rest of the Tertiary, there are no seismic reflections that characterize the offshore continuation of the limestone or that can be used to delineate its top or bottom.

Tambo River Formation and Jemmy's Point Formation:

As seen from the Stratigraphic Column these two formations occupy the upper portion of the Tertiary, generally classed as Pliocene. They are shallow water marine deposits made up of sands, marls, glauconite and abundant fossil remains. A thickness of 860 feet is attained in Seacombe No. 1. Thickening offshore probably accounts for a substantial portion of the upper Tertiary, but the seismic data affords no clue as to the amount. However, it does suggest in a general manner that the uppermost Tertiary contains some rather prominent eastward wedging.

Haunted Hills Gravels:

These beds are assigned to the uppermost portion of the Tertiary. They are mainly river terrace gravels that are prominently represented at several localities.

There are five or six fairly large rivers presently flowing from the mountainous region into the lowlands of Gippsland and they bring down much coarse igneous and metamorphic debris. It would appear that these or equivalent rivers contributed much clastic material to the upper part of the Tertiary of the overall basin.

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BASIN TECTONICS:

The Jurassic graben represents the first stage of the eastward trending sedimentary basin to have developed over the north-south course of the Palaeozoic orogenic belt in the region of general breakdown between Victoria and Tasmania.

No attempt is made to discuss the tectonic background of the Gippsland basin as superimposed on the Palaeozoic trend. However, two observations are offered:

1. A large area of granite is exposed between Victoria and Tasmania. The presence of the granite suggests regional arch-like uplift of the basement.
2. There is an association between regional basement arches and occurrence of grabens. The upper Rhine graben and the Red Sea graben are examples of grabens that developed over regional basement arches.

The Index Map serves to illustrate the setting of the Gippsland basin within the region of metamorphosed Palaeozoics and granite rocks, especially the granites of the Bass Ridge that form the separation between Gippsland and the Bass basin.

Outline of Tectonic Events:

1. Jurassic Graben:

A graben developed 40 - 65 miles wide, 200 plus miles long and containing an estimated thickness of 11,000 feet of (onshore) non-marine "dumped" sediments.

Structural movements, believed to be basically normal faulting, occurred during development of the graben.

The Jurassic was extensively eroded and levelled during the hiatus prior to Tertiary.

2. Tertiary Subsidence:

The basin cycle was resumed after a long pause.

Subsidence is considered to have been continuous, with oscillations, spreading offshore over a larger area than occupied by Jurassic. A thickness of 9,500 feet was attained in the eastern portion of the basin.

Fault block movements, initially accompanied by basalt flow, extended through the Tertiary. This movement, however, was confined to the onshore portion of the basin.

Regional uplift in late Tertiary resulted in the present land form of the onshore basin.

Jurassic Basin:

The Sketch Illustrating Jurassic Graben, Fig. 13, shows the main elements in a simplified form. More detail is to be found on the Jurassic Thickness map along with the supporting cross sections of both onshore and offshore.

The basin occupies a belt of 40 to 65 miles in width that extends from Mornington Peninsula eastward 200 miles to the continental slope and beyond. The western onshore portion is well defined on the north, west and south by old rocks. It seems unlikely that there was ever any appreciable extension or spill-over southward or westward during sedimentation, for this area seems to have been relatively stable with only a slight eastward tilt and is underlain by two basement ridges. However, the area was not stable to the exclusion of structural movements, probably faulting. Several disturbed zones with steep dips have been observed. The Jurassic of this western area is thin (estimated 3,000 feet maximum) and a large area of it is capped by basal Tertiary basalt, indicating that a considerable period of erosion was required to have levelled the surface prior to the basalt flows.

From the basement ridge eastward there is rapid thickening in the form of a graben (illustrated by dip symbols on the Sketch), with north and south boundary faults. These faults are discussed under the topic of Faults.

It is estimated (map Jurassic Thickness) that the Jurassic attains a thickness of about 11,000 feet near the coast and it is assumed from the presence of the elongated structural features that the graben is still well developed near the continental slope and shows no sign of thinning.

The Jurassic overlaps its trough both to the north and to the south. The south graben fault and overlap onto the platform show up well from the seismic data. (Cross sections G-2, 3 and 8). The overlap is thin (3,000 feet maximum) and pinches out within 5 to 8 miles.

The overlap onto the north side of the basin is thicker (7,000 feet (?) maximum) and more extensive (15 miles) than on the south side. In this respect it resembles more the normal flank of a basin rather than a platform adjacent to a graben. This is probably because the fault is not so pronounced as the one on the south side. The fault itself is not seen and its position is inferred (see Faults).

As pictured on the Sketch, both the north and south sides flanking the graben have relatively less eastward tilt than the graben itself. Actually, very little tilt would be expected in association with a graben.

An important question pertaining to the graben concerns the facies of the Jurassic sediments. In the western (onshore) 100 miles, the sediments are prevailing greywackes, arkoses, mudstones, etc., seemingly deposited under non-marine conditions. They were apparently "dumped" without sorting and the sands are "dirty" and lack permeability. (Stratigraphic Column). No noticeable difference in type of sediments has been detected within this area and it is wondered if any appreciable changes can be expected in the remaining 100 miles covering the eastern half of the graben out to the continental slope. Of the two principal deficiencies - permeable beds and marine facies - perhaps the most needed is permeability.

Salt water and a showing of gas and oil fluorescence have been found in the onshore bores. In the Otway Basin substantial showings of both gas and oil were obtained, but in all cases permeability was lacking.

Structural movements in the offshore area (mainly elongated anticline-like structures) occurred during the Jurassic which, before Tertiary time, was extensively levelled by erosion - (see Faults and Folds). However, in the onshore area the Jurassic was further affected by block faulting during Tertiary time.

Tertiary Basin:

The Tertiary basin offshore occupies a much larger area than that of the Jurassic, (Sketch Illustrating Tertiary Basin, Fig. 14). The western limit of the well developed portion of the basin may be taken along the edge of the Jurassic uplift. Here it is about 50 miles wide and spreads out to a width of about 125 miles near the continental slope, some 100 miles to the east. In most places where the Tertiary thins out gradually, the limit is drawn arbitrarily near the 1,000 - 2,000 foot contour.

The Tertiary is 4,500 feet thick at the coast and increases to about 9,500 feet at the eastern end of the mapped area.

The hiatus between Jurassic and Tertiary represents a long period of time during which the Jurassic was strongly eroded and extensive areas levelled. The unconformity appears to be as strongly developed far offshore as it is near the coast. Mainly because of this it seems improbable that transitional or intervening beds (part of the Upper Cretaceous for example) would come in undetected between Jurassic and Tertiary.

Apparently a large area of the Jurassic was land at the beginning of the Tertiary, for the first deposits were either basalts and terrigenous material or coal measures.

There are remnants of Tertiary sediments and basalt on the eastern plunge of the Balook block, indicating that uplift began shortly after the outflow of basalt. Although westward to Western Port Bay there is considerable basal Tertiary basalt, it is unlikely that any appreciable amount of Tertiary was deposited in this region.

In the inland portion of the basin, Tertiary sediments were deposited in fault blocks adjacent to blocks that were rising. This part of the basin inland from the coast is on the margin of what appears to be an interplay of two factors - regional uplift and basin subsidence - both of which commenced with the Tertiary.

