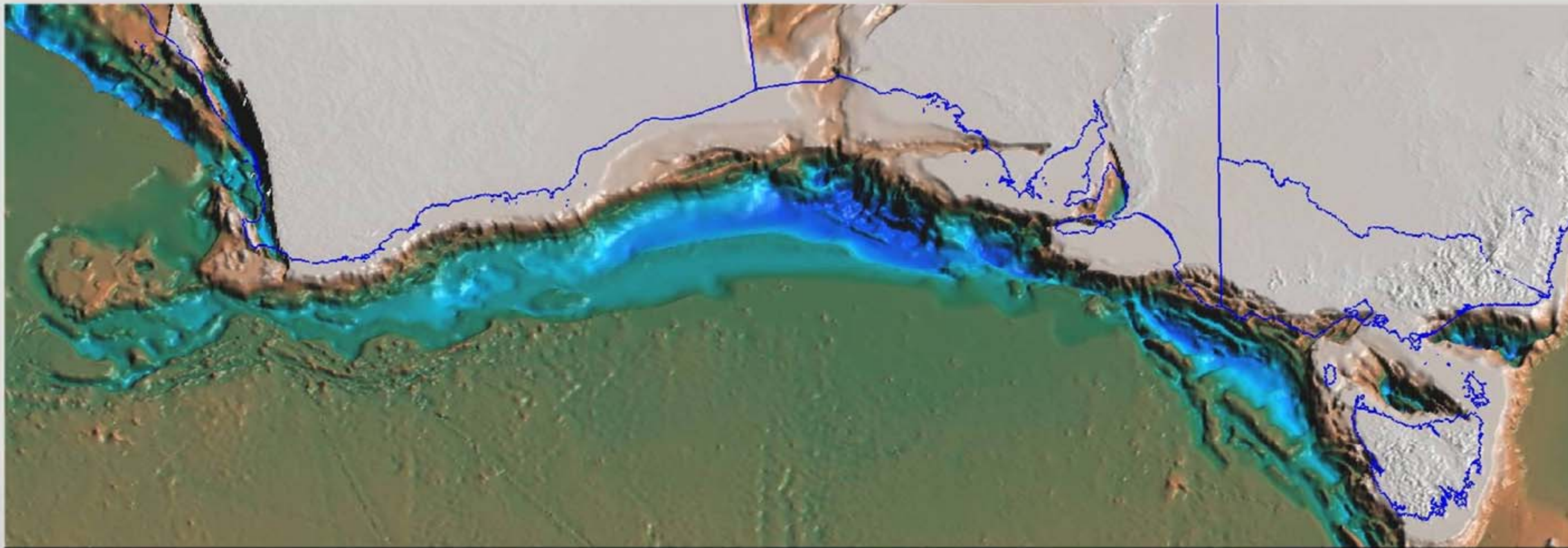

AUSTRALIAN SOUTHERN MARGIN SYNTHESIS

February 2008

FrOG Tech Project Code

GA707

FrOG Tech
From Oil to Groundwater

Australian Government
Geoscience Australia

Australian Southern Margin Synthesis

February 2008

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EXECUTIVE SUMMARY

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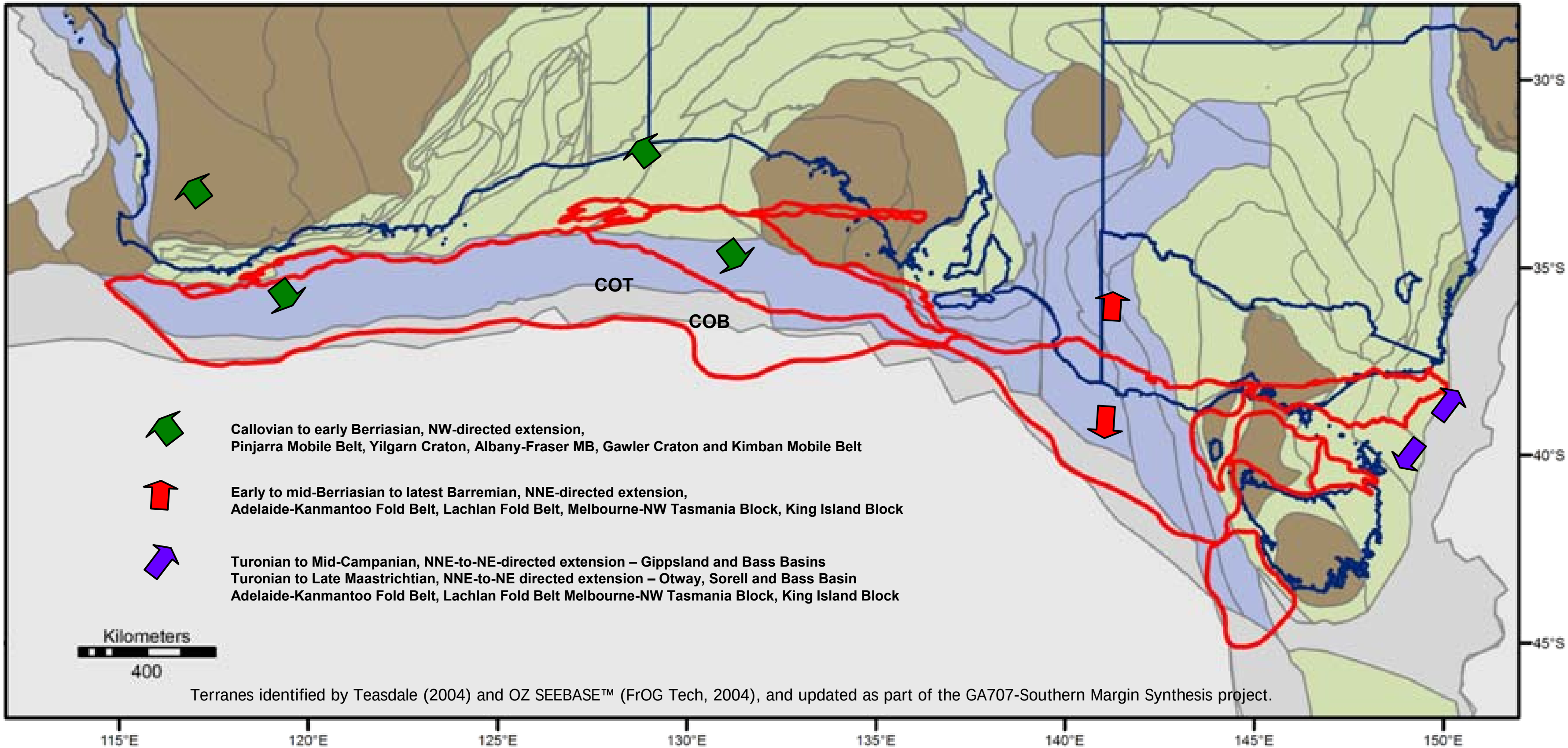
Executive Summary

- The tectonostratigraphic synthesis of the Southern Margin Basins has identified three major rift phases and one transitional rift phase. While the entire Southern Rift System was the locus of crustal instability, the response to extensional stresses (rift basin formation) appears to have propagated from west to east. It can be argued that the mid-Callovian onset of extension in the Southern Margin has no clear expression (i.e., active faults) in the Otway, Bass and possibly the Gippsland basins.
- The basal lacustrine and volcanic sediments which floor the early rifts in the Otway and Gippsland basins are near age equivalent to the cessation of upper crustal extension in the Bight Basin. The subsequent onset of extension in the Otway and Gippsland appears to have responded to north-northeast-directed extensional stress – a shift from the earlier northwest-directed extension which affected the Bight Basin.
- The Rift Transition Phase (Aptian-Albian) is the most ambiguous of all phases, as the interpreted response and tectonostratigraphic record shows differential movement on selected fault/fault sets across the southeastern basins. However, this is a viable scenario given the documentation of fault movement along the western margin of Tasmania at this time.
- The Late Cretaceous Rift Phase affected the southeastern basins but was related to a convergence of stresses associated with the final separation, fragmentation and clearance between Australia and Antarctica, and rifting in the Tasman Sea. The continuation of fault activity in the western Bass Basin and along the west Tasmanian margin is attributed to far-field stresses associated with final clearance.

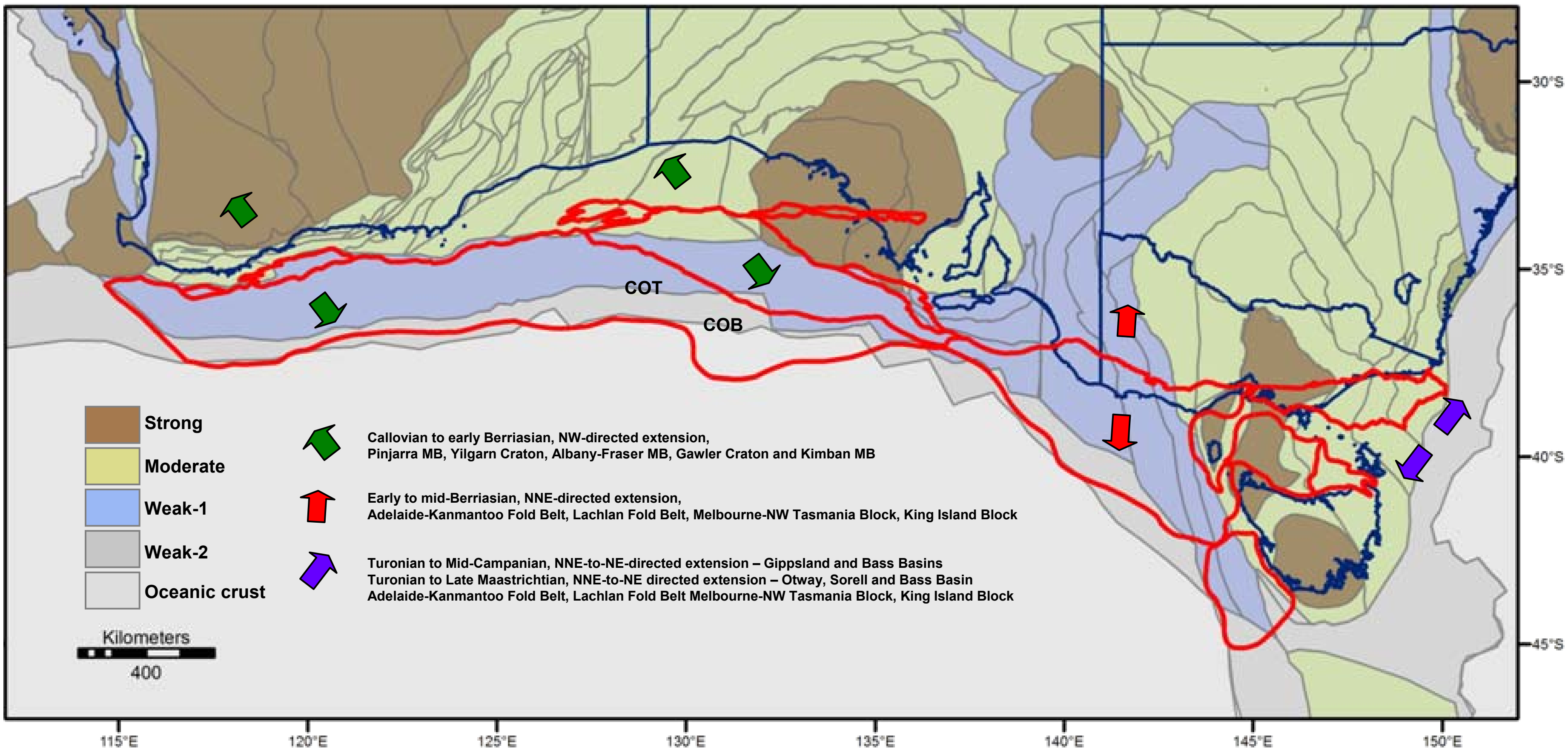


Terranes identified by Teasdale (2004) and OZ SEEBASE™ (FrOG Tech, 2004), and updated as part of the GA707-Southern Margin Synthesis project.

Terrane Rheology and Composition

The basement response to extensional stresses varied along the length of the Southern Rift System due to inherent basement properties of fabric and rheology. Lower crustal processes were also influential but these have not been included here (see Miller et al., 2002). While it is beyond the scope of this study to integrate basement response and tectonostratigraphy of the overlying basin, some simple observations can be stated. Northeast-to-northwest trending terrane boundaries and moderately strengthened crust responded to oblique stresses along the western Southern Margin, while the southern edge of the Gawler Craton (strong crust) formed the northeastern boundary of the Ceduna Sub-basin. In the east, terranes of the Adelaide-Kanmantoo Fold Belt underlie the Otway Basin, while terranes of the Lachlan Fold Belt underlie the Bass Strait Basins.

Terranes identified by Teasdale (2004) and OZ SEEBASE™ (FrOG Tech, 2004), and updated as part of the GA707-Southern Margin Synthesis project.



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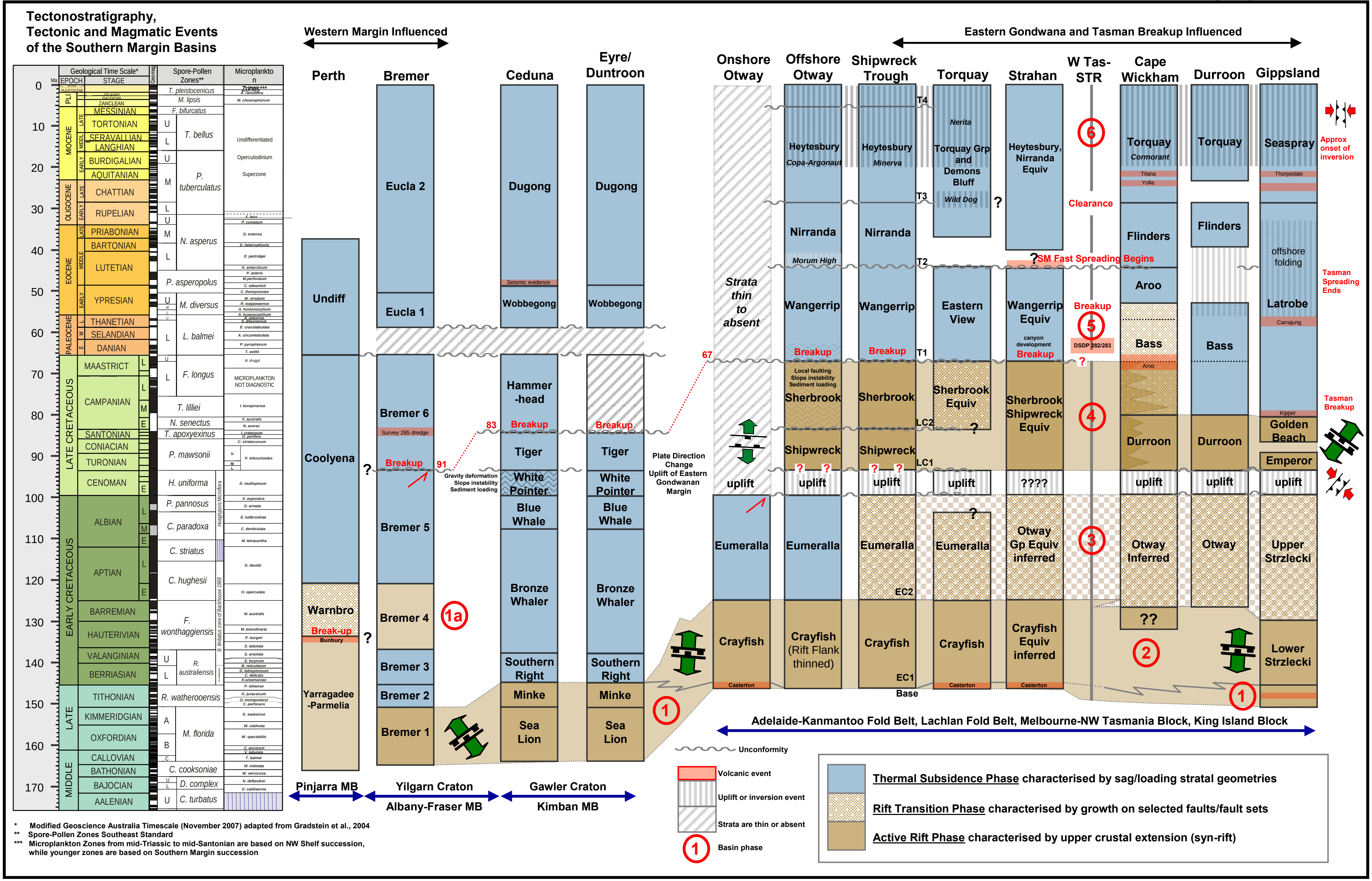
Australian Southern Margin Synthesis – GA707

Mesozoic to Recent Tectonostratigraphic Chart



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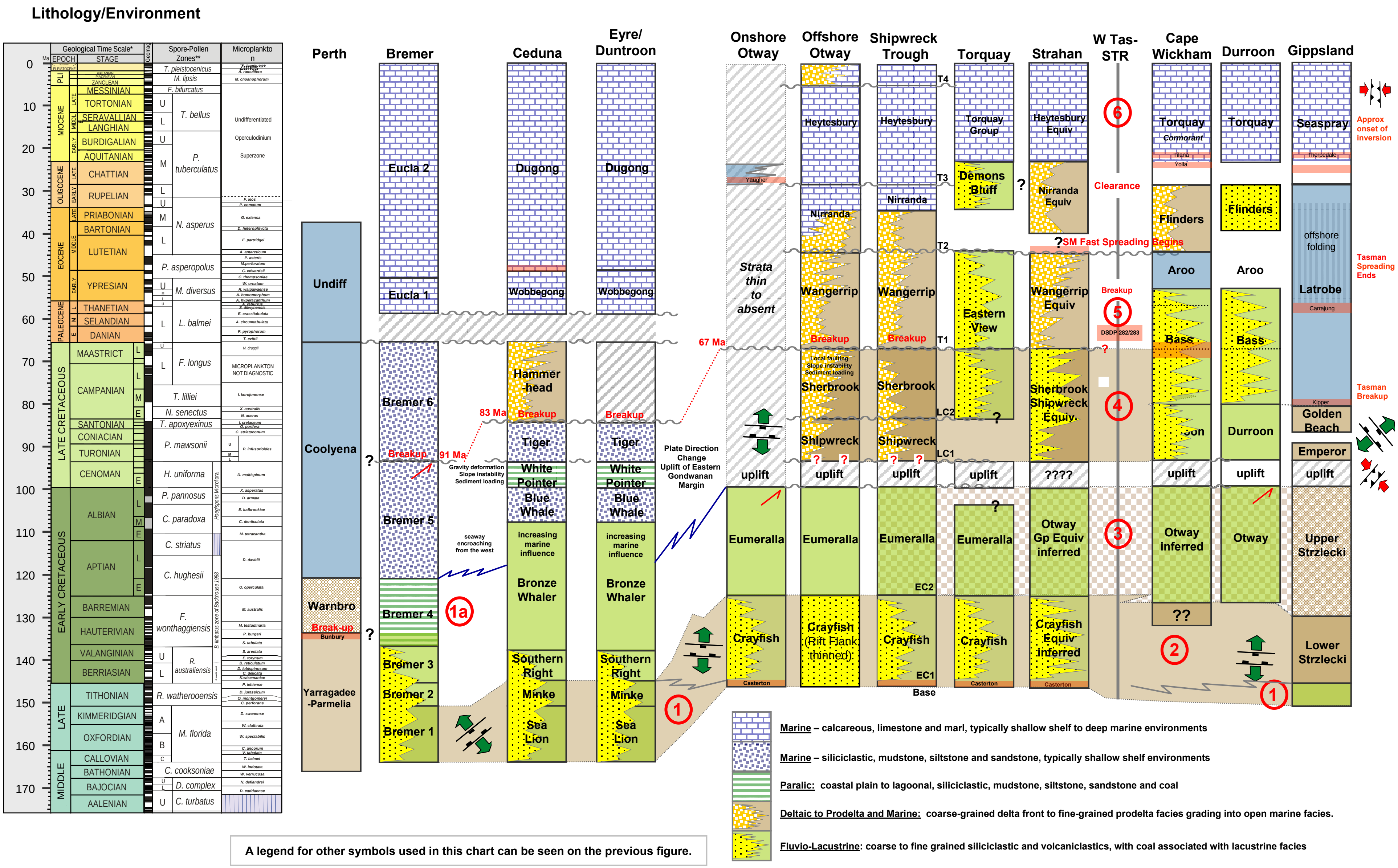

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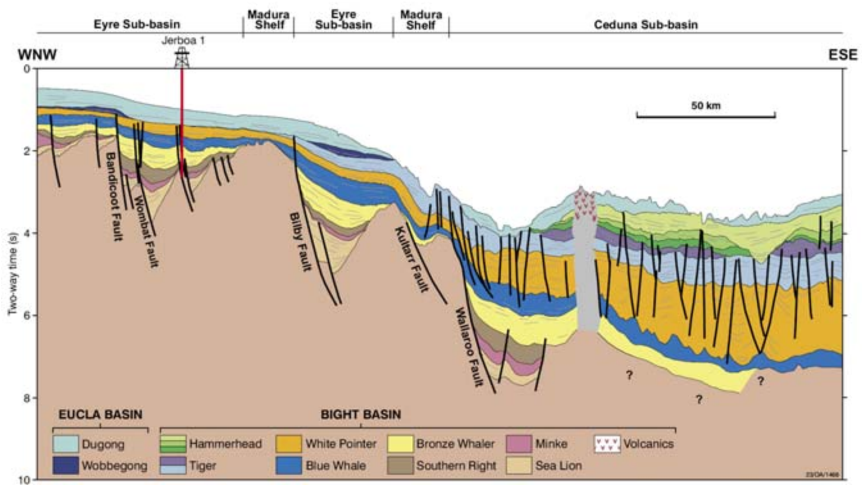
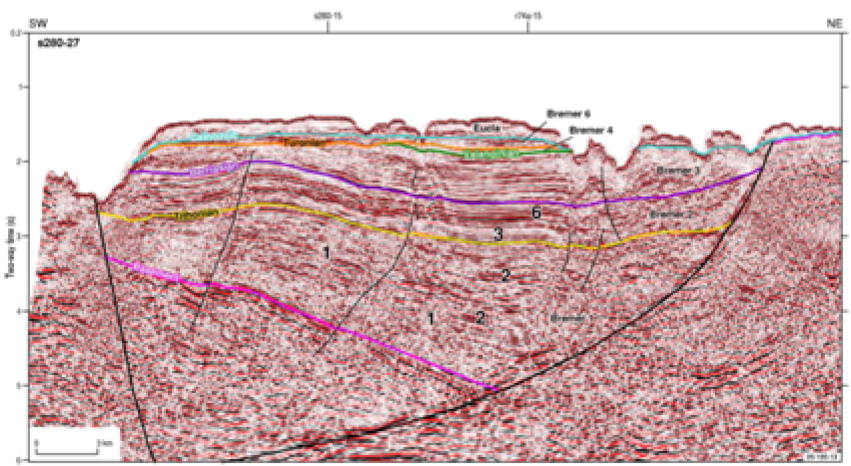
Phases 1 & 2: Late Jurassic – Early Cretaceous Extension





Middle Jurassic magmatism in areas along the Southern Margin has been attributed to mantle instability which preceded the onset of upper crustal extension in the Callovian (Stagg et al., 1990). This instability resulted in the widespread extrusion of dolerites across Tasmania and in the adjacent Bass Strait region, and also the basalts on Kangaroo Island east of the Bight Basin. Correlation of these magmatic rocks suggest they have close geochemical affinities (Farrand, 1995; Foden et al., 2002), while isotopic dating suggest basaltic eruptions occurred during the Bajocian and Bathonian (Farrand, 1995; Foden et al., 2002; Dance et al., 2004).

The onset of upper crustal extension in the eastern Bight Basin is reasonably well-constrained based on regional correlations with Jerboa-1 (Eyre Sub-basin), where the well intersected the upper part of the syn-rift wedge (?Callovian-Kimmeridgian Sea Lion and Tithonian-early Berriasian Minke supersequences; Totterdell et al., 2000). Similar age rocks were interpreted to lie in deeper half graben within the Duntroon Sub-basin, although the syn-rift facies themselves have not been intersected by drilling. In the Ceduna and Recherche sub-basins, half graben can be imaged on seismic data in some areas, and these structures have been correlated to structures in the Eyre Sub-basin (Totterdell et al., 2000; Bradshaw et al., 2003). In the eastern Bight Basin, the onset of extension has been interpreted as mid-Callovian (near base of *M. florida* zone) or possibly slightly older.

In the western Bight Basin, seismic and dredge sample correlations in the Bremer Sub-basin suggest the onset of rifting also began in the early Callovian based on results from four dredge samples (Bremer 1; Bradshaw, 2005). A lower confidence is given to the western Bight Basin results because of the nature of the samples and their approximate ties to seismic packages. In addition, it appears unclear whether these samples represent the base of the syn-rift succession. If the four samples yielded minimum ages, then it is possible that extension in the Bremer Sub-basin began as early as Bathonian. This would mean that rift onset was synchronous with extension in the Perth Basin (166 Ma, Yarragadee Formation).

Timing of the onset of upper crustal extension in the Otway and Gippsland basins is less clear because of uncertainty in the age and nature of the basal syn-rift sections – the Casterton and Lower Strzlecki formations, respectively. In the Otway Basin, the Casterton Formation overlies basement and its distribution is restricted to the early horst and graben fault system. Only minor growth is apparent into major bounding faults, and the unit varies in thickness from 26 to 500+m (Krassay et al., 2004). The age of the Casterton Formation has long been a contentious issue due to a wide range of isotopic dates (Mitchell et al., 1997) and the absence of decisive key palynological taxa (Sinclair and Monteil, 2004). Previous work indicates the formation ranges in age from Late Jurassic to Early Cretaceous. To further complicate matters, Mitchell et al (1997) suggest that the Casterton Formation is not a chronostratigraphic unit, with the 'Casterton' east of the Merino High being younger than 'Casterton' facies in the western Otway Basin. Recent work on the Casterton Formation at Sawpit-1 (western Otway Basin) by Sinclair and Monteil (2004) indicates a clear age of Valanginian based on a definitive presence of *G. mutabilis* dinoflagellate cysts.

Figure (top). Geoscience section across the Eyre and Ceduna Sub-basins (Bight Basin) showing evidence of Late Jurassic to earliest Cretaceous upper crustal extension (from Bradshaw et al., 2003).

Figure (bottom). Geoscience Australia seismic line S280-27 showing the divergent syn-rift character of the Middle to Late Jurassic succession (Callovian-Kimmeridgian; Bremer 1; from Bradshaw, 2005).

Phases 1 & 2: Late Jurassic to Early Cretaceous Extension

Clearly, more intersections and detailed work may resolve the age(s) of the Casterton Formation, and whether there is one continuous unit or if the 'Casterton' is a time-transgressive facies that signals the onset of rifting and therefore varies in age. Nonetheless, the absence of significant growth geometries observed within the Casterton Formation would indicate that upper crustal extension was still at an early stage of development.

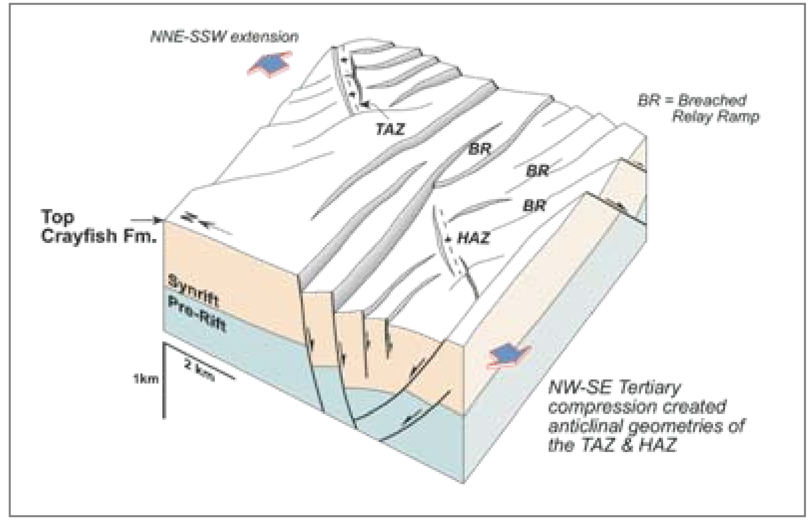
Based on the tectonostratigraphic framework established by Krassay et al (2004), significant growth on the early rift faults in the Otway Basin occurred during the 'post-Casterton' depositional phase of the Crayfish Supersequence (EC1 of Krassay et al., 2004). This would mean that growth occurred during Berriasian to Barremian time (*R. australiensis* to *F. wonthaggiensis* zones), and is thus not time equivalent to extension in the Bight Basin (i.e., the Sea Lion-Minke sequences which are older).

It is suggested here that deposition of the 'Casterton Formation' in the Otway Basin represents the early or far-field response to Bight Basin extension. In this scenario, once significant upper crustal extension ceased in the Bight Basin (early Berriasian), the focus of extension shifted to the Otway Basin with deposition of the Crayfish Supersequence (Berriasian to Barremian). This would imply that two progressive, but different phases of extension affected these basins.

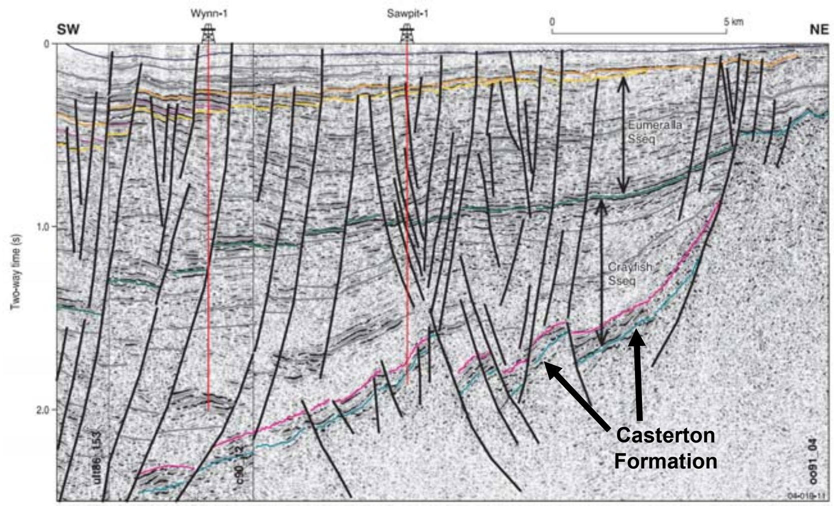
This scenario is also supported by the disparity between the extensional stress directions that have been interpreted during early rifting in the Otway and Bight basins. While the Bight Basin was affected by northwest/southeast-directed extensional stresses (e.g., Stagg and Willcox, 1990; Totterdell et al., 2000), the Otway Basin appears to have formed under a north-northeast/south-southwest-directed stress regime (e.g., Chantraprasert et al., 2001; Krassay et al., 2004). Regional stress in both basins was oblique to the underlying basement fabric and this is reflected in fault trends and offsets across accommodation zones that are sub-parallel to the interpreted extensional direction (e.g., Chantraprasert et al., 2001). There is also clearly some element of basement (or deeper) control on the apparent partitioning of the regional stress regime. This is probably related to the transition between the Gawler Craton-Kimban Mobile Belt (Bight Basin) and the Adelaide-Kanmantoo Fold Belt (western Otway Basin).

