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EPP 23

OTWAY BASIN

PROGRESS AND TECHNICAL REPORTS FOR THE PERIOD
24/6/87 TO 6/3/92

Submitted by

Cultus Resources NL and BHP Petroleum Pty Ltd
1992

MINES and ENERGY RESOURCES SOUTH AUSTRALIA

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EPP 23, OTWAY BASIN, SOUTH AUSTRALIA
EVALUATION REPORT

Submitted by

BHP Petroleum Pty Ltd
1991

ENVELOPE 8006 R 19

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EPP 23

OTWAY BASIN, SOUTH AUSTRALIA

EVALUATION REPORT

DECEMBER 1991

C.W. Luxton/M.J. Egan

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1.0 ABSTRACT

In order to examine the prospectivity of EPP 23 BHP Petroleum have re-examined well data in and around the permit and have interpreted recently acquired seismic data.

Source studies indicate that the Eumeralla Formation probably has the greatest potential to source liquid hydrocarbons with peak hydrocarbon generation occurring in the latest Cretaceous. The Belfast Mudstone tends towards gas proneness but has the potential to produce up to one billion barrels of acumulatable hydrocarbons.

Reservoir quality of the Waarre/Flaxmans Formations and the Paaratte Formation above 3,000 m are quite good. However, in the deeper parts of the Voluta Trough where the Waarre/Flaxmans Formations reach depths in excess of 4,000 m, porosities and permeabilities are low.

Mapping of the recently acquired seismic data has failed to improve on the potential of any of the existing prospects and leads within EPP 23.

Increased faulting and lack of dip closure evident with improved seismic data resolution as well as the very localised nature of roll-over in some leads have downgraded many of the prospects and leads. None could be recommended for drilling at this stage.

2.0 INTRODUCTION

The petroleum exploration permit EPP 23 is located in the South Australian portion of the Offshore Otway Basin. It has an area of approximately 4640 square kilometres and water depths are generally less than 200 metres. The permit was awarded in 1987 to a joint venture with Cultus Petroleum N.L. as operator. On 10th August, 1990 BHP Petroleum (Victoria) Pty Ltd farmed into EPP 23 with BHP Petroleum Pty Ltd becoming operator.

Since then two rounds of seismic acquisition have added over 600 kilometres of new seismic data to the permit. In addition to this, data from wells in and around the EPP 23 permit area were subjected to a palynological and geochemical re-examination.This report summarises results derived from the new information.

On 25th June, 1991 BHP Petroleum (Victoria) Pty Ltd withdrew from the permit and BHP Petroleum Pty Ltd resigned as operator.

3.0 GEOLOGICAL SETTING

3.1 Otway Basin

The Otway Basin straddles the southern Australian coastline for 500 km from Robe in South Australia to Cape Otway in Victoria (Figure 3.1.1). It is one of a series of Mesozoic to Tertiary basins formed along Australia's southern margin during rifting and continental breakup between Australia and Antarctica.

The offshore portion of the Otway Basin may be broadly subdivided into four structural elements: the Crayfish Platform in the west, the Voluta Trough in the south and centre, the intervening Chama Terrace, and the Mussel Slope in the east (Figure 3.1.1, cf., Williamson *et al.*, 1987).

Sedimentation within the Otway Basin has occurred in three major phases. The Early Cretaceous Otway Group is dominated by volcanogenic fluvial and lacustrine sandstones, siltstones, shales and coals and is up to 7,000 m thick. These sediments were deposited in an intracratonic setting in a series of northward dipping half grabens during rifting (Valanginian to Barremian Pretty Hill Formation) and as a relatively conformable sequence across the rotated fault blocks of the half grabens during post rift thermal subsidence (Aptian to Albian Eumeralla Formation).

A regional unconformity separates the Otway Group from the overlying Late Cretaceous Sherbrook Group. The Sherbrook Group was deposited in a marginal marine setting and is up to 5,000 m thick. It may represent a second phase of rifting involving further down to the south fault block rotation (Waarre/Flaxmans Formations), followed by thermal subsidence associated with continental separation and the initiation of sea floor spreading (Flaxmans, Belfast, Paaratte and Curdies Formations, cf., Mutter *et al.*, 1985, Veevers, 1988).

A further regional unconformity separates the Sherbrook Group from the overlying Palaeocene to Eocene marine clastics of the Wangerrip Group, the Oligocene clastics and carbonates of the Nirranda Group, and the Late Oligocene to Recent shelfal marls and limestones of the Heytesbury Group. These Tertiary to Recent sediments are up to 2,500 m thick and have been deposited in a marine environment on the trailing edge of the southern Australian passive margin (Figure 3.1.2 cf., Holdgate *et al.*, 1986, Williamson *et al.*, 1987 and Laing *et al.*, 1989).

3.2 Voluta Trough

The Voluta Trough forms the central and southern portion of the offshore Otway Basin, and the permit EPP 23 lies almost exclusively within this trough (Figure 3.1.1). The Otway Group has not been penetrated within the offshore Voluta Trough (NB Reassessment of the palynology of Copa 1 indicate that this well did not penetrate the Otway Groups, contrary to the original interpretation). Its presence may therefore only be assumed. The known sedimentary sequence within the trough is dominated by up to 5,000 m of Sherbrook Group, with a veneer of about 350 m or less of Tertiary sediment in the northwest, increasing to perhaps 2,500 m in the southeast (cf., Holdgate *et al.*, 1986).

The basal Sherbrook Group is represented by the fluvio-deltaic Waarre/Flaxmans Formations, comprising overall upwards fining and thinning sandstones and mudstones. In the eastern part of the Voluta Trough these units appear to have been rotated by down to the south faulting. These basal Sherbrook facies are downlapped by the Belfast Mudstone, a prodelta mudstone/siltstone deposited at rates of up to 250 m/Ma during a period of rapid subsidence in the Turonian to Campanian. The overlying Paaratte and Curdies Formations are an overall upwards coarsening sequence deposited in delta plain to fluvial environments as subsidence rates declined and the delta system prograded basinwards.

The overlying Wangerrip Group represents a further clastic deltaic sequence, with the basal transgressive sandstones of the Pebble Point Formation overlain by the prodelta mudstones of the Pember Mudstone and the deltaic sandstones of the Dilwyn Formation. The Nirranda and Heytesbury Groups represent carbonate and minor clastic deposition in gradually deepening water.

3.3 Chama Terrace

The far northern corner of EPP 23 lies within the Chama Terrace (Figure 3.1.1). The Chama Terrace is intermediate both geographically and geologically between the Voluta Trough to the south and the Crayfish Platform to the north.

Unlike the Voluta Trough, the Crayfish Platform is dominated by the Early Cretaceous Otway Group, with only a relatively thin cover of Sherbrook Group and Tertiary sediment. The Pretty Hill Formation has been strongly rotated, forming a series of half grabens which have been partially eroded prior to deposition of the Eumeralla Formation. The Eumeralla Formation is relatively flat lying, and shows only minor tectonic disturbance.

Within the Chama Terrace, the tectonic style and stratigraphy of the Crayfish Platform grades into that of the Voluta Trough from north to south, with the Sherbrook Group thickening and post Eumeralla Formation faulting becoming progressively more intense.

4.0 PREVIOUS EXPLORATION

4.1 Wells

The first well in EPP 23 was Argonaut 1A, drilled by Esso in 1968. Ultramar drilled Breaksea Reef 1 in 1984 and Cultus drilled Copa 1 in 1989 (see Figure 4.1.1 for well locations).

No commercial hydrocarbons have been found in the offshore Voluta Trough, although some minor shows and high mud gas readings have been recorded. Technical difficulties, particularly related to overpressuring within the Belfast Mudstone, have resulted in lack of proper testing of the Waarre Sandstone in some of these wells, especially Breaksea Reef 1.

4.2 Seismic Data

Throughout the sixties and early seventies seismic data ranging from single-fold to a twenty-four fold survey in 1972 were acquired in the permit.

After the 1972 survey no further seismic acquisition took place in EPP 23 until 1981 when a forty-eight fold survey was acquired for Shoreline Petroleum. The 1981 survey, along with subsequent surveys in 1982 (Ultramar, 48 fold), 1985 (Ultramar, 60 fold), 1988 (Cultus, 60 fold), 1990 (BHPP, 75 fold) and 1991 (BHPP, 60 fold) have provided a total of 3422 kilometres of modern seismic throughout the permit. These data provide a regional grid with detailed infill (Figure 4.2.1). Acquisition parameters for the 1972 and post-1980 seismic surveys are listed in table 1

5.0 HYDROCARBON POTENTIAL

5.1 Voluta Trough

The hydrocarbon potential of the Voluta Trough has been assessed on the basis of all previously available data from throughout the Otway Basin, supplemented by new data collected during the course of this study. Models and analogies from similar basins throughout the world have been used to augment the study.

5.1.1 Source Rocks

The major potential source rocks recognised within the Otway Basin are the Early Cretaceous Eumeralla Formation and the Late Cretaceous Belfast Mudstone. The Tertiary sequences also contain potential source rocks (e.g., the Pember Mudstone), but these rocks are immature throughout the basin and will not be considered further.

The Eumeralla Formation has not been penetrated within the offshore Voluta Trough. If present, it would be at depths greater than about 5,000 m, probably representing vitrinite reflectance values of greater than 1% (cf., Figure 5.1.1). This may place the upper parts of the Eumeralla Formation in the region of peak hydrocarbon generation for coaly source rocks beginning at vitrinite reflectance values of about 0.95% and continue up to as high as 1.3% (e.g., Hunt *et al.*, 1989). Portions of the Eumeralla Formation at greater depths and vitrinite reflectance values may have sourced liquid hydrocarbons, as recent kinetic and experimental considerations (Mango, 1991) indicate that the rate constants for the decomposition of liquid to gaseous hydrocarbons under the time and temperature conditions of petroleum generation are such that any liquid hydrocarbons generated and expelled from the Eumeralla Formation since the end of the Early Cretaceous should still be present in any appropriate structures. However, the lack of direct evidence for the presence (and nature) of the Eumeralla Formation within the Voluta Trough does not allow it to be considered as more than a supplementary hydrocarbon source.

The Belfast Mudstone Formation is therefore the most important potential source rock within the Voluta Trough, as its presence and nature are known, and it is mature for hydrocarbon generation throughout much of the Voluta Trough.

5.1.2 Geological Setting and Quantity

The Belfast Mudstone Formation is a time transgressive, Turonian to Campanian unit within the Late Cretaceous Sherbrook Group, and is encountered throughout the Voluta Trough and its margins. It was deposited in a marginal marine, prodelta setting as part of a major transgressive - regressive delta system which built out into the rapidly subsiding Voluta Trough, and consists predominantly of carbonaceous siltstones and mudstones, with occasional sandstone lenses. It is up to at least 2,000 m thick

(Figure 5.1.2), and was deposited very rapidly, with sedimentation rates of between 100 and 250 m/Ma (Figure 5.1.3).

5.1.3 Quality

Both organic petrography and Rock-Eval pyrolysis indicate that the dispersed organic matter within the Belfast Mudstone is principally Type III (terrestrially derived) kerogen (Figure 5.1.4). Type III kerogen is generally considered to be predominantly gas prone, but gas shows with components up to C_7 and extract gas chromatograms with significant n-alkane components up to C_{30} suggest that the Belfast Mudstone may also have some potential as a liquid hydrocarbon source. Liquid hydrocarbons with a Type III kerogen source are also known from the Beaufort-Mackenzie basin in Canada (Snowdon and Powell, 1982).

The potential source rock quality of the Belfast Mudstone is variable throughout the Voluta Trough. Total organic carbon (TOC) and hydrogen index (HI) values range between about 0.5 and 3.0 wt% and 10 and 350 mg/gTOC respectively (Figure 5.1.5, 5.1.6, 5.1.7). These values are comparably with those from the main Niger delta source rocks, which are known to have produced billions of barrels of oil (Figure 5.1.7, cf., Ekweozor and Telnaes, 1990). We have taken an HI value of 100 as a lower limit for potential source rock and calculated a 'net Belfast source' parameter defined as the thickness of Belfast Mudstone with HI > 100. This parameter indicates that the best quality Belfast Mudstone occurs in the vicinity of Argonaut 1 and Breaksea Reef 1 in EPP 23 and Normanby 1 and Bridgewater Bay 1 in Vic/P14. This area of better quality Belfast Mudstone may be depositionally controlled, or may be related to overpressuring within the Belfast Mudstone. This overpressuring is evident from both drilling and well log data, and appears to correspond approximately with the highest HI values.

5.1.4 Maturity

Vitrinite reflectance data and maturity modelling suggest that the top of the hydrocarbon window ranges between about 3,500 and 4,500 m throughout the central part of the Voluta Trough (Figure 5.1.1, 5.1.8, 5.1.9). This indicates that there is up to 1,500 m of mature Belfast Mudstone in the deeper parts of the Voluta Trough (Figure 5.1.10). When only the net Belfast source is considered (as defined above), there is still up to 1,000 m of mature potential Belfast source rock (Figure 5.1.11). The zero edge of net mature Belfast source passes to the south of many of the exploration wells within the Voluta Trough, and this may be a major contributing factor in the failure of these wells.

These calculations are based on the assumption that Type III kerogen enters the hydrocarbon window at a vitrinite reflectance of about 0.8%. If the hydrocarbon window is entered at lower vitrinite reflectance levels, as suggested by Snowdon and Powell (1982), the volume of mature Belfast Mudstone will be even greater.

Maturity modelling also suggests that the base of the Belfast Mudstone should be at peak hydrocarbon generation in the deeper parts of the Voluta Trough (Figure 5.1.12). Entry of the base of the Belfast Mudstone into the hydrocarbon window began at about 70 Ma and continued until about 50 Ma. Slow subsidence since 50 Ma has resulted in little change in maturity since then (Figure 5.1.13).

5.1.5 Migration

Overpressured intervals of the Belfast Mudstone appear to be overlain by normally pressured intervals of the same unit. This gives rise to the possibility that during rapid subsidence, generation of hydrocarbons accompanied by thermal expansion of pore fluids within overpressured compartments of the Belfast Mudstone may lead to the periodic fracturing of compartment seals (Hunt, 1990). This process may provide an important mechanism for primary migration.

Calculations of the volume of oil necessary to saturate the pore spaces within the mature portion of the Belfast Mudstone suggest that there may have been insufficient hydrocarbon generation to allow efficient expulsion of liquid hydrocarbons throughout much of the Voluta Trough (cf., Forbes *et al.*, 1991). However, expulsion of liquid hydrocarbons should be more efficient in the deeper parts of the Trough, where the level of maturity is higher, and porosity is lower. Expulsion is much more efficient for gas than for oil, and primary migration of gas should have occurred throughout the mature portion of the Belfast Mudstone.

Secondary migration is believed to occur along fault planes which extend from within the Otway Group, through the Sherbrook Group, and terminate at various levels within the Tertiary sequence (Figure 5.1.14).

5.1.6 Volumetrics

Volumetric calculations based on the method proposed by Moshier and Waples (1985) suggest that a slab of Belfast source with a net thickness of 200 m and a radius of between 20 and 34 km should be capable of generating, expelling, migrating and accumulating 100 MMBBL of oil equivalent, although, as discussed above, the expulsion efficiencies for oil are considered to be low (Figure 5.1.15). Given these parameters and a total volume of net mature Belfast source of some 2,000 km^3 (cf., Figure 5.1.11), the Belfast Mudstone within the Voluta Trough should have the potential to source accumulations totalling up to 1 billion BBL of oil equivalent.

5.1.7 Timings

The relative timing of important events with regard to the hydrocarbon potential of the Voluta Trough is summarised in (Figure 5.1.16). Belfast Mudstone deposition began at about 92 Ma and continued until about 84 Ma. The base of the Belfast Mudstone began moving into the hydrocarbon window at about 70 Ma, but the level of maturity has not changed significantly since about 50 Ma.

Fault terminations within the Voluta Trough range from the base of the Tertiary sequence to occasional scarps on the present sea floor (Figure 5.1.14). These faults were active from at least the latest Cretaceous to recent time, and have therefore been available as conduits for hydrocarbon migration since about the time that the Belfast Mudstone became mature.

Timing of expulsion and migration is not easily quantified, but recent work by Ozkaya and Akbar (1991) suggests that expulsion and migration occur during or soon after generation.

5.1.8 Conclusion

The Belfast Mudstone is considered to be the major potential source rock within the Voluta Trough, although there is some possibility that Eumeralla Formation at depth may also contribute hydrocarbons. The Belfast Mudstone has the potential to produce up to 1 billion barrels of accumulatable hydrocarbons throughout the Voluta Trough, and any structures within the deeper parts of the Trough which have been in place since about the Palaeocene have potential to contain hydrocarbons. The Belfast Mudstone probably tends towards gas proneness, but the possibility that it has sourced liquid hydrocarbons cannot be discounted.

5.2 Chama Terrace

5.2.1 Source Rocks

The major potential source rock recognised within the Chama Terrace is the Eumeralla Formation, which is known to be thicker and more coaly than the time equivalent Eumeralla Formation within the Crayfish Platform. Rock-Eval pyrolysis and C_{12}+ saturated hydrocarbon extract gas chromatograms indicate that the source rock qualities of the Eumeralla Formation within the Chama Terrace are superior to those within the Crayfish Platform.

5.2.2 Geological Setting and Quantity

The Eumeralla Formation is interpreted as having been deposited within a fluvial to lacustrine setting during thermal subsidence of the Otway Basin following Early Cretaceous rifting. It ranges between about 2,000 and 3,000 m thick within the Chama Terrace. Wells within the Chama Terrace suggest a model in which basin margin sediments are predominantly fluvial in character, with lacustrine influence increasing towards the basin centre (i.e., towards the south).

5.2.3 Quality

A change in depositional setting from predominantly fluvial to predominantly lacustrine from north to south should be reflected in a change from predominantly Type IV kerogen at the basin margin through to Type III, Type II and finally Type I in the lacustrine dominated basin centre. While Type I kerogen has not been recognised within the Eumeralla Formation, Type II kerogen appears to become more prevalent towards the south.

The most promising potential source rock intervals occur in the lower Eumeralla Formation, and are characterised by abundant, thinly bedded liptinite rich coals with TOC values around 35% and HI values around 275. These coals are associated with DOM rich siltstones having TOC values around 4% and HI values around 150. C_{12}+ saturated hydrocarbon extract gas chromatograms from a 200 m coal rich interval of lower Eumeralla Formation penetrated in Chama 1A are very similar to gas chromatograms of oil recovered from Lindon 1. This gives some confidence in suggesting the lower Eumeralla Group as the source for the oil in Lindon 1. The Eumeralla Group is therefore believed to have potential to source both oil and gas.

5.2.4 Maturity

Vitrinite reflectance data and maturity modelling suggest that the Eumeralla Formation is immature to marginally mature for hydrocarbon generation in the northern parts of the Chama Terrace, but the thickening of the Sherbrook Group across progressively down-faulted Eumeralla Formation to the south resulted in the lower Eumeralla Formation entering the hydrocarbon window during Sherbrook Group deposition in the southern Chama Terrace. Maturity has not increase significantly since the end of the Late Cretaceous.

5.2.5 Migration

Primary migration from the lower Eumeralla Formation within the southern parts of the Chama Terrace may have occurred across faults and into the sandstones of the Pretty Hill Formation. Secondary migration may then have been buoyancy driven within the Pretty Hill Formation.

5.2.6 Timings

Maturity modelling has highlighted the importance of the Sherbrook depositional period to the maturity of the lower Eumeralla Formation within the Chama Terrace. Deposition of a relatively thick Sherbrook Group has pushed the lower Eumeralla Formation into the hydrocarbon window in the southern parts of the terrace, with peak hydrocarbon generation occurring towards the end of this period (the end of the Late Cretaceous). Traps which have been in place since at least the end of the Cretaceous therefore have the best potential to contain Eumeralla sourced hydrocarbons.

5.2.7 Conclusion

The Eumeralla Formation is the primary potential source rock within the Chama Terrace, and probably has the greatest potential to source liquid hydrocarbons of any known interval within the Otway Basin. Both source rock potential and maturity appear to increase towards the south, with peak hydrocarbon generation occurring during the latest Cretaceous.

6.0 RESERVOIR

6.1 Voluta Trough

The two major potential reservoirs recognised within the Voluta Trough are the Flaxmans/Waarre Formations at the base of the Sherbrook Group and the Paaratte Formation near the top of the Sherbrook Group.

The Flaxmans/Waarre Formations have been the major exploration targets within the Voluta Trough, due in part to their porosity and permeability, and in part to their favourable stratigraphic position beneath the Belfast Mudstone Formation which provides a regional seal. Porosities of up to 20% are maintained to depths of about 2,500 m within the Waarre Formation (Figure 6.1.1), with permeabilities ranging between 100 and 3,000 md. By depths of 4,000 m or greater, porosities have decreased to below 10% and are adversely affected by secondary quartz and chlorite growth, and pemeabilities are expected to be very low.

The Paaratte Formation consists of interbedded sandstones and mudstones of the order of 10 m thick and relies on intraformational seal. Core analyses from Argonaut 1A indicate that porosities of 20% are maintained to depths of about 2750 m (Figure 6.1.2), with permeabilities ranging between about 15 and 250 md.

6.2 Chama Terrace

The Pretty Hill Formation is the major potential reservoir within the Chama Terrace. The sandstones within this formation appear to change from arkosic at the base to quartz rich at the top. The quartz rich sandstones in the upper portions of the Pretty Hill Formation have better permeabilities than the arkosic sandstones, although their porosities are similar at similar depths. Porosities of 20% are maintained to about 2,500 m (Figure 6.2.1), with permeabilities ranging between about 1 and 500 md.

7.0 GEOPHYSICAL REVIEW

For this geophysical review data of pre-1980's vintage was considered adequate only for coarse structural definition. For a detailed interpretation a total of 2,100 kilometres of recently acquired or reprocessed seismic data was used. A map of this data is shown in Figure 7.1.1. It includes data from the 1991, 1990, 1988, 1985, 1982 and 1981 surveys, as well as two 1972 lines, and provides seismic lines in the dip direction with a two kilometre spacing over each of the identified prospects. The data of 1985, 1982, 1981 and 1972 vintage have been reprocessed since 1988 and are of good quality. Lines UA82-9 and UA82-11 were the only lines of these vintages that were interpreted that had not been reprocessed and were of inferior quality. Reprocessing of the remainder of the 1985,1982 and 1981 seismic surveys would enable an accurate regional interpretation of the permit to be made. The use of the dip move out (D.M.O.) routine in the processing has been particularly useful for fault resolution in this highly faulted area. The seismic data quality in EPP 23 is good overall for the Tertiary and Late Cretaceous section.The Early Cretaceous section has good resolution at Top Pretty Hill level but is of poorer quality at lower levels.

8.0 LEADS AND PROSPECTS

8.1 Introduction

B.H.P.Petroleum became operator of EPP 23 as data from the 1990 Rhonda Seismic Survey was being acquired. The 300.5 kilometre survey was concentrated over leads and prospects that had been identified by Cultus who were the previous operators of EPP 23. The survey was concentrated in two distinct areas of the permit. A total of 112.4 kilometres of data were acquired over the Ipanema Prospect in the Voluta Trough and 188.1 kilometres of data were acquired over three leads in the Chama Terrace portion of the permit. As the 1990 data was being interpreted, the fourth permit year commitment of the acquisition of a minimum 300 kilometres of seismic data began.

With the addition of the 1990 data, the seismic coverage over the Chama Terrace portion of EPP 23 was considered sufficient for detailed mapping of that area. The 1991 EPP 23 seismic survey was therefore concentrated solely on leads and prospects in the Voluta Trough (Figure 8.1.1). It was composed of nine lines totalling 305.2 kilometres and included a regional strike line through the three EPP 23 wells. The remainder of the survey was acquired over the Ipanema Prospect and the Buffon/Bungaloo leads. With the addition of the 1990 and 1991 surveys there is sufficient good quality seismic to map both the Voluta Trough and the Chama Terrace prospects and leads (Figure 8.1.2).

8.2 Voluta Trough

The 1990 seismic survey provided a two kilometre dip line spacing over the Ipanema Prospect. The 1991 survey added an additional dip line through the crest of the Ipanema Prospect and tied the prospect to the Argonaut 1A well. The Buffon lead was identified in an area of the EPP 23 permit that had sparse seismic coverage. As part of the 1991 survey, a two kilometre grid was positioned over this lead and the lines were extended to the south to give coverage over the Bungaloo Lead. A schematic diagram of Voluta Trough play types is shown in Figure 8.1.1.

8.2.1 Ipanema Prospect

The Ipanema Prospect is a structure located just shoreward of the continental shelf break and approximately eight kilometres south of the Argonaut 1A well. The structure is formed by roll-over of Late Cretaceous sediments into a large listric normal fault. Primary objectives are sandstones of the Paaratte and Waarre/Flaxmans Formations. Seal would be provided by Intra-Paaratte siltstones and the Belfast Mudstone respectively. Hydrocarbons generated in the Belfast Mudstone and/or Eumeralla Formation would migrate to the reservoirs along the listric normal faults that proliferate in this portion of the basin.

Seismic line UA82-17 (Figure 8.2.1) is a dip line through the Ipanema Prospect. It shows that there is significant closure in the southern (basin-ward) portion of the Ipanema block but there is less roll-over into the fault on the northern edge of the block. The amount of roll-over into this fault diminishes eastwards towards the crest of the Ipanema Prospect (Figure 8.2.2) causing this prospect to rely largely on fault closure. The Paaratte Formation is an interbedded sequence of sandstone and mudstone and fault seal within this sequence is difficult to predict. The lower portions of the Paaratte Formation on the hanging wall block would still be considered a target where fault seal can be expected against the Belfast Mudstone. The Waarre/Flaxmans Formation play remains an attractive play type with sandstones from these formations being sealed vertically by the Belfast Mudstone and sealed laterally by the Eumeralla Formation. Both the Belfast Mudstone and the Eumeralla Formation are potential sources for this play type. The Top Waarre/Flaxmans Formation (Base Belfast) is at a depth greater than 4,600 metres at the Ipanema Prospect and reservoir quality is likely to be poor.

Earlier mapping by Cultus indicated that the Top Paaratte was increasingly fractured to the east and over the crest of the structure by antithetic faults associated with the major listric normal faults and thus made targets at this level unattractive. Cultus maps at Near Top Belfast levels however indicated that the antithetic faults did not penetrate the Belfast Formation and it was possible that some of the basal Paaratte sediments were also unaffected by this faulting. The Ipanema Prospect was therefore mapped by B.H.P. Petroleum at an Intra-

Paaratte Horizon (Enclosure 1) as well as at the Water Bottom (Enclosure 2), Base Tertiary (Enclosure 3). Near Top Belfast (Enclsoure 4) and Base Belfast (Enclosure 5) levels. Seismic data from the 1990 and 1991 surveys enabled a detailed mapping of the prospect. The new seismic had very good fault resolution and showed that the faults penetrated deeper into the section than could be interpreted on the pre-existing seismic. Seismic line OH91-411 (Figure 8.2.3) was a reshoot over a 1981 line over the Ipanema Prospect and through the Argonaut 1A well. A comparison of the data quality is shown in Figure 8.2.4.