The idea that the raised blocks, notably the Jurassic Balook and Narracan blocks, are part of regional uplift rather than features unique to the basin is prompted by the similarity of elevations with those of Wilson's Promontory (composed of granite) and the highlands immediately north of the basin (metamorphosed Palaeozoics). (Topography and Water Depth map). This area forms the eastern limit of the physiographic province, Southern Uplands.

It is interesting to note that the blocks in which Tertiary was deposited, adjacent to the uplifts, are not actually down-faulted independently, for the base of the Tertiary may be projected with normal slope from them to the main part of the basin. In other words, these blocks of Tertiary have subsided as part of the Tertiary basin rather than as individual blocks. In similar manner, the Jurassic horsts rose from the near-peneplane as part of the regional uplift. Nevertheless, relative to one another the blocks have risen and subsided simultaneously.

In broad contour it is seen that the Tertiary basin has a trough, although relatively thin, that is somewhat flat with relation to the flanks. The north-south cross section G-3 shows this relationship of trough to flank. Eastward the trough thickens more than do the flanks, showing that progressive eastward tilting was a major factor in development of the basin. The relationship in Tertiary time of trough to flank coincides with those features of the Jurassic, as though influenced by its thick and thin components.

It is believed that the Tertiary basin subsided in a continuous manner, with minor oscillations, and without regional transgressions or regressions that would produce widespread unconformities. This concept necessarily calls for lateral changes in facies between non-marine and marine deposits. (Stratigraphic Column). These lateral changes are illustrated on the Latrobe Valley Thickness map and also on the onshore and offshore cross sections. The question is discussed further under Facies - Tertiary.

The Tertiary sediments as seen in the onshore part of the basins were deposited under varying conditions, including swamps, lagoons, beaches and open sea, apparently in relatively shallow water. The overall setting could have been somewhat like that of today, including the source material from the highlands to the west as they began to rise in early Tertiary, as well as from the Bass Ridge to the south. Presently there are five fair-sized rivers coming into the basin from the highlands.

For mapping purposes the Tertiary is divided into two main stratigraphic divisions, non-marine in the lower and marine in the upper. Thicknesses, distribution and facies changes of these units are shown on the maps Latrobe Valley Thickness and Post-Latrobe Valley Thickness.

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FACIES - TERTIARY:

It is recognised that large scale facies changes and sedimentary wedges exist in both the onshore and offshore portions of the basin. Basinward changes are noted in both lower and upper parts of the Tertiary. These stratigraphic features are of great interest because of their trap potentialities.

During the early stage of this basin study considerable confusion was experienced because of the facies changes between continental and marine beds of the lower part of the Tertiary. The continental Latrobe Valley onshore is seen from subsurface well data (map Latrobe Valley Thickness) to vary considerably in thickness up to 2,500 feet or more. It is seen also from nearby well control in the onshore and near-offshore that its top or upper portion produces strong reflections, the first at depth and the only ones to persist over an appreciable area.

In the original mapping by Western it was recognised that the good reflections came from the coal measures. However, the contractor apparently did not know that much variation in thickness existed. Consequently the undulating top of the Latrobe Valley was interpreted in terms of structural uplift on their map Basal Tertiary Reflection Horizon.

Two maps have been prepared that incorporate the stratigraphic changes noted within the Tertiary. These are:-

1. The Latrobe Valley Thickness which takes in the lower part of the Tertiary and,
2. The Post-Latrobe Valley Thickness which covers the remaining upper part of the Tertiary.

Onshore Facies Changes between Continental and Marine Beds:

As shown on the Latrobe Valley Thickness map, three facies changes are recognised. Beginning in the northeast and extending inward the three changes represent step-like advances of marine environment during deposition of Tertiary sediments. All three are present in cross section No. 1. It may also be seen from the cross section that continental environment prevailed in the innermost reaches of the basin throughout the Tertiary.

It is felt that in all probability the coastal area and the relationship between fresh water and marine sedimentary conditions during the Tertiary did not differ much from present day conditions in southeast Victoria.

1. The first and lowest of the three facies changes occurs in the northern onshore area and is a transition from the continental Latrobe Valley to the marine beds of Colquhoun Gravels. Both are relatively thin, less than 500 feet. (Latrobe Valley Thickness map and cross sections G. 19 and No. 1). Points of control are the Lakes Entrance bores and well No. 45 on the marine side and Sperm Whale Head No. 1 and others on the continental side.

   Inasmuch as this change involves the continental and marine of the lowermost portion of the section, the Tertiary to the north and northeast is therefore entirely marine. The change cannot be detected in the offshore seismic and the line of demarcation has therefore been projected as shown on the map.

2. The second facies change, referred to as the Rosedale feature, is a step higher in the stratigraphic column and occurs between the marine Lakes Entrance Formation and the continental Latrobe Valley. The control points onshore are between wells Wellington Park No. 1 and Hollands Landing No. 1. Cross section No. 1 shows the marked difference in thickness between the Latrobe Valley and the Lakes Entrance Formation on either side

of the line. The westward extension of this facies change cannot be followed because control is lacking. Both this and the first facies change indicate that the continental facies is fuller developed in the sheltered inland portion of the basin.

This second facies change has its offshore continuation in the Rosedale feature. It will be discussed along with the offshore features.

3. The third and highest facies change is the most extensive. It occurs along a north-south line passing through the western part of the Tertiary basin. On the inward side of this line the Tertiary is 2,000 to 3,000 feet thick and composed entirely of continental Latrobe Valley. On the outward side of the line all except about 1,000 feet of the Latrobe Valley is in marine facies. The points of control are not close, the nearest being six miles, and therefore there is some question concerning the abruptness of the feature. The facies change is noted between the following wells:-

(a) Woodside No. 2 and well No. 35. Cross section No. 1 Well No. 35 passed from coal measures into limestones and back again into coal measures.

(b) Woodside No. 2 and Yarram No. 1.

(c) Bellbird No. 1. No limestone here. Well began in coal measures.

(d) Wurruk Wurruk No. 1 and Rosedale No. 1. Cross section No. 4. Rosedale is entirely continental and Wurruk Wurruk has marine underlain by coal measures.

It is mainly this third facies change that forms the basis for considering that the continental and marine beds were contemporaneous and that the relation between the two is a matter of lateral facies changes rather than erosion followed by transgression. (Stratigraphic Column, Fig. 2).

Apart from the above three prominent facies fronts it is seen from the Latrobe Valley Thickness map that the continental beds thicken and thin to a remarkable degree. This variation in thickness also is attributed to lateral facies change. However, the pattern is irregular and apparently localised as would result from lagoons and water passages.

Offshore Facies Changes Within the Latrobe Valley:

In constructing the Latrobe Valley Thickness map the subsurface well data were used in the onshore area. In the offshore area the seismic contour map Basal Tertiary Reflection Horizon was taken to represent the approximate top of the Latrobe Valley. This subtracted from the contours of the map Top Jurassic Structure gave the thickness of the Latrobe Valley.

From a comparison of the Latrobe Valley Thickness map with the map Top Jurassic Structure it is apparent that the eastward protrusion or distribution of the Latrobe Valley is confined mainly within that portion of the basin which at the Tertiary-Jurassic contact is flat in relation to the steeper sloping sides of flanks. The position of these components appears to have been determined by the boundary of the Jurassic graben.