A similar situation may also have occurred in the Gippsland Basin, with volcanics of the lowermost Lower Strzlecki Formation signaling the proximity of rifting, rather than the onset of significant upper crustal extension. Similar to the Casterton Formation of the Otway Basin, the interpreted Jurassic part of the Strzlecki Formation is rarely penetrated onshore and poorly imaged in the deeper initial rift basins offshore. Indeed, Power et al (2001) interpreted the onset of rifting in the Gippsland Basin as Neocomian, not Jurassic.

Extension in the western Bight Basin (Bremer Sub-basin; Bremer 1 unit) ceased in the Kimmeridgian-Tithonian – approximately 5Ma earlier than in the eastern Bight Basin (O'Leary et al., 2005). The cessation of extension is confidently constrained by only two samples which came from the overlying sag section, while several more samples from other dredge sites are unresolved whether they originated from the Bremer-1 (syn-rift) or Bremer-2 (sag) stratigraphic units. O'Leary et al (2005) concluded that Bremer-2 was deposited during a time of diminished growth on bounding faults in the eastern Bight Basin. Alternatively, the poor spatial constraint of these rocks could mean that they originated from Bremer-1 (syn-rift) and that extension in the Bremer Sub-basin ceased in the earliest Berriasian – a timeframe that is more consistent with the Perth and eastern Bight basins.



3D block diagram showing the evolution of the Penola Trough structures during the late syn-rift extension phase (Otway Supergroup) in the Otway Basin (from Chantraprasert et al., 2001). This interpretation suggests NNE-SSW extension in the western Otway Basin.



Seismic section across the Penola Trough show the syn-rift Crayfish Supersequence (from Krassay et al., 2004). The volcanic Casteron Formation can be observed as the base of the syn-rift section.

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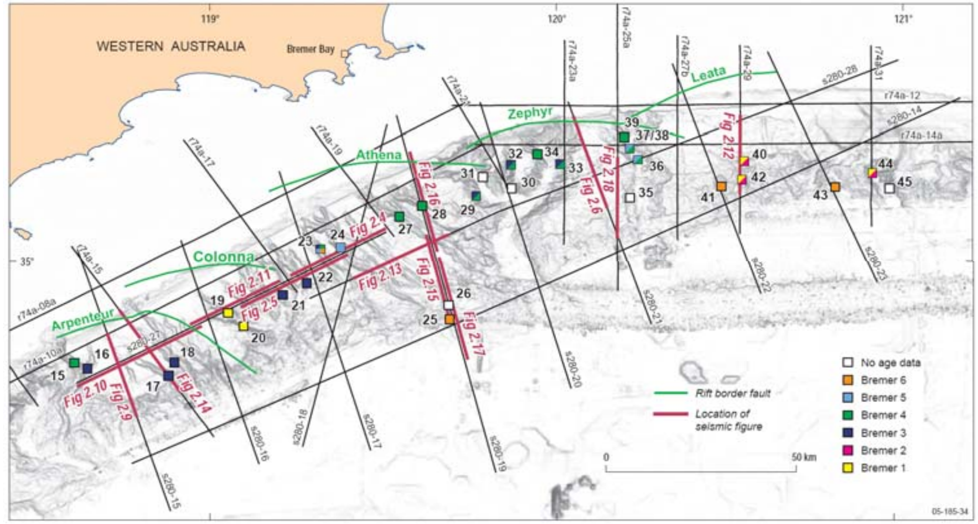
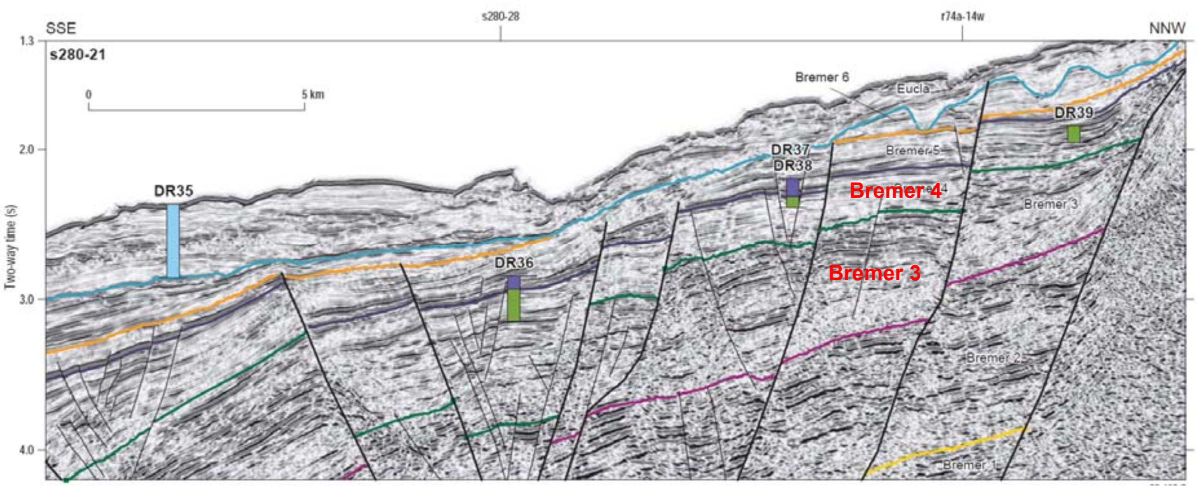
Phase 1a: Mid-Valanginian to Late Aptian Extension

Mid-Valanginian to Late Aptian extension (Phase 1a) was identified on seismic data in the Bremer Sub-basin (eastern Bight Basin) and correlated to stratigraphic unit Bremer-4 (O'Leary et al., 2005). The age of this event is well constrained by dredge samples and confident ties to seismic data. O'Leary et al (2004) described Bremer-4 unit as a 'parallel, sheet-like fill', although the 'upper part of Bremer 4 forms a divergent wedge geometry in the hanging wall blocks of the Arpenteur, Colonna and Leata depocenters'. Uplift and large anticlines were also formed in the eastern and western parts of the basin (Nicholson and Ryan, 2005)

Evidence of active extension during this time period has not been observed in the eastern Bight basins, although breakup and the onset of seafloor spreading in the Perth Basin was coeval with the onset of Bremer-4 deposition (mid-Valanginian). It is likely that deposition of Bremer-4 resulted from the influence of transtensional stresses associated with the onset of seafloor spreading on the southwestern margin. This event was unrelated to fault movement observed in some of the eastern basins during this time period.



Summary of stratigraphic units at sampled at Survey 265 dredge sites in the Bremer Sub-basin overlain on a high-resolution bathymetry image (from O'Leary et al., 2005).



Geoscience Australia seismic line S280-21 showing the nature of Bremer-4 (Extension-2) package in the Bremer Sub-basin (from O'Leary et al., 2005).

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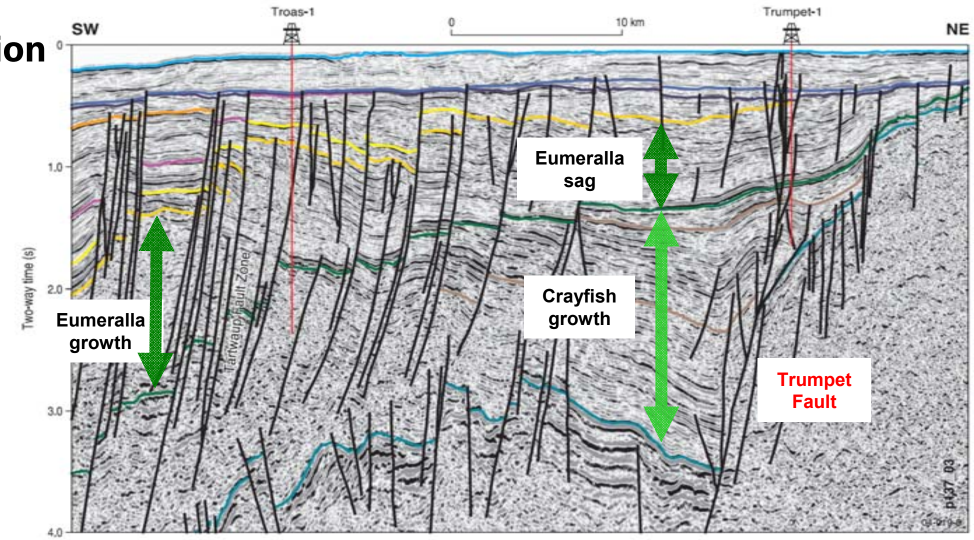
Phase 3: Albian-Aptian Post-Rift and Rift Transition

An extended period of subsidence and accelerated subsidence followed the early Berriasian cessation of upper crustal extension in the Bight Basin (Totterdell et al., 2000). Likewise, the onshore Otway Basin and much of the offshore basin experienced sag conditions after the cessation of upper crustal extension in the latest Barremian (Krassay et al., 2004). Norvick and Smith (2001) describe the Aptian-Albian as a post-rift phase in the southern and southeastern basins.

However, it remains clear that some tectonic activity continued in various parts of the eastern basins during the Aptian to Albian period (Otway Sequence/Bass Basin, Eumeralla Supersequence/Shipwreck Trough and Torquay Sub-basin and Upper Strzlecki Sequence/Gippsland Basin). In these areas, syn-tectonic growth on selected faults/fault sets is observed, with 5% extension modeled in the Gippsland Basin (Power et al., 2001) and sag with minor faulting described from Geosec™ restorations by Palmowski et al. (2004) in the western offshore Otway Basin. The Eumeralla Supersequence is up to 2300m thick in well intersections and estimated to reach up to 4500m in the Shipwreck Trough (based on calculated seismic velocities; this study) The Aptian-Albian was also a period of prolific volcanic eruptions to the east and input of volcaniclastic sediments into the eastern basins (Mortimer et al., 2005)

Observations of active fault movement appear to cluster in the eastern Otway Basin (Palmowski et al., 2004; Krassay et al., 2004; this study), Torquay Sub-basin (Cooper and Hill, 1997; this study), possibly the western Bass Basin (Blevin et al., 2005; this study), and in the western Gippsland Basin (Power et al., 2001). Other workers (e.g., Cockshell et al., 1995; Morton et al., 1995; O'Brien et al., 1994) describe deposition of the Eumeralla Formation in the Otway Basin as an uppermost syn-rift sequence deposited during a slower, second rifting phase where fault activity was reduced in the onshore basin, but continued offshore. To the east, the New Zealand margin entered an extensional phase around 120 Ma (mid-Aptian) following the end of subduction and Rangitata metamorphism (Norvick and Smith, 2001). Some extension continued in New Zealand during the Albian.

Collectively, the observed evidence does not support a period of pervasive upper crustal extension across the southeastern basins during the Aptian-Albian. The areas that appear to have been active mostly overlie terranes of the Lachlan Fold Belt and easternmost Delamarian crust. These terranes and the boundary between them continued to be tectonically active as a major strike/slip system along the west Tasmanian margin until the Eocene – indicating this was a zone of weakness that was important during the separation and final fragmentation of the Australian and Antarctic plates. It is feasible that episodic transtensional movement along this system resulted in localised fault movement (Shipwreck Trough) and far-field stresses in nearby areas (Torquay Sub-basin, western Bass and Gippsland basin) during the Aptian-Albian period.



Geoscience Australia seismic line 137-03 showing the sag nature of the Eumeralla Supersequence inboard of the Tartwaup Fault Zone, and the growth that occurs within the same section outboard of the fault system (modified after Krassay et al., 2004).

Part of the difficulty in resolving the nature of the Aptian-Albian event is that only the upper part of the succession is intersected in the offshore Otway and Gippsland basins, thus much of the correlation is seismic-based. In the western Bass Basin and Strahan Sub-basin where Eumeralla and Crayfish equivalent units have been interpreted to lie at depth (Cummings et al., 2004; Boreham et al., 2002), the oldest sediments intersected are Maastrichtian in age.

For these reasons, Phase 3 is best described as 'Post-Rift' (sag) in basins where no evidence of fault movement (extension) is present such as the Bight Basin and onshore Otway Basin. Areas that show evidence of growth on selected faults are described as 'Rift Transition Phase', with movement attributed to localised extensional, transtensional and far-field stresses.

While it is out-of-scope for the current study, further work (synthesis) to incorporate plate-scale kinematics of eastern Gondwana during this period will help to resolve the uncertainty of the 'Rift Transition Phase' period in eastern Australia. Also, more detailed work on the wells used in the Geosec ™ models of the Gippsland (Power et al., 2001) and Otway basins (Palmowski et al., 2001) would help to understand the confidence of these correlations at a detailed level. 2D/3D structural modeling restorations modeling could also help in the Torquay Sub-basin, although such work in the Bass Basin could be inhibited by a lack of chronostratigraphic control on the deeper syntectonic section.

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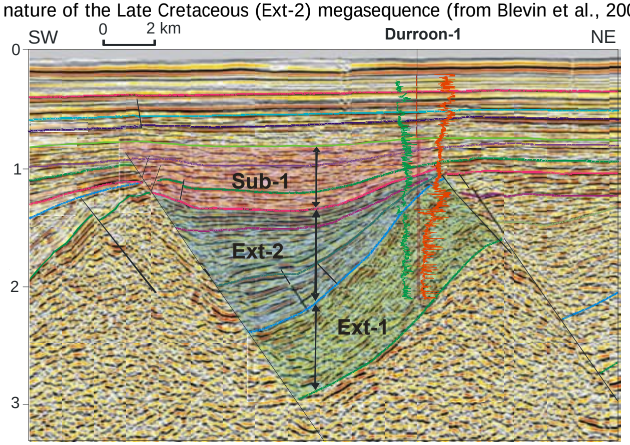
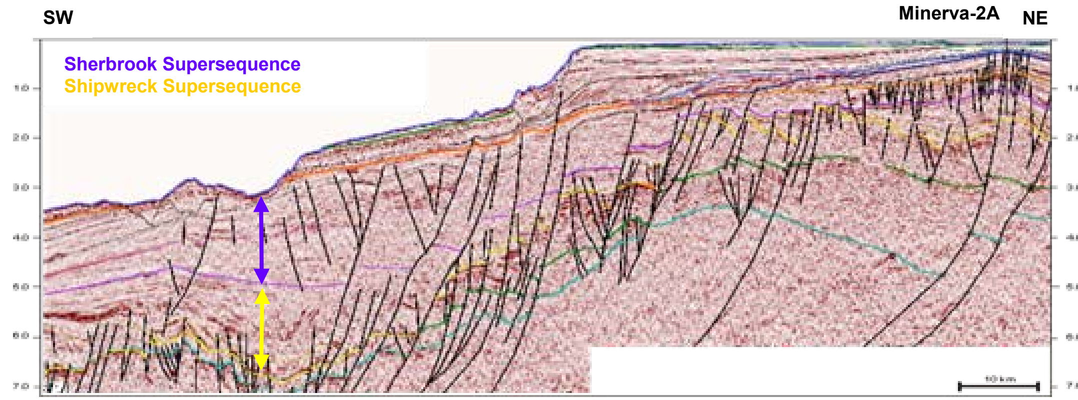
Phase 4: Late Cretaceous Extension

The Late Cretaceous Extension (Phase 4) is well documented in the offshore Otway Basin where the Shipwreck and Sherbrook supersequences were deposited seaward of the Mussel-Tartwaup fault zone as the locus of extension moved outboard of the early rift basins (e.g., Krassay et al., 2004). Here, growth sections in excess of 3000m thick are observed in the offshore basin. Extension occurred in two phases – 1) Turonian to latest Santonian (Shipwreck); and 2) Campanian to late Maastrichtian (Sherbrook). The boundary between these two phases coincides with breakup outboard of the Ceduna and Recherche sub-basins (approximately 83 Ma; Sayers et al., 2001). Overall, the amount of observed growth decreases upward in the younger Sherbrook Supersequence. Extension direction is interpreted to be north-south and driven by the later stages of Southern Margin rifting. The end of rifting in the offshore Otway Basin is marked by breakup and the onset of seafloor spreading at 67 Ma (Krassay et al., 2004). Previous authors have interpreted breakup off the Otway Basin as Cenomanian (Boult and Hibburt, 2002;) or mid-Eocene (43 Ma; Norvick and Smith, 2001).

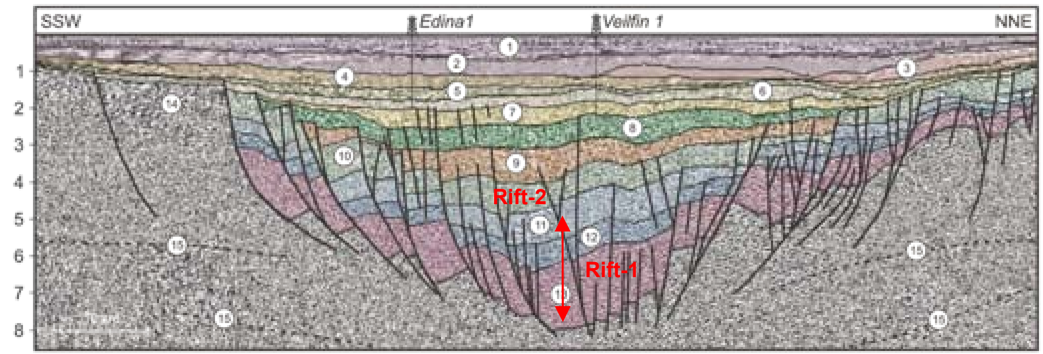
In the Gippsland and Bass basins, Late Cretaceous extension is also well documented, e.g. at Durroon-1, where the event is recorded by strata with clear divergent geometries in the initial rift phase followed by decreasing extension in the later stages (Ext-2). In the Gippsland Basin, the two pulses of rifting are recorded as the Emperor (early stage) and Golden Beach (later stage) events. Many of the stratigraphic charts of the basin (e.g., Norvick and Smith, 2001) shown an unconformity between these two stages, but it is likely that deposition was continuous within the deeper half graben.

Interpreted seismic line across the eastern Durroon Sub-basin showing the syn-tectonic nature of the Late Cretaceous (Ext-2) megasequence (from Blevin et al., 2005).





Geoscience Australia seismic line 137-09 across the Nelson Sub-basin showing interpreted syn-rift growth during deposition of the the Shipwreck and Sherbrook supersequences.



Interpreted seismic line across the Gippsland Basin showing the major megasequences mapped (from Powers et al., 2001). A key to the numbered stratigraphic units are shown in Power et al (2001) and later in this report.

Extension in the Gippsland and eastern Bass Basin occurred from the Turonian to mid-Campanian and was driven by rifting in the Tasman Sea to the east. A northeast-oriented extension direction has been interpreted. Breakup in the Tasman Sea was approximately coeval with breakup off the Ceduna Sub-basin – 80-83 Ma (early Campanian). The cessation of extension in the Bass and Gippsland was slightly later, as the spreading ridge propagated north from the initial ridge.

While the early phase of the Late Cretaceous Extension event is coincident in the southeastern basins (Turonian to mid-Campanian), the stresses are associated the final stages of separation between Australian and Antarctica (Otway/Bass) and breakup of eastern Gondwana (Bass/Gippsland). Tasman Sea breakup was rapid and post-rift subsidence commenced in the mid-Campanian, while the prolonged fragmentation and clearance between Australia and Antarctica meant that extensional stresses continued to affect the western Bass Basin until the Early Eocene. During this period, continued extensional and transtensional movement is observed on selected faults/fault sets (Rift Transition Phase).

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Project Aims, Background & Datasets

Project Aims

FrOG Tech P/L was contracted by the Geoscience Australia to undertake a synthesis of the tectonostratigraphic evolution of basins along the Australian Southern Margin (Southern Rift System; Stagg et al., 1990 Figure 1). The main aims of the study as described by the client were:

- compare the sedimentary record in the depocentres along the margin, adding lithological details to the regional basin tectonostratigraphic framework;
- document the variations in subsidence history, accommodation and deposition, and how different tectonic events are expressed along the margin; and,
- documentation of results in a report.

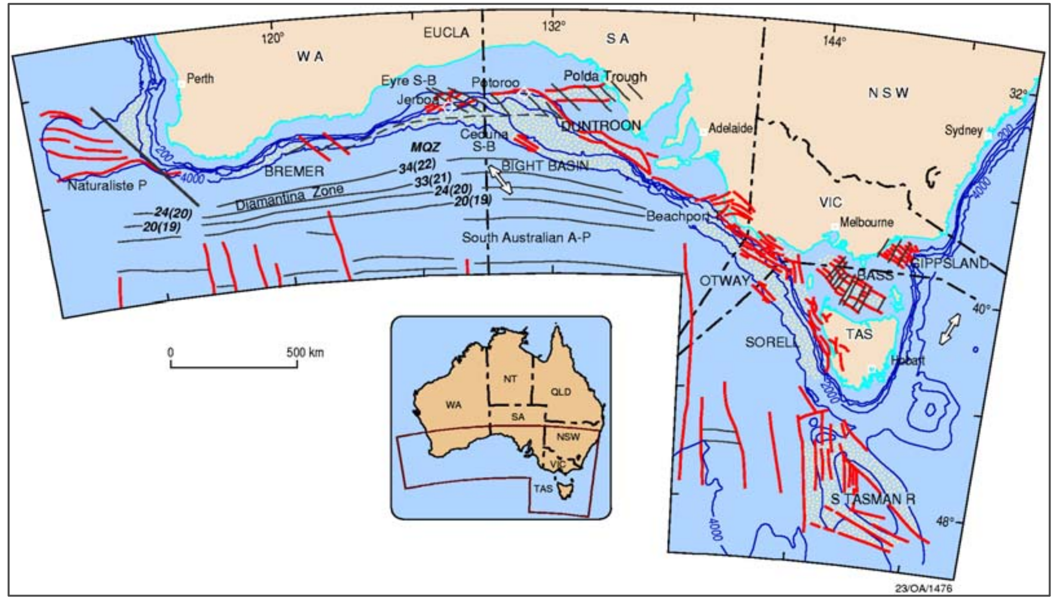

Figure 1. The Southern Rift System as defined by Stagg et al (1990) and Willcox (1990). The arrows indicate the postulated sense of lithospheric extension and fault movement.

Background

In 1998-99, Geoscience Australia (through Seismic Australia) acquired new seismic data across the Ceduna Sub-basin (eastern Bight Basin) in the central Great Australian Bight. This survey built on previous programs and years of research carried out under BMR's Continental Margins Program, and served to reinvigorate research and exploration activity in this frontier region. The Bight Basin seismic survey was followed by other acquisition programs (seismic, dredges, sediment cores) along the Southern Margin and included reprocessing of existing industry seismic datasets.

Since that time, Geoscience Australia has utilised these new and upgraded datasets to undertake research projects aimed at further understanding the tectonic, structural and stratigraphic evolution of frontier basins along the Southern Margin – in particular, the Bight, Otway and Bass basins. Ultimately, these studies have been used to assess the petroleum resource potential of the basins with results underpinning the Offshore Acreage Release program. Other related scientific studies in the region include ODP Leg 189 in the South Tasman Rise and the southwest Tasmanian margin, numerous swath mapping programs and the Law of the Sea seabed boundary definition in the deepwater Bight Basin and South Tasman Rise. Geoscience Australia also commissioned a study of plate reconstructions of the Southern Margin (Norvick, 2005).

The *Southern Margin Synthesis Project* was seen as a means to rapidly consolidate the results of the different projects and other external work published in the literature. The bibliography of this report lists the key references consulted during the current study, although not all references are specifically cited in the text. Structural mapping was not within the scope of this project, as this constitutes on-going work that is presently underway in Geoscience Australia.

Datasets and Methods

Since 2000, SRK Consulting has undertaken a number of SEEBASE™ projects on Southern Margin basins for a range of government and industry clients (e.g., SRK Consulting, 2001, 2002). In 2003/4, SRK Consulting undertook a 'stitch' of all previous SEEBASE projects along the Southern Margin for Geoscience Australia (Teasdale et al., 2003; Teasdale, 2004).

In 2004, FrOG Tech completed the OZ SEEBASE™ Project for Shell Australia and provided the first continent-scale depth to basement image for the country (Figure 2; FrOG Tech, 2004). The SEEBASE™ image (Figure 2) shows the distribution of Palaeozoic basins across the Australian Plate. The Southern Margins stitch undertaken in 2003/4 was incorporated into OZ SEEBASE™. In 2006, the OZ Proterozoic SEEBASE™ Project extended this work to include all Proterozoic basins (FrOG Tech, 2006). The extent of the current *Southern Margin Synthesis Project* is shown on Figure 2.

Some of the datasets used in the Southern Margin stitch and OZ SEEBASE™ were utilised for the current study and are shown in the following pages. However, the events as defined by Teasdale (2003, 2004) have been reviewed and significantly revised, as the current study used a much broader dataset of detailed seismic to constrain the age and nature of tectonic events. A rapid review of the basement terranes was also undertaken for this study. A copy of the Teasdale (2004) report is included on the DVD that accompanies this report.

For the *Southern Margin Synthesis Project,* Geoscience Australia provided access to all in-house seismic datasets, reports, ArcGIS basins outlines, seismic navigation data and regional images of gravity, magnetics and DEM. The approach taken involved a basin-by-basin review and compilation of the event histories and tectonostratigraphy as documented in the published literature.

The event histories for all basins were assessed for consistency in approach and validated using the regional interpreted seismic grid and selected well information. The results of the basin compilations were tabulated against the 2007 Geoscience Australia timescale and correlated between basins to understand the margin scale nature of events. Two time-based summary charts were produced: 1) *Tectonostratigraphy, Tectonic and Magmatic Events*; and 2) *Lithostratigraphy and Environments*.

From this synthesis, it is clear that several key questions remain on the tectostratigraphic correlations – particularly within the eastern basins and mainly due to a lack of well penetrations to valid age constraints of seismically defined units. A more rigorous understanding of margin evolution would also involve using the results of this study (and other datasets) to construct and test kinematic models and basement response at a plate scale.

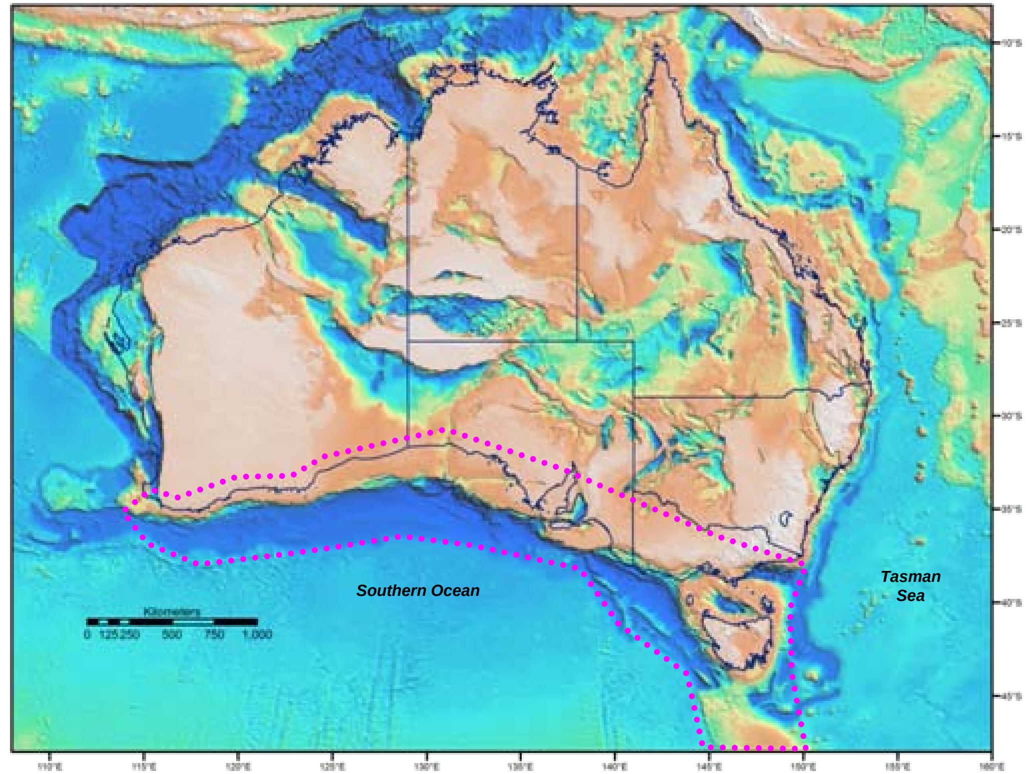

Figure 2. The OZ SEEBASE™ depth-to-basement image as constructed by FrOG Tech (2004). The image shows the distribution of basins across the Australian Plate. The approximate study area of the Australian Southern Margin Synthesis Project is shown by the dotted-pink polygon.

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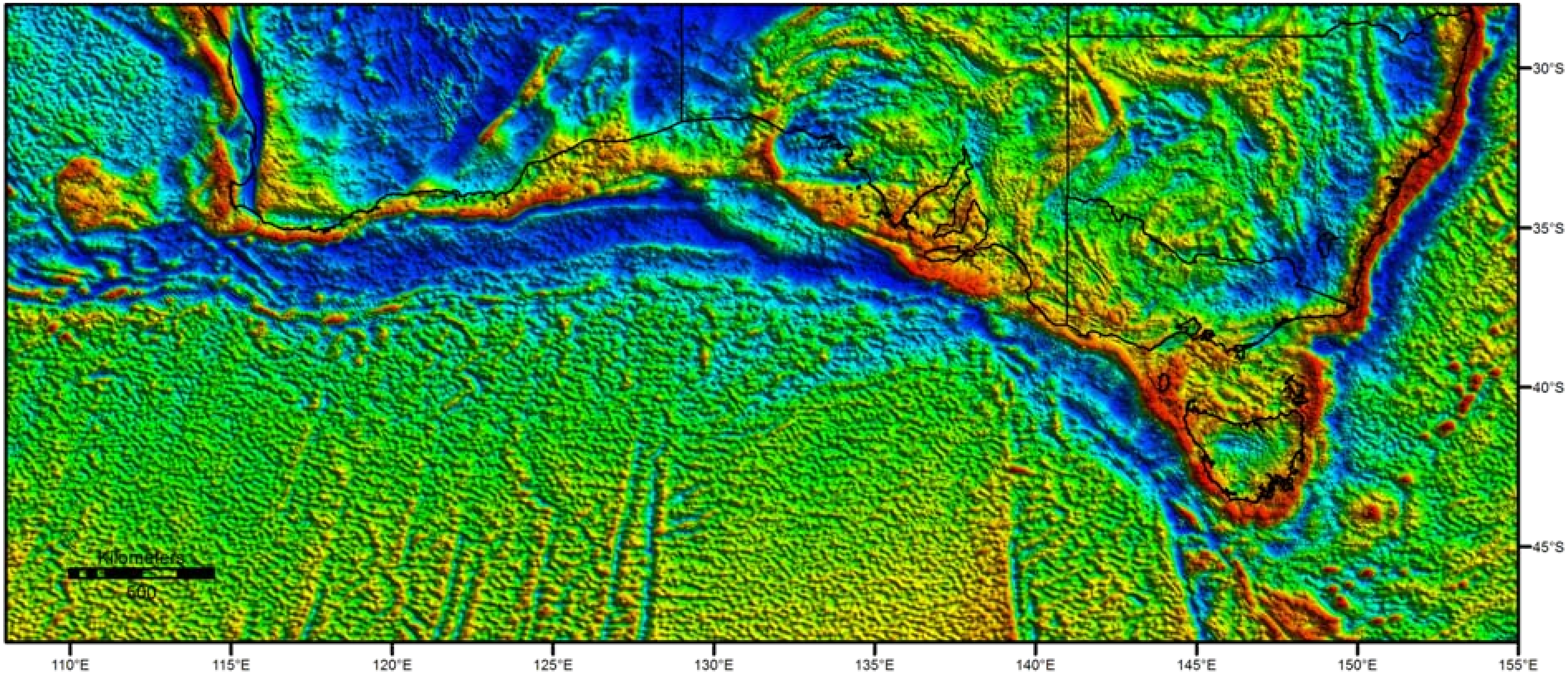
Gravity

Gravity data maps subtle changes in the Earth's gravitational field caused by variations in the density of the underlying rocks. Although the resolution of this dataset is relatively low, it provides valuable information on basement topography and the nature of the deeper parts of the crust and mantle beneath the basins. Important intra-basin elements often have an associated gravity signature indicating that each element is related to a deep basement structure. For the previous Southern Margin project (Teasdale, 2004), the Geoscience Australia 2001 National Gravity Grid was imaged in ERMapper using a Hue-Saturation-Intensity colour model. The new Geoscience Australia gravity grid is a compilation of Bouguer-corrected onshore and free-air offshore survey data, free-air Geosat satellite gravity offshore, and marine ship track data. In order to evaluate the source of a gravity anomaly, data interpretation must be calibrated with geology. Gravity images show density contrasts within the crust and upper mantle, but the source of the contrast is not unique. By combining onshore gravity data with mapped geology, sources of many of the anomalies can be interpreted and extrapolated offshore. Determining the source of anomalies may require geophysical modelling which also must be constrained by a geological model. The results of these gravity models are presented in Teasdale (2004; see DVD included).

