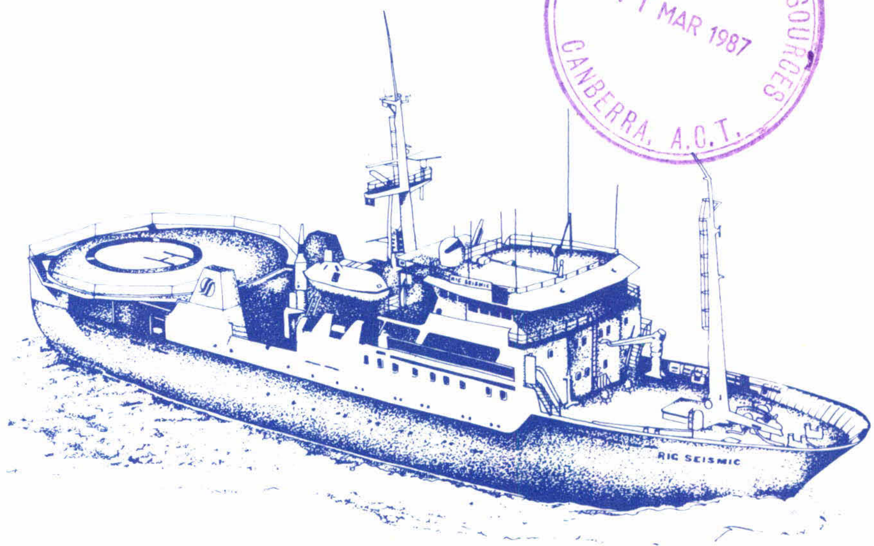
XTENDED ABSTRACT

BMR



OTWAY BASIN WORKSHOP

BMR Record 1987/9
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The Bureau of Mineral Resources, Geology & Geophysics

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EXTENDED ABSTRACTS

Otway Basin Workshop

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CONTENTS

Tectonic Setting of the Otway Basin

D.A. Falvey & P.E. Williamson, BMR

The plate tectonic setting of a continental margin provides the structural and geothermal framework for understanding the evolution of those sedimentary basins which are formed in response to continental breakup and seafloor spreading. In broad terms, a continental margin sedimentary basin will consist of a deeper subbasin, older than the oldest oceanic crust beneath the adjacent deep sea floor (the "pre breakup" section) and having the morphology and genesis of an intra cratonic rift. Overlying this will be a younger, post breakup section, deposited across the entire margin from some coastal hinge line to the deep ocean basin.

Sediments deposited in pre breakup rift basins are commonly marginal marine or marine ingressive to fluvial. The section is deeply faulted, giving a horst and graben structural style. Basin subsidence rates are initially high, but decrease towards the time of breakup, which is commonly marked by an unconformity of regional extent ("breakup unconformity"). This is now thought to be more an effect of the interaction between sealevel fluctuation and changing subsidence patterns before and after breakup, than due to any specific vertical tectonic episode. Post breakup sedimentation is often non-marine just on top of the breakup unconformity, but a major marine transgression rapidly occurs as seafloor spreading produces a widening and deepening ocean basin. In the early stages of such basin evolution, oceanographic conditions change rapidly sometimes leading to phases of submarine erosion and redeposition. Seabed falls, such as those at the end of the Cretaceous and in the late Oligocene, produce widespread regional unconformities in nearer shore environments. After the breakup unconformity, subsidence rates are again high, decreasing exponentially with time.

Basin subsidence driving mechanisms are clearly different before and after breakup. In the latter case, the form of the exponential subsidence pattern indicate thermal contraction of the underlying lithosphere as the heat source represented by the mid ocean ridge is removed by seafloor spreading. The prebreakup rift, on the other hand clearly forms in a rising heatflow, intracratonic setting. Chief amongst probable driving mechanisms is lithosphere (and hence crustal) thinning by extension, although the rising heatflow environment will clearly give rise to major metamorphic changes in the deep crust which may also contribute to prebreakup subsidence.

The plate tectonic setting of the southern Australian continental margin is the story of the timing and kinematics of the final breakup of Gondwanaland : The separation of Australia and Antarctica. The original seafloor spreading magnetic anomaly signature identified by Weissel and Hayes (1971) placed breakup at 55 Ma B.P. (early Eocene). Falvey erected a model which classified the Tertiary section as postbreakup, the late Cretaceous as "rift" and the early Cretaceous as "prerift", based on this interpretation. However, Denham and Brown (1976) presented strong evidnece of late Cretaceous shelf edge sediments, which suggested an earlier breakup. By the late 1970's cracks were starting to appear in what was apparently an over-simplified magnetic anomaly pattern identification.

In 1982, Cande and Mutter provided a revised identification, placing breakup at mid Cretaceous.. Half seafloor spreading rates during the Cretaceous, Paleocene and early Eocene were a very low 4.5 mm/yr, compared to 22 mm/yr late in the Tertiary. This kinematic pattern, in many ways, resembles that of the Red Sea and Gulf of Aden in the Neogene.

In 1985, Mutter, Hegarty, Cande and Weissel extended this concept by taking account of basin subsidence patterns recorded in exploration wells in the Great Australian Bight and Otway Basins. They postulate a time transgressive breakup, ranging from 110 Ma B.P. in the west of the Bight, to 60 ma B.P. in the eastern Otway region. The younger age was considered a 'thermal breakup'. Magnetic anomaly identifications east of the Bight were recognized to be at best, obscure. The final work to date is from Veevers (1986). He proposed a breakup age of 95 ± 5 Ma B.P. based on a detailed analysis of the gap between the oldest identifiable anomaly (34) to the continent ocean boundary in the central Bight region (Fig. 1). Mid ocean ridge crest jumps were proposed to explain the apparent truncation of seafloor spreading anomalies from the Bight to the Otway region. This could explain the various subsidence patterns noted by Mutter et al., but it is clearly not the end of the story of the relationship between seafloor kinematics and continental margin basin tectonics.

In the present study the age of rifting in the Otway Basin is placed at 102 ±

5 Ma B.P. from seismic and well data. Calculated driving mechanism values for the differing structural elements in the Basin (Fig. 2) suggest the onset of spreading was about 90 Ma B.P. although spreading was apparently very slow until the late Tertiary as was argued by Mutter et al. for the west of the Australian Southern Margin.

References

Cande, S.C. & Mutter, J.C., 1982 - A revised identification of the oldest sea floor spreading anomalies between Australia and Antarctica; Earth and Planetary Sci. Lett., (58), 151-160.

Mutter, J.C., Hegarty, K.A., Cande, C.S. & Weissel, J.K., 1984 - Breakup between Australia and Antarctica: A brief review in the light of new data, Tectonophysics, 114, 255-279.

Veevers, J.J., 1986 - Breakup of Australia and Antarctica estimated as mid-Cretaceous (95 ± 5 Ma) from magnetic and seismic data at the continental margin; Earth and Planetary Sci. Lett., (77), 91-99.

Weissel, J.K. & Hayes, D.E., 1971 - Asymmetric spreading south of Australia, Nature,231 (5304), 517-521.

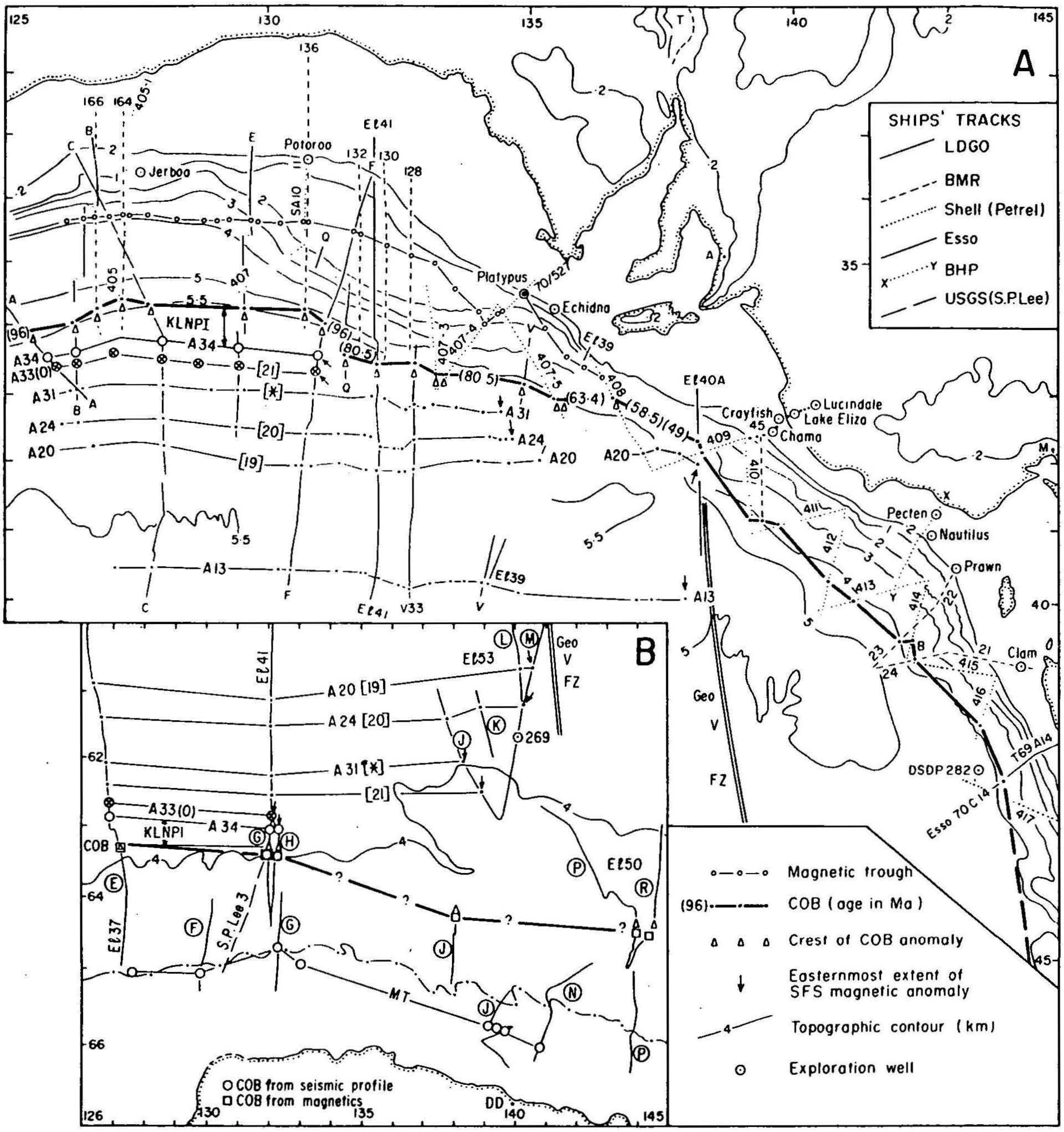


Fig. 1. A. Southern Australian margin between 125° and 145°E, showing ships' tracks (Lamont-Doherty Geological Observatory [3,4,14]; Bureau of Mineral Resources [15,16], and J.C. Branson, personal communication; Shell [5]; Esso [17] and personal communication; and BHP [18]), seafloor-spreading magnetic anomalies, modified from Konig [4] and Cande and Mutter [1], as shown in Table 1, with easternmost determinations marked by arrow: A33(o) is the older boundary of anomaly 33 [6]; continent-ocean boundary (COB) (heavy line) and crest of COB anomaly (triangle) from Fig. 2A, and magnetic trough [1,4,16]; exploration wells [5,12,19–21]; and bathymetry [22]. *KLNPI* = Cretaceous long normal polarity interval. *A* = Adelaide, *M* = Melbourne. Mercator projection. B. Wilkes Land, Antarctica, margin, at similar scale to A, and conjugate with southern Australian sector west of line 408 [3], showing location of ships' tracks (Eltanin 37E, F, G', J, N and 41G, H [14], and 50P, R and 53J–M [4,23,24]; "S.P. Lee", line 3 [10]), seafloor-spreading magnetic anomalies, modified from [1], old determinations [4] in brackets, as shown in Table 1; COB (from "S.P. Lee" seismic profile, line 3 [10] and from COB anomaly (crest located by triangle) on Eltanin 37 and 41, and tentatively from J, P and R, from Fig. 2B), and magnetic trough (*MT*) (circles [1,4]). Coastline, shelf/slope break (0.8 ± 0.2 km isobath, dot-and-dashed line) and 4-km isobath (full line) [25]. *KLNPI* = Cretaceous long normal polarity interval. *DD* = Dumont d'Urville. Mercator projection. (After Veevers, 1986)

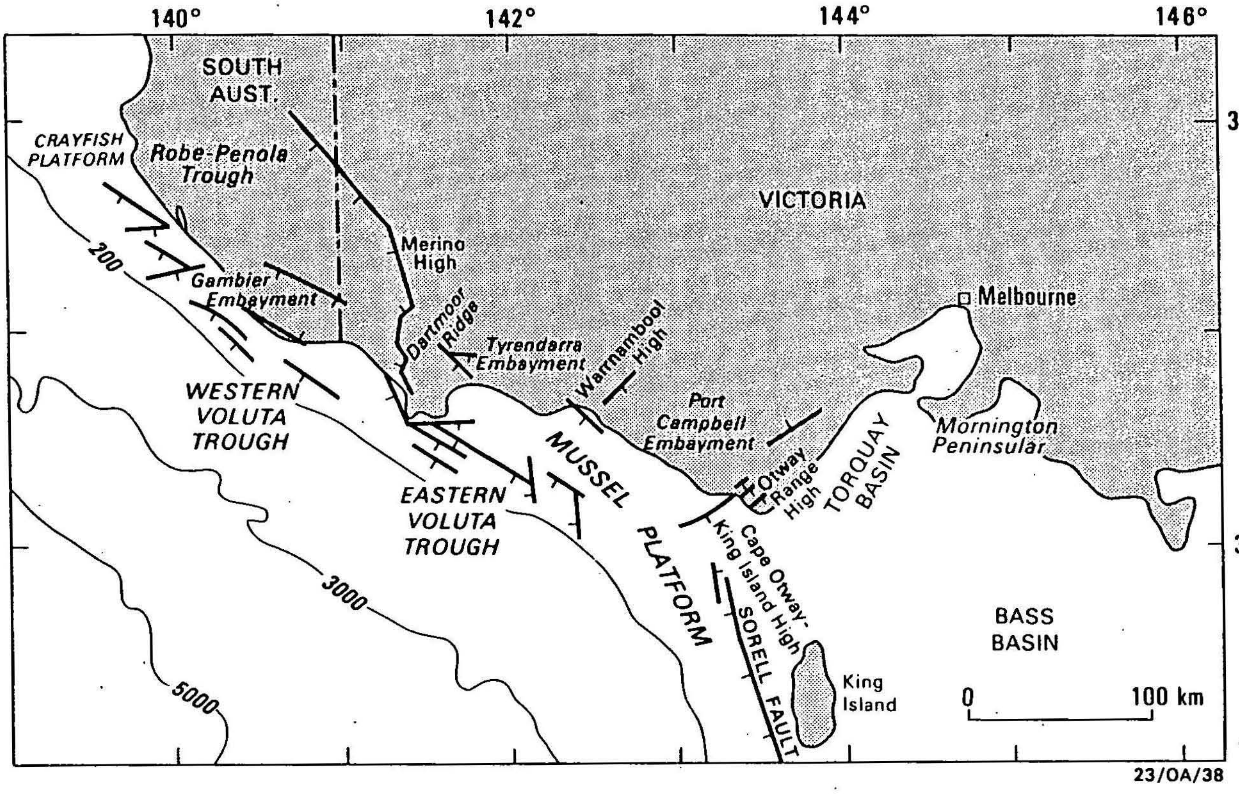


Figure 2 Tectonic elements of the Offshore Otway Basin

Structural Mapping and Petroleum Resource Potential of the Offshore Otway Basin

P.E. Williamson, BMR

The offshore Otway basin occurs west of the Bass and Gippsland Basins in the Bass Strait region. It exhibits differing structural characteristics and consequently structural closures at different levels across the basin. Reservoir, seal and, source lithologies (O'Brien, this volume; McKirdy, this volume), likely migration paths and suitable thermal histories (O'Brien, this volume) are present giving promise of substantial remaining petroleum exploration potential for the Cretaceous and Tertiary section (Williamson et al, 1987).