In the offshore area the north side of the eastward protrusion of Latrobe Valley follows closely the line of demarcation between flat trough and steeper flank. This line not only coincides with the assumed position of the Jurassic graben fault, but also ties in with the eastern extension of the second facies change called the Rosedale feature.

On the north side of this feature the Latrobe Valley is thin, less than 500 feet, as determined from the onshore bores and the character of the seismic reflections. Here the mapped reflector is seen to be near the Tertiary-Jurassic unconformity. At the Rosedale feature there is an abrupt step-up of 500 to 800 feet, comparable in magnitude to the second facies change described in the onshore area. It is accompanied by strong reflections, upon which the mapped reflector climbs. (Mapped as a fault in the contractor's map Basal Tertiary Reflector Horizon).

This facies feature, also called build-up, may be seen on all the seismic lines between the coast and G-3, with the exception of perhaps G-15 and G-21. Cross sections G-1, 2, 3, 9, 19, 10, 11 and 12 show the Rosedale feature with reference to the areas adjacent north and south (see map Latrobe Valley Thickness for contour values of the build-up). G-2 is probably the most representative of the feature. Both this line and G-11 display horizontal reflections that extend under the build-up, showing that the feature is not uplifted structurally.

The salient points concerning the extension offshore of the main body of the Latrobe Valley may be seen in the Sketch Diagrammatic Cross Section of Offshore Gippsland Basin, Fig. 11. The cross sections G-13, 8 and 9 are representative and give a good picture of this area.

The Sketch begins with (1) the onshore facies change (the third) between continental and marine of the upper part of the Tertiary as discussed in connection with onshore facies changes. The Latrobe Valley Coal Measures (2) is shown extending toward the coast and beyond into the facies ridge. It is believed that the Latrobe Valley may lose part of its coal content (3) and become somewhat mixed with marine beach limestones and sands, coquina and reefal material, as would be the case with a barrier ridge. The Latrobe Valley or its equivalent is seen to thin and play out farther offshore (4) and is shown by a line on the map representing the eastern limit of the protrusion of Latrobe Valley. The other numbers on the Sketch pertain to the Post-Latrobe Thickness map.

As brought out by the Sketch, cross sections and Latrobe Valley Thickness map, the most important item of offshore Latrobe Valley is the facies or barrier ridge that attains an estimated thickness of 3,000 feet (about the same as onshore) and is prominent over a distance of 50 miles.

Facies or Barrier Ridge:

Without full consideration of the background onshore of the Latrobe Valley Coal Measures and its characteristics it would be difficult to determine the nature, structural or stratigraphic, of the facies ridge. There now appears to be little question but that the feature is purely stratigraphic and that it is the eastward extension of the Latrobe Valley in one facies or another.

The seismic lines are adequately tied in with bores so that it is clear that the strong reflection band (within which is the mapped reflector) represents the stratigraphic equivalent of the top or uppermost part of the Latrobe Valley. These reflections in characteristic form extend eastward to beyond the ridge and the point at which they die out is taken to be the east limit of the Latrobe Valley. The question remaining, therefore, is to what extent the Latrobe Valley changes in lithologic components and still gives off the characteristic reflections.

According to the Sketch referred to above as well as the cross sections and thickness contours there is a strong suggestion that the elongated form of the ridge and its general conformity in thickness with the onshore Latrobe Valley represents the outer seaward extension of the Latrobe Valley.

Perhaps the clearest indication that the ridge is actually the outward extension of the Latrobe Valley is from cross section G-9 that passes through the thick portion of the onshore Latrobe Valley. The cross section shows that in this area there is no prominent saddle or appreciable thinning between the main mass and the ridge. In this connection, the very thin Latrobe Valley appearing on cross section G-13 is due possibly to a marine tongue that persisted throughout most of the Latrobe Valley time.

It would be expected that an outer extension such as pictured in this ridge would necessarily have to be of a barrier type and contain a considerable accumulation of marine debris. With this in mind a line was drawn on the Latrobe Valley Thickness map (point (3) of the Sketch), along the west side of the facies ridge representing the possible eastward extent of coal facies, or rather, the point where the continental beds become mixed with marine sediments. An attempt was made to illustrate the development of such a facies ridge in the Sketch Illustrating Ridge or Barrier Within the Offshore Equivalent of the Latrobe Valley, Fig. 12.

Offshore Facies Post-Latrobe Valley:

From the Sketch Diagrammatic Cross Section of Offshore Gippsland Basin, Fig. 11, it may be seen that the Tertiary is divided into two units, the upper one of which is marine and appears on the map Post-Latrobe Valley Thickness.

The seismic reflections within the Post-Latrobe Interval are insufficiently diagnostic to distinguish either the Lakes Entrance Formation or the Gippsland Limestone for any distance offshore. Nevertheless, within the general interval basinward thickening and variations in the character of the sediments are suggested from the seismic reflections. Also, a distinct change is observed in the overall section eastward from the facies ridge, perhaps indicating deeper water deposits. (Point (7) of Sketch).

Sedimentary Wedge:

Within the marine Post-Latrobe Valley interval depositional irregularities such as erratic slopes and pinchouts are common. The most prominent and persistent of these is a large wedge spreading seaward from the Latrobe Valley facies ridge. The wedge is illustrated on the Sketch (Fig. 11) and an explanation of this feature is attempted in the Sketch Illustrating Ridge or Barrier within the Offshore Equivalent of the Latrobe Valley, Fig. 12.

The sedimentary wedge is shown on the offshore cross sections and appears on all of the seismic lines, except G-10, that cross the ridge. From the Post-Latrobe Thickness map and cross sections it can be seen that the wedge commences over the top of the ridge and thickens to about 4,000 feet a mile or so east of the edge of the ridge. The eastern extent of the wedging is indefinite but may be followed five miles and more to where it flattens out.

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FAULTS:

Many faults appear on the published maps of the onshore portion of the Gippsland basin. They were derived from liberal interpretation of geophysical data (mainly gravity), geological and topographical features and from exploratory coal bores. It is apparent that some of these faults do not exist and many are inconsequential to the overall structural interpretation. Still others may be interpreted in a different manner. All, however, are normal or tensional faults.

In preparing the Tectonic Map (Fig. 1) a careful selection was made so as to include only the important faults, those having a bearing on the main structural features of the basin. Some were selected from field observations of morphological features and others from subsurface studies based on bore data. Those faults indicated by steep gravity gradients were substantiated from geological evidence.

The faults are grouped into three categories:

1. Pre-Jurassic
2. Jurassic
3. Tertiary

1. The Pre-Jurassic Faults:

The Pre-Jurassic Faults are considered to be those associated with the two basement ridges in the western area. The faults are marked by steep gravity gradients (Gravity Map, Fig. 15). Although the faulting appears to be Palaeozoic, probably rejuvenation of movement during Jurassic produced the ridge-like features. Cross sections Nos. 2 and 3 were drawn to illustrate the ridges and their general position within the framework of the basin. It is noted that the ridges are within the westernmost portion of the basin, immediately east of which the Jurassic commences to thicken appreciably. (Sketch Illustrating Jurassic Basin, Fig. 13).

2. <u>Jurassic Faults</u>:

Apart from rejuventated pre-Jurassic faults, others are the north and south graben faults and the hypothetical faults associated with the Jurassic structural highs in the offshore portion of the basin.