Figure 3. Free-air gravity image of the Australian margin from the Geoscience Australia 2001 National Gravity Grid (from Teasdale, 2004).



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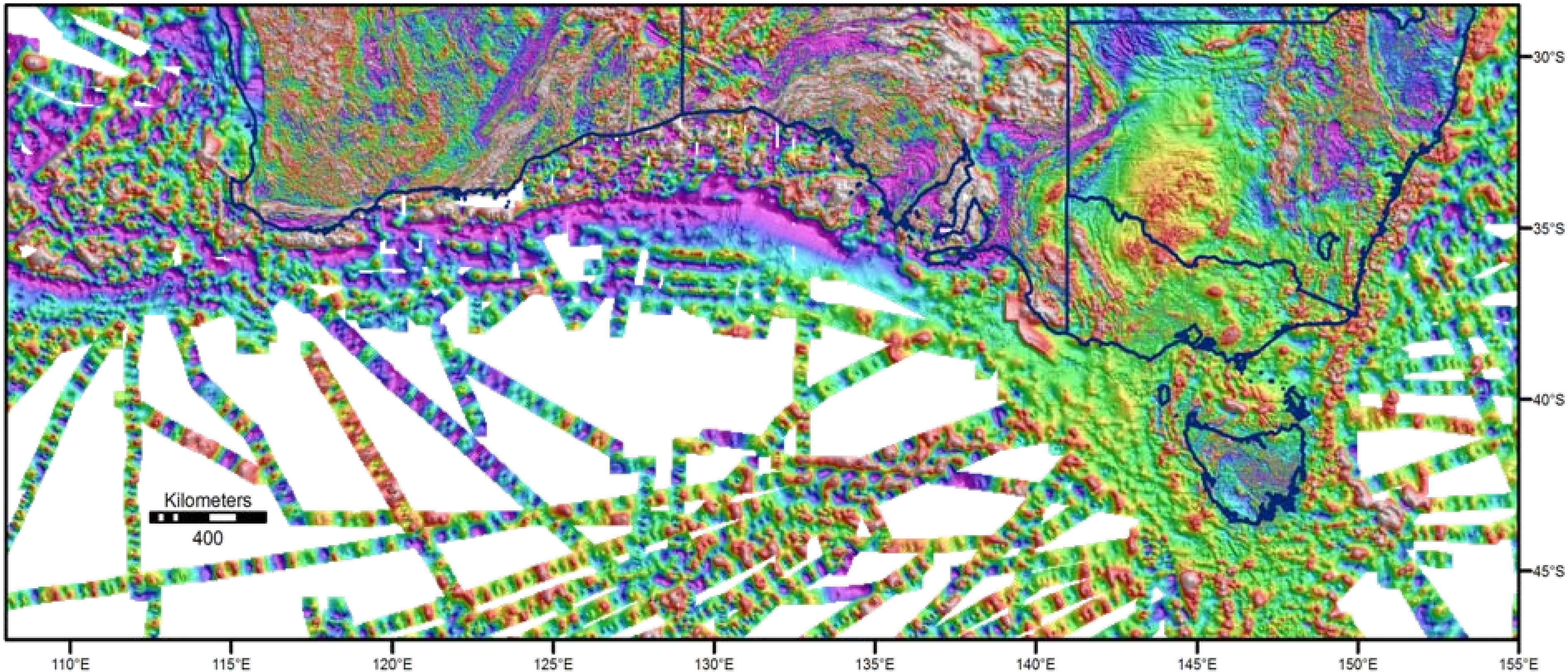
Magnetics

Aeromagnetic data measures variations in the Earth's magnetic field caused by variations in the magnetic susceptibility of the underlying rocks. It provides information on the structure and composition of the magnetic basement. Most bodies within the basement have a distinctive magnetic signature which is characterised by the magnitude, heterogeneity and fabric of the magnetic signal. When calibrated with known geology, terranes can be mapped under a cover of sedimentary rock and/or water. The most important and accurate information provided by magnetic data is the structural fabric of the basement. Major basement structures can be interpreted from consistent discontinuities and/or pattern breaks in the magnetic fabric. Once the structures have been evaluated and combined with those interpreted from the gravity data, a model for the evolution of the basement and overlying basins can be developed. The results of these magnetic models are presented in Teasdale (2004, see DVD included).

Figure 4. A mosaic of three Total Magnetic Intensity (TMI) grids: 1) Geoscience Australia National 400m magnetic grid; (2) PIRSA 100m magnetic grid of South Australia; (3) Flinders DW magnetic data from the Great Australian Bight (from Teasdale, 2004).

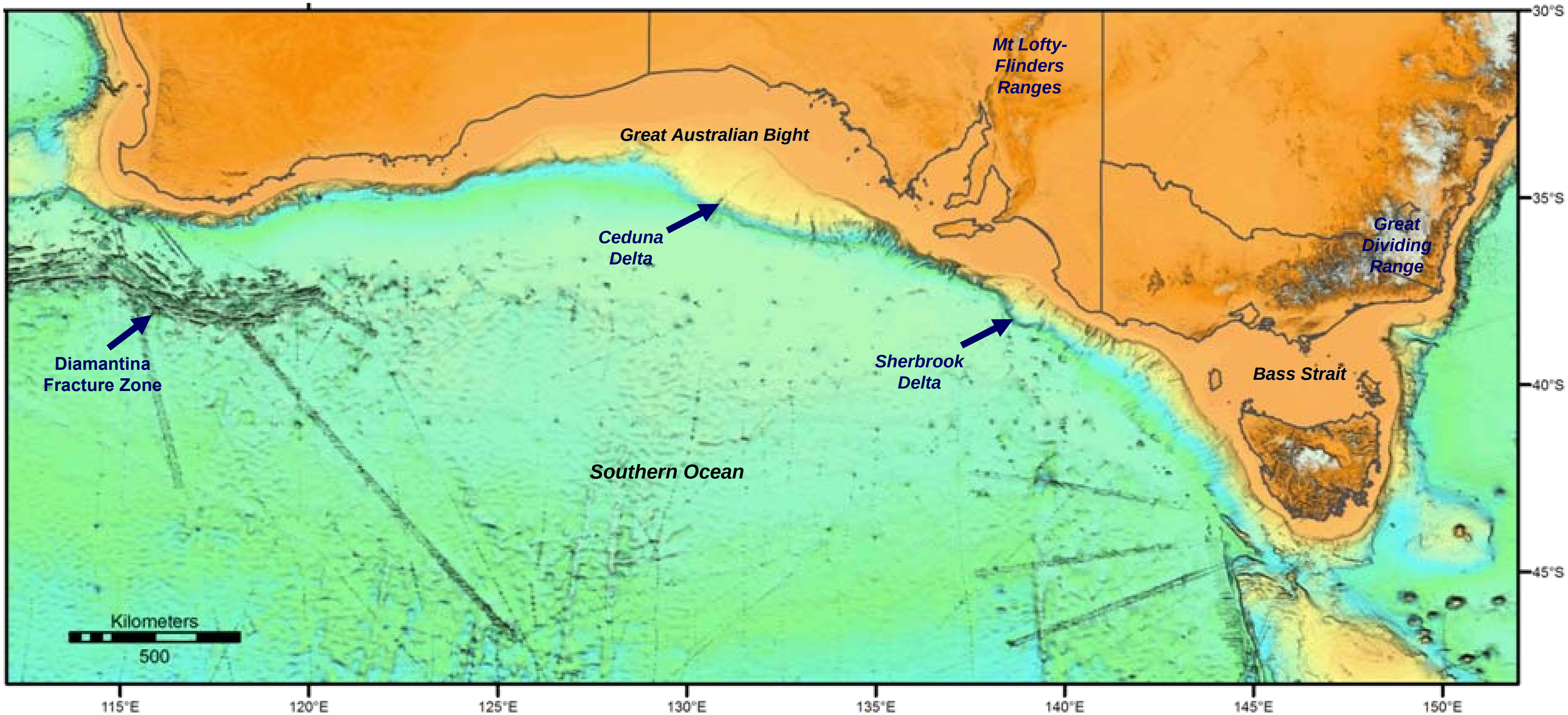


Digital Elevation Model

A Digital Elevation Models (DEM) often shows the youngest structures and any active geological structure. For these reasons, they are widely used for neotectonic analysis. In addition, exposed terranes often differ in their resistance to weathering due to inherent compositional variations, and these features may be evident on the DEM.

The DEM image shown below is the 2003 national 1km grid from Geoscience Australia, and shows areas in the southeast uplifted during the Late Cretaceous to Recent (Great Dividing Range, Mt Lofty-Flinders Ranges, Tasmania), the very flat continental shelf (including Bass Strait), the steep continental slope transected by numerous submarine canyons, and the abyssal plain of the Southern Ocean at 4-5km depth. The massive Cretaceous Ceduna delta system is also prominent in the outer Great Australian Bight. A similar age, although much smaller delta system is evident in the offshore part of the western Otway Basin (informally referred to here as the Sherbrook delta).

Figure 5. Geoscience Australia's Digital Elevation Model (DEM) image of the Southern Margin annotated to show geologically significant modern topographic features.



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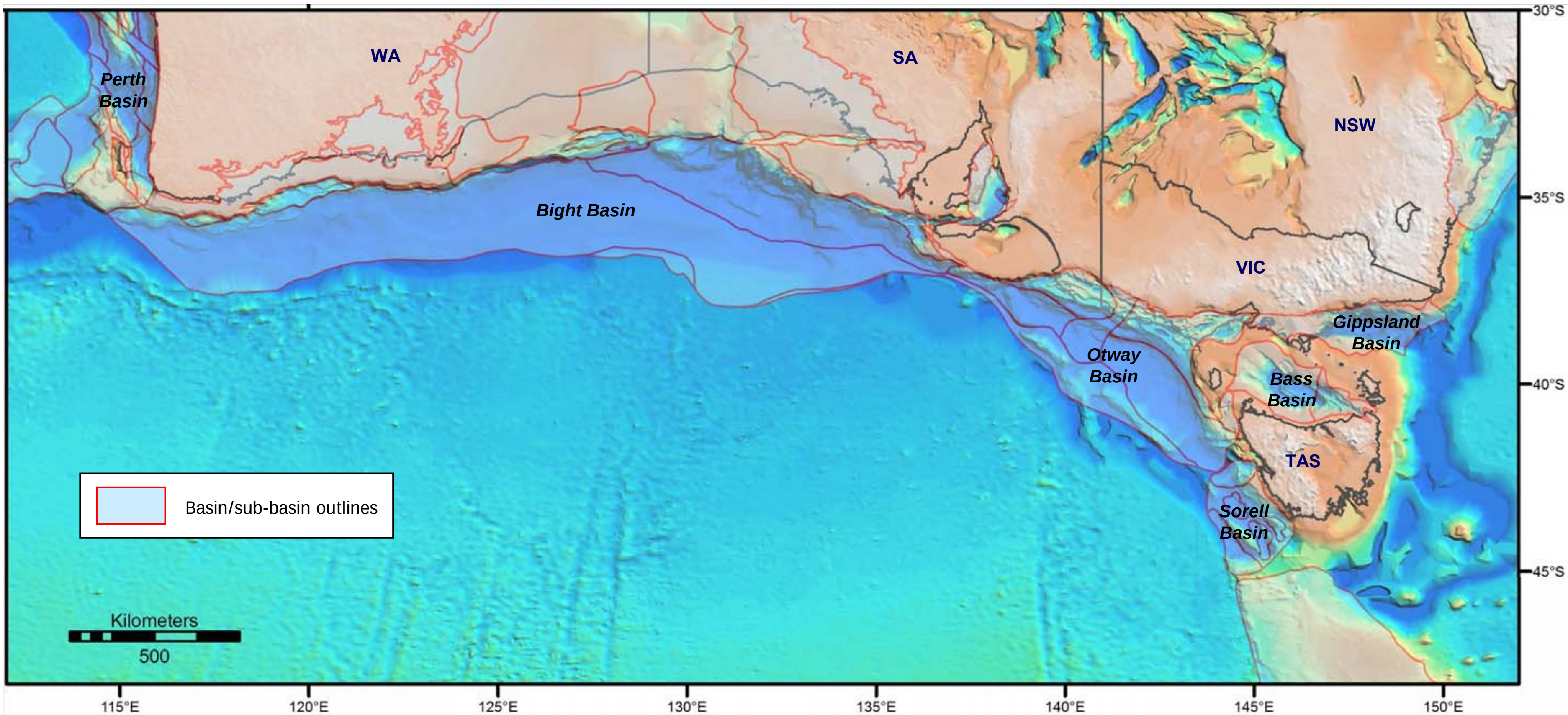
OZ SEEBASE™ and Basin Outlines

Figure 6 shows the OZ SEEBASE™ depth-to-basement image for the Australian Southern Margin. The basin and sub-basin outlines shown are published by Geoscience Australia and available as ArcGIS files via download at www.ga.gov.au.

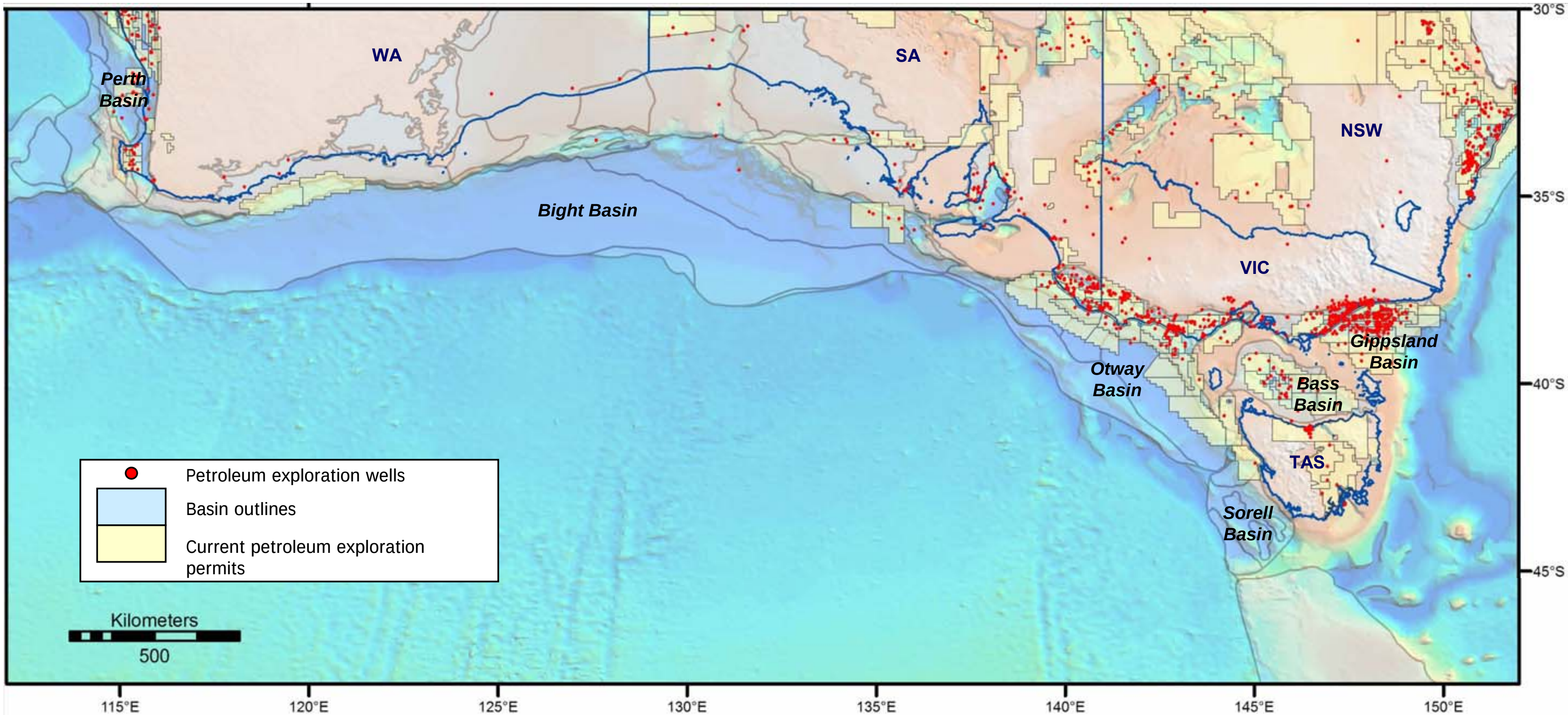
Figure 6. OZ SEEBASE image (FrOG Tech, 2004) of the Southern Margin Synthesis project area overlain with basin and sub-basin outlines from Geoscience Australia's PROVS database.



Wells and Permits

Figure 7 shows the distribution of petroleum exploration wells and current permits along the Southern Margin based on data extracted from Encom GPInfo (December 2007). The basin outlines shown are published by Geoscience Australia and available as ArcGIS files via download at www.ga.gov.au. The recent and upcoming permit relinquishments in the Ceduna Sub-basin (eastern Bight Basin) means that exploration activity in one of Australia's most prospectivity frontier regions has waned, while nearby areas (Bremer, Otway, Bass, Gippsland and Sorell basins) have rarely seen such high levels of concurrent activity.

Figure 7. OZ SEEBASE™ image (FrOG Tech, 2004) of the Southern Margin Synthesis project area overlain with basin outlines (Geoscience Australia's PROVS database), permits and wells (Encom GP Info, December 2007).



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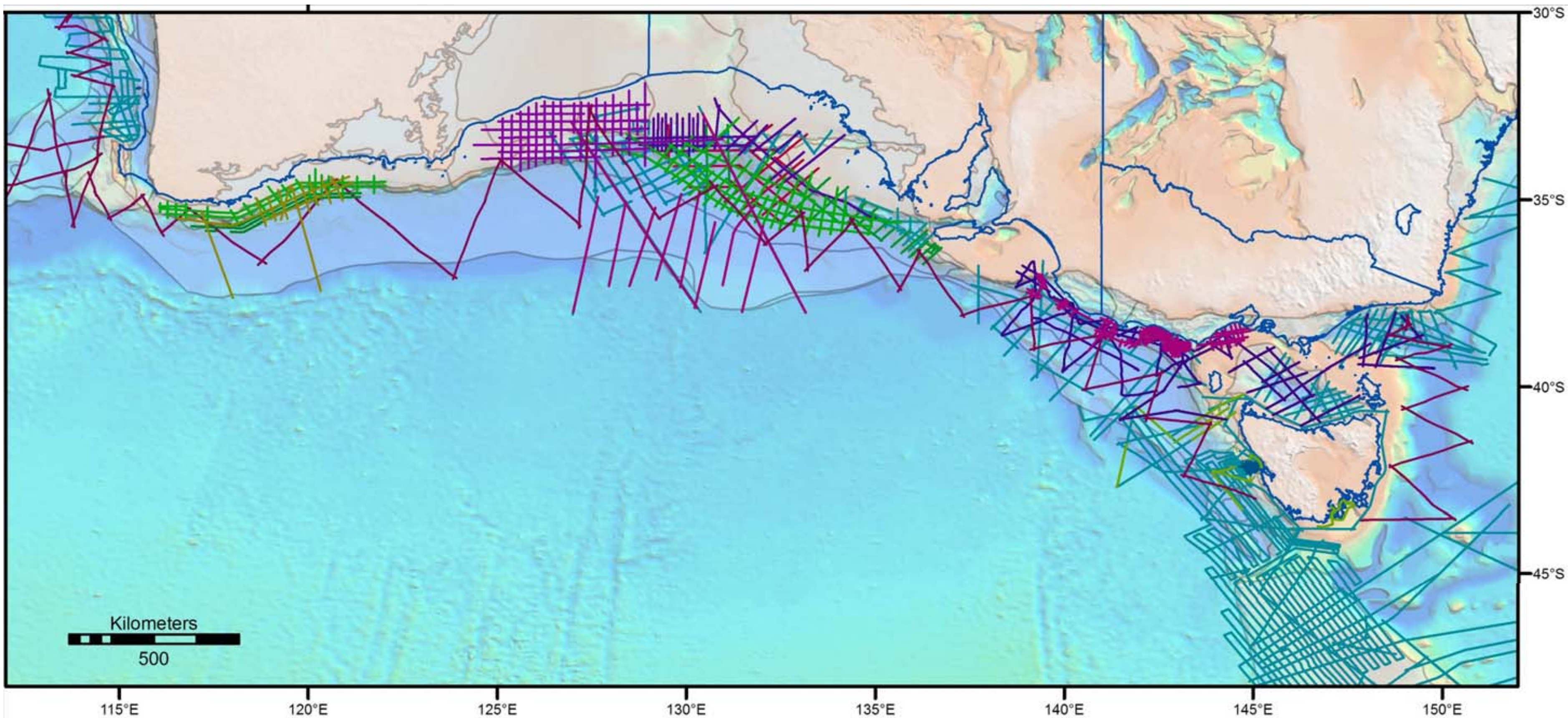
Seismic Data

Geoscience Australia's seismic coverage across the Southern Margin is shown in Figure 8. Most of the data in the Bight, Otway and Bass basins was either recently acquired or reprocessed, and much of this data has been interpreted in past projects. Several datasets from the offshore western Tasmania and the South Tasman Rise are of variable quality and generally not interpreted in a digital format. Digital datasets of reprocessed industry seismic data in the Bass Basin are not shown. Only the Geoscience Australia deep seismic datasets in the Gippsland Basin are shown.

Figure 8. OZ SEEBASE™ image (FrOG Tech, 2004) of the Southern Margin Synthesis project area overlain by basin outlines (PROVS database) and line locations of Geoscience Australia's in-house seismic datasets.



Basement Terranes & Plate Reconstructions

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Present-Day Basement Terranes

A basement terrane is defined as a discrete, mappable, structurally bounded block of crust of regional extent with a tectonostratigraphic history different to that of adjacent terranes (Jones et al., 1977; Howell, 1995). The interpretation of the present-day basement terranes across southern Australia (Figure 9) is primarily based on potential field data, calibrated with mapped geology (Teasdale et al., 2003; Teasdale, 2004; FrOG Tech, 2004; this study). The contrasting basement terranes and structures within and between the terranes acted as first-order controls on the evolution of the Southern Margin and other basins. A description of the megaterranes is presented in Table 1.

In basin analysis, the importance of understanding basement terranes lies in knowing the fabric, rheology and boundaries of a given terrane in order to understand its response to tectonic stresses. Within this framework, the evolution of faults, structures, the reactivation history, tectonostratigraphy and petroleum systems of a basin may be more clearly understood.

Figure 9. Terranes identified by Teasdale (2004) and OZ SEEBASE™ (FrOG Tech, 2004), and updated as part of the Southern Margin Synthesis project.

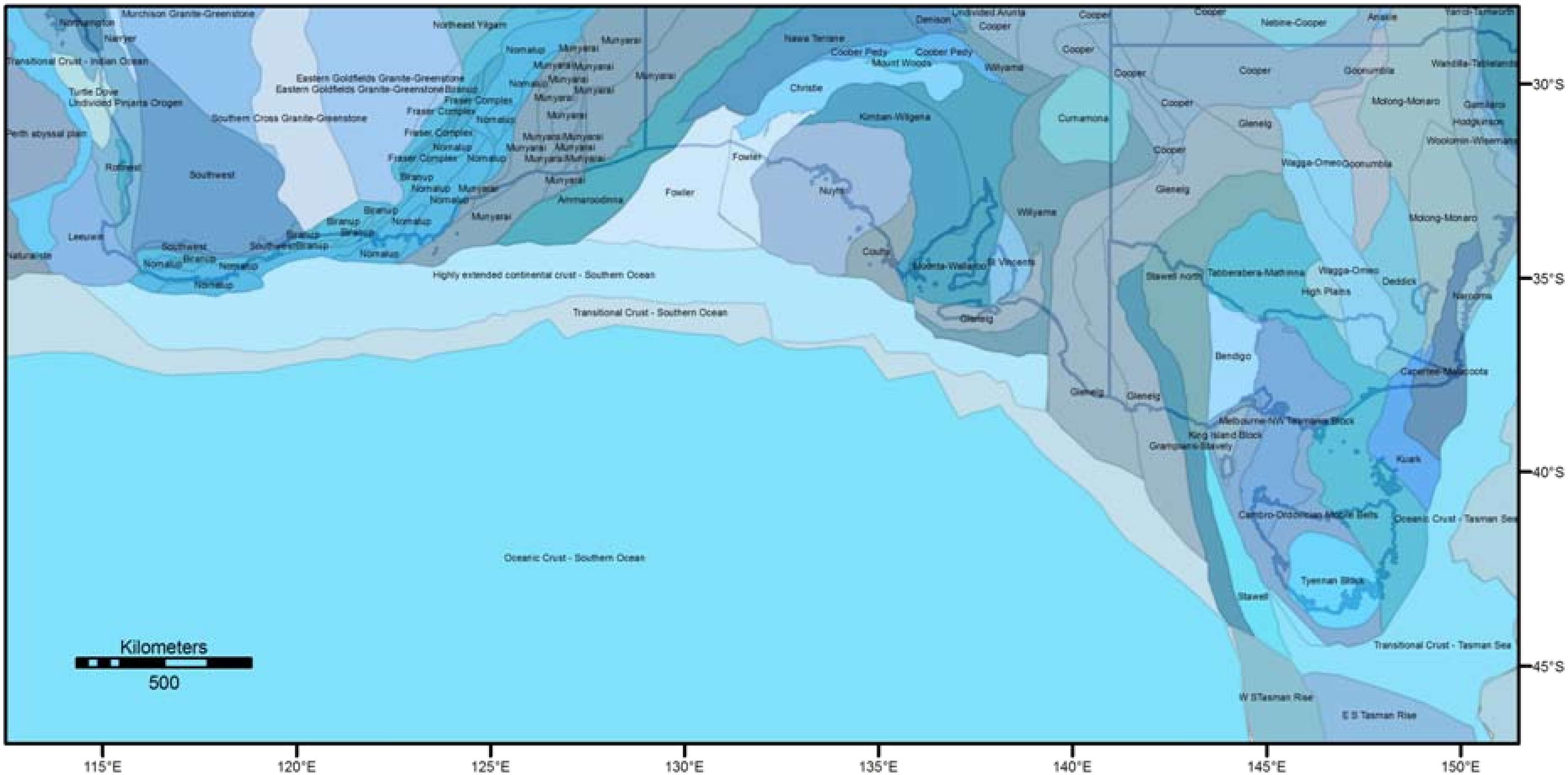

Table 1. Key to Interpreted Basement Terranes

Key	Terrane Name	Crust Type	Max Age (Ma)	Min Age (Ma)	Description
1	Ammaroodinna	CONTINENTAL	1850	1400	High grade metasedimentary-mafic gneiss with abundant granitoid intusives
2	Anakie	CONTINENTAL	545	434	meta-mafic volcanics, calc-silicates, limestone, serpentinite, clastic metasediments
3	Bendigo	CONTINENTAL	490	425	Deformed Ordovicain turbidite sequence deposited on extended Proterozoic continental crust; overlain by Silurian to Late Devonian continental sediments; intruded by Devonian granite
4	Biranup	CONTINENTAL	1700	1600	High-grade metamorphics: Reworked edge of Yigarn Craton
5	Cambro-Ordovician Mobile Belts	CONTINENTAL	800	490	Complex, variably deformed and metamorphosed Cambro-Ordovician mobile belts wrapping around Neoproterozoic crustal blocks. Includes Cambrian tholeiitic and boninitic volcanic complexes, and older sediments.
6	Capertee-Malacoota	CONTINENTAL	495	292	Ordovician-Lower Silurian sandstone, mudstone, shale; Lower Devonian marine sediments; with Silurian and Late Devonian-Carboniferous granite intrusions
7	Christie	CONTINENTAL	2550	1700	High grade Archean metasediments intruded by Palaeoproterozoic granitoids, reworked during the Mesoproterozoic
8	Connors-Auburn-Camboon-Baldwin Arc	CONTINENTAL	414	230	Felsic, and lesser mafic and intermediate volcanics and intrusions
9	Coober Pedy	CONTINENTAL	1850	1400	Fe-rich metasedimentary gneiss with mafic and pelitic gneiss
10	Cooper	CONTINENTAL	2000	545	Extended Proterozoic block overlain by Neoprot-Cambrian sediments deformed during the Cambro-Ordovician (Delamerian)
11	Coulta	CONTINENTAL	2550	1000	High grade Archean metasediments, granodiorites and granite gneiss intruded by Mesoprot granites
12	Curnamona	CONTINENTAL	2500	1000	Rigid basement block caused by large mid-upper crustal pluton, intruding complex gneiss terrane
13	Deddick	CONTINENTAL	490	384	Metamorphosed Ordovicain marine sediments and volcaniclastics; Silurian clastics,; Siluro-Devonian granite intrusions
14	Denison	CONTINENTAL	2550	1000	Complex high grade gneiss terrane with abundant Paleoproterozoic intrusives
15	Eastern Goldfields Granite-Greenstone	CONTINENTAL	3500	2500	Granite, metasedimentary and metamorphic
16	Fowler	CONTINENTAL	1850	1000	Highly deformed Palaeoproterozoic mafic-intermediate intrusives with interlayered metasediments
17	Fraser Complex	CONTINENTAL	1320	1280	High-grade metamorphics
18	Gamilaroi	OCEANIC - NORMAL	503	354	Island arc sequence
19	Glenelg	CONTINENTAL	1000	490	Cambro-Ordovician (Delamerian) fold-thrust belt containing thick Neoprot?-Cambrian shallow to deep marine metasediments and volcanics overlying extended Proterozoic crust at least in part
20	Goonumbla	CONTINENTAL	490	369	felsic and mafic metavolcanics, metasediments
21	Grampians-Stavely	CONTINENTAL	545	490	Low grade metasediments, tholeiitic-boninitic rocks and calc-alkaline volcanics
22	High Plains	CONTINENTAL	490	369	Metamorphosed Ordovician-Silurian turbidite sequences overlain by Late Silurian-Early Devonian sediments and volcanics; Early Silurian to Late Devonian Granite; probably overlying extended Proterozoic crust
23	Highly extended continental crust - Southern Ocean	CONTINENTAL - THINNED	2500	1000	Highly extended, deformed Palaeoproterozoic mafic-intermediate intrusives with interlayered metasediments
24	Hodgkinson	CONTINENTAL - THINNED	490	314	mainly meta turbidite, lesser limestone, chert, mafic volcanic
25	Kimban-Wilgena	CONTINENTAL	2550	1550	Complex upper crustal Archean basement intruded by numerous Proterozoic granitoids metasediments and volcanics

