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(with a contribution by A.E. Constantine, Monash University)

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PREFACE

Most of this record was originally published as a paper (Willcox & others, 1992) in the Proceedings of the Joint AusIMM (Melbourne Branch) and PESA (Vic-Tas Branch) Gippsland Basin Symposium held in Melbourne from 22 to 23 June 1992 (AusIMM, 1992). This record includes additional material (particularly the plates) supporting the conclusions reached in that paper, as well as providing the figures and our seismic interpretations at a more-legible scale.

ABSTRACT

A unique grid of deep (12-14 second record length) seismic reflection and refraction data was recorded by the Australian Geological Survey Organisation (formerly the Bureau of Mineral Resources, Geology & Geophysics) across the offshore Gippsland Basin and parts of the adjacent Bass Basin in 1988-1989. These data have been interpreted to produce a new model for the development of the Gippsland and adjacent Bass Strait basins as well as giving a greater understanding of the basins' petroleum potential.

In general terms, the Gippsland Basin contains up to 16km of sediment in an ESE-trending depocentre bounded on its north and northwestern margins by a detachment ramp, and on its southern side by a relatively linear, listric fault system. The basin, together with the adjacent Bass and Otway Basins, appears to have formed as part of a linked, largely- strike-slip to 'transtensional' system, which started to extend through Bass Strait, probably during the latest Jurassic. Each of the basins developed by movement on a common detachment or detachment complex, which produced headwall extension at their western ends, in the areas now occupied by the Strzelecki Ranges, Otway Ranges - Torquay Sub-basin, and Robe Trough. Adjustments and reactivation from the mid Cretaceous of several postulated microplates in the region, largely in response to Tasman Basin rifting, gave rise to the wrench-related and compressional structures which form the major petroleum targets in the Gippsland Basin. However, the same process formed largely extensional structures in the Bass Basin.

Our interpretation of the tectonic history of the Gippsland Basin leads us to the conclusion that there may have been several phases of petroleum generation and migration, and that potential petroleum traps appear to exist in the deeper section, in structures sometimes not reflected at the top or near-top Latrobe Group levels.

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INTRODUCTION

Since the first discovery of significant hydrocarbons in the basin in 1965, the Gippsland Basin (Figures 1 and 2) has been one of Australia's most prolific pctroleum-producing provinces. The basin extends both onshore and offshore, mainly in water depths of less than 100m but extending into deeper water in the east where it is cut by the Bass Canyon (Plate 1). Although 'mature' by Australian exploration standards, little information has been available until recently to define its basin-forming architecture and deep structure. This is because of the traditional concentration of exploration activity at the relatively shallow 'top' or 'near-top' Latrobe Group levels, where all of the major oil and gas discoveries have been made, and the difficulty in penetrating seismically the extensive Cretaceous-Tertiary coal measures present in the basin. Since major exploration work began in the basin, over 80 000 km of seismic data have been collected, in excess of 140 exploration and appraisal wells drilled offshore, and 45 economic or sub-economic accumulations discovered (Brown, 1986; Mebberson, 1989; Stephenson & others, 1991). All of the commercial hydrocarbon discoveries (including several giant fields) have been offshore, mainly within the central part of the basin. Structurally, the basin is divided into a number of zones, including the main depocentre (the 'Central Deep'), and areas of shallow basement, the 'Northern and Southern Platforms' (Figure 2).

This record details results of a regional seismic reflection (12-14 second record length) and refraction study of the deep structure of the offshore Gippsland Basin undertaken by the Australian Geological Survey Organisation (AGSO; formerly the Bureau of Mineral Resources, Geology & Geophysics) since 1988. It utilises 1650 km of deep reflection profiles recorded by the R/V *Rig Seismic* in the Gippsland Basin (Surveys 82 and 90), and makes reference to similar profiles from the adjacent Bass Basin and Boobyalla (Durroon) Sub-basin, and older, conventional seismic data. Initial results of the study were reported by Williamson & others (1991) and Collins & others (1991). The work follows an analysis of 6 second record length seismic reflection data which led Etheridge & others (1985, 1987) to suggest that the Gippsland Basin, and the adjacent Bass and Otway Basins, formed by NNE-SSW lithospheric extension, largely in the Early Cretaceous. Objectives of the present study included a test of the Etheridge & others model for the Gippsland Basin, the provision of information on possible new play types, and the establishment of regional seismic correlations. When combined with the results of mapping in the Strzelecki Ranges and regional geological data, the study suggests that the Gippsland Basin developed, not through conventional extension, but as part of a largely 'transtensional' system extending through Bass Strait, linked to the development of other basins on the 'Southern Margin'.

GEOLOGICAL BACKGROUND

Aspects of the geology, regional setting and petroleum potential of the Gippsland Basin have been discussed by numerous authors, including Weeks & Hopkins (1967), Hocking (1972), Threlfall & others (1976), Robertson & others (1978), Smith (1982), Stainforth (1984), Brown (1986), Thompson (1986), Ozimic & others (1987), Esso (1988), Douglas & Ferguson (1988), Mebberson (1989), Maung (1989), Maung & Nicholas (1990), and Rahmanian & others (1990). In general terms the Mesozoic-Tertiary basin is bounded to the north, northwest and south by Palaeozoic rocks of the Lachlan Geosyncline (Douglas & Ferguson, 1988), and to the east by Late Cretaceous oceanic crust of the Tasman Basin (Shaw, 1978, 1979). It appears to have been joined, at least in the ?Late Jurassic-Early Cretaceous, to the Torquay Sub-basin of the Otway Basin and probably the Bass Basin, although it is now separated from these basins by basement ridges, the Mornington High in the west and Bassian Rise in the south (Figure 1).

From a genetic point of view, the basin lies near the eastern end of a complex rift system which extended along the southern margin of Australia and onto the Lord Howe Rise region during the Jurassic and Early Cretaceous -a precursor to seafloor spreading between the Australia, Antarctic and Lord Howe Plates. The azimuth of lithospheric extension within the 'Australia-Antarctic supercontinent' along this margin has been most clearly defined in the Eyre and Ceduna Sub-basins of the Great Australian Bight Basin (Willcox & Stagg, 1990). Here the mapping of basement tilt-blocks and transfer faults has indicated a NW-SE extensional direction which is probably applicable to the Southern Margin (and the Bass Strait/Tasmania region) as a whole. The rifting, as dated from the synrift section penetrated in Jerboa-1 exploration well, commenced in or before the Berriasian (latest Jurassic or earliest Cretaceous; about 140 Ma according to Haq & van Eysinga, 1987), and had ceased by the Barremian (latest Neocomian; about 120 Ma; Stagg & others, 1990; Blevin, 1991). The subsequent onset of drifting/seafloor spreading is less clear: in the earliest analysis of magnetic seafloor spreading anomalies, Weissel and Hayes (1972) concluded that separation of the two continents took place in the Paleocene, at about Anomaly 22 time; however, revisions by Cande & Mutter (1982) and Veevers (1986) have pointed to separation in the Cenomanian at 95 $\pm$ 5 Ma, somewhat before Anomaly 34 time. Most recently, based on an interpretation of the stratigraphy south of the Eyre Sub-basin, Stagg & Willcox (1992) have concluded that the oceanic crust in the western Great Australian Bight is far older than the previously interpreted, and that a Neocomian or even older episode of spreading has taken place.

Development of the Gippsland Basin has also been partly linked to 'Eastern-Margin' (Australia-Lord Howe Rise) rifting, and to the formation of the Tasman Basin from the Late Cretaceous (Anomaly 33 time) to the Eocene (Anomaly 24 time) (Weissel & Hayes, 1977; Shaw, 1978, 1979; Jongsma & Mutter, 1978; Rahmanian & others, 1990). Along this margin, rift-basin development seems to have occurred within a zone of left-lateral, oblique extension, with minimal basin preservation on the Australian Plate after breakup (Symonds & Willcox, 1990). The southern part of this rift system appears to have been highly volcanic and may have been a major source of volcanogenic detritus to rift-stage sediments. According to Shaw's (1978, 1979) mapping of the magnetic anomalies, seafloor spreading in the Tasman Basin propagated northwards, with the earliest (Anomaly 33) spreading occurring from the Gippsland Basin southwards.

Traditionally, the sediments in the basin have been divided into three major units: the non-marine, largely volcanogenic, ?Late Jurassic-Early Cretaceous Strzelecki Group; the mainly non-marine, Late Cretaceous-Eocene Latrobe Group (the major petroleum producer in the basin); and the overlying marine, Oligocene and younger Seaspray Group made up of the Lakes Entrance Formation and Gippsland Limestone (Figure 3). In recent years, the recognition of a regional unconformity of Campanian age has led to the splitting off of the lower Latrobe Group (Smith,1988) as a separate unit, the Golden Beach Group (Lowry, 1987; Lowry & Longley, 1991). Although the Latrobe Group has been widely drilled in the basin, intersections of the Golden Beach Group are confined principally to the margins of the 'Central Deep', whereas intersections of the Strzelecki Group are confined to the onshore areas and to the so-called 'Strzelecki Terraces' offshore (Figure 2). Basement (granites and metasediments) has been drilled offshore at only a few sites, always on the Southern Platform (Figure 2). Although Strzelecki Group sediments of only Early Cretaceous age have been dated in the Gippsland Basin, analogy with their Otway Basin equivalent (the Otway Group) and with sediments in other Southern Margin basins, suggests that Strzelecki sediments extend back to the Late Jurassic.

Tectonically, the Gippsland Basin has undergone multiple phases of deformation. Two major structural styles have been described for the offshore part of the basin by previous workers: (i) poorly-defined extensional tilt-blocks with normal rotational, and accommodation faults, active principally during basin formation and basin subsidence (Early Cretaceous to Early Eocene); and (ii) sub-parallel anticlines and shear faults generated by Tertiary compression (Threlfall & others, 1976) and thought by Etheridge & others (1985) to be related to a reactivation of Early Cretaceous normal and transfer faults. Onshore, the major, largely southeasterly-trending offshore faults wrap around into a series of principally northeasterly-trending, Middle to Late Tertiary anticlines and reactivated faults (Brown, 1986; Hocking, 1988; Figure 4). Over the years, models which have been proposed for the basin's evolution include broadly northeast-southwest extension related to rifting along the southern margin of Australia (Griffiths, 1971; Etheridge & others, 1985), development as a failed arm of the Tasman Basin rift system (Burke & Dewey, 1973), and development in response to dextral shear on a major, east-west shear zone extending through Bass Strait (Davidson, 1980; Carey, 1986).

Recent, detailed tectonostratigraphic and structural analyses undertaken by companies in parts of the basin (for example, by Petrofina in the southeast) indicate that the basin has a complex geological history involving at least localised wrenching, the development of positive flower structures, extension, compression and thermal subsidence (Duff & others, 1991). In the offshore part of the basin, compression is variously thought to have started between 80 Ma (Duff & others, 1991) and 45-50 Ma (Etheridge, 1988), or even earlier (this paper). Available maps of the top Latrobe structures (for example, Brown, 1986; Maung, 1989) indicate that the axial trends of the anticlines and synclines in the offshore basin range from northeast to southeast.

DATA ACQUISITION

SEISMIC REFLECTION DATA

AGSO's Gippsland Basin deep-seismic data set consists of approximately 1650 line kms of 12-14 second record-length, 96-channel data recorded in 1988/89 (Willcox & Colwell, 1989; Williamson & Swift, 1989). Eight 'dip' lines and three 'strike' lines comprise the set (Figure 2). The dip lines were orientated parallel to the direction of extension proposed by Etheridge & others (1985, 1987) in their model of the basin's formation, and were extended to provide coverage onto the platform areas beyond the Central Deep. Thirty-five well ties were made. In addition, as part of the same acquisition program, two 14-second seismic lines were shot in the main part of the Bass Basin, and ten 10-second lines were collected mainly in the Boobyalla (Durroon) Sub-basin part of the Bass Basin (Figure 1).

SEISMIC REFRACTION DATA

During the marine reflection surveys in the Gippsland Basin, onshore recording stations were set up in Victoria, Tasmania and on Deal Island by AGSO and the Department of Earth Sciences, Monash University (Collins & others, 1990). Long-offset, wide-angle reflection and refraction data were obtained at these stations from the traverses across the basin, using air-gun shots fired during the reflection survey as the energy source. In addition, two specific refraction traverses (Lines 82/201 and 82/202, Figure 1) were run along parallel lines stretching NNE from the Deal Island area. Arrivals were observed at offsets of over 200 km from the source on some lines. Because of the close shot-spacing, either 37.5 or 50 m, and the large number of shots, up to 5000 per traverse, stacking and other signal enhancement techniques were possible.