The offshore basin consists of three main tectonic units : the Mussel Platform in the east, the Voluta Trough in the centre of the basin, and the Crayfish Platform in the west. Structures are formed predominantly by Cretaceous normal faults, downthrown to the continent-ocean boundary, and bounding landward-dipping fault-blocks in the Cretaceous section. Sediment thickness is up to 10 km. Tertiary and younger reactivation of rift faulting, sometimes with a minor reverse component, occurs particularly in the western Voluta Trough and on the margins of the Crayfish Platform, and lateral offsets associated with oblique separation of the Tasmanian and Antarctic margins, occur in faulting in the eastern Mussel Platform.

Shows of oil, gas and condensate have been widespread both onshore and in the 17 offshore wells, though only two small economic fields have been discovered, both onshore. Exploration offshore, particularly during the 1960s and 1970s, was hampered by poor seismic data quality, due predominantly to the presence of shallow carbonates.

The first phase of the BMR study of the offshore basin, involved the collection, during 1985, of 3700 km of regional multi-channel seismic reflection data by BMR research vessel, Rig Seismic (Exon, Williamson et al, 1987; Fig. 3). BMR and selected existing industry seismic data were then used along with well data to analyse structure and hydrocarbon potential on an approximate 10 km square grid over the continental shelf.

The structure of the Mussel Platform is normally composed of northwest trending rift faults and suggests the presence of suitable Waarre Sandstone traps overlying fault-bounded highs at the mapped Top Otway level for the southern and western platform. Dip reversals associated with some faults on the far eastern platform reflect oblique separation at the Tasmanian margin. Faults in this region trend north-northwest and northeast. The relative lack of Upper Cretaceous reactivation of faulting in the region (Fig. 5) implies that the ability to charge shallower, thermally immature reservoirs via fault zones accessing deeper mature source rocks may be poor, except in isolated areas where suitable late reactivation of faulting has occurred. In the north of the Mussel Platform, strong intra Lower Cretaceous seismic events are observed and it is possible that an untested play, analogous to the Pretty Hill Formation play on the Crayfish Platform, may exist.

In the eastern Voluta Trough, significant structural closures are present at Top Otway levels, and the Waarre Sandstone (or equivalent) play is again present. Reactivation of rift faulting occurs in the lower Late Cretaceous, and may have allowed some secondary hydrocarbon migration into shallower Late Cretaceous reservoirs. However, the predominantly shaley nature of the Upper Cretaceous Belfast Mudstone in the eastern Voluta Trough suggests that vertical migration may have been difficult. Vertical migration is more likely to occur where late fault reactivation has been more significant and/or where sandier Upper Cretaceous facies exist around the basin margin. This may have been the case where oil shows were encountered in the base Tertiary at Lindon 1, on the flank of the Portland Trough.

The western Voluta Trough (Fig. 4) shows the most intense fault reactivation in the basin extending to the Tertiary and younger section. The Waarre Sandstone (or equivalent) play is basically similar to that seen in the eastern Voluta Trough. In addition, significant fault-bounded structural leads are defined at Top Cretaceous levels and the more intense Upper Cretaceous and Eocene/Oligocene fault reactivation increases the probability of vertical migration into shallower Upper Cretaceous, and possibly Tertiary, reservoirs. Thermal gas has recently been sampled by BMR in water bottom sediments associated with fault zones in this region (McKirdy and Heggie, this volume; Exon and Lee, this volume) . On the western margin of the western Voluta Trough (abutting the Crayfish Platform), and on the southern margin of the Crayfish Platform, the combination of sandier Upper Cretaceous and Tertiary facies, and Upper Cretaceous and Tertiary fault reactivation, may have significantly enhanced vertical migration.

On the Crayfish Platform "proper", the Pretty Hill play is present. On the Platform margins, the Waarre play exists, and Upper Cretaceous fault reactivation is similar to that seen in the western Voluta Trough. This suggests that shallower Upper Cretaceous, and possibly Tertiary, plays also exist depending on the effectiveness of vertical migration in the Upper Cretaceous. Vertical migration would be enhanced by both the late fault reactivation, and also the tendency for facies to become sandier, in those intervals, towards the Platform margins.

References

Williamson, P.E., O'Brien, G.W., Swift, M.G., Felton, E.A., Scherl, A.S., Marlow, M., Lock, J., Exon, N.F., & Falvey, D.A., 1987 - Hydrocarbon potential of the offshore Otway Basin., APEA Journal (in press).

Exon, N.F., Williamson, P.E., et al., 1987 - Rig Seismic Research Cruise 3 : Offshore Otway Basin, Southeastern Australia. BMR Report 279

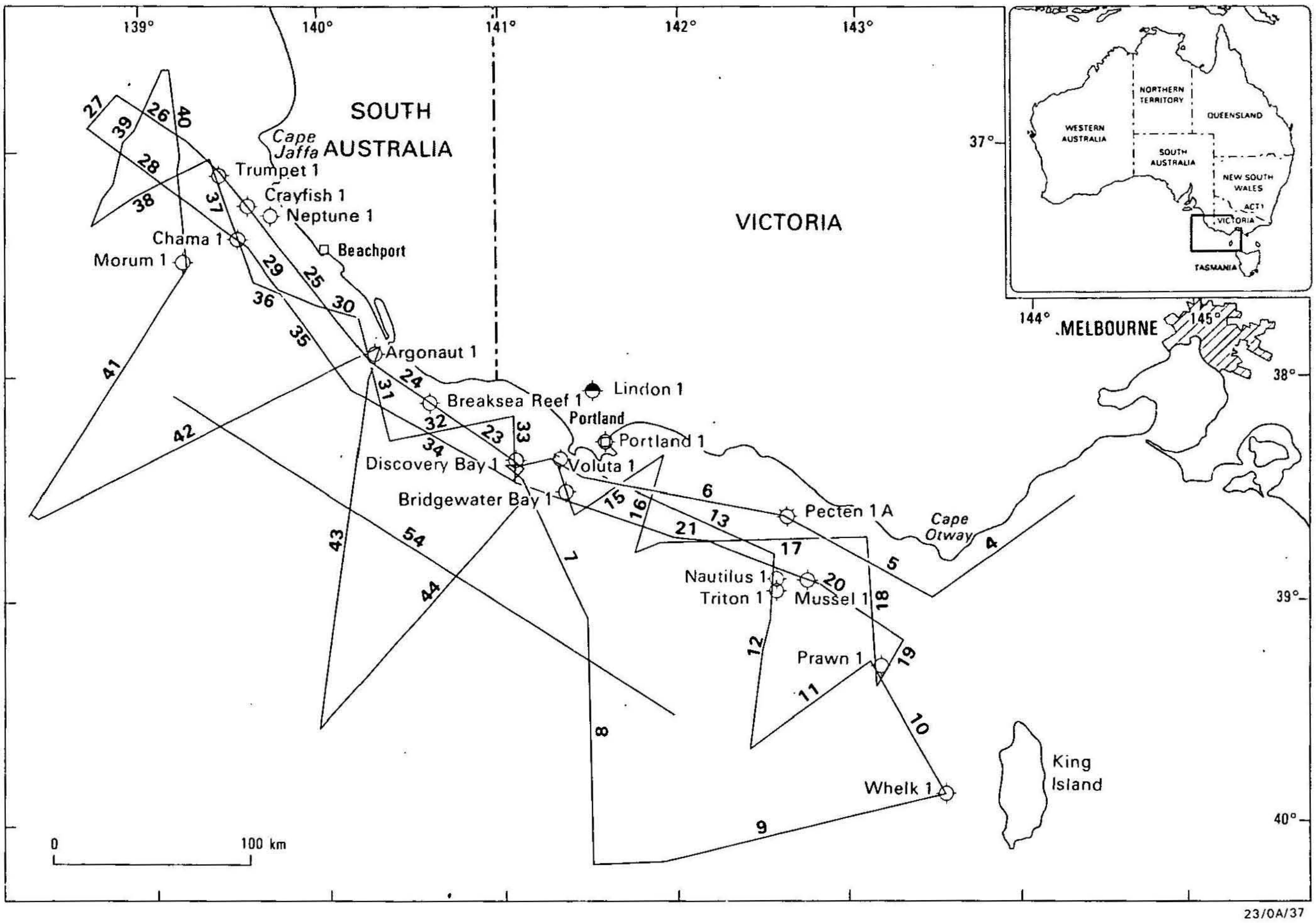


Figure 3 Seismic reflection data collected in the Otway Basin in 1985 by the BMR vessel Rig Seismic.

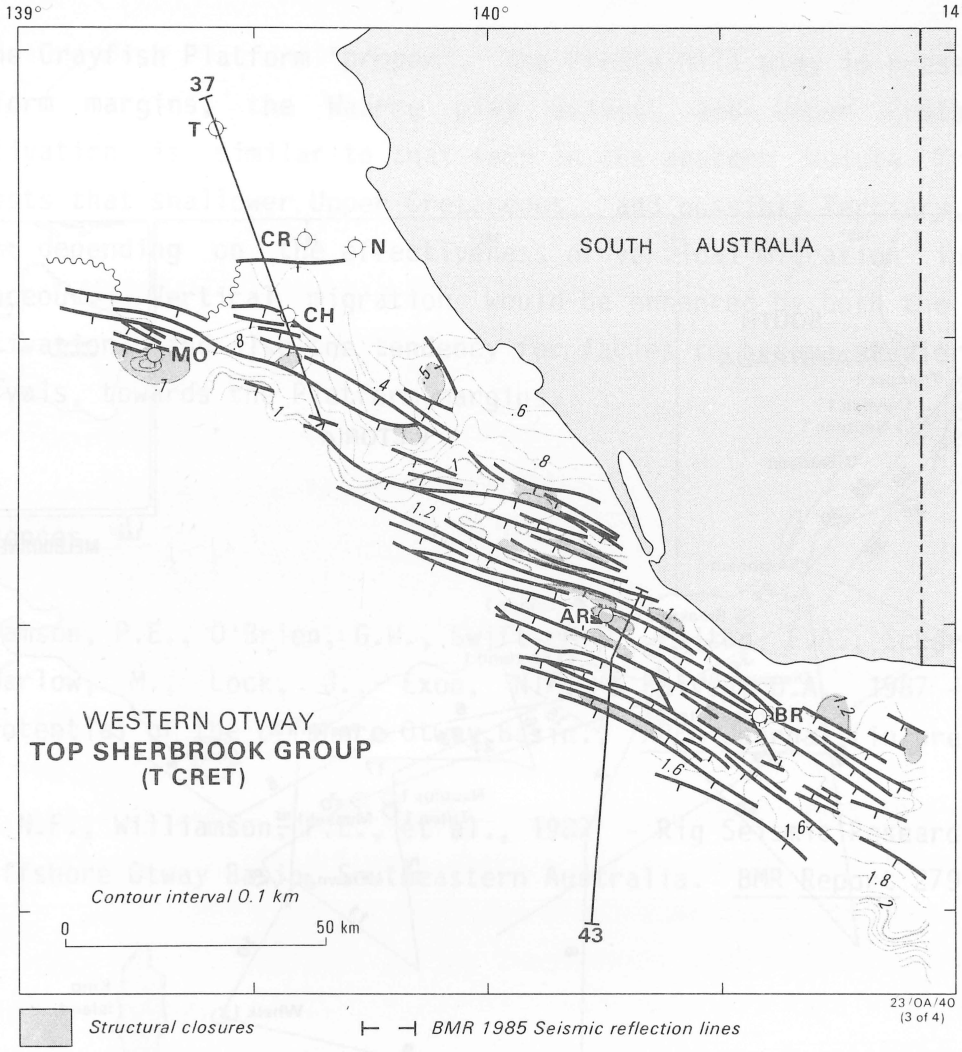


Figure 4 Top Cretaceous (Top Sherbrook Group) depth structure map of the western Offshore Basin.

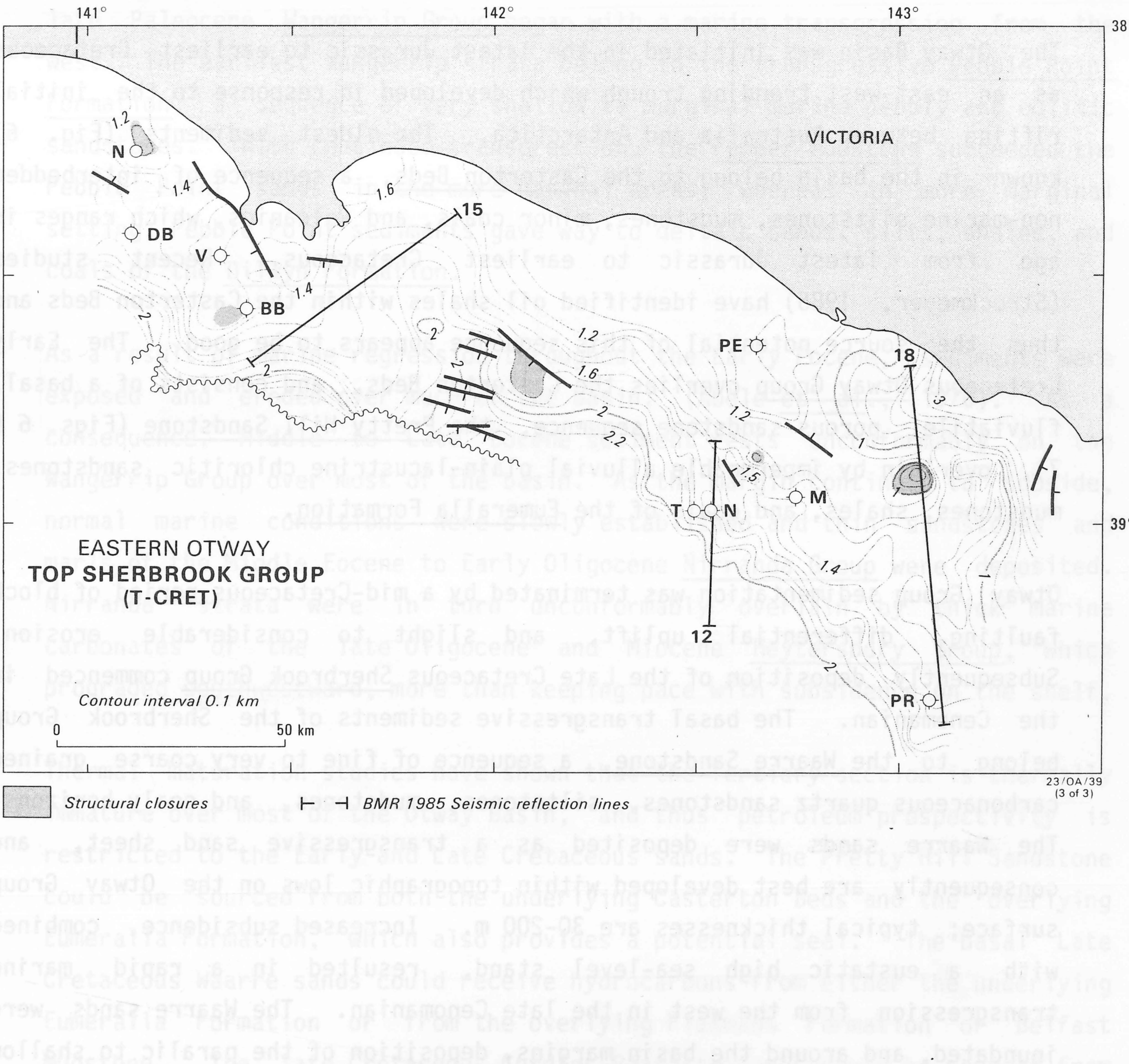


Figure 5 Top Cretaceous (Top Sherbrook Group) depth structure map of the eastern Offshore Otway Basin.