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Table 1. Key to Interpreted Basement Terranes

Key	Terrane Name	Crust Type	Max Age (Ma)	Min Age (Ma)	Description
26	King Island Block	CONTINENTAL	800	550	Neoproterozoic crustal block relatively undeformed during Palaeozoic orogenesis. Mostly overlain by Lachlan Fold Belt sediments.
27	Kuark	CONTINENTAL	495	384	Ordovician to Silurian sandstone and metamorphics with Siru-Devonian granites and Lower Devoniuan volcanics
28	Leeuwin	CONTINENTAL	780	540	Granulite, granite, migmatite: Reworked mobile belt
29	Melbourne-NW Tasmania Block	CONTINENTAL	800	369	Neoproterozoic crustal block relatively undeformed during Palaeozoic orogenesis, mostly overlain by Early Silurian to Late Devonian sediments and volcanics; Devonian granite intrusion
30	Molong-Monaro	CONTINENTAL	545	380	metasediments, volcanics and meta-igneous complexes
31	Moonta-Wallaroo	CONTINENTAL	1850	1400	Complex, mildly deformed Paleo-Mesoproterozoic terrane
32	Mount Woods	CONTINENTAL	1850	1400	Fe-rich metasedimentary gneiss with mafic and pelitic gneiss
33	Munyarai	CONTINENTAL	1850	1000	High grade felsic and metasedimentary gneiss
34	Murchison Granite-Greenstone	CONTINENTAL	3500	2500	granite, metasedimentary and metamorphic
35	Narooma	TRANSITIONAL - ACCRETIONARY	545	440	subduction complex: melange, metabasics, serpentinite, volcanics
36	Narryer	CONTINENTAL	3320	2600	
37	Naturaliste	CONTINENTAL - THINNED	2500	1600	Hard, stable craton
38	Nawa Terrane	CONTINENTAL	2550	1000	Complex high grade gneiss terrane with abundant Paleoproterozoic intrusives
39	Nebine-Cooper	CONTINENTAL	2000	1000	Paleoproterozoic block overlain by Neoprot-Cambrian sediments deformed during the Cambro-Ordovician (Delamerian)
40	Nornalup	CONTINENTAL	1560	1280	granitic and metasedimentary gneiss, low grade overlying Mesoproterozoic metasediments
41	Northampton	CONTINENTAL	1100	1080	High-grade psammitic gneiss:Reworked mobile belt
42	Northeast Yilgarn	CONTINENTAL	3320	2600	Stacked basins onlap NE margin
43	Nuyts	CONTINENTAL	2500	1000	Paleoproterozoic granitoids with Mesoproterozoic felsic volcanic and granitoid province, locally deformed
44	Oceanic Crust - Southern Ocean	OCEANIC - NORMAL	55	0	normal oceanic crust
45	Oceanic Crust - Tasman Sea	OCEANIC - NORMAL	142	66	normal oceanic crust
46	Perth abyssal plain	OCEANIC - NORMAL	130	0	normal oceanic crust
47	Rottnest	CONTINENTAL	1100	545	Reworked mobile belt
48	Southern Cross Granite-Greenstone	CONTINENTAL	3500	2500	granite, metasedimentary and metamorphic
49	Southwest	CONTINENTAL	3320	2600	Med-high grade metamorphic
50	St Vincents	CONTINENTAL	1600	1400	Mesoproterozoic intrusives
51	Stawell	CONTINENTAL	500	425	Deformed Cambro-Ordovician turbidites overlying Cambrian oceanic volcanics and sequence and probable extended Proterozoic continental crust; intruded by Devonian granite

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Table 1. Key to Interpreted Basement Terranes

Key	Terrane Name	Crust Type	Max Age (Ma)	Min Age (Ma)	Description
52	Stawell north	CONTINENTAL	500	425	Deformed Cambro-Ordovician turbidites overlying Cambrian oceanic volcanics and sequence and probable extended Proterozoic continental crust; intruded by Devonian granite
53	Tabberabera-Mathinna	CONTINENTAL	495	380	Deformed Ordovician turbidite and Early Silurian sediments intruded by Siluro-Devonian granites; overlain by Early to Late Devonian sediments and volcanics; possibly aoverlies extended Proterozoic crust
54	Transitional Crust - Indian Ocean	TRANSITIONAL	2500	65	highly attenuated continental crust with abundant oceanic intrusives & extrusives
55	Transitional Crust - Southern Ocean	TRANSITIONAL	2500	65	highly attenuated undifferentiated continental crust with abundant oceanic intrusives & extrusives
56	Transitional Crust - Tasman Sea	TRANSITIONAL	545	298	highly attenuated undifferentiated continental crust with abundant oceanic intrusives & extrusives
57	Turtle Dove	CONTINENTAL	1100	1080	High-grade metamorphics: Reworked mobile belt
58	Tyennan Block	CONTINENTAL	800	550	Neoproterozoic crustal block relatively undeformed during Palaeozoic orogenesis. Mostly overlain by Lachlan Fold Belt sediments.
59	Undivided Arunta	CONTINENTAL	1860	1560	
60	Undivided Pinjarra Orogen	CONTINENTAL	1100	700	Includes Leeuwin, Northampton and Mullingarra Complex.
61	W STasman Rise	CONTINENTAL			
62	Wagga-Omeo	CONTINENTAL	490	430	Metamorphosed Ordovician-Silurian turbidite sequences overlain by Late Silurian-Early Devonian sediments and volcanics; Early Silurian to Late Devonian Granite
63	Wandilla-Tablelands	TRANSITIONAL - ACCRETIONARY	434	293	
64	Willyama	CONTINENTAL	1690	1530	high- to low- grade metamorphics: migmatite, gneiss, metasediment, quartzite, metavolcanic-granitic suite
65	Woolomin-Wisemans	TRANSITIONAL	425	335	
66	Yarrol-Tamworth	CONTINENTAL	369	207	orearc sediments and volcanics

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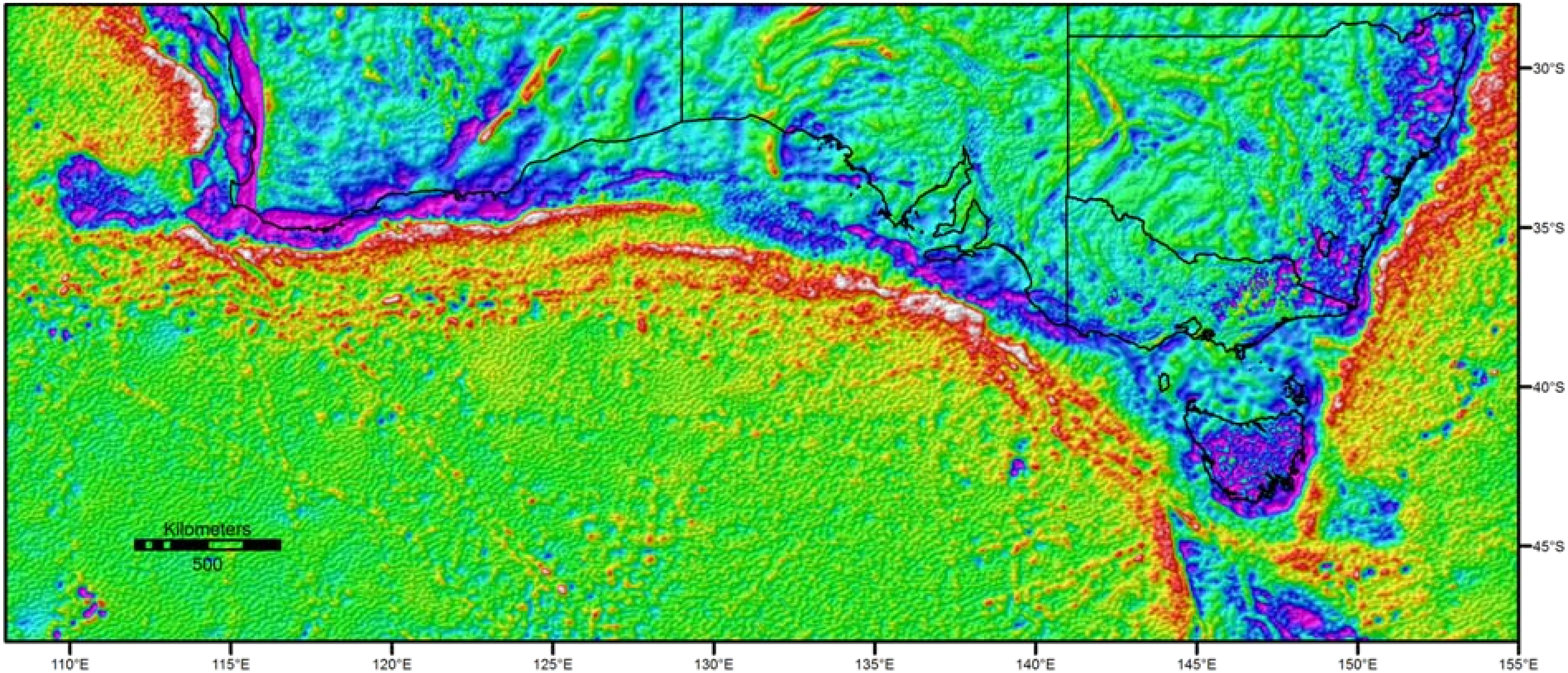
Residual Gravity Image from Geoscience Australia

Geoscience Australia made available Geotiff images of Bouguer residual gravity (M. Morse, Geoscience Australia, pers. comm., 2007). The image shown in Figure 10 is the result of a subtraction of the 25 km upward continuation of the surface Bouguer grid from the surface Bouguer grid. This method is effectively a regional removal of the deeper data, with the resulting gravity signal effectively coming from the upper 0 to 12.5 km of the crust. This image allows a clearer understanding of basin distribution with the sedimentary succession lying shallower than 12.5 km having a low density signal. This image is used later to highlight the relationship between basin distribution (low density) and terrane boundaries as defined by previous work (Teasdale, 2003, 2004; FrOG Tech, 2004; this study).

Figure 10. Bouguer isostatic residual gravity image supplied by Geoscience Australia showing the density of the upper 0 to 12.5 km of the crust.



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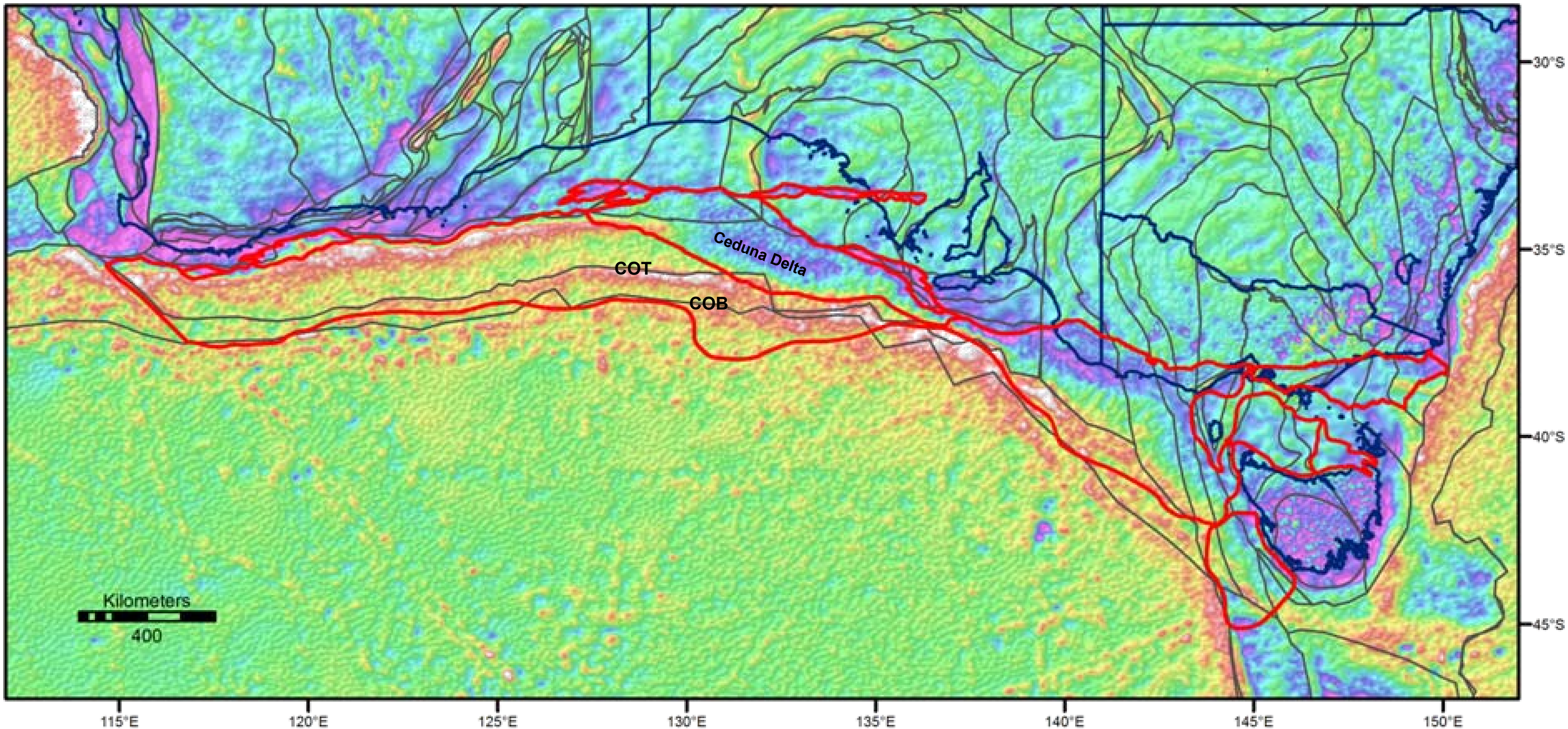
Residual Gravity Image, Basement Terranes and Mesozoic Basin Outlines

The Geotiff image of Bouguer residual gravity shown in previous Figure 10 (M. Morse, Geoscience Australia, pers. comm., 2007) is shown in Figure 11 overlain with the interpreted basement terranes (see Figures 9 and 9a; Teasdale et al., 2003; Teasdale, 2004; FrOG Tech, 2004; this study) and outlines of the Mesozoic Southern Margin basins (see Figure 6). In this spatial comparison, it is apparent that some terrane boundaries coincide with the overlying boundaries of basins that formed during Mesozoic extension – i.e., the Bremer, Denmark, Duntroon and eastern Ceduna sub-basins. In contrast, the boundaries of basins in the southeast (Otway, Bass and Gippsland basins) appear to cross-cut the dominant N/S-trending terrane boundaries of the underlying Palaeozoic and Proterozoic foldbelts. The Sorell Basin (western offshore Tasmania) formed parallel to terrane boundaries in a largely strike/slip setting.

Figure 11. Terranes identified by Teasdale (2004) and OZ SEEBASE™ (FrOG Tech, 2004), and updated as part of the Southern Margin Synthesis project.



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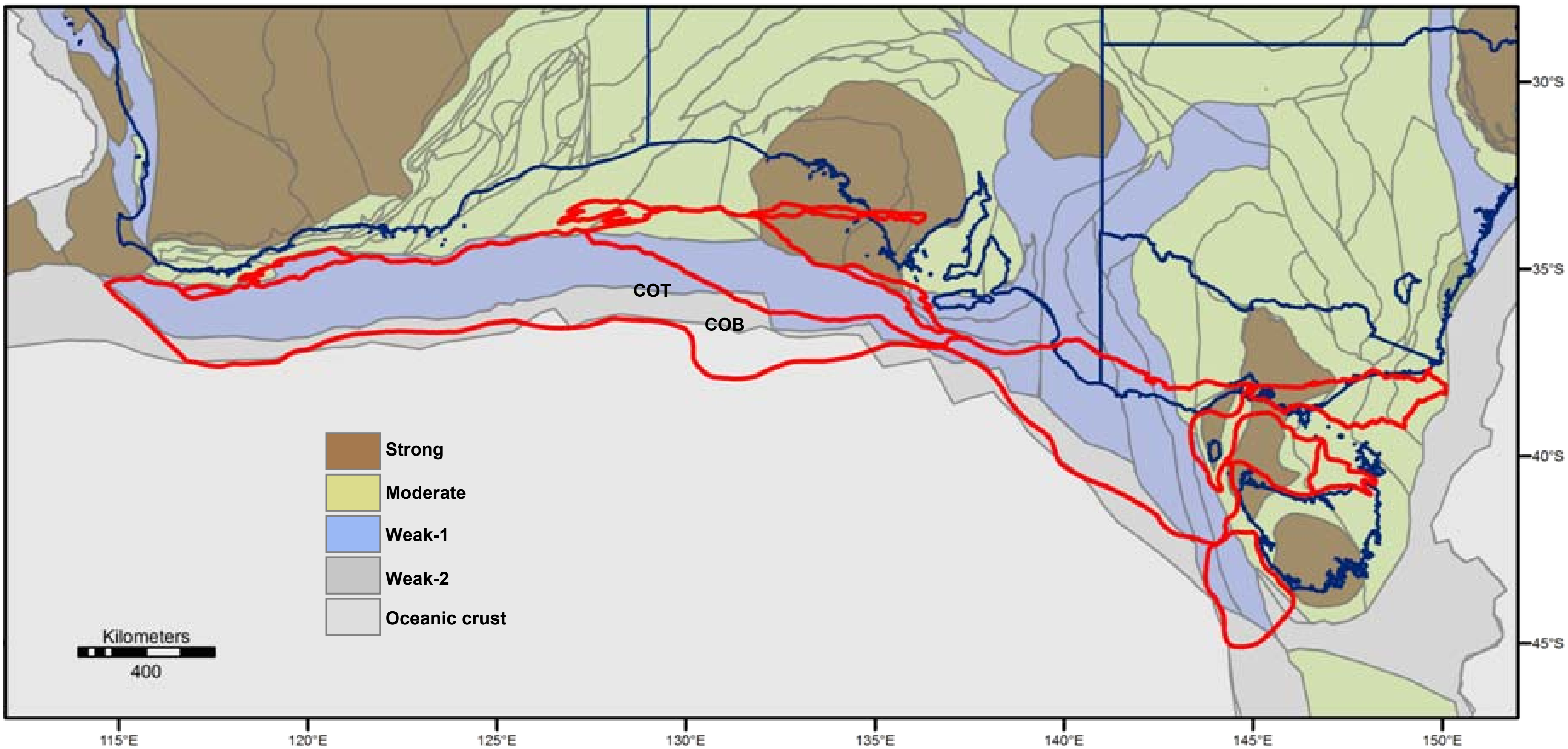
Terrane Rheology and Composition

The terranes identified during the OZ SEEBASE™ study have been reviewed and modified as part of on-going work at FrOG Tech. These updated terranes are shown below classified by their composition and rheologic properties at the time of Jurassic to Tertiary rifting of the Southern Margin. In many instances, the original rheology of a terrane may have been modified by emplacement of granitic material which serves to strengthen the terrane. In the map shown below, the terranes have been assigned a generalised description that reflects crustal strength during rifting – **Strong** (cratonic blocks or microcontinent/granitic cores), **Moderate** (moderately deformed continental basement with granitic emplacement), **Weak-1** (mobile belts), and **Weak-2** (highly extended continental crust, transitional crust and oceanic crust). The boundaries of individual terranes are shown by the grey polygons, and this also gives some indication of the intra-terrane fabric. The outlines of Mesozoic sedimentary basins are shown by the red polygons. Most depocentres clearly show strong basement control on their formation. Further analysis of these controls are discussed later in this report.

Figure 12. Terranes identified by Teasdale (2004) and OZ SEEBASE™ (FrOG Tech, 2004), and updated during the current project (COB=continent-ocean boundary; COT=continental-ocean transition).



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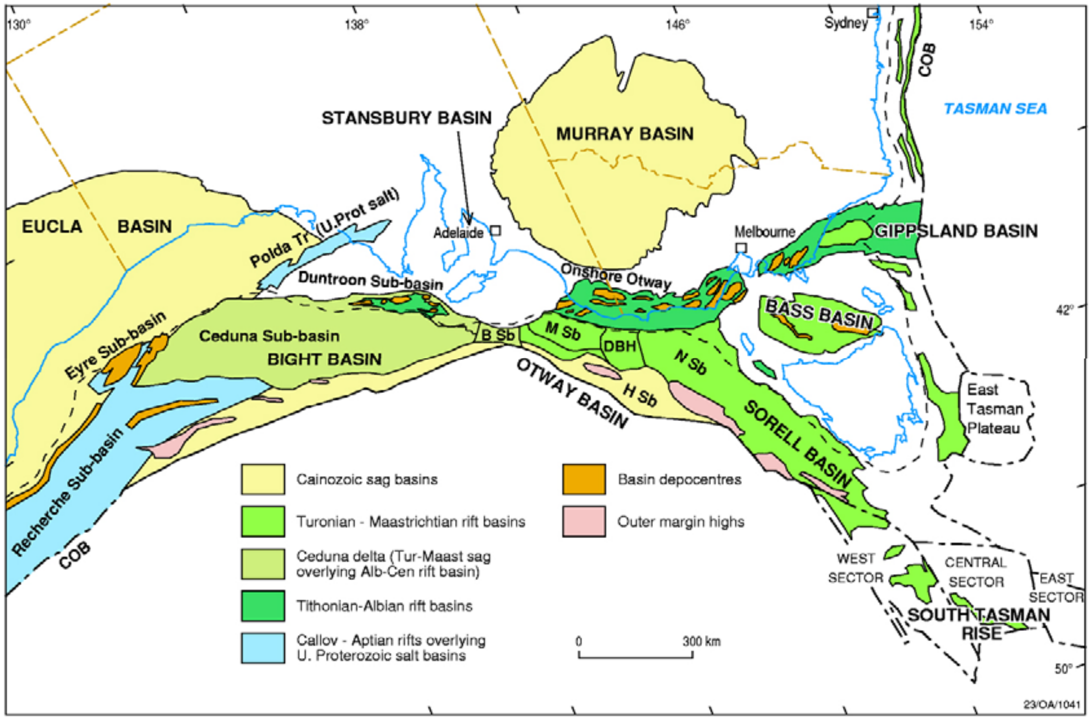
Southern Margin Framework and Plate Reconstructions

Stagg et al (1990) introduced the concept of the 'Southern Rift System' to describe the extensional basins of the Southern Margin that developed as a result of fragmentation of Gondwana. Willcox and Stagg (1990) argued that the Southern Rift System developed as a result of two distinct and differently oriented phases of extension. The first phase occurred in the Late Jurassic along a northwest-southeast azimuth, resulting in formation of the Eyre, Ceduna and Duntroon sub-basins, and reactivation in the Polda Trough. During the Early Cretaceous, a major change in the stress field took place, resulting in a north/northeast-south/southwest-directed extensional system that resulted in rift basin development in the Otway, Sorell and Gippsland basins.

Norvick and Smith (2001) subdivided the Southern Australian breakup history into three phases. **Phase 1** began with Callovian rifting in the western Bight Basin (c. 159-165 Ma) followed by rift onset extending east in the Duntroon, Otway and Gippsland basins during the Tithonian (c. 142-146 Ma). **Phase 2** began during the Cenomanian (c. 92-97.5 Ma) with uplift in eastern Australia, stress reorganisation and divergence of basin development. During **Phase 2**, the Otway, Sorell and Great South Basins (NZ) formed in a transtensional regime, while slow extension caused thinning of continental crust in the Bight and Otway basins. Oceanic spreading begin in the southern Tasman Sea (c. 85 Ma), followed by breakup south of the Bight Basin in the Early Campanian (c. 83 Ma). **Phase 3** is marked by the change to fast spreading in the Southern Ocean during the Eocene (c. 44 Ma), final separation of Australian and Antarctica, and cessation of Tasman Sea spreading.



During **Phase 1**, Norvick and Smith (2001) differentiate two main rift episodes – a) Late Jurassic to Early Cretaceous (Rift No. 1) that affected the Bremer, Recherche and Eyre sub-basins and Polda Trough; and, b) Early Tithonian (Rift No. 2) that saw continued extension in the Bight Basin and the onset of extension ('new grabens' of Norvick and Smith, 2001) in the Duntroon, Gippsland and Otway basins. Extensional stress were assumed to be 'a minor rearrangement of extension directions between Antarctica and eastern Australia'.

Valanginian/Hauterivian rifting saw the continuation of rifting in east-west-oriented half graben in the Gippsland and onshore Otway basins, while thermal sag conditions prevailed in the Bremer, Recherche and Eyre sub-basins (Norvick and Smith, 2001). While Norvick and Smith (2001) do not distinguish this period as a separate rift phase, it is implied that extensional stresses are only active in the eastern part of the Southern Margin, while accommodation is driven by thermal subsidence in the western parts of the margin.

Figure 13. Structural elements map of southeast Australia (from Norvick and Smith, 2001).

Southern Margin Plate Reconstructions

A tectonostratigraphic correlation chart produced by Norvick and Smith (2001) indicates that the Bight Basin underwent two phases of extension lasting from the mid-Callovian to late Aptian (Figure 14). In addition, the 'Minke Sequence' (Totterdell et al., 2000) was classified as part of the second rift stage which is correlated to the onset of extension in the Otway and Gippsland basins. A syn-rift/post-rift phase followed that lasted from the mid-Albian to the latest Santonian, although sag geometries are mostly reported (Figure 2 of Norvick and Smith, 2001).

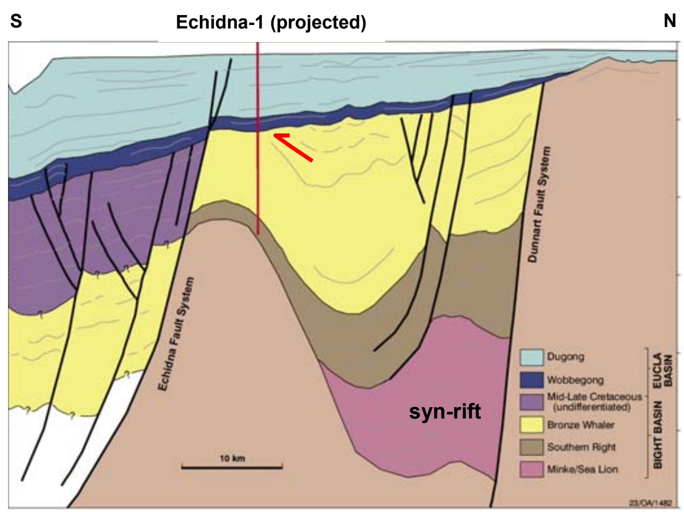
Results from Bradshaw et al (2003), Totterdell and Bradshaw (2004) and the current study highlight that previous megasequence definitions in the Duntroon Sub-basin (Smith and Donaldson, 1995) may have biased the interpreted prolonged extensional phase in the Bight Basin. Recent updated correlations suggest that only two wells lie in the Duntroon Sub-basin proper, and that neither of these wells actually penetrated the initial syn-rift sediments. Of particular interest is Echidna-1 (Figure 15), in the Duntroon Sub-basin, which reached total depth in Berriasian age strata (*R. australiensis*; Morgan, 1999). A re-interpretation of seismic data by Bradshaw et al (2003) suggest that the well intersected early post-rift sediments, while the main syn-rift package is untested.

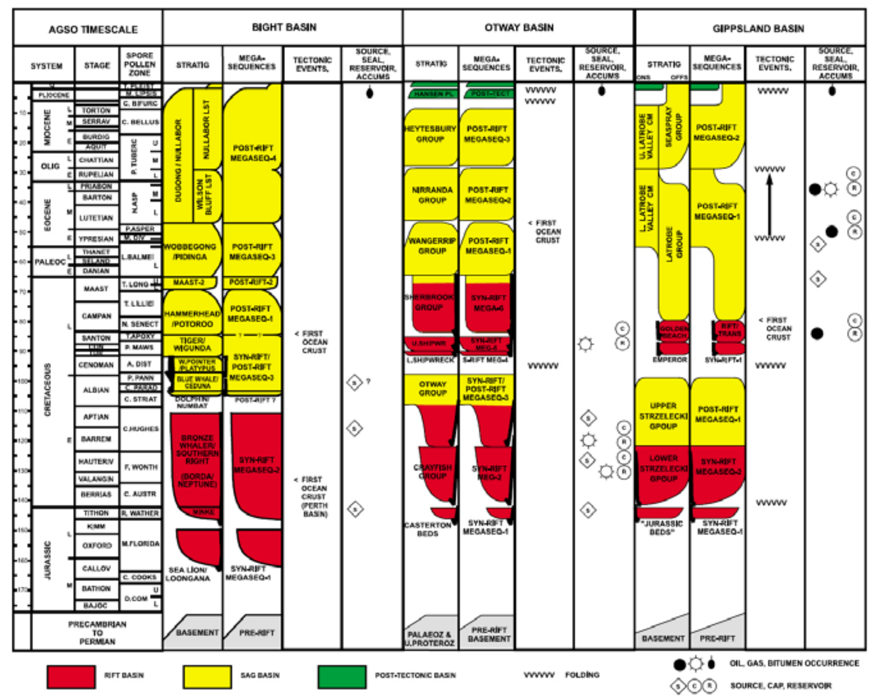
The overlying succession (Figure 15; Southern Right and Bronze Whaler), which had been interpreted as syn-rift by Smith and Donaldson (1995) is more likely to be post-rift (sag phase deposition). It should also be noted that at the time of publication of Smith and Donaldson (1995), breakup age along the Southern Margin was interpreted as 95 Ma ±5 (Veevers and Ettreim, 1988; Veevers et al., 1991; Cenomanian), and in that context, they interpreted a major marine transgression during the Cenomanian as a post-breakup flooding event. Smith and Donaldson (1995) also noted strong evidence of uplift and tilting in the Duntroon Sub-basin in the latest Santonian. A re-interpretation of breakup off the Ceduna Sub-basin to 83 Ma (Sayers et al., 2001) indicates the latest Santonian uplift and reorganisation event was related to breakup.

If the Minke Sequence was included in the initial syn-rift phase as suggested by Totterdell et al (2000), this would imply that upper crustal extension in the Bight Basin is limited to the Late Jurassic to earliest Berriasian, and thus is not coeval with extension in the Otway and Gippsland basins.

Figure 14 (left). Comparative stratigraphy of Australia's southern margin basins (from Norvick and Smith, 2001).

Figure 15 (below). Geoseismic section across the Duntroon Sub-basin (Bight Basin) showing that the well did not penetrate the basal syn-rift section as interpreted by Bradshaw et al (2003) and Totterdell et al (in press).