ONSHORE MAPPING

Mapping of structures within the onshore Strzelecki Ranges was undertaken by Andrew Constantine at Monash University as part of a structural/sedimentological Ph. D. study. Initial results of this work were detailed in Constantine (1991). Overall, the onshore mapping has assisted the interpretation of the offshore profiles by providing information on the trend, style and age of Strzelecki-Group and younger faulting.

OFFSHORE MAPPING

Detailed interpretations of the AGSO Survey 82 and 90 deep-seismic data were digitised and manipulated using PETROSEIS software running on a MicroVax computer. In addition , interpretations of conventional seismic from Esso's G80A survey (4 second record length, reprocessed by GSI in 1985), and AGSO's Surveys 40 (6 second record length) and 68 (7.5 second record length) were included in the mapping exercise to fill in gaps in the seismic grid and to extend the regional coverage (Plate 2). The final data set gave a coverage with an approximate 15-20km line spacing.

Eight major horizons (sequence or megasequence boundaries) were mapped , although not all on all lines (particularly G80A lines because of their short record length):

WB - water bottom
TL - top of the Latrobe Group (time transgressive - Paleocene-Oligocene)
LP - Late Paleocene, intra-Latrobe Group (*L. balmei)*
MA - Maastrichtian, intra-Latrobe Group (*T. longus*)
CA - top of ?Golden Beach Group (Campanian, *N. senectus)*
TS - top of Strzelecki Group (middle Cretaceous)
IS - intra-Strzelecki Group
TB - top of pre-Strzelecki basement

A series of time-structure, isopach and depth-converted structure maps were produced by Petroseis from the database (see Plates 4-16). On the time-structure maps (Plates 4,6,8-11), values are posted to show the distribution of data points which control the contours. Data points were machine contoured with minor manual editing in places.

The time-horizon values were used to calculate time-isopach and depth values. Depth values were produced for the two deepest surfaces (top basement and StrzeleckiGroup) using the following average interval velocities derived from well velocity information and seismic refraction velocities (see later section): sealevel -WB (water column) 1500m/sec; WB-TL (Seaspray Group) 2700m/sec; TL-CA (Latrobe Group) 3600m/sec; CA-TS (Golden Beach Group) 3800m/sec; TS-TB (Strzelecki Group) 4000m/sec; and pre-Strzelecki basement 5900m/sec. It is believed that these values provide a reasonable estimation of the overall velocity structure. Depth conversions were not performed for the younger horizons because of the complex velocity structure in the upper part of the section caused by, for example, infill in Tertiary channels.

Although the 15-20km average line spacing of the data grid precludes detailed resolution of the structure within the basin (including fault correlation), the deep seismic data provide a unique insight into the gross geometry and overall evolution of the basin. The basin is clearly a complex feature.

BASIN STRUCTURE AND DEVELOPMENT

ONSHORE GEOLOGY (by A. E. Constantine, Monash University)

The generally-recognised structural trends of the Gippsland Basin are shown in Figure 4. The offshore Central Deep is dominated by NW- to WNW-trending extensional faults and NE- to ENE-trending anticlines, bounded to the north and south by E- to ESE-trending fault systems. In contrast, the onshore basin is dominated by NE- to E-trending anticlines, synclines, monoclines, extensional faults, compressional faults, and subordinate NW-SE striking extensional faults. In the southern part of the onshore Gippsland Basin, major faults, monoclines, anticlines, and synclines trend NE, but as they approach its northern margin, they bend eastwards.

The onshore basin is characterised by two, NE-trending, uplifted blocks of Strzelecki sediments - the Narracan and Balook Blocks (Figure 4). The Mornington High at the western end of the Gippsland Basin, with outcropping Palaeozoic basement, is a similar NE-trending feature.

Traditionally, the Gippsland and Otway Basins have been interpreted as individual basins because of the supposed absence of ?Late Jurassic-Early Cretaceous Strzelecki Group sediments on the Mornington High and under the western half of Western Port Bay (for example, Douglas & others, 1988; Thompson, 1986). However, subsurface remnants of ?Late Jurassic-Early Cretaceous sediments are present on the Mornington High (Mallett & Holdgate, 1985); at Tyabb (Keble, 1950) and Koo-wee-rup in the Western Port region; and at the western end of Phillip Island. Furthermore, two isolated remnants are exposed on the Mornington High at Arthurs Seat (McHaffie, 1974) and Sunnyside Beach (Douglas, 1969). The presence of Strzelecki Group sediments on the Mornington High indicates that the Gippsland and Otway Basins were connected during the ?Late Jurassic-Early Cretaceous.

The Strzelecki Group crops out extensively, and is present at shallow depths, over most of the onshore Gippsland Basin. Constantine (1991) identified four fault stages within the Strzelecki Group, based on structural information from the Wonthaggi, Jumbunna, Kilcunda and Korumburra coal fields, and detailed structural mapping onshore. The relative timing of the four stages is determined by cross-cutting relationships, and the ages of volcanic dykes intruding fault planes.

The oldest faults (Stage 1) in the onshore Gippsland Basin were active during deposition of the Strzelecki Group. They strike between NE-SW and E-W and show normal displacements of up to 230 m. Kinematic analysis of Stage 1 fault planes and associated slickensides lineations indicates that Stage 1 faults formed during NNW-SSE extension. In the Wonthaggi coalfield, syn-depositional Stage 1 faulting controlled the lateral extent and thickness of the Aptian coal seams and associated underlying sediments. More than 1600 coal bores have been drilled in the Wonthaggi area alone; 17 of them intersected Palaeozoic basement. The main coal seam mined at Wonthaggi occurs between 210 m and 635 m above Palaeozoic basement. Using the main seam as a horizontal datum, cross-sections through the Wonthaggi coal field show the sedimentary sequence between the datum coal seam and the underlying Palaeozoic basement thickens to the NNW, by 425 m over a horizontal distance of 11 km. In addition, isopach mapping of a distinctive, red-coloured basal conglomerate, present in 9 of the 17 bores which intersected Palaeozoic basement, indicates it was deposited in a NE-trending asymmetric sub-basin which thickened to the NW.

Stage 2 faults strike NW-SE and have normal displacements of typically less than 5 metres. Kinematic analysis of fault-planes and associated slickenside lineations indicates Stage 2 faults are related to a NE-SW extensional event. Some Stage 2 faults have been intruded by dolerite and basaltic dykes. Two of these dolerite dykes have been dated at 78 $\pm$ 6 Ma (Lindsay, 1982) and 85.5 Ma (Bowen, 1974), which suggests that the faulting is Late Cretaceous, or earlier, in age. Since these faults are in the same orientation and are of approximately the same age as NW-SE striking extensional faults in the offshore Gippsland Basin, the fault sets are probably related.

Stage 3 faults comprise N-S striking fault zones up to 6 m wide with observed normal displacements of up to 120 m. The age of Stage 3 faults is uncertain as the presence of high- and low-angle lineations on some fault planes suggests some reactivation. Stage 3 faults do, however, offset those of Stages 1 and 2.

Stage 4 faults are subdivided into two groups: NW-SE striking reverse faults with low-angle lineations, and NE-SW striking reverse faults with high-angle lineations. Kinematic analysis of fault planes and associated slicken-side lineations from both sub-groups indicates that reverse faulting is related to NNW-SSE compression. The presence of faults with normal offset, but with lineations indicating reverse movement, suggests that at least some of the reverse faults may be reactivated Stage 1 and 2 faults. Some Stage 3 faults with low-angle lineations have probably been reactivated by NNW-SSE compression.

The dominant onshore faults are those of Stage 4. Major faults bounding the Mornington High and the Narracan and Balook Blocks have previously been interpreted as extensional (Victorian Mines Department, 1971a, 1971b; Hocking, 1988). Mapping indicates that most, if not all, of the major NE-trending onshore faults are compressional. The Mornington High, and Narracan and Balook Blocks, are essentially 'pop-up' structures bounded by reverse faults dipping towards each other.

Steep dips of up to 50° or more, towards the margins of the Narracan and Balook Blocks, are related to drag associated with reverse movement on the bounding faults. Many monoclines within the Tertiary cover sediments overlying the Strzelecki Group parallel to the margins of the uplifted Strzelecki blocks and elsewhere onshore, probably reflect reverse faulting within the Strzelecki Group. A west-east striking cross-section through the onshore Gippsland Basin (Figure 5) illustrates some of the stratigraphic and structural relationships of the Strzelecki, Golden Beach, Latrobe, and Seaspray Groups. Monoclines in the Tertiary appear to reflect faulting in the Strzelecki and Palaeozoic basement, with broad anticlines developing due to crustal shortening. The relationship between the Strzelecki Group and Palaeozoic basement shown in Figure 5, and the position of monoclines in the Tertiary, suggest that Tertiary to Recent faulting may be occurring on reactivated ?Late Jurassic-Early Cretaceous or Late Cretaceous faults.

BASIN GEOMETRY

In general, the gross geometry of the Gippsland Basin can only be ascertained from deep seismic data which at present are confined to the offshore area. AGSO's deep seismic data show that, in broad terms, the basin is an ESE-trending depocentre, about 80 km wide and extending to the continent/ocean boundary at about 150° E - a total basin length of nearly 400 km. It is underlain by, and formed within, a basement of Palaeozoic, Lachlan Geosyncline rocks.

As shown in Figure 6 and Plates 3,17-21, the main basin depocentre (the Central Deep) is bounded by a relatively gently sloping northern ramp (a low-angle 8-30° fault or detachment plane), which typically dips southward from about 2km depth near the coast to 14-16km depth along the basinal axis, and a more steeply dipping listric southern-bounding fault or fault system. Our regional data indicate that the southern bounding fault (Foster Fault System) over most of tits length is a relatively simple, mildly sinuous feature (Figure 2). Only in the southeastern part of the basin does it appear more complex; it splays and gives rise to features such as the Pisces Sub-basin and basement blocks which underlie the continental slope. The northern ramp is an undulating surface within basement which follows the general easterly-trend of the basin (Plate 3). It appears to wrap around the western, onshore end of the basin, to form a headwall beneath the Strzelecki Ranges. In several areas, the ramp is overlain by tilt-blocks, probably consisting of basement. On the profiles across the basin (Figure 6, Plates 17-21), these blocks seem to be sporadically distributed and usually their tilt shows no systematic relationship to the geometry of the ramp; that is, they cannot be balanced within the plane of the NNE profiles. On the axial profile (Figure 7, Plate 22), the basin is floored by a few major tilt-blocks which may reconstruct by sliding to the WNW. The basin shows evidence of compression at the end of the Early Cretaceous, with apparent westward/southward overthrusting and reverse faulting of the ramp/detachment surface. The deep seismic profiles show that the detachment surface floors the basin and continues as a major seismic event at about 16 km depth (6 seconds two-way time) beneath the Southern Platform/Bassian Rise, thus linking the Gippsland and Bass Basins (Figures 8 and 9)

SEDIMENTARY FILL AND STRUCTURING

The maximum sedimentary fill within the basin is approximately 8.5 seconds reflection time (about 16km) and occurs offshore, within the western part of the axial depocentre (Plates 4, 5 and 12). The section can be divided into a number of megasequences on the basis of the deep seismic data. These are the principal tectonostratigraphic units within the region, and are similar to units recognised by Duff & others (1991) in the southeast corner of the basin.

The first (oldest) megasequence consists of the largely volcanoclastic sediments of the ?Late Jurassic-Early Cretaceous Strzelecki Group (Figure 3, sequence TB-TS; Figures 6 & 7; Plates 17-22). This sequence is known from the Strzelecki Ranges and from its penetration in wells on the Strzelecki Terraces(Fig. 2). According to our interpretation, the Strzelecki Group has a maximum thickness of about 5 seconds two-way time (Plate 13), or about 10 km, and comprises the major part of the basin infill within the Central Deep and in troughs (possible grabens or half grabens) in the northern part of the basin. The upper surface of the sequence reaches its maximum depth of just over 6 seconds two-way time (approximately 7.5 km) in the central eastern part of the basin (Plates 6 and 7). As noted by previous workers, the unit is absent from the Southern Platform.