Otway Basin Stratigraphy : A General Review

G.W. O'Brien, BMR

The Otway Basin was initiated in the latest Jurassic to earliest Cretaceous as an east-west trending trough which developed in response to the initial rifting between Australia and Antarctica. The oldest sediments (Fig. 6) known in the basin belong to the Casterton Beds, a sequence of interbedded non-marine siltstones, mudstones, minor coals, and volcanics, which ranges in age from latest Jurassic to earliest Cretaceous. Recent studies (Struckmeyer, 1986) have identified oil shales within the Casterton Beds and thus the source potential of this sequence appears to be good. The Early Cretaceous Otway Group overlies the Casterton Beds, and consists of a basal, fluviatile, porous sandstone sequence, the Pretty Hill Sandstone (Figs. 6 & 7), overlain by impermeable alluvial plain-lacustrine chloritic sandstones, mudstones, shales, and coals of the Eumeralla Formation.

Otway Group sedimentation was terminated by a mid-Cretaceous period of block faulting, differential uplift, and slight to considerable erosion. Subsequently deposition of the Late Cretaceous Sherbrook Group commenced in the Cenomanian. The basal transgressive sediments of the Sherbrook Group belong to the Waarre Sandstone, a sequence of fine to very coarse grained carbonaceous quartz sandstones, siltstones, mudstones, and coaly horizons. The Waarre sands were deposited as a transgressive sand sheet, and consequently are best developed within topographic lows on the Otway Group surface; typical thicknesses are 30-200 m. Increased subsidence, combined with a eustatic high sea-level stand, resulted in a rapid marine transgression from the west in the late Cenomanian. The Waarre sands were inundated, and around the basin margins, deposition of the paralic to shallow marine Flaxmans Formation and Nullawaare Greensand commenced. The Voluta Trough was subsiding much more rapidly than the Mussel Platform or the eastern or western basin margins and, consequently, sedimentation of deep marine (prodelta) mudstones (Belfast Mudstone) was quickly established in the central Voluta Trough. Shallow water sedimentation continued around the periphery of the Voluta Trough, and at the basin margins. Marine regression in middle Late Cretaceous time was accompanied by the progradation of the terrigenous, fluvio-deltaic Paaratte Formation, and the continental Curdies Formation, over the Belfast Mudstone, and into the central Voluta Trough.

Non-deposition and erosion were common throughout the western Otway Basin during the earliest Tertiary, and consequently Tertiary sediments commonly unconformably overlie the Sherbrook Group. Sedimentation of the middle to late Paleocene Wangerrip Group began with a marine transgression from the west. The earliest Wangerrip strata belong to the transgressive Pebble Point Formation, a sequence of very shallow to marginal marine pebbly and oolitic sandstones. With continued transgression, the Pember Mudstone succeeded the Pebble Point sands in the more basinal areas, whereas in more marginal setting, Pebble Point sediments gave way to deltaic sands, silts, shales, and coals of the Dilwyn Formation.

As a result of marine regression throughout the Early Eocene, sediments were exposed and eroded over much of the basin. (Abele et al., 1976). As a consequence, Middle to Late Eocene sediment rests unconformably on the Wangerrip Group over most of the basin. As the margin continued to subside, normal marine conditions were slowly established and thin sandstones and marls of the Middle Eocene to Early Oligocene Nirranda Group were deposited. Nirranda strata were in turn unconformably overlain by thick marine carbonates of the late Oligocene and Miocene Heytersbury Group, which prograded southwestward, more than keeping pace with subsidence on the shelf.

Thermal maturation studies have shown that the Tertiary section is thermally immature over most of the Otway Basin, and thus petroleum prospectivity is restricted to the Early and Late Cretaceous sands. The Pretty Hill Sandstone could be sourced from both the underlying Casterton Beds and the overlying Eumeralla Formation, which also provides a potential seal. The basal Late Cretaceous Waarre sands could receive hydrocarbons from either the underlying Eumeralla Formation or from the overlying Flaxmans Formation or Belfast Mudstone. The late Cretaceous Curdies-Paaratte sands could be sourced from any underlying Early and Late Cretaceous source beds, and also from the coals which occur within both formations.

References

Abele, C., Kenley, P.R., Holdgate, G., & Ripper, D., 1976- Otway Basin (Tertiary). In : Geology of Victoria, Geol. Soc. Vic. Spec. Publ. No. 5, Douglas, J.G. & Ferguson, J.A. (Editors), Melbourne, p. 198 - 229.

Struckmeyer, H.I.M., 1986 - Organic petrology of the sedimentary sequence at Robertson No. 1. Unpublished report.

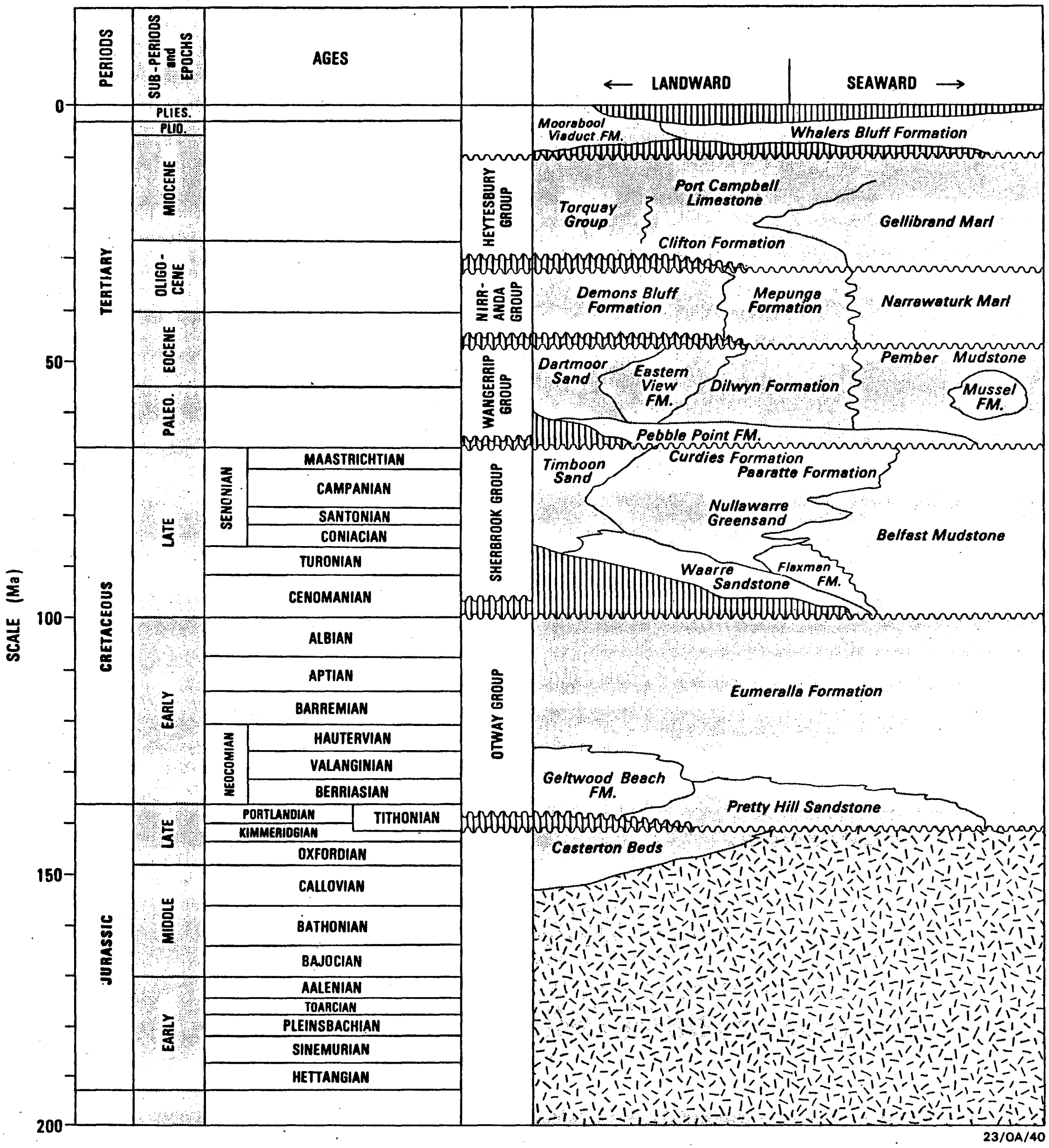


Figure 6 Generalized stratigraphy of the Otway Basin.

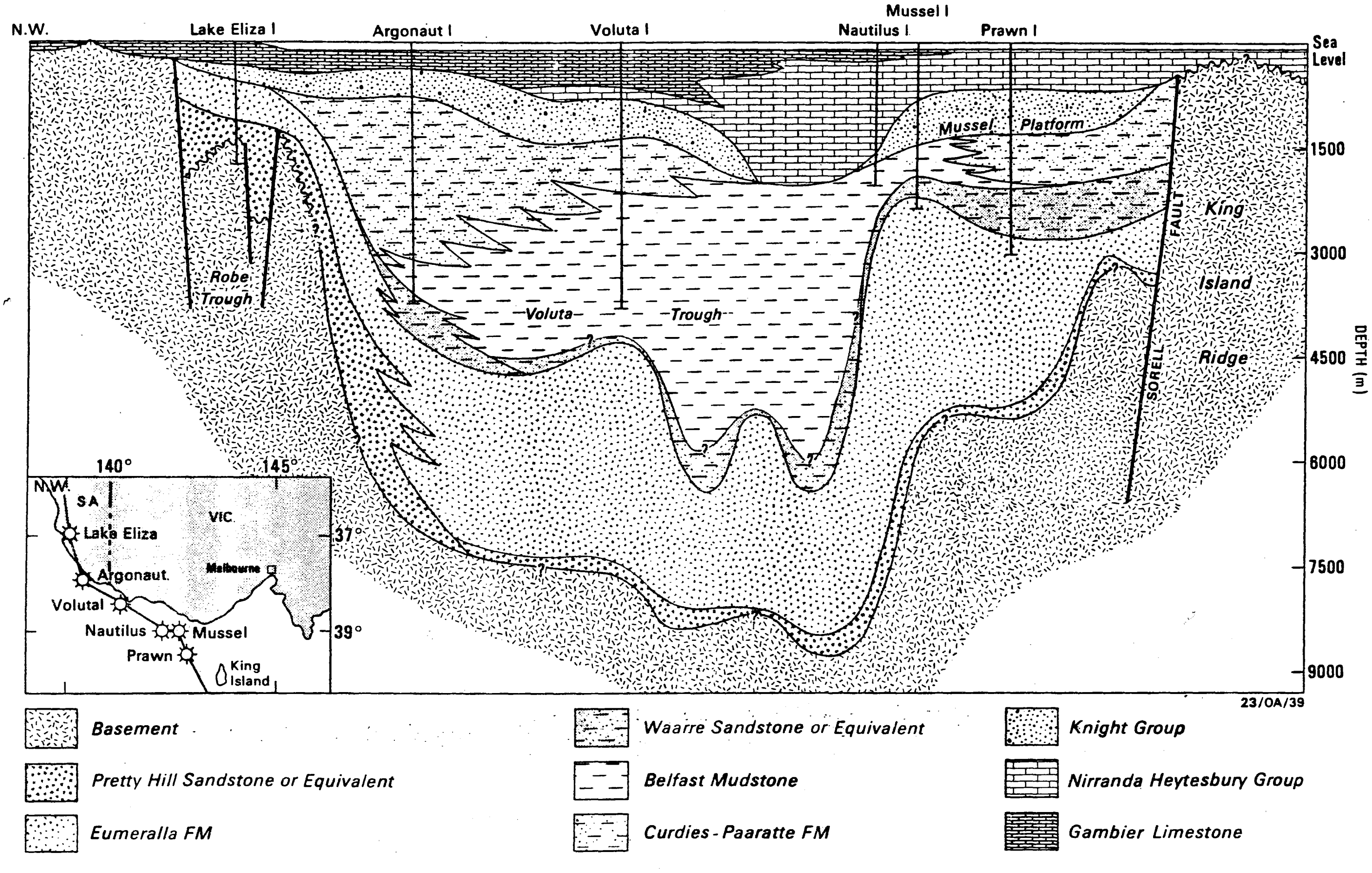


Figure 7 Generalized stratigraphic cross section of the Otway Basin.

Cretaceous Sedimentation Patterns in the Otway Basin

E.A. Felton, University of Wollongong

The Lower Cretaceous Otway Group (Fig. 6) is best known onshore, where, lacking unequivocal marine fossils, it has been ascribed a non marine origin. It is succeeded by the Upper Cretaceous Sherbrook Group, which was deposited largely in marine conditions, the result of eustatic sea-level rise and basin subsidence.

Sedimentary sequences in the Otway Group are variable in both time and space. In the northwest of the basin, fine quartzose braided stream-channel sandstone is succeeded abruptly by thick lithic alluvial plain deposits dominated by silty mudstone and siltstone with minor thin coals. Mature, coarse quartzose clastics at the top of the sequence interfinger with, and overlie, the lithic deposits on the northern margin of the basin. In the northeast, thin fine grained coaly alluvial plain deposits grade into stacked channel-fill deposits of medium grained lithic-quartz sandstone, deposited by southeasterly to southwesterly draining streams; along the basin margin, overlying coarse mature clastics complete the sequence. In both areas, the coarse clastics show southwesterly palaeocurrent trends.

The appearance of mature coarse clastics along the basin margin at the end of the Early Cretaceous, derived from the Palaeozoic rocks to the north, implies that the margin began to be uplifted relative to a depocentre to the south at this time. Much of the coarse clastic accumulation was removed by erosion as uplift continued and it was transported south to be incorporated in the Waarre Sandstone. Lower Cretaceous lithic facies provided the detritus for the Belfast Mudstone.

Otway Basin Source Rocks : Observation and Inference

D.M. McKirdy, AMDEL

The sedimentary sequence of the Otway Basin contains organic-rich siltstone, mudstone and thin coals ranging in age from Jurassic to Eocene. However, vitrinite reflectance data and thermal modelling studies indicate that, throughout most of the basin, Tertiary sediments lack adequate maturity to have been effective sources of commercial hydrocarbons. Potential source units include the non-marine Casterton Beds (Late Jurassic-Early Cretaceous); the fluviatile-lacustrine Pretty Hill Sandstone and Eumeralla Formation. (Early Cretaceous Otway Group); and the marine prodelta Belfast Mudstone (Late Cretaceous Sherbrook Group).

Cretaceous dispersed organic matter is common to abundant (0.5-10% by volume) and is dominated by inertinite (generally I > V > E). Locally (eg. in the Robe-Penola Trough and the western Voluta Trough) vitrinite-rich coals are present in the upper Pretty Hill Sandstone and lower Eumeralla Formation Rock-Eval pyrolysis demonstrates that these Otway Group coals and associated fine-grained clastics (E > V > I) contain mature Type II-III organic matter and are good potential sources of oil and gas. (S_1+S_2 = 10-150 kg hydrocarbons/tonne; hydrogen index = 150-375 mg S_2/g TOC). By contrast, the source potential of the Sherbrook Group is only poor to fair (S_1+S_2 = 0.5-5 kg hydrocarbons/tonne; hydrogen index = 20-150 mg S_2/g TOC) reflecting the presence of mostly gas-prone Type III-IV kerogen.

Shows of waxy paraffinic oil encountered in Lindon 1 (33° API, Pebble Point Formation) and Port Campbell 4 (38° API, Eumeralla Formation), and an economic accumulation of biodegraded gas-condensate at North Paaratte 1 (Waarre Sandstone), all probably originated in the Eumeralla Formation. At Caroline 1, production of volcanic CO_2 is accompanied by a small amount (ca. 1 bbl/yr) of aromatic condensate (15% API, 0.2% S) apparently stripped from poor quality inertinitic organic matter dispersed throughout the Waarre Sandstone reservoir.