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Regional Tectonic Events, Tectonostratigraphy & Basin Summaries

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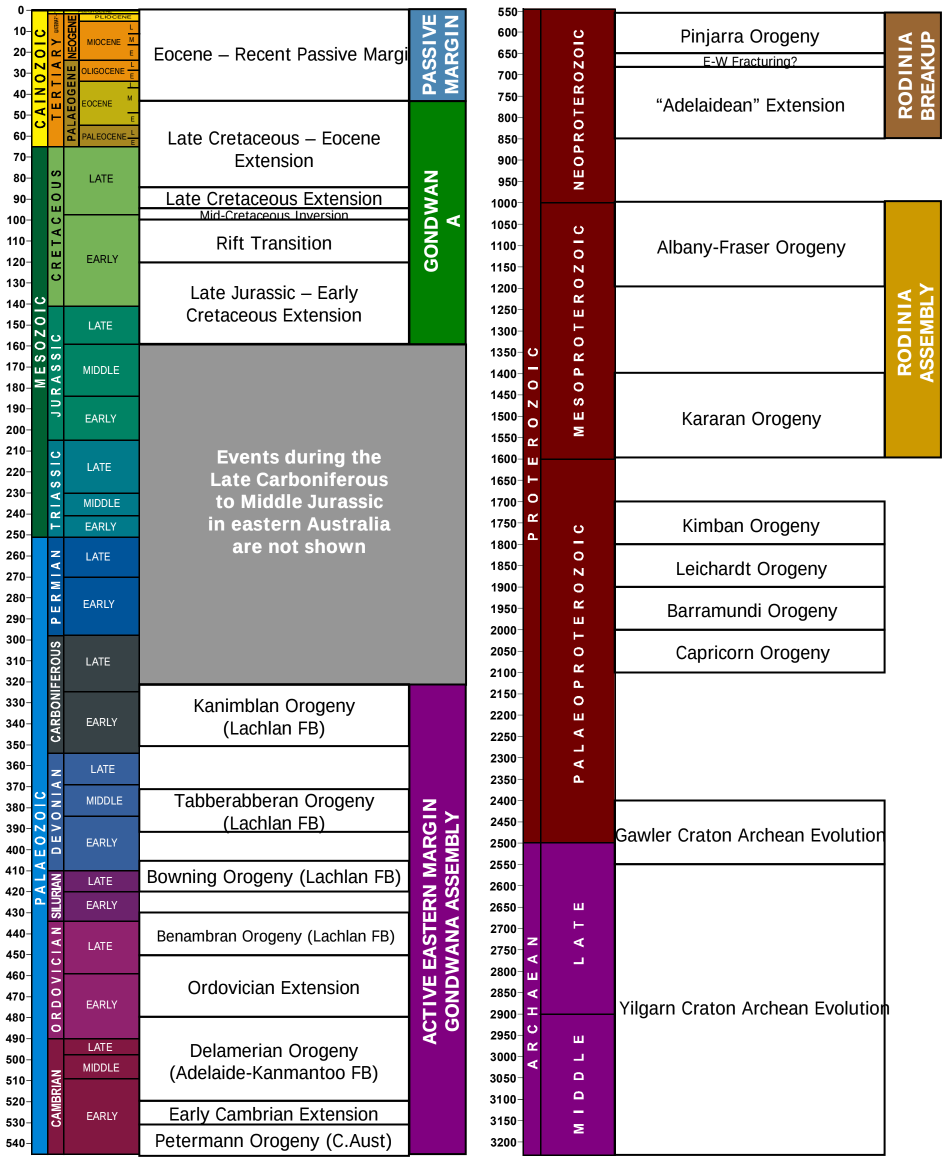


Regional Tectonic Events

The basement cratons and mobile belts of southern Australia underwent complex, multi-phase tectonic evolution, crustal growth and deformation during the Archean to Carboniferous. A summary of these events is shown in Figure 16 (shown left; Teasdale, 2004; FrOG Tech, 2004). The contrasting basement terranes and the structures within and between them acted as first-order controls on all subsequent deformation in the region, especially during later Mesozoic basin formation. A brief review and update of the previous terrane analysis of Teasdale et al (2003), Teasdale (2004) and FrOG Tech (2004) has also been completed as part of this synthesis.

The present-day basins of southern Australia evolved during tectonic events that can be grouped into four broad phases:

- Mesoproterozoic to Cambrian: assembly and breakup of the Rodinia supercontinent,
- Cambrian to Triassic: back-arc and intracontinental setting to an active eastern Gondwanan margin,
- Late Jurassic to Eocene: breakup of Gondwanan supercontinent, and,
- Eocene to Recent: passive margin of Australia.

This synthesis focuses on the tectonic events associated with the rifting, fragmentation and separation of eastern Gondwana during mid-Jurassic to Recent times. In particular, the sedimentary response to rifting within the evolving depocentres which includes the basin's accommodation history and tectonic drivers, dominant lithologies and environments, and key evidence for timing of events.

It is clear from previous studies (e.g., Norvick and Smith, 2001) that rift events which affect basin evolution along the Southern Margin appear to change significantly in their dominant (interpreted) stress direction and timing, and become progressively younger in an west-to-east fashion along the margin. An analysis of these observations is a central outcome of this synthesis.

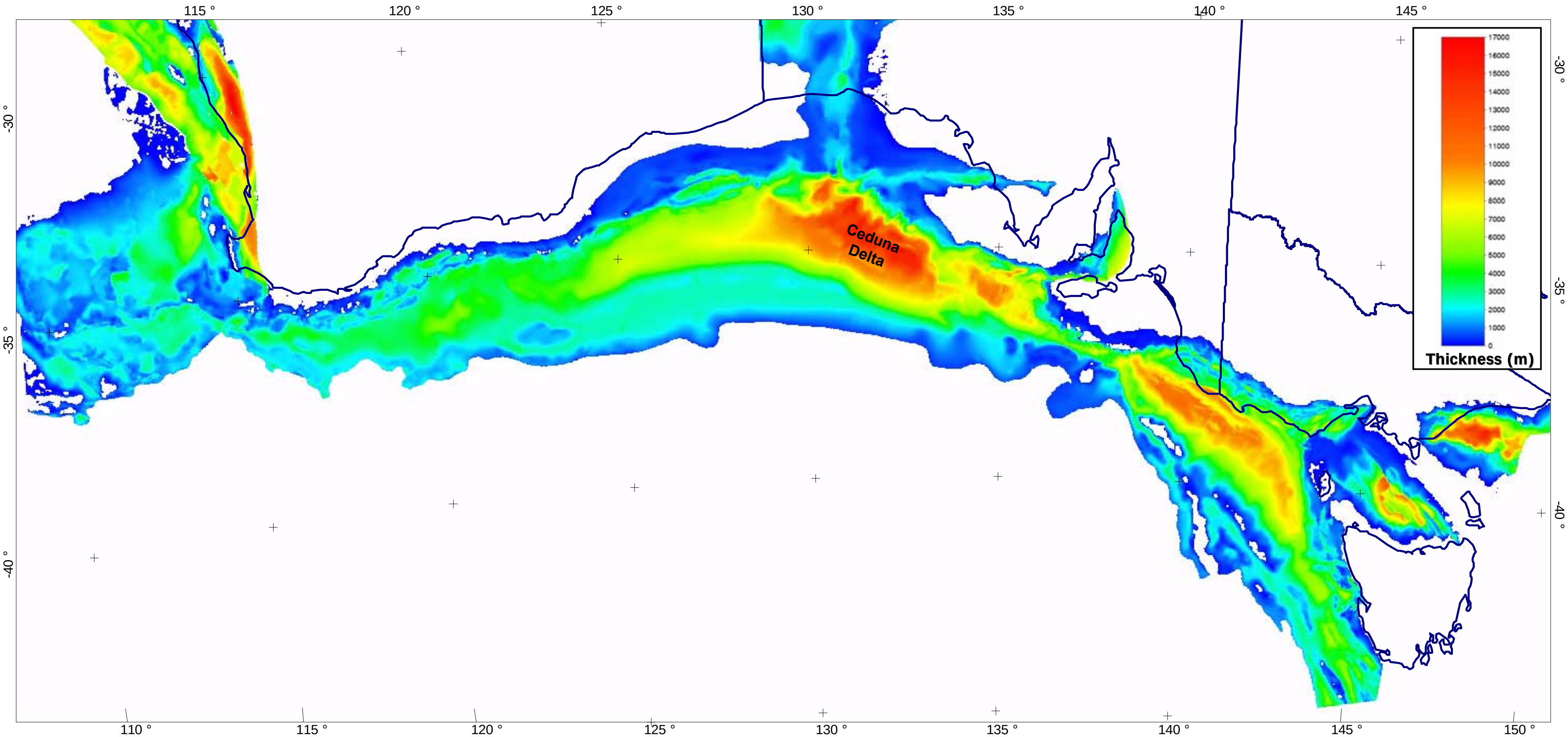
Another area of debate centers on the timing of breakup along 'segments' of the Southern Margin. This has been complicated by complex features such as the Diamantina Zone, a highly extended/intruded transition from continental to oceanic crust (COT), the previously interpreted presence of the 'Cretaceous Magnetic Quiet Zone' in the central Great Australian Bight, and the complex period of final separation between Antarctica, western Tasmania and the South Tasman Rise. In addition, stresses associated with rifting and breakup along the western and eastern margins of Australia manifest as short-lived extensional events which affected selected parts of the margin.

In this synthesis, the sedimentary succession in each depocentre has been assigned to basin phases that are characterized by a single mechanism of subsidence. Individual phases are separated from one another by changes in the type of subsidence mechanism, or the magnitude or rate of subsidence. Basin phase boundaries correspond to plate-scale tectonic events and in turn to major megasequence boundaries.

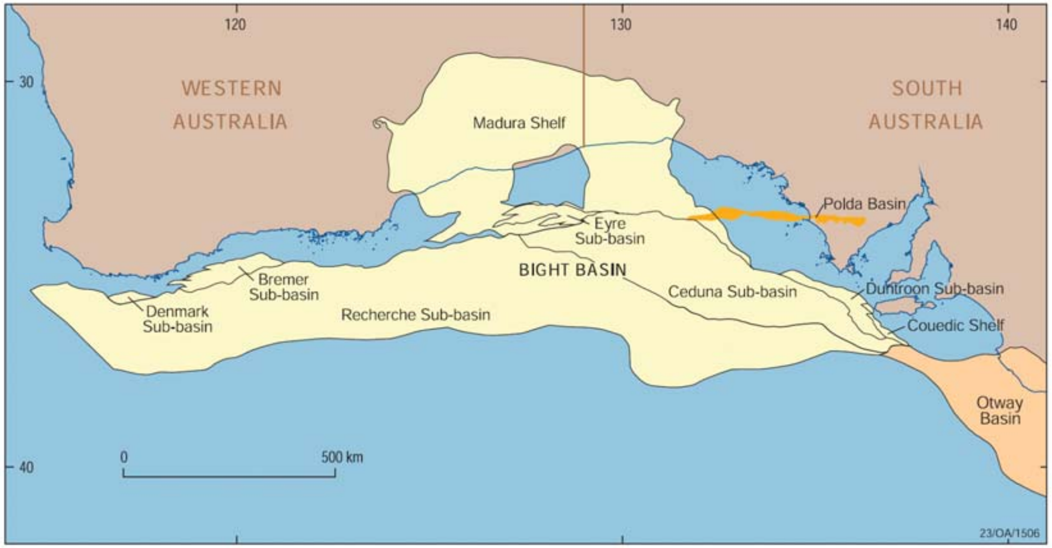
Southern Margin Sediment Thickness

The Southern Margin sediment thickness grid was constructed by calculating the difference between OZ SEEBASE™ (depth to basement) and topography/bathymetry (Teasdale, 2004). It shows the main depocentres and structural influences on sediment thickness and distribution.

Figure 17. Calculated sediment thickness map of the Southern Margin (from Teasdale, 2004).



Basin Summary – Bight Basin



The Bight Basin has been redefined to include not only the Eyre, Ceduna, and Recherche sub-basins, but also the Denmark, Bremer and Duntroon sub-basins (formerly 'basins') and the Madura Shelf (Figure 18; Bradshaw et al., 2003; Totterdell and Bradshaw, 2004). The Polda Trough is now known as the Polda Basin and considered a separate entity to the Bight Basin.

Geoscience Australia has undertaken extensive studies into the Bight Basin since 1999 – including updating the basin stratigraphy (Totterdell, et al., 2000; Krassay and Totterdell, 2003), structure and tectonic history (Totterdell and Krassay, 2003; Bradshaw et al., 2003; Totterdell and Bradshaw, 2004; Totterdell et al., in press) and petroleum systems (Blevin et al., 2000; Boreham et al., 2001; Ruble et al., 2001; Struckmeyer et al., 2001, 2002). Other published work by Woodside Offshore Petroleum (former permit holders in the Ceduna Sub-basin) includes Somerville (2001), Bruins et al (2001) and Tapley et al (2005). Much of this work has focused on the Eyre, Ceduna and Recherche sub-basins, thus only a brief overview is given of these areas. Minor adjustments wer made to precise timing of events due to changes inherent in the 2007 Geoscience Australia timescale. Recent dredging and new seismic acquisition in the Bremer Sub-basin has allowed a more direct assessment of these depocentres. Figure 19 shows the interpreted basement terranes (FrOG Tech, 2004; this study), Bight Basin outline and basement faults mapped from seismic data in the Bremer, Eyre and northern margin of the Ceduna sub-basins (fault files supplied by Geoscience Australia).

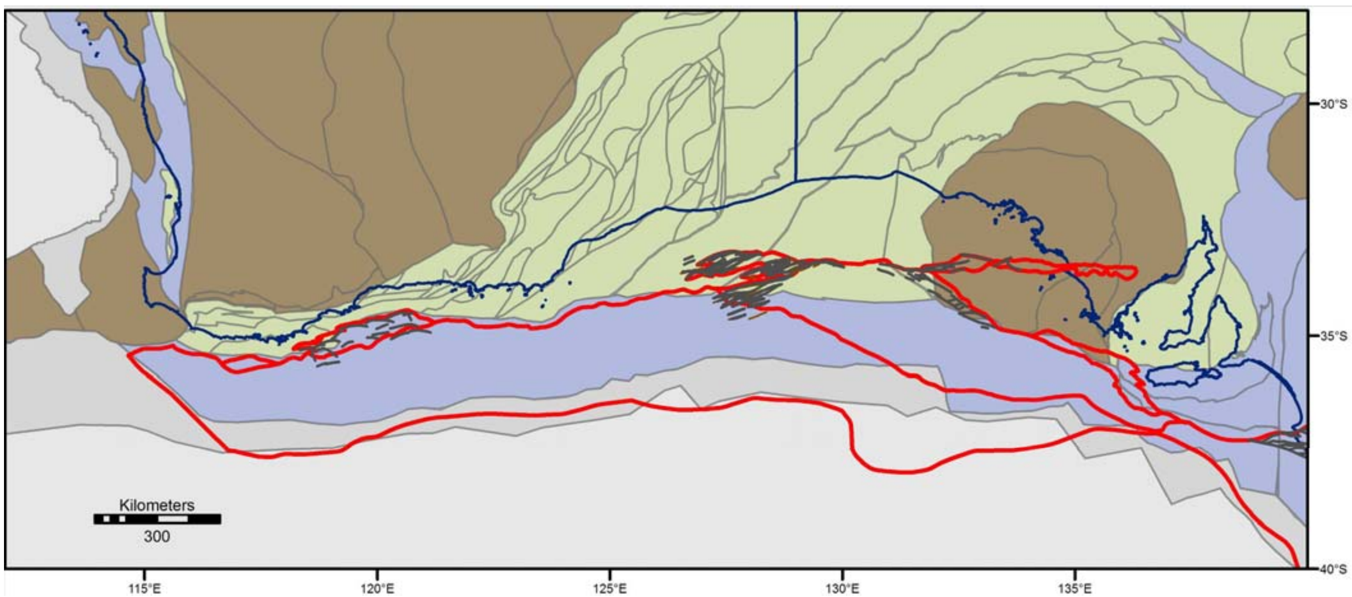


Figure 18. Location of the Bight Basin along the southern Australian margin with component sub-basins (from Totterdell and Bradshaw, 2004).

Figure 19. Interpreted terrane map of the southwest Australian margin (Teasdale, 2004; this study) coded for present-day rheology (see previous Figure 12 for an explanation of colours), overlain by basin outlines (red lines) and basement faults (bold grey lines; faults supplied by Geoscience Australia).

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Basin Summary – Western Bight Basin

Two phases of extension have been interpreted in the Bremer Sub-basin (western Bight Basin; Figure 20) – Extension-1 – Callovian to late Kimmeridgian (lasting 18 Ma); and Extension-2 – mid-Valanginian to late Aptian (lasting 23.5 Ma), separated by a shorter period of thermal subsidence (O'Leary et al., 2005; Nicholson and Ryan, 2005). Interpretation of the events is based on the seismic geometry of the syn-tectonic packages that are tied to dated dredge rocks recovered during Survey 265. Rocks from Extension-1 (Bremer 1) are constrained with some degree of confidence at only four sites (Survey 265-DR20, -DR28, -DR42 and -DR44) (O'Leary et al., 2005), while Extension-2 is constrained at eight sites. The age of breakup (91Ma) is based on a regional unconformity associated with uplift near the base of the Turonian, and the thin, passive margin nature of overlying Late Cretaceous and younger age sediments.

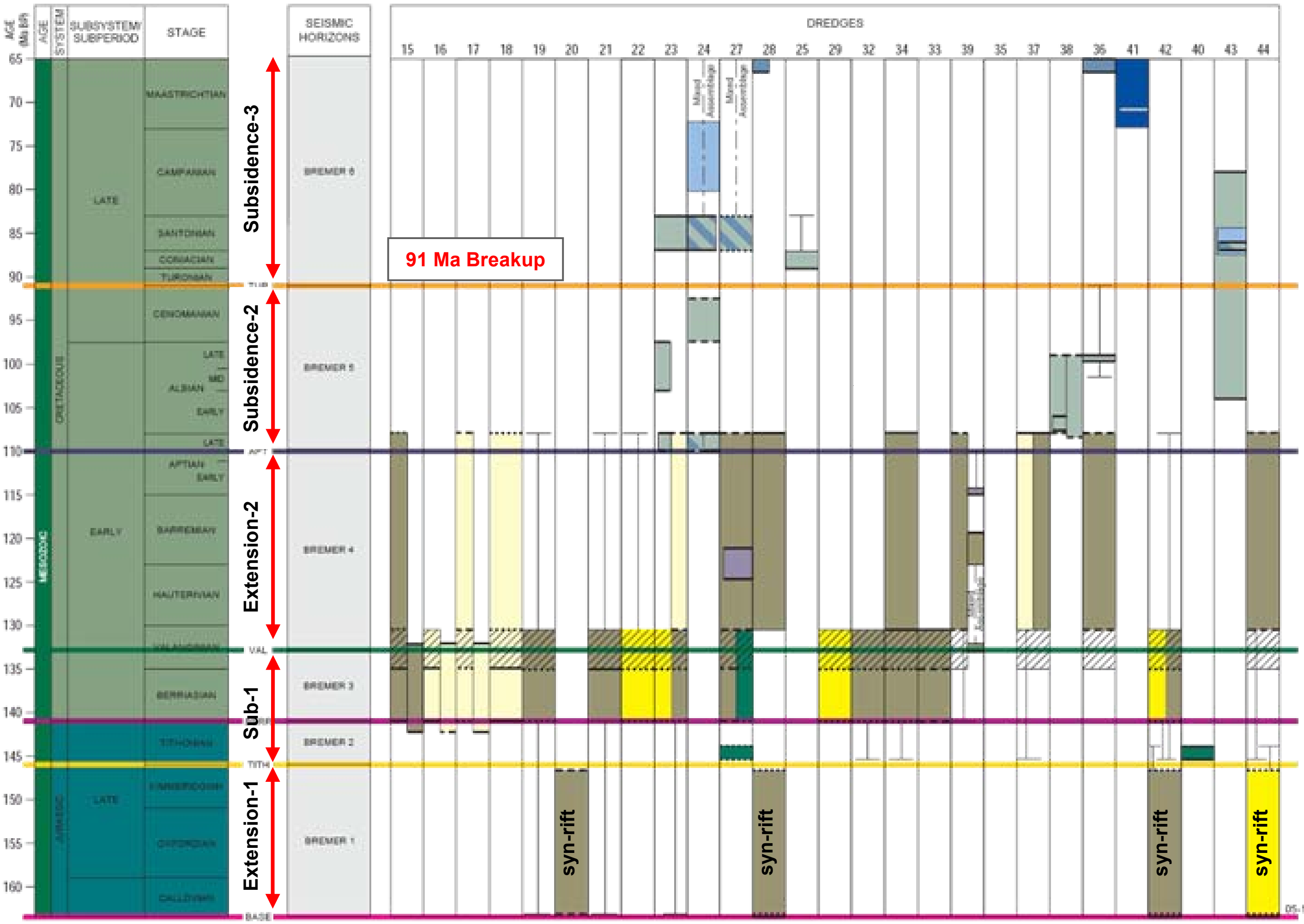

Figure 20. Bremer Sub-basin mid-Jurassic to Cretaceous biozonation and dredge summary chart (from O'Leary et al., 2005). A map showing the dredge samples locations is shown in Figure 21. Further information on the chart and other details of dredge ties are available as Appendix E in Bradshaw (2005).

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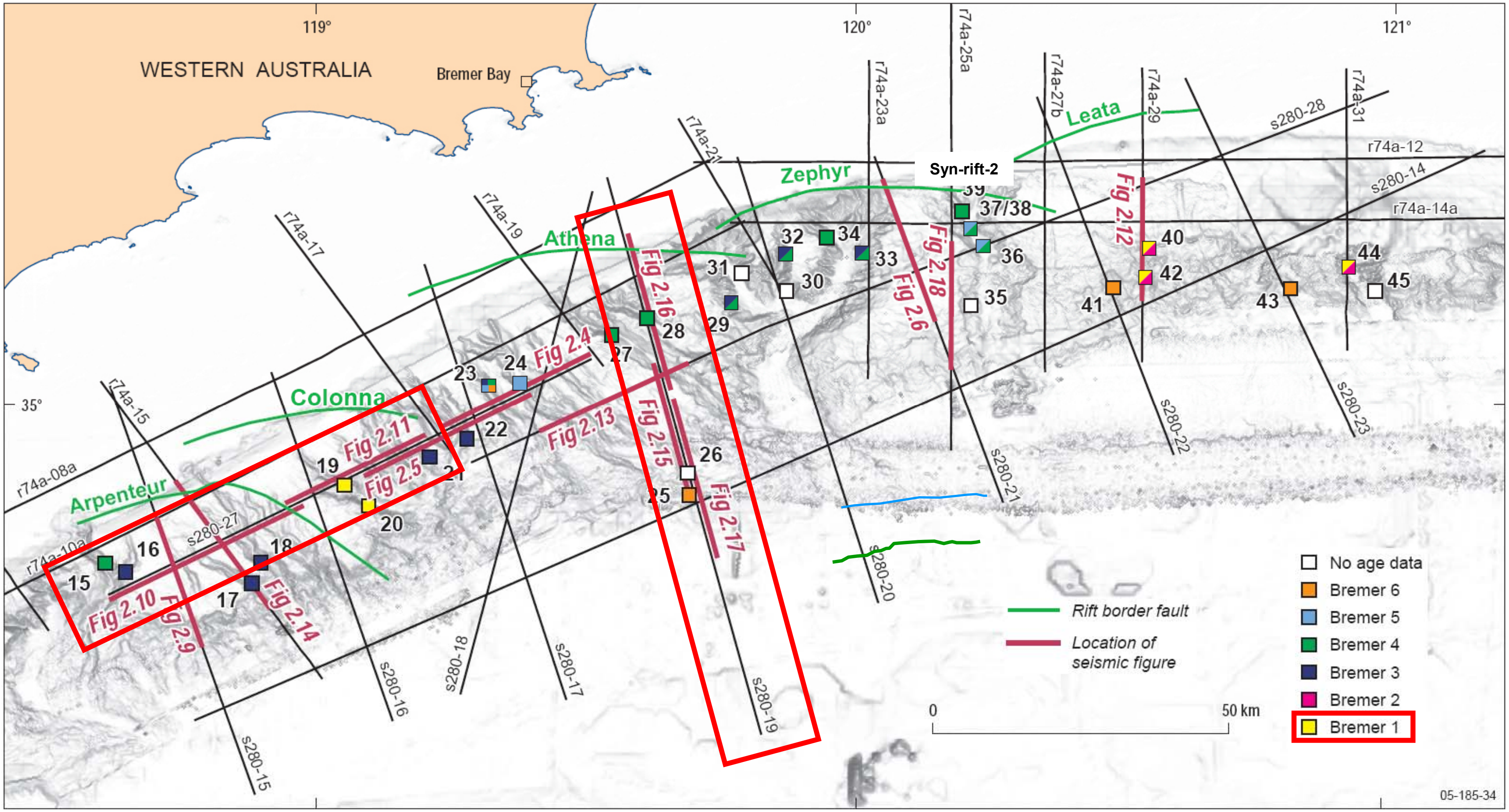
Basin Summary – Western Bight Basin

Figure 21. Summary of stratigraphic units at sampled at Survey 265 dredge sites in the Bremer Sub-basin overlain on a high-resolution bathymetry image (from O'Leary et al., 2005). Seismic examples of Extension-1 (Bremer 1) are shown in following figures with locations indicated by the red boxes (from O'Leary et al., 2005). Note that the single dredge interpreted to tie the Bremer 1 unit with the highest degree of confidence (DR20; see previous Figure 20) does not lie directly on a seismic line from either of the regional surveys (S280 or R74a).



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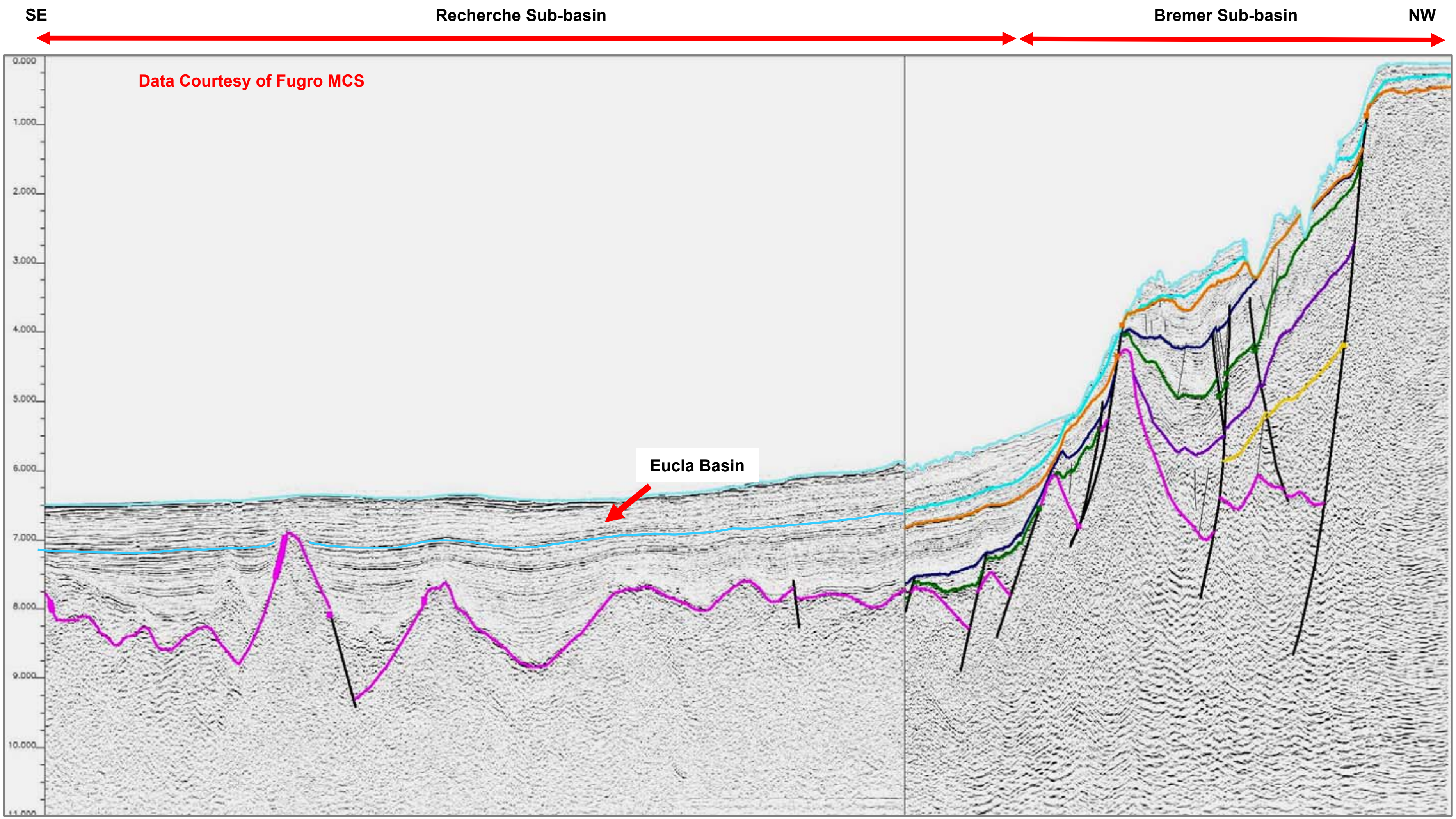
Basin Summary – Western Bight Basin

Figure 22. Geoscience Australia seismic line S280-19 and reprocessed Shell Petrel line N401 across the western Bight Basin (Bremer and Recherche sub-basins) showing the divergent syn-rift character of the Middle to Late Jurassic (Callovian-Kimmeridgian; Bremer 1) succession (interpreted seismic image supplied by Geoscience Australia).



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Bremer Extension-1

The observed seismic geometries clearly show the divergent nature of strata and the syn-tectonic nature of the megasequence packages within a series of en-echelon half graben (Bremer 1, Extension-1; Figures 23a to c). The age of this sequence is defined by rocks dredged at sites S265-DR20, -DR28, -DR42 and -DR44. Dredge 20 has the highest degree of confidence based on the available biostratigraphy. However, this dredge does not lie directly on a seismic line, thus a confidence to the basal syn-rift section can only be inferred. As the seismic image of the Dredge 28 shows, the sample sites may not have reached the syn-rift section – while also noting that the absolute location of the sample site is unclear given the nature of the dredging process.

Given the uncertainty in the dredge ties, the onset of extension in the Bremer Sub-basin could have been earlier than the actual sample dates indicate – possibly as early as Bathonian which would make the rift onset synchronous with extension in the Perth Basin (166 Ma, Yarragadee Formation). Upper crustal extension in the Perth Basin continued until breakup at approximately 133.5 Ma. Breakup age in the Perth Basin is largely constrained by dating of the pre-breakup Bunbury Basalt.

Analysis of a weathered basalt dredged during Survey 265 yielded an age range of 83 to 85 Ma and may represent the minimum age for original igneous crystallisation (Fraser, 2006). Younger ages obtained (~73 Ma) probably represent a maximum age for mineralogical alteration. As such, the Bremer basalt sample is probably not related to the Bunbury Basalt as originally suspected, but more related to Southern Margin breakup.