<u>The south graben fault</u> is well documented. East from Foster a prominent fault is present at the boundary between Basement and Jurassic. Projected eastward offshore into the survey area, the fault ties in with the boundary fault between the platform and the trough. On the platform side the seismic data shows the Jurassic to be thin (maximum about 3,000 feet) and to pinch out from 5 to 8 miles to the south. This is the overlap from the trough and is illustrated on the Jurassic Thickness map and on cross sections G-2, G-3, G-8.

On the north side of the fault two lines, G-3 and G-4, show reflections within steeply dipping Jurassic, indicating a thickness in excess of 7,500 feet. The differential subsidence of the Jurassic during deposition amounted to some 4,000 feet.

The movement along the south graben fault apparently either did not die out with the Jurassic or more likely was later rejuventated to the extent of about 1,500 feet. This is discussed in connection with Tertiary faulting.

<u>The north graben fault</u>: Although this fault is inferred, there is nevertheless indirect evidence of its presence. Its position is based on the position of the Rosedale fault and a continuation of the Rosedale line to the east and to the west. The Rosedale fault itself (from about the west side of Lake Wellington to near Rosedale No. 1) has considerable displacement and is of Tertiary age. Its position is along the north edge of the Jurassic horst (Balook block) which in turn is believed to be the north edge of the Jurassic trough. In other words, the Jurassic block rose along the same hinge by which it subsided as a graben-like trough.

The second point of inference is the western continuation of the above line which would mark the north side of the Narracan block. The Narracan block contains relatively thick (relative to that area) Jurassic whereas just a few miles to the north it thins out against the Palaeozoics. That is, there is little latitude here for the line of demarcation between trough and north limit of sediments. It is probably clearer here than in the Rosedale area that the Tertiary fault along the north side of the Narracan block represents the edge of the trough and position of the north graben fault. It is well recognised that in basin areas where vertical movements have reversed themselves, the up and down blocks follow approximately the same fault zone.

The third point of inference is in the offshore area along the eastward continuation of the Rosedale line and called the Rosedale feature. Vertical displacement is not recognised beyond the coast but a slight hinging effect at the Tertiary-Jurassic contact is noted on some cross sections, G-10 for example. North of the line the general slope is 2^{o} to 3^{o}, whereas to the south it decreases to about $1^{o}30'$. Seismic reflections from the Jurassic wedging in from the north (cross sections G-1, G-2, G-3) do not extend far enough south to substantiate the position of the fault. However, the assumption is that the hinging effect at the Rosedale feature points to a faulting condition at the boundary between platform and trough of the Jurassic. It is estimated that north of the graben fault the Jurassic is 6,000 - 7,000 feet thick. An arbitrary figure of 10,000 - 11,000 feet was taken for the thickness within the trough (Jurassic Thickness map) and the cross sections were constructed accordingly to show from 2,000 - 4,000 feet of fault movement.

Jurassic Faults of Individual Offshore Structural Features:

It is thought that the six elongated anticline-like features shown on the "G" cross sections result from normal faulting or block faulting associated with the movement of the graben. It is for this reason that the structures were illustrated on the cross sections with token faults. The seismic events available within the Jurassic are insufficient to indicate such faulting.

3. Tertiary Faults:

The prominent block fault system characteristic of the inland portion of the basin developed during the Tertiary. The fault movements began in early Tertiary, accompanied initially by basalt flows and continued through the Tertiary. One of the main points concerning this faulting is that it is confined to the inland portion of the basin and does not extend offshore. (Gravity map and cross section No. 1). The explanation of this structural condition is given in the discussion of the Tertiary Basin.

The more important faults are described briefly. (Tectonic Map).

Rosedale and Narracan Faults:

The Rosedale fault is the most important of the onshore faults. It is the boundary fault between the uplifted Balook block of Jurassic on the south and the Tertiary block on the north. The maximum differential movement involved amounts to some 4,000 feet. The course of the fault is marked on the Gravity map by closely spaced gradients.

The course of the Rosedale fault is interesting. Its eastern portion has an east-west trend which, between Sale and Traralgon, swings to the south-west, thus giving the Balook block its northeast trend. (Structure Top Jurassic). It also permitted a wedge-shaped block of Tertiary to form between the Balook and Narracan blocks.

The southwest swing of the Rosedale fault somehow may be related to the westward thinning of the Jurassic trough in proximity to the Fish Creek-Morwell basement ridge. Another thought is that the portion of the fault having the northeast-southwest trend may, in reality, be a cross fault stemming from the basement ridge. In this case the Rosedale fault, after being interrupted by the cross fault, would be resumed in the fault on the north side of the Narracan block. (Cross section No. 3).

In either of the above alternatives it is believed that the east-west portion of the Rosedale fault and the east-west trending Narracan fault were developed during the Tertiary along the north edge of the Jurassic trough, thus being a reversed movement of the Jurassic graben fault. This was further discussed under the topic of the north graben fault.

The Rosedale fault is confined to the onshore area and as such dies out before reaching the coast. The steep gravity gradients (Gravity Map) that mark the course of the fault also end before reaching the coast. The displacement of the fault and its eastward termination is indicated from the contours of the map Structure Top Jurassic.

The <u>fault north of Traralgon</u> is also a prominent topographic feature that forms a sharp boundary for a portion of the basin edge, between Tertiary and old rocks. Commercial deposits of thick brown coals developed along the Tertiary side of the fault north of Morwell-Traralgon. (Cross section No. 5).

The <u>fault along the south side of the Balook block</u> may be seen at the outcrop as one main break. However, northeastward along its course it appears to assume either several breaks or to develop into a somewhat steep flexure. For this reason it was not carried farther to the northeast. Although there is a difference in elevation of some 2,000 feet from the top of the Balook block to the Yarram area, there is no well defined scarp as on the north side of the block. (Topographic map, Fig. 3).

Rejuvenation of the south graben fault: In the discussion of the Jurassic south graben fault it was pointed out that there appears to have been post-Jurassic rejuvenation to the extent of at least 1,500 feet. Rather than rejuvenation this could be looked upon as a continuation of differential sag between platform and trough that produced in the Tertiary a flexure (G-7, 8) in some parts and fault (G-2, 3, 13) in others. At the east end of the surveyed area (G-4, 9) the movement has apparently died out or become equalized, for there is neither fault nor flexure at the Tertiary-Jurassic contact.

The possibility of a 1,500 foot sedimentary tongue (for example, Upper Cretaceous) coming in between Jurassic and Tertiary has been considered. However, in view of the strong unconformity it does not seem likely that intervening beds would go undetected, in other words, intervening beds should either decrease the amount of apparent unconformity or show two unconformities.

Fault on north side of basin observed in lines G-12, 21 & 1: This is the only offshore fault of magnitude recognised in the Tertiary at this stage of the investigation. Its general north-south trend suggests that it may be connected with the basin framework and southward swing of the Jurassic pinchout.

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FOLDS:

The folding and flexing both onshore and offshore results from tensional movements and is closely related to block faulting. No compressional folding is recognised.

Fold-like features were produced both onshore and offshore. In the offshore Tertiary the fold movements are limited to draping over ridges. It is seen from onshore outcrops that the Jurassic was further complicated by movements during Tertiary time. Inasmuch as these Tertiary movements did not extend offshore, the individual structural features within the Jurassic of this portion of the basin stand out in a fairly clear manner.