The biological marker and isotope geochemistry of waxy paraffinic and paraffinic-naphthenic crude oils emanating from submarine seeps in the western Otway Basin can be used to predict the existence of widespread lacustrine source beds rich in the remains of the green alga Botryococcus sp. and freshwater dinoflagellates (McKirdy et al., 1986). Sediments containing oil-prone Type 1 kerogen could have accumulated in large meromictic lakes which formed in Late Jurassic-Early Cretaceous rift valleys associated with the continental breakup of Australia and Antarctica. No such source rocks have yet been found during exploration drilling, although oil shale comprising lamalginite (in part derived from dinoflagellates) and Botryococcus-related telalginite has recently been identified in the Casterton Beds at Robertson 1 (Struckmeyer, 1986).

References

McKirdy, D.M., Cox, R.E., Volkman, J.K. and Howell, V.J., 1986. Botryococcane in a new class of Australian non-marine crude oils. Nature, 320, 57-59.

Struckmeyer, H.I.M., 1986. Organic petrology of the sedimentary sequence at Robertson No. 1. Unpublished report.

Maturation and Subsidence History : Otway Basin

G.W. O'Brien, BMR

The Otway Basin can be loosely sub-divided into three structural provinces which have distinctly different subsidence and maturation histories. These are: 1) the Crayfish Platform; ii) The Mussel Platform; and iii) the Voluta Trough (Fig. 2). The varying subsidence rates have, in turn, strongly influenced the types of sedimentary facies developed within the basin.

SUBSIDENCE AND SEDIMENTATION

Early Cretaceous

Subsidence and sedimentation rates appear to have been moderately constant during the Early Cretaceous throughout the offshore Otway Basin. On the Crayfish Platform, sediment accumulation rates typically averaged between 150-250m/Ma during Otway Group deposition, though rates appear to have increased to 300-400 m/Ma during the late Aptian - early Albian in some wells. Accumulation rates on the Mussel Platform were probably also in the range 150-250m/Ma.

Late Cretaceous

Early Cretaceous Otway Group sedimentation was terminated by a mid-Cretaceous period of block faulting, differential uplift, and slight to considerable erosion. The basin became divided into a series of slowly subsiding "platforms" and rapidly subsiding "troughs".

The inshore part of the Crayfish Platform (near the Crayfish 1 and Neptune 1 well locations) was characterized by very shallow water, slow (10-20m/Ma) sedimentation throughout the Late Cretaceous. In contrast, sedimentation at the more basinal Morum 1 location occurred in deeper water and was much more rapid (200-300 m/Ma). The Mussel Platform was also characterised by relatively shallow water sedimentation throughout most of the Late Cretaceous. Sediment accumulation rates were typically in the range 150-200m/Ma, though rates appear to have been significantly slower at the more marginal Pecten 1 and Mussel 1 well locations.

In contrast to both the Crayfish and Mussel Platforms, the Voluta Trough subsided rapidly during the Late Cretaceous, and quickly became a site of deepwater sedimentation. While sandy, shallow water facies developed on the adjacent platforms, the Voluta Trough accumulated deep marine mudstones (Belfast Mudstone). Sedimentation rates in the Voluta Trough were typically in the range 250-350 m/Ma throughout most of the Late Cretaceous, through rates reached 400-600 m/Ma during Belfast Mudstone deposition.

MATURATION STUDIES

Crayfish Platform

The geohistory plot for Crayfish 1 (Fig. 8a) provides a model for the maturation history of the Crayfish Platform, located in the western part of the Otway Basin. The overall subsidence curve is characterised by rapid subsidence (with a brief period of uplift and erosion) from the Berriasian to the late Albian, followed by relatively slow subsidence to the present day. The basal part of the Pretty Hill Sandstone entered the oil window (Ro = 0.7) approximately 76 Ma B.P. (Campanian). Because of the gentle subsidence, only the basal 600 m of the Pretty Hill Sandstone is thermally mature, and even then, maturity is only slightly greater than Ro = 0.8. Algal source rocks within the underlying Casterton Beds could source the Pretty Hill Sandstone at the Crayfish 1 location. In contrast, the overlying Eumeralla Formation, which is both a potential source and seal to the Pretty Hill Sandstone, is thermally immature. The top of the present day oil window (Ro = 0.7) occurs at a depth of approximately 2.6 km. Since most of the structures in this area had developed by the end of the Early Cretaceous, suitable reservoirs could receive hydrocarbons generated from the Campanian to the present day.

Mussel Platform

The maturation history of the eastern Otway Basin is summarised by the geohistory plot of the Prawn 1 well (Fig. 8b). The subsidence history is characterised by a period of generally rapid subsidence throughout the Cretaceous, with a period of relative uplift and erosion spanning the Early Cretaceous-Late Cretaceous boundary. Subsidence slowed considerably from approximately 76 Ma B.P. to the present day.

The base of the Otway Group (Pretty Hill Sandstone equivalent level) probably entered the top of the oil window (Ro = 0.7) approximately 88 Ma B.P. (Coniacian), and has remained within the oil window to almost the present day (Fig. 8b). In contrast, the upper part of the Eumeralla Formation (of Albian age) has reached thermal maturity only in the last 10-15 Ma. The present day liquid hydrocarbon window at the Prawn 1 location occurs between 3.0 km and 4.9 km. The following conclusions can be drawn from the Prawn 1 geohistory analysis:

1. Hydrocarbon generation post-dates trap (structure) development in this area.
2. Pretty Hill Equivalent sands, if present in this area, are in the late mature, or condensate, window.
3. Waarre sands, though thermally immature, are underlain by marginally mature Eumeralla Formation. The Eumeralla Formation immediately underlying the Waarre has entered the oil window only in the last 10-15 Ma. The marginally mature nature of the uppermost Eumeralla indicates that substantial vertical migration from deeper, more mature Eumeralla source rocks, may have been necessary to fill traps in this region.

The Late Cretaceous Belfast Mudstone, and the overlying Paaratte-Curdies sands, are thermally immature. The Paaratte-Curdies sands are therefore probably non-prospective, unless vertical migration, from mature Eumeralla source rocks, has occurred.

Voluta Trough

The geohistory analysis of the Voluta 1 well, which is situated within the Voluta Trough in the central offshore Otway Basin, is presented in Fig. 8c. The base of the Otway Group entered the top of the oil window (Ro = 0.7) during the Albian, approximately 110 Ma B.P. Moderately rapid subsidence pushed this horizon out of the oil window (Ro greater than 1.3) by the early Cenomanian (96 Ma B.P.). Subsidence and sedimentation were very rapid during the early Late Cretaceous (Cenomanian), but slowed significantly from the Santonian (86 Ma B.P.); the Top Eumeralla-Base Waarre Sandstone Equivalent horizon entered the oil window during the Campanian, approximately 80 Ma B.P.

At about this time, the base of the Late Cretaceous Belfast Mudstone also entered the oil window. Stratigraphically higher levels within the Belfast Mudstone progressively entered the oil window from the Campanian to the Quaternary. Present day maturity for liquid hydrocarbon generation at Voluta 1 occurs at a depth of approximately 3.0 km, while the base of the oil window is at about 4.6 km.

The following conclusions can be drawn from Fig. 8c:

1. The basal Cretaceous Pretty Hill Sandstone (or equivalent) play, if present in this part of the basin, has probably been overmature since the early Cenomanian.
2. Basal Late Cretaceous Waarre (or equivalent) sands could have been charged with liquid hydrocarbons from the overlying Belfast Mudstone, and liquid and gaseous hydrocarbons from the underlying Eumeralla Formation, since the Campanian, about 80 Ma B.P.
3. The top of the Belfast Mudstone, and the Paaratte and Curdies sands, are thermally immature. It is therefore unlikely that the Paaratte or Curdies sands are prospective in this area, unless substantial vertical hydrocarbon migration has occurred. Vertical migration may be possible in the western Voluta Trough, where intense Late Cretaceous reactivation of rift faults has occurred.
4. The lower half (1.0 km) of the Belfast Mudstone, and the upper 600 m of the Eumeralla Formation are within the present day oil window. Suitable structures could thus be sourced in their present configurations.

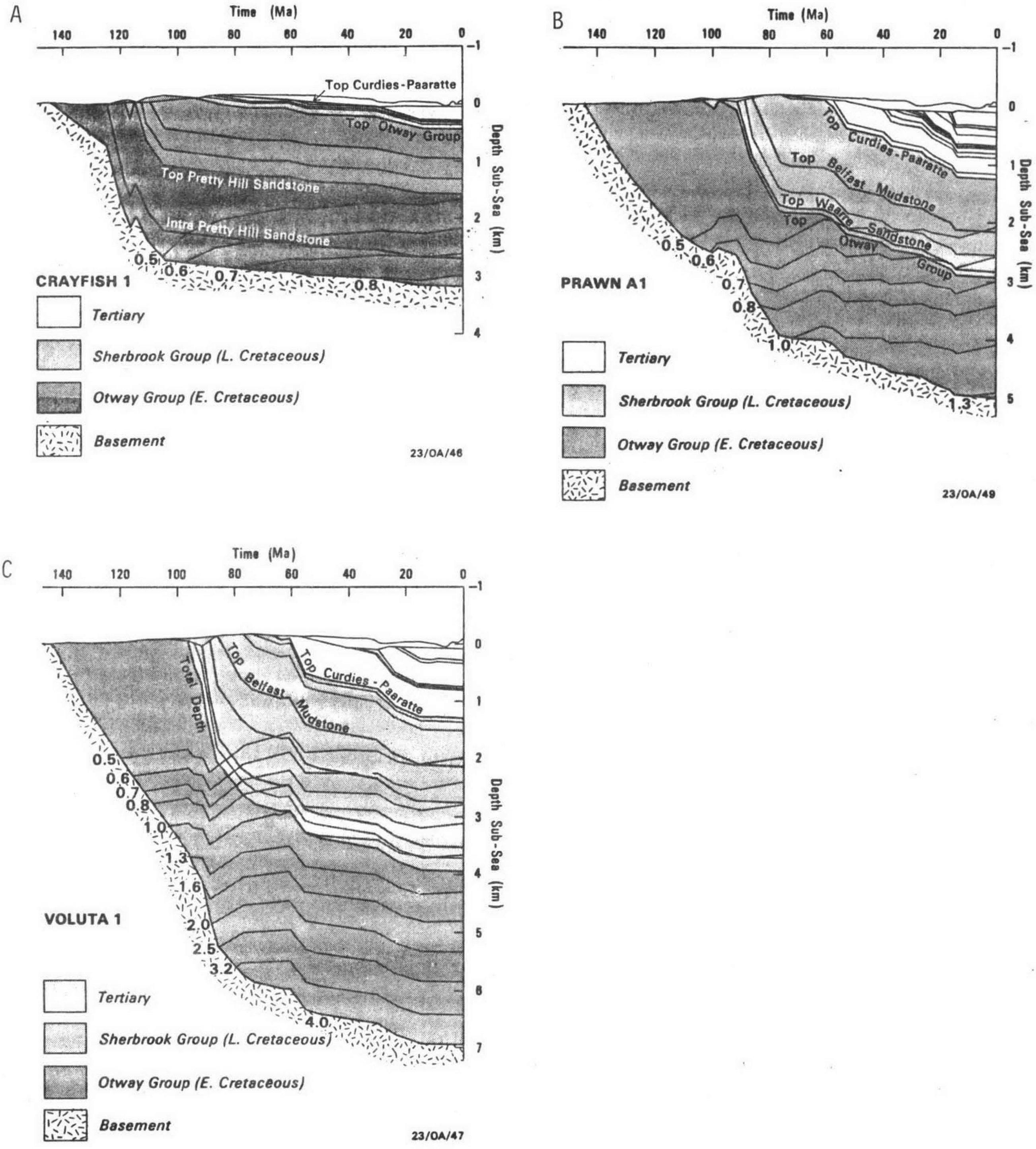


Figure 8 Geohistories of a) Crayfish 1, b) Prawn A1 and c) Voluta 1 wells showing iso-vitrinite reflectance contours.

Offshore Geochemical Prospecting for Hydrocarbons in the Otway Basin and West Tasmania

D.M. McKirdy, AMDEL & D.T. Heggie, BMR

Direct evidence of hydrocarbon generation at depth in offshore sedimentary basins can be obtained from light hydrocarbons (C_1-C_5) in the upper 1-3 metres of fine-grained sediment on the seafloor. During January-February 1987 the R/V Rig Seismic successfully completed the first basin-wide reconnaissance of an offshore area of Australia using the direct detection method. This geochemical survey was based on 43 sites located along 6 seismic profiles of the continental margin between southeastern South Australia and western Tasmania.

Eighty seven samples of wet sediment from gravity cores (up to 3.5 metres long) were canned, degassed and their C_1-C_5 hydrocarbons analysed by shipboard gas chromatography. Such hydrocarbons may be of biogenic and/or thermogenic origin. Several parameters were used to distinguish thermogenic gas: (1) $C_1/C_2+C_3 < 500$ (2) $C_2/C_{2:1} > 1$ (3) $C_3/C_{3:1} > 3$ (4) $\underline{i}\text{-}C_4/\underline{n}\text{-}C_4$ = 0.2-0.5. Hydrocarbon concentrations were generally in the range 0.1-2 μl C_1-C_4/l of wet sediment. Major anomalies (up to 490 μl/l) were identified at a total of 12 localities (4 off South Australia, 6 off Victoria, 2 off Tasmania). These sites (Figs. 9 & 10) appear to be active gas seeps in water depths of 750-2500 metres. Most of the seeps lie above major faults, some of which intersect the seafloor. These faults are fracture zones which appear to be acting as conduits for petroleum-related gas migrating upwards from thermally mature source rocks of Cretaceous age.

Early Results of 1987 "Rig Seismic" Geoscience Sampling Cruise

N.F. Exon & C.S. Lee, BMR

BMR's R.V. "Rig Seismic" in February completed a one month sampling cruise in the offshore Otway Basin of South Australia dn Victoria, and along the west Tasmanian margin (Exon, Lee and others, 1987). Participants came from BMR, AMDEL (largely funded by SADME) and Flinders University. This work continued the research program begun in 1985 with three cruises, one by "Rig Seismic" (Williamson, this volume) and two by the West German R.V. "Sonne" (Hinz et al., 1987). The earlier cruises provided 4700 km of multichannel seismic data and 40 geological samples. The overall aim of this study is to better define the geology of the sedimentary basins of this part of the Australian margin, and especially to provide new information relevant to petroleum exploration. The field techniques were simple underway geophysics, geological and geochemical sampling and measurement of the earth's heatflow. Altogether,there were 130 stations :- 23 dredge, 54 core, 33 grab and 20 heatflow, in water depth varying from 50 to 5000 m, but concentrated on the upper continental slope (Figs 9 & 10).

The major analytical technique applied on board was headspace gas analysis of selected intervals from virtually all the cores and many of the grab samples (McKirdy & Heggie, this volume). This work showed that thermogenic hydrocarbons were widespread, with background readings of 1-2 ppm. Particularly anomalous readings came from twelve cores : 4 western Otway, 6 eastern Otway, two western Tasmania. In general, the highest readings were associated with faults extending to, or nearly to, the surface, in areas where Tertiary cover was not thick. It appears that mature hydrocarbon source rocks are present almost everywhere on the upper continental slope. Dredge and corer recovered pre Quaternary rocks and sediments at 22 stations :- Palaeozoic volcanics and metasediments, Otway Group sandstones, Cretaceous mudstones, Early Tertiary siltstones and peat, and Late Tertiary carbonates. These results, in conjunction with the earlier ones, show that continental basement and Early and Late Cretaceous detrital sedimentary rocks crop out on the lowermost continental slope in water 4000-5000 m deep. The mid-slope is characterized by Early Tertiary detrital sediments, and the upper slope by Late Tertiary carbonates. All samples were taken along seismic profiles, and can be added to data from outcrop and shelf wells to help refine knowledge of the regional geology.