The presence of faulting at the crest of the Ipanema Prospect at depth (3,500+ metres) combined with the absence of significant four-way dip closure and the poor location for access to good Belfast Mudstone source has down-graded the prospectivity of this structure at Intra-Paaratte levels. The depth (4,600+ metres) to reservoirs of the Waarre/Flaxmans Formations detracts from this play type at the Ipanema Prospect.

8.2.2 Buffon Lead

The Buffon Lead is a similar play type to the Ipanema Prospect. It is a Late Cretaceous structure located just shoreward of the continental shelf break and rolling over into a large listric normal fault. The primary objective for this lead are the Intra-Paaratte sandstones which would be sealed by Intra-Paaratte siltstones. Waarre/Flaxmans Sandstones are, as for the Ipanema Prospect, too deep to be a primary objective. The Buffon Lead was identified on line UA82-11 (Figure 8.2.5) which is an unreprocessed seismic line in an area of sparse seismic coverage. It could not be mapped properly with the few lines available. The 1991 seismic acquisition programme therefore included a seismic grid with two kilometre dip line spacing over the Buffon Lead.

The Buffon lead was downgraded when the 1991 seismic data demonstrated that the roll-over present in line UA82-11 was localised and did not continue onto the adjacent lines (Figure 8.2.6). Source rock studies (section 5) found that the lead was a considerable distance away from mature Belfast. Two-way time structure maps were made for the Water Bottom, Encloure 6 Base Tertiary (Enclosure 7), Intra-Paaratte Formation (Enclosure 8) and the Near Top Belfast Formation (Enclosure 9).

8.2.3 Bungaloo Lead

The Bungaloo Lead was identified further basinward (south-west) of the Buffon Lead. It is located beyond the continental shelf edge in a water depth of 350 metres. The Bungaloo Lead is seen as an anticlinal structure in the strike direction on seismic line CO88-38 (Figure 8.2.7) and the limited seismic data available indicated a possible roll-over in the dip direction into a listric normal fault. It was noted that the high on line CO88-38 coincided with a channel of Tertiary age and it was suspected that high velocity channel fill (probably derived from limestones of the Heytesbury Group) could be causing a pull-up effect on the seismic data. The primary objectives for this play are sandstones of the Paaratte Formation that would be sealed by intra-formational siltstones. The 1991 lines over the Buffon Lead were extended southwards in order to define the Bungaloo Lead. In the meantime seismic modelling of line CO88-38 proceeded in order to determine the robustness of the structure underneath the channel. This was done by digitising the separate sequences and applying different interval velocities to each then plotting the section in depth.

The 1991 seismic data demonstrated negligible roll-over in the dip direction for the Bungaloo Lead (Figure 8.2.8) and the modelling of the channel-fill with a high velocity showed a significant reduction in closure in the strike direction when the structure was viewed in depth (Figure 8.2.9). The Bungaloo Lead was consequently down-graded. The Bungaloo Lead mapping is included on the Buffon Lead maps.

8.2.4 Conclusion

The acquisition of new data with improved fault resolution has enabled more accurate mapping of the Voluta Trough Prospects and Leads. The results have shown that the Ipanema Prospect is more deeply faulted at its crest and has shown that other leads were localised rollovers that did not extend to seismic lines nearby. These factors, when combined with the depth to Waarre/Flaxmans targets (4,600+m) and the considerable distance from good Belfast Source, have downgraded the potential of the Voluta Trough prospects and leads.

8.3 Chama Terrace

Mapping by Cultus had previously identified two Top and one intra-Pretty Hill leads. The OC90B survey provided more information on the Chama Terrace and subsequent mapping revealed one further Top Pretty Hill closure. All the Top Pretty Hill leads rely on fault seal to provide closure. The intra-Pretty Hill closure relies upon pinchout on a basement high.

8.3.1 Lead "A" - Socrates

Lead "A" is an intra-Pretty Hill rollover over a basement high. The OC90B data has reduced the degree of certainty of this being a valid closure. Seismic data quality in the intra-Pretty Hill section is not of sufficient quality to clearly define a closure. The Cultus mapping relied upon roll observed on line UA85-100 that can not be supported by the new data.

8.3.2 Lead "B" - Dundee

Lead "B" is situated on the high side of a major easterly trending fault (~400 ms throw) but relies on a minor fault branching off the major fault to seal in order for there to be a trap. A small amount of independent closure is present but fault seal is required for there to be a sizeable closure. The OC90B survey contributed one line to the lead with no noticeable change occurring from the Cultus mapping.

8.3.3 Lead "C" - Pearl

Lead "C" is situated on the downthrown side of the major fault mentioned in the discussion of Lead "B". It was the largest of the leads identified by Cultus but the new OC90B data showed that the amount of roll on the northwest flank of the lead was not as large as previously mapped. This was the critical closure direction and, subsequently, the volume of the lead has been reduced.

8.3.4 Lead "D"

The OC90B survey has allowed a new lead to be identified. Lead "D" is situated on a SSW-plunging structural nose with faults defining the northeast and southwest boundaries. Data quality at Top Pretty Hill level is not good and thus adds to the risks associated with this lead.

8.3.5 Other leads

On the northeastern boundary of EPP 23 is the Beachport High. It is possible that the Pretty Hill pinches out against the basement high producing stratigraphic traps. Reliable mapping of the intra-Pretty Hill would be required but the discontinuous nature of intra-Pretty Hill reflectors makes the task difficult.

No Eumeralla plays were considered or mapped.

8.3.5 Conclusion

New data acquired over leads in the Chama Terrace in EPP 23 have been interpreted. Results have failed to improve the viability of any of the leads and have downgraded the structure of some.

9.0 REFERENCES

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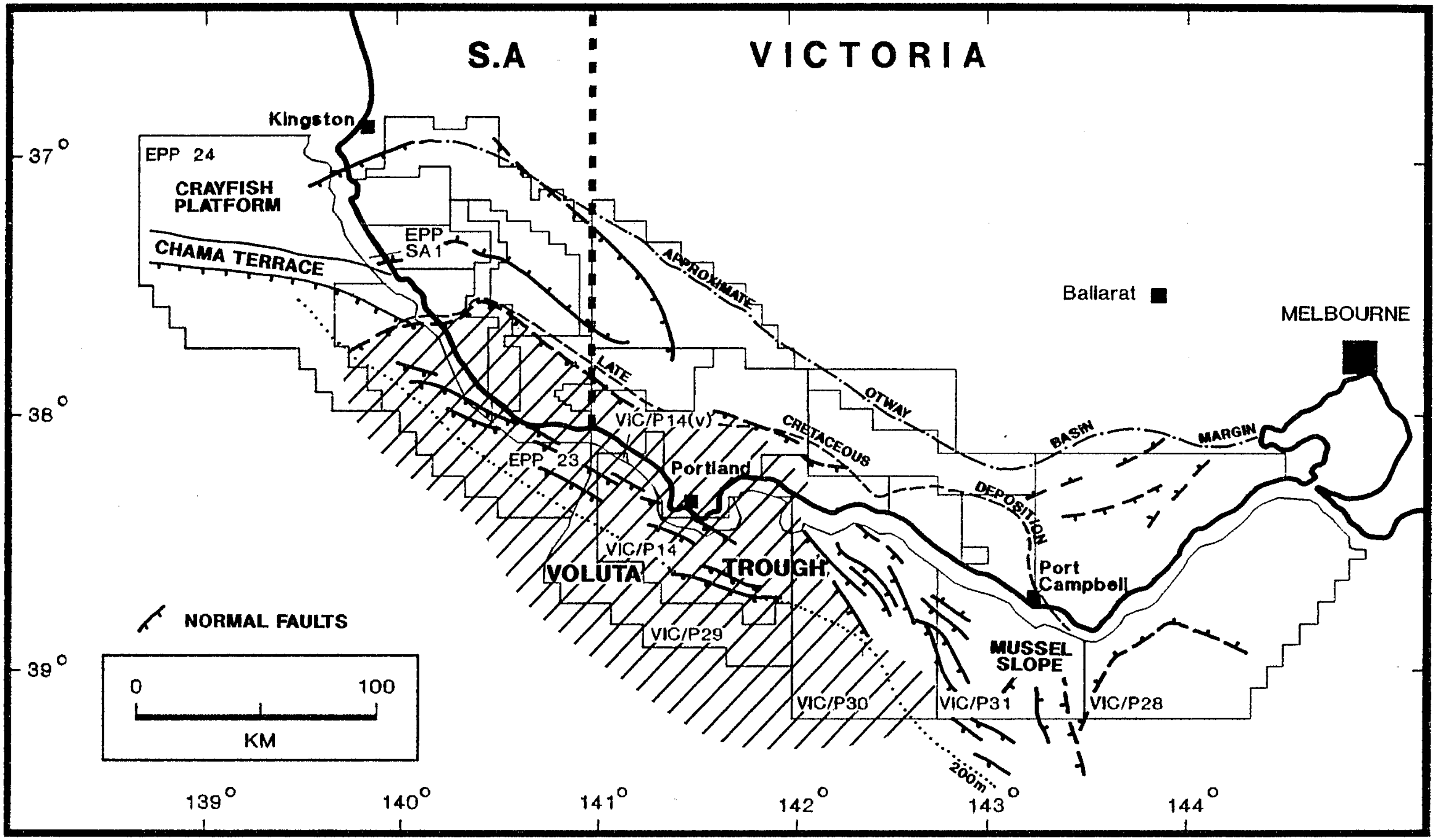

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OTWAY BASIN

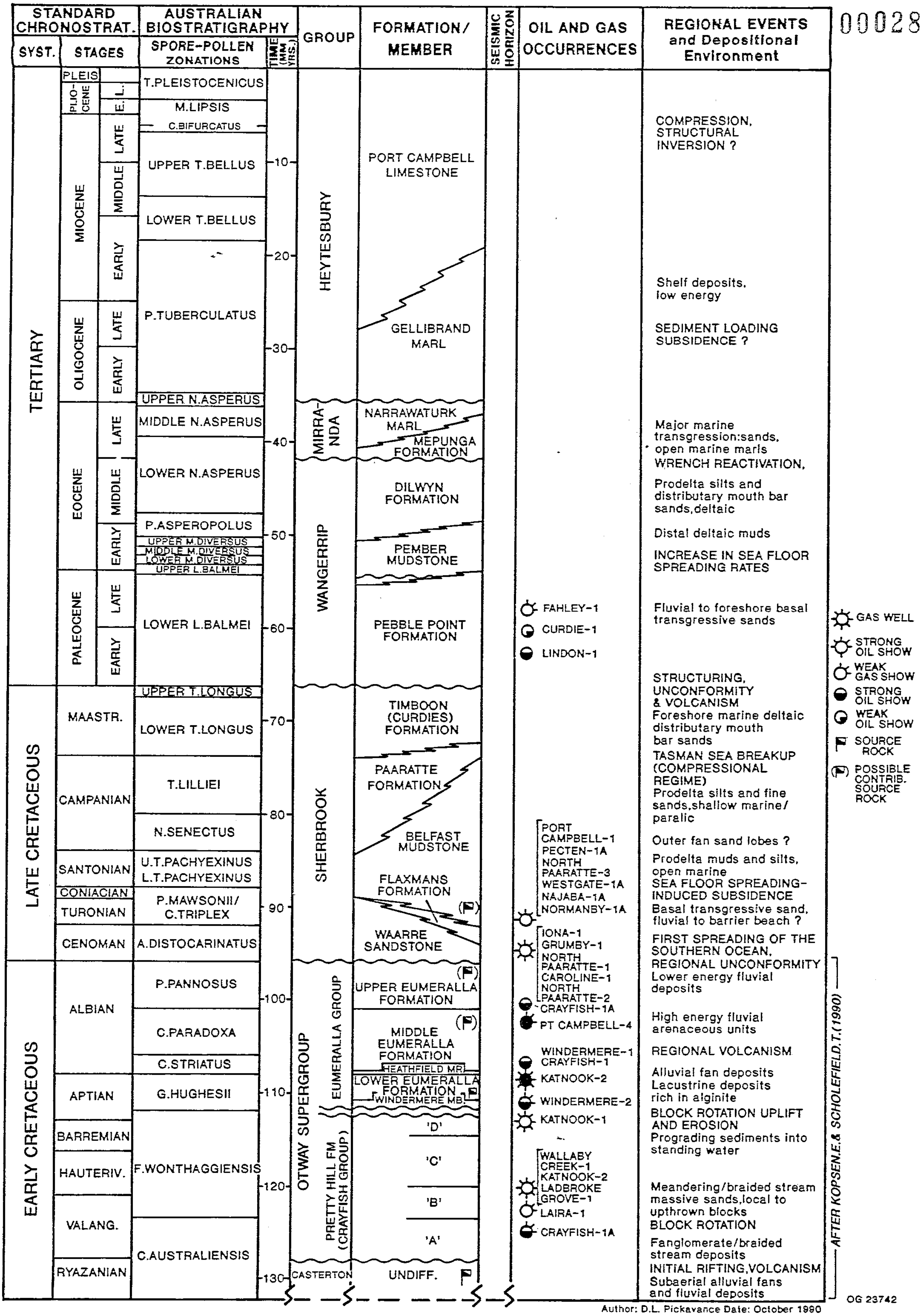
GENERALISED STRUCTURAL ELEMENTS

Date: December 1991 **Drawn by: A.S.Czigler**

Figure 3.1.1

00027

OG 24805



Author: D.L. Pickavance Date: October 1990

OFFSHORE OTWAY BASIN

STRATIGRAPHIC COLUMN

Figure 3.1.2

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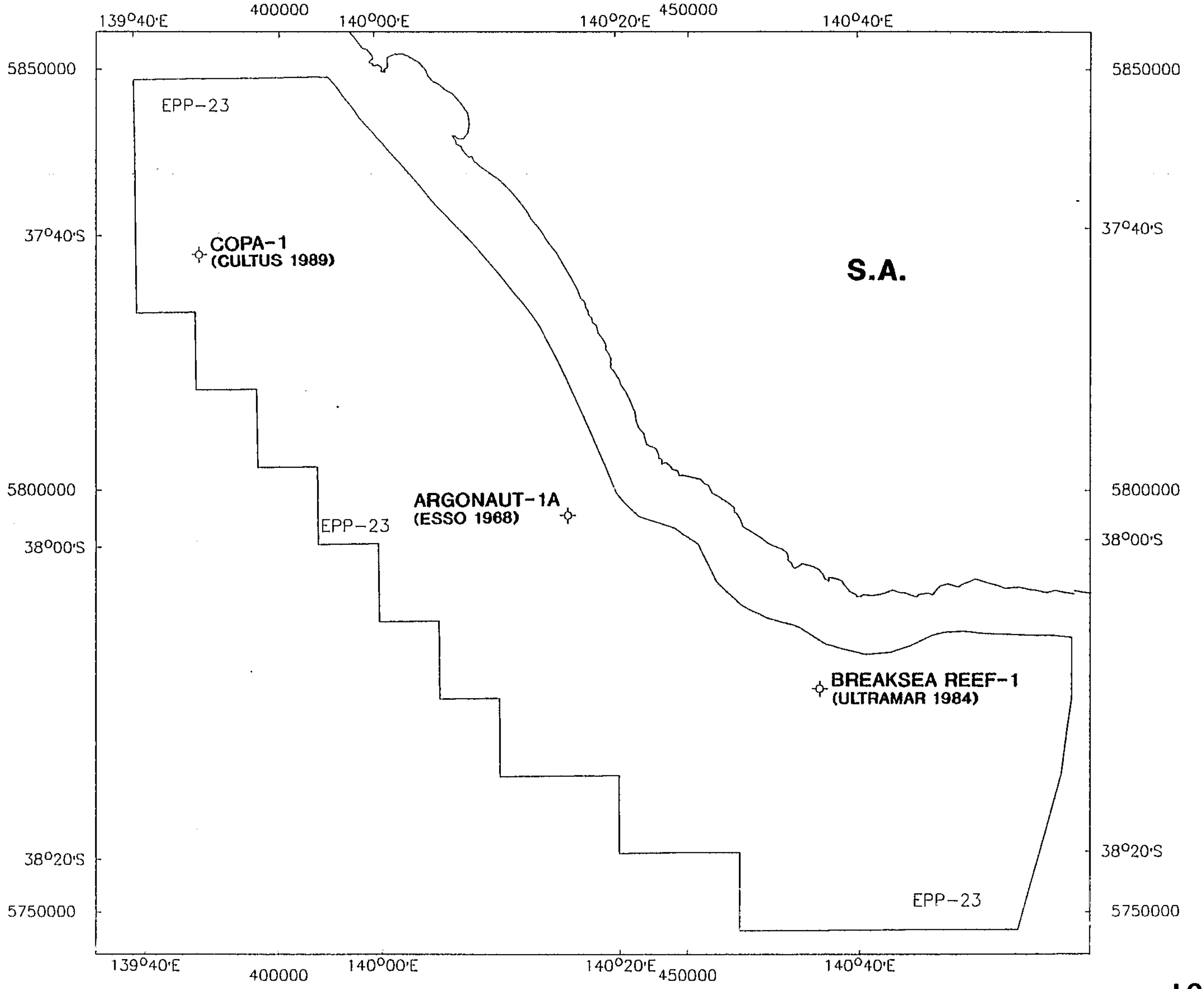

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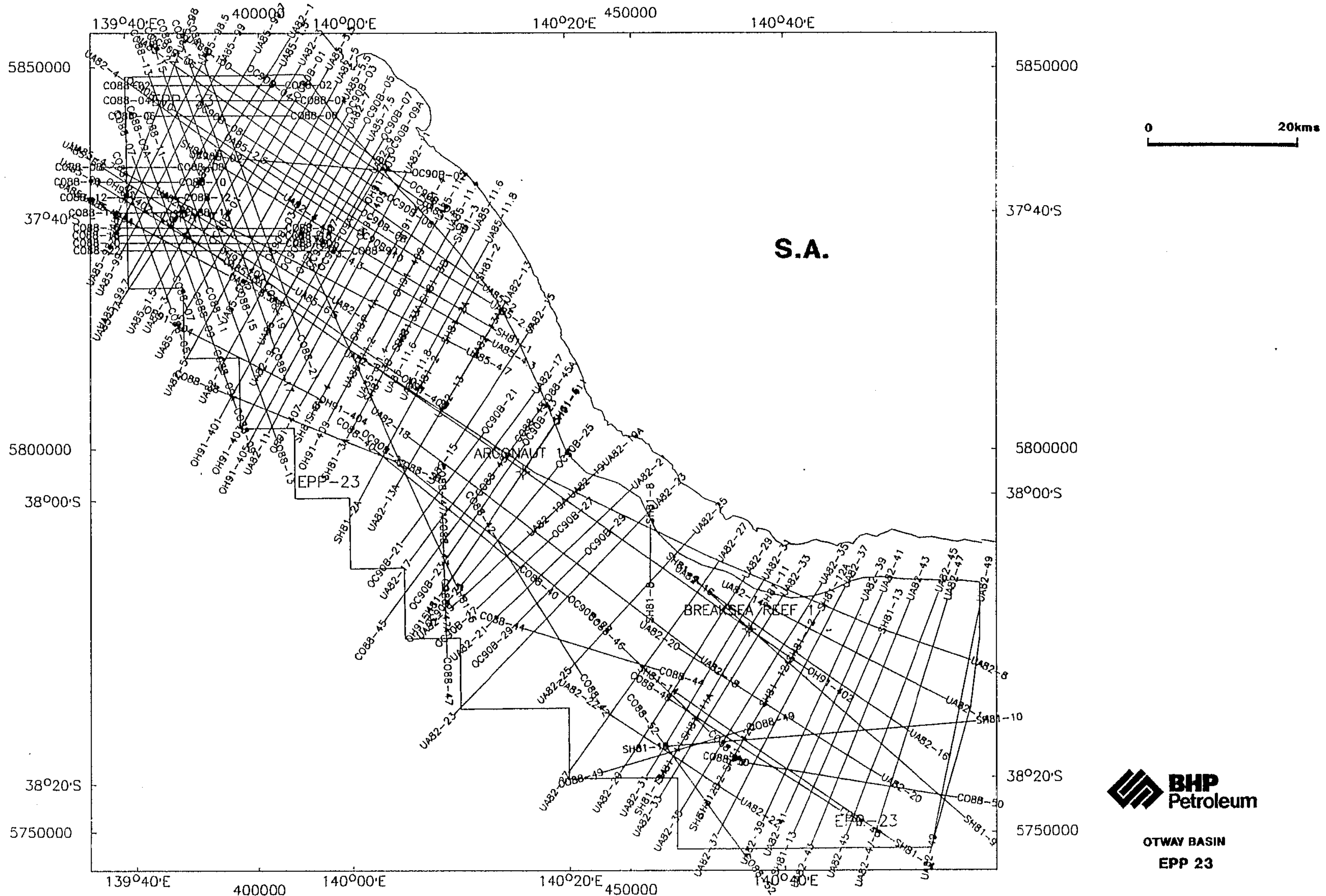
OTWAY BASIN

EPP 23

LOCATION OF WELLS

Figure 4.1.1



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OTWAY BASIN

EPP 23

POST-1980 SEISMIC DATA

Figure 4.2.1

YEAR	1972	1981	1982	1985	1988	1990	1991
OPERATOR	Esso	Shoreline	Ultramar	Ultramar	Cultus	BHPP	BHPP
SURVEY	O72A	SH81	UA82	UA85	CO88	OC90B	OH91
CONTRACTOR	GSI	Western	Western	Western	Western	Halliburton	Western
SOURCE	Airgun Array	Airgun Array	Airgun Array	Airgun Array	Airgun Array	Airgun Array	Airgun Array
GUN VOLUME	1300 cu.in	555 cu.in	760 cu.in	1530 cu.in	1565 cu.in	2180 cu.in	2250 cu.in
GUN PRESSURE	-	-	4500 psi	4600 psi	4500 psi	1800 psi	2000 psi
RECORD LENGTH	5 sec	5 sec	5 sec	5 sec	6 sec	6 sec	6 sec
SAMPLE RATE	4 ms	2 ms	2 ms	2 ms	2 ms	2 ms	2 ms
INSTRUMENTS	DFS III	DFS V	DFS V	LRS 16	LRS 16A	Titan 1000	LRS 16A
FORMAT	SEGC (712 BPI)	SEGB (1600 BPI)	SEG B (1600 BPI)	SEG D	SEG D (6250 BPI)	SEG D (6250 BPI)	SEG D (6250 BPI)
CABLE LENGTH	2350m	2375m	2375m	3200m	3200m	3750m	3200m
NO. OF GROUPS	48	96	96	240	240	300	240
NEAR TRACE OFFSET	296.5m	261.7m	194.65m	131.67m	127.9m	154m	190m
GROUP INTERVAL	50m	25m	25m	13.33m	13.33	12.5	13.33m
SHOT INTERVAL	200m	25m	25m	26.67m	26.67m	25m	26.67
FOLD	24	48	48	60	60	75	60
TOTAL KMS	-	433.3	1086.65	570.11	726.38	300.475	305.178
PROCESSED BY	GSI Sydney	Western Singapore	CCG Calgary	GECO N.Z	Horizon, WA	Digital Brisbane	Tensor Pacific Melbourne

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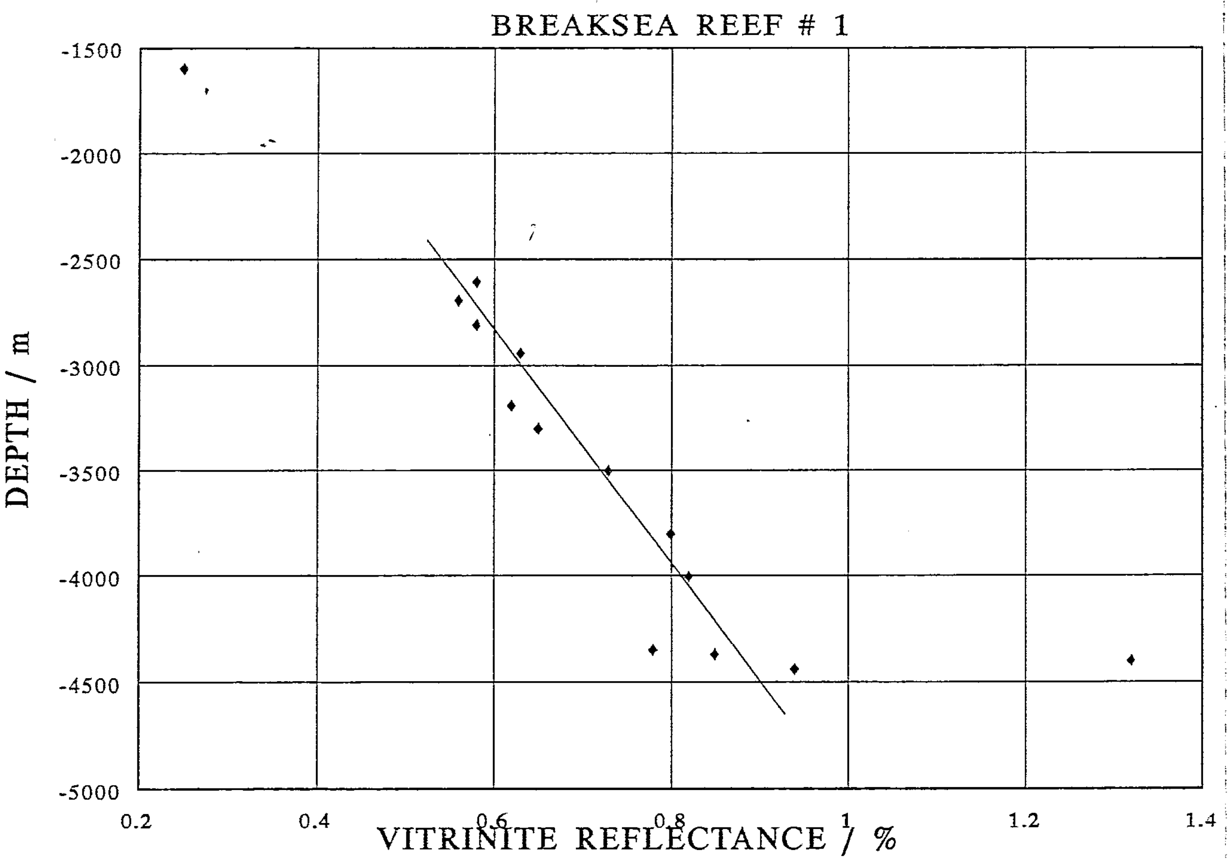
OTWAY BASIN

ACQUISITION PARAMETERS FOR 1972 AND POST-1980 SEISMIC

Figure 4.2.2



This profile is representative of that found throughout the Voluta Trough.