Our deep-seismic data show that a lower section of Strzelecki sediments (seismic sequence TB-IS) was deposited as a thick wedge extending basinwards from the headwall created by the northern ramp, and attaining a maximum thickness of about 5-6 km at the western end of the axial depocentre. These 'lower' Strzelecki sediments downlap and onlap the basement and, in places, exhibit structurally controlled 'synrift-type' geometries, probably comprising paludal and/or lacustrine deposits bounded by uptilted edges of the blocks. This phase of deposition, which by analogy with other Southern Margin basins may be largely Jurassic in age, was probably dominated by alluvial-fan and fluvial deposits. It was terminated by a strong erosional event.

The 'upper' Strzelecki has a distinct seismic character in the terrace areas, comprising a relatively high frequency, continuous, strongly reflecting sequence up to 4 km thick (seismic sequence IS-TS). These sediments may once have been far more extensive, as indicated by depositional remnants on the Mornington High to the west. Similar ?Late Jurassic-Early Cretaceous sequences (Otway Group) are also present in the Bass/Boobyalla basins, the Otway Basin, and probably in the Sorell Basin west of Tasmania, suggesting that ?Late Jurassic-Early Cretaceous sediments once formed an extensive blanket over the region (see, for example, the Otway/Strzelecki (KI) seismic correlation, Figures 9 and 10).

The seismic character of Strzelecki Group sediments in the terrace areas (Figure 10B & C) is generally not maintained basinward of the terrace margins. Indeed, without deep drill results, it can only be assumed that the Strzelecki Group is present in the Central Deep. If this were not the case, the Gippsland Basin must have developed in two stages: initially as a ?Late Jurassic-Early Cretaceous Strzelecki depocentre, which then further opened to create a Late Cretaceous basin into which a huge thickness (up to 14 km) of Golden Beach/Latrobe Group sediments was deposited. We consider this fairly unlikely. However, the significance of the faults which separate the Strzelecki Terraces from the Central Deep is unclear. The northern of these fault systems (Rosedale Fault System) may result from re-activation of deep-seated faults bounding basement blocks (Figure 6B, Plate 18). The southern fault (Darriman Fault of Maung, 1989) appears to propagate from the intersection of the northern basinal ramp and the listric southern-bounding fault (Foster Fault System).

The west-east profile (Line 90/2; Figure 7, Plate 22) shows that the upper Strzelecki Group onlaps a major basement block under Hapuku-1 in the deeper water part of the basin. Further east, on Line 68/14 (Figure 7, Plate 22) below the continental slope and rise, the Strzelecki appears to change seismic facies and has a seismic signature in keeping with stacked volcanic flows. These flows onlap a major basement ridge which appears to lie adjacent to the continent/ocean boundary (COB). It is unclear whether this ridge marks the original eastward termination of the Gippsland Basin or if part of the basin once extended onto Lord Howe Rise. The basement ridge may be a southern continuation of the Dampier Ridge, which dredge hauls have shown to be of continental origin (Roeser & others,1985), and which is offset across a prominent Tasman Basin transform fault. Palaeocurrent measurements within the Strzelecki Ranges (Constantine, pers. comm.) indicate provenance of the volcanoclastic sediments from an eastern source - possibly the basement ridge or the volcanic province on southern Lord Howe Rise (Veevers & others, 1982; Willcox & others, 1980).

As noted by previous workers (for example, Davidson and Morrison, 1986), a major structuring and erosional event took place at the end of Strzelecki time (mid Cretaceous). In the Gippsland Basin this is expressed as:

- numerous near-vertical faults and 'flower fault structures' which generally detach on the northern ramp and extend upwards to the top Strzelecki (Figure 6, Plates 17-21),

- block-faulting along the southern edge of the basin, giving rise to the Southern Strzelecki Terrace and Southern Platform, and accentuating the Central Deep (Figure 8A),

- the first development of wrench-related anticlines with attendant onlap of the overlying sequence (Figure 8B),

- intense wrenching and faulting to create the Northern Strzelecki Terrace and folding which detaches on the basement ramp (Figure 8C), and

- overthrusting of the Strzelecki Group and the ramp surface, towards the headwalls (Line 90/2, Figure 7, Plate 22).

This event is also recognised in the Boobyalla Sub-basin, where it gave rise to extensional structures - a suite of clearly defined tilt-blocks which trend NNW and incorporate the Otway (Strzelecki equivalent) Group (Baillie and Pickering, 1991; Figure 10A).

The end of Strzelecki event appears to correlate with the early stages of plate drifting in the central and eastern parts of the Great Australian Bight (Willcox and Stagg, 1990), and with the onset of rifting in the Boobyalla Sub-basin and possibly along the margins of the Tasman Basin.

The overlying seismic sequence (TS-CA; Figures 3, 6 and 7; Plates 17-22) broadly correlates with the Late Cretaceous Golden Beach Group of Lowry and Longley (1991). In the Gippsland Basin it shows a broad synrift relationship to the underlying Strzelecki - onlapping the early wrench anticlines (for, example, the Whiting and Veilfin structures), infilling the downfaulted area of the Central Deep while being absent from the basin margins, and becoming systematically thicker against some of the active tilt-blocks in the southeastern part of the basin. The upper surface of the sequence generally lies at a depth of 2-3 seconds two-way time (Plate 8) over most of the offshore part of basin. Its thickness typicallly ranges from a few hundred to about 1600 milliseconds two-way time (about 0.5-3 km assuming an average interval velocity of 3800m/sec), with its greatest thickness occurring along the Tasman Basin margin (Figure 7, Plate 14). In the Boobyalla Sub-basin, sediments of the same age form a classical synrift relationship to the tilt-blocks (Figure 10A). The age of the Golden Beach Group, from about 96-80 Ma, and its structural relationship to the underlying Strzelecki suggest that it is a tectonostratigraphic unit associated with Tasman Basin 'rifting'.

Sequence CA-MA (Figures 3, 6 and 7; Plates 17 -22) ranges from the Campanian (top *N. senectus* zone) to the Maastrichtian (*T. longus* zone), corresponding largely with the Late Cretaceous part of the Late Cretaceous-Eocene Latrobe Group. In places (e.g. on Lines 90/7 and 90/21+11; Plates 18 and 19), the sequence thickens against the Foster Fault System, and/or against the faults separating the Southern Strzelecki Terrace from the Central Deep, showing that the southern margin of the Gippsland Basin was still active at this time. It is unlikely that it ever extended onto the platform areas, which were probably being planated, thereby providing a source of sediment. The Maastrichtian unconformity which is the upper boundary of this sequence (Plate 9), marks a major erosional event within the basin. At that time, or shortly thereafter, large parts of the platform and terrace areas, the Bassian Rise, and the exposed edges of Strzelecki blocks along the southern flank of the basin, were peneplaned. The basin boundary fault systems were then largely inactive, except in the western offshore area where some reactivation continued.

The dating of magnetic anomalies within the Tasman Basin shows that seafloor spreading adjacent to the Gippsland Basin commenced at about Anomaly 33 time (that is, during the Campanian or earliest Maastrichtian). Sequence CA-MA appears as the last stage of rift-fill within the Gippsland Basin, prior to thermal subsidence along the newly formed margin and progressive onlap of younger sequences onto the planated basement platforms.

Sequence MA-TL (Figures 3, 6 and 7; Plates 17-22) corresponds to the latest Cretaceous-Eocene part of the Latrobe Group. It includes a prominent intra-Latrobe unconformity (Horizon LP, Plate 10) which has been dated as Late Paleocene (*L. balmei* zone). This megasequence forms a classic 'steers horn' component of basin fill, associated with steady sag of the basin and continental margin. It is extensively eroded at the eastern end of the basin (e.g. Figure 7, Plate 22), partly due to channelling.

Overall, the Latrobe Group (CA-TL) ranges in thickness from less than 200 milliseconds two-way time (<0.3 km) on the platform areas to 1600 milliseconds (~3 km assuming an average interval velocity of 3600m/sec) in the Central Deep (Plate 15). It thins to the east into deep water and may be exposed in the lower part of the Bass Canyon (Figure 7, Plate 22).

The deep seismic data indicate that sporadic structuring occurred in the basin from the mid Cretaceous (top Strzelecki time) until the Oligocene (top Latrobe time). The most prominant structures are wrench-related anticlines which have an ENE-WSW to E-W trend, and structures created by reactivation, reversal, and even overthrusting, of faults near the basin boundaries. These features appear to be a product of intermittent movements along the boundary faults and the relative adjustment of several basement blocks (microplates) within the region. Movements culminated, and largely ceased, at approximately top Latrobe time or shortly thereafter (?mid Oligocene), a time that apparently corresponds to the clearance of the Australia and Antarctic Plates.

Sequence TL-WB(seabed) correlates with the marine marls, shales and limestones of the Seaspray Group (Lakes Entrance and Gippsland Limestone formations). This unit, which is extensively channelled in the east, reaches a maximum thickness of about 1800 milliseconds two-way time (~ 2.4 km assuming an average interval velocity of 2700m/sec) along the edge of the present-day shelf (Plate 16). The Lakes Entrance Formation forms a regional seal for the top Latrobe hydrocarbon accumulations.

DETACHMENTS AND DEEP CRUSTAL STRUCTURE

The deep reflection seismic profiles show a consistent pattern of deep reflection events which are considered to be non-spurious, and to result from mid to deep crustal impedance contrasts (Figures 6, 7 & 8; Plates 17-22). These events have been interpreted in conjunction with a refraction velocity/depth model, computed along Line 90/7, from shots recorded at stations near Orbost and on Deal Island (Figures 1 & 11). The refraction model was derived from the first-arrival times, and constrained by earlier models for Victoria (Gibson & others, 1981) and Tasmania (Richardson, 1980). Additional velocity information from well and sonobuoy data (Figure 1) was used for the shallow sediments within the basin. The model was then refined iteratively, by ray-tracing, until a satisfactory agreement between the calculated and observed travel times was achieved. The refraction model shown in Figure 11B has been used to generate a synthetic reflection time overlay, which compares favourably with the actual reflection profile in Figure 11A.

The results of the reflection/refraction modelling are summarised below.

- Gross geometry of the Gippsland Basin is shown to be comparable in both the reflection and refraction profiles, with velocities of the Strzelecki 'synrift' section = 4.0 km/s, Golden Beach/Latrobe 'rift' section = 3.8 km/s, Latrobe 'post-breakup' section = 3.0 to 3.5 km/s, Tertiary 'limestones' = 2.7 km/s.

- Maximum sedimentary thickness is about 16 km.

- Detachment. A sub-horizontal surface, at 5-8 seconds reflection time or about 12-16 km depth over most of the area, underlies the basin and extends beneath the Bassian Rise and Northern Platform. A similar, probably contiguous, surface occurs under the Bass Basin, the King Island High, and probably also under Tasmania (see, for example, the juxtaposed Gippsland/Bass Basin profiles, Figure 9). It occurs in the mid crust, presumably within the Lachlan Geosyncline basement complex, at the boundary between layers with velocities of 5.9 and 6.3 km/s. This surface connects with the 'northern ramp' and is interpreted as a primary basin-forming detachment ('D' in Figure 11). Its sub-branches form the southern-bounding fault system of the basin ('S/D' in Figure 11).

The AGSO survey data are unique in allowing such a well-defined detachment to be mapped over much of the basin (Plate 3): it is seen to create a headwall-type structure along the northern and western edges of the basin, and to emerge from beneath basement tilt-blocks and the 'outer ridge' at the continent-ocean boundary (Figures 6 and 7, Plates 17-22). In the E-W profile (Figure 7, Plate 22), the detachment surface exhibits westerly overthrusting, apparently at top Strzelecki (mid Cretaceous) time. On some of the NNE-SSW profiles there are similar indications - the 'northern ramp' having been thrust southwards along the southern boundary fault.

- A more highly-reflective and stratified crustal layer corresponds with the 6.3 km/s velocity. There is still no consensus on the origin of such deep crustal reflection properties, but hypotheses include (Klemperer and BIRPS Group, 1987; Holbrook & others, 1991):
    - lithological layering due to sill-like mafic intrusions
    - mylonites and ductile strain fabrics
    - presence of a fluid phase or partial melt.

  We speculate that the stratified crust underlying the Gippsland Basin is most likely related to mylonites and ductile strain. Lying at 15+ km deep, and immediately below or just within the main detachment zone, it is at the optimal depth for the brittle to ductile crustal transition (Sibson, 1982; Smith and Bruhn, 1984).