Quaternary sediments were obtained in most cores and grab samples, again along seismic profiles. Grab sampling has established the nature of the outer shelf sands, largely bryozoal, which provide turbidites to the Quaternary sediments on the continental slope, otherwise pelagic and hemipelagic in nature. All these samples will help to establish, for the first time, a detailed model of sedimentiaton on the southern margin, which can be extended back well into the Tertiary. Temperature gradient measurements at 20 stations, made by a heatflow probe penetrating the tope 3 metres of sediment, in conjunction with thermal conductivity measurements on sediment cores, have enabled heatflow calculations to be made. These measurements on BMR seismic line 48/043 south of Argonaut No.1 well, and "Sonne" seismic line S036-46 west of Cape Sorell No. 1 well, vary from 25 to 70mW/m^2, values consistent with the accepted breakup history of the margin, and suggest that the zone of thermal maturation of hydrocarbons generally lies at depths of 2-4 km.

Most lithotypes found beneath the shelf are present on the continental margin. The depths at which sediments originally deposited near sea level were dredged and cored are : Early Cretaceous sandstone at 4000-4300 m, Cretaceous mudstone at 3900-4500 m, and Eocene at 1800-4000 m. This compares with depths in shelf wells of Early Cretaceous 500-3200 m, Late Cretaceous 350-4500 m, and Eocene 300-1700 m. Maximum depths are hence comparable in the Cretaceous, where there is thick overburden on the shelf, but Eocene sediments lie much deeper on the slope than anywhere on the shelf. Additional subsidence on the Eocene on the outer margin averages 1500-2000 m.

A full interpretation of new data, and its integration with the pre-existing seismic data, will enable a more reliable outline of the margin's stratigraphy, structure and geological history to be established, and will aid in regional assessment of petroleum potential.

References

Exon, N.F., Lee, C.S. and shipboard party, 1987: Rig Seismic Research Cruise : Otway Basin and west Tasmania sampling. preliminary Postcruise Report. BMR Record.

Hinz, K., Willcox, J.B., Whiticar, M., Kudrass, H.R., Exon, N.F., & Feary, D.A., 1987 : The West Tasmanian margin : an underrated petroleum province? Second Southeastern Australia Oil Explortion Symposium. PESA Journal.

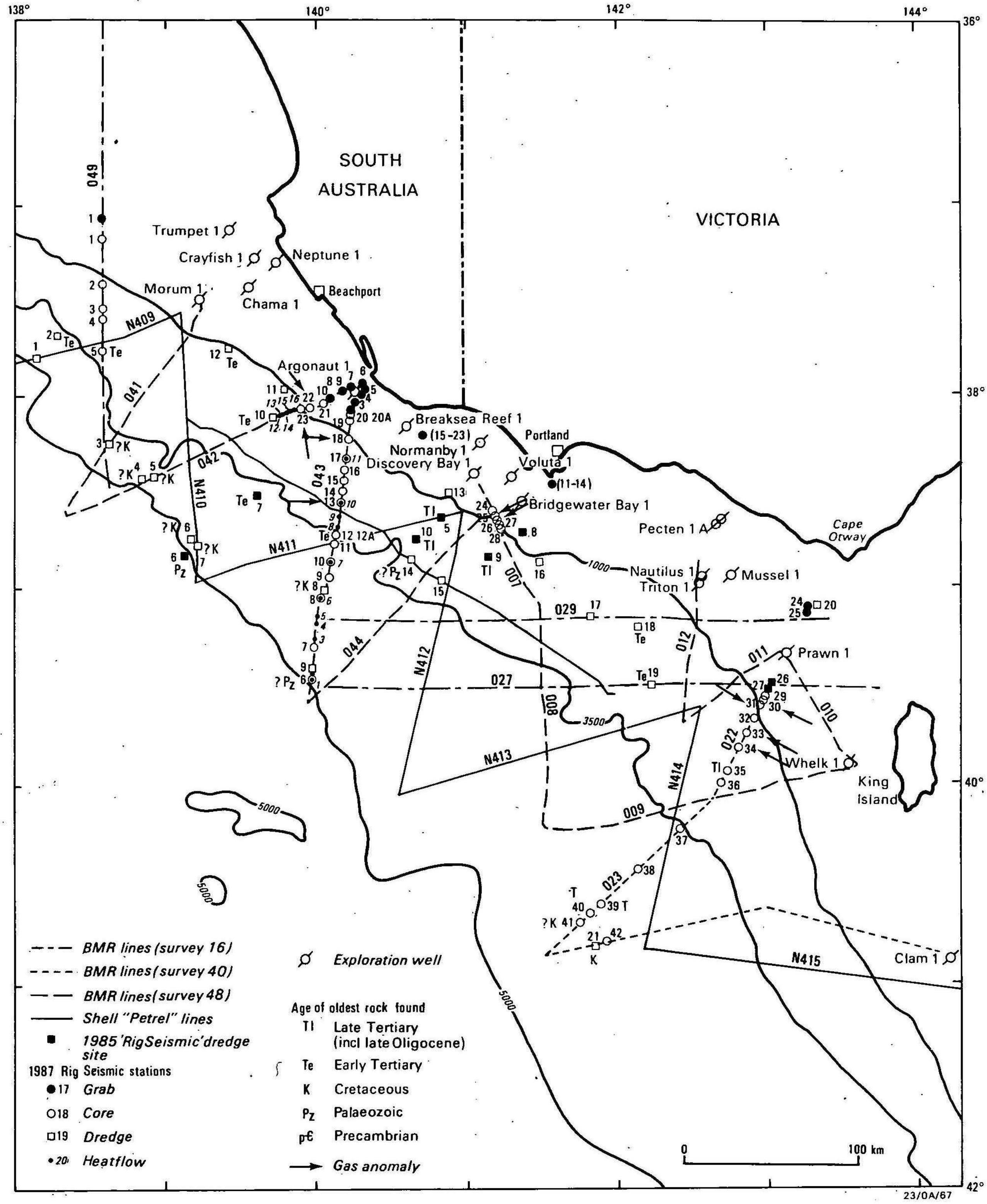


Figure 9 Sampling and heatflow stations for 1985 and 1987 "Rig Seismic" Otway, Basin cruises, showing petroleum exploration wells, key deepwater seismic lines, and major gas anomalies in surface sediment.

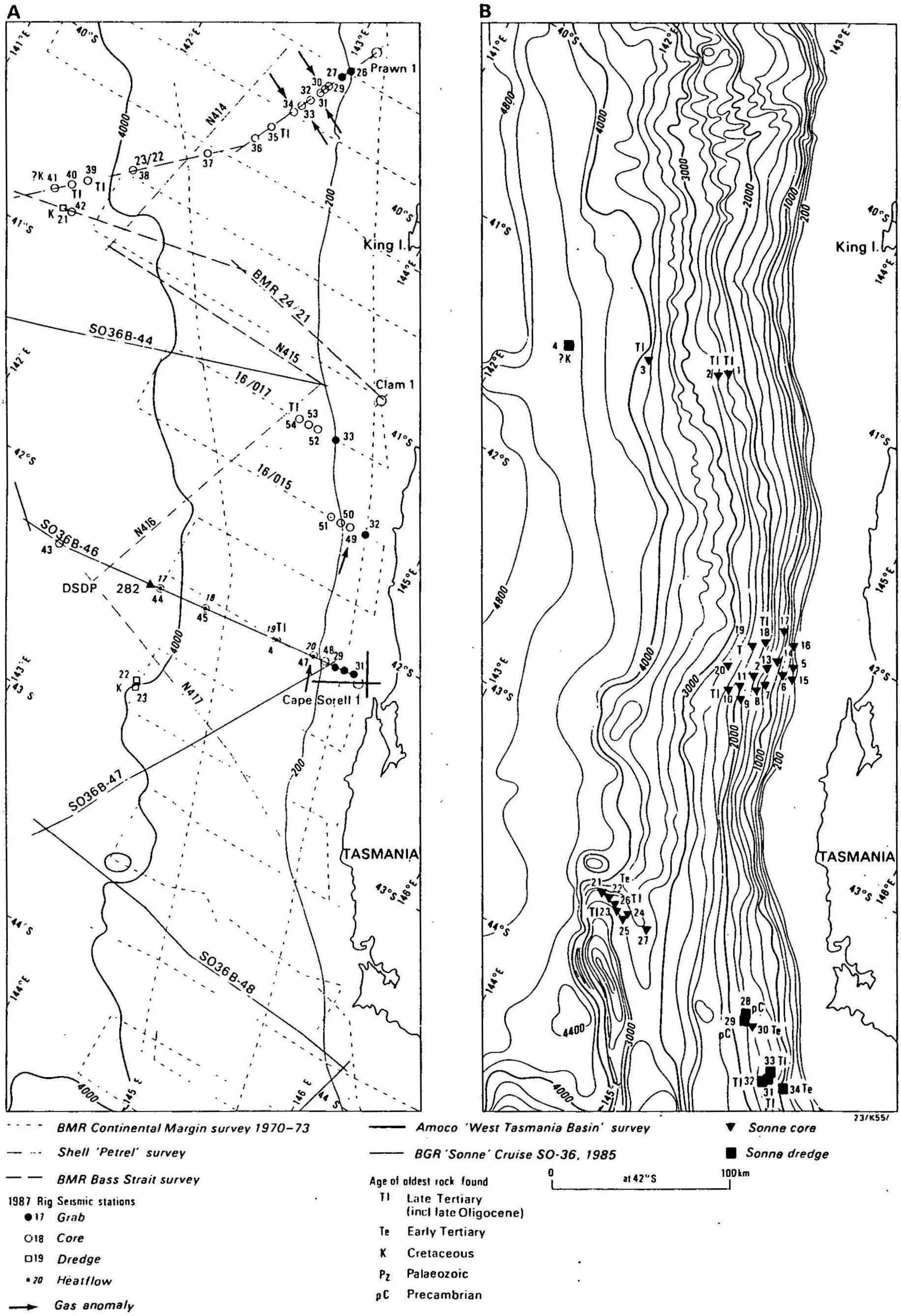


Figure 10 Sampling and heatflow stations for 1985 "Sonne" and 1987 Rig "Seismic" west Tasmanian cruises, showing petroleum exploration wells, bathymetry, key deepwater seismic lines, and major gas anomalies in surface sediments.

Victorian Otway Basin : Regional Setting

M. Megallaa, Petroleum Division, Victorian Dept.of Industry, Technology & Resources.

The passive continental margin Otway Basin extends from the Mornington Peninsula in Victoria to Cape Jaffa in South Australia. In Victoria the basin covers an area of about 18,500 km² onshore and 26,000 km² offshore.

Denham and Brown (1974) divided the offshore area west of the Sorell Fault (Fig.11) into the gently dipping Mussel Platform and the Voluta Trough. Wopfner and Douglas (1971) divided the onshore area into a number of basins or embayments separated by structural highs or ridges. These elements from west to east are:

> The Gambier Embayment - Dartmoor Ridge (including the Merino uplift) - Tyrendarra Embayment - Warrnambool High - Port Campbell Embayment - Otway Ranges High - and the Torquay Sub-basin and Port Phillip Embayment.

Recent work (Megallaa, 1985) showed the Tertiary Tyrendarra and Port Campbell Embayments as well as the Ardonachie and Portland Troughs, previously mapped at Late Cretaceous and Tertiary levels (McNicol, 1984), to be basement features. The Elingamite and Colac Troughs and a number of un-named troughs (Fig. 13) were also the result of basement collapse. Offshore, basement elements have a predominantly NW - SE trend. The Portland Trough extends to the upper slope to about the 2000m isobath. The trough reaches a depth of 10,000 below sea level and the thickness of infilling Cretaceous and Tertiary sediments may be up to 8000m. The Portland Trough is almost 250 km long and its axial plane dips southwest. The Voluta Trough is a graben which bifurcates from the Portland Trough. The faults bounding this graben have more than 2000m displacement in places, with the south-bounding fault being a hinge extending into South Australia. The Voluta High is a basement ridge separating the Voluta and Portland Troughs and its southern end plunges southeasterly. The Otway Margin Trough is separated from the Portland Trough by the Otway Margin Basement High. The Otway Margin Trough, a narrow northwesterly trending depression parallel to the 3000m isobath, reaches a depth of 10,000m below sea level and is believed to delineate the southern margin of the Otway Basin.

The structural history of the basin is complex because of the action of several successive tectonic orogenies. This complexity does not always allow the recognition of the various elements associated with any one particular tectonic episode. The Early to Middle Cretaceous Otway Group sequence is uplifted and broadly folded to form the Merino uplift, the Otway Ranges High (which extends offshore) and the Cape Otway-King Island and King Island-Mornington Highs. Recent mapping of the top of the Otway Group (Megallaa, 1985) shows that in the Mussel Platform area the horizon has a prominent angular unconformity. The horizon depth is less than 3000m below sea level and the Otway Group sediments thin out to possibly 1000m. In the Portland and Voluta Troughs the top Otway Group seismic horizon attains greater depths (7000m or more) through a series of down-to-basin faults with throws in excess of 1000m in places. In these troughs the Otway Group sediment thickness is between 3000 to 5000m. The horizon also shows an abundance of en-echelon northwest trending faults. Northerly tilted fault blocks with generally down-to-the-south displacement are demonstrated on the seismic sections. This pre-breakup block faulting was associated with Middle Cretaceous rifting.

The Sherbrook Group sediments of Late Cretaceous age were deposited over the faulted and eroded Otway Group but in the deeper parts of the basin (continental margin area) deposition may have been continuous throughout the Cretaceous. The top Sherbrook Group seismic horizon is an extensive unconformity and separates the predominantly non-marine Sherbrook Group sediments from the overlying predominantly marine sediments. Deposition within the Torquay sub-basin in the Late Cretaceous is restricted to a thin sandy unit (Nerita No.1) indicating a delay in its subsidence. The northwesterly trending faults seen at the top of the Otway Group horizon are also seen in the Sherbrook Group horizon. Also, seismic data indicate that faulting may have been syn-sedimentary. The isopach map for the Sherbrook Group shows a thickness of 6000m along a depositional axis located in the Upper Slope. South of this axis the Late Cretaceous sequence thins rapidly and is entirely missing along a large portion of the continental/oceanic boundary.

The Tertiary prograding marginal marine Wangerrip Group was deposited disconformably over the Sherbrook Group and by the end of the Wangerrip Group time the Otway Basin was a shelf across which carbonate sequences were developed. In the lower shelf area, in western Victoria, the Tertiary carbonate sequence exhibits antithetic block-faults which trend parallel to the shelf break. During the Eocene rising sea level and basin subsidence led to the development of the Torquay sub-basin and Port Phillip Embayment. On the continental slope, however, there is no direct evidence of Eocene sediments. A major regional Oligocene unconformity was interpreted by Branson (in prep.) to extend down the base of the continental slope and truncate older Tertiary successions. The Tertiary section reaches a maximum thickness of 2000m along an axis which runs parallel to and west of the Portland Trough axis. Beyond the 2000m isobath the Tertiary thickness diminishes to less than 250m. The coincidence of the axis of maximum Tertiary deposition with the Portland Trough axis is mainly due to its filling with sediments and probably the orientation of the pre-present day shelf edge in that direction.

References

Branson, J.C., in prep. (in R.C. Glenie et al.) - Otway Basin Petroleum Exploration, Spec. Publ. Victoria Dept. Industry Technology and Resources, South Australia Dept of Mines & Energy. BMR & Tasm. Dept. of Mines.

Denham, J.I., & BROWN, B.R., 1976 - A new look at the Otway Basin, APEA Journal: 16(1), 91-98.

McNicol, M.D., 1984 - The structural development of the Otway Basin, in : ASEG Second Australian Petroleum Geophysics Symposium, volume of papers (Unpublished).

Megallaa, M.N., 1985 - Tectonic development of Victoria's Otway Basin - A seismic interpretation. Petroleum Exploration Society of Australia Second South Eastern Australia Oil Exploration Symposium, (in press).