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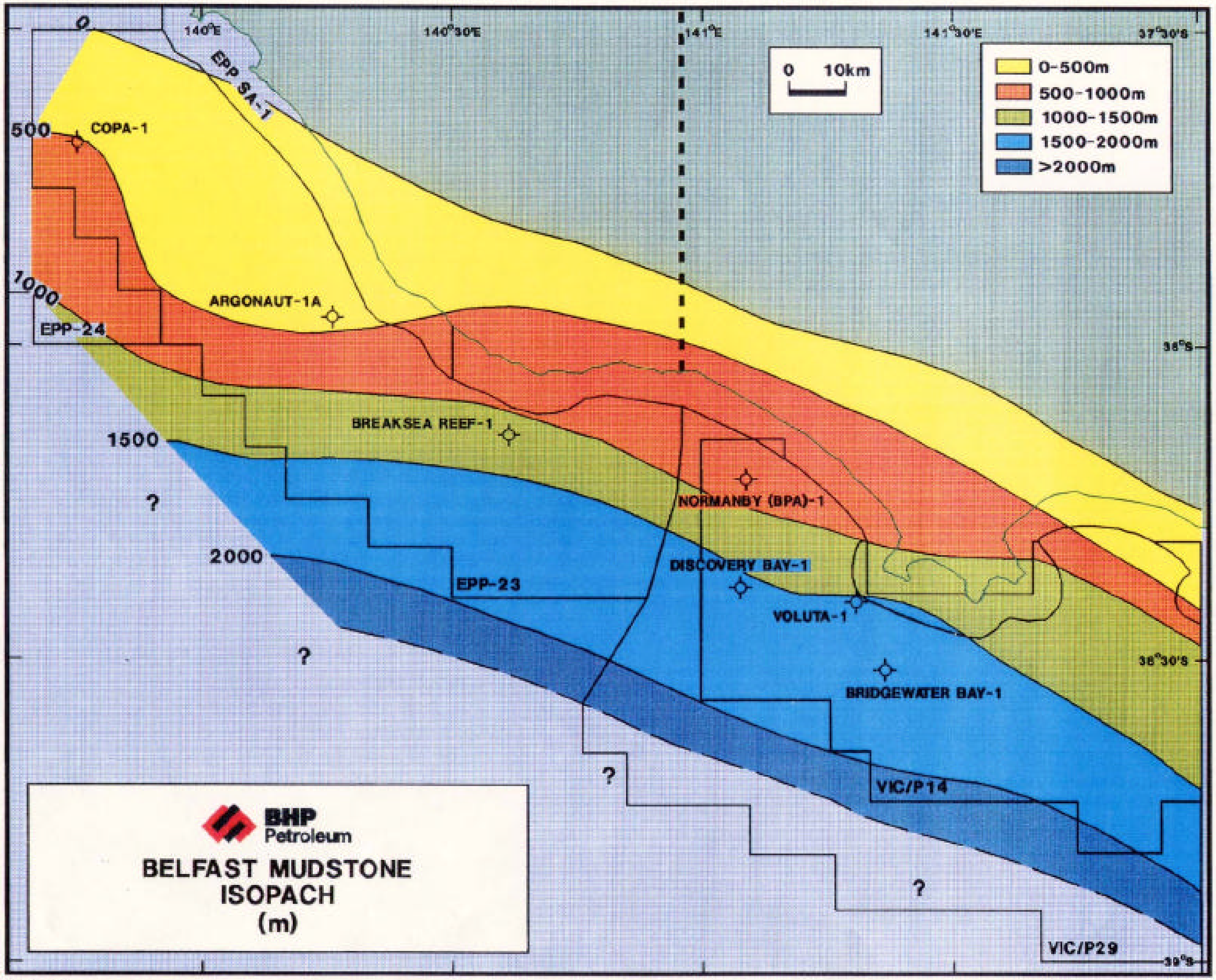
BREAKSEA REEF-1
VITRINITE REFLECTANCE PROFILE

Figure 5.1.1



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BELFAST MUDSTONE ISOPACH (m)

Figure 5.1.2

OCTOBER, 1991

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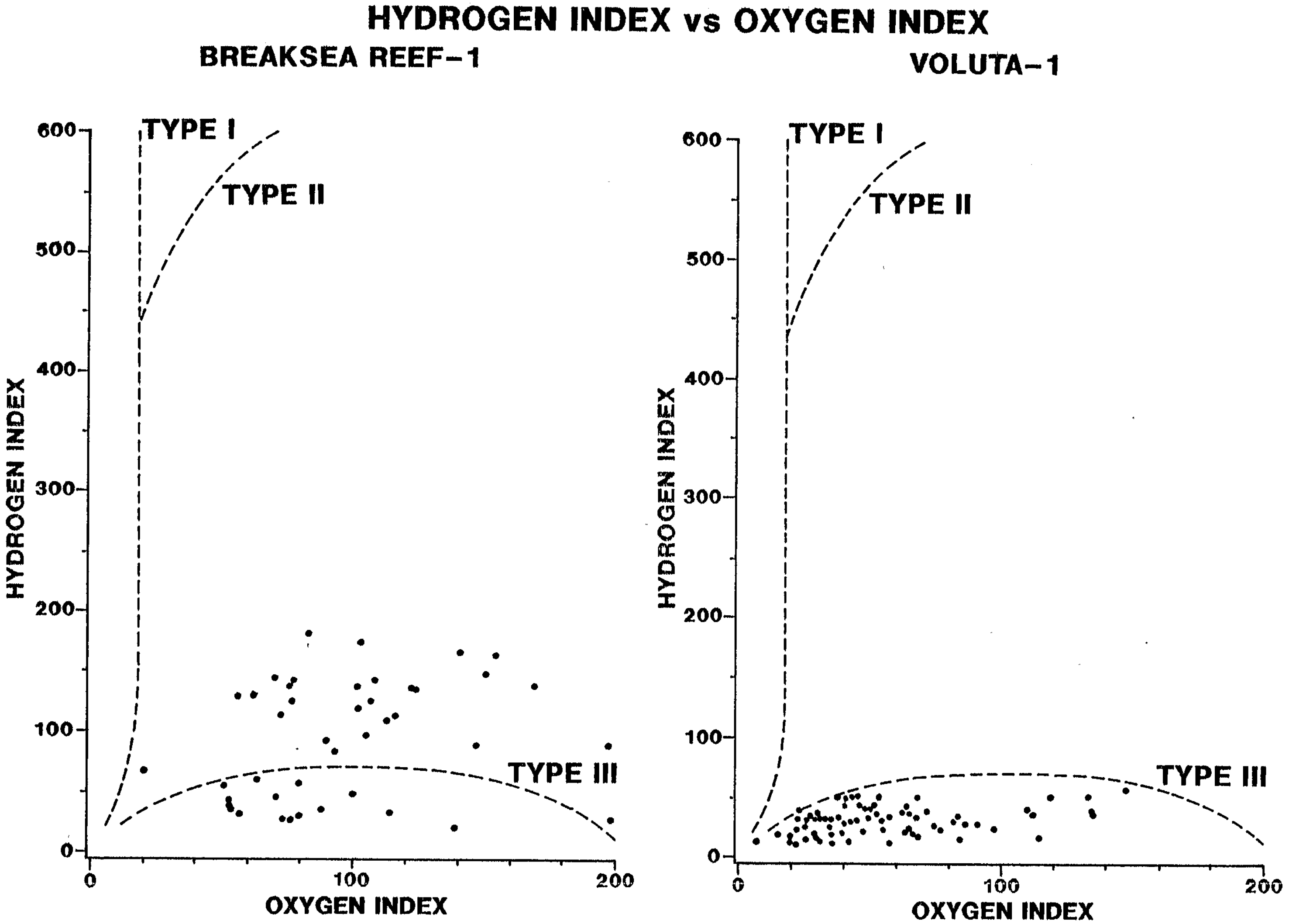
00033

BELFAST MUDSTONE SEDIMENTATION RATES - VOLUTA TROUGH

WELL	TOP BELFAST AGE/Ma	BASE BELFAST AGE/Ma	BELFAST TIME/Ma	BELFAST THICKNESS/m	SEDIMENTATION RATE/m/Ma
COPA #1	86+/-1	89+/-1	3	501	167
ARGONAUT #1	87+/-1	89+/-1	2	481	241
BREAKSEA REEF #1	86+/-1	91+/-1	5	1360	272
NORMANBY #1	85+/-1	92+/-1	7	684	98
VOLUTA #1	84+/-1	92+/-2	8	1810	226
BRIDGEWATER BAY #1	85+/-1	92+/-2	7	1420	203

AGE OF TOP AND BASE BELFAST BASED ON SPORE-POLLEN & DINOFLAGELLATE ZONATION

Figure 5.1.3



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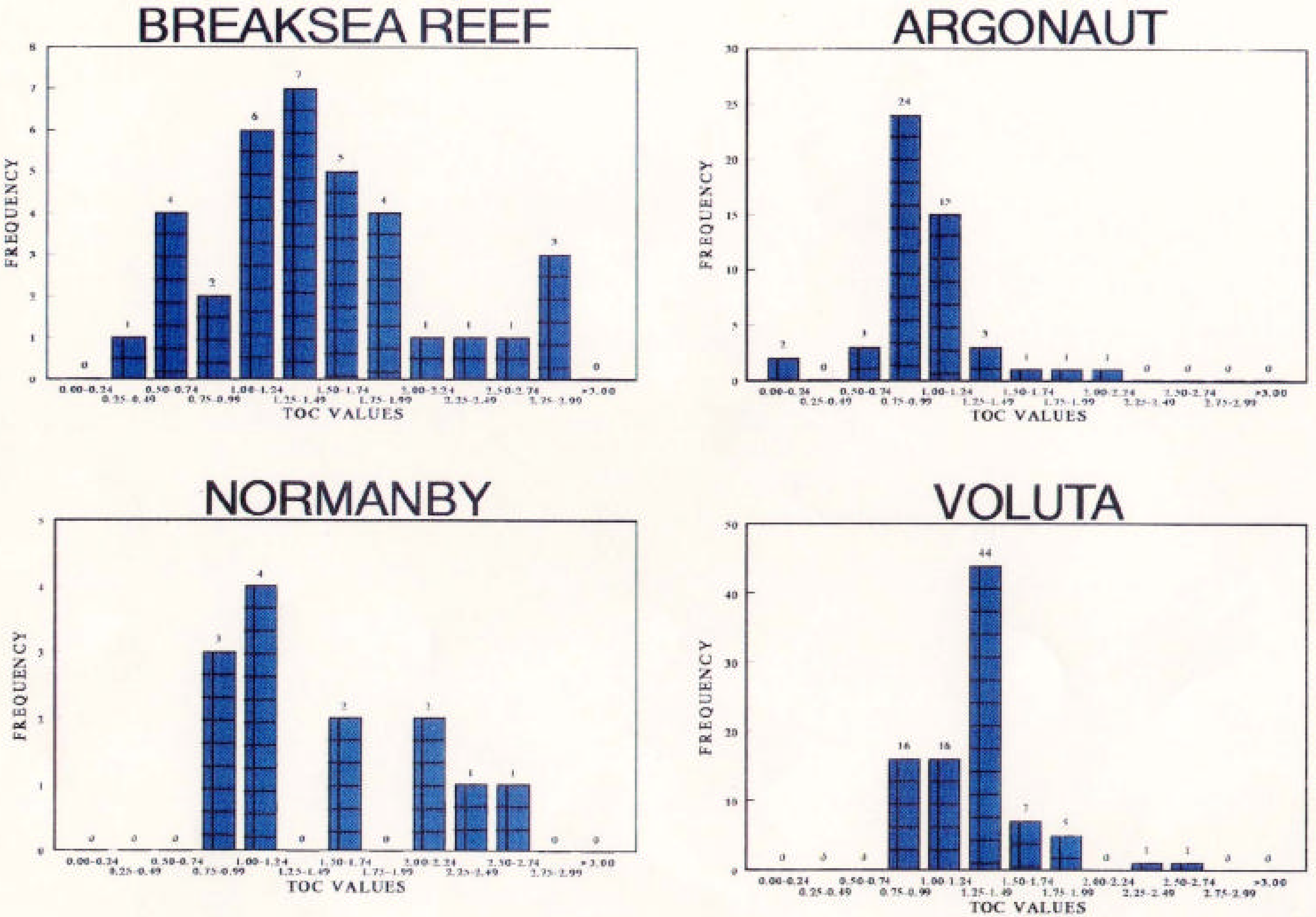
OTWAY BASIN

MODIFIED VAN KREVELEN DIAGRAMS FOR THE BELFAST MUDSTONE FORMATION

Figure 5.1.4



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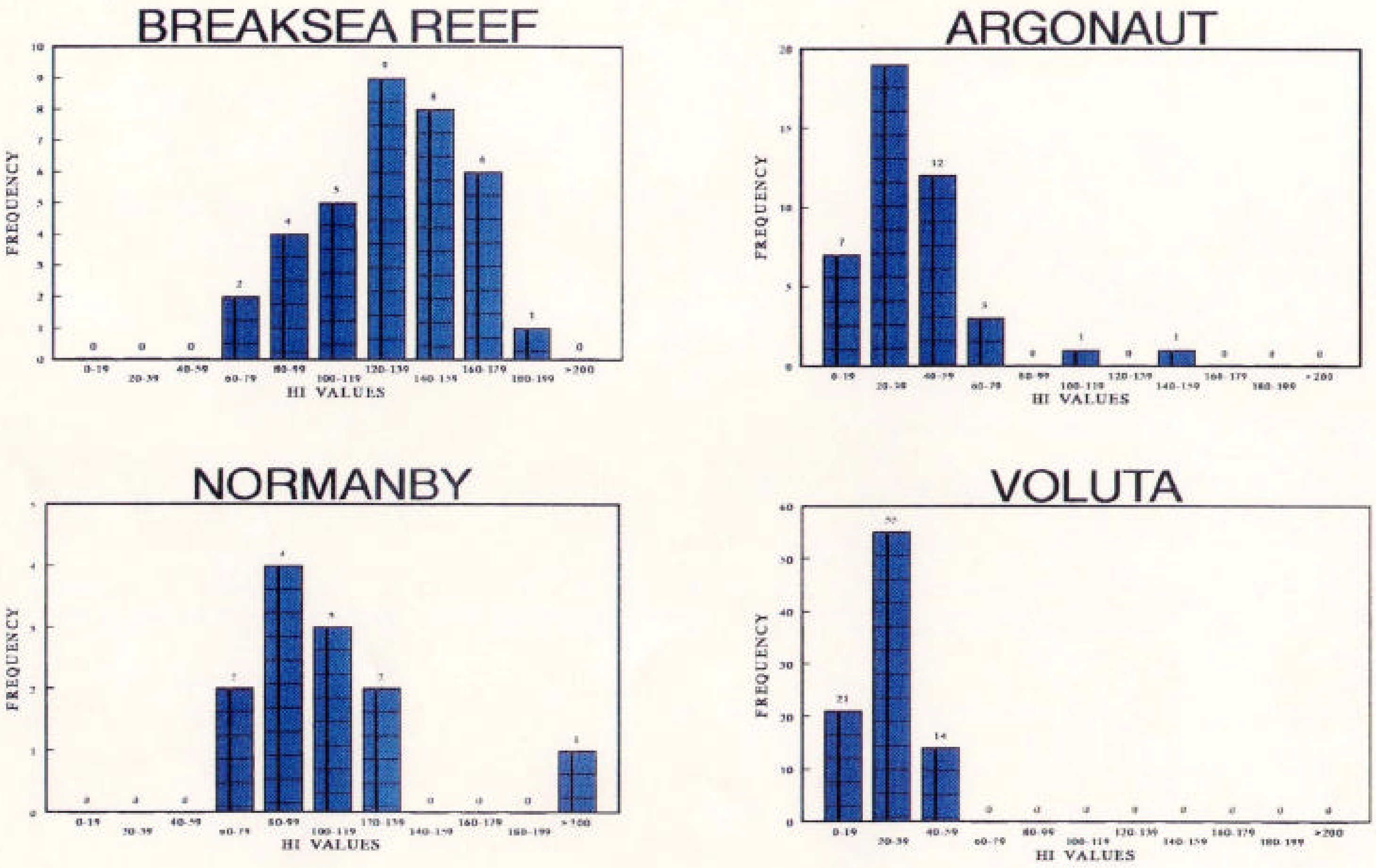
FREQUENCY OF TOC VALUES WITHIN THE BELFAST MUDSTONE FOR SELECTED OTWAY BASIN WELLS

Figure 5.1.5



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FREQUENCY OF HI VALUES WITHIN BELFAST MUDSTONE FOR SELECTED OTWAY BASIN WELLS

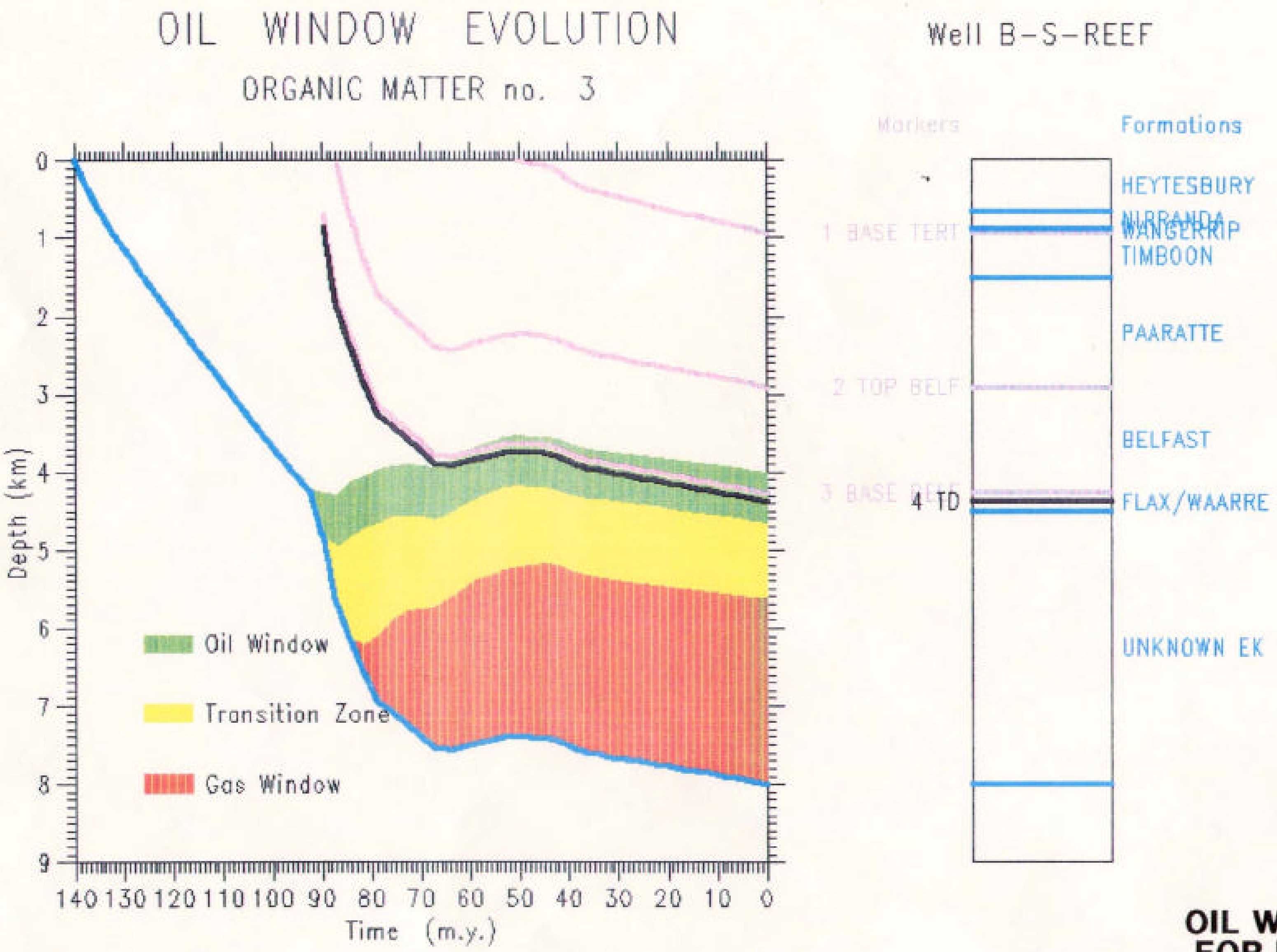
Figure 5.1.6

BELFAST MUDSTONE ORGANIC MATTER PROPERTIES - VOLUTA TROUGH

WELL	TOC/wt%		HI/mg/gTOC	
	RANGE	MEAN	RANGE	MEAN
COPA #1	0.71-1.16	0.89	46-128	72
ARGONAUT #1	0.71-1.31	0.96	20-149	44
BREAKSEA REEF #1	0.48-2.94	1.51	63-181	133
NORMANBY #1	0.90-2.50	1.46	64-356	114
VOLUTA #1	0.75-2.56	1.30	10-59	28
BRIDGEWATER BAY #1	0.55-2.93	1.30	28-211	84
NIGER DELTA MIOCENE TO OLIGOCENE SOURCE ROCK SHALES *				
40/6-ADC1	0.67-3.65	1.70	37-157	88
35/22-OU1	0.61-1.18	0.78	52-139	80

* NIGER DELTA DATA FROM EKWEOZOR & TELNAES, 1990

Figure 5.1.7



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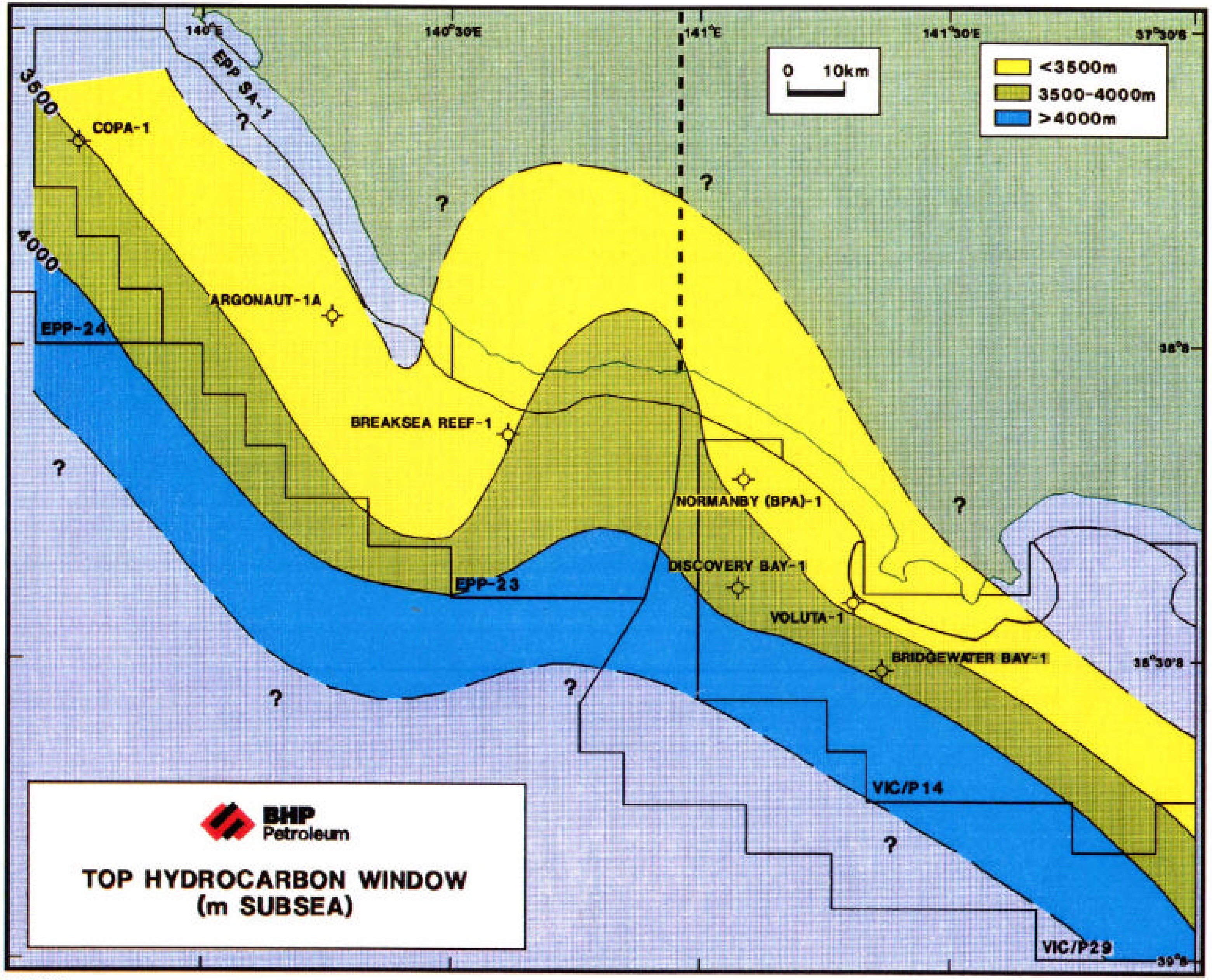
OTWAY BASIN
EPP 23

OIL WINDOW EVOLUTION
FOR BREAKSEA REEF-1

Figure 5.1.8

00039



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TOP HYDROCARBON WINDOW
(m SUBSEA)

Figure 5.1.9

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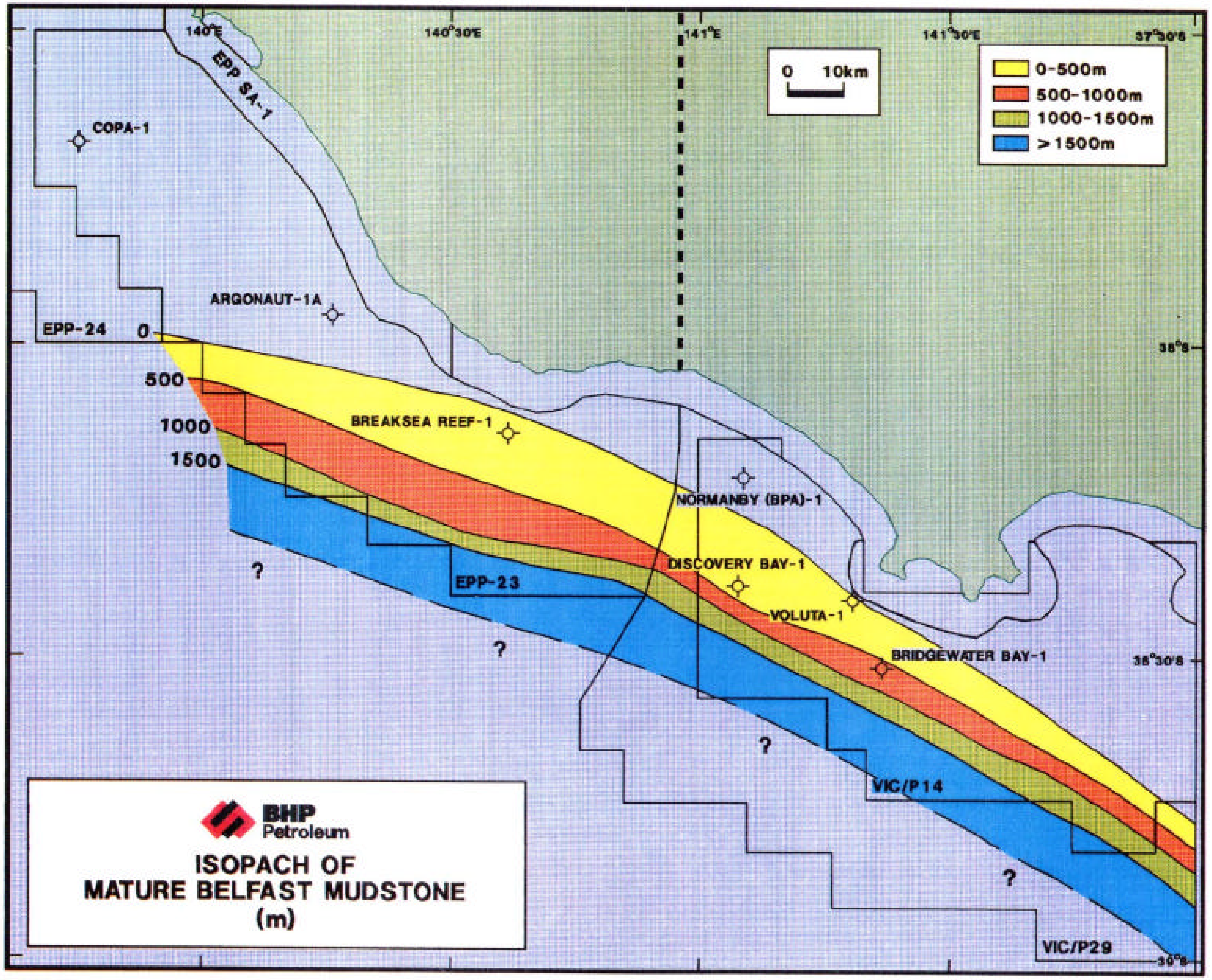
Figure 5.1.10