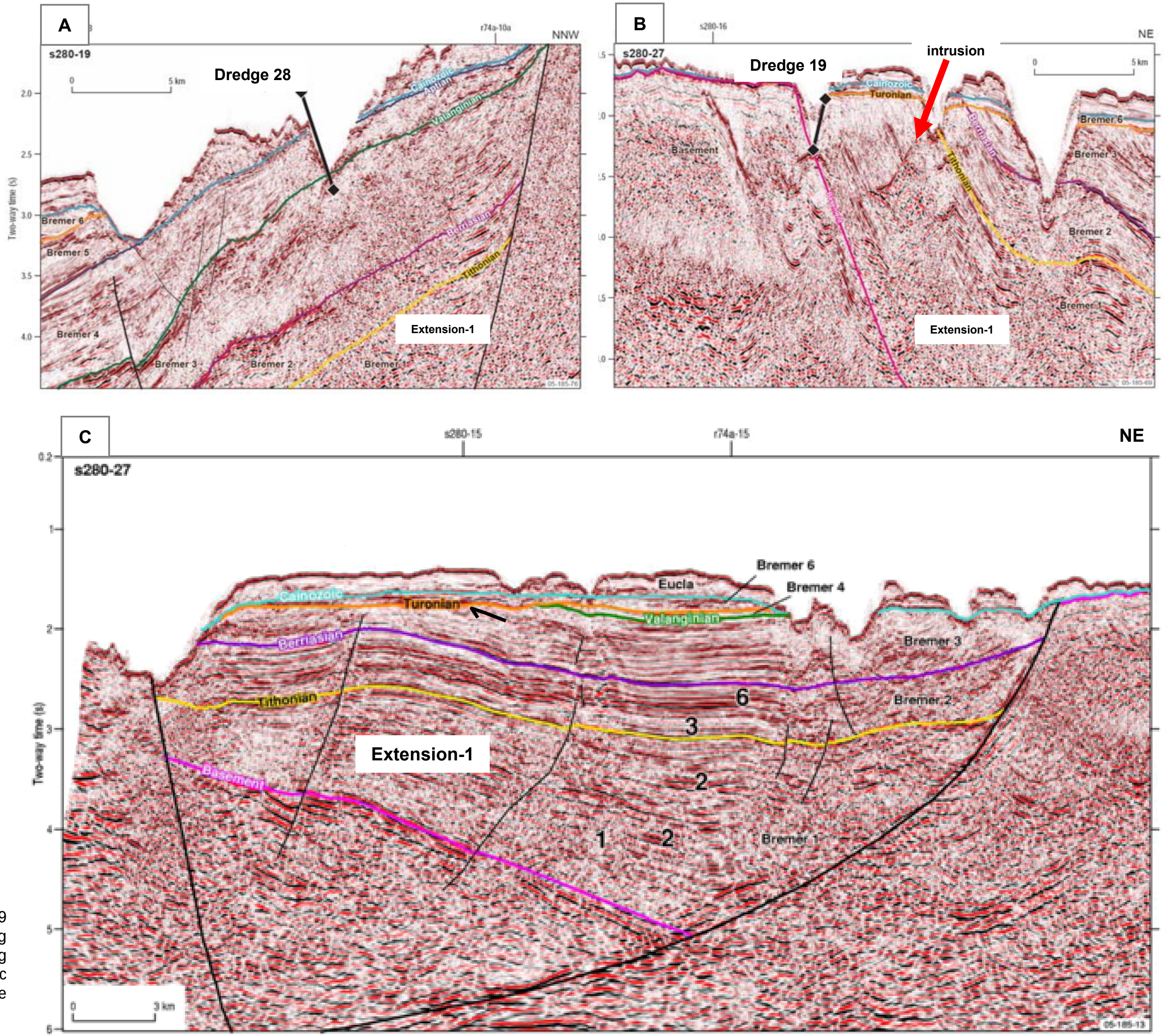

Figure 23. Geoscience Australia seismic lines: a) S280-19 showing the location of Dredge S265-28; b) S280-27 showing the location of dredge S265-19; and c) S280-27 in showing the divergent syn-rift character of the Middle to Late Jurassic (Callovian-Kimmeridgian; Bremer 1) succession. All figures are from Bradshaw (2005).

Bremer Extension-2

Mid-Valanginian to Late Aptian extension (Bremer Extension 2) was identified on seismic data and correlated to stratigraphic unit Bremer-4 (O'Leary et al., 2005). The age of this event is well constrained by dredge samples and confident ties to seismic data. O'Leary et al (2005) described Bremer-4 unit as a 'parallel, sheet-like fill', although the 'upper part of Bremer 4 forms a divergent wedge geometry in the hanging wall blocks of the Arpenteur, Colonna and Leata depocenters'. Uplift formed large anticlines in the eastern and western parts of the basin (Nicholson and Ryan, 2005).

Evidence of active extension during this time period has not been observed in the eastern Bight basins, although breakup and the onset of seafloor spreading in the Perth Basin was coeval with the onset of Bremer-4 deposition (mid-Valanginian). Deposition of Bremer-4 may have resulted from the influence of transtensional stresses associated with the onset of seafloor spreading on the southwestern margin (Perth Basin). This event was unrelated to fault movement that is observed in some of the eastern basins during the same time period.

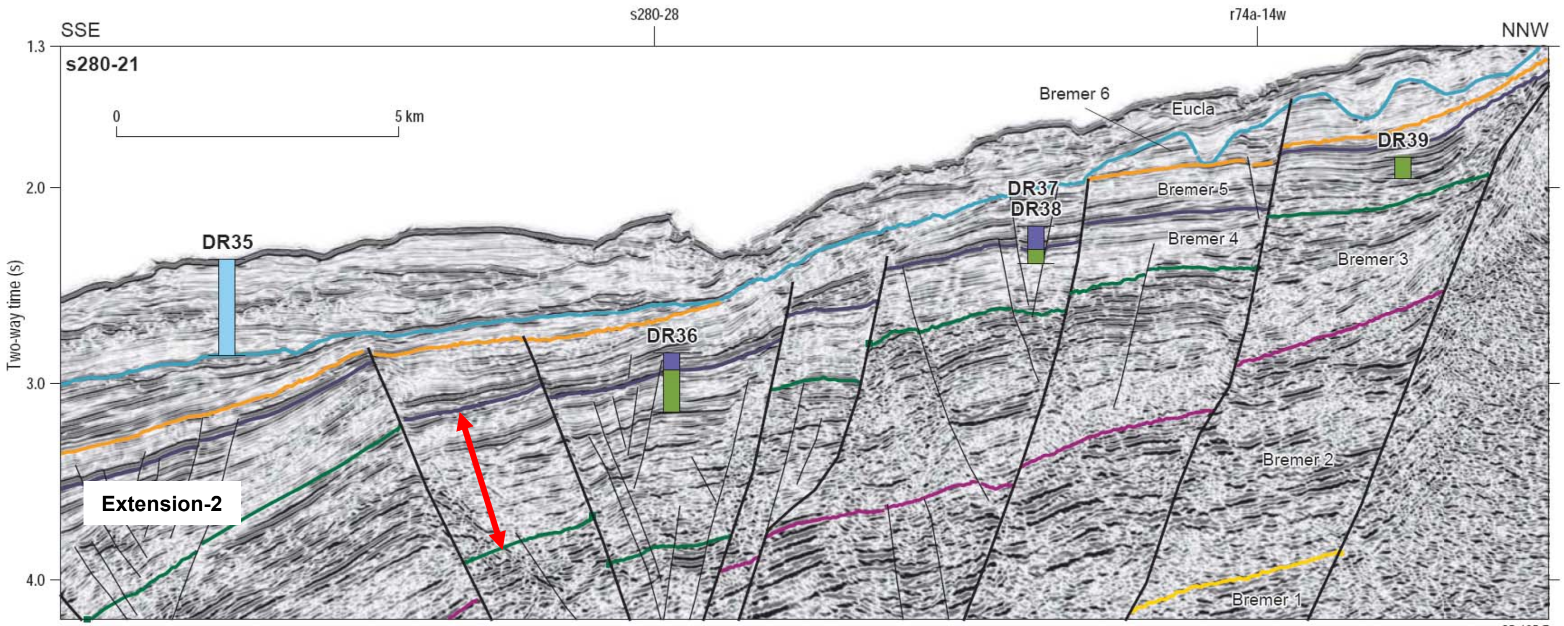

Figure 24. Geoscience Australia seismic line S280-21 showing the nature of Bremer-4 (Extension-2) package in the Bremer Sub-basin (from O'Leary et al., 2005).

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Basin Summary – Eastern Bight Basin

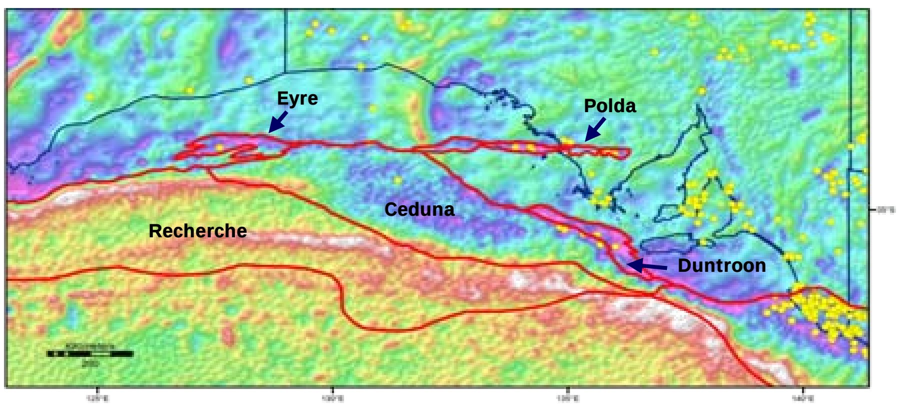
The eastern Bight Basin consists of four main Mesozoic depocentres – the Eyre, Ceduna, Recherche and Duntroon sub-basins (Figure 25). The Polda Basin is an older feature that underwent reactivation during Mesozoic extension and is not considered part of the Bight Basin. Basement has had a profound influence on the structural development of the Bight Basin, controlling the location and orientation of early basin-forming structures (Stagg et al., 1990; Totterdell et al., 2000). Thin platform cover areas are present along the northern and eastern margins of the Mesozoic depocentres.

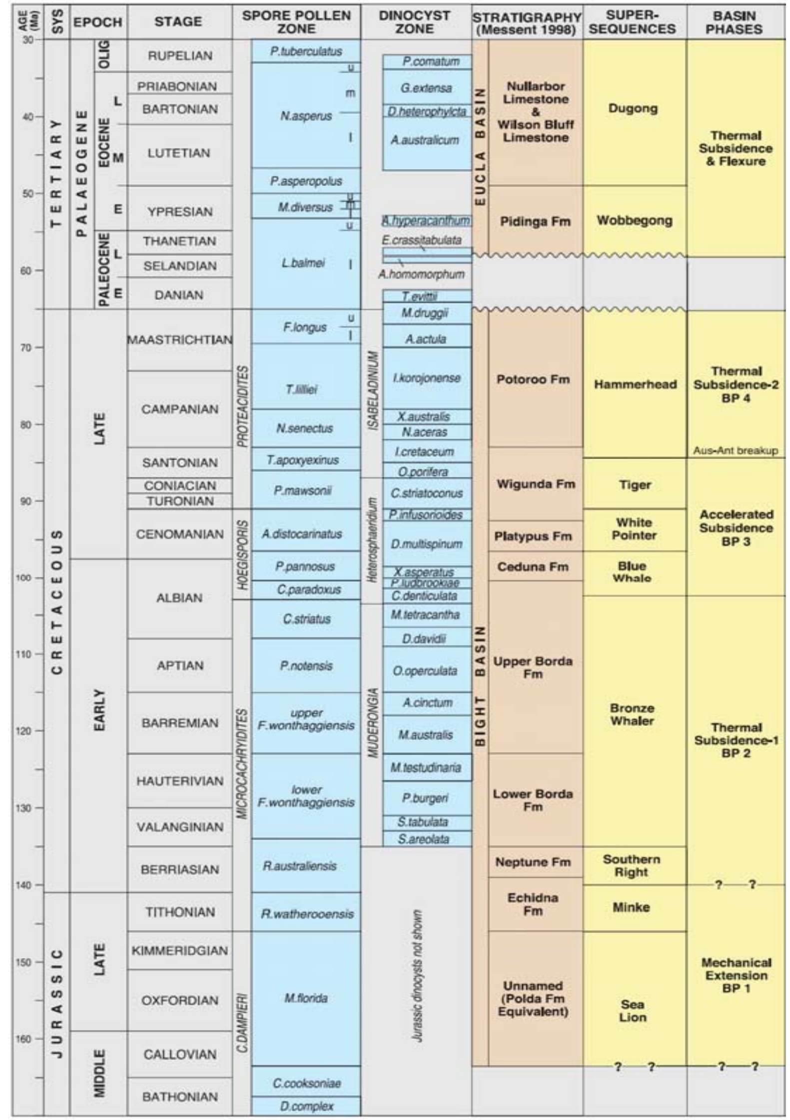
Geoscience Australia has undertaken extensive studies into the Bight Basin since 1999 – including updating the basin stratigraphy (Figure 26; Totterdell, et al., 2000; Krassay and Totterdell, 2003), structure and tectonic history (Totterdell and Krassay, 2003; Bradshaw et al., 2003; Totterdell and Bradshaw, 2004; Totterdell et al., in press) and petroleum systems (Blevin et al., 2000; Boreham et al., 2001; Ruble et al., 2001; Struckmeyer et al., 2001, 2002). Further details on these topics covering the eastern Bight Basin are available in these publications.

Short summaries on the Eyre and Ceduna sub-basins are presented in the following pages. A more detailed review of the Duntroon Sub-basin is presented as this area contains several key points that are relevant to understanding the relationship between the Bight and Otway basins, as highlighted by Norvick and Smith (2001).

Figure 25 (below). Residual gravity image from Geoscience Australia (2007) overlain with outlines of the Jurassic and Cretaceous depocentres that comprise the eastern Bight Basin

Figure 26 (right). Bight Basin correlation chart showing the relationship between sequence stratigraphy, lithostratigraphy, basin phases and sea level (Totterdell et al., 2000; Totterdell and Bradshaw, 2004).





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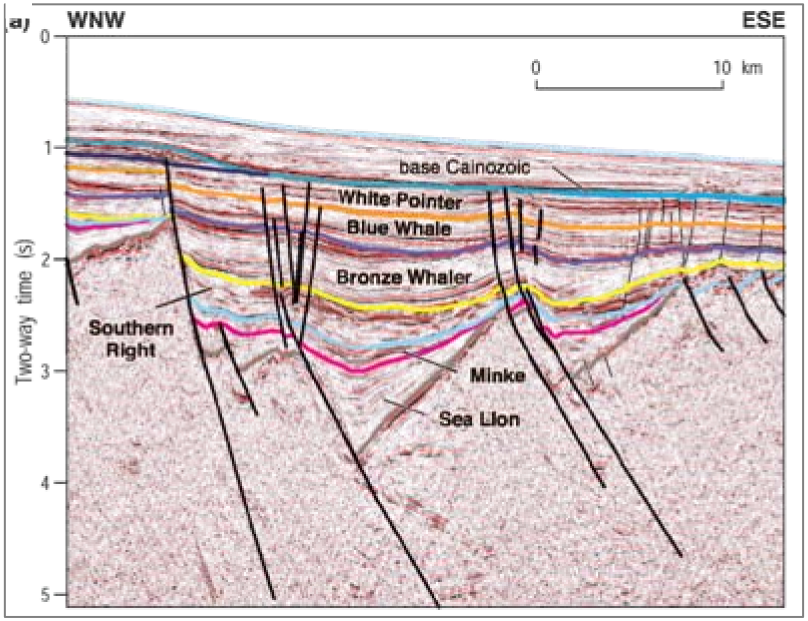


Basin Summary – Eyre Sub-basin

The Eyre Sub-basin is a perched, Middle Jurassic to Early Cretaceous rift basin with an *en-echelon* half graben structural style (Figures 27 to 29; Bein and Taylor, 1981; Stagg et al., 1990; Totterdell et al., 2000). The Jerboa-1 well and good seismic coverage enables a clear understanding of the basin's structure, tectonostratigraphy and event history.

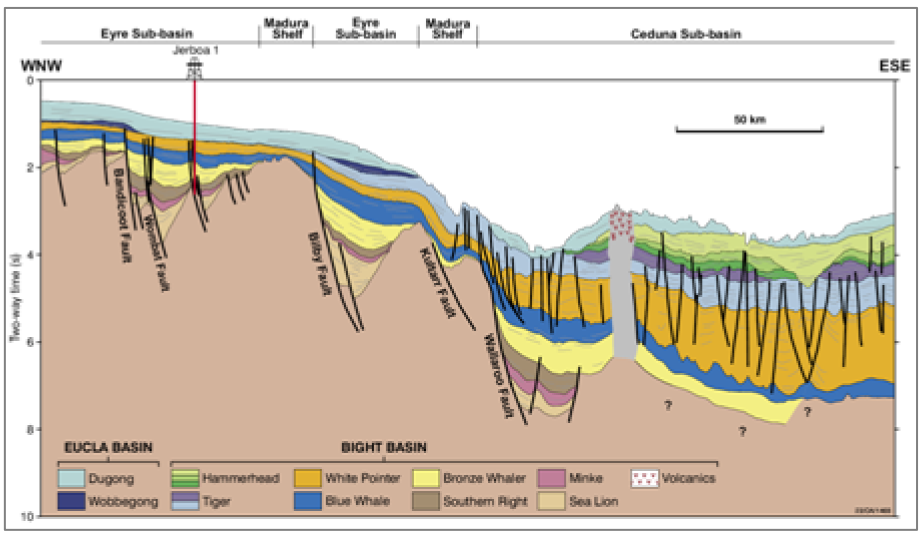
A single phase of extension is recognised as the syn-rift Middle Jurassic to Early Cretaceous Sea Lion and Minke supersequences (Totterdell et al., 2000). The Sea Lion Supersequence shows good divergent geometries on seismic data suggesting relatively continuous growth during extension, while the overlying Minke Supersequence is thinner and represents a decreased rate of extension. The overlying Southern Right to White Pointer supersequences (Figures 27 to 29) were deposited during post-rift subsidence (sag) and thicken slightly over the former depocentre.

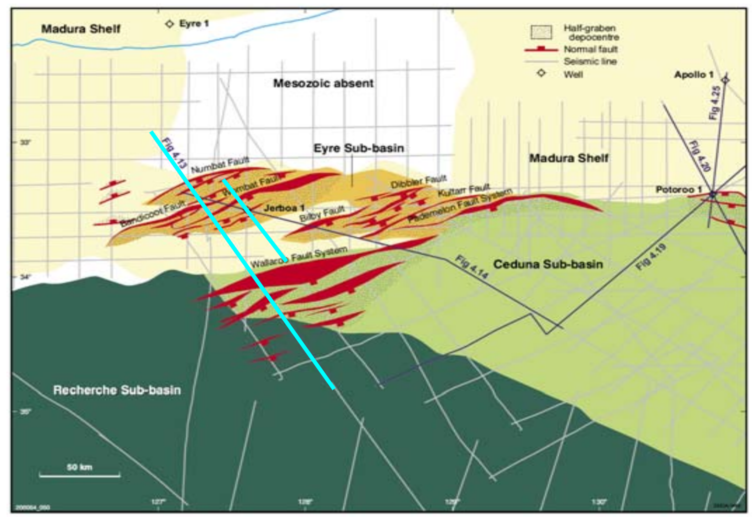
The syn-rift succession consists of fluvio-lacustrine sediments which comprise the principal source rocks in the sub-basin. Coals within the overlying Southern Right also have source potential but may be immature.

Figure 27 (above left). Seismic line showing the typical half graben structural style of the Eyre Sub-basin (from Totterdell et al., 2004).

Figure 28 (below left). Cross-section through the Eyre Sub-basin showing the regional structural style, setting and interpreted tectonostratigraphy (from Totterdell and Bradshaw, 2004).

Figure 29 (below left). Structural elements map for the Eyre Sub-basin and northwest Ceduna Sub-basin (from Totterdell and Bradshaw, 2004).





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Basin Summary – Ceduna Sub-basin

The Ceduna Sub-basin is the largest and thickest depocentre of the Bight Basin and contains in excess of 15km of mostly Mesozoic sediment overlain by thinner Cenozoic sediments of the Eucla Basin. The northern margin of the sub-basin is characterised by a series of fault-bounded half graben that contain Middle Jurassic to Early Cretaceous syn-rift fill (Sea Lion and Minke supersequences), overlain by Early to Late Cretaceous post-rift fill (Southern Right to Hammerhead sequences; Figures 30a and b; Bradshaw et al., 2003). The sub-basin is also distinguished by the deposition of massive fluvio-deltaic to marine sediments of mid-Albian to latest Maastrichtian age (Accelerated Subsidence/Basin Phase 3; Thermal Subsidence/Basin Phase 4; Totterdell et al., 2000; see previous Figure 26). The Blue Whale Supersequence was deposited during a mid-Cretaceous highstand that saw much of central-eastern Australia covered by an inland seaway, while the overlying thick White Pointer and Tiger supersequences are the result of the inland drainage systems that were diverted during the Cenomanian uplift of eastern Australia. The massive Hammerhead delta (Totterdell et al., 2000; Krassay and Totterdell, 2003) was deposited after breakup which occurred during the latest Santonian/ early Campanian (Sayers et al., 2001). The distinguishing structural feature of the basin is the presence of gravity-driven extensional faults and associated structures that detach within ductile shales (Totterdell and Krassay, 2003).

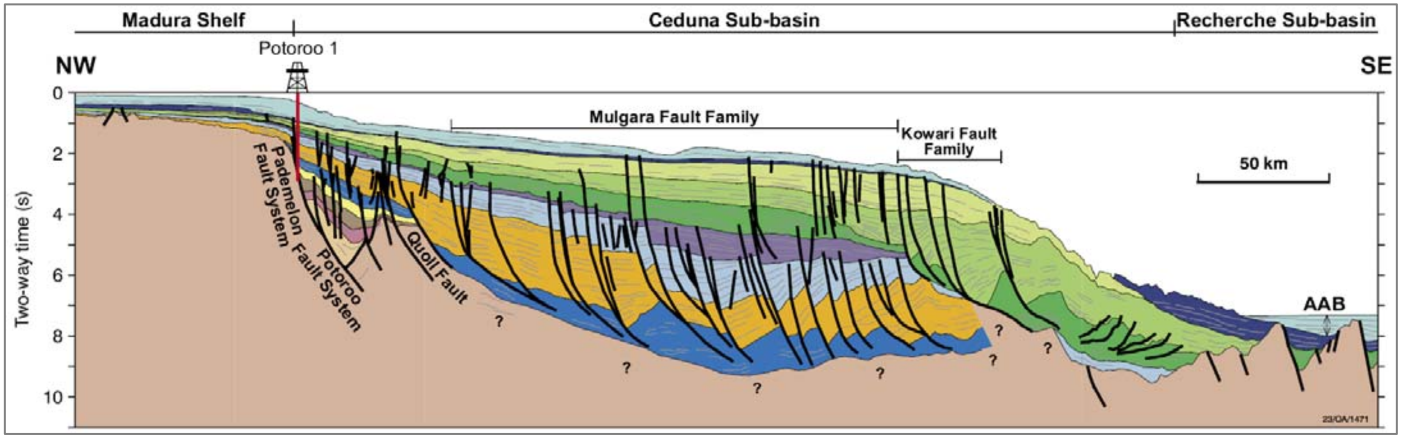
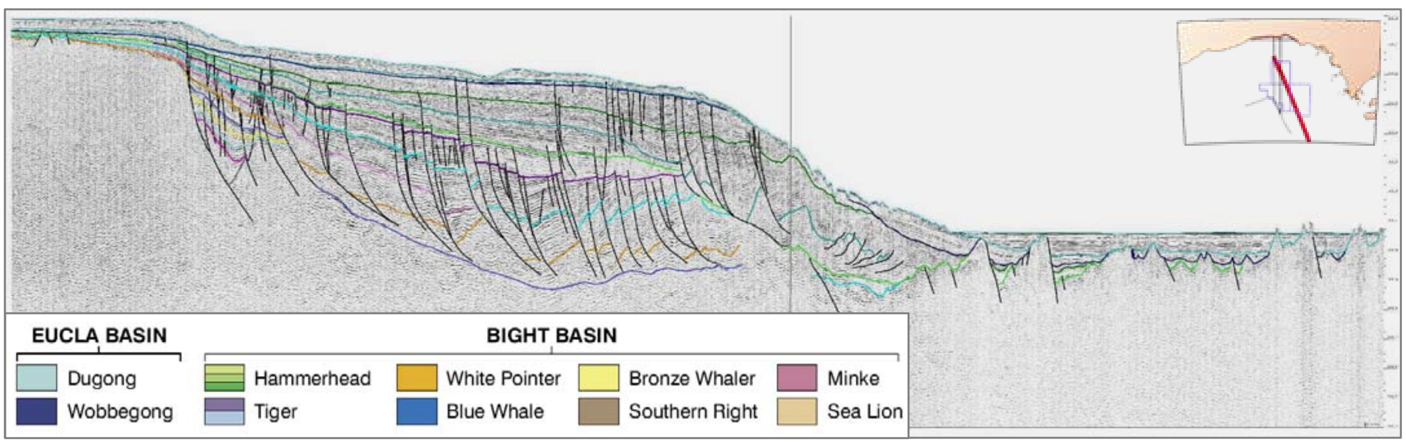


Figure 30a (left). Cross-section through the Madura Shelf, Ceduna and Recherche sub-basins showing the structural style and stratigraphy of the eastern Bight Basin (from Totterdell et al., in press).

Figure 30b (lower left). Interpreted Geoscience Australia seismic line of the cross-section shown in Figure 30a.

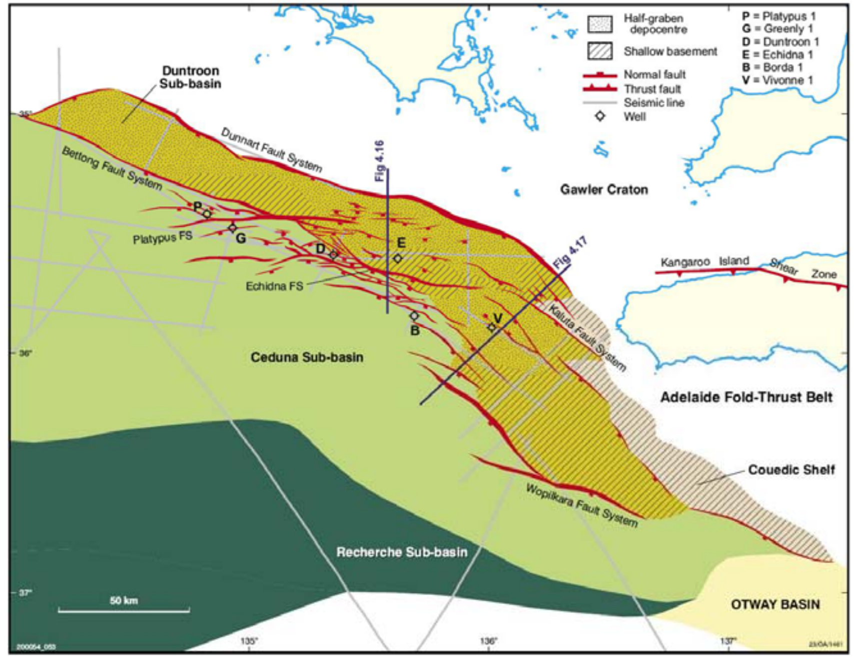


Basin Summary – Duntroon Sub-basin

The Duntroon Sub-basin (formerly the Duntroon Basin) was redefined by Bradshaw et al (2003) and Totterdell and Bradshaw (2004) to reflect the structural similarities between the Eyre Sub-basin and the Duntroon Basin's 'Inner Basin', and the lateral continuity of the Ceduna Sub-basin that lies seaward of the 'Late Cretaceous Hinge' (Figures 31 and 32). In the revised definition shown in Figure 32, the Duntroon Sub-basin refers only to the half graben system that lies northeast of the 'Late Cretaceous Hinge', while seaward of the 'Late Cretaceous Hinge' lies the along-strike continuation of the Ceduna Sub-basin.

In the eastern Duntroon Sub-basin, Smith and Donaldson (1995) describe basement dipping to the north and north-northeast and propose that initial extension occurred in this direction. More recent work indicates the development of Late Jurassic to Early Cretaceous half graben are more likely to be the result of northwest-southeast oriented oblique extensional stresses (Bradshaw et al., 2003; Totterdell and Bradshaw, 2004). These trends are consistent with extensional stress associated with the formation of the Eyre Sub-basin and related half graben along the northern margin of the Ceduna Sub-basin (Totterdell and Bradshaw, 2004).

Stagg et al (1990), Smith and Donaldson (1995) and Totterdell and Bradshaw (2004) also note the influence of basement fabric (Gawler Craton and Adelaide Fold Belt) on the subsequence evolution of fault trends and basin segmentation in the Duntroon Sub-basin during Late Jurassic to Early Cretaceous rifting (Figure 33).



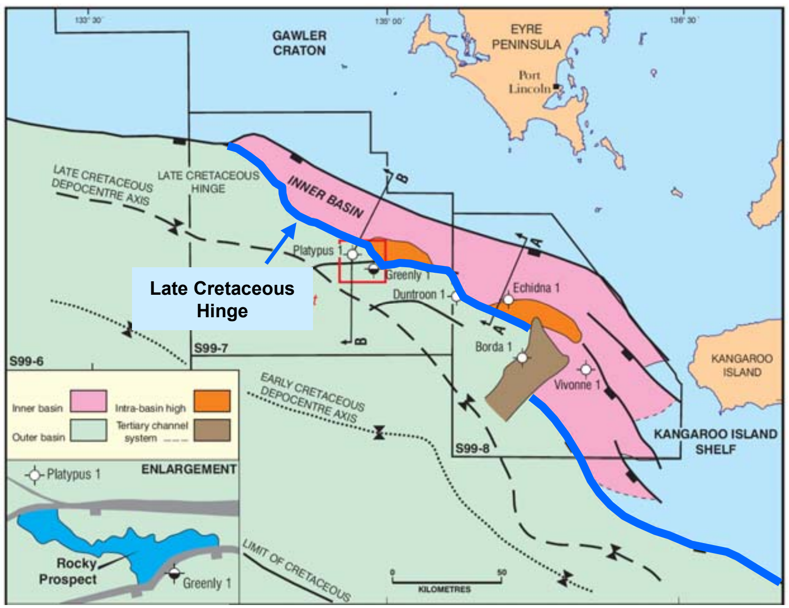
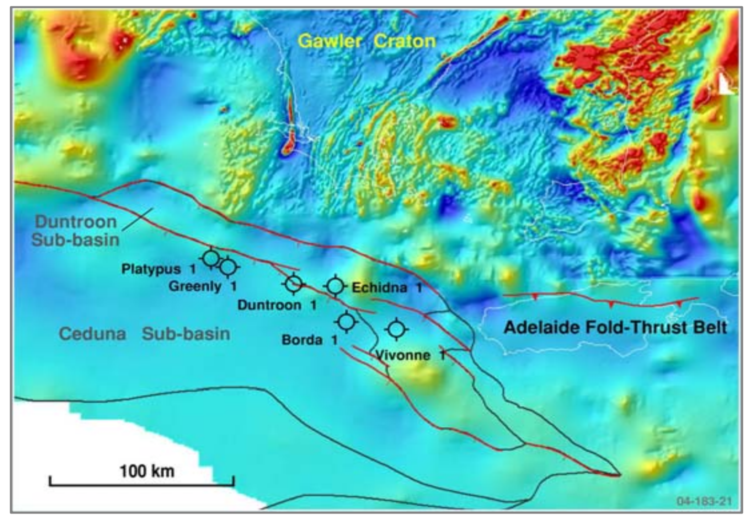


Figure 31 (left). Structural elements map of the Duntroon Basin as originally defined by Smith and Donaldson (1995) (extracted from Hill, 1999). The 'Late Cretaceous Hinge' is shown by the blue line.