Wopfner, H. & Douglas, J.G., (eds), 1971 - The Otway Basin of South Eastern Australia. Spec. Bull., Geol. Surveys of Vic. and S. Aust. pp 464

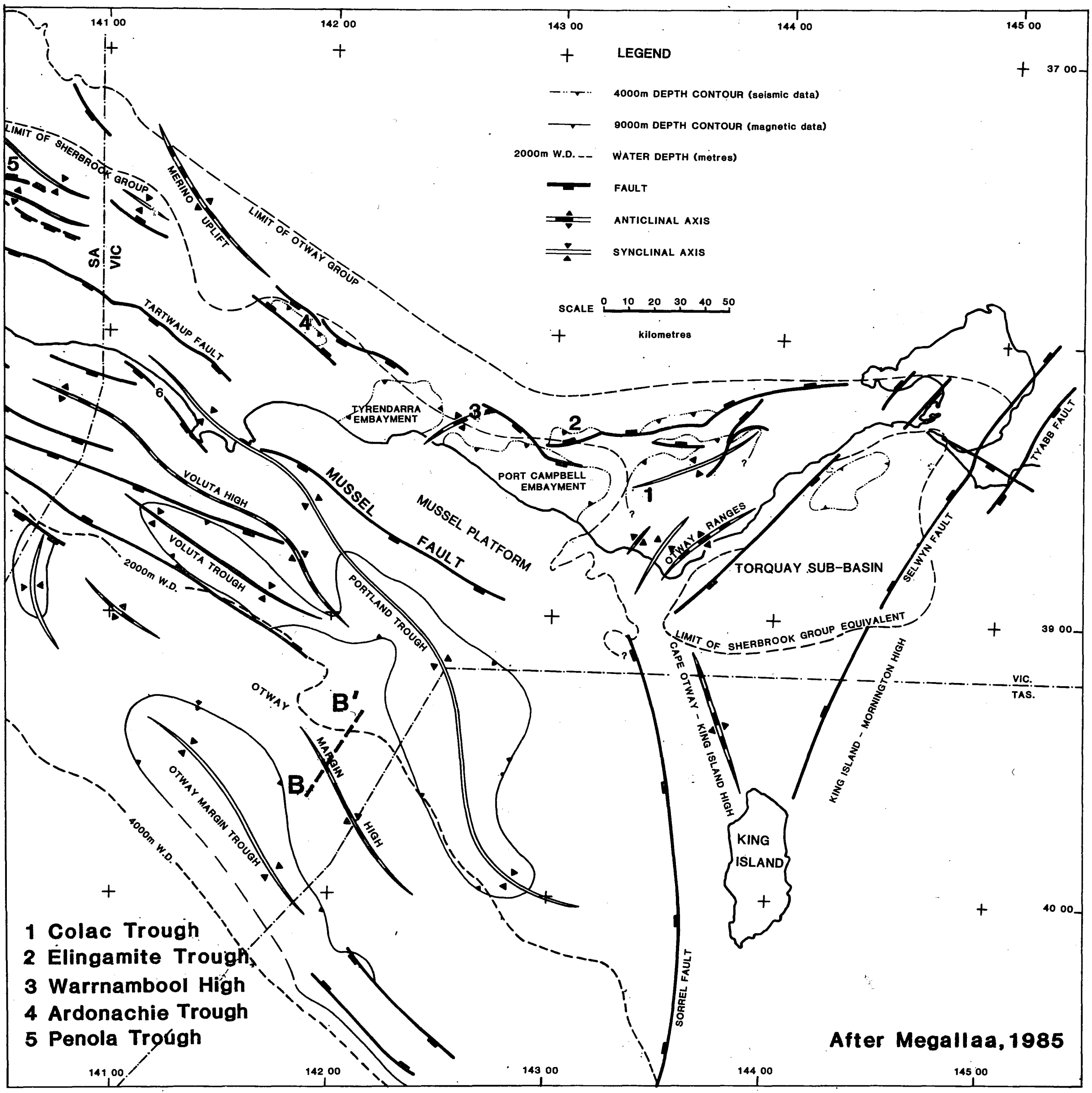


Figure 11 Structural elements of the Otway Basin

The Structural Development of the Victorian Onshore Otway Basin

M.D. McNicol, Beach Petroleum N.L.

Seismic surveys in the onshore Victorian Otway Basin and the subsequent integration of well control into the basin show the basin is rich in seismic reflections. The basin has had a very active structural history and there are abundant examples of the initiation of a tectonic style being followed by reactivation of this style through the basin's history. As might be expected the basin exhibits quite clear depositional cycles.

The basin began in the form of a geosyncline in the Upper Jurassic followed by thick Lower Cretaceous sediments being deposited under non-marine conditions. A series of rifts or grabens were present, one of which was the Ardonachie Trough. The sediments consisted of first cycle deposits and lithics or rock fragments which had little opportunity for sorting. Deposition was rapid. There was active volcanism, the Basal Volcanics consisting both of primary volcanics and of volcanogenic sediment.

Deposition of the Pretty Hill Sandstone followed. This unit appears as wedges of sediment on the flanks of major basement highs but its areal distribution has proved difficult to predict as most of the well control is located on tops of structures. Often the assumed lateral time equivalent Geltwood Beach Formation is present and it lacks porosity and permeability where intersected. The Lower Cretaceous Eumeralla Formation overlies the Geltwood Beach Formation unconformably. Intense folding, then peneplanation, occurred at the close of the Lower Cretaceous. Seismic sections confirm the top Lower Cretaceous unconformity to be of basin-wide significance.

Deposition of the Upper Cretaceous Sherbrook Group commenced. During the early Upper Cretaceous, but after the deposition of the prospective Waarre Formation, a right lateral couple was gradually applied which appears to have had maximum effect in the Port Campbell Embayment. Compressional forces due to this couple resulted in a series of north-north-east-trending anticlines such as the Port Campbell High where the North Paaratte, Wallaby Creek and Grumby gas fields are located.

The sea encroached and the marine Belfast Mudstone was deposited. In a style similar to the Atlantic margin, pull apart tectonics were acting during Belfast Mudstone times and continued during the deposition of the Paaratte Formation. A series of down-to-the-continental-margin faults, such as the Tawtwaup, Boggy Creek and Timboon Faults, are seen which could in part be reactivated faults of the initial pull-apart. This was a period of significant continental accretion.

The Tertiary began with the deposition of the conglomeratic Pebble Point Formation which rests on a major unconformity. It is important to recognize the presence of laterite in this formation. At Curdie 1 in the Port Campbell Embayment an oil show occurred in very porous and permeable sands directly beneath an 11m lateritic cap. The laterite occurs in situ which is why an unconformity is recognised at the top of the Pebble Point Formation. This unconformity is confirmed by seismic data.

In the Tyrendarra Embayment the Pebble Point Formation can be up to 100m thick and lateritic materials are present throughout. Here the laterite occurred at the Pebble Point's provenance on the edge of the basin and was transported into the basin along with other sediment. There is some evidence that additional lateritization occurred in situ. The oil recovery at Lindon 1 was at the top of the Pebble Point Formation and the presence of laterite had resulted in poor reservoir quality. It is only below in the Upper Cretaceous Timboon Sands that good reservoir quality sands occur.

The break up of Australia and Antarctica gained pace. Presumably this occurred preferentially on one of the rifts dating back to the Upper Jurassic.

The overlying Dilwyn Formation is seen as a prograding delta building out basinwards over successive down-to-the-basin fault-blocks. The presence of the Older Volcanics at the top of the Dilwyn Formation is probably related to this faulting. Faults responsible for Pebble Point structure often terminate in the Dilwyn Formation.

At the close of Dilwyn Formation time a major south-west-plunging anticline was developing in the Tyrendarra Embayment. The Stokes River Anticline, located just to the north of Dartmoor, is mapped in outcrop and with the use of shallow stratigraphic drilling. Within the core of the anticline the Otway Group, the Pebble Point Formation and Dilwyn Formation are seen at outcrop in the bed of the Stokes River.

The Nirranda Group followed and is overlain by the Heytesbury Group, the deposition of marl generally giving way to limestone, with open marine conditions prevailing.

A further period of right lateral wrenching occurred during the Neogene which resulted in a series of low amplitude folds. This coincides with the New Volcanics which are a series of basalt sheets covering much of Western Victoria.

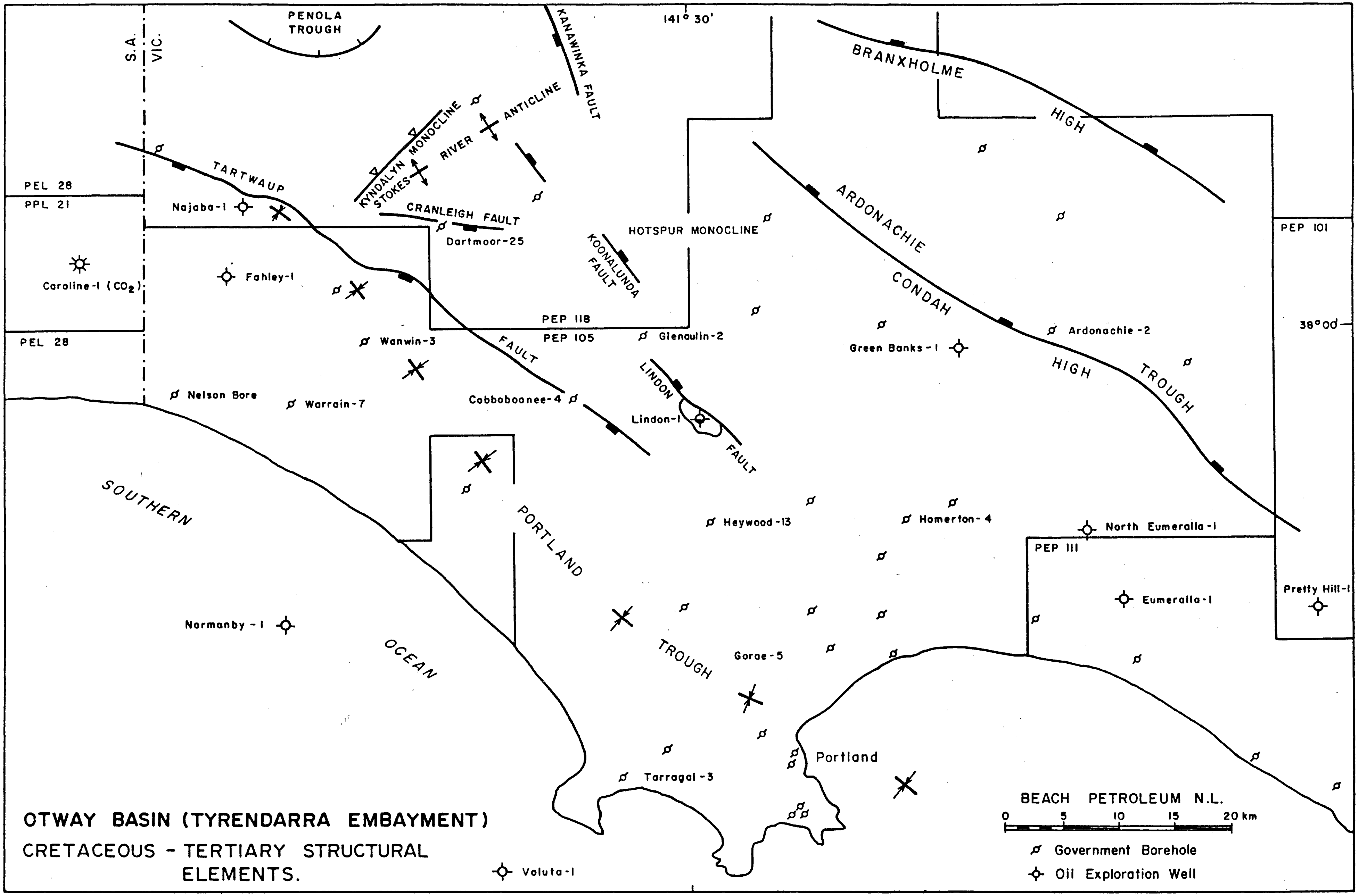
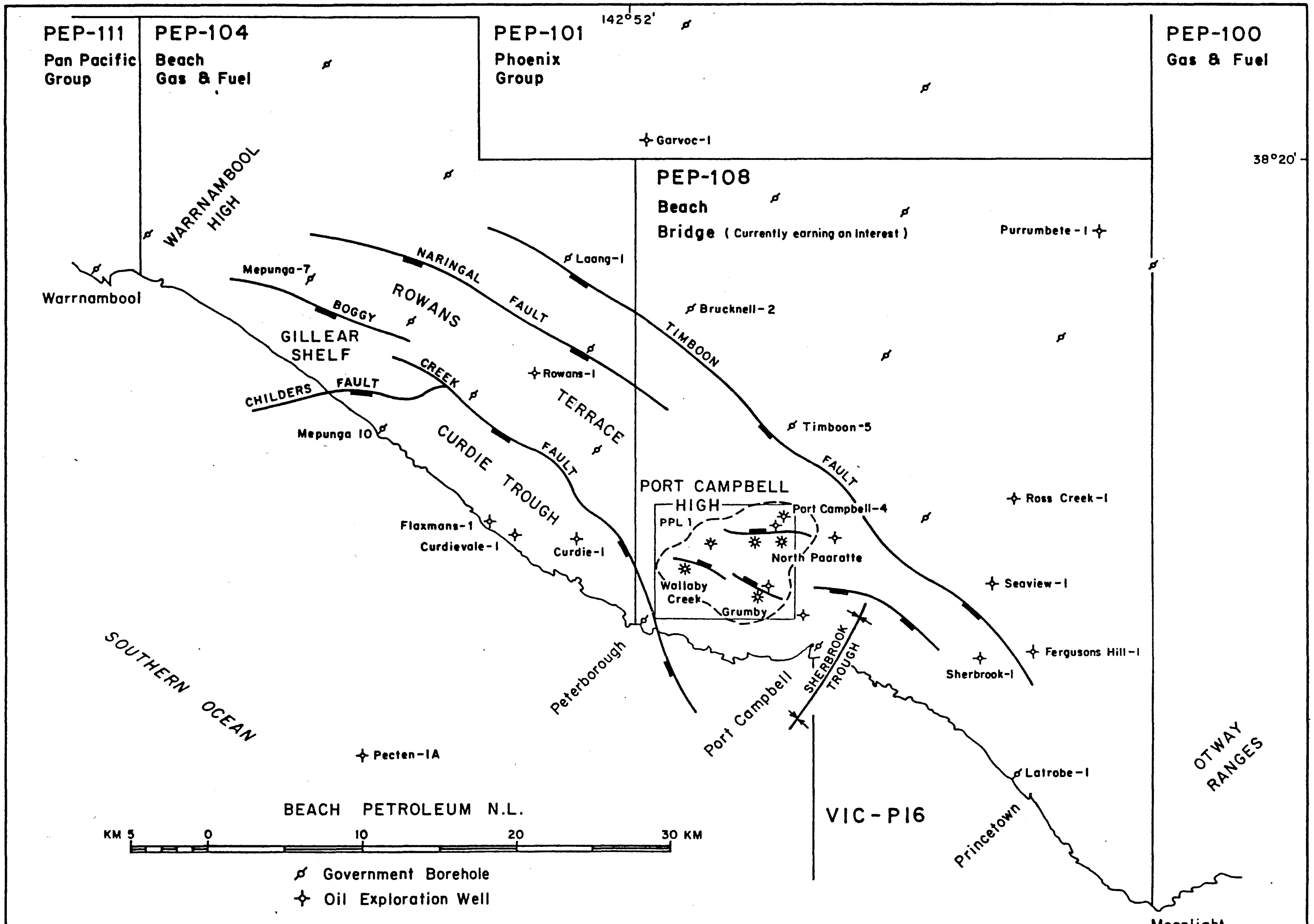

OTWAY BASIN (TYRENDARRA EMBAYMENT)
CRETACEOUS - TERTIARY STRUCTURAL ELEMENTS.
BEACH PETROLEUM N.L.
0 5 10 15 20 km
Government Borehole
Oil Exploration Well
PENOLA TROUGH
S.A.
VIC.
KANAWINKA FAULT
141° 30'
BRANXHOLME HIGH
KYNDALYN MONOCLINE
STOKES RIVER ANTICLINE
TARTWAUP FAULT
PEL 28
PPL 21
Najaba-1
CRANLEIGH FAULT
Dartmoor-25
HOTSPUR MONOCLINE
KOONALUNDA FAULT
ARDONACHIE CONDAH HIGH TROUGH
PEP 101
Caroline-1 (CO_2)
Fahley-1
PEP 118
PEP 105
Glenaulin-2
Ardonachie-2
38°00'
PEL 28
Wanwin-3
Green Banks-1
LINDON FAULT
Nelson Bore
Warrain-7
Cobboboonee-4
Lindon-1
SOUTHERN OCEAN
PORTLAND TROUGH
Heywood-13
Homerton-4
North Eumeralla-1
PEP 111
Pretty Hill-1
Eumeralla-1
Normanby-1
Gorae-5
Portland
Tarragal-3
Voluta-1

Figure 12



OTWAY BASIN (PORT CAMPBELL EMBAYMENT) MID CRETACEOUS STRUCTURAL ELEMENTS

Figure 13

Otway Basin : South Australia

J.G.G. Morton & C.D. Cockshell, SADME

In 1984-86 SADME undertook a review of the Otway Basin in South Australia. All known company data were compiled and Gamma Ray and Sonic Logs for all wells were digitized. Recent high quality seismic data were also included to provide an up-to-date regional structural interpretation of the major horizons, and digitizing of well logs clarified stratigraphic relationships and enabled a new stratigraphic scheme for the Otway Basin in South Australia to be developed (Fig. 14).