The most prominent feature of the onshore area is the Balook block. It is basically a horst but displays strongly flexed sides and a strong eastward plunge. As viewed by Boutakoff (1955), the main structure is made up of several en echelon structures and noses arranged around the central theme of the Balook uplift. Whereas the overall axis of Balook is oriented E.N.E. - W.S.W., the axes of these en echelon appendices are more nearly east and west, or even E.S.E. - W.N.W. for some. Although some of these features are recognised as faults, it would be difficult to conform in general with Boutakoff's structural interpretation of this area.

Several structural highs were mapped by land seismic surveys and subsequently drilled by Darriman No. 1 (a domal feature), Wellington Park No. 1 (E - W trending anticline with closure against a fault), North Seaspray No. 1 (a small, high E - W anticline), Merriman's Creek No. 1 (structural "high") and Carr's Creek No. 1 (an anticline about 8 miles long). All of these were mapped within or on top of the Latrobe Valley Coal Measures with apparent substantial structural relief of 350 to 700 feet. According to ARCO (who drilled all four except Darriman) the structure is due to differential compaction and draping effect of the coal measures over a Jurassic topographic high. However, it is suspected that these highs are not really structural but rather represent thick and thin phases of the Latrobe Valley. (Cross section No. 1).

Six lines of elongated anticline-like structures have been recognised offshore within the Jurassic. For purposes of identification they are labelled from seismic lines through which they pass. The longest of these, "G-2, 9, 4" may be followed for 45 miles. Three others are about 25 miles each and the remaining two may be short, for they are recognised in crossing only one seismic line. The western terminations of these structures are not known for they are masked by the strong reflections of the overlying Latrobe Valley. The representative width of the individual feature is about six miles and a rough estimate of the structural uplift is from 1,500 to 2,500 feet.

Some remarks concerning these Jurassic structures have been given under the topic of Faults, and further discussion will be found in connection with Prospective Areas.

The structures are breached to some extent and extensively eroded. As may be noted from the map Structure Top Jurassic, all except a portion of "G-16, 10, 4" are levelled off and show no topographic relief at the contact Tertiary-Jurassic. On cross section G-10, it is seen that Structure "G-16-10-4" forms a topographic relief of 2,000 feet and was an island during initial deposition of the Tertiary.

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OIL POSSIBILITIES:

Structural and stratigraphic traps of several types are amply represented in the offshore portion of the Gippsland basin, in the Tertiary and in the Jurassic, the sediments of both of which are believed to have generated hydrocarbons. The subsurface oil seepage at Lakes Entrance and the minor gas shows and oil fluorescence in other bores point to this inference.

The extent beyond the coast of the water flushed condition within the Tertiary is, of course, a matter of speculation. However, some retarding action resulting from facies changes may be expected shortly offshore. Moreover, whatever oil had been generated within the flushed area of the Tertiary could have been transported downdip and lodged in traps offshore.

As to the Jurassic it is open to question whether or not it changes facies progressively from the apparently non-marine environment to partly marine conditions and better reservoir beds offshore.

The oil at Lakes Entrance is believed to be a subsurface seepage from offshore. It is generally attributed to a Tertiary source, inasmuch as the Tertiary sediments of the northern portion of the basin are entirely marine. However, the manner of occurrence does not exclude the possibility of Jurassic origin.

Tertiary:

Onshore there are adequate reservoir beds within the Tertiary. Clean quartz sands are well developed within the Latrobe Valley, and a thick glauconitic sand is at the base of the marls of the Lakes Entrance Formation. The overlying Gippsland Limestone also contains good porosity in part. Beyond the coast, the Latrobe Valley unit, with reasonable assurance of good sand conditions, is mapped over about half of the offshore basin (map Latrobe Valley Thickness).

The marine Tertiary increases basinward from 4,000 feet at the coast to 9,500 feet at the eastern end of the surveyed area. In the coastal area the lower portion is marl, grading up to marly and sandy limestone and then to sands and clays in the uppermost part. It is felt that the lower portion of the section is more likely to represent source material than the shallow water limestones. Farther out in the basin, there is a progressive change in the character of the seismic reflections which is interpreted as a change in sedimentary conditions, probably deeper water environment.

An interesting and important feature is noted in connection with the potential source beds, especially those in the lower portion of the marine section. It is seen in all of the five Tertiary prospects that the sediments were deposited contemporaneously with the development of the stratigraphical or structural trap. While, for example, the facies ridge was building up, it was being flanked by deposition of source beds. These potential source beds are also involved in the draping over the facies ridge and in the sedimentary wedge along the east side of the ridge. A similar situation exists in draping over the Jurassic structure "G-16-10-4" and in the basal Tertiary wedging against the flexure or the fault on the south side of the basin.

Jurassic:

The sediments of the Jurassic, estimated about 11,000 feet thick, are generally considered to have been deposited under non-marine conditions. This is mainly based on the presence of plant remains and on the fact that no marine fossils have been found. However, plant materials could have been floated into marine waters, and the presence of salt water in both Gippsland and Otway basins suggests strongly that either marine environment was near or that the sediments were actually deposited under marginal or partly marine conditions, which for reasons such as extreme muddiness did not favour growth of marine fauna (Chart Jurassic Water Salinity and Hydrocarbons, Fig. 19).

Whether partially marine or not, showings of oil and gas indicate that the sediments were capable of generating hydrocarbons. The general lack of porosity, however, has been quite evident in the onshore bores that penetrated as much as 8,000 feet of the Jurassic.

There are two distinct possibilities for better reservoir conditions to be present in the offshore portion of the basin. One is that sediments become marine eastward, and the other that clean sands develop along the north and south edges of the graben where the sediments overlap and pinch out on basement rock of the platform.

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PROSPECTIVE AREAS:

Summary:

The prospective areas resulting from this basin study are listed below and discussed separately. Their positions are shown on the two Evaluation Maps (Figs. 9, 10). Water depths varying between 125 and 250 feet are indicated on Fig. 3 Topography and Water Depth. The prospects lie within moderate drilling depths and only tests of the Jurassic would exceed 10,000 feet.

Although the reconnaissance grid covering these areas is generally wide, it is felt that some of the features (marked *) are sufficiently prominent and clearly enough defined to be drilled without further seismic survey.

			Area Sq. Miles
Tertiary:			
*	1.	Facies or barrier ridge in lower Tertiary	350
*	2.	Draping over barrier ridge	250
*	3.	Sedimentary wedge	325
	4.	Basal Tertiary wedging, south side of basin	90
*	5.	Draping over Jurassic structure "G-16-10-4"	100
		Total:	1,115
Jurassic:			
	6.	Elongated anticline-like structures (six)	650
	7.	Nose extending basinward from Lakes Entrance.	50
	8.	Pinchout, north side of basin	80
	9.	Fault and pinchout, south side of basin	350
		Grand Total:	2,245

Tertiary:

1. Facies or Barrier Ridge:

This ridge of thick Latrobe Valley is prospective mainly from the standpoint of reservoir potentialities, somewhat in the manner of a reef.

Onshore, the Latrobe Valley is known to contain a large percentage of clean quartz sand interbedded with clays, carbonaceous clays and, in the eastern area, from 9% - 30% of brown coal. It contains fresh water under an artesian head.