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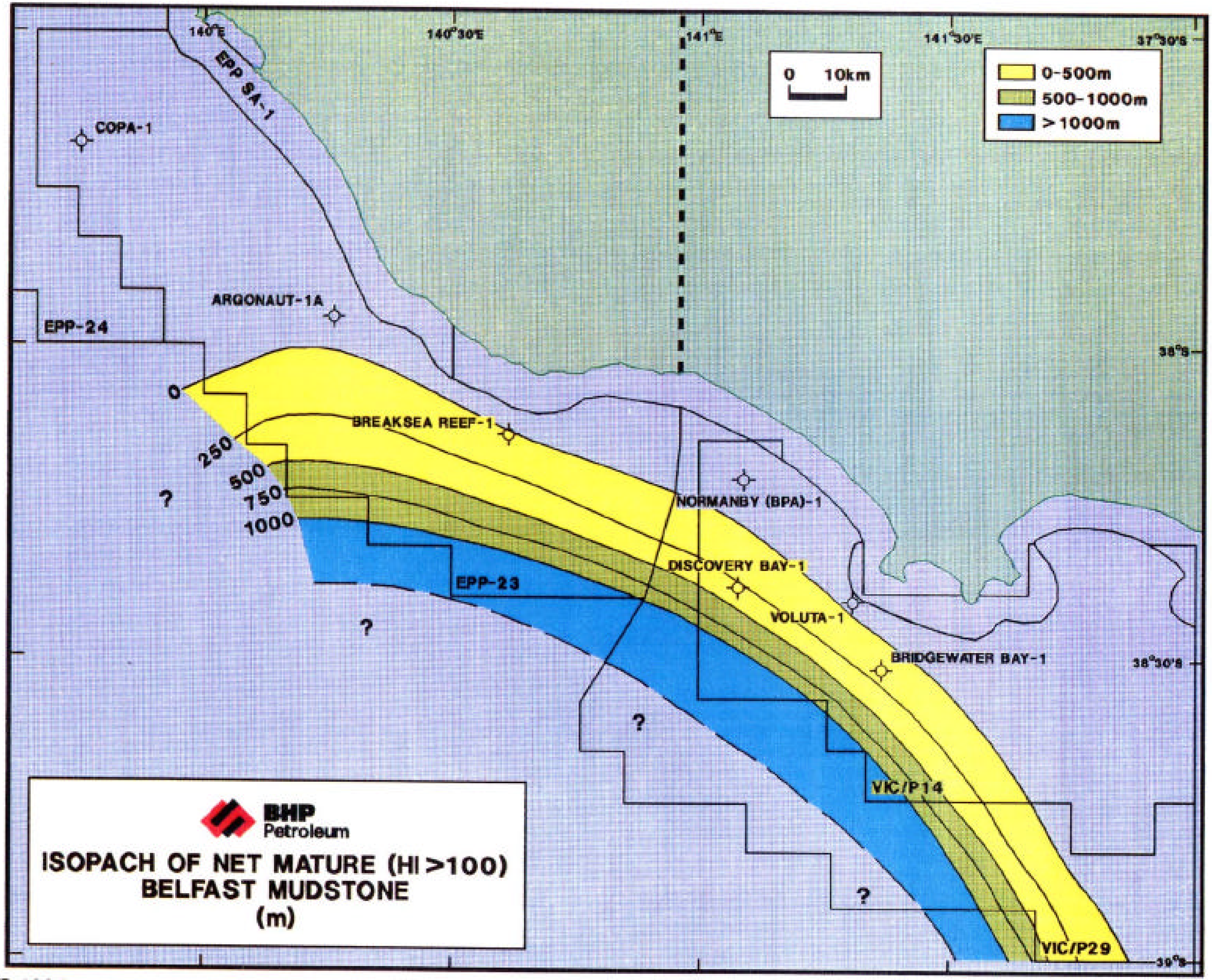
ISOPACH OF
MATURE BELFAST MUDSTONE
(m)

OCTOBER, 1991

C3550

Figure 5.1.11



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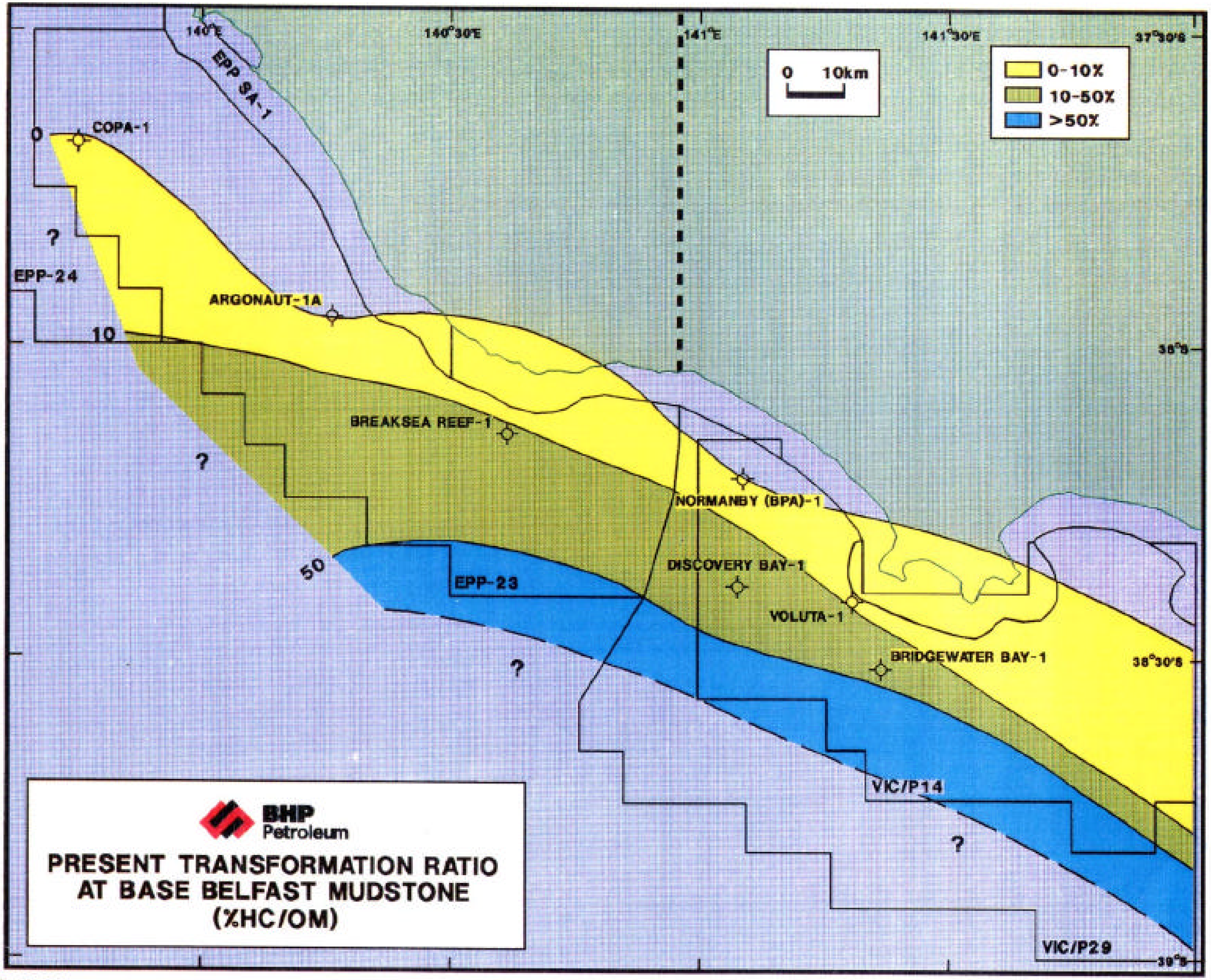
ISOPACH OF NET MATURE (HI >100) BELFAST MUDSTONE (m)

OCTOBER, 1991

C3551

Figure 5.1.12



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PRESENT TRANSFORMATION RATIO AT BASE BELFAST MUDSTONE (%HC/OM)

OCTOBER, 1991

C3547

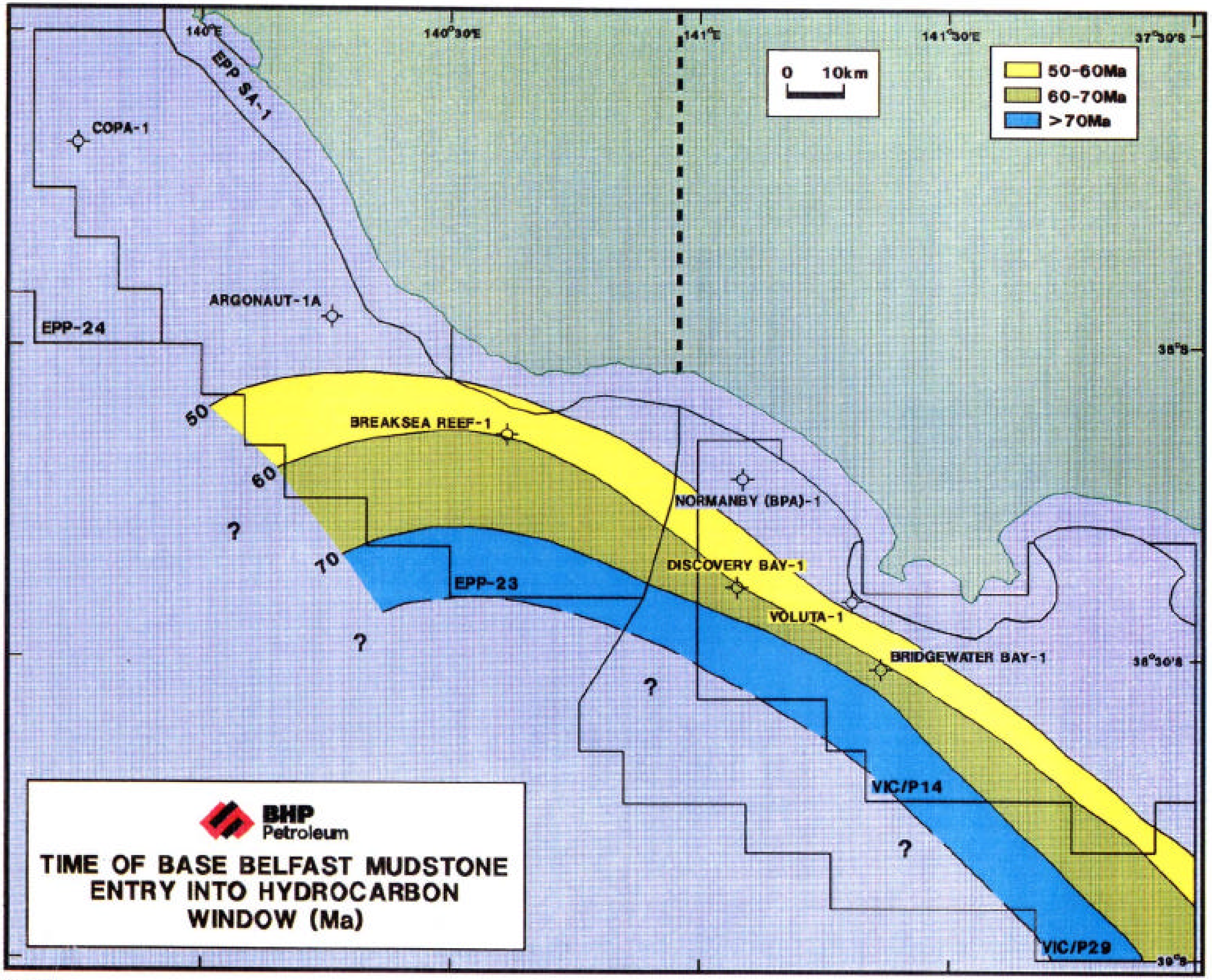


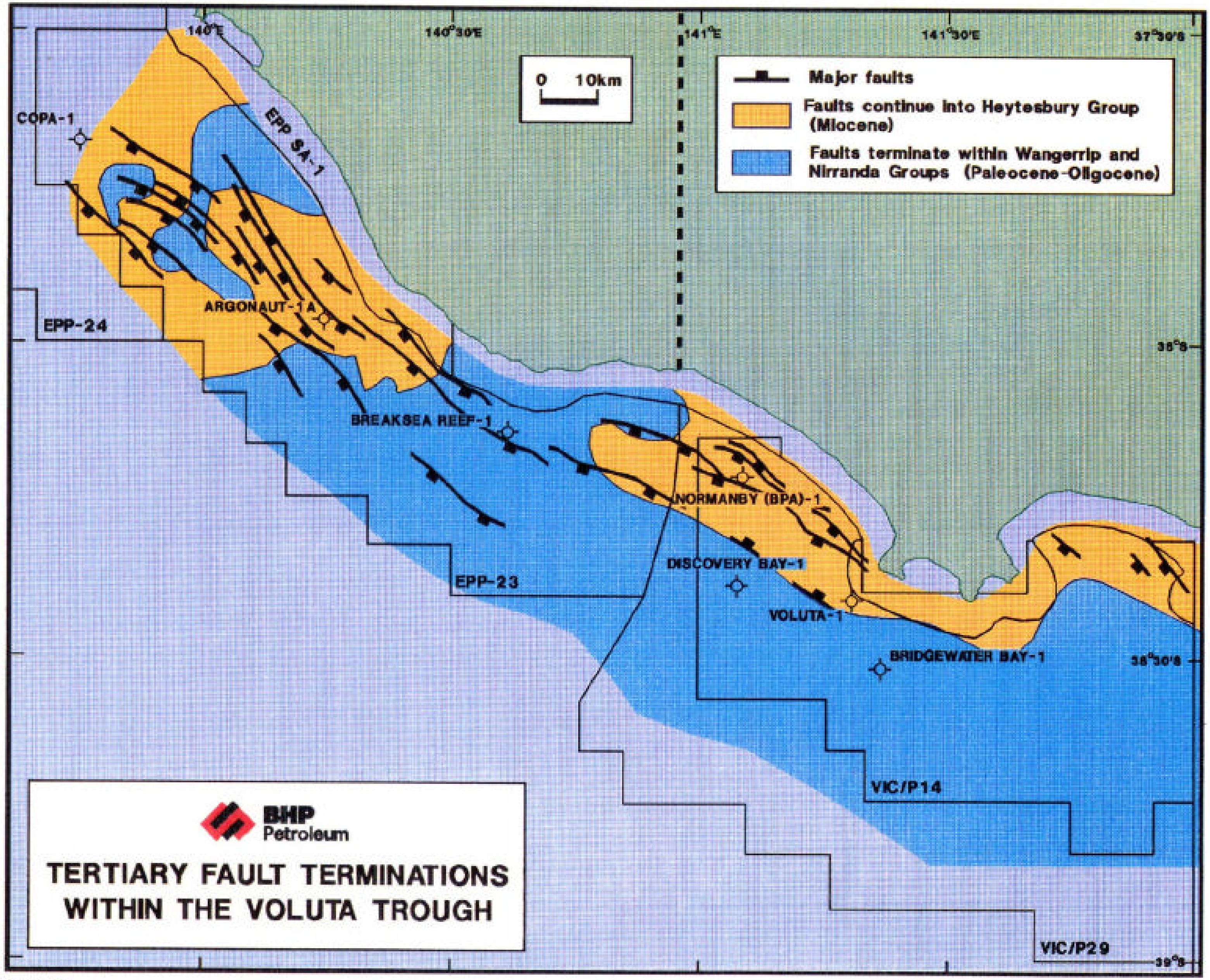
Figure 5.1.13

TIME OF BASE BELFAST MUDSTONE ENTRY INTO HYDROCARBON WINDOW (Ma)

OCTOBER, 1991

C3552

Figure 5.1.14



TERTIARY FAULT TERMINATIONS WITHIN THE VOLUTA TROUGH

OCTOBER, 1991

c3692

$$\text{Petroleum Yield} = [(TOC) \times (HI) \times K \times f \times A \times T] + [(S1) \times 100 \times K]$$

where TOC = %Total Organic Carbon
HI = Hydrogen Index from Rock-Eval pyrolysis
K = Conversion constant (0.168 for shales)
f = Thermal maturity as a fraction
A = Area of source rock (in km^2)
T = Thickness of source rock (in km)
S1 = Free hydrocarbon yield from Roc-Eval pyrolysis

Belfast Mudstone with HI>100 is taken to have source potential. For this portion of the Belfast Mudstone:

TOC = 1.15
HI = 141
S1 = 0.93

Representative values for:

f = 0.2
T = 0.2

Area necessary to generate 100 MMBBL OE = 77.4 km^2.

Accumulatable Hydrocarbons = (Petroleum yield) x (Expulsion Efficiency) x (Accumulation Efficiency).

Expulsion efficiency for gas may be taken as 0.5, while accumulation efficiency for long migration from a poorly defined catchment area is likely to be in the range 0.05 to 0.15. Using these criteria, the total area of Belfast Mudstone 200 m thick needed to accumulate 100 MMBBL OE is 3657 to 1209 km^2. This is equivalent to a circle of radius 20 to 34 km.

Figure 5.1.15. Volumetric calculations for the Belfast Mudstone Formation within the Voluta Trough.

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RELATIVE TIMINGS WITHIN THE VOLUTA TROUGH

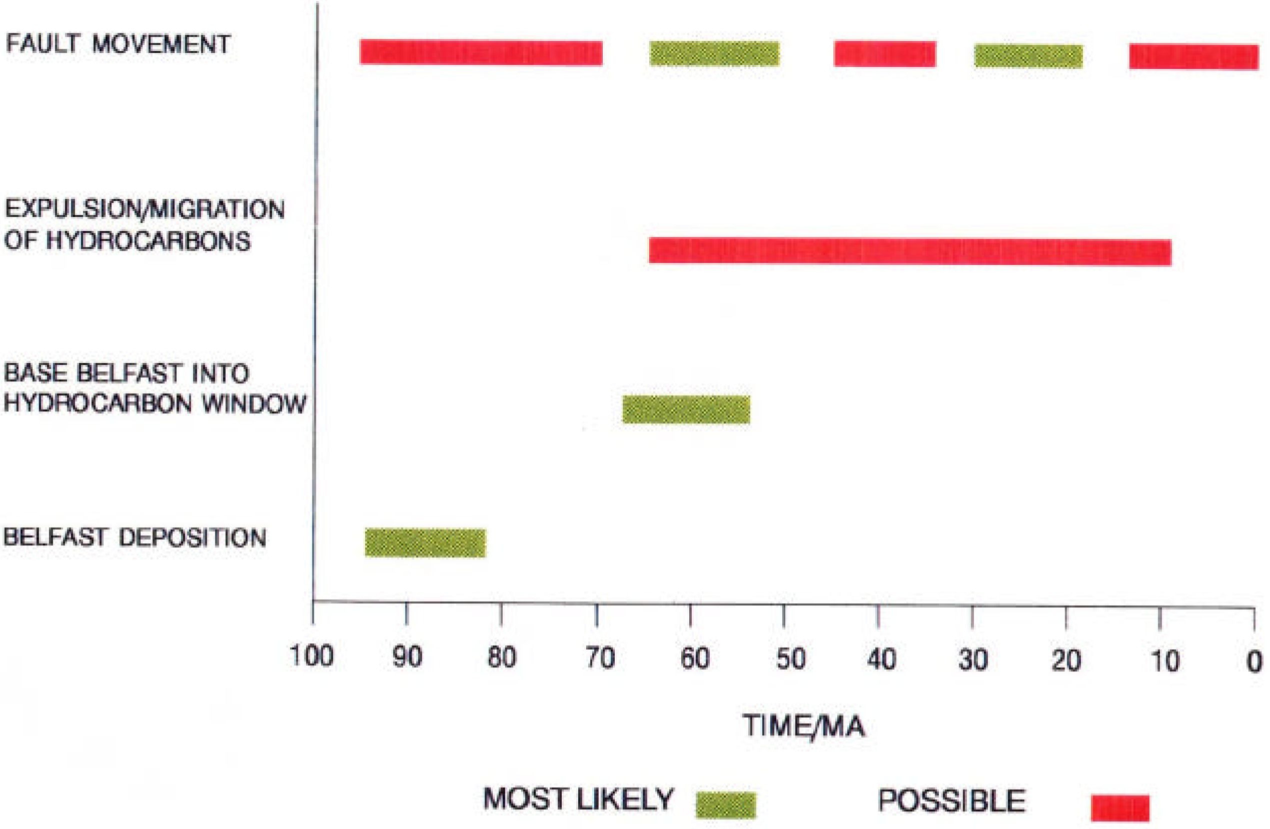
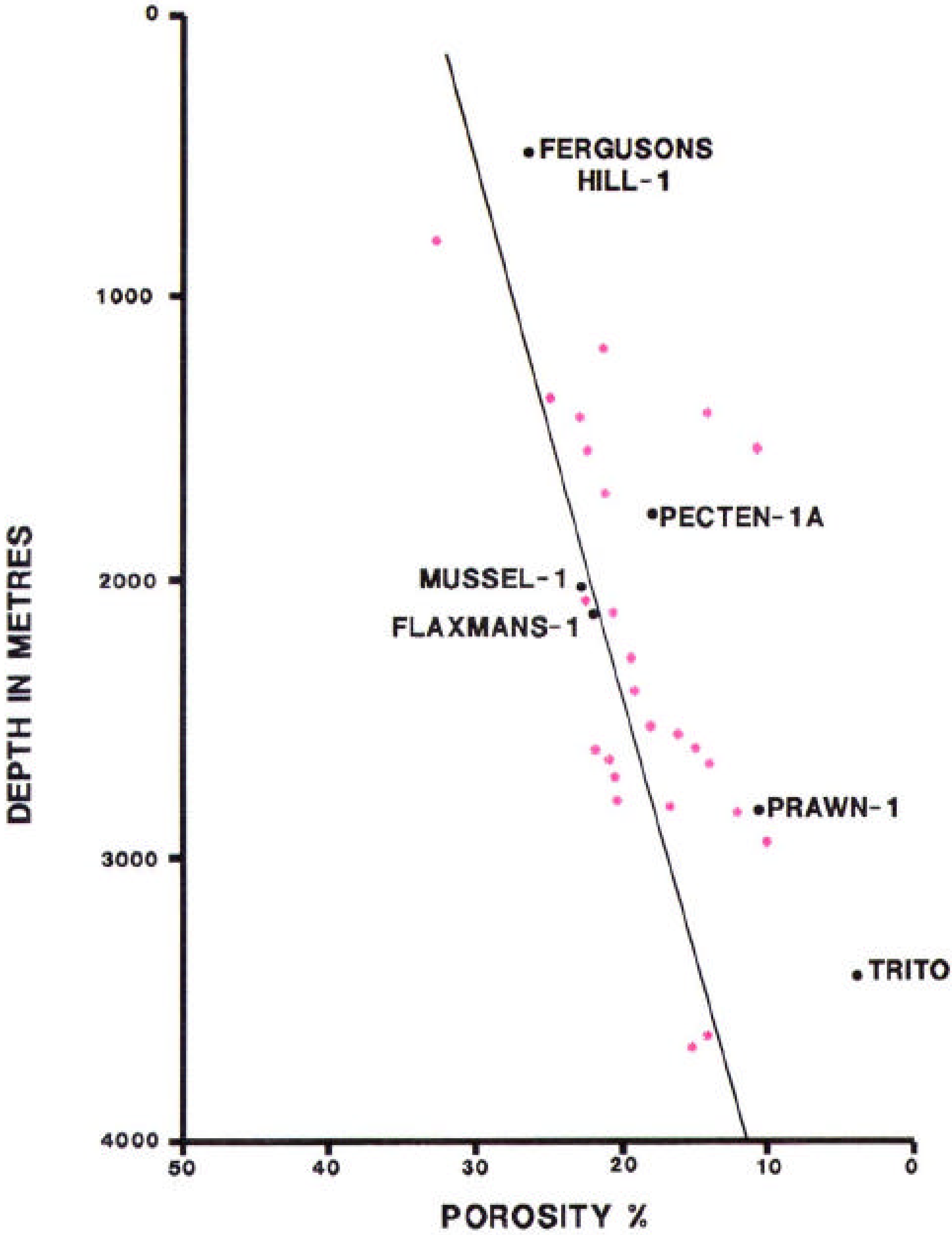


Figure 5.1.16 Relative timings withing the Voluta Trough.