The Earliest Cretaceous sediments (comprising the Otway Group) were deposited in the early phase of rifting in the east-west orientated Robe-Penola Trough, which is probably an aborted rift. Otway Group sediments were also deposited to the south in the main rift valley, but little is known of the Otway Group in this area due to the thick overlying Sherbrook Group sediments restricting drilling depths. The sequence consists of the lower Pretty Hill Sandstone (braided fluvial) and the upper Eumeralla Formation (fluvial - lacustrine). Palaeocurrent and isopach data indicate a probable broad east to west transport direction.

The thick Late Cretaceous post-breakup sequence, (the Sherbrook Group), contrasts in depositional style to the underlying Otway Group. The sequence consists of Flaxman, Belfast, Paaratte and Timboon Formations deposited in a large, southerly prograding delta complex, comparable in size to the Niger Delta. Areas to the north that were not underlain by thinned continental crust or new oceanic basement, and hence underwent much less subsidence, have a sandy condensed Sherbrook Group sequence that is at least an order of magnitude thinner and is probably mostly of fluvial origin. Evidence of fully marine conditions such as the Nullawarre Greensand and marine molluscs found further east, are absent, suggesting more restricted conditions in the South Australian portion of the basin.

Although the Basin in South Australia has almost certainly generated oil (as evidenced by the numerous reported occurrences of coastal bitumen, including a recent stranding of approximately 1000+ tonnes of bitumen on Kangaroo Island), the lack of successful drilling so far is probably due to poor seismic and stratigraphic data, and future success will rely heavily on high quality integrated structural - stratigraphic techniques.

Since 1985, 4848 kms (including 2068 kms offshore) of high quality seismic data has been acquired by the various operators of the PEL's (Fig. 15). Further seismic and the drilling of at least 4 and up to 6 exploration wells are planned during 1987.

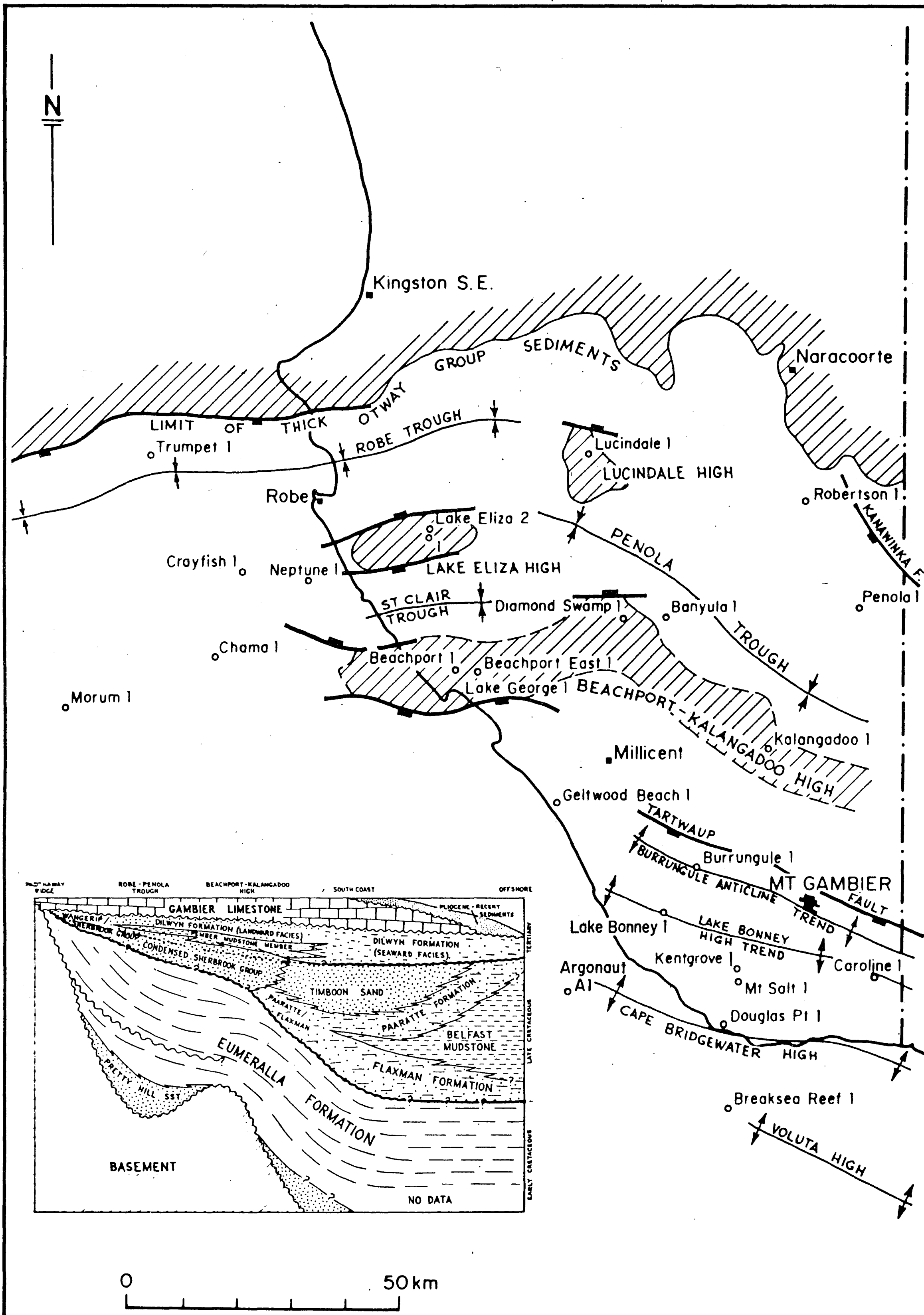
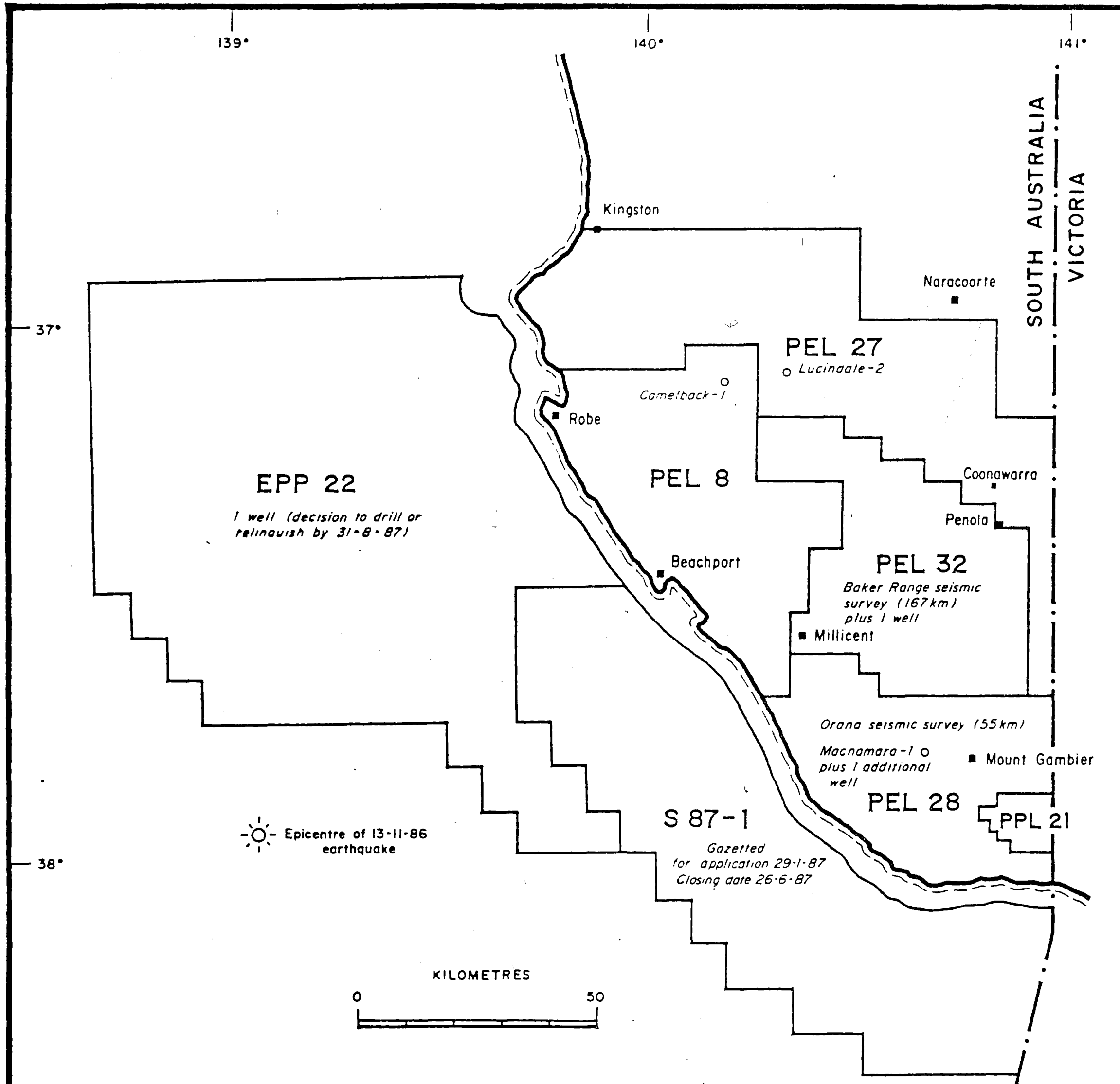


Figure 14
Otway Basin South Australia, stratigraphy and major structural elements



OTWAY BASIN
1987 PETROLEUM EXPLORATION PROGRAM

HOLDERS OF PETROLEUM TENEMENTS
(as at 1/1/87)

PEL 8 — Hartogen Energy Limited
Beach Petroleum N.L.
Western Mining Corporation Limited
Poseidon Oil Pty. Ltd.
Alliance Oil Development Australia N.L.
Alliance Minerals Australia N.L.
Chevron Overseas Petroleum Ltd.
(Expiry date 30/4/89)

PEL 27 — Hartogen Energy Limited
Offshore Oil N.L.
Cluff Oil (Pacific) Limited
Permian Petroleum Corporation Limited
Poseidon Oil Proprietary Limited
(Renewal date 30/7/89)

PEL 28 — Beach Petroleum N.L.
Home Energy Company Limited
Gas & Fuel Exploration No Liability
Mount Isa Mines Limited
Poseidon Oil Pty. Ltd.
(Renewal date 13/11/89)

PEL 32 — Ultramar Australia Inc.
Muswellbrook Petroleum Pty. Limited
Minora Resources N.L.
United Petroleum Reserves N.L.
Ocean Resources N.L.
(Renewal date 18/2/90)

PPL 21 — Liquid Air Australia Limited
(Renewal date 30/4/2000)

EPP 22 — Chevron Overseas Petroleum Limited
(Renewal date 6/1/91)

Figure 15

West Tasmanian Marginal Basins

P.W. Baillie, Tasmanian Mines Department

The continental margin of western Tasmania (including King Island) consists of the southeastern sector of the Otway Basin and the northern sector of the Cape Sorell Basin (Fig. 16). The basins are part of a continental margin which formed as a result of the separation of the Australian and Antarctic Plates during the Mesozoic breakup of eastern Gondwanaland and contain Late Mesozoic to Recent sedimentary infill up to eight kilometres thick (Hinz et al., in press; Willcox et al., 1985).

Whereas the Otway Basin is both rift and wrench related, the Cape Sorell Basin is predominantly wrench related (Willcox, Exon & Branson, 1985). The basins are separated by a basement high, which is probably a continuation of the King Island-Mornington Ridge that began to form in the Miocene and separated the Torquay and Bass Basins.

Otway Basin

The main part of the Otway Basin is onshore and offshore in Victoria and South Australia. The southern portion of the basin is in Tasmanian waters west of King Island and trends northwesterly, its southwest margin being the base of the continental rise at about 4.5km water depth. To the northeast it is separated from the Bass Basin by the King Island-Mornington Ridge.

The Tasmanian sector of the Otway Basin is part of the Voluta Trough and the most important well for correlative purposes in Prawn A1 (Fig. 16) which was drilled by Esso/Hematite in 1968 and penetrated the following sequence (all depths below mean sea level):

Depth (m)	Description
81 - 725	Carbonate sequence; marl, limestone, calcareous sandstone (Miocene - Oligocene Heytesbury Group).
725 - 766	Marl (Late Eocene Nirranda Group).
766 - 1238	Dominantly sand sequence (Eocene - Paleocene Wangerrip Group).

1238 - 2917	Interbedded sandstone, mudstone, calcareous sandstone and conglomerate (Late Cretaceous Sherbrook Group).
2917 - 3166	Lithic sandstone sequence (Early Cretaceous Otway Group).

Otway Group sediments, similar to equivalent rocks in the Bass and Gippsland Basins, consist of fining-upward sequences of dominantly grey coloured volcaniclastic sandstone with subordinate mudstone. Subsidence during Otway Group deposition was very rapid, typical of rift valley fluviatile sedimentation. Vitrinite reflectance values indicate that the rocks are thermally mature for oil generation (Paltech, 1982).

The remainder of the Prawn succession is essentially sandy, and reflects proximity to the basin margin. Fining - and coarsening - upwards sequences are well-developed on the Sherbrook Group, in particular in the Belfast and Flaxman correlates (2000-2800m). Vitrinite reflectance values indicate that the Belfast correlate in transitionally mature.

Whelk 1 was drilled by Esso/Hematite in 1970 to test an updip pinchout of Waarre Formation on basement. The predicted sands were found to onlap shallow basement at 1406 m (subsea), but no hydrocarbons were recorded. Vitrinite reflectance values are less than 0.5 (Van Dieman's Land Resources, 1982).

Fig. 17 shows a SW-trending section through the Prawn A1 well and was constructed from BMR seismic line 22/23 utilising stratigraphic control from the well (modified after Hinz et al., in press). The section indicates that approximately 50 km of extension on a NNE azumith is present.