The facies ridge has been discussed mostly under Facies-Latrobe Valley. It is shown on Latrobe Valley Thickness map and in the offshore cross sections. Essentially it is an elongated area of thick continental sediments probably mixed with marine sands, coquinas and beach limestones, and believed to represent the seaward extension of thick Latrobe Valley in the form of a barrier ridge.

An idea of the magnitude of the ridge may be obtained from the thickness contours on the Latrobe Valley Thickness map. It is 5 to 8 miles wide and about 50 miles long, with the culmination about midway where crossed by line G-9. The westward closure, which is considerably less than that to the east, amounts to as much as 1,500 feet.

2. Draping over Facies or Barrier Ridge:

Above the greater part of the facies ridge there is from 4,000 to 5,000 feet of marine Tertiary. The draping is confined to the lower 2,000 feet of this interval, the upper part being essentially flat. The arrow lines on Post-Latrobe Valley Thickness map indicate the area affected by draping. It is estimated to be about six miles wide and about 2,000 feet thick, extending the length of the ridge (50 miles).

The culmination of the draped area necessarily coincides with that of the ridge, that is, approximately at the crossing of G-9.

The westward drape is comparatively short and dips in general about 1°, whereas the eastward drape is part of the regional tilting and therefore longer and steeper, about $2^{\circ}30'$. At this rate, there is from 200 to 400 feet of effective closure.

The potentiality of this major prospect hinges mainly upon the reservoir properties of the beds involved in the drape. It is fairly certain that they are marine, and limestone may possibly be built up over the ridge.

3. Sedimentary Wedge:

The position of this feature is shown on the Post-Latrobe Valley Thickness map. It is seen on all the seismic lines that cross the ridge, except G-10.

The wedging commences in the marine beds approximately over the crest of the facies ridge, thickening to about 4,000 feet a mile or so east of the edge of the ridge. Its extent eastward is indefinite but may be followed for five miles and more to where it flattens out. Inasmuch as the wedge is intimately associated with the ridge, the high area of the two will coincide.

It is fairly certain that the sediments involved in the wedge are marine. Furthermore, it can be seen from the seismic data that the overall wedge is made up of a series of individual pinchouts, resulting from the decreasing angle at which the sediments were deposited.

4. Basal Tertiary Wedging, South Side of Basin:

In connection with the Jurassic south graben fault there appears to have been post-Jurassic rejuvenation to the extent of at least 1,500 feet; or it could be continuation of differential sag between platform and trough that produced in the Tertiary a flexure (G-7, 8) in some parts and fault (G-2, 3, 13) in others, finally disappearing at the eastern extremity of the area (G-4, 9).

The result of this differential movement is that at least 500 to 1,500 feet of basal Tertiary butts against the north side of the fault or wedges against the flexure. In turn these beds are overlapped by beds spreading horizontally from the platform.

This feature forms an interesting prospect in a belt two miles or more wide extending northward from the fault. In this portion of the basin the lower part of the Tertiary is marine. If it is petroliferous, there is a broad strip along the southern side of the basin open to updip migration.

5. Draping over Jurassic Structure "G-16-10-4":

Of the six elongated Jurassic structures only "G-16-10-4" has topographic relief at the Jurassic-Tertiary contact (map Structure Top Jurassic). The others were levelled apparently by pre-Tertiary erosion. The maximum amount of relief of this feature is 2,000 feet on line G-10. There is less on G-16, very little on line G-19, and none on G-4. Only about 15 miles of the 25 miles of observed structure has topographic relief.

Draping is present over the topographic expression. On line G-10, for example, the culmination is overlain by 7,000 feet of Tertiary, the lower 1,500 - 2,000 feet of which displays draping. The maximum slope of the drape is about 3°. This would produce about 1,000 feet of closure.

Thus, the Jurassic topographic high produced not only draping but formed an island around which the early sediments of the Tertiary were deposited as overlapping wedges.

Jurassic:

6. Elongated Anticline-like Structures:

Six of these features appear on the maps of Jurassic Thickness and Structure Top Jurassic. For identification they are referred to according to the seismic lines through which they pass.

It is believed that these structures are basically block faults formed in connection with the graben. Although the seismic data is inadequate to show such detail, token faults are used in illustrating the structures on the cross sections.

Although only a few reflections are seen in each of these structures, following them through from one seismic line to another substantiates the overall picture. The western extensions of the four structural lines within the graben proper are masked by the strong reflections of the Latrobe Valley. It is only where the Latrobe Valley is thin or absent that it is possible to see the base of the Tertiary and the Jurassic below the unconformity.

The structures developed during Jurassic time and no movement carried over into the overlying Tertiary. Furthermore, in all cases except for part of "G-16-10-4" there is no topographic relief at the unconformity, the Jurassic having been extensively eroded and levelled prior to the Tertiary.

The elongated structures appear to be all of the same type, except possibly "G-1-2-12", which may differ from the others because of its position north of the graben proper, where the Jurassic is no more than about 6,000 feet thick.

In general, the elongated structures are 5 to 8 miles wide, with estimated structural relief of 1,500 to 2,500 feet. The southernmost of them is in evidence for 45 miles and the others, except the two very short ones, are followed for about 25 miles each.

7. <u>Nose Extending Basinward from Lakes Entrance</u>:

This feature is indicated by a pronounced south-eastward bulge of the thickness contours and the zero line shown on the map Jurassic Thickness. The south-eastward swing amounts to 3 to 5 miles and the influence of nosing within the Jurassic extends south-eastward for about 6 miles. The nose is about 10 miles wide. As drawn on cross section G-1, structural uplift amounts to more than 1,000 feet.

Although the nose is a Jurassic feature, some structural movement continued possibly into the Tertiary. (Cross Section G-1 and map Structure Top Jurassic).

The importance of this feature is its apparent relationship to the Lakes Entrance oil seepage. If the oil originated within the Tertiary the question of fresh water flushing must be considered. However, in the case of Jurassic oil, the wedgeout in connection with the nose should be highly prospective.

Further mapping is needed in this area, especially to establish the relationship between the nose and the elongated structure "G-1-2-12" immediately to the south of the nose.

The greater portion of this prospective area is within ARCO's tenement.

8. Pinchout, North Side of Basin:

The pinchout of the Jurassic along the north side of the basin is well controlled and shows clearly on the seismic lines. It is illustrated on cross sections G-1, G-2, and G-3.

There is a pronounced swing beginning just offshore of the line of pinchout that produces two large noses. (Map Jurassic Thickness). The first nose is that extending south-eastward from Lakes Entrance, described separately under prospective areas.

The other nose is represented by a southwest bulge on seismic line G-3. The Jurassic pinchout within this area is further affected by a post-Jurassic fault ten miles west of the nose. (Map Structure Top Jurassic). The fault trends NE-SW and is seen on lines MA-2, G-1, G-12 and G-21. It is up on the east side and has a displacement of 500 - 800 feet. The fault, together with the nose, form a structurally high area along the Jurassic pinchout for a distance of at least 15 miles.

9. <u>Fault and Pinchout, South Side of Basin</u>:

Both the south graben fault and the overlap and the pinchout of the sediments onto the platform form potential traps as shown by the contours on the Jurassic Thickness map. A good picture of the conditions is obtained from the seismic lines that cross the fault and extend onto the platform. Of these lines, cross sections G-2, G-3 and G-8 are representative.