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OTWAY BASIN

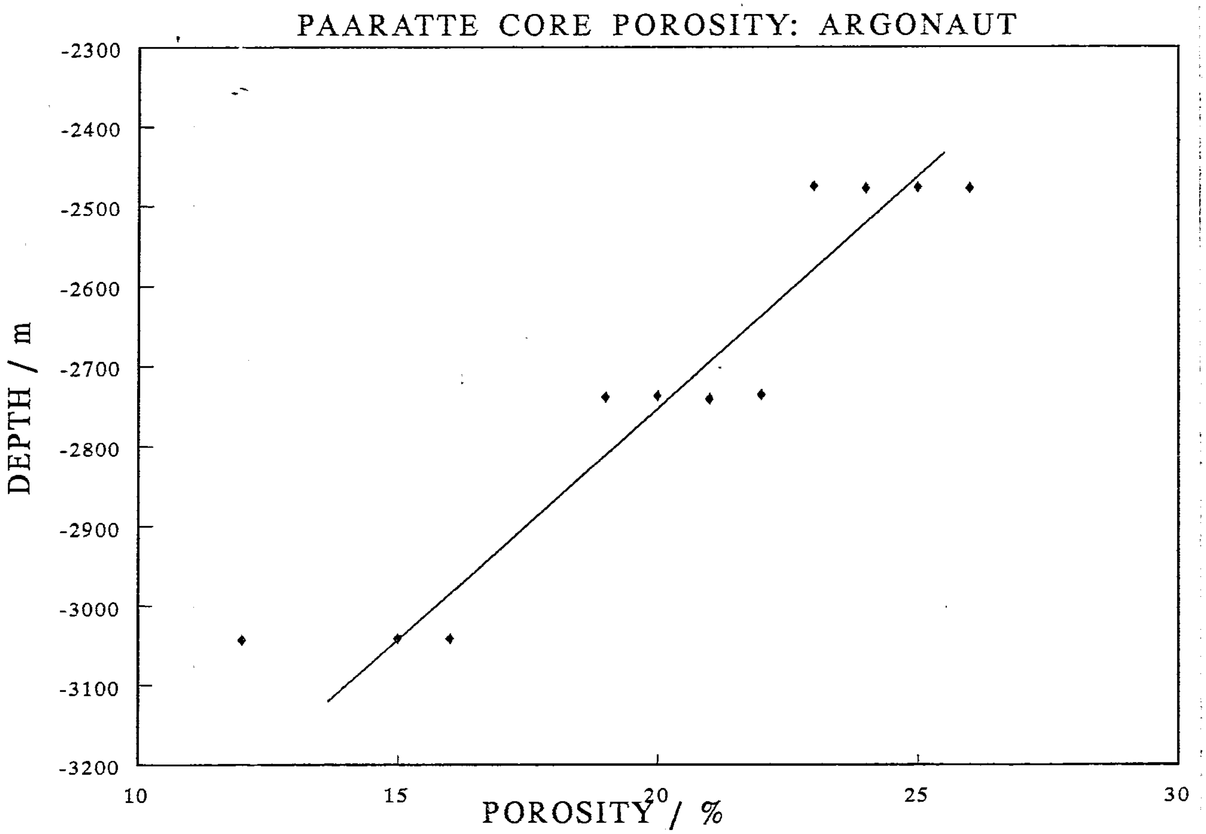
POROSITY vs DEPTH WAARRE FORMATION

Fig. 6.1.1

Author : D.Pickavance

OCTOBER, 1990

C2891



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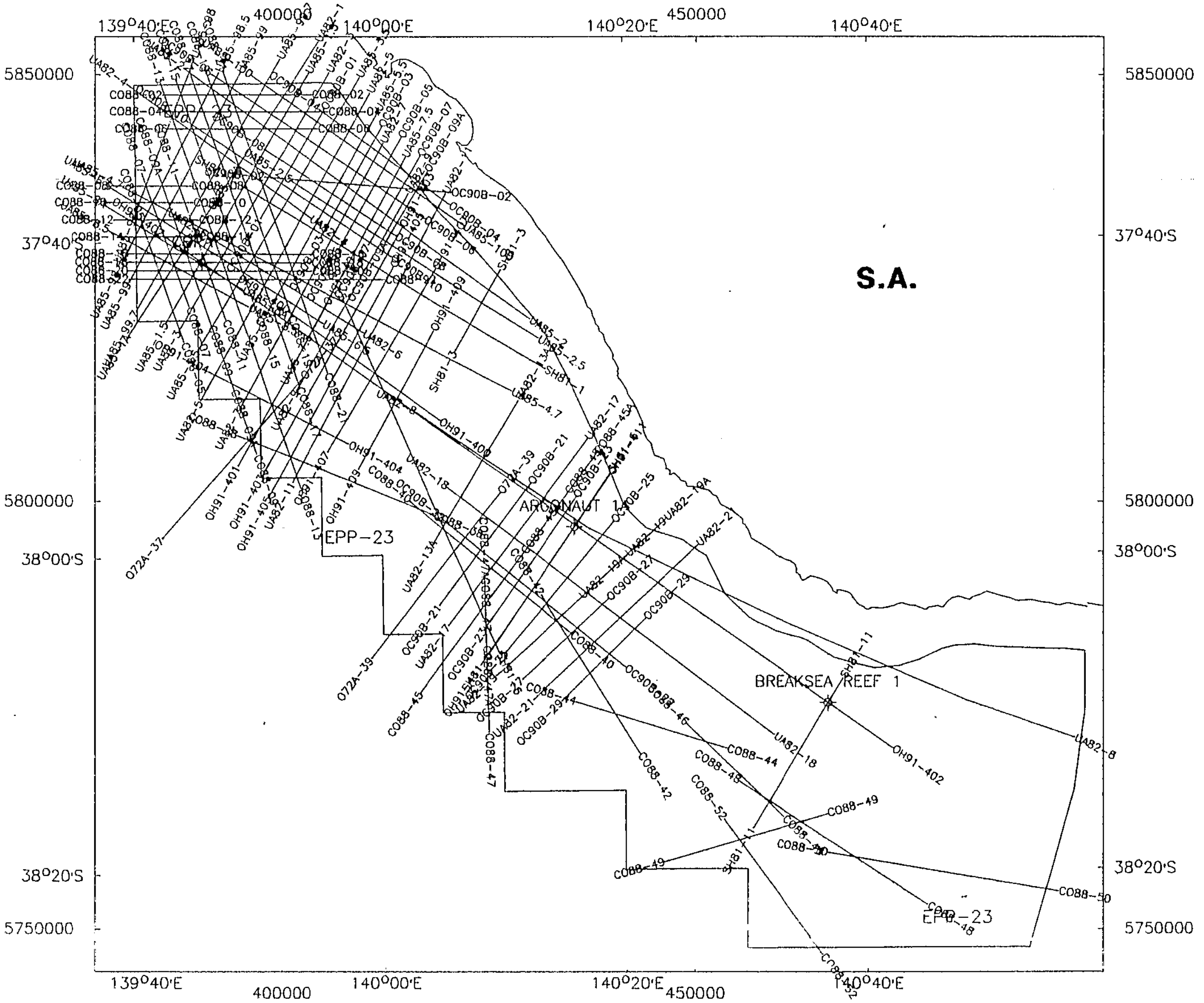
PAARATTE FORMATION (ARGONAUT-1A) POROSITY vs DEPTH

Figure 6.1.2



0 20kms

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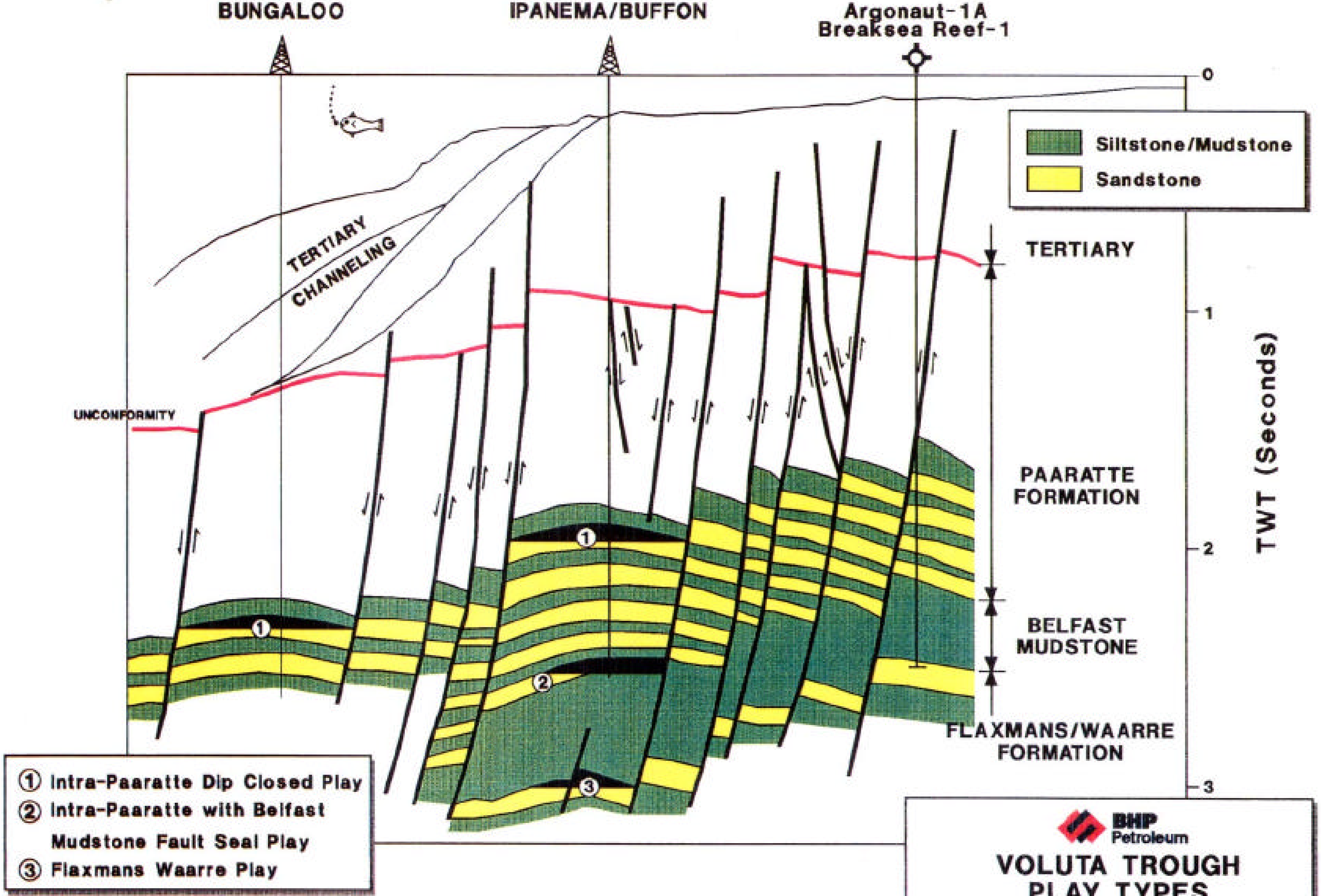
OTWAY BASIN

EPP 23

SEISMIC DATA ON INTERACTIVE WORKSTATION

Figure 7.1.1

000520



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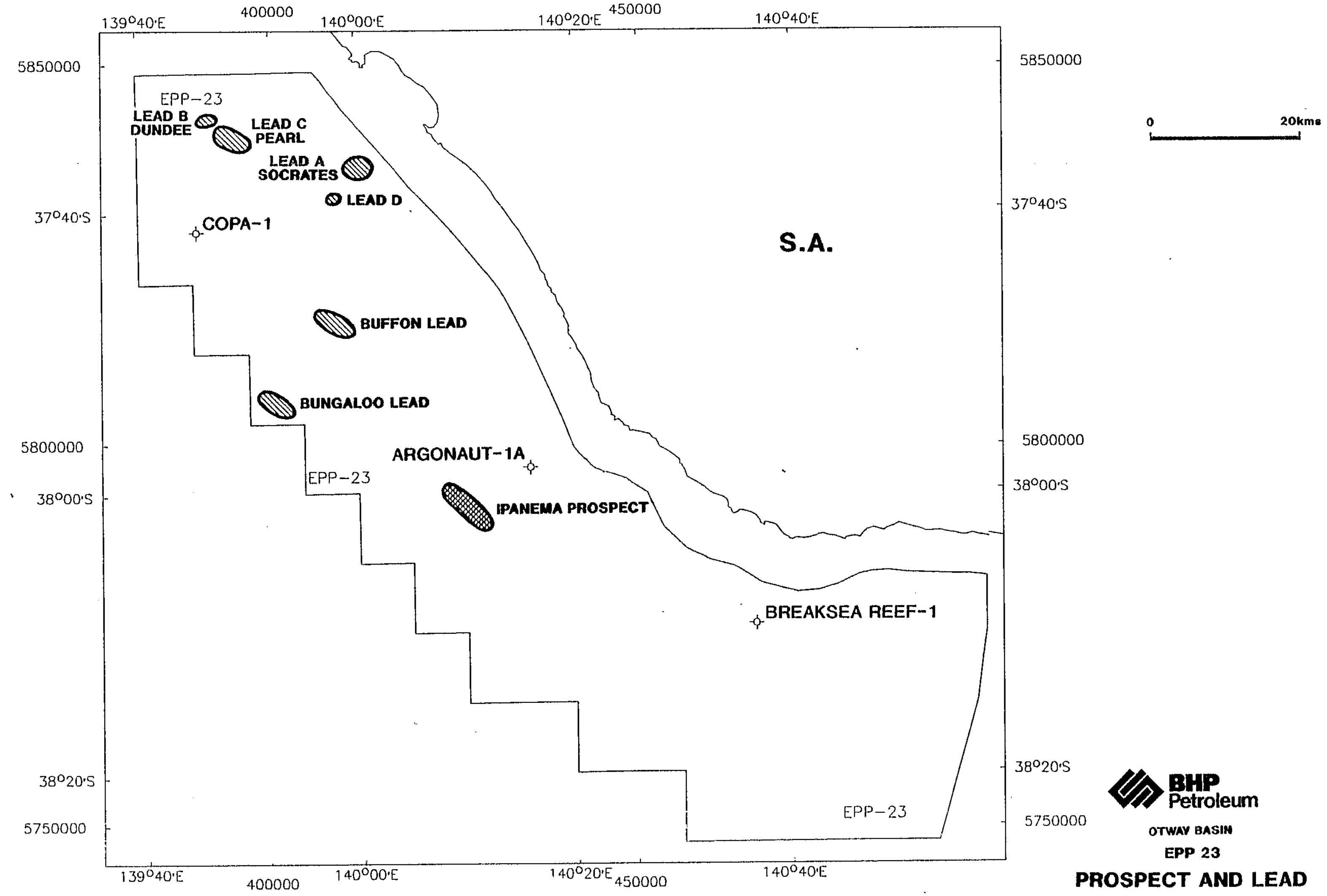
VOLUTA TROUGH
PLAY TYPES
Figure 8.1.1

OCTOBER, 1991

C3541



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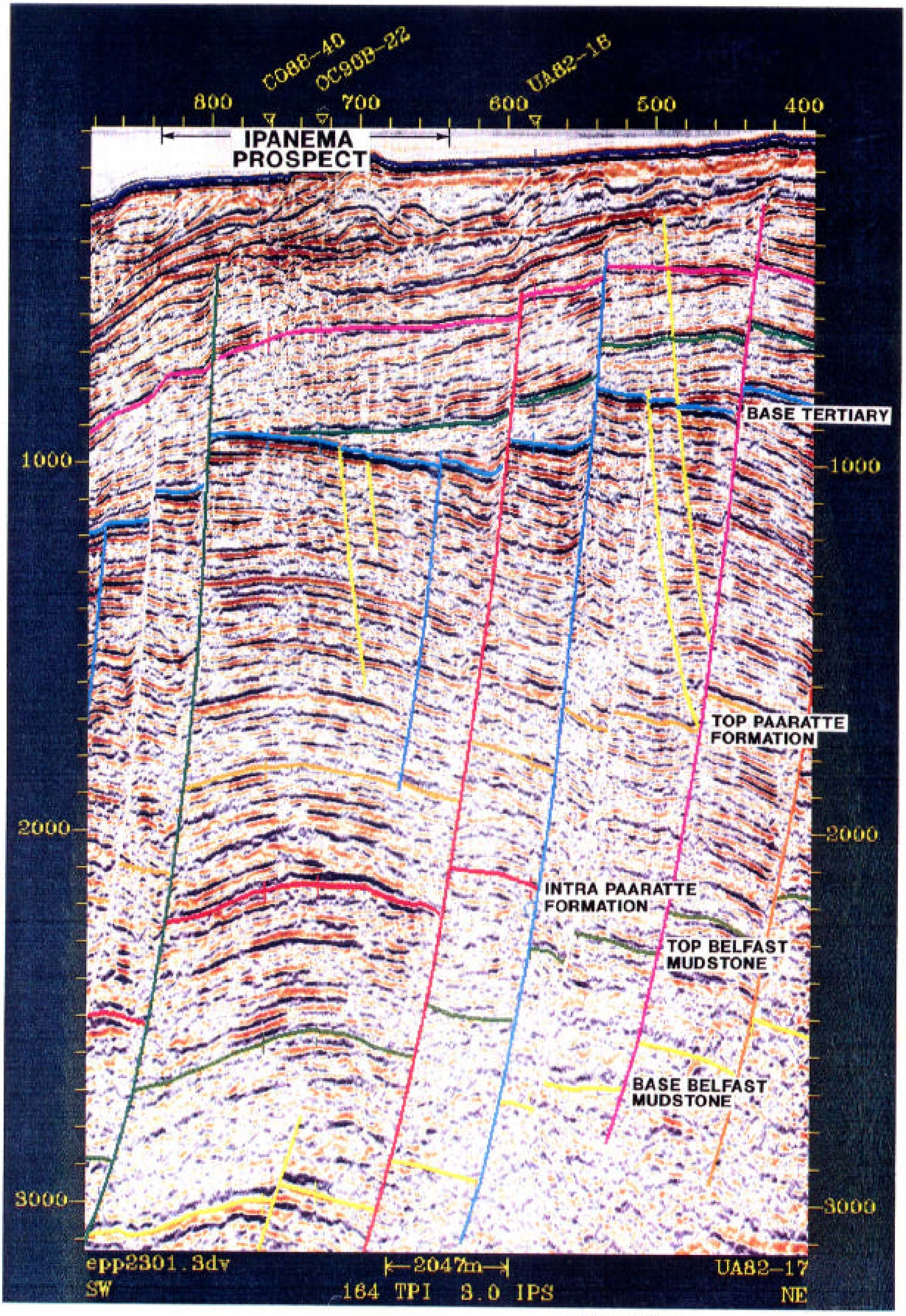
OTWAY BASIN

EPP 23

PROSPECT AND LEAD LOCATIONS

Figure 8.1.2



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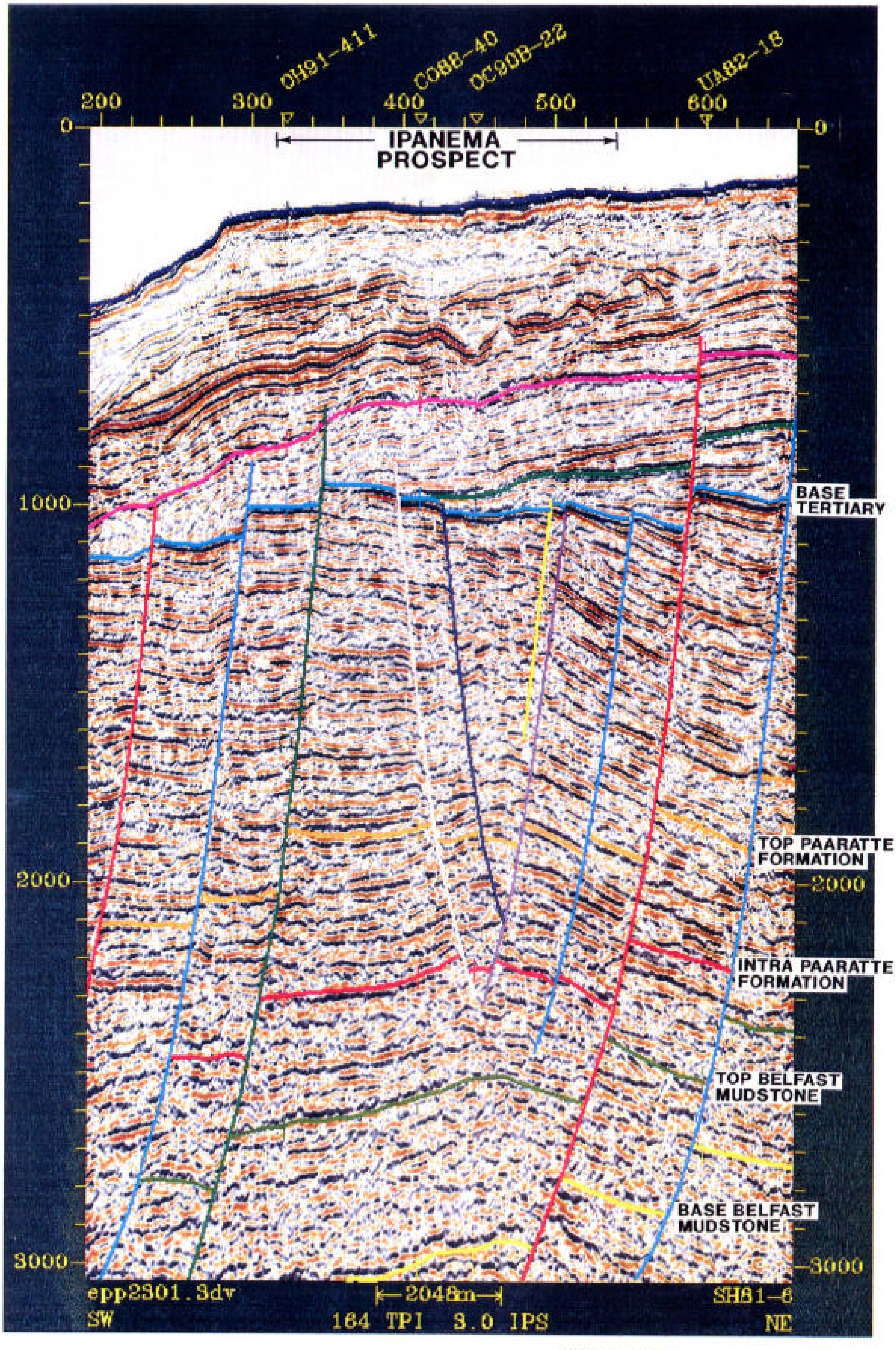
OTWAY BASIN
EPP 23

**IPANEMA PROSPECT
SEISMIC LINE UA82-17**

Figure 8.2.1



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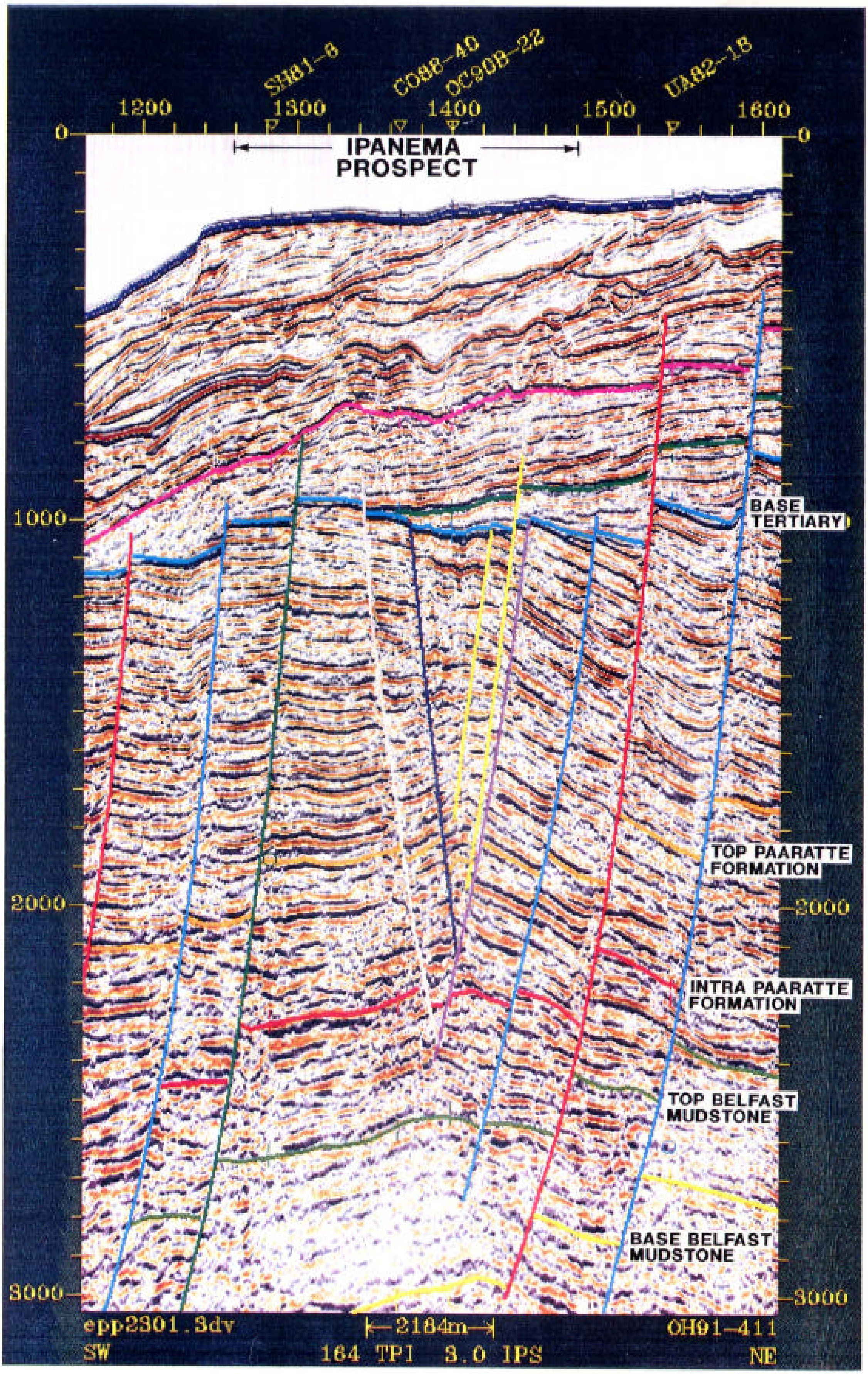
OTWAY BASIN
EPP 23