Cape Sorell Basin

Clam 1 was drilled in the northern part of the basin and encountered shallow basement at a depth of 1462 m subsea (Lunt, 1969). "Red beds" encountered from 1272-1462 m have previously been regarded as Devonian-Carboniferous (Lunt, 1969); a correlation made with Victorian rocks because of a lack of known similar rocks in Tasmania. There are, however, similarities between these rocks and the Cretaceous rocks of the Durroon Sub-basin (Moore et al., 1984), which were unknown at the time Clam was drilled.

Fig. 17 shows a stratigraphic/seismic section constructed in a WSW direction from the Clam 1 well (modified after Hinz et al., in press).

The Cape Sorell Basin has a shallow onshore extension known as the Macquarie Harbour Graben (Fig. 16) which contains approximately 500 m of infil near the mouth of the Harbour. The oldest known sediments are Early Eocene (middle M. Diversus) in age and were deposited in a marginal marine environment (Baillie et al., 1986)

The Cape Sorell 1 well (Fig. 16), drilled by Amoco in 1982, shows a remarkable thickening of the Tertiary sequence as exposed onshore. The following is a log of the sequence penetrated (all depths below mean sea level):

Depth (m)	Description
94- 412	Carbonate sequence: limestone, sandstone, mudstone, minor dolomite (Miocene - Oligocene).
412-1759	Dominantly sandstone, minor mudstone, limestone (Middle - Early Eocene).
1759-3528	Dominantly sandstone with subordinate mudstone and conglomerate, minor coal (Paleocene - ?Late Cretaceous).

The thick Eocene section contains glauconite, dinoflagellates and foraminifera, suggesting that the depositional environment was marine. Rare arenaceous forams are also present in the Paleocene section. A very thick sand is present between 1892 and 2806 m. Dipmeter analysis of crossbedding indicates that the body was formed by northerly-flowing currents, perhaps influenced by the nearby Macquarie Harbour Graben.

Vitrinite reflectance values indicate that mudstones encountered below 3100 m are mature for oil generation. This is in agreement with the recording of oil shows in the interval (Amoco, 1982).

Fig. 17 shows a seismic/stratigraphic section constructed along an approximate line between Cape Sorell 1 and DSDP Hole 282 (modified after Hinz et al., in press).

References

Amoco Australia Petroleum Company, 1982 - Cape Sorell No. 1. Well completion report. (Unpublished).

Baillie, P.W., Bacon, C.A., Morgan, R., 1986 - Geological observations on the Macquarie Harbour Beds at Coal Head, western Tasmania. Unpublished Report Tasmania Department of Mines, 1986/73.

Exon, N.F., Williamson, P.E. & Others, 1987 - Rig Seismic Research Cruise 3: Otway Basin. BMR Report 279.

Hinz, K., Willcox, J.B., Whiticar, M., Kudrass, H.R., Exon, N.F., Feary, D.A. - The west Tasmanian margin; an underrated petroleum province? PESA Symposium, Melbourne. (In press).

Lunt, C.K. 1969 - Esso Clam No. 1. Well completion report. (Unpublished).

Moore, W.R., Baillie, P.W., Forsyth, S.M., Hudspeth, J.W., Richardson, R.G., Turner, N.J. 1984 - Boobyalla Sub-basin: a Cretaceous onshore extension of the southern edge of the Bass Basin. APEA Journal, 24:110-117.

Paltech Pty. Ltd. 1982 - Burial and thermal geohistory analysis of Flaxmans - 1, Mussel-1, Nautilus A1, Nerita-1, Pecten 1A, Port Campbell-1, Prawn A1, Sherbrook-1, Snail-1, Whelk-1. Paltech Report 1982/27. (Unpublished).

Van Dieman's Land Resources N.L. 1982 - Annual Report, Year 2, T/17P, Otway Basin, Tasmania. (Unpublished).

Willcox, J.B., Branson, J.C., Exon, N.F. 1985. A proposal for ODP drilling on continental margin in the Otway Basin/West Tasmania region. Record Bureau of Mineral Resources, Geology & Geophysics, Australia. 1985/43.

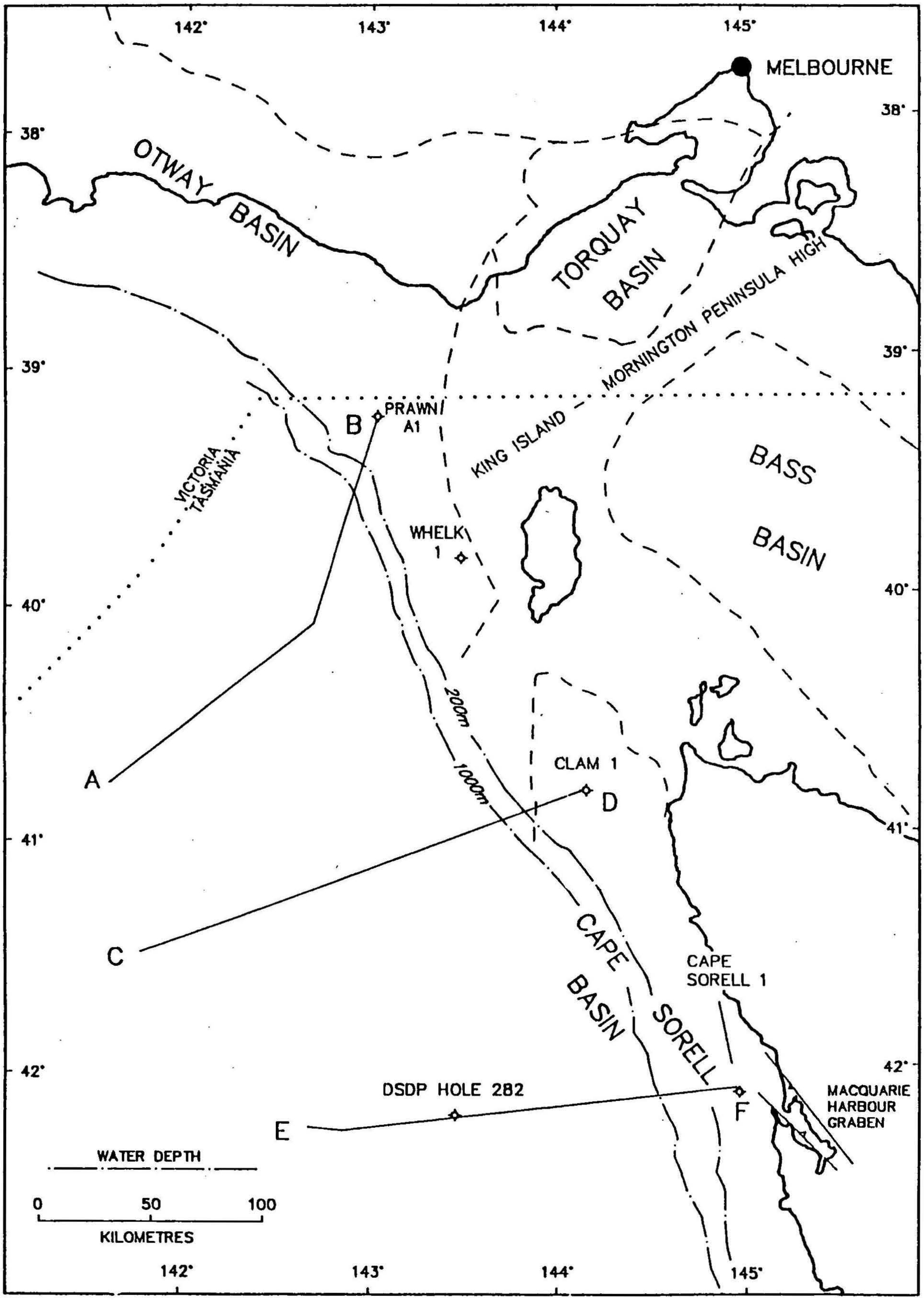


Figure 16 Locality map, showing major structural elements and location of Fig. 17 section lines

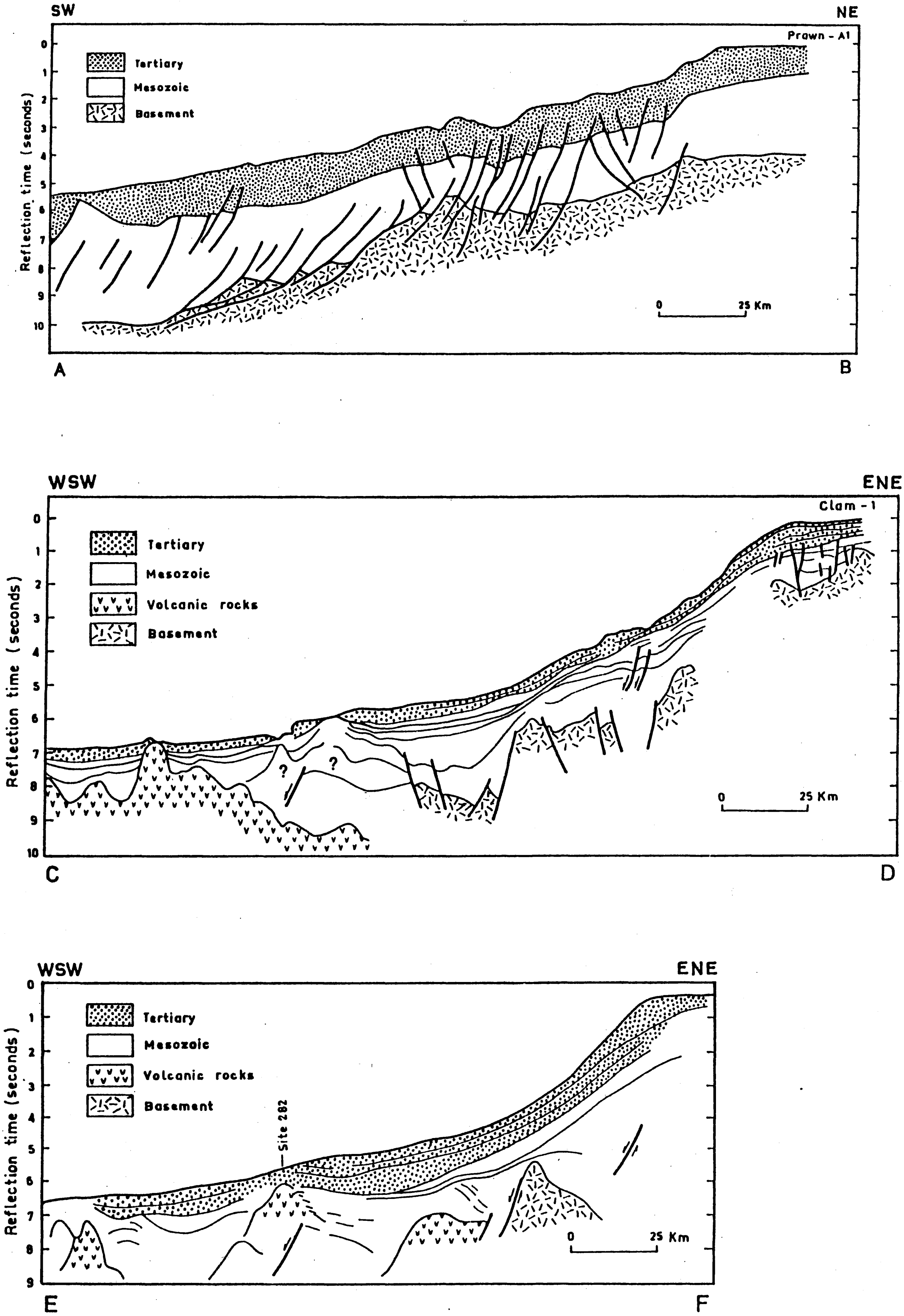


Figure 17 Sections across the west Tasmanian continental margin (modified after Hinz et al., 1986). For location of section lines refer to Fig. 16.

Otway Basin : Summary of Petroleum Exploration and Development

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The Otway Basin has attracted oil exploration since the latter part of the 19th Century, stimulated initially by reports of bituminous material stranded along the coast of western Victoria and southeast South Australia, and of interpreted oil seeps in South Australia. Shallow holes drilled prior to World War Two encountered no significant indications of hydrocarbons. The selection of drilling sites was based on surface mapping and hampered by the lack of good outcrop in the basin. Most of the wells were terminated in Tertiary sediments, but one hole, drilled near Robe in South Australia in 1915 demonstrated the presence of a thick section of Lower Cretaceous sediments beneath the Tertiary sequence.

The modern era of exploration began with a resurgence of interest in the basin in the 1950's and the conducting of the first geophysical surveys. Government agencies and exploration companies were both involved during this period. Australia's first marine seismic survey was carried out in the Otway Basin in 1961, and the first offshore well in the basin was drilled in 1967. Through the 1970's to the present, although there have been significant fluctuations in the level of activity, the exploration industry has maintained a continuing interest in the basin both onshore and offshore. Since 1959, fifty-one new-field wildcat wells have been drilled onshore, and seventeen wells have been drilled offshore. Pre-1975 seismic survey activity in the Otway Basin is reviewed in Denham and Brown (1976), and post 1979 activity in Megallaa (In Glenie in press).

Prior to the discovery of the North Paaratte gas field in the Port Campbell Embayment in 1979 only non-commercial quantities of oil and natural gas had been encountered in the Otway Basin. The North Paaratte No. 1 well established a gas flow of 0.27 x $10^6 m^3$ (9.6 x $10^6 ft^3$) from the basal Late Cretaceous Waarre Sandstone, and defined the first commercial reserves (207 x $10^6 m^3$ in the basin) (McPhee and others, 1981). In 1981 additional gas reserves of 276 x $10^6 m^3$ were established through the drilling of the Grumby and Wallaby Creek prospects. The basin's total initial recoverable gas reserves as of 30 June 1986 were estimated at 483 $10^6 m^3$ (Beach Petroleum, 1986).

The North Paaratte gas field was brought on stream in April 1986, supplying gas to the city of Warrnambool, Western Victoria, through a 34 km-long pipeline of 16.8 cm diameter. Production from the Wallaby Creek gas accumulation is envisaged to commence in the 1990s. The development plans for the Grumby accumulation are not yet known.

In addition to natural gas, several carbon dioxide accumulations have been discovered in the onshore basin during the course of petroleum exploration drilling. Only one, the Caroline accumulation in South Australia is being commercially exploited. Over 300 000 tonnes of carbon dioxide have been produced since 1968. The presence of nitrogen and helium in association with gaseous and/or liquid petroleum, has also been demonstrated (Ozimic, _In_ Glenie in press).

At the present time, the major part of the onshore Otway Basin is held under petroleum exploration permit. Permittees have announced plans to drill five wells in the first half of 1987 in the western part of the basin, three in Victoria and two in South Australia. Exploration in the western area has been encouraged by the recovery of oil from the basal Tertiary Pebble Point Formation in the Lindon No. 1 well drilled in 1984 (PEP 105) some 25 km northwest of Portland (Tabassi & Davey, _In_ Glenie (in press)).

Currently there are only two active exploration permits in the offshore basin. However, applications have recently (28 January 1987) been invited for the award of permits over one area off South Australia, three off Victoria and two off the northwest coast of Tasmania. Of the two Tasmanian areas, the northern one overlies the Otway Basin and extends into Victorian waters, and the southern area overlies the adjacent Sorell Basin.

In total over 400 graticular blocks (over 22 000 km^2) of the offshore Otway Basin are available for award of exploration permit.

References

Beach Petroleum N.L. 1986 - Annual Report and Notice of Meeting.

Denham, J.I., and Brown, B.R., 1976 - A new look at the Otway Basin. APEA Journal, 16 (1), 91-98.

Glenie, R.C. (Editor), 1986 - Proceedings of the Second South-eastern Australian Oil Exploration Symposium, Melbourne, 1985. Victoria - Tasmanian Branch Petroleum Exploration Society of Australia.

McPhee, I., McNicol, M.D., and Harrison, D.M., 1981 - The North Paaratte gas discovery. APEA Journal, 21(1), 78-84.