Figure 32 (above right). Structural elements map of the Duntroon Sub-basin as redefined by Bradshaw et al (2003; from Totterdell et al., in press).

Figure 33 (right). A gravity image of the Duntroon Sub-basin and surrounding region suggesting strong basement control on the development of rift faults in the Mesozoic basin (from Totterdell and Bradshaw, 2004).



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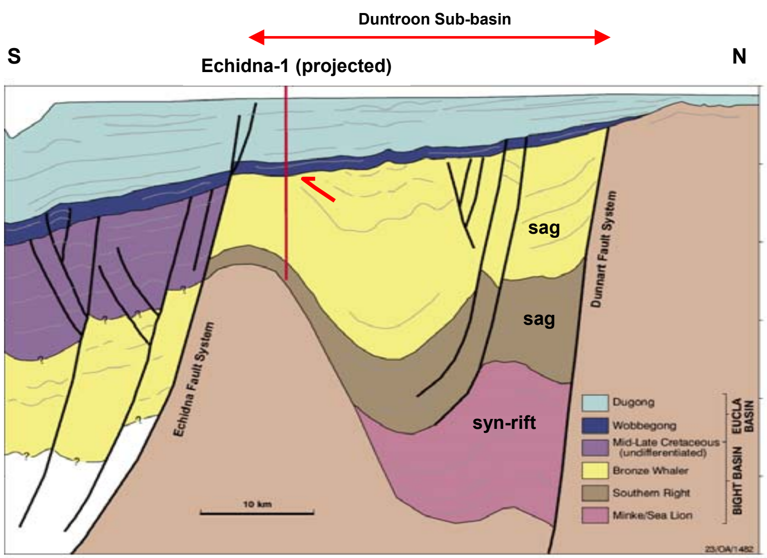
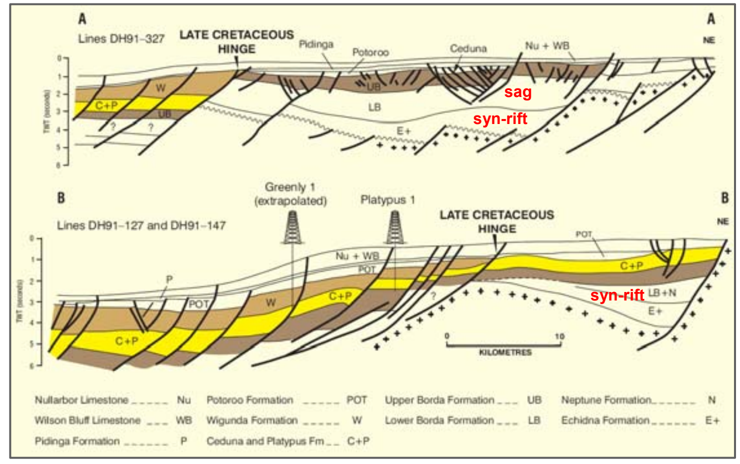
Basin Summary – Duntroon Sub-basin

In the Duntroon Sub-basin, widespread deposition of clastics in fluvial and lacustrine environments was associated with early rift development (Figure 34). Smith and Donaldson (1995) interpreted the syn-rift section to comprise the Echidna Formation with the rift basin developing from the Late Jurassic to early Berriasian – consistent with the timing of events observed in the Eyre Sub-basin (Totterdell et al., 2000).

However, Smith and Donaldson (1995) also report that while sag like geometries are observed in the overlying Lower Borda to Neptune formations in the eastern part of the basin, these age strata have syn-rift geometries in the western part of the basin (Figure 35). This interpretation would imply that the western part of the Duntroon Sub-basin was tectonically active until latest Barremian time. If this is correct, this part of the basin would have been undergoing extension during the deposition of the Crayfish Supersequence (i.e., the syn-rift section in Otway Basin), while sag conditions prevailed throughout the rest of the eastern Bight Basin (i.e., Southern Right and lower Bronze Whaler sequences).

Bradshaw et al (2003) have reinterpreted seismic data in the Duntroon Sub-basin using Bight Basin sequence definition and nomenclature, and suggest that the syn-rift succession is age equivalent to the Sea Lion-Minke sequences (Figure 36) in the Eyre Sub-basin where well control is relatively good (Jerboa-1). However, as the reinterpreted lines published by Bradshaw et al (2003) come from the eastern part of the Duntroon Sub-basin (sag conditions), further validation should be pursued to exclude tectonic activity in the western part of the sub-basin (i.e., along the northwestern part of the Dunnart Fault System; see previous Figure 32).





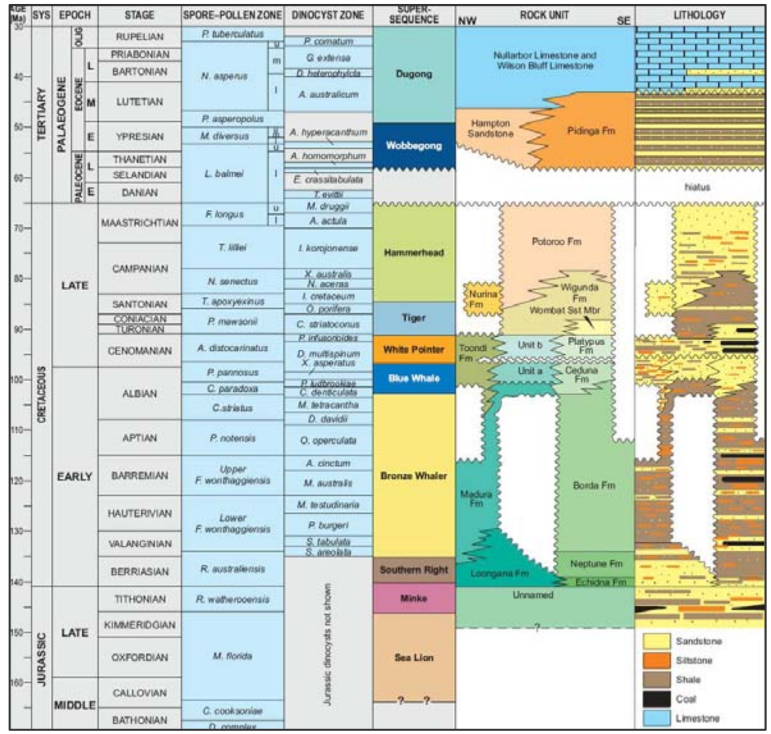


Figure 34 (right). Stratigraphic correlation table for the eastern Ceduna Sub-basin showing sequence stratigraphic units of Totterdell et al. (2000).

Figure 35 (above right). Cross-sections of the Duntroon Sub-basin as originally defined by Smith and Donaldson (1995) (extracted from Hill, 1999). Note the different structural style of the Lower Borda Formation (LB) on the two sections.

Figure 36 (left). Cross-section through the northern Duntroon Sub-basin (from Bradshaw et al., 2003).

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Basin Summary – Duntroon Sub-basin

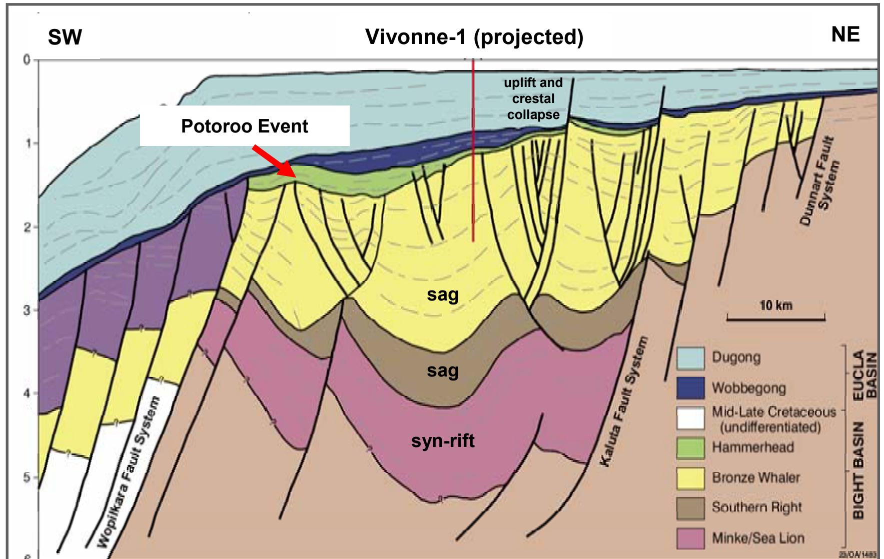
The fluvial and lacustrine sediments of the syn-rift succession are overlain by extensive paralic, deltaic and marginal marine sediments of the Borda, Ceduna and Platypus Formations of Barremian to Cenomanian age. Smith and Donaldson (1995) note the absence of major structuring during Cenomanian breakup and the deposition of transgressive sands of the Wombat Member (Platypus Formation). A later, more significant episode of structuring in the Late Santonian was described as the basal 'Potoroo Event' (Smith and Donaldson, 1995) , and interpreted as a major hiatus in the 'Inner Basin' and a shift in deposition to the 'Outer Basin' (Ceduna Sub-basin). The event also produced localised inversion of half graben and tiling of the basin.

Since those observations, the timing of breakup off the Ceduna Sub-basin has been revised from 96 Ma (Cenomanian; Veevers and Ettreim, 1988; Veevers et al., 1991) to 83 Ma (latest Santonian to earliest Campanian; Sayers et al., 2001). This is consistent with the 'Potoroo Event' of Smith and Donaldson (1995) equating to breakup off the Ceduna Sub-basin. A similar effect of breakup is observed in the reactivation of basement features in the Eyre Sub-basin. The age of the 'Potoroo Event' is constrained mostly through seismic correlations because only Vivonne-1 and Echidna-1 are drilled in the Duntroon Sub-basin proper. These wells intersect the unconformity but have significant section missing (e.g., *P. notensis* /Aptian overlain by *N. senectus* /Campanian at Vivonne-1). The question may still arise whether the Duntroon Sub-basin experienced any effect of the margin-scale uplift that affected much of the eastern Gondwana during the Cenomanian. This event was driven by a change in the movement direction of the Pacific Plate. Flattened seismic data shown in Figure 38 is ambiguous as to whether there are two events, although further investigation of seismic across the basin may resolve this point.

In general, the effects of this inversion/uplift event were largely focused in the regions east of Kangaroo Island. The uplift also resulted in broad-scale reorganisation and redirection of inland drainage systems. West of Kangaroo Island and in the Ceduna Sub-basin, the response to this event is recorded by the subsequent progradation and aggradation of massive deltaic complexes beginning in the Cenomanian (White Pointer and Hammerhead sequences) – presumably through the reorganisation of inland drainage systems. Massive sediment loading in the Bight Basin is associated with accelerated subsidence (Basin Phase 3 of Totterdell et al., 2000) and suggests crustal weakness or instability accommodated this massive loading. The dramatic basinward shift in Late Cretaceous deposition may also result from more rigid crust beneath Eyre and Duntroon sub-basins (less accommodation), with weaker basement terranes (mobile belts) under the Ceduna and Recherche sub-basins allowing greater subsidence.

In addition, the contrasting responses to the Cenomanian event in the eastern Bight (loading) and Otway (uplift) basins, suggests there is a fundamental change in basement geology or crustal structure between the two basins. This partitioning of events between the two basins in observed later during breakup, when along-strike propagation of the spreading ridge was terminated just west of the Otway Basin.

An overall transgressive phase of sedimentation in the early Tertiary was followed by the establishment of widespread, open-marine carbonate sedimentation as a result of accelerated rates of seafloor spreading from the Early Eocene onwards.



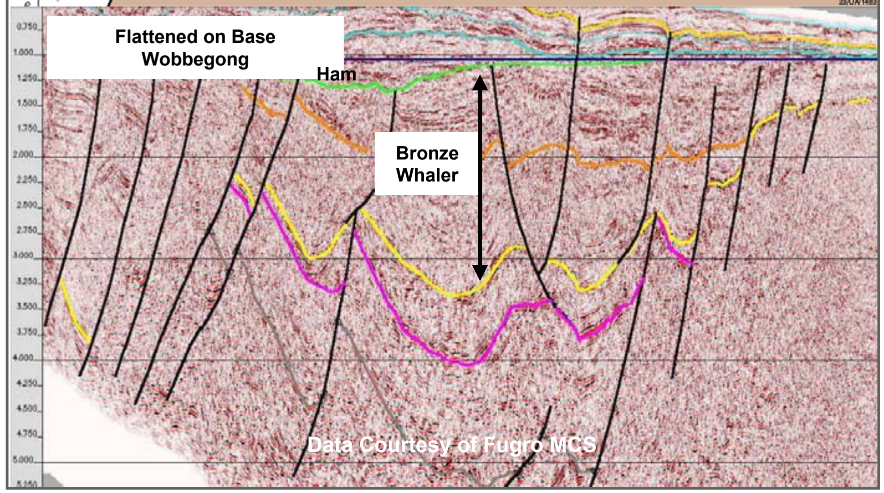


Figure 37. Cross-section across the southeastern Duntroon Sub-basin showing the stratigraphic level of the 'Potoroo Event' as described by Smith and Donaldson (1995) (from Totterdell et al., in press).

Figure 38. Interpreted seismic section of the same line shown in Figure 37 but flattened on the 'Base Wobbegong Sequence' boundary.

Basin Summary – Otway Basin

The Otway Basin contains Jurassic to Recent continental to marine sediments that were deposited in syn-rift, transitional, post-rift, inversion and transtensional tectonic settings (e.g., Miller et al., 2002; Krassay et al., 2004;, Palmowski et al., 2004) that resulted from the fragmentation of southern and eastern Gondwana.

The basin is subdivided for the purpose of a tectonostratigraphic synthesis into the following four areas, based on the timing and nature of sedimentary/fault responses to the plate-scale tectonic events:

- **Western and Onshore Otway Basin**, locus of Early Cretaceous, Southern Margin intracontinental rifting
- **Torquay Sub-basin**, similar to onshore Otway in the Early Cretaceous.
- **Offshore Otway Basin**, basinward of the Mussel, Tartwaup fault zones, locus of late Cretaceous, Southern Margin intracontinental rifting
- **Shipwreck Trough**, Early Cretaceous Southern Margin rift, Early Cretaceous transition (far-field plate interactions of East Gondwana fragmentation between Antarctica and New Zealand) and Late Cretaceous transtension (Southern Margin and Tasman rifting).

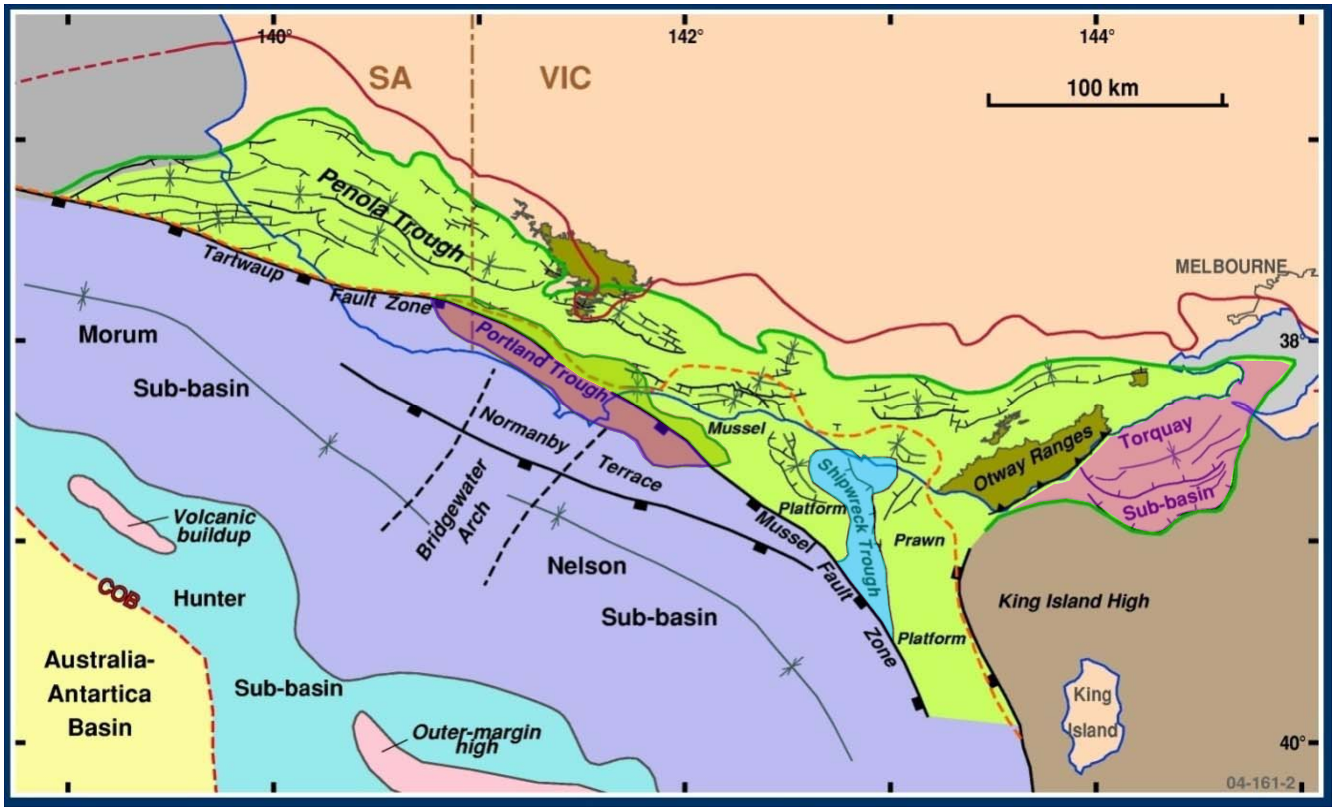


Figure 39. Tectonic elements map of the Otway Basin (after Krassay et al., 2004).

Western and Onshore Otway
Offshore Otway Basin
Shipwreck Trough
Torquay Sub-basin

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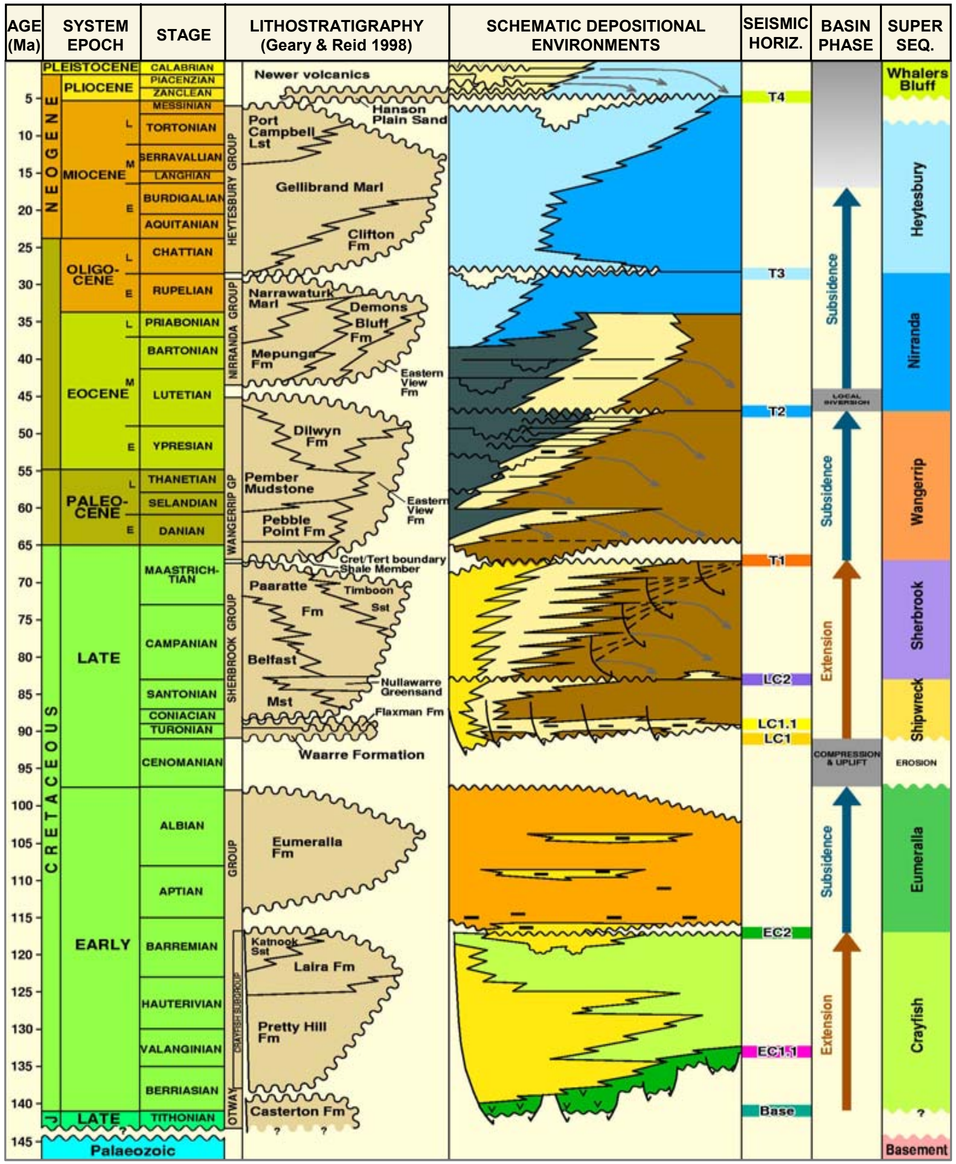

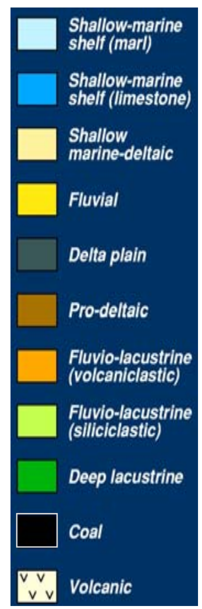

Basin Summary – Otway Basin

Regional seismic mapping and well correlation undertaken by Krassay et al (2004) have redefined the stratigraphic succession of the Otway Basin into tectonostratigraphic units. The study recognised deposition of eight supersequences during seven basin phases – including two rift phases (Crayfish and Shipwreck/Sherbrook sequences) and an intervening sag phase (Eumeralla Sequence).

The Early Cretaceous Eumeralla Sequence is lithostratigraphically distinctive due to its high percentage of volcaniclastic content. A similar high volcaniclastic content of Aptian-Albian age sediments is also observed in the Gippsland and Bass basins (see subsequent pages on *Volcaniclastic Sedimentation*). The high influx of volcaniclastic sediment into the southeastern basins during this period means that units such as the Eumeralla Sequence can comprise an abnormally thick sag section.

The Otway Basin experienced increasing marine influence from the Late Turonian onward, with greater deltaic influence from the Santonian to early Oligocene. Krassay et al (2004) have defined the timing of breakup in the Otway Basin as 67 Ma (approximately the base of Upper *F. longus* zone), and this differs from the 43 Ma assigned for breakup by Norvick and Smith (2001) and Norvick (2005).

Figure 40. Tectonostratigraphy column for the Otway Basin (from Krassay et al., 2004).

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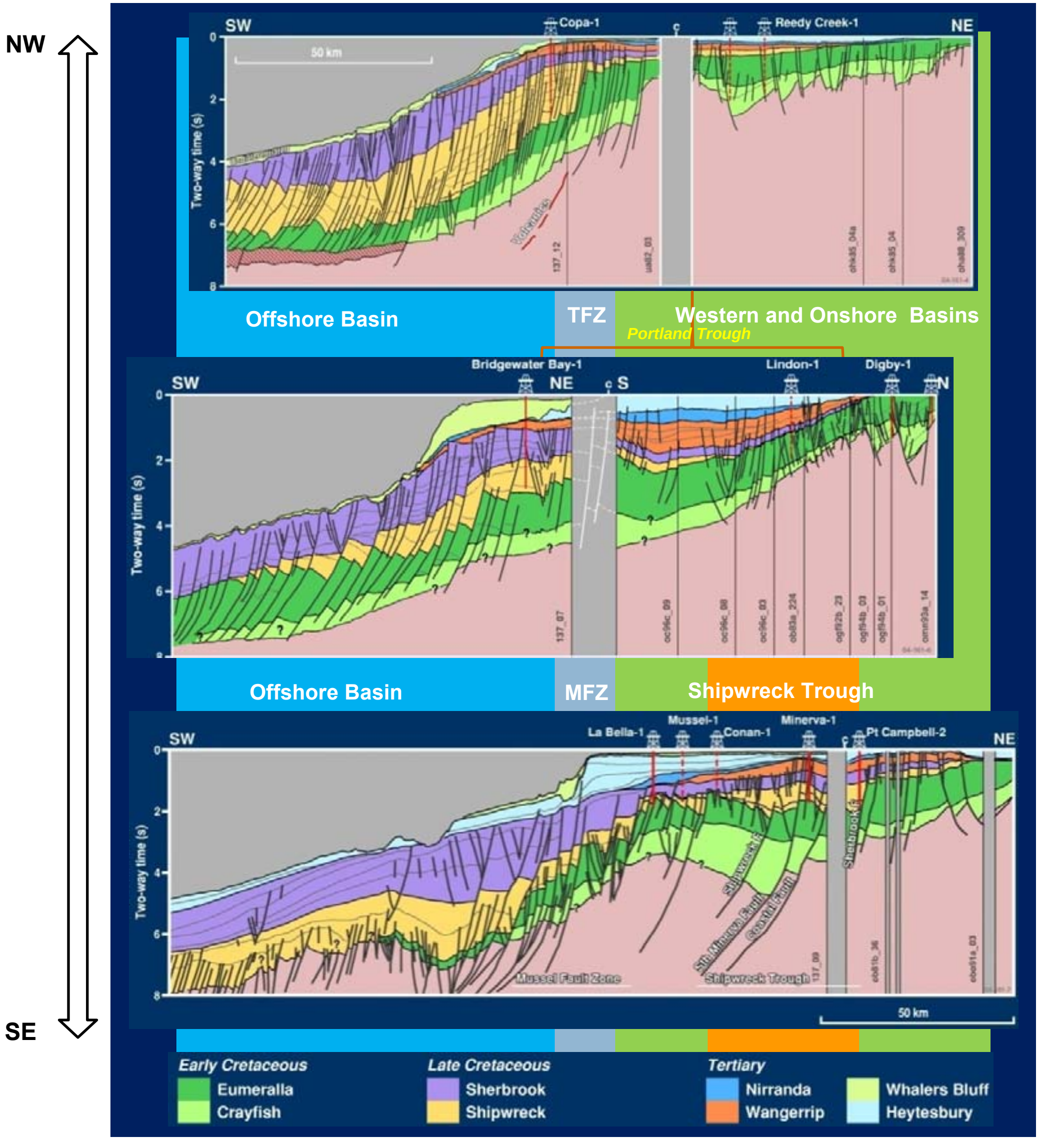

Basin Summary – Otway Basin

The Otway Basin is subdivided into Western and Onshore Basins; the Offshore Basin and the Shipwreck Trough. The Torquay Sub-basin is discussed later. Regional trends within these areas are summarised below:

• Onshore region dominated by Early Cretaceous rift geometries in the Crayfish Sequence and sag geometries in the Eumeralla Sequence (note that the Robe Trough is not shown here);

• Offshore region dominated by Late Cretaceous growth during deposition of the Shipwreck and Sherbrook sequences;

• Complex load related faulting occurred in the offshore part of the basin in the central and western Otway;

• Shipwreck Trough experienced growth in the Early and Late Cretaceous (Crayfish/Eumeralla and Sherbrook/Shipwreck);

• the Late Cretaceous and Tertiary successions are thin to absent to the west and north;

• the Tertiary succession is dominated by sag geometries with isolated inversion (e.g., Minerva);

• The Portland Trough forms a Paleocene-Eocene sag depocentre just inboard, and overlapping, the Tartwaup and Mussel fault zones (TFZ and MFZ); the tectonic controls on this thickening are poorly understood.

• Progradation and aggradation of Miocene cool water carbonates was greatest to the south on the Mussel Platform (see La Bella-1). This interval is subject to major canyon development in the central Otway.

•Pliocene progradation dominated in the central Otway Basin

Figure 41. Geoseismic cross-sections across the Otway Basin (modified from Krassay et al., 2004) annotated for tectonic sub-divisions as discussed in this report.

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Basin Summary – Western and Onshore Otway Basin (Early Cretaceous rift)

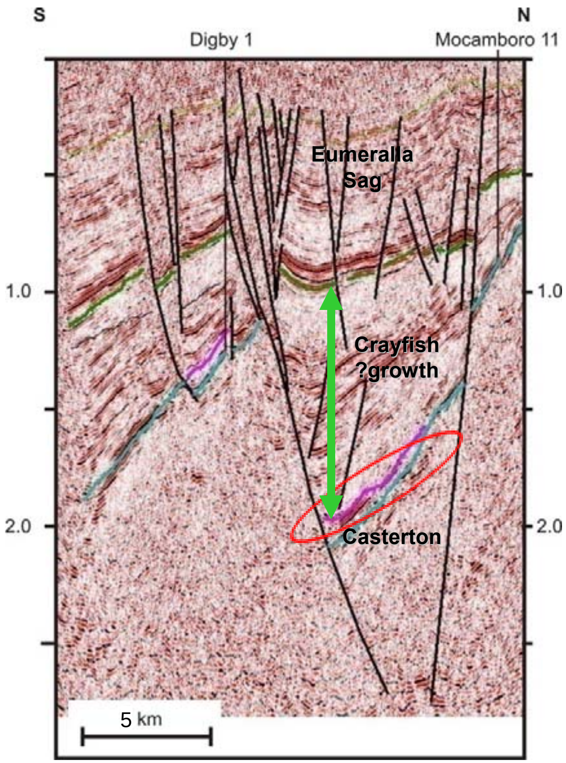

Figure 42. Seismic line OMN93A-14 showing the Early Cretaceous half graben structural style of the Digby and Mocamboro troughs. Note that post-rift Late Cretaceous and Tertiary sediment are very thin.

The Western and Onshore Otway Basin has been regionally mapped by Woollands and Wong (2001), Boult and Hibburt (2002) and Krassay et al (2004). The inner portion of the Otway Basin (termed here the Western and Onshore Otway Basin) consists of numerous half graben (see Krassay et al. 2004 for locations) that trend NW-SE (Penola, St Clair, Digby, Mocamboro, Tantanoola, Ardonachie, Morenda and Koroit troughs), E-W (Robe, Rivoli and Elignamite troughs) and NE-SW (Torquay Sub-basin, Ombersely, Colac and Gellibrand troughs).