IPANEMA PROSPECT
SEISMIC LINE SH81-6

Figure 8.2.2



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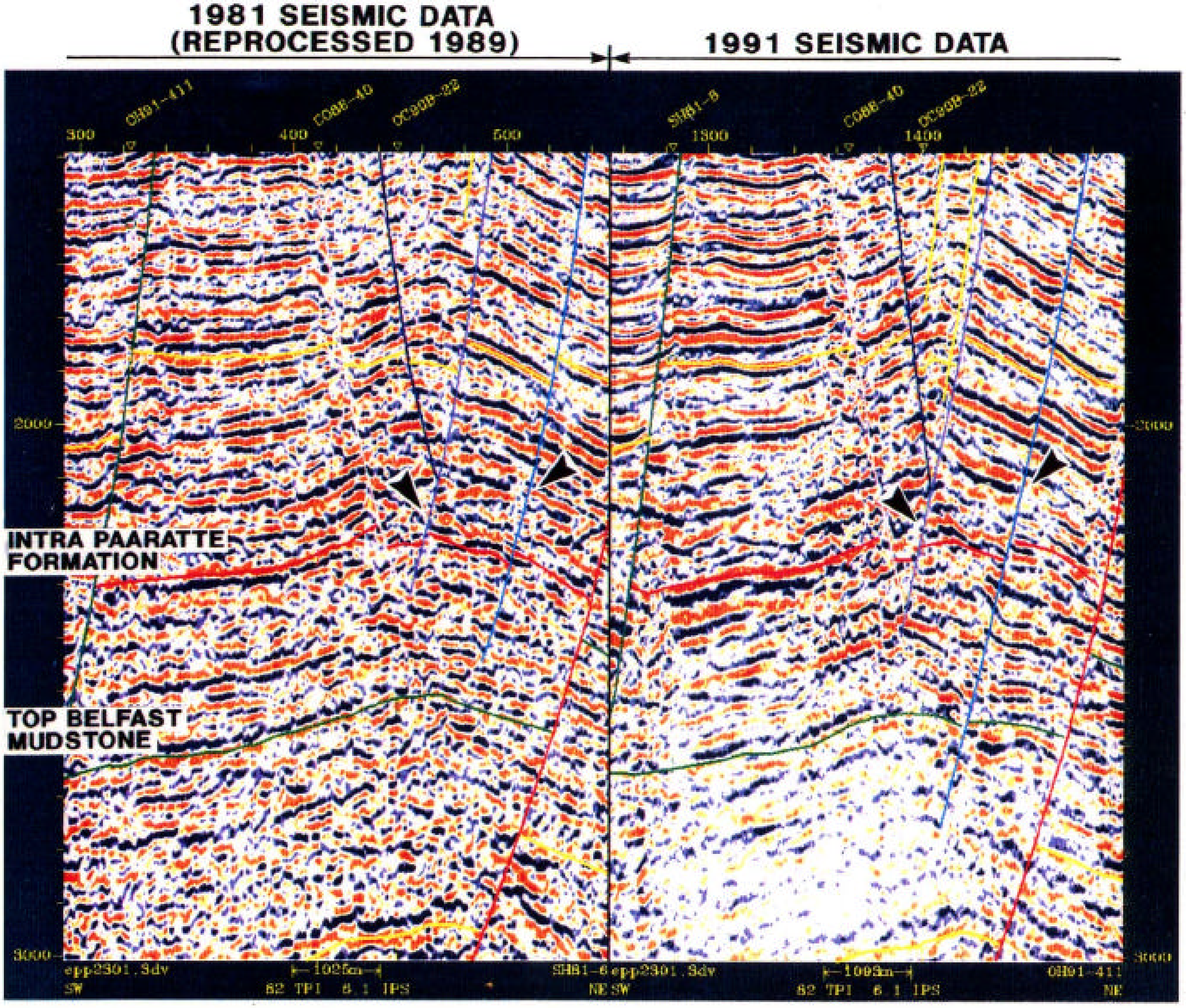
OTWAY BASIN
EPP 23

IPANEMA PROSPECT
SEISMIC LINE OH91-411

Figure 8.2.3



NOTE THE IMPROVED RESOLUTION OF THE ARROWED FAULTS

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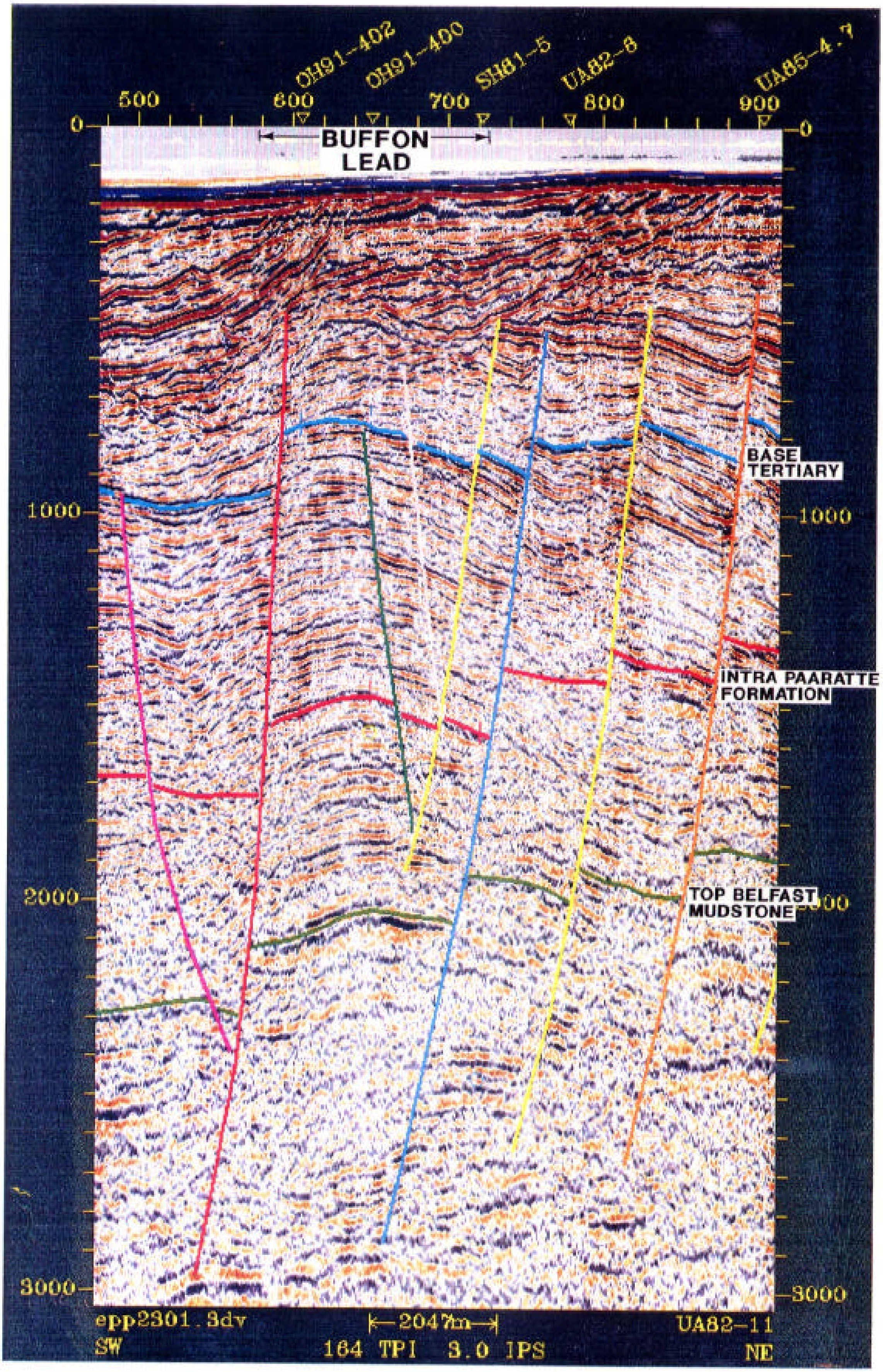
OTWAY BASIN
EPP 23

IPANEMA PROSPECT
SEISMIC DATA COMPARISON BETWEEN LINE SH81-6 (1981) AND OH91-411 (1991)

Figure 8.2.4



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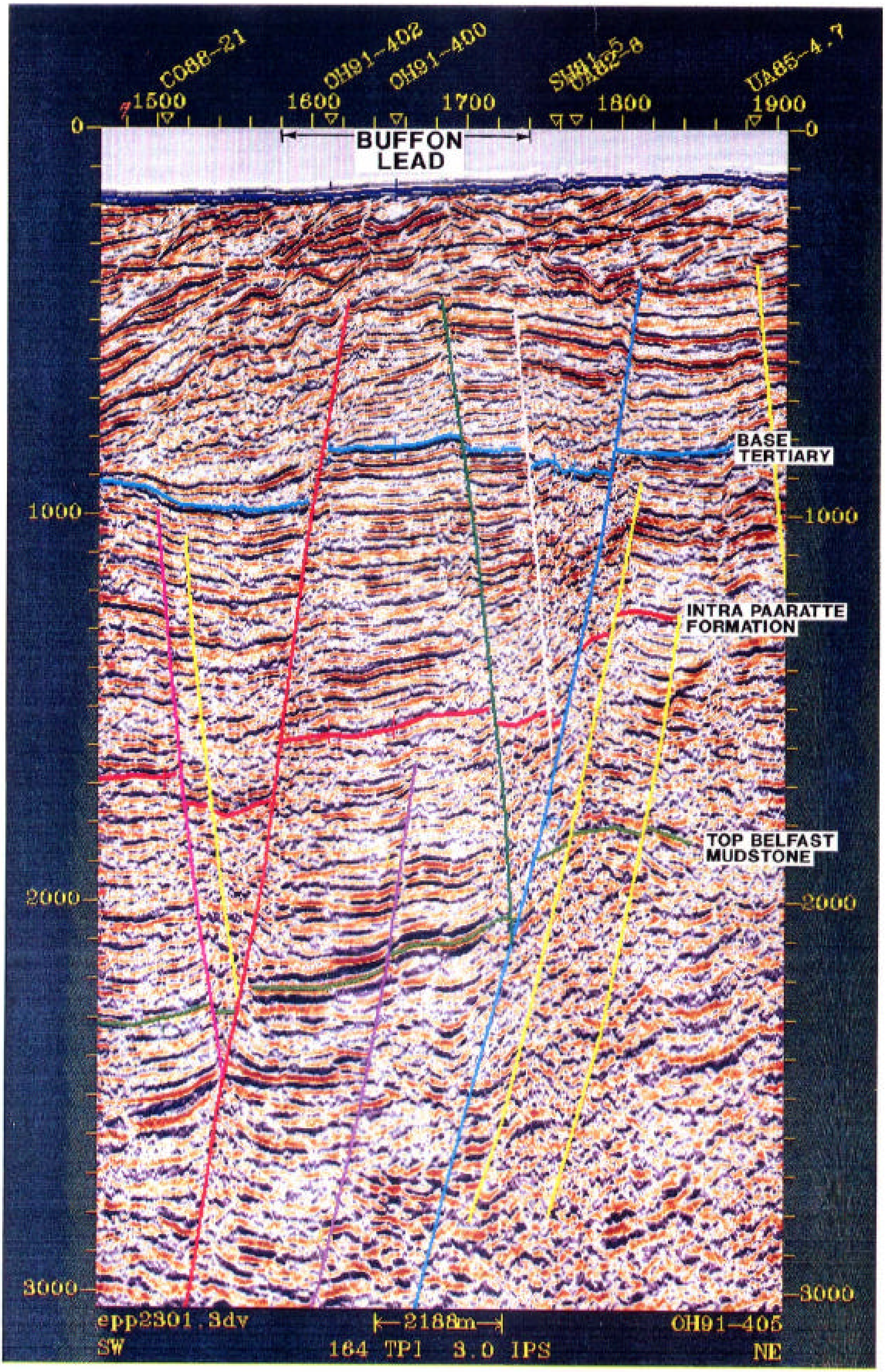
OTWAY BASIN
EPP 23

BUFFON LEAD
SEISMIC LINE UA82-11

Figure 8.2.5



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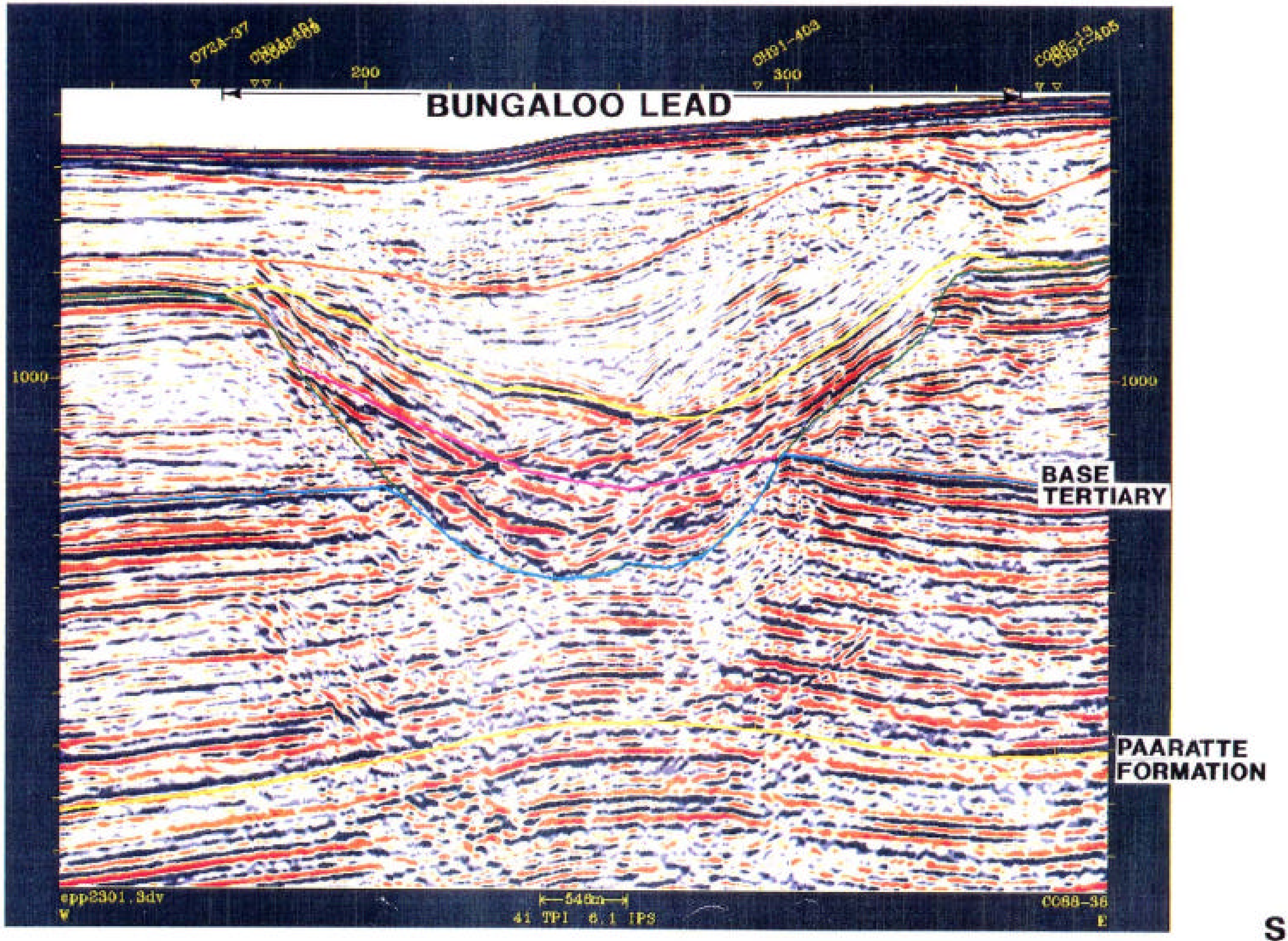
OTWAY BASIN
EPP 23

BUFFON LEAD
SEISMIC LINE OH91-405

Figure 8.2.6



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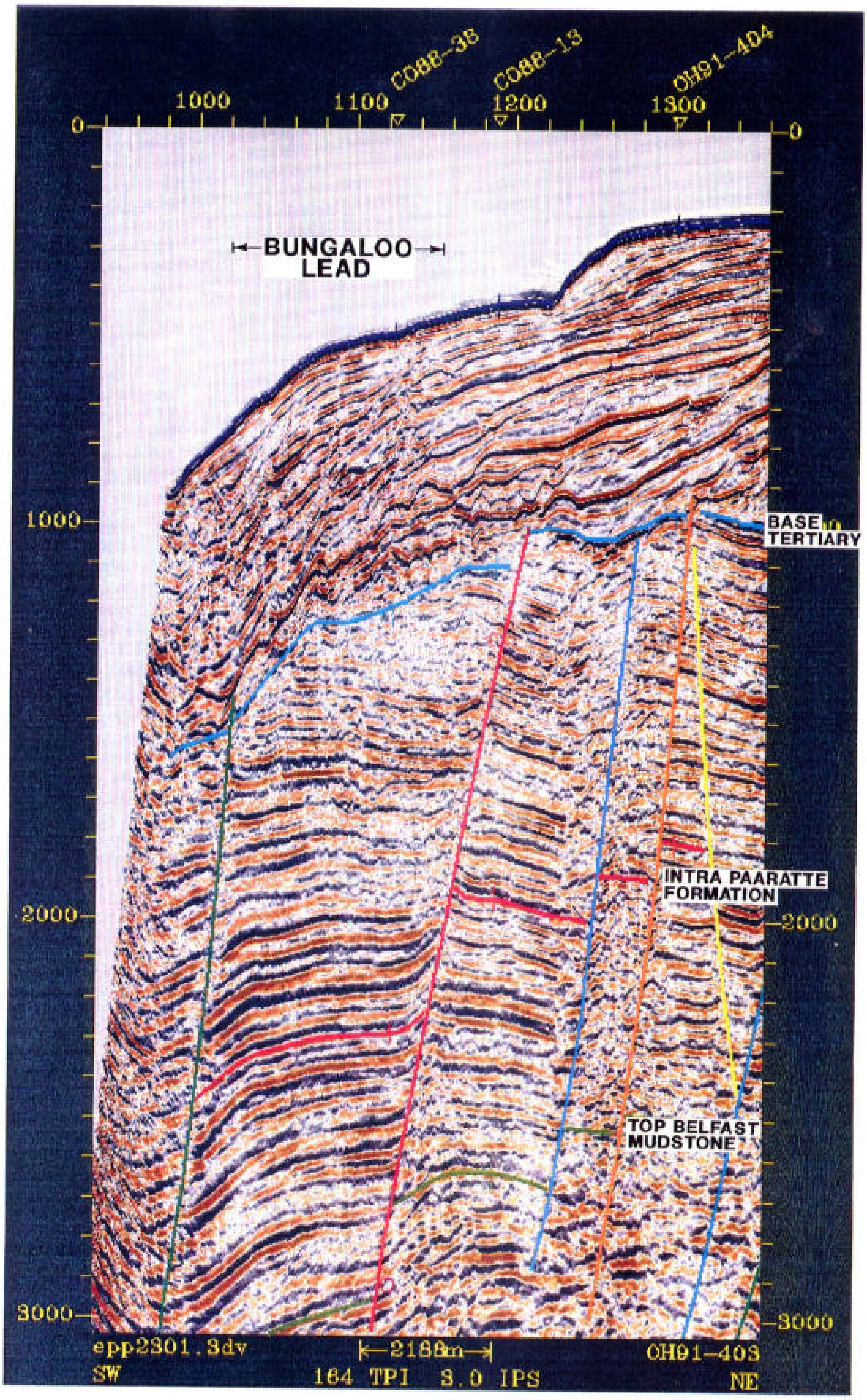
OTWAY BASIN
EPP 23

BUNGALOO LEAD
SEISMIC LINE CO88-38

Figure 8.2.7



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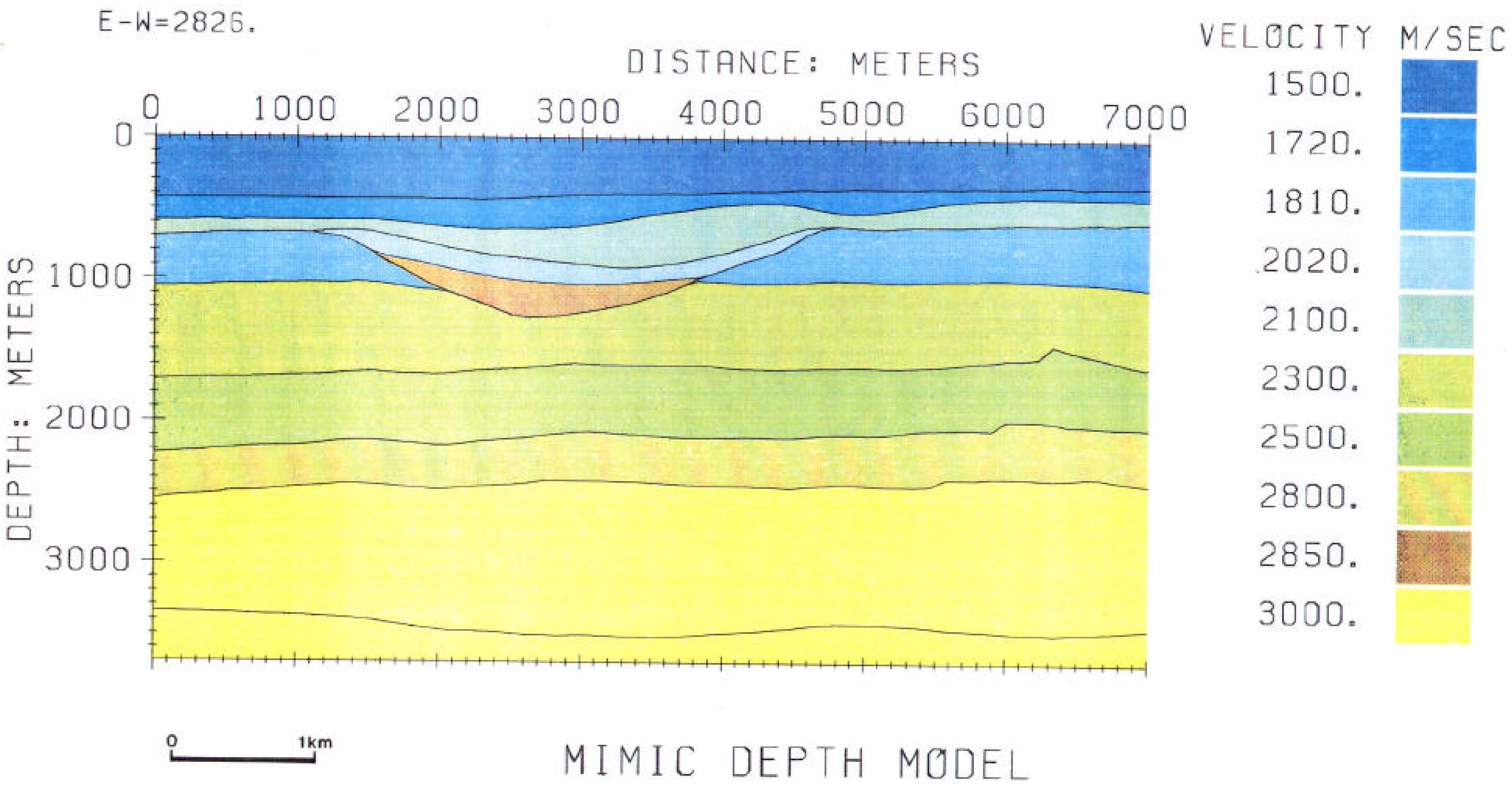
OTWAY BASIN
EPP 23

BUNGALOO LEAD
SEISMIC LINE OH91-403

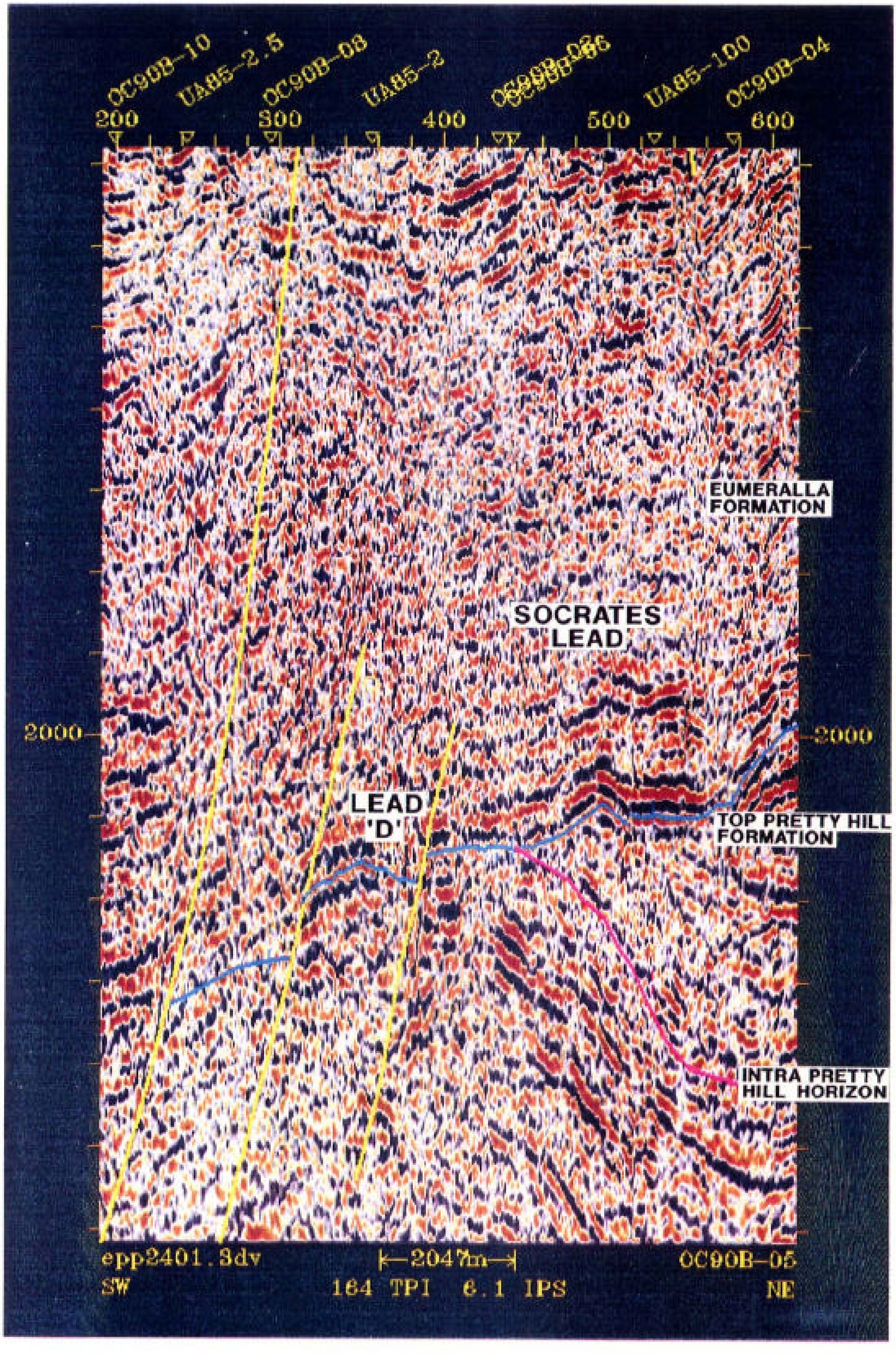
Figure 8.2.8



OTWAY BASIN

BUNGALOO LEAD
DEPTH MODEL OF LINE CO88-38

Figure 8.2.9

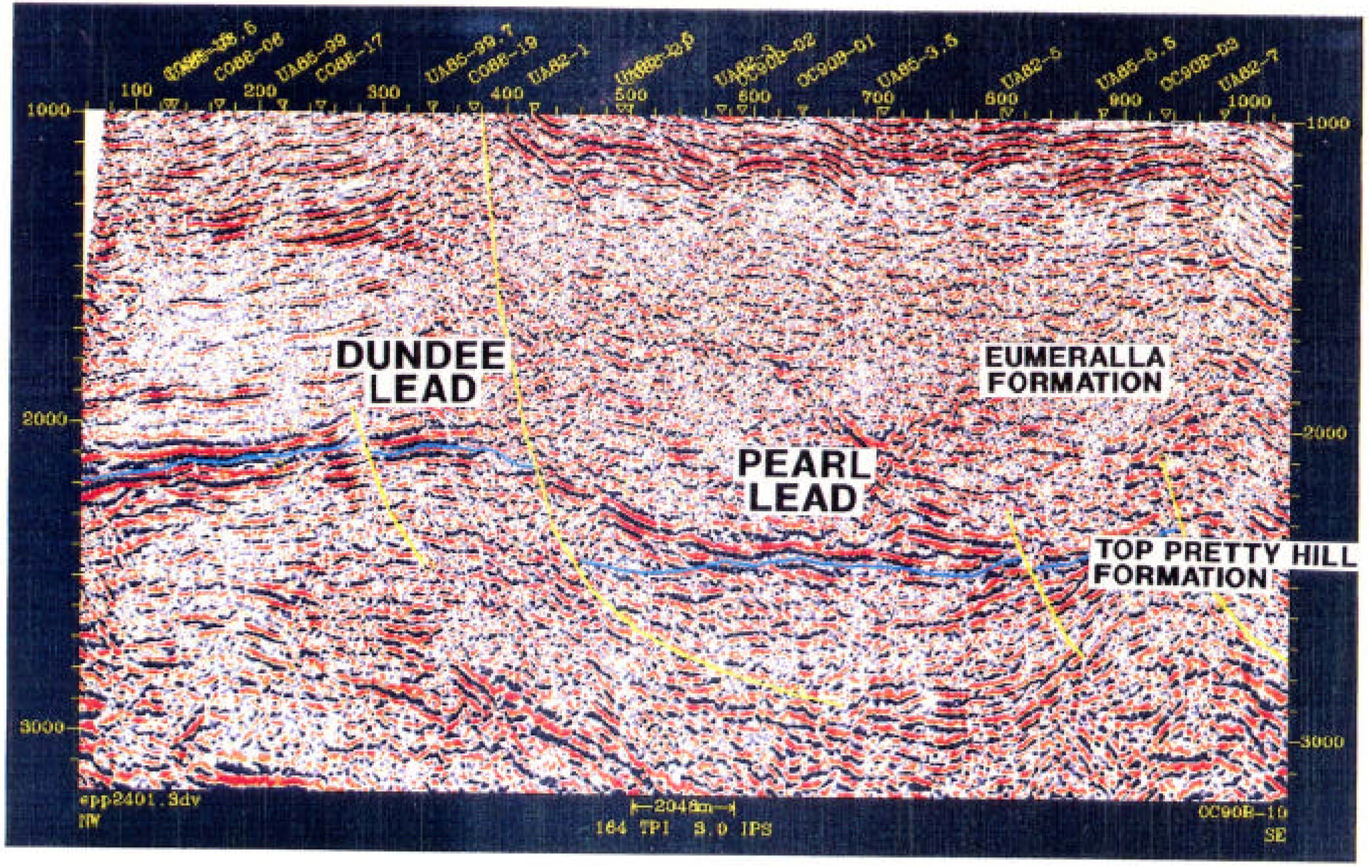


BHP Petroleum

OTWAY BASIN
EPP 23

SOCRATES LEAD
SEISMIC LINE OC90B-05

Figure 8.3.1



BHP Petroleum

OTWAY BASIN
EPP 23

DUNDEE / PEARL LEADS
SEISMIC LINE OC90B-10

NUMBER 8006 R 20

EPP 23

OTWAY BASIN

PROGRESS AND TECHNICAL REPORTS FOR THE PERIOD
24/6/87 TO 6/3/92

[Open File Report no. 20]