It is seen that the graben fault was active during deposition of the Jurassic. The southward thin overlap could represent either a foreshortened section of the Jurassic or parts of it. In any event the sedimentary conditions of this area could have favoured deposition of cleaner clastics and therefore better porosity than usually found in the (onshore) Jurassic.

The zone of interest is considered to be about eight miles wide. Of this, two to three miles cover an area of north slope extending northward from the fault. The remainder is distributed over the pinchout on the platform.

. . . . .

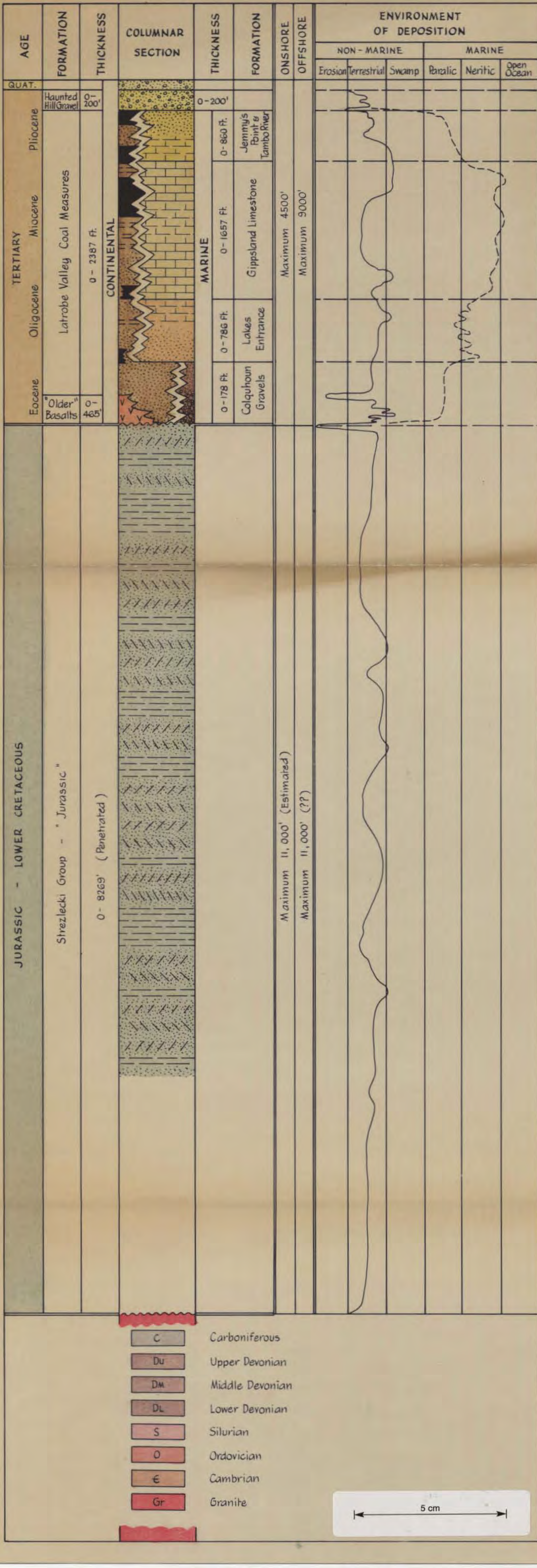
<u>Lyman C. Reed</u>

MELBOURNE
22/4/1964
LCR:MSW

EAST BASS BASIN part 8 fig 2 OR-045

024052

FIG. 2 GENERALISED STRATIGRAPHIC COLUMN - GIPPSLAND BASIN (ONSHORE)



DESCRIPTION

QUATERNARY : River terraces. Sand, clay, boulder conglomerates and river gravels, trace of lignite.
Q

HAUNTED HILL GRAVELS : Gravels, coarse, fine and gritty with white, purple and green clays. Leaf beds at base.
TR

JEMMY'S POINT FORMATION : Sands, abundant fossil remains and some argillaceous material.
TR

TAMBO RIVER FORMATION : Marls, brown and grey, silty and sandy in part. Glauconitic. Sands, fossiliferous, white, fine to medium grained. Marginal facies.
TR

GIPPSLAND LIMESTONE : Limestone, sandy, impure, generally unconsolidated but contains thin dense bands, tan-cream, fine grained and fossiliferous with some porosity. Marls, shades of grey and brown, very fossiliferous. Glauconitic. Becomes more argillaceous at base.
GLs

LAKES ENTRANCE FORMATION : Marls and siltstones, soft, foraminiferal. Glauconitic throughout, increasing with depth. 75' of glauconitic sand at base containing oil at Lakes Entrance.
LE

COLQUHOUN GRAVELS : Gravels and sands; some clays. Marine, containing foraminifera, fish remains and bryozoa.
CG

OLDER BASALT : Basalt, dark grey, fine to medium grained with small sub-angular phenocrysts. Often found weathered in the sub-surface. Not recognised in Eastern half of onshore basin.
V

LATROBE VALLEY COAL MEASURES : Sands, fine to coarse grained, mainly quartz, but often argillaceous. Good porosity and permeability. Brown coal (lignite) well developed in part of basin and is variable in thickness and extent. (80% of section at Yallourn-Morwell, 20% of section at Wellington Park Nº1) Minor amounts of siltstone (in places calcareous and dolomitic) and brown carbonaceous clays.
LV

STREZLECKI GROUP - "JURASSIC" : Chiefly arkoses, mudstones with minor grit, conglomerate and some black coal. Arkoses are composed of angular grains of quartz, oligoclase, orthoclase, biotite and andesitic tuff cemented by chlorite and secondary feldspar. Calcite often replaces cementing material. Feldspars are relatively fresh.
J

Irregular, gritty and conglomeritic phases; a little coaly material throughout section. Fine to medium grained rocks, grey-green colour predominates. Arkosic material also classified as greywacke and sub-greywacke.

Poorly preserved plant fragments and spore content in some areas. Apparent non-marine environment, although contains some connate (?) salt water.

Arkoses derived from igneous rocks, whereas mudstones derived chiefly from (?) Palaeozoic sediments.

Onshore, the same general rock types throughout section, therefore the stratigraphic sequence is not mappable by lithological methods. Found in bores to be hard, dense and only an occasional bed with fair porosity and permeability.