- Mohorovicic Discontinuity. A band of prominent, sub-horizontal, almost continuous reflectors occurs throughout the Gippsland Basin area at about 10 seconds reflection time ('C' in Figure 11A; see also, Figure 9). The refraction modelling allows reasonable correlation with a relatively thin 7.0-7.8 km/s crustal layer, which separates a thick 6.3 km/s layer above from a 7.8-8.1 km/s layer below. We interpret this ?transition zone as the 'Moho'.

  The refraction data and depth-converted reflection data show that the Moho shallows from a regional depth of about 30 km to 25 km under the Gippsland Basin, and that the width of compensation is about one and a half times the width of the original 'rift' basin (Figure 11B). In the NNE-SSW direction, the crustal thinning associated with basin formation is almost coincident for the 'upper' and 'lower crust'. The 'lower crust' (the 6.3 km/s layer), thins from about 15 km to 10 km under the basin axis, and may once have been exposed at the detachment surface. In the axial, WNW-ESE direction, there are indications that the 'lower crust' thins towards the Tasman Basin (Figure 7). The basin/crustal asymmetry in this orientation is consistent with our proposed NW-SE azimuth of basin-forming 'transtension'.

GEOLOGICAL EVOLUTION AND TECTONIC MODEL

Our research indicates that the Gippsland Basin is an ESE-trending depocentre overlying considerably thinned 'upper' and 'lower crust'. Maximum crustal asymmetry occurs in the axial profile. The basin is floored on its northern side by a detachment ramp which wraps around to form the northwestern margin of the basin. Its southern edge is a relatively linear, listric fault system. Although some basement tilt-blocks lie on the 'northern ramp', they show no systematic increase in tilt towards the axis of the basin, and they cannot be balanced in the NNE plane. In fact, many tilt-blocks seem to have moved sub-parallel to the basin margins. This is consistent with observations from the onshore, western, part of the basin, where basin-forming structures are inferred to result from NNW-SSE extension.

The 'northern ramp' merges with a main sub-basinal detachment at about 15-16 km depth. This detachment appears to extend southwestwards under the Bassian Rise, Bass Basin, King Island High, and probably Tasmania, suggesting that these features are products of linked fault/detachment system. This conclusion tends to be supported by tectonostratigraphic similarities between the basins, most strikingly between the Gippsland and adjacent Bass Basins, as is indicated by the juxtaposition of deep seismic profiles (Figure 9). Other basins on the Southern Margin, including the Otway and Great Australian Bight Basins, are probably also of similar age, and all basins in the region could reasonably be expected to have commenced formation under the influence of a common stress field (Willcox and Stagg, 1990). This was a precursor to the breakup of the 'Australia-Antarctic supercontinent'. The orientation of this stress field can best be determined from areas such as the Eyre Sub-basin, in the western part of the Bight, where well-developed extensional structures have been mapped (Stagg & others, 1990). These point to an episode of NW-SE orièntated extension which commenced in or before the Berriasian (latest Jurassic or earliest Cretaceous). Stagg and Willcox (in press) have recently reported on the likely presence of Valanginian or pre-Valanginian oceanic crust in this area.

During the ?Late Jurassic-Early Cretaceous, synrift Strzelecki Group/Otway Group sediments filled in the main depocentres and once blanketed the Bass Strait region. The seismic stratigraphic consistency of these deposits is clearly seen from the character correlation of the Otway Group in the Boobyalla Sub-basin with the Strzelecki Group on both the southern and northern flanks of the Gippsland Basin (Figure 10). The earliest Strzelecki sediments in the Gippsland Basin form an eastward thickening wedge, probably derived from the western headwall.

The extensive structuring which took place in the mid Cretaceous led to the development of many Gippsland Basin anticlines; folds and tilt-block re-activation, particularly over the shallower part of the 'northern ramp'; overthrusting to the south and west; and uplift/tilting of the onshore basin. The apparently synchronous development of both Strzelecki fault-blocks and anticlines could only have occurred in a wrench-related stress field. We believe that the disposition of reverse faults and anticlines in the onshore and offshore Gippsland Basin can largely be attributed to reactivation of the ?Late Jurassic-Early Cretaceous NE-SW to E-W striking normal faults in the headwall of the basin, and of normal and wrench-related faults on the basin's flanks, as well as to continued growth and faulting of early compressional features in the main basin depocentre.

During the mid Cretaceous, extension started in the Boobyalla Sub-basin, so that the Otway Group, itself a synrift deposit, has a pre-rift relationship to the overlying sequence (Figure 10A).

In the Bass Basin proper, high-angle faulting occurred, but with none of the concurrent folding that is so evident in the Gippsland Basin. It is inferred that considerable thicknesses of Strzelecki Group sediments were eroded from the basin margins and 'platform areas' during the mid Cretaceous. In the Banks Strait area (south of Flinders Island) folding and uplift of the Early Cretaceous Otway Group was followed by erosion of perhaps 2000 metres of section. This major mid Cretaceous structuring event in the Bass Strait region correlates with the onset of limited (slow) spreading along the 'Southern Margin' at 95 $\pm$ 5 Ma, and appears to have resulted from significant plate adjustments in the Bass Strait region.

Most of the Late Cretaceous was a period of rift infilling in the Gippsland Basin region, probably brought about by a poorly-understood rifting process between the Lord Howe Rise and Australia Plates. In the Maastrichtian, a major uplift and erosional event is recorded in the region, and this seems to have been widespread, affecting areas as distant as the outer part of the Ceduna Terrace in the Great Australian Bight Basin (Stagg & others, 1990). This event may be related to a thermal pulse which preceded more widespread and faster breakup/spreading in the Southern Ocean, and the commencement of spreading in the Tasman Basin. It indicates that despite the Cenomanian 95 $\pm$ 5 Ma age attributed to the initial breakup of the Southern Margin, the plates must still have been in direct contact, at least until the end of the Cretaceous. In the latest Cretaceous (Maastrichtian) to Eocene, the Gippsland Basin was subject to sag-phase deposition, in response to Tasman Basin spreading. Wrench-related structuring continued in the Gippsland Basin throughout this period, probably in response to further plate readjustments. It was not until the mid Oligocene that most of this movement ceased, probably as a result of complete clearance of the Antarctic and Australia Plates.

This interpretation leads us to the conclusion that the Gippsland Basin is <u>not</u> the product of NNE-SSW orientated extension, with associated largely normal northern and southern bounding faults and extensional compartments separated by NNE-trending accommodation zones or transfer faults, as postulated by Etheridge (1985, 1987). Such a model is particularly restrictive, as it necessitates using a ?Late Jurassic or Early Cretaceous extensional direction in the Bass Strait region, which is almost orthogonal to that interpreted from high-quality seismic data in the western Great Australian Bight (Willcox and Stagg, 1990).

We conclude that the Gippsland Basin is primarily a result of 'transtension' (that is, oblique extension) in an approximate NW-SE sense, and is an integral part of a linked system of 'Southern Margin' and Bass Strait basins. The basin-forming movement was left-lateral, strike-slip, and bears close analogy to the Magnus Basin of the North Sea, as shown in Figure 12D (Gibbs, 1987). In this model, the Bassian Rise is the 'upper plate' (U), and the Northern Platform and its continuation to the west is the 'lower plate' (L).

We consider that most of the tectonic features of the Bass Strait region can be explained in terms of relative movements between the Australia and Antarctic Plates and three postulated 'microplates' - namely, a 'Lord Howe Plate', a 'Bassian Plate', and a 'King Island-Tasmania Plate'. A fourth -'South Tasman Rise Plate'- has been discussed elsewhere (Willcox and Stagg, 1990). Conceptual sketches for the evolution of the region are presented in Figure 12. We envisage that the main stages of movement to have been:

Pre-Late Jurassic (Figure 12A)

In the latest Jurassic, or possibly earlier, NW-SE orientated lithospheric extension occurred within the 'Australia-Antarctic supercontinent'. This was expressed as simple extension in the western Great Australian Bight area, but must have been accommodated by largely strike-slip movements west of Tasmania and through Bass Strait, along major crustal fractures, the Gambier-Gabo Lineament (Harrington & others,1974) and Tamar Fracture System (Williams, 1978). Outpourings of mid-Jurassic dolerite accompanied initial movements along the Tamar Fracture.

?Late Jurassic-Early Cretaceous (Figure 12B)

Relative movements between the Australia and Antarctic Plates, and compensatory movements of the 'microplates', initiated the formation of a linked-system of largely extensional and transtensional basins (Robe and Penola Troughs, Otway, Torquay, Sorell, Bass, and Gippsland Basins, and Great Australian Bight Basin to the west). Most importantly, in the Bass Strait region, the Bassian Plate slid right-laterally along the Tamar Fracture, and underwent clockwise rotation. Its motion with respect to the Gambier-Gabo Lineament was left-lateral. We postulate that rotation of the Bassian Plate had the simultaneous effect of creating headwall, extensional 'sub-basins' in the Otway Ranges-Torquay Sub-basin and Strzelecki Ranges, as well as forming the roughly NW-SE trending strike-slip to transtensional Gippsland and Bass Basins. The mainly-extensional, predominantly NE-SW to E-W trending, Stage 1 and ?Stage 2 faults of the Strzelecki Ranges developed at this time as a result of these movements. Largely-volcanogenic Strzelecki/Otway Group sediments filled in the depocentres and probably blanketed the region.

Late Cretaceous (Figure 12C)

During much of the Late Cretaceous, at least from Cenomanian to Campanian times (about 95-80 Ma), the Bassian and Lord Howe Plates appear to have remained linked despite incipient Tasman Basin rifting. The Lord Howe Plate moved in a highly oblique, left-lateral sense, with respect to the Australia Plate, whereas the Bassian Plate underwent slight anti-clockwise rotation to produce compression and wrenching in the Gippsland Basin. These complex microplate movements appear to have given rise in the Gippsland Basin to westward and southward overthrusting of the of the Strzelecki Group and the basin-forming detachment, many of the basin's anticlinal structures, and possibly the Stage 3 faults of the Strzelecki Ranges.

The effect of these movements in the Bass Basin was to produce largely extensional faulting, leading to the marked structural contrast between the two basins, as has been noted by previous workers such as Davidson & others (1984). At the trailing edge of the Bassian Plate, the movements produced extension, which started tilting and block formation of Otway Group sediments, thus producing the Boobyalla Sub-basin. The basin-forming structure of this area can be derived from as little as 10 km of movement.

Structuring in the region, most notable in the Gippsland Basin, continued through the Late Cretaceous to the mid Oligocene, by which time Tasman Basin spreading had ceased and the Australia and Antarctic Plates had totally cleared. Minor structuring, including Stage 4 reactivated faulting in the Strzelecki Ranges, has continued through to the present in response to NW-SE compressional stresses, probably generated along the Australia/Pacific Plate boundary (Denham and Windsor, 1991). As noted by previous workers (for example, Smith, 1982), these stresses may have contributed to the general NE-SW orientation of some of the anticlines at the top Latrobe Group level.

IMPLICATIONS FOR PETROLEUM EXPLORATION

Although most of the early exploration in the Gippsland Basin concentrated on large structural or combined structural/stratigraphic traps at the top Latrobe Group level, during the last decade or so considerable work has been directed at exploring deeper (Late Cretaceous and Paleocene) levels within the Latrobe Group (see for example, Clark and Thomas, 1988). Our deep-seismic data show that:

- The basin has had a complex structural and stratigraphic history that probably involved several phases of petroleum generation and migration.
- There are a number of potential structural and combined structural/stratigraphic traps at the top Strzelecki, top Golden Beach and lower Latrobe Group levels, which are not reflected at the shallower, commonly-explored top or near-top Latrobe Group horizons.
- The Golden Beach Group occurs throughout the Central Deep, thickens to the east, and probably offers a good exploration target along most of the margins of the Central Deep.
- A thick sequence of undrilled, highly-structured 'Strzelecki Group' sediments occurs in the Central Deep. Although now overmature for all but dry gas generation (Smith, 1988; Stephenson & others, 1991), these sediments may have been a significant source for liquid hydrocarbons now trapped higher in the section.
- Small pockets of sediment appear to be caught up on the Southern Platform. Where these occur adjacent to major fault systems, they may be prospective.

CONCLUSIONS

Interpretation of AGSO's regional grid of deep seismic data from the Gippsland Basin, has allowed an unprecedented opportunity to study basin formation. Apart from the regional significance of this study, the characteristics of the basin-forming structures and the basin-forming mechanism should have wider, possibly global, application.