Submitted by

Cultus Resources NL
1987

ENVELOPE 8006 R 20

TENEMENT: EPP 23; Otway Basin

TENEMENT HOLDER: Cultus Petroleum (Australia) NL (operator), Petrocorp Ltd, Hershey Oil Corp., Fay, Richwhite and Co. Ltd, Drakar Holdings Pty Ltd and BHP Petroleum (Victoria) Pty Ltd

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	Dauzacker, M.V., 1987. Hydrocarbon potential of [the gazetted as available for offshore exploration permits for petroleum] S87-1 application area, Otway Basin (Brazil Consultants Pty Ltd, June 1987).	**8006 R 20** 3-17 [2xA3]	
PLANS			
	Interpreted seismic sections:		
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Fig. 5	Line SH81-06, SPs 101 to 1120.	Pg. 15	*A3*
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Brazil Consultants Pty. Ltd.
As Trustee for the Brazilco Unit Trust

0003

OPEN FILE

HYDROCARBON POTENTIAL OF
S87-1 APPLICATION AREA
OTWAY BASIN

PREPARED BY: DR. M.V. DAUZACKER

June 1987

REF: BLCO-S87-1

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Fax No. (09) 322 5321 Telex No. 94752

1. LOCATION

The S87-1 Application Area lies in the offshore portion of the western Otway Basin and comprises 80 graticular blocks covering approximately 4,640 square kilometres. The area is located between the shoreline and the break of the continental shelf and roughly follows the 200 metre bathymetric contour (Figures 1 and 2).

2. GEOLOGIC SETTING

The Otway Basin is one of three sedimentary basins of the Bass Strait Area and exhibits a northwest-southeast trend between the Mornington Peninsula in Victoria and Cape Jaffa in South Australia. The offshore portion has an area of approximately 25,000 square kilometres (50 x 500 kilometres).

From east to west the main tectonic features are: the Mussel Platform, the Voluta Trough and the Crayfish Platform. The S87-1 Area is located in the Western Voluta Trough.

Seismic evidence confirms the existence of sedimentary thicknesses of 10 kilometres or even more. The sediments range from contintental at the base of the section to open marine at the top, in accordance with the evolution of a typical mature pull-apart basin. The oldest known sediments are from Late-Middle Jurassic (Casterton Beds) and the youngest are Quaternary in age (Whalers Bluff Formation)(Table I). The tectonic framework, the structural styles and the sedimentary sequences can be correlated not only with other Australian marginal basins but also, regardless of the age of tectonic evolution and sediments, with other marginal basins around the world.

3. PREVIOUS EXPLORATION

The offshore portion of the Otway Basin has been only sparsely explored. Since the early 1960's only 17 offshore exploration wells have been drilled which gives a density of 1 well per 1,470 square kilometres within the basin. In the S87-1 offshore Area only 2 exploratory wells (Argonaut A-1 and Breaksea Reef-1) were drilled giving a density of 1 exploratory well per 2,320 square kilometres.

The Argonaut A-1 well was drilled by Esso in 1968 to a total depth of 3,708 metres; the Breaksea Reef-1 well was drilled by Ultramar Australia in 1983 to a total depth of 4,468 metres. Both wells stopped within the Waarre Formation of the Sherbrook Group which is Late Cretaceous in age. No hydrocarbon shows were reported. The failure of these wells can be explained by either the absence of conduits linking a deep source rock with the reservoirs drilled in both wells or lack of a deep source rock in the area.

Since 1963 fifteen seismic reflection surveys have been carried out by different companies in the present S87-1 Application Area (Table II). A total of 4,380 kilometres of seismic lines have been acquired and the coverage varies from reconnaissance to semi-detailed and detailed grids. A total of 313 kilometres of seismic profiles have been reprocessed so

TABLE.1.

0005

OTWAY BASIN
OFFSHORE GENERALISED STRATIGRAPHY

AGE		GROUP	FORMATION	ENVIROMENT OF DEPOSITION	SIGNIFICANCE-FOR HYDROCARBONS
QUATERNARY		POST-HEYTESBURY	WHALES BLUFF FORMATION	MARINE	
TERTIARY	PLIOCENE		NEWER VOLCANICS		
	MIOCENE	HEYTESBURY	PORT CAMPBELL LIMESTONE GAMBIER LIMESTONE		
	OLIGOCENE		GELLIBRAND MARL		
			CLIFTON FORMATION		
	EOCENE	NIRRANDA	NARRAWATURK MARL		
			MEPUNGA FORMATION		
	PALAEOCENE	WANGERRIP	DILWYN FORMATION		
			PEMBER MUDSTONE MEMBER		Sl
			PEBBLE POINT FORMATION		● R
LATE CRETACEOUS		SHERBROOK	CURDIES FORMATION		R
			PAARATTE FORMATION		✳ R
			BELFAST MUDSTONE		So
			FLAXMAN FORMATION		R
			WAARRE FORMATION		☼☼ R
EARLY CRETACEOUS		OTWAY	EUMERALLA FORMATION		✳● So, Sl, R
			PRETTY HILL SANDSTONE		● R, So
LATE-MIDDLE JURASSIC		?	CASTERTON BEDS	CONTINENTAL	
PALAEOZOIC			BASEMENT		

EXTRAPOLATION FROM ONSHORE DATA
- Reservoir (R)
- Source (So)
- Seal (Sl)

☼ Gas field/well
✳ Gas show
● Oil show

ADAPTED FROM MANY AUTHORS.

TABLE II

SEISMIC COVERAGE FOR S87-1 OTWAY BASIN

SURVEY	YEAR	COVERAGE	RE-PROCESSED
BMR SURVEY 48	1985	519 km	
ULTRAMAR UA-85	1985	536 km	
ULTRAMAR UA-82	1982	1086 km	
SHORELINE SH-81	1981	415 km	
O-72-A	1972	94 km	(1981) 62.5 km
PORT MACDONNELL	1972	25 km	
O-70-A	1970	32 km	(1981) 17.5 km
O-69-A	1969	8 km	
GELTWOOD BEACH	1969	2 km	
EU	1968	5 km	(1981) 5 km
ER	1968	282 km	(1981) 228 km
EP	1968	403 km	
EO	1967	258 km	
SS	1965	330 km	
SA	1963	387 km	
	TOTAL	4382 km	313 km
	SUM TOTAL =	4695 km	

far. During 1985, the Bureau of Mineral Resources (BMR) acquired 3,700 kilometres of regional multi-channel seismic reflection data in both shallow and deep waters of the Otway Basin (2,000 and 1,700 kilometres of data respectively). More than 500 kilometres of the BMR seismic data was acquired in the S87-1 Application Area (Figures 3A & B). This survey is important because it clearly shows the structural-sedimentary pattern of the entire Otway Basin.

4. SOURCE ROCK, GENERATION AND MIGRATION

Generation, migration and accumulation of oil and gas occurred in the Otway Basin as indicated by the North Paaratte onshore gas-condensate field and, more recently, by oil recovered in the Windermere-1 well in the Eumeralla sandstones. Other shows of waxy paraffinic oil were encountered in Lindon-1 and Port Campbell-1 wells. Also several occurrences of waxy paraffinic and paraffinic-naphthenic crude oils have been found along the coastlines of Victoria and South Australia. The oil is inferred to have come from widespread lacustrine source beds (McKirdy et al, 1986) and was supposedly formed in Late Jurassic-Early Cretaceous rift valleys associated with the continental breakup of Australia and Antarctica. This model is in accordance with the model developed to explain all hydrocarbon accumulations along the Brazilian pull-apart basins where all the oil is lacustrine in origin and associated with the continental breakup of South America and Africa. In 1986 BMR scientists found gases indicative of liquid hydrocarbon generation (ethane, propane and butane) in samples collected along the break of the present shelf edge. Such results indicate that hydrocarbons have migrated along deep faults up to the surface. Williamson and others (1987) came to the same conclusion via structural analyses of the Western Voluta Trough.

5. RESERVOIRS

The stratigraphic table (Table I) of the Otway Basin ranges from Cretaceous continental sequences to Tertiary and Quaternary marine sequences. Therefore, fluvio-deltaic lacustrine and marginal-marine reservoirs are expected to occur throughout. Fluviatile and fluvio-deltaic reservoirs are found in the Otway Group (Pretty Hill Sandstone) and in the Sherbrook Group (Waarre Formation, Flaxmans Formation and Curdies Formation), ranging in age from Early to Late Cretaceous.

Both Argonaut A-1 and Breaksea Reef-1 wells penetrated reservoirs within the Sherbrook Group (Waarre and Flaxmans Formations). Reservoir qualities in the Otway Group are not known in the Application Area since both wells did not penetrate this section; however, seismic correlation shows that these reservoirs can be reached to the southwest along a large trend at shallower depths. Correlation of subsurface-seismic profiles indicate that both the Argonaut and the Breaksea Reef-1 wells were drilled along the same structural low where the reservoirs were reached at equivalent depths with similar petrophysical conditions; hence they were subjected to similar diagenetic conditions.

6. TRAPS

Most of the traps expected in the area are purely structural. Seismic interpretation indicates the existence of a large structural trend almost coincident with the present shelf edge. It is bounded to the southwest by a major fault system oriented northwest-southeast. Critical closures to the northeast are supported by dip inversions and/or antithetic faulting (Figures 4, 5 and 6). Therefore, it is postulated that an external high occurs, forming a major trend roughly coincidental with (and also controlling) the present shelf edge (Figure 7).

In pull-apart basins, external highs are developed during the continental break up when large basement blocks are faulted and antithetically tilted. The general configuration of a mature pull-apart basin is manifested by an internal confined basin separated from an external unconfined basin by the edge of the tilted block. Large listric faults occur along the edge, thus connecting source rocks within the deep unconfined basin to any trap along that major hinge line. Although the configuration of this model is quite common in similar basins in the world, particularly along some Brazilian Basins, it has not yet been tested in the Otway Basin.

The drainage area for traps along such a regional high is enormous and comes from two sub-basin sources (a) the confined sub-basin, between the present basin margin and the external high, and (b) from the external unconfined deep oceanic basin. However, mapping the prospective area in order to choose the best drilling location requires a knowledge of the model and an adequate exploration plan with at least two phases of seismic surveys (semi-detailed and detailed), each phase being interpreted and results applied to the geologic model.

7. SUMMARY AND CONCLUSIONS

A. The offshore portion of the Otway basin, particularly the S87-1 Application Area has been sparsely explored. Although 4,380 kms of seismic reflection profiles were shot, only seismic data acquired in the last seven years is of sufficient quality to provide accurate structural definition. This is due to the structural complexity and the presence of shallow carbonates in the area. Therefore about half of the previously acquired seismic data cannot be utilised. Only two exploratory wells were drilled in an area of 4,640 square kilometres. The two wells, Argonaut A-1 and Breaksea Reef-1, were drilled structurally on strike; i.e. they tested the same type of prospect and penetrated equivalent stratigraphic sections. Consequently sediments towards the centre of the basin are unknown and in that direction both the Otway and Sherbrook Group reservoirs can be encountered at shallower depths as shown by seismic reflection data.

B. The Otway Basin generated hydrocarbons as shown by small onshore gas fields and, more recently, the Windermere-1 exploratory well which produced oil. Also, oil has been found along some of Victorian and South Australian shores. It is believed that the oil seepage was caused by reactivation of an old fault system which connects deep accumulations along the edge of the continental shelf and/or in the deep oceanic basin with the sea bottom.

C. The Otway Basin is composed of two main sub-basins: a confined internal sub-basin and an unconfined external deep oceanic sub-basin separated by a major external high (Figure 8).

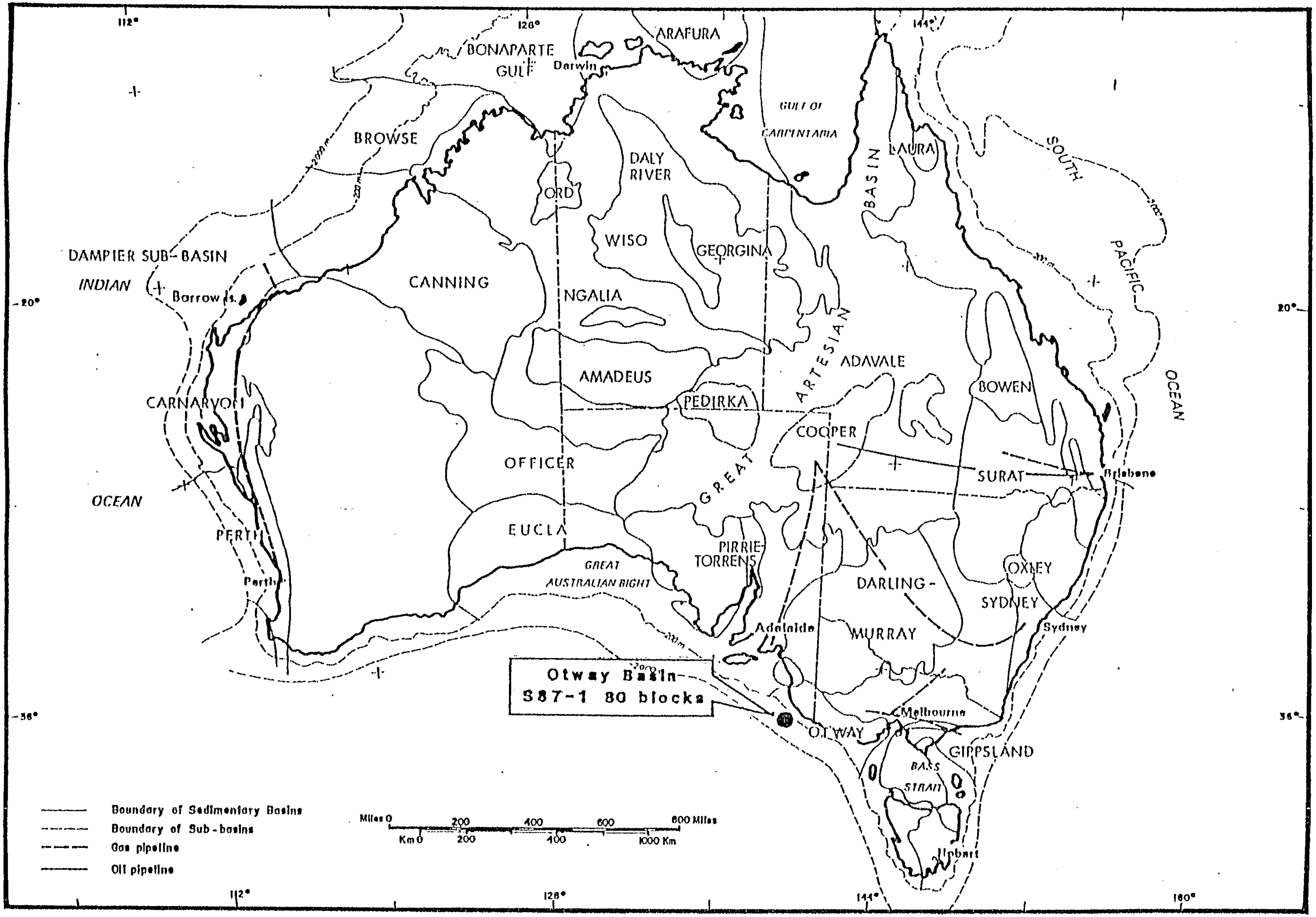
D. The model developed for the Otway Basin is found in several pull-apart basins around the world where external highs constitute major targets for hydrocarbon exploration. Prospects along such a regional high have not been tested yet in the Otway Basin. This trend, bounded by normal faults, drained large areas. To properly test the subject exploratory concept a specific model-orientated seismic program at semi-detail and detail levels is required in order that the best drilling location can be chosen.

E. Only deep wells can properly test the proposed model. This conclusion is arrived at by considering the following: (1) The sedimentary facies, and consequently the reservoir distribution along the external high, was controlled by structural development. The type and characteristics of reservoirs along the regional high would be more favourable than the same as those penetrated by the Argonaut A-1 and the Breaksea Reef-1 wells located along a major regional low. (2) The external high, which is bounded by a major extensional fault system to the south and by dip inversion and/or another fault system to the north, is draining large areas and is clearly a multiple target prospect. (3) Deep exploratory wells, properly located, will penetrate a basal section - probably Early Cretaceous in age - not yet tested in this portion of the Otway Basin.

REFERENCES:

McKIRDY, D.M., 1987 - Otway Basin Source Rocks: Observation and Inference. Otway Basin Workshop, BMR Record/9 17 March, Canberra, pages 18-19.

WILLIAMSON, P.E., G.W. O'BRIEN, M.G. SWIFT, E.A. FELTON, A.S. SCHEPL, M. MARLOW, J. LOCK, N.F. EXON, and D.A. FALVEY 1987 - Hydrocarbon Potential of the Offshore Otway Basin. Preprint; 32 pages and 25 figures.



Otway Basin
S87-1 80 blocks

FIG 1.

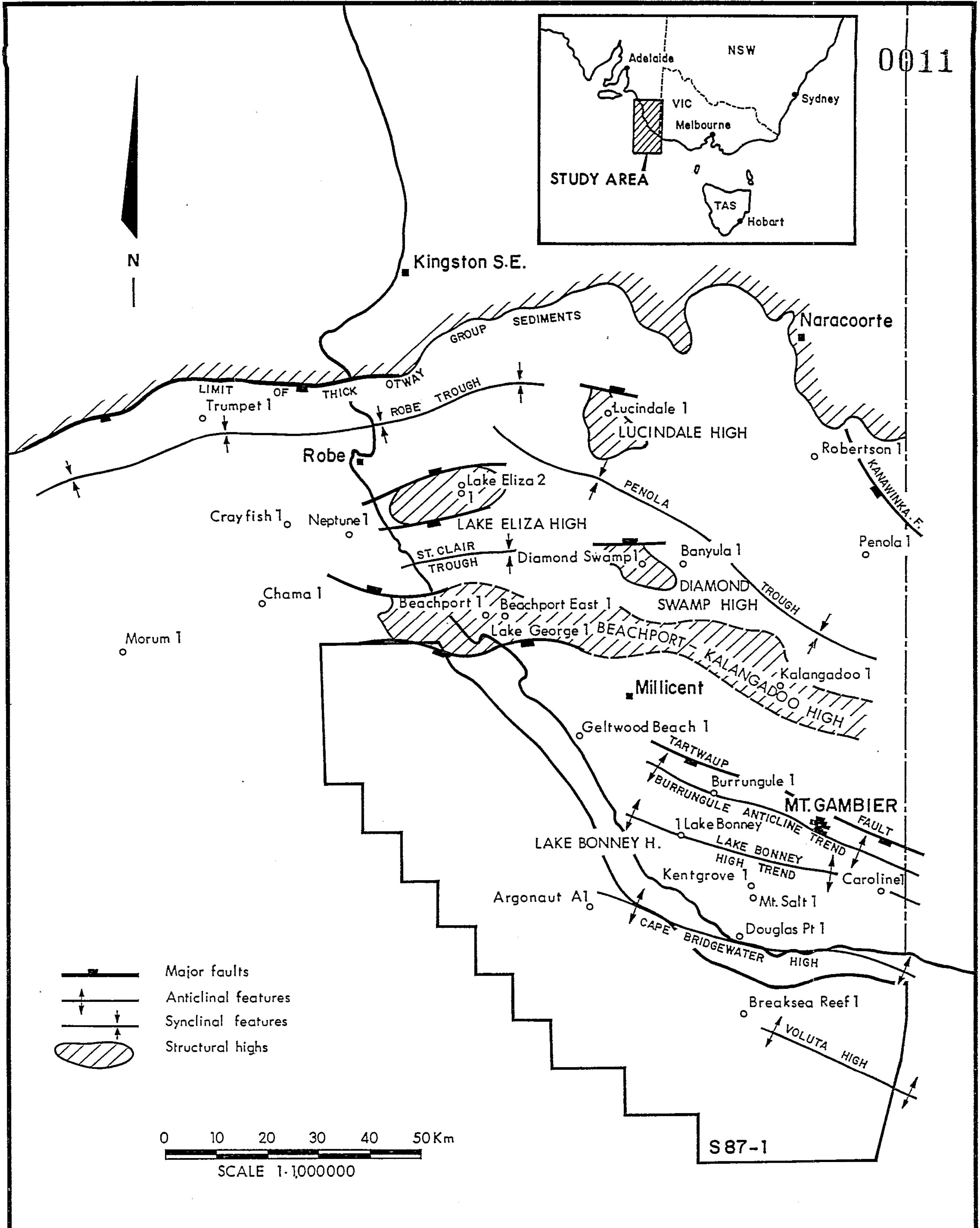


Figure .2.

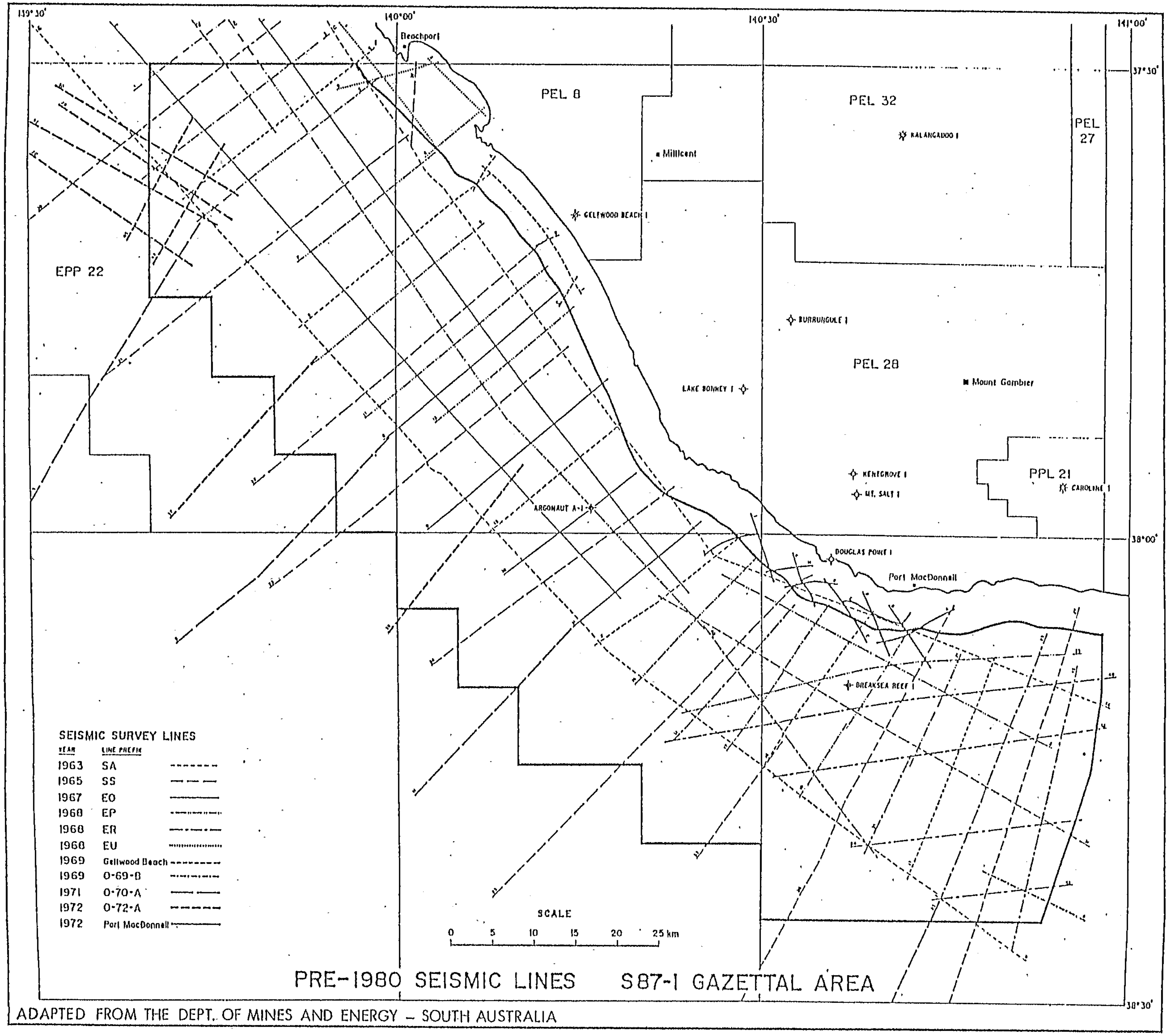
CULTUS RESOURCES N.L.