BASEMENT : "Basement" includes the unmetamorphosed Upper Devonian to Carboniferous, of varicoloured shales, siltstones, sandstones and volcanic interbeds. Conglomerate facies predominate near base. Non-marine origin.
B

- C – Carboniferous
- Du – Upper Devonian
- DM – Middle Devonian
- DL – Lower Devonian
- S – Silurian
- O – Ordovician
- € – Cambrian
- Gr – Granite

HAEMATITE EXPLORATIONS OG-632


HAEMATITE EXPLORATIONS PTY. LTD.
GIPPSLAND
TECTONIC MAP
TOPOGRAPHY AND WATER DEPTH
MODIFIED FROM ARMY TOPO MAP
CONTINUOUS FATHOMETER RECORDINGS
5 cm
G.H.H. FEBRUARY, 1964
L.C. REED
SCALE OF MILES
0 5 10 15 20
1: 253.440
OG-644
024053
FIG. 3
CR-045
EAST BASS BASIN
part 8 fig 3
WARBURTON
DANDENONG
PORT PHILLIP BAY
FRANKSTON
WESTERN PORT BAY
FRENCH ISLAND
WESTERN PORT
CAPE WOOLAMAI
WARRAGUL
MOE
TRARALGON
MORWELL
LATROBE R.
THOMSON R.
MAFFRA
STRATFORD
SALE
LAKE WELLINGTON
LAKE VICTORIA
LAKE KING
BAIRNSDALE
LAKES ENTRANCE
ORBOST
CAPE CONRAN
CAPE EVERARD
TAMBO R.
MITCHELL R.
MACALISTER R.
GLENMAGGIE RESERVOIR
ROSEDALE FAULT
LIMIT OF TERTIARY
LIMIT OF JURASSIC
TERTIARY ON BASEMENT
WARRAGUL
WARRACAN BLOCK
BALOOK BLOCK
BASEMENT RIDGE
WONTHAGGI
CAPE PATTERSON
FOSTER
FISH CREEK
YARRAM
WOODSIDE
CORNER INLET
WARATAH BAY
CAPE LIPTRAP
DIRECTION ISLANDS
GLENNIE GROUP
ANSER GROUP
VICTORIA
TASMANIA
RODONDO ISLAND
MONCOEUR ISLANDS
HOGAN GROUP
BASS STRAIT
CUTTER ROCK
CROCODILE ROCKS
DEVIL'S TOWER
BASS RIDGE
KENT GROUP
CURTIS GROUP
TERTIARY
37°30'
38°00'
38°30'
39°00'
39°30'
145°00'
146°00'
147°00'
148°00'
149°00'
149°20'


EAST BASS BASIN
part 8 fig 4
JURASSIC PROSPECTS
4 NOSE S.E. OF LAKES ENTRANCE
5 ELONGATED STRUCTURES
6 PINCHOUT AT FAULT – PLATFORM
7 PINCHOUT, N. SIDE OF BASIN
HAEMATITE EXPLORATIONS PTY. LTD.
GIPPSLAND
JURASSIC THICKNESS
G.H.H. FEBRUARY, 1964
L.C. REED
SCALE OF MILES
0 5 10 15 20
1 : 253,440
OG-621
024054
FIG. 4
CR-045
BASEMENT RIDGE
NARRACAN BLOCK
BALOOK BLOCK
NORTH GRABEN FAULT
SOUTH GRABEN FAULT
LIMIT OF JURASSIC
LAKE WELLINGTON
LAKES ENTRANCE
BAIRNSDALE
SALE
MAFFRA
STRATFORD
TRARALGON
MORWELL
YARRAM
WOODSIDE
FOSTER
WONTHAGGI
CAPE PATTERSON
CORNER INLET
WILSON PROMONTORY
WESTERN PORT BAY
PORT PHILLIP BAY
PHILLIP ISLAND
FRENCH ISLAND
CAPE WOOLAMAI
CAPE LIPTRAP
WARATAH BAY
DANDENONG
FRANKSTON
WARBURTON
WARRAGUL
ORBOST
CAPE CONRAN
CAPE EVERARD
GLENMAGGIE RESERVOIR
DIRECTION ISLANDS
GLENNIE GROUP
ANSER GROUP
RODONDO ISLAND
MONCOEUR ISLANDS
HOGAN GROUP
CUTTER ROCK
CROCODILE ROCKS
DEVIL'S TOWER
KENT GROUP
CURTIS GROUP
VICTORIA
TASMANIA
BASS STRAIT
BASS RIDGE


EAST BASS BASIN
part 8 fig 5
FACIES CHANGES FROM CONTINENTAL TO MARINE
All continental Latrobe Valley coal measures
Upper half replaced by marine facies (Gippsland Limestone & Lakes Entrance Formation.)
FROM CROSS SECTION Nº1
FROM CROSS SECTION Nº4
Lower half continental Latrobe Valley coal measures
Further replacement of Latrobe Valley by marine Lakes Entrance formation
FROM CROSS SECTION Nº1
Thin continental Latrobe Valley coal measures
Remainder replaced by marine Colquhoun gravels
FROM CROSS SECTION Nº1
EVALUATION
TERTIARY PROSPECTS
1 FACIES RIDGE LOWER TERTIARY
(A) POROSITY IN RIDGE FLANKED BY MARINE BEDS
(B) DRAPING OVER RIDGE
(C) SEDIMENTARY WEDGE EAST SIDE OF RIDGE
2 WEDGING AGAINST FAULT
3 DRAPING OVER JURASSIC STRUCTURE
HAEMATITE EXPLORATIONS PTY. LTD.
GIPPSLAND
LATROBE VALLEY
THICKNESS
G.H.H. JANUARY, 1964.
L.C.REED
SCALE OF MILES
0 5 10 15 20
1:253.440
OG-623
FIG. 5
024055
OR-045
BASEMENT RIDGE
NARRACAN BLOCK
BALOOK BLOCK
ROSEDALE FAULT
COLQUHOUN MARINE
LIMIT OF JURASSIC TERTIARY ON BASEMENT
LIMIT OF LATROBE VALLEY UNDIFFERENTIATED TERTIARY MARINE
JURASSIC GRABEN FAULT
PLATFORM
LIMIT OF TERTIARY
BASS STRAIT
VICTORIA
TASMANIA

HAEMATITE EXPLORATIONS PTY. LTD.
GIPPSLAND
TECTONIC MAP
TERTIARY THICKNESS
G.H.H. SEPTEMBER 1963
L.C. REED
SCALE OF MILES
0 5 10 15 20
1: 253.440
OG-636
024056
GENERALISED STRATIGRAPHIC COLUMN
GIPPSLAND BASIN
EAST BASS BASIN
part 8 fig 7
BAIRNSDALE
ORBOST
CAPE CONRAN
CAPE EVERARD
LAKES ENTRANCE
LAKE KING
LAKE WELLINGTON
SALE
MAFFRA
STRATFORD
TRARALGON
MORWELL
MOE
WARRAGUL
DANDENONG
FRANKSTON
PORT PHILLIP BAY
WESTERN PORT BAY
FRENCH ISLAND
PHILLIP ISLAND
CAPE WOOLAMAI
WONTHAGGI
CAPE PATTERSON
KORUMBURRA
FOSTER
FISH CREEK
YARRAM
WOODSIDE
CORNER INLET
WARATAH BAY
CAPE LIPTRAP
WILSON PROMONTORY
GLENNIE GROUP
ANSER GROUP
RODONDO ISLAND
MONCOEUR ISLANDS
HOGAN GROUP
KENT GROUP
CURTIS GROUP
DEVIL'S TOWER
CUTTER ROCK
CROCODILE ROCKS
DIRECTION ISLANDS
GLENMAGGIE RESERVOIR
WARBURTON
BASS STRAIT
BASS RIDGE
VICTORIA
TASMANIA
BASEMENT RIDGE
NARRACAN BLOCK
BALOOK BLOCK
PLATFORM
LATROBE VALLEY
LIMIT OF TERTIARY
LIMIT OF JURASSIC TERTIARY ON BASEMENT
SOUTH GRABEN FAULT
ROSEDALE FAULT

FIG. 7

OR-045

CROSS SECTION G3

SCALE NORMAL

024057

CROSS SECTION G8

SCALE NORMAL

024058