In summary, the Gippsland Basin is unlikely to be a product of NNE-SSW orientated extension in the Early Cretaceous as was proposed by Etheridge & others (1985, 1987). It appears to be of strike-slip to 'transtensional' origin, with the earliest movement in the Late Jurassic or pre-Late Jurassic, in a left-lateral sense, sub-parallel to the basinal axis (that is, approximately NW-SE). It was one of a linked system of 'Southern Margin' basins, which included the Bass and Otway Basins, and which probably formed on a common detachment or detachment complex. The seismic megasequences within the basin clearly reflect major tectonic events associated with rifting and breakup/seafloor spreading in the Southern Ocean and the Tasman Basin. Continued adjustments and reactivation of the several 'microplates' which we postulate for the region, from mid Cretaceous to Oligocene, gave rise to the wrench-related and compressional structures which form the principal petroleum traps.

This study clearly shows that the Gippsland Basin is a 'poly-history' basin, with its structural growth occurring in several stages since formation. We envisage that this multiple phase history has led to several opportunities for the migration and entrapment of petroleum, particularly in mid Cretaceous and early Late Cretaceous structures, commonly not reflected at the traditionally explored top and near-top Latrobe levels.

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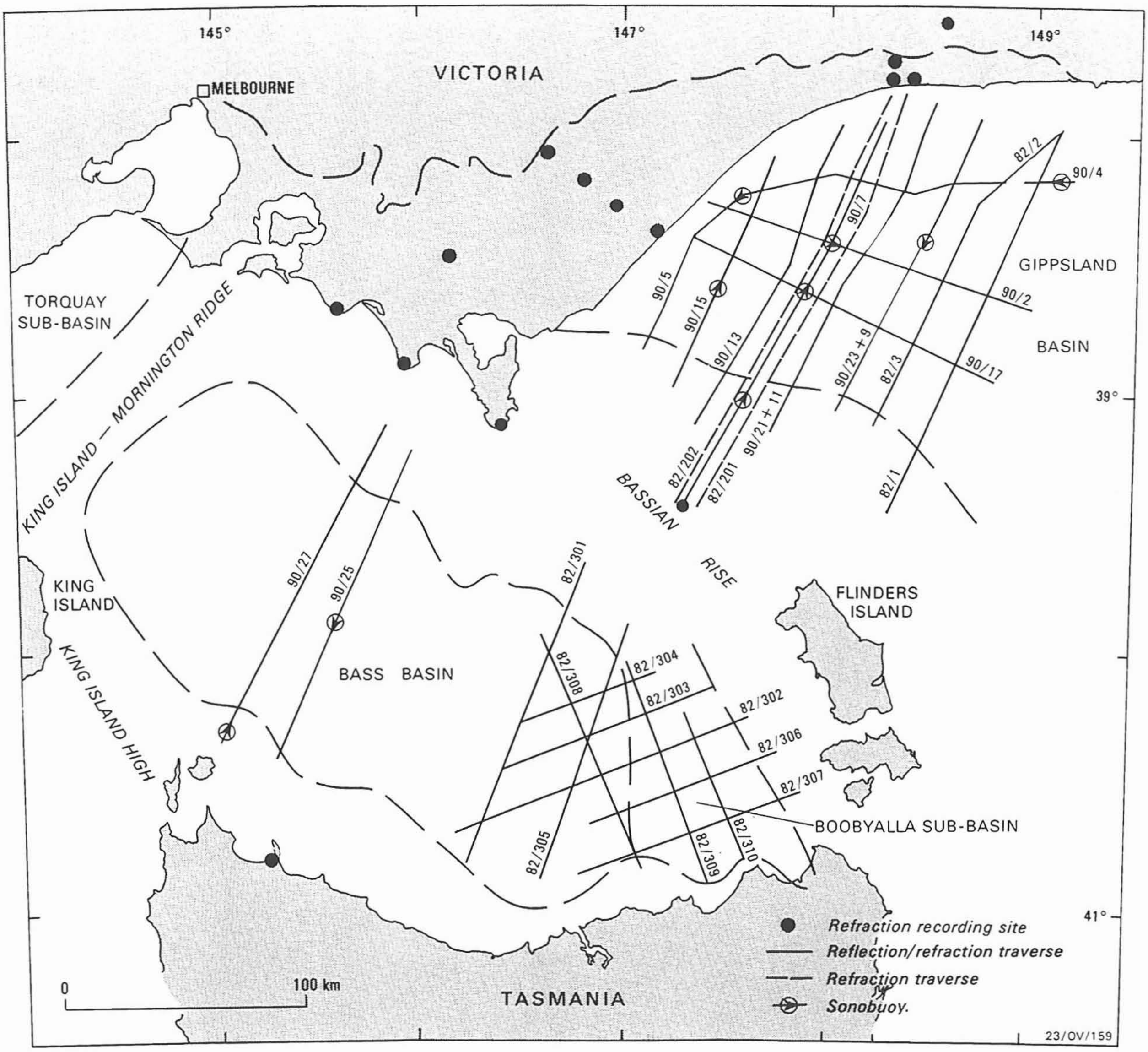

Figure 1. Regional setting of the Gippsland and Bass Basins showing the location of AGSO's deep-seismic reflection/refraction lines.

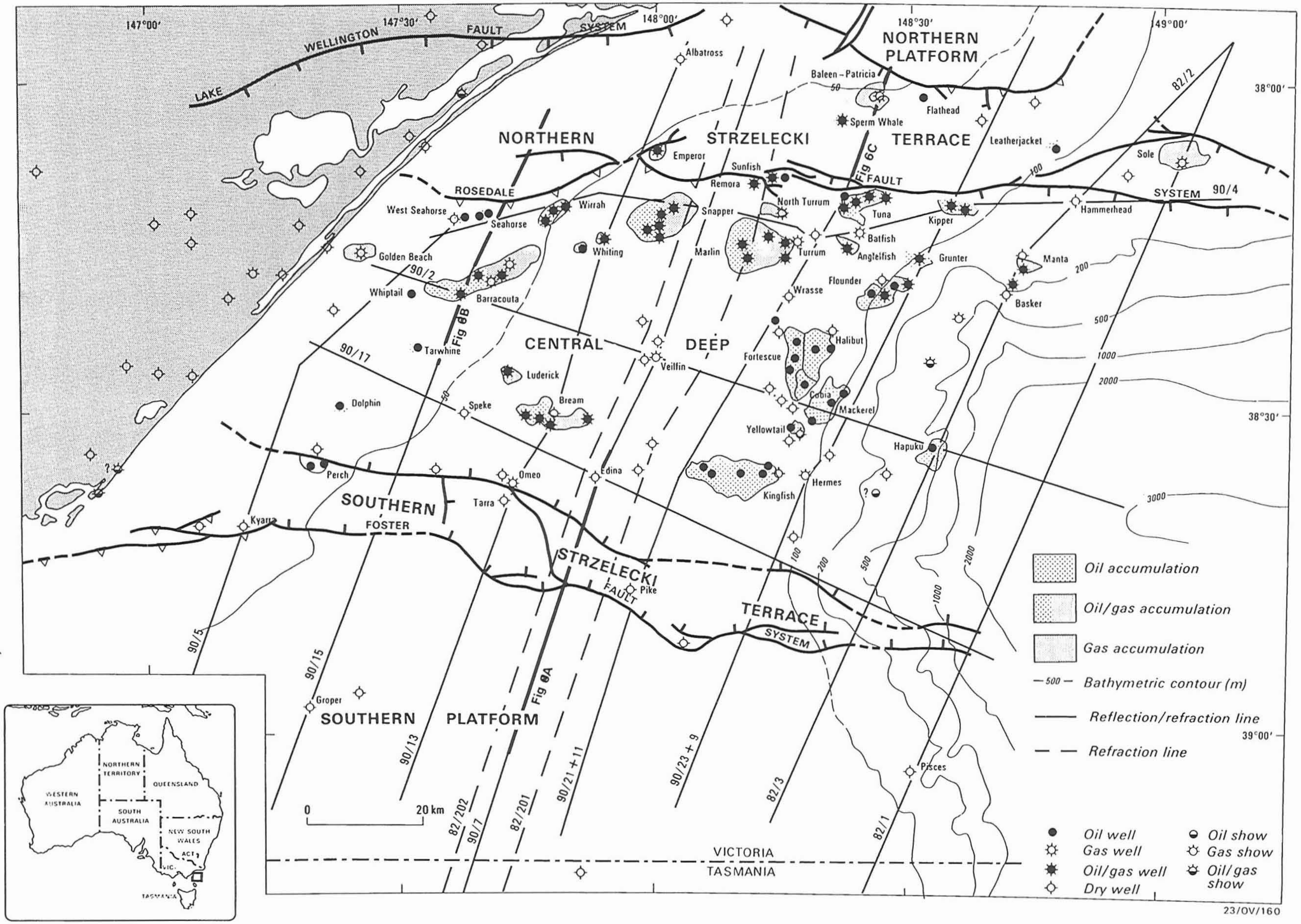

Figure 2. Location of AGSO's deep-seismic reflection/refraction lines in the Gippsland Basin with respect to the basin's main structural elements. Base map after Maung (1989).

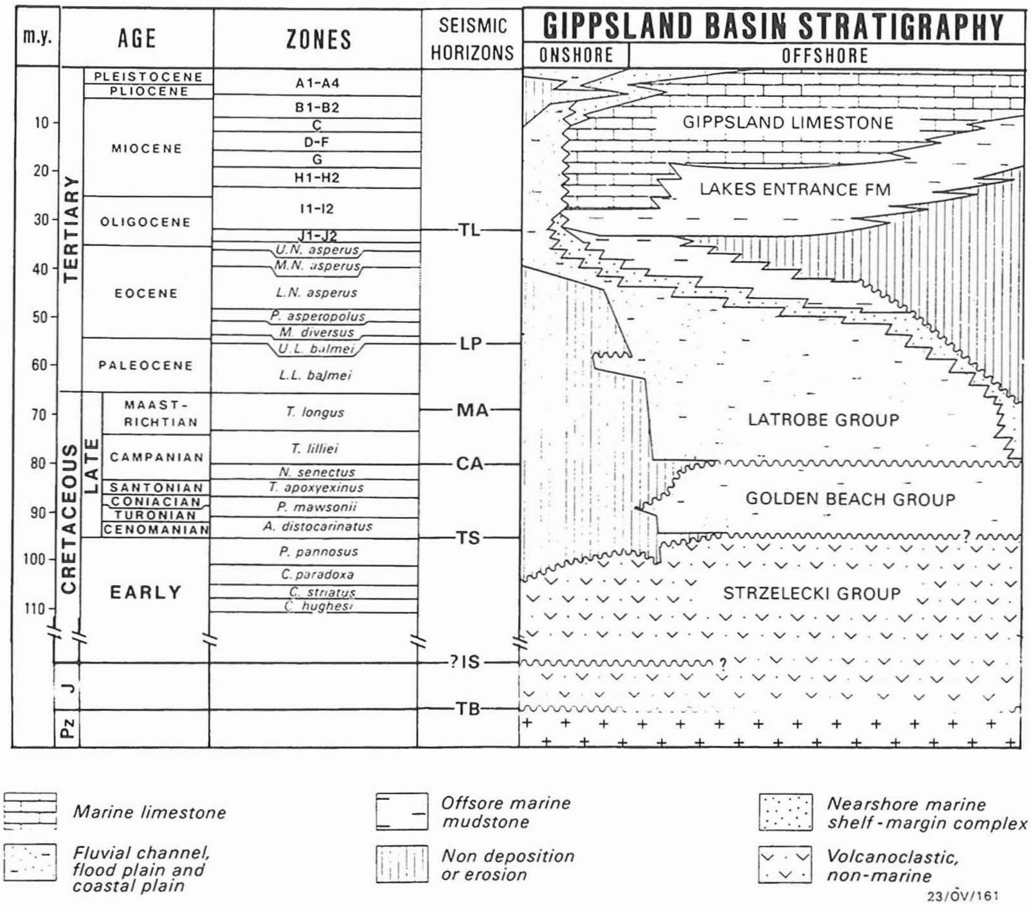

Figure 3. Gippsland Basin stratigraphy (after Esso,1988 and Rahmanian & others, 1990) showing the age of the main seismic horizons.