OTWAY BASIN — SOUTH AUSTRALIA

MAJOR STRUCTURAL FEATURES

(MODIFIED FROM DEPT. MINES AND ENERGY, SOUTH AUST.)

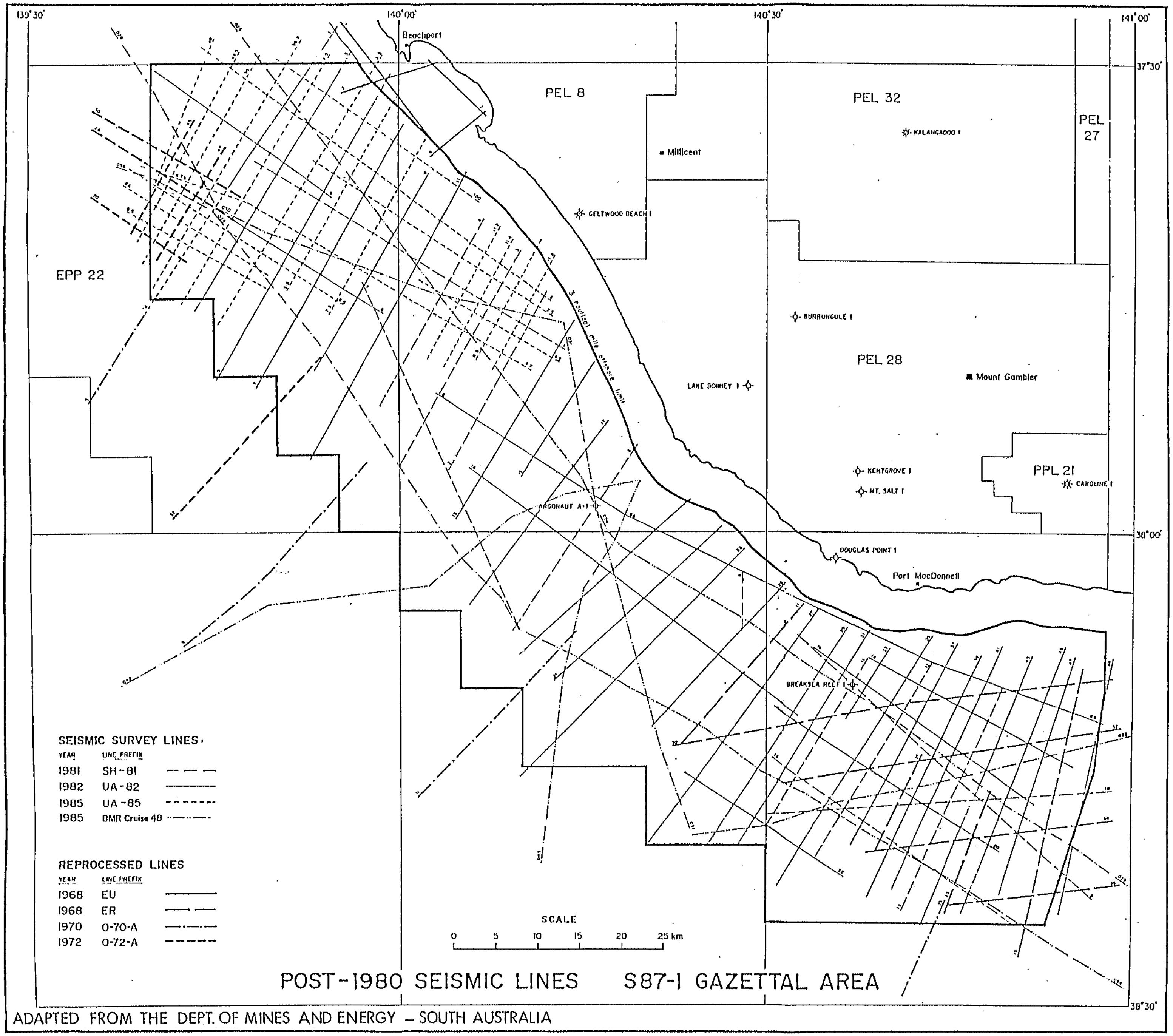
Date: MAY'87	Scale: 1:1000 000



PRE-1980 SEISMIC LINES S87-1 GAZETTAL AREA

ADAPTED FROM THE DEPT. OF MINES AND ENERGY – SOUTH AUSTRALIA

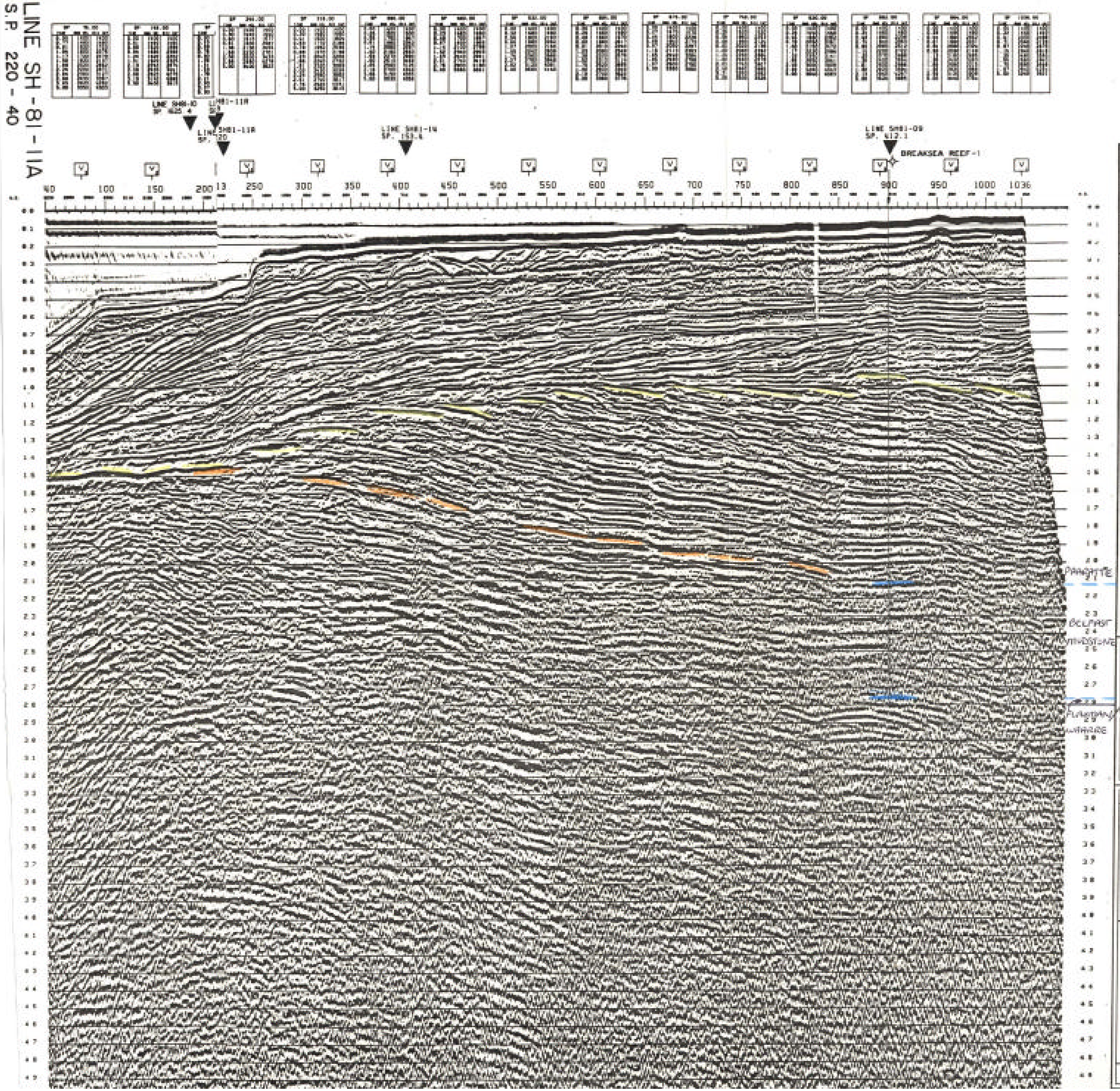
FIG. 3a)



POST-1980 SEISMIC LINES S87-1 GAZETTAL AREA

ADAPTED FROM THE DEPT. OF MINES AND ENERGY – SOUTH AUSTRALIA

FIG. 3 b)



DOC. No. [illegible]

LINE SH81-11
S.P. 1036 to S.P 213

AIR GUN

LEGEND
▼ = INTERSECTION
V = VELOCITY ANALYSIS
WATER DEPTH IN METRES

NNE

1 KM

FINAL STACK

ULTRAMAR AUSTRALIA LTD

AREA : OTWAY BASIN

WESTERN GEOPHYSICAL
DIVISION OF LITTON INDUSTRIES
SINGAPORE DIGITAL CENTRE

RECORDED MARCH 1981
PROCESSED MAY 1981
FINAL REEL No 95273

RECORDING DATA

BOAT	Western Odyssey	Party 86
	Navigation	Magnavox
	Nav Locations	CDP Position
SOURCE	Air Gun	550 Cu. Ins.
	Gun Depth	6.0 M
	S.P. Interval	25 M.
	Pop Interval	25 M.
	Shooting Rate	40 Pops/Km.
	Pops/S.P.	1
INSTRUMENTS	System	DFS V
	Filter	8 Hz - 128 Hz
	Record Length	5 Sec.
	Sample Rate	2 Ms.
	Format	Seg - B 6&F
	Polarity	Normal
CABLE	Streamer	2400 M.
	Groups	96
	Seismometers	20 Per Group
	Group Interval	25 M.
	Lead In	263 TM
	Cable Depth	8M. Max.

SP Referenced To CDP Position

PROCESSING SEQUENCE PARAMETERS

EDIT	Demultiplex To Trace Sequential, Geophone Amplitude Fl. Pt. Sample Rate	 4 Ms.
PRE-PROCESSOR	Data Arranged Into Common Depth Position	
D. B. S.	Geometric Spreading Compensation Conversion To Fixed Point Format D.B.S. Type - Least Squares Minimum Phase Inverse Filter 1 Window Auto. Corr. Length Min. Prediction Lag. Operator Length Sample Rate	 500 Ms. 16 Ms. 288 Ms. 4 Ms.
VELOCITY ANALYSIS	2 Cdfs Values Every [illegible]	
N.M.O. - STACK	4800 % N.M.O. Correction Sample Rate	 4 Ms.
RESIDUAL	S.C. Of Stacking Velocities Reshot If Necessary	
GAIN	A.G.C. Gain 800 Ms. Window	
T.V. FILTER	Slope 18 - 36 db/oct. Sample Rate	 4 Ms.
FIELD FILTER OFFHAND		
PLAYBACK	Scale - Horizontal Vertical Sample Rate Geopsych Gain	40 Tr./1 Km. 96 Tr./In. 3.75 In./Sec. 4 Ms. 10 db.

TIME ZONE	L.C.	H.C.
0	10	60
2000	10	60
4000	10	40
4900	10	40

DATUM PLANE SEA LEVEL

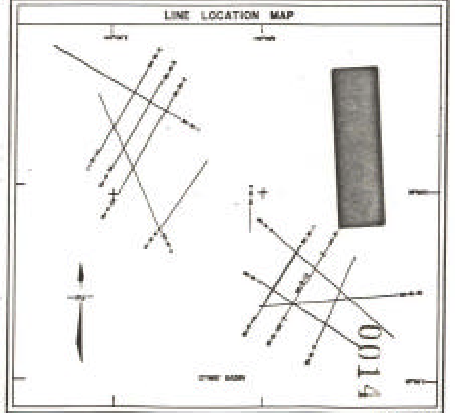
CORRECTION APPLIED

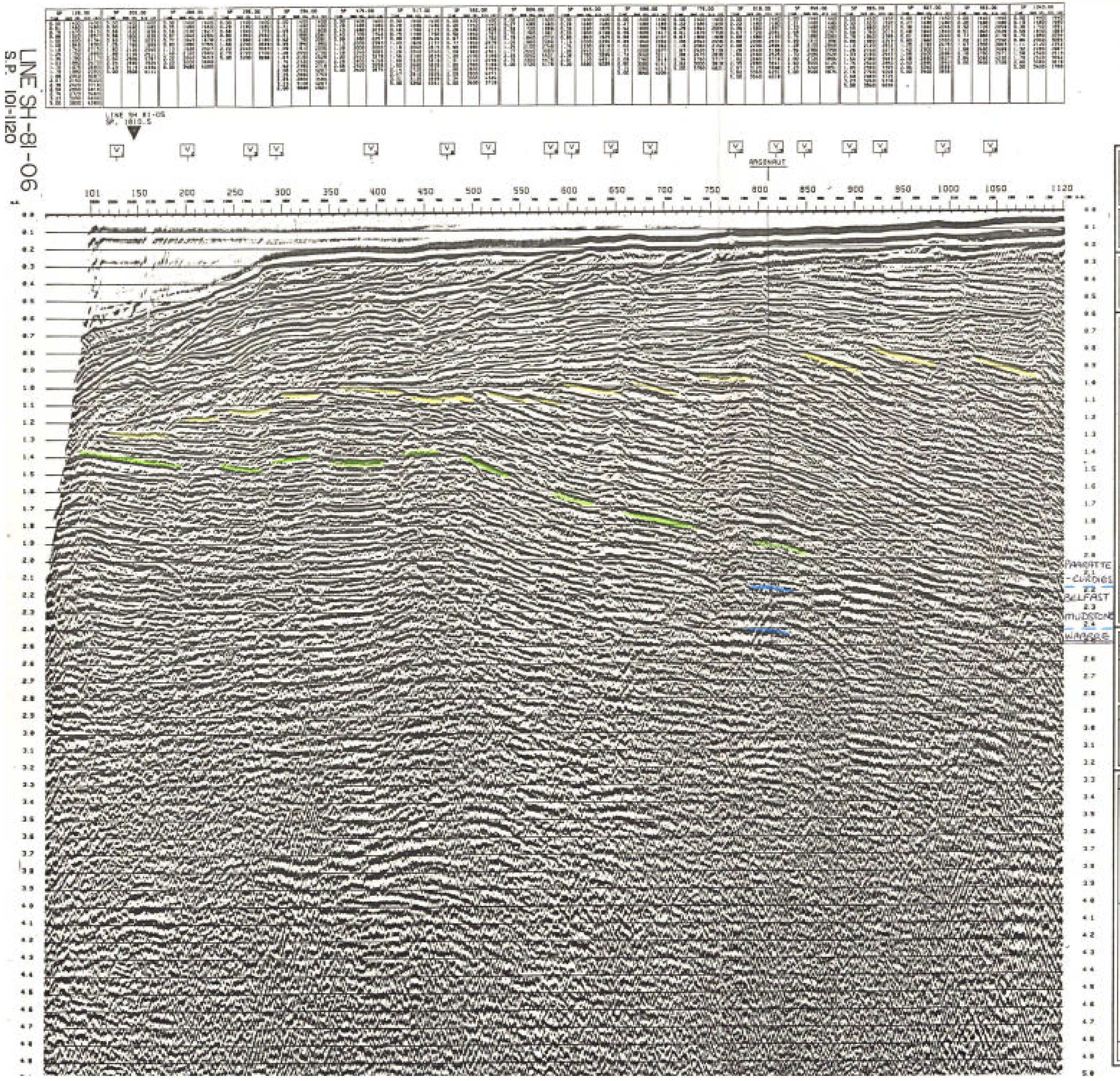
GUN DEPTH + 8 ms.
CABLE DEPTH + 8 ms.
TOTAL CORR. + 8 ms.

NORMAL POLARITY

COMPRESSION PULSE REPRESENTED
BY NEGATIVE TROUGH

LINE LOCATION MAP





LINE SH81-06
S.P. 101 to S.P 1120

AIR GUN

LEGEND
▼ = INTERSECTION
V = VELOCITY ANALYSIS
WATER DEPTH IN METRES

NNE

FINAL STACK

ULTRAMAR AUSTRALIA LTD

AREA : OTWAY BASIN

WESTERN GEOPHYSICAL
DIVISION OF LITTON INDUSTRIES
SINGAPORE DIGITAL CENTRE

RECORDED MARCH 1981
PROCESSED MAY 1981
FINAL REEL No 9514802

RECORDING DATA

BOAT	Western Odyssey	Party 99
	Navigation	Magnavox
	Map Location	CDP Position
SOURCE	Air Gun	550 Cu.Ins.
	Gun Depth	6.0 M.
	S.P. Interval	25 M.
	Pop Interval	25 M.
	Shooting Rate	40 Pops/Km.
	Pops/S.P.	1
INSTRUMENTS	System	DFS V
	Filter	8 Hz - 128 Hz
	Record Length	5 Sec.
	Sample Rate	2 Ms.
	Format	Seg - B GAP
	Polarity	Normal
CABLE	Streamer	2400 M.
	Groups	96
	Seismometers	20 Per Group
	Group Interval	25 M
	Lead In	250 - TW
	Cable Depth	8M. Ave.

SP Referenced To CDP Position

DATUM PLANE SEA LEVEL

CORRECTION APPLIED

GUN DEPTH + 3 ms.
CABLE DEPTH + 5 ms.
TOTAL CORR. + 8 ms.

NORMAL POLARITY

COMPRESSION PULSE REPRESENTED
BY NEGATIVE TROUGH

PROCESSING SEQUENCE PARAMETERS

EDIT	Demultiplex To Trace Sequential, Geophone Amplitude Fl. Pt.	
	Sample Rate	4 Ms.
PRE-PROCESSOR	Data Arranged Into Common Depth Families	
D. B. S.	Geometric Spreading Compensation Conversion To Fixed Point Format D.B.S. Type – Least Squares Minimum Phase Inverse Filter 1 Window	
	Auto Corr Length	300 Ms.
	Min. Prediction Lag	16 Ms.
	Operator Length	200 Ms.
	Sample Rate	4 Ms.
VELOCITY ANALYSIS	2 Cdfs Values Every Analysis	
N.M.O.-STACK	4800 % N.M.O. Correction	
	Sample Rate	4 Ms.
RESIDUAL	Q.C. Of Stacking Velocities Residual If Necessary	
GAIN	A.G.C. Gain 800 Ms. Window	
T.V. FILTER	Slope 18 - 36 db/oct	

TIME ZONE	L.C.	H.C.
0	10	60
2000	10	60
4000	12	40
4950	12	40

Sample Rate 4 Ms.

FIELD FILTER OFFPHASE

PLAYBACK	Scale :	80 Tr./1 Cm.
	Horizontal	96 Tr./In.
	Vertical	3.75 In./Sec.
	Sample Rate	4 Ms.
	Resample Rate	10 Ms.

LINE LOCATION MAP

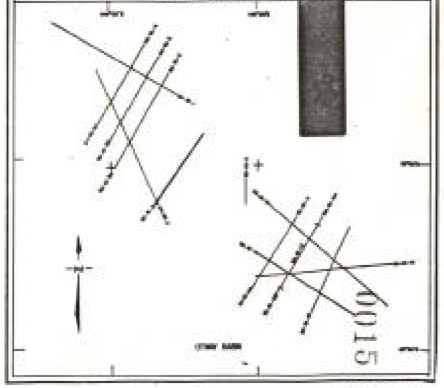


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FIG. 5

SCHEMATIC MODEL FOR WESTERN OTWAY BASIN

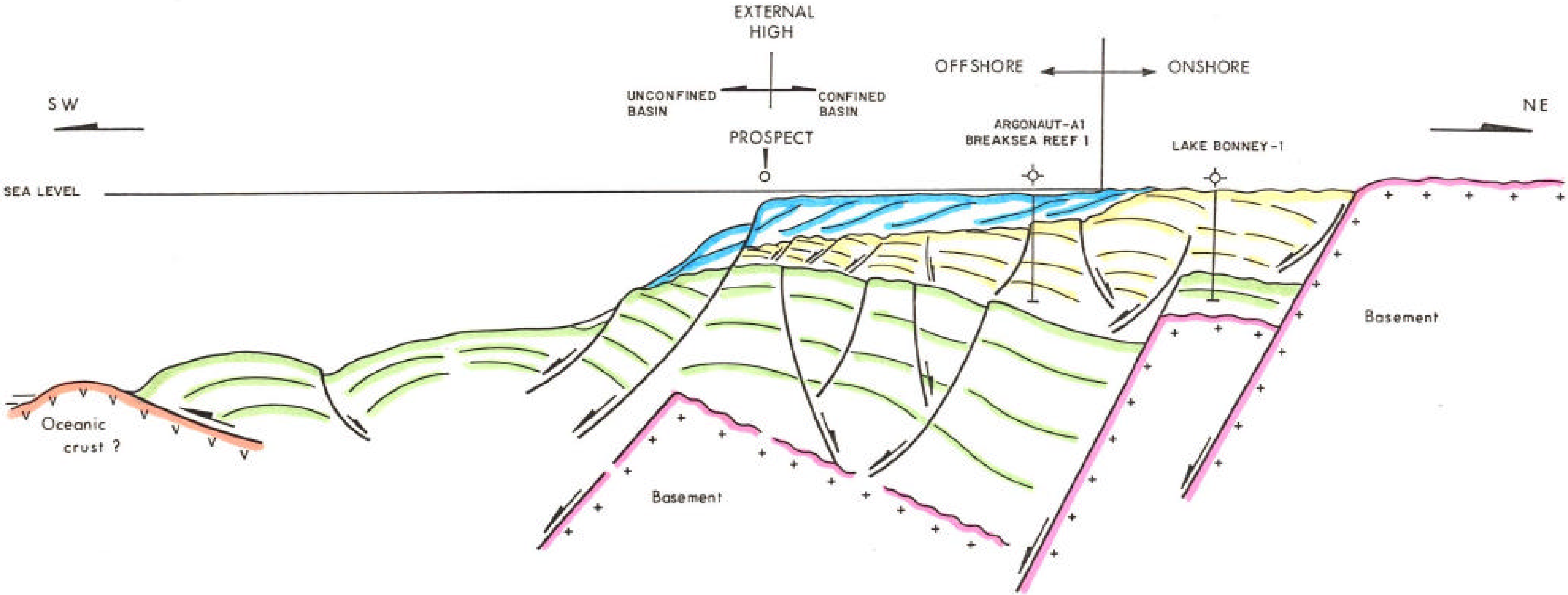
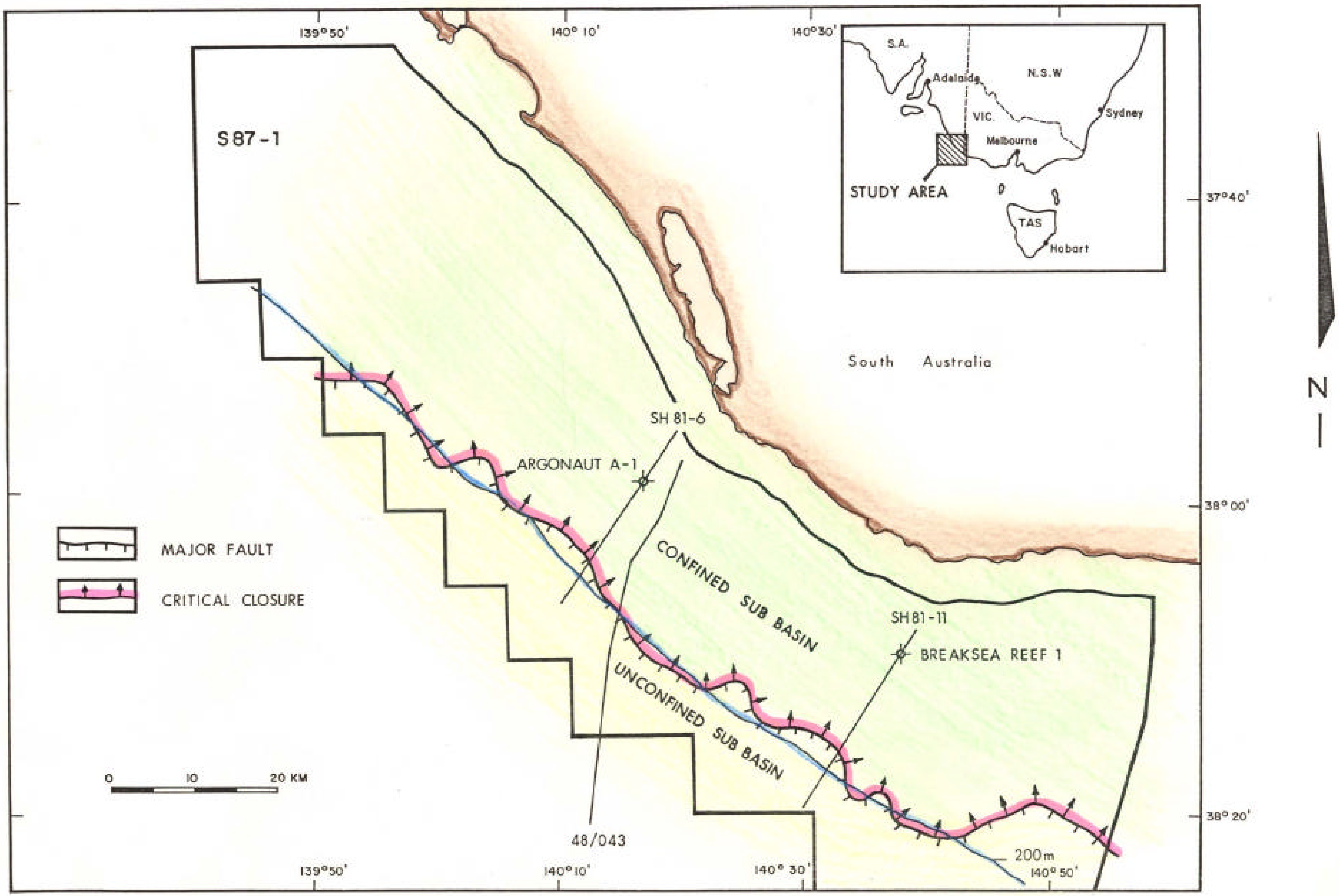


FIGURE .7.



OTWAY BASIN S87-1 PERMIT AREA — PRELIMINARY STRUCTURAL FRAMEWORK MAP

FIGURE. 8.