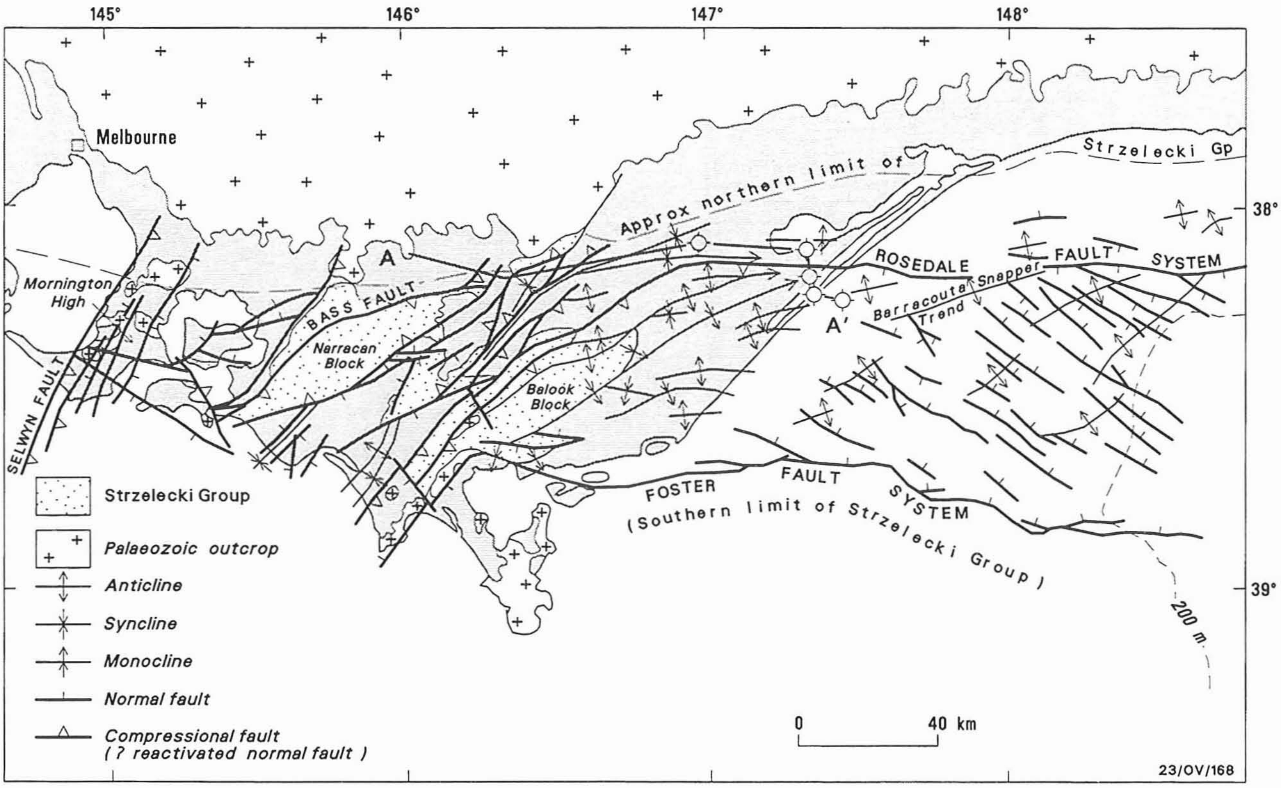

Figure 4. Map of the major fault trends within the Gippsland Basin. Offshore structures after Hocking (1988). Onshore structures based upon mapping by A. E. Constantine. Note that although many of the onshore faults have undergone compressional reactivation, they are interpreted to have been part of a normal, largely-extensional, headwall fault system during basin formation.

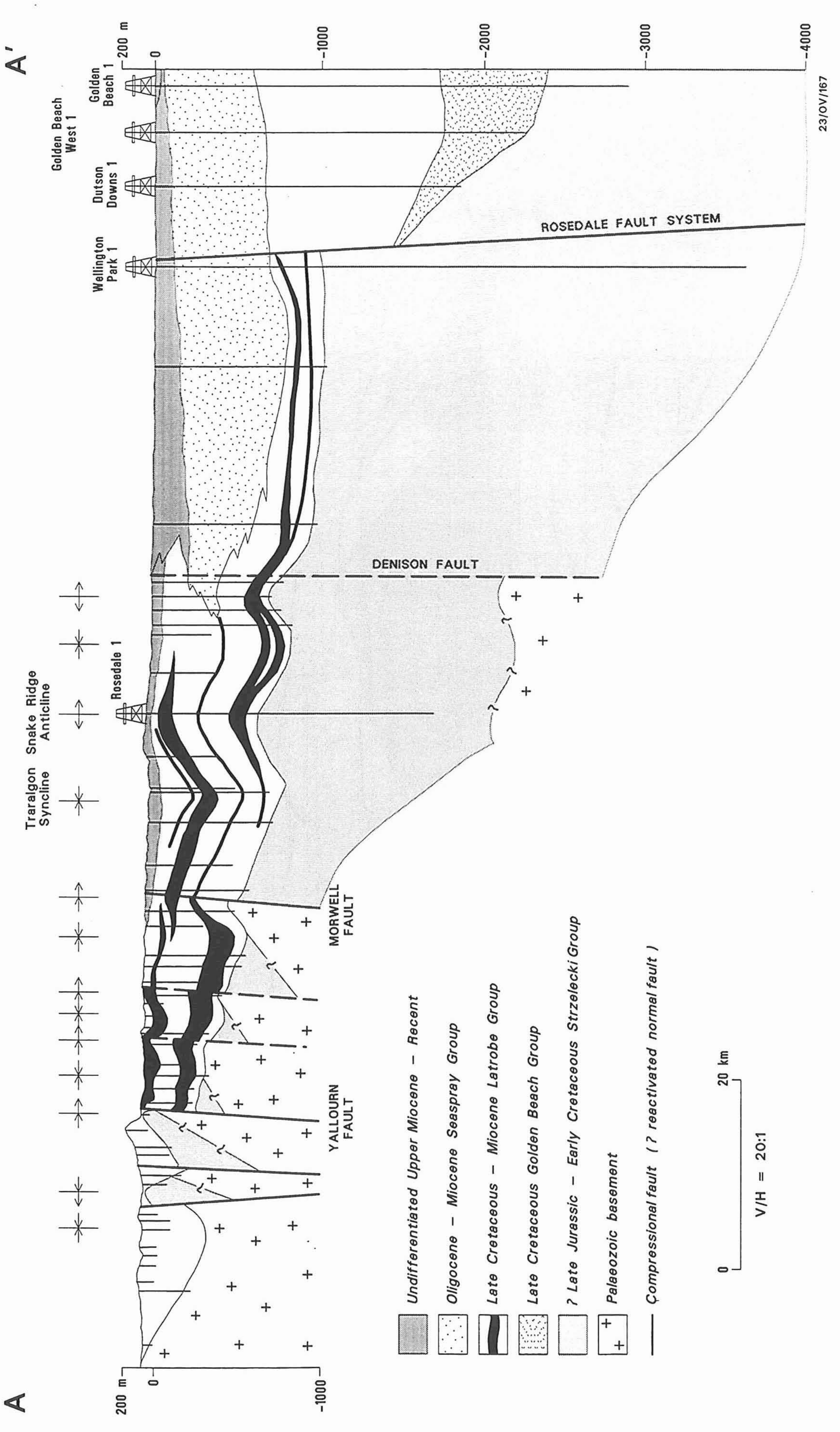

Figure 5. Section across the onshore Gippsland Basin (location shown in Figure 4) constructed from coal bores, petroleum exploration wells, and mapping. Shows folding, and compressional reactivation of many of what are interpreted to be originally normal, basin-forming faults. This section forms an onshore continuation to Line 90/2 (Figure 7, Plate 22).

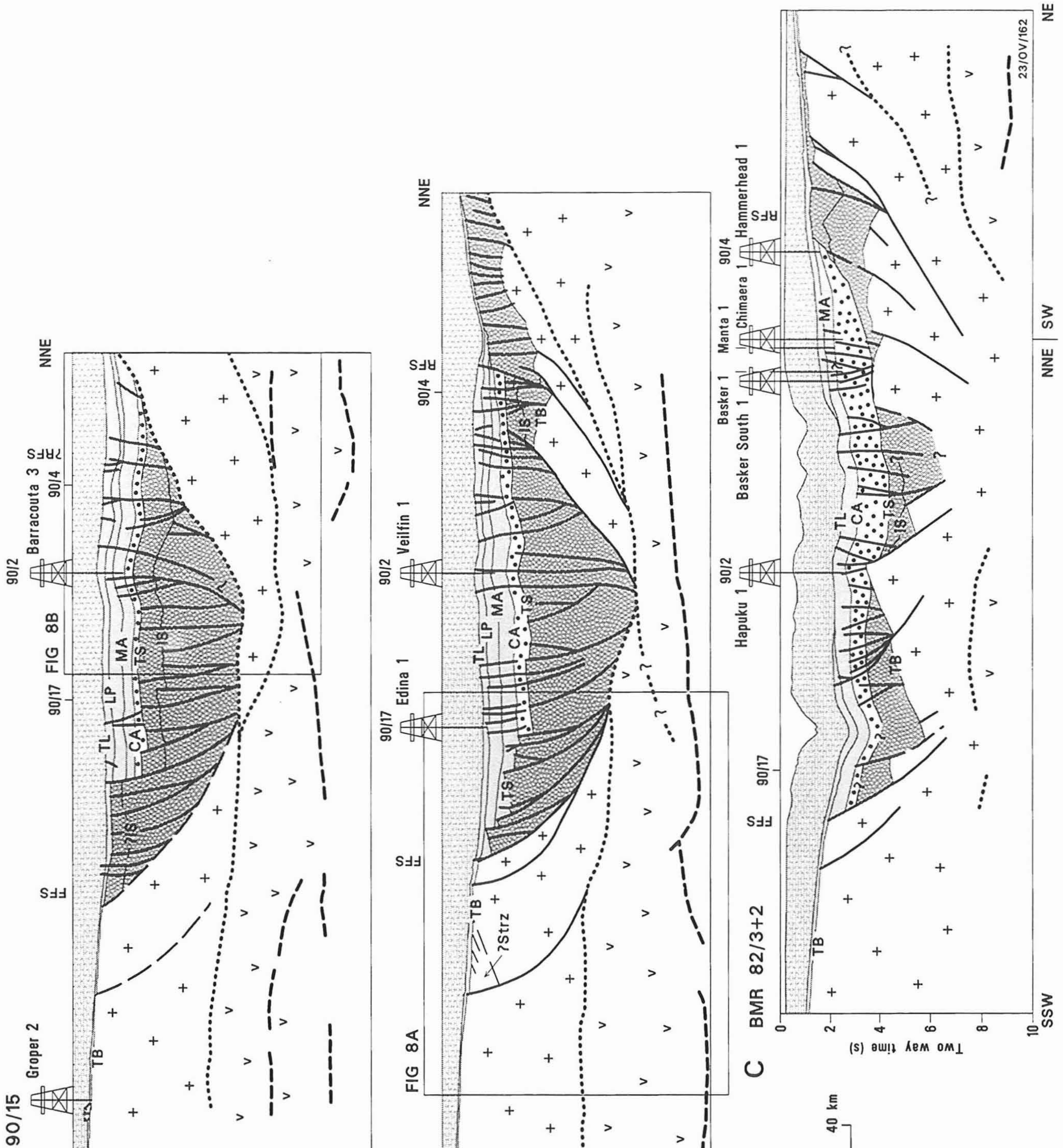

Figure 6. Line drawings of AGSO Lines 90/15, 90/7, and 82/2 & 3 across the Gippsland Basin. Location of profiles shown in Figures 1 and 2. Profiles aligned on the trace of Line 90/2 along basin axis. See Figure 7 for legend.

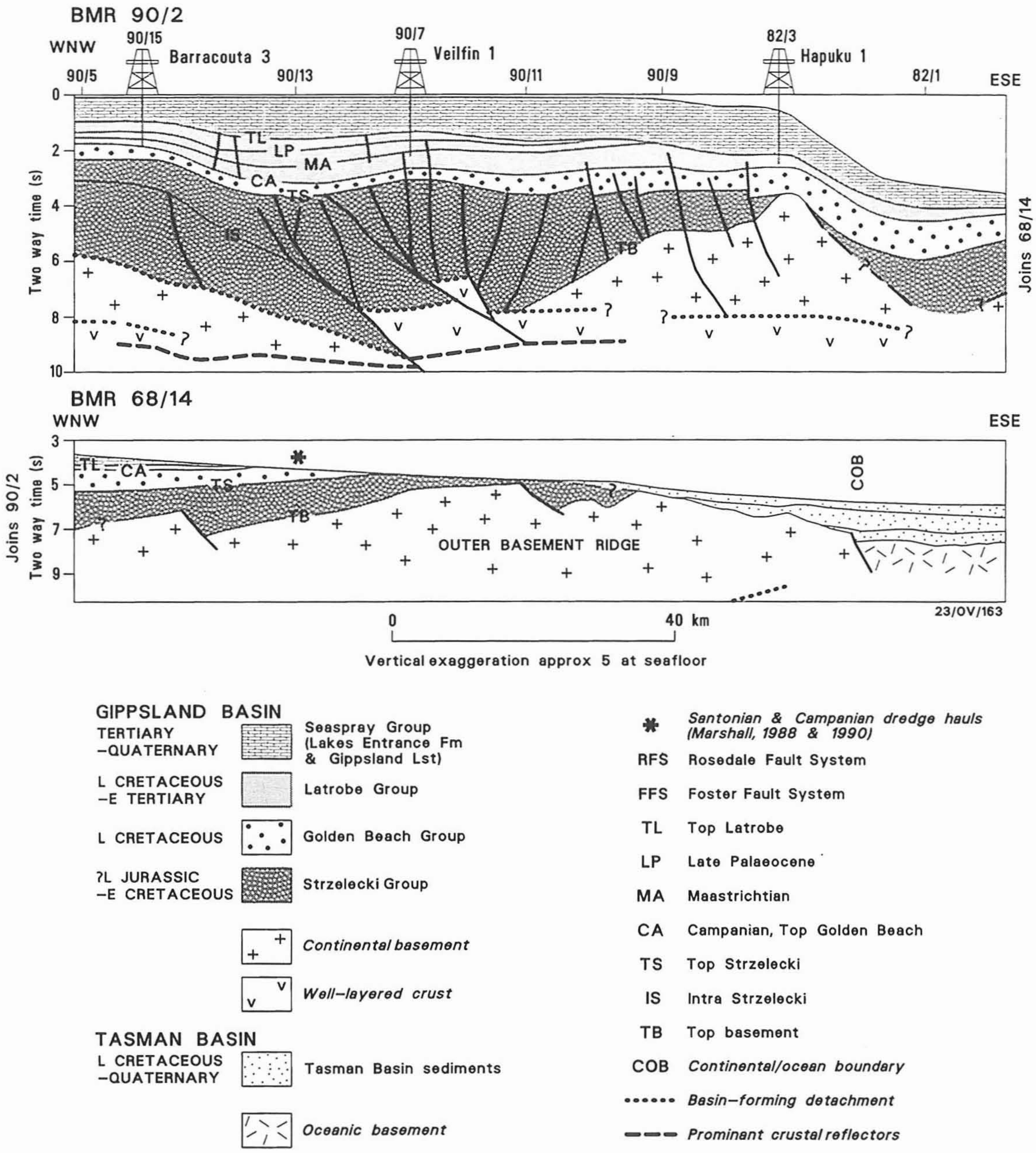

Figure 7. Line drawings of AGSO Lines 90/2 and 68/14 extending down the axis of the Gippsland Basin. Location of Profile 90/2 shown in Figures 1 and 2. Profile 68/14 forms a direct continuation of Profile 90/2 out to the ESE, crossing the continent/ocean boundary (COB) at about 150^{o} E.

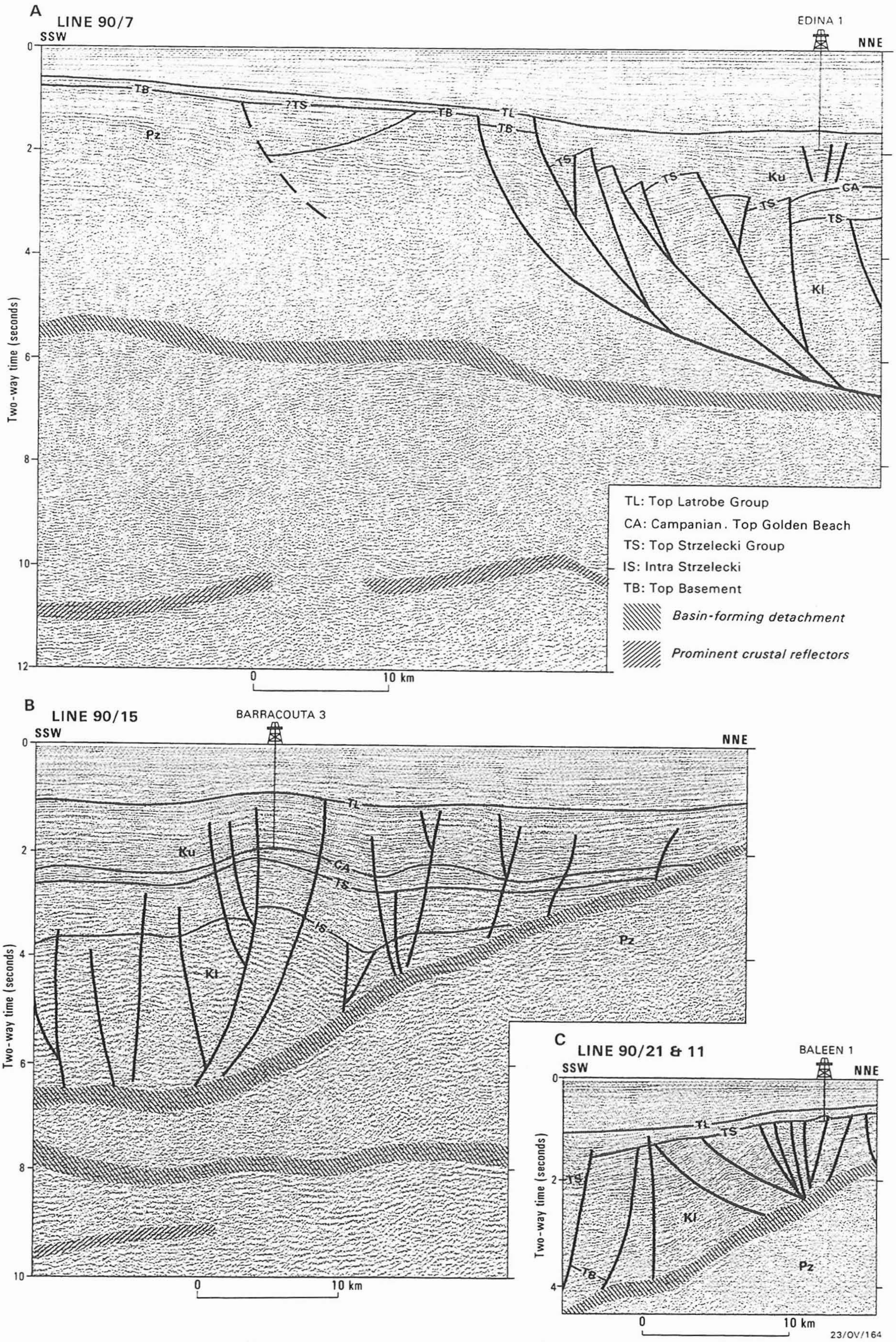

Figure 8. Interpretation of parts of AGSO's deep-seismic data set. Location of profiles shown in Figures 2 and 6. (A) shows the 'Southern Platform' and fault-blocks within the ?Late Jurassic-Early Cretaceous Strzelecki Group section ('Southern Strzelecki Terrace'). Note the basin-forming detachment and probable 'Moho'. (B) shows the Barracouta anticline, considered to have commenced formation in the mid Cretaceous (top Strzelecki time). Note the 'northern ramp' detachment surface. (C) shows wrench-related structures in the Strzelecki Group section on the 'Northern Strzelecki Terrace'.

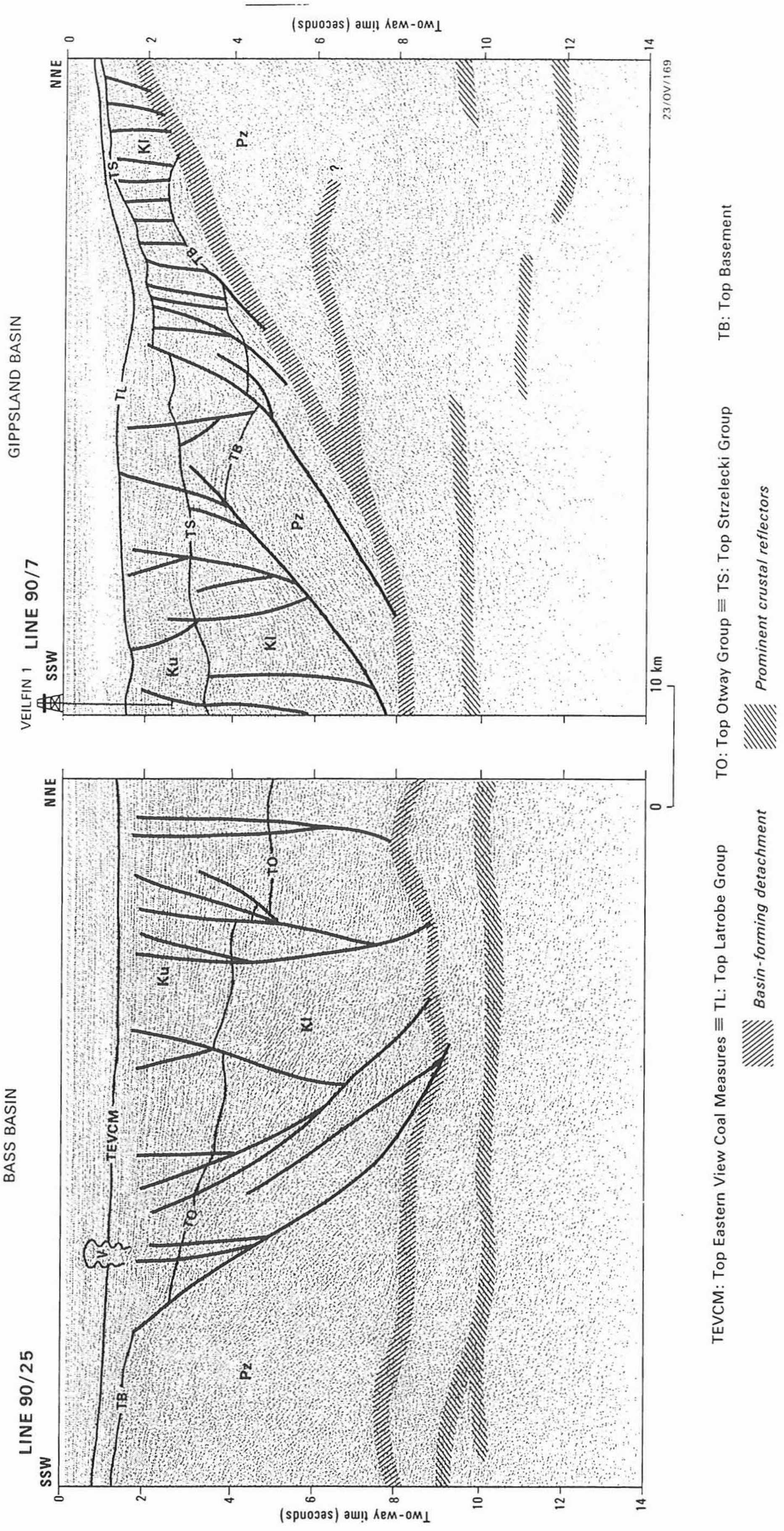

Figure 9. Interpreted seismic profiles of the southern half of Line 90/25 (Bass Basin) and the northern third of Line 90/7 (Gippsland Basin) showing the similarity of structure and seismic character in both basins. Profiles separated by approximately 200 km. Note the common detachment surface which apparently links the basins: it extends from the 'northern ramp', under both basins, and to the SSW beneath the King Island-Tasmania area.

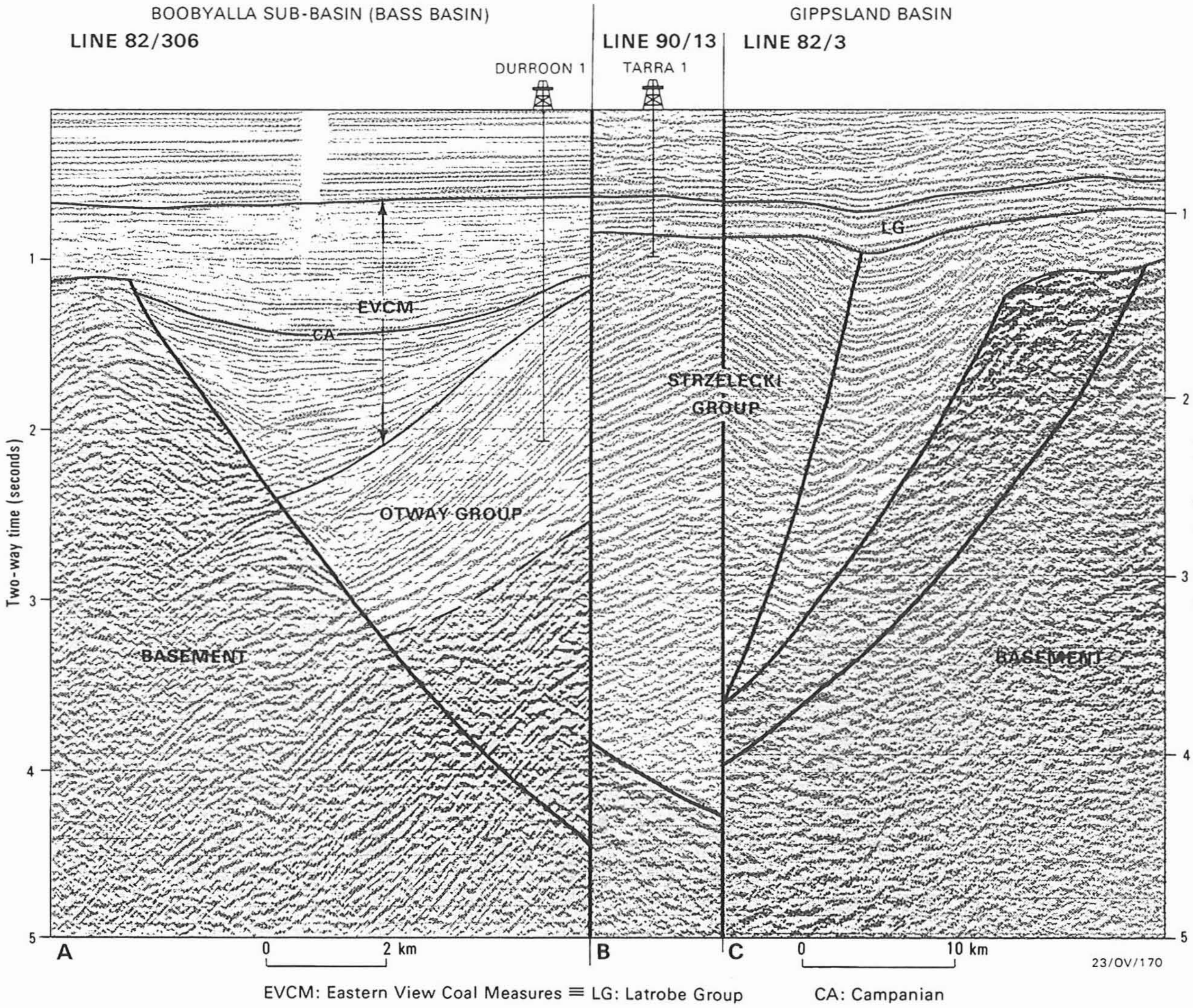

Figure 10. Juxtaposition of seismic data from (A) Boobyalla Sub-basin of the Bass Basin (Line 82/306), (B) the Southern Strzelecki Terrace (Line 90/13), and (C) the Northern Strzelecki Terrace (Line 82/3) showing similarity of Otway/Strzelecki Group seismic character in each of the areas.

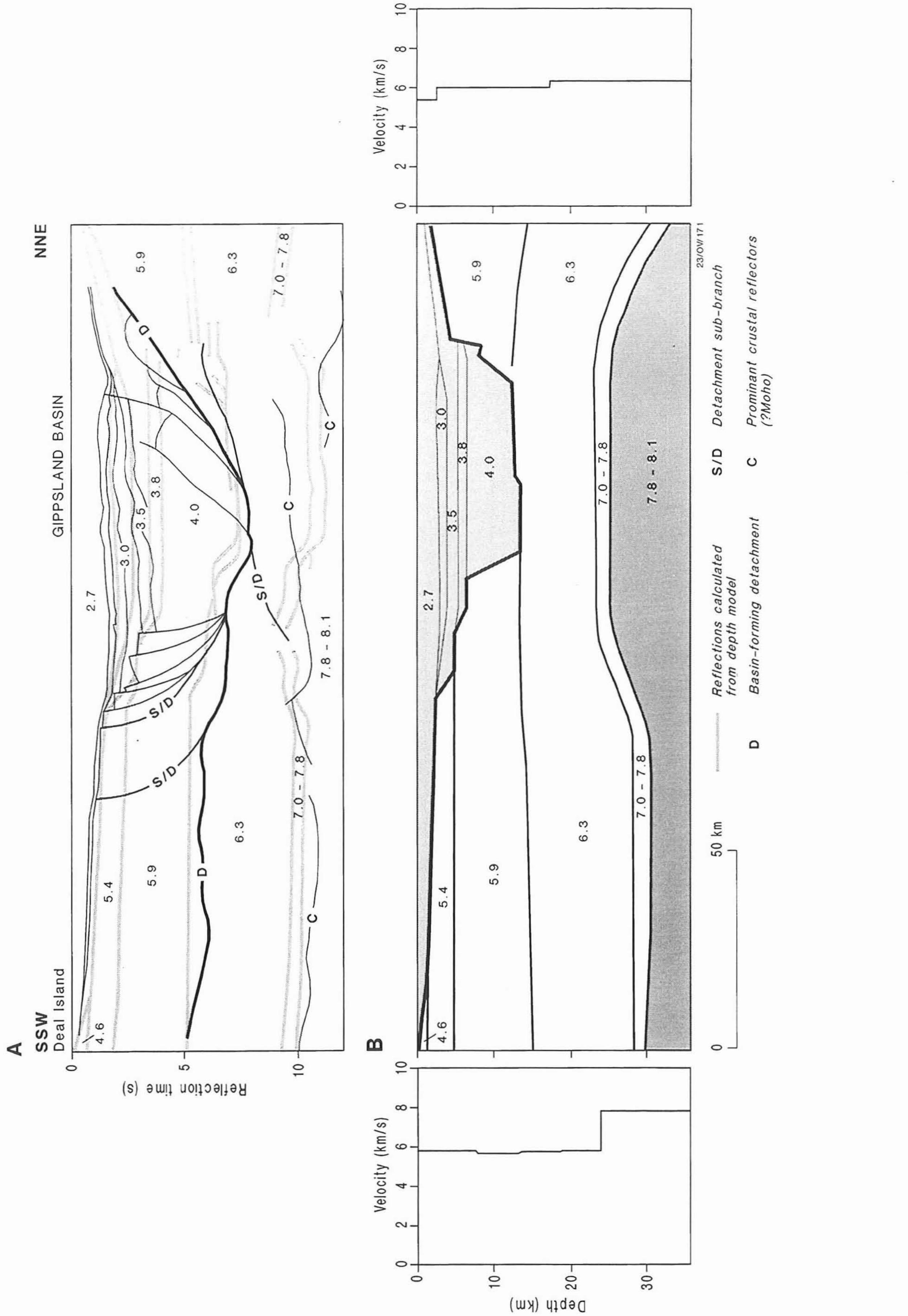

Figure 11. Refraction velocity/depth model for Line 90/7 computed by C. Collins. Based on first-arrival travel times and constrained by wells and sonobuoy data, and by earlier models for Victoria (Gibson and others, 1981, right hand end of 11B) and Tasmania (Richardson, 1980, left hand end). Figure 11A shows the model converted to reflection time and overlain on our interpretation of the deep seismic reflection profile. Note that the main discontinuities identified by the reflection and refraction techniques show good correspondence.

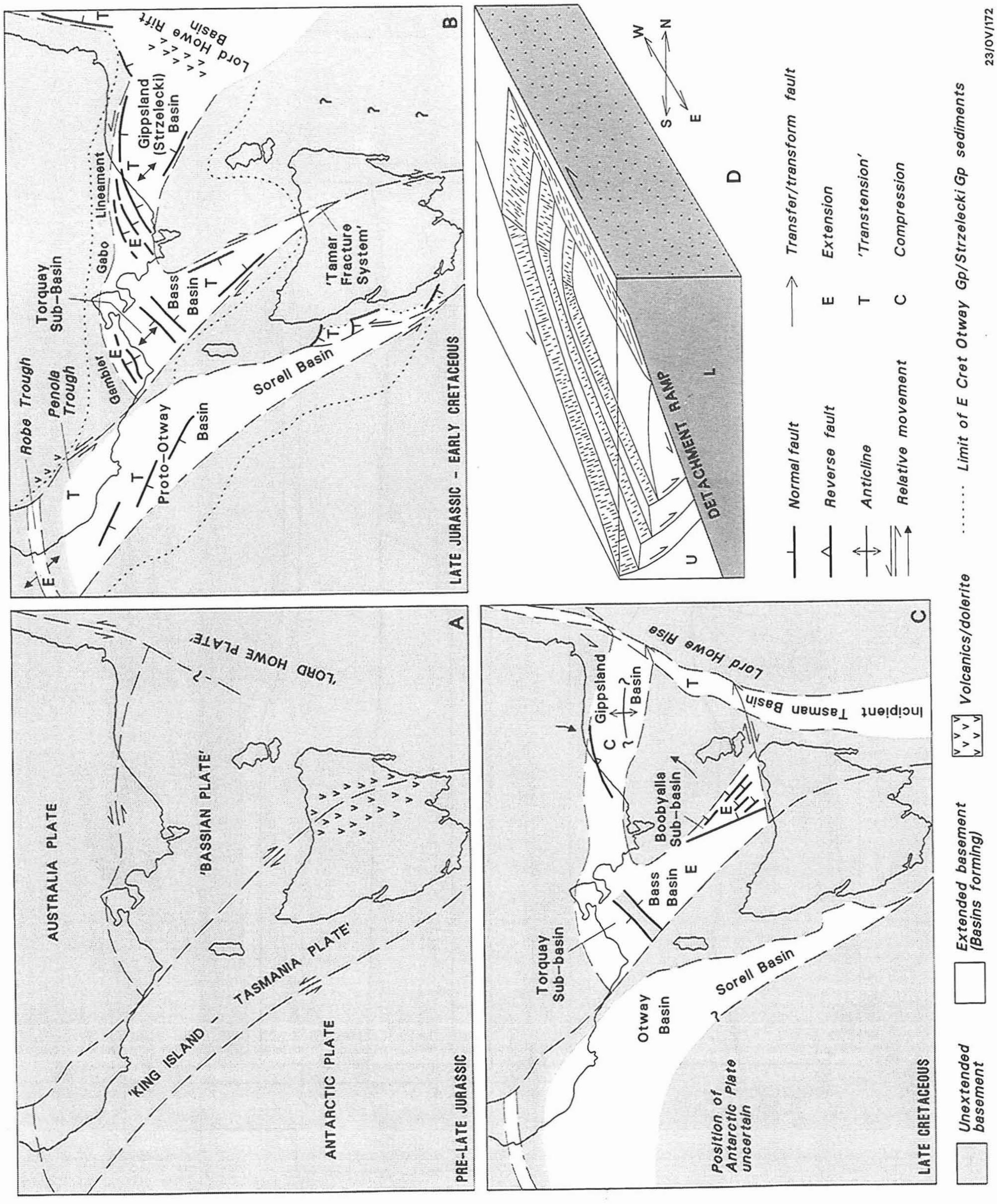

Figure 12. Conceptual model for the development of the Gippsland and other Bass Strait Basins as part of a linked, largely-transtensional system. Block diagram (D), after Gibbs (1987), based upon the Magnus Basin of the North Sea, shows how the Gippsland and other Bass Strait basins each formed by slip on sidewalls and major basin-forming detachments; orientation correct for the Gippsland Basin. Extension at the western end of (D) broadly corresponds to the Strzelecki Ranges, the Otway Ranges and Torquay Sub-basin, and the Robe Trough, of the Gippsland, Bass and Otway Basins, respectively. Structures in the Torquay Sub-basin after Young & others (1991).