These half graben represent the locus of intracontinental rifting, propagating from west to east, during the Late Jurassic to Early Cretaceous with growth into faults that dip NE to NW (Megalla, 1986; Perincek et al., 1994; Cooper and Hill, 1997; Krassay et al., 2004). The 'swing in extension direction' that created these half graben has been attributed to rheological variations of the lithosphere between the Lachlan and Delamerian fold belts (Miller et al., 2002) under a broadly north-south extensional regime (Krassay et al., 2004). The half graben are filled with non-marine sediments of the Crayfish Supersequence, ranging from Tithonian to Berriasian in age, and consisting of carbonaceous lacustrine shales, volcanics and sandstones, to Berriasian-Barremian fluvio-lacustrine siliciclastics (Krassay et al., 2004; Sinclair and Monteil, 2004). Thick post-rift, volcanoclastic fluvio-lacustrine sediments of the Eumeralla Supersequence are less affected by the Early Cretaceous faulting, with thickness variations due to primary deposition (decreasing to the west), and uplift and erosion across much of the margin during the Cenomanian. Anomalous to this general trend is potential growth during Eumeralla deposition in the Torquay Sub-basin (see *Basin Summary-Torquay Sub-basin*). The volcaniclastic material in the Eumeralla Sequence was sourced from volcanic eruptions that occurred to the east. Bryan et al (1996) propose the source of volcanoclastic material in all of the eastern margin basins was the Whitsunday Volcanic Province which formerly extended along the entire margin and has subsequently been rifted away from mainland Australia.

The late Cretaceous to Tertiary interval is generally very thin or absent in the west, although Palmowski et al (2004) have interpreted a significant thickness of these sediments in sag basins. The Tertiary is relatively thick on the Mussel Platform, as a result of highstand progradation of non-marine to shallow marine, deltaic siliciclastics from the north, and subsequent cool water shallow marine carbonates during the mid to late Tertiary. The western and onshore Otway Basin was influenced by three phases of uplift and erosion during the Cenomanian, Maastrichtian and Late Miocene-Pliocene, as indicated by burial history and fission track data (Cooper and Hill, 1997). Uplift also resulted in the creation of inversion anticlines and abundant incision in the Tertiary.

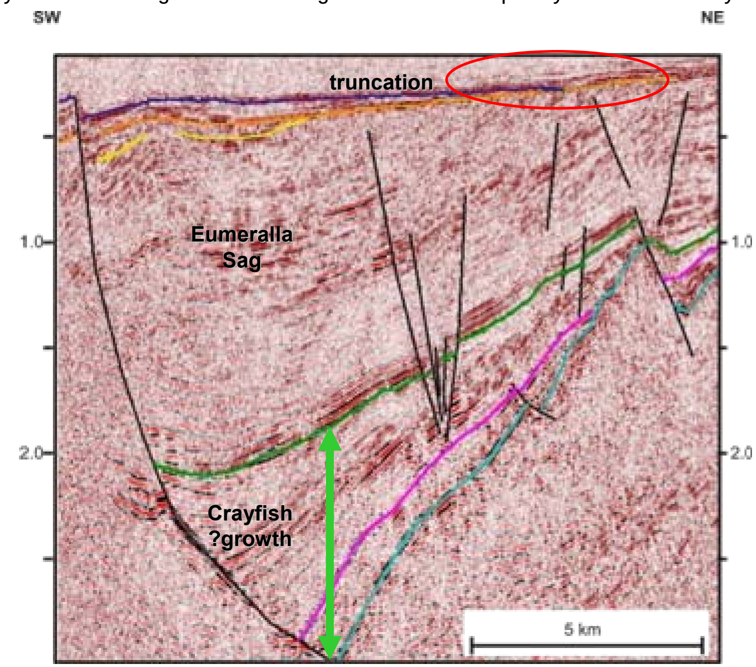

Figure 43. Early Cretaceous half graben of Morenda Trough. The Eumeralla Supersequence is considerably thicker than to the west. Thinning to the north is a result of uplift and erosion on the northern margin. Inversion along the boundary fault in the mid Eocene. Note thin late Cretaceous-Tertiary section. Seismic line OC95-103

Early Cretaceous intracratonic rifting post dates initial extension to the west, where post-rift (Bight Basin) to transitional (Perth Basin) and second rifting (Bremer Basin) basin phases were active. This delay has previously been attributed to the eastward propagation of the Southern Rift System (Willcox and Stagg, 1990), although the on-going breakup and fragmentation of eastern Gondwana may also impart far-field effects on this part of the margin. The Southern Margin basins may be further influenced by east Gondwana fragmentation, as the Tasman Rift propagated to the north (e.g., transitional phases, post-rift with local extension, in the Shipwreck Trough, Bass and Gippsland basins).

Basin Summary – Western and Onshore Otway Basin (Early Cretaceous rift)

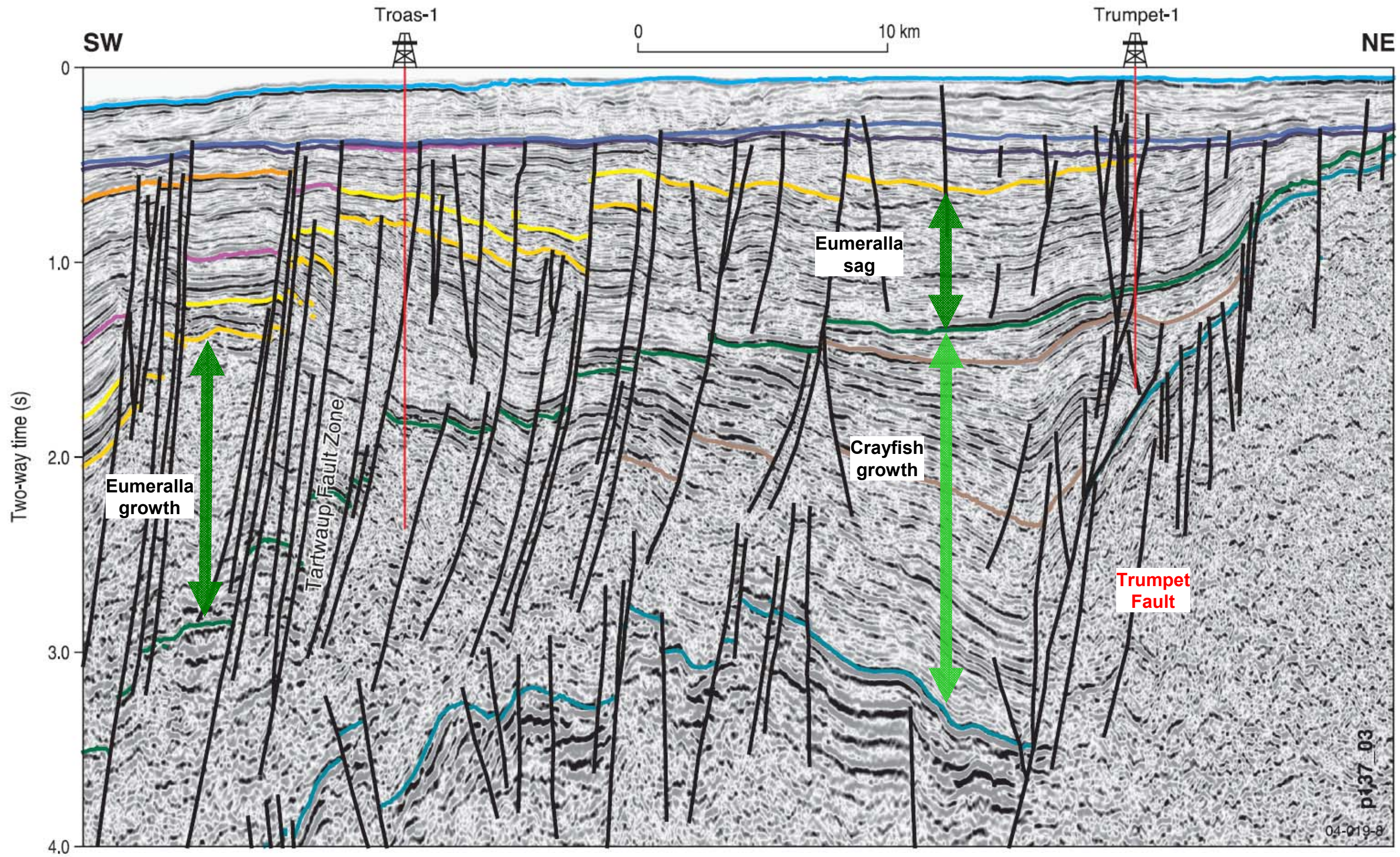

Figure 44. Geoscience Australia seismic line 137-03 showing Early Cretaceous (Crayfish) growth against the Trumpet Fault in the Robe Trough, with truncation beneath the Early Cretaceous-2 marker (EC2, dark green) and an overlying thin Late Cretaceous to Tertiary succession (section above the above yellow horizon). Note that the Eumeralla Supersequence thickens southwest of the Tartwaup Fault Zone (modified after Krassay et al., 2004).

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Basin Summary – Offshore Otway Basins (Late Cretaceous Rift)

The offshore Otway Basin has been mapped by Moore et al (2000) and Krassay et al (2004). The offshore part of the Otway Basin consists of the Nelson and Morum sub-basins – large NW-SE trending depocentres separated by the Bridgewater Arch. These sub-basins and the Shipwreck Trough were the locus of sedimentation during the Late Cretaceous rifting phase with active growth controlled by the Tartwaup-Mussel fault zones (Moore et al., 2000; Krassay et al., 2004). Late Cretaceous sediments are thin to absent on the Crayfish Platform, the northern margin, across many of the onshore half graben (see Krassay et al., 2004 for location) and in the Torquay Sub-basin. Early Cretaceous sediments have not been intersected basinward of the Tartwaup-Mussel fault zones, and are interpreted to thin basinward in the Nelson Sub-basin while maintaining consistent thickness in the Morum Sub-basin.

The outer Otway basins and the Shipwreck Trough are interpreted to have formed under broadly north-south extension during Early Cretaceous rifting (Miller et al., 2002; Krassay et al., 2004). The depocentres are filled with non-marine fluvio-lacustrine, deltaic and marine siliciclastics of the Shipwreck and Sherbrook sequences. Stratal geometries indicate that structural control decreased during deposition of the Shipwreck Sequence. Turonian sediments clearly show growth on closely spaced faults, while growth occurred on more widely spaced faults during the Coniacian combined with regional sag. Faults were generally inactive during the Santonian.

Similarly, the amount of fault movement decreased upwards during deposition of the Sherbrook Sequence. Fault growth due to mechanical extension occurred basinward of the Tartwaup-Mussel fault zones. Numerous listric fault blocks showing significant rotation and growth related to deltaic sedimentation and loading are apparent in the western and central offshore Otway Basin. Fault control decreased during deposition of the upper Sherbrook Sequence and reduced accommodation resulted in progradation of the sedimentary succession.

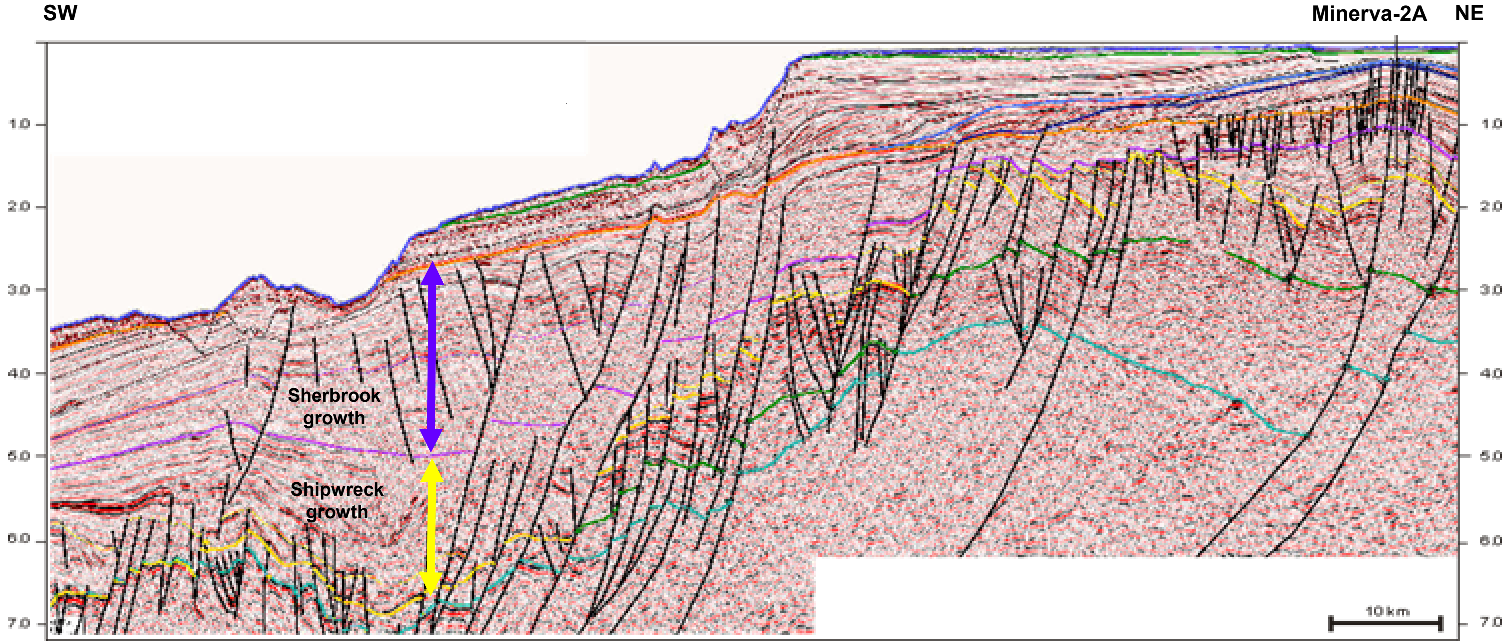

Figure 45. Geoscience Australia seismic line 137-09 across the Nelson Sub-basin basinward of the Mussel Fault Zone. The Late Cretaceous succession shows growth during deposition of the Shipwreck and Sherbrook sequences. Inversion rollover structures are present in the upper Sherbrook Sequence.

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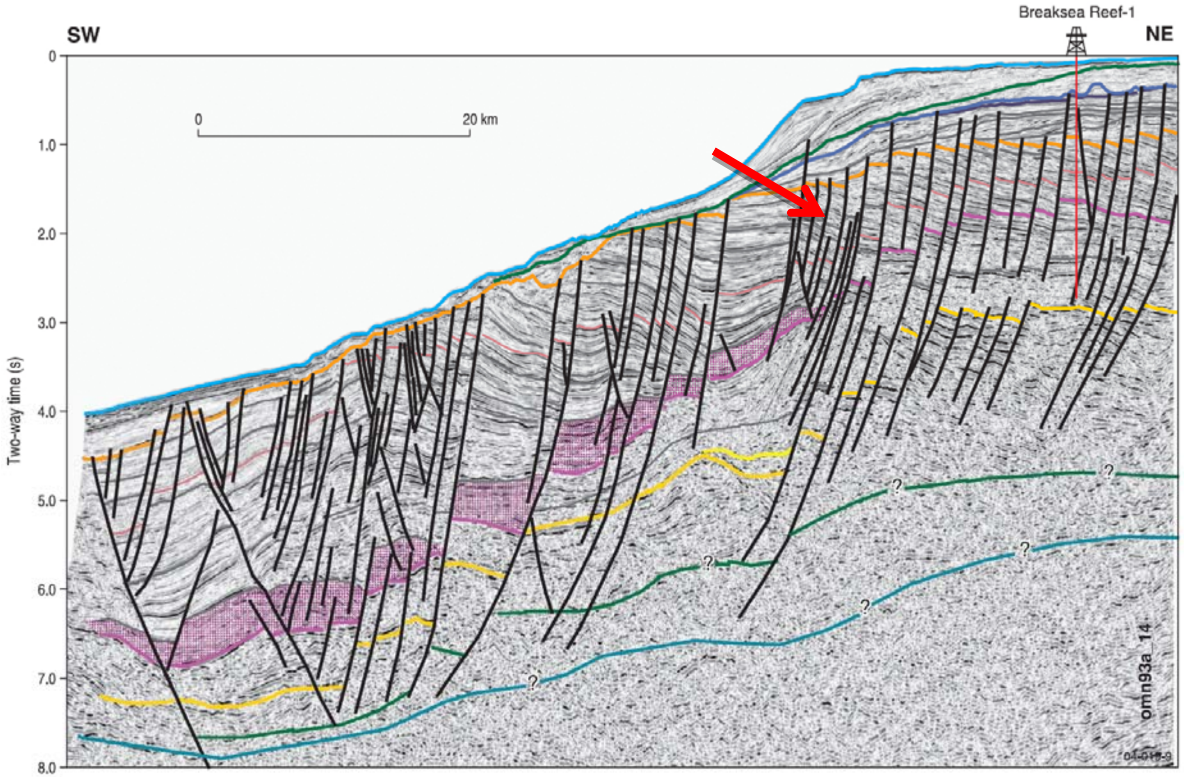
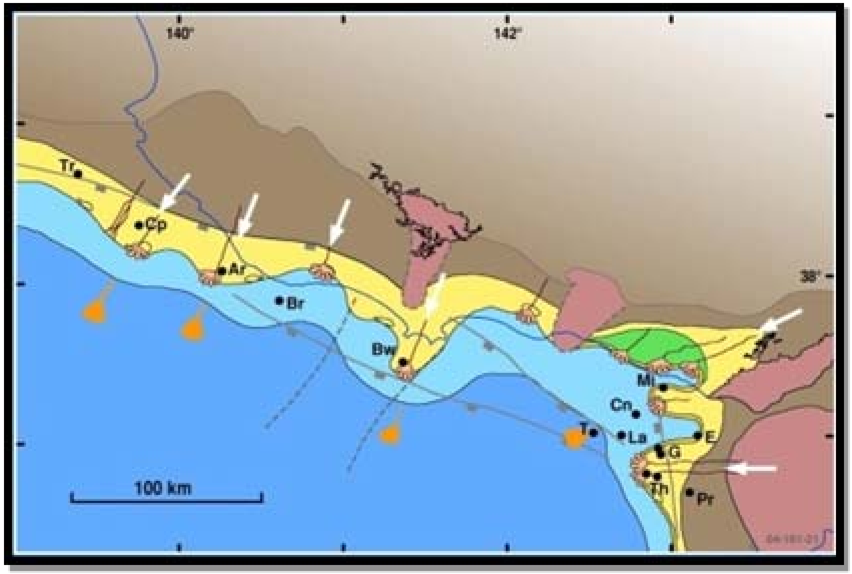


Figure 46. Geoscience Australia seismic line 137-04 across the Morum Sub-basin, basinward of the Tartwaup Fault Zone. (from Krassay et al., 2004). The Late Cretaceous succession was highly faulted in response to sediment loading by deltaic siliciclastics. Shading highlights the interpreted LST succession within the Sherbrook Sequence. The equivalent interval landward is a bypass zone. Note growth in Paleocene strata adjacent Breaksea Reef-1.

Basin Summary – Outer Otway Basins (Late Cretaceous Rift)

The Tertiary interval is dominated by sag geometries, and incision and sediment distribution is largely independent of the major depocentres that were active during the Cretaceous. Regional subsidence (sag) was interrupted by local inversion on earlier extensional faults (e.g., the Minerva, Copa and Argonaut structures at ~20 Ma; Krassay et al., 2004) and the Morum High (~44 Ma; Duddy et al., 2003). Tertiary sediments are relatively thin on the Crayfish Platform, which remained high during the Paleocene and Eocene (Krassay et al., 2004). The NW-trending Portland Trough straddles the Tartwaup-Mussel fault zones and developed as a sag feature in the Paleocene and was the main depocentre for the Wangerrip and Nirranda sequences. Local rotation and growth is observed on reactivated faults around Breaksea Reef at the same time (Figure 46; red arrow).

Clastic deltaic sediments of the Wangerrip and Early Nirranda sequences progressively gave way to prograding cool water carbonates across the margin in the mid to Late Eocene. Progradation continued into the Oligocene and Miocene with the maximum thickness of sediments observed on the Mussel Platform (Heytesbury Sequence). The locus of deposition shifted in the Pliocene-Recent (Whalers Bluff Sequence) to accommodation created locally in the central Otway Basin between the uplifted Copa-Argonaut structures and the Oligocene-Miocene highstand of the Heytesbury sequence.



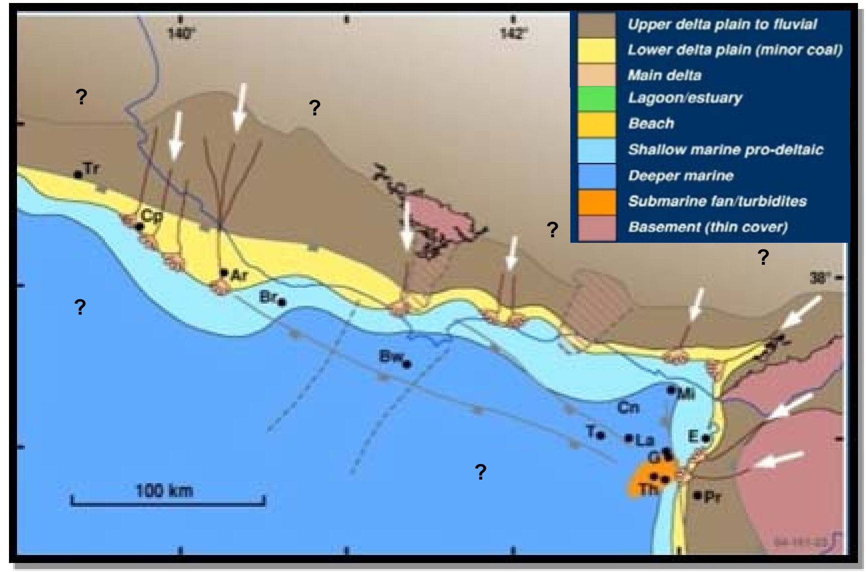


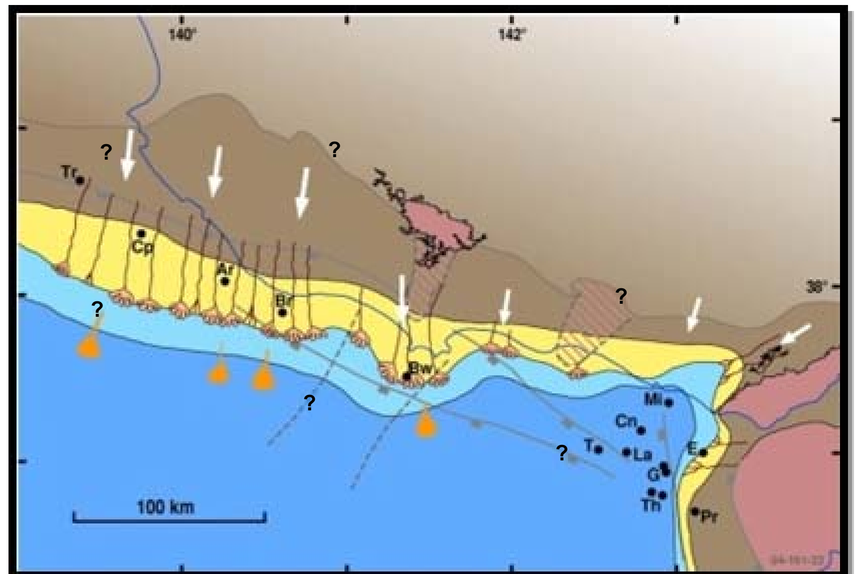
Figure 47 (above left). Paleogeographic map for the Late Turonian Shipwreck Sequence (late lowstand deposition of the 'Upper Waarre' facies at 90 Ma; from Krassay et al., 2004). The legend for environments is shown in Figure 48.

Figure 48 (above right). Paleogeographic map for the Early Santonian Shipwreck Sequence (early highstand deposition of the Belfast Mudstone at 87 Ma; from Krassay et al., 2004).

Figure 49 (lower right). Paleogeographic map for the Early Campanian Sherbrook Sequence (early highstand 'Paaratte/Skull Creek' facies at 81 Ma; from Krassay et al., 2004).

Paleogeographic maps of the Shipwreck and Sherbrook sequences show the major influence of deltas on the margin during the Late Cretaceous (Krassay et al., 2004). Large deltas existed to the west and the east in the Late Turonian, supplying siliciclastic material to the Morum Sub-basin and Shipwreck Trough (main reservoir in the Shipwreck Trough). A marine environment with turbidites existed in the Nelson Sub-basin.

Deltas stepped back during the Coniacian-Santonian and the locus of sedimentation was further restricted to the west. Progradation of numerous small deltas is interpreted during Campanian time in the in the Morum Sub-basin with prodeltaic and marine environments on the Mussel Platform, Shipwreck Trough and Nelson Sub-basin to the east.



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Basin Summary – Shipwreck Trough (Otway Basin)

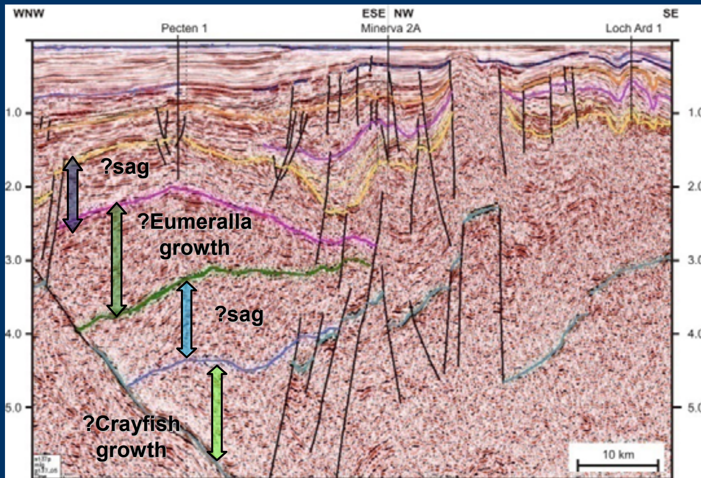

Figure 50. Geoscience Australia seismic line 137-05 showing Early Cretaceous syndepositional growth and sag in the Crayfish and Eumeralla sequences.

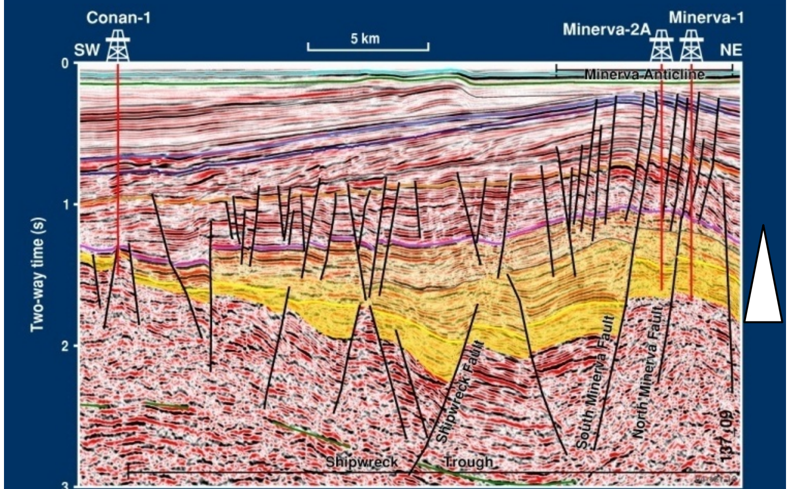

Figure 51. Geoscience Australia seismic line 137-09 across the Shipwreck Trough and Minerva Anticline showing evidence of three separate phases of Late Cretaceous (Shipwreck Sequence) syndepositional growth (Modified after Krassay et al., 2004).

The Shipwreck Trough is a north/northeast-trending graben that overlies the eastern edge of the Delamerian Terrane. It is bound on the east by the Prawn Platform and to the west by the Mussel Platform and forms the eastern limit of significant Late Cretaceous rifting in the Otway Basin. Two Early Cretaceous sequences are interpreted at the base of the proto-Shipwreck Trough – the Crayfish and Eumeralla sequences, although only the upper part of the Eumeralla Formation is intersected in the area (Palmowski et al., 2004). Growth and sag geometries are present in the interpreted Crayfish and Eumeralla sequences, with a switch in growth direction from east to west respectively. The proto-Shipwreck Trough and the Torquay Sub-basin are the only areas in the Otway Basin where Eumeralla extensional geometries are interpreted, leading to an interpretation of rift transition (rather than sag/subsidence) in these depocentres.

The Shipwreck Trough also shows growth in the Shipwreck Sequence with accommodation controlled by sinistral transtension during the Late Cretaceous (Miller et al., 2002). The transtensional regime was set up in response to underlying basement controls that inhibited extension to the east along the Delamerian-Lachlan boundary (Miller et al., 2002). The Late Cretaceous trough received deltaic sediments from the east (see Figures 50 and 51). The Shipwreck Sequence in this area contains both the most significant reservoir (Waarre Formation) and regional seal (Belfast Mudstone). This effective reservoir-seal combination is also present in SE South Australia (Caroline-1) and around Breaksea Reef but not in the western Otway Basin (near Copa-1) due to the continued influx of sand-rich proximal deltaic sediments. The Shipwreck Trough remained in a pro-delta to marine environment throughout the Late Cretaceous, while deltaic sedimentation was focused in the central and western Otway Basin (Krassay et al., 2004).

The Tertiary succession is dominated by sag geometries, siliciclastic (Paleocene-Eocene) to cool water carbonate progradation (Oligocene and younger) and incision. Regional subsidence was interrupted by local inversion of earlier extension faults. Interpreted initiation of these structures ranges from Campanian-Maastrichtian to Miocene for the Minerva anticline (Krassay et al., 2004; Schneider et al., 2004) and Late Cretaceous for the Prawn Platform structures (Woollands and Wong, 2001). Based on the seismic section below, inversion across the Prawn Platform began in the Paleocene. These structures continue onshore into the Colac Trough and Otway Ranges (Woollands and Wong, 2001).

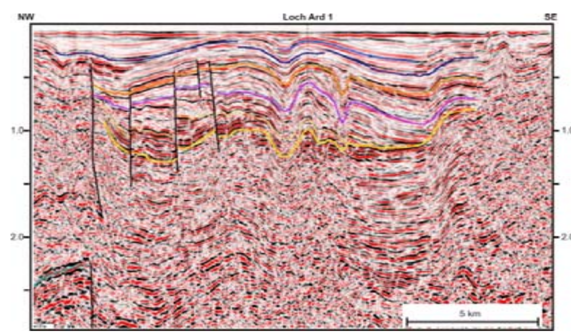

Figure 52. Geoscience Australia seismic line 137-05 showing southwest plunging folds on the Prawn Platform. Evidence of syndepositional growth above Horizon horizon T1 (orange) to the east suggests folding may have initiated in the Paleocene.

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Basin Summary – Torquay Sub-basin (Otway Basin)

The northeast-trending Torquay Sub-basin overlies terranes of the Lachlan Fold Belt. The sub-basin shows affinities with the onshore Otway Basin in the Early Cretaceous, and with the Bass Basin following uplift of the Otway Ranges during the Cenomanian. The northeasterly orientation of major structures such as the Snail Terrace and Nerita Trough (see Woollands and Wong, 2001, figure C10, for location) are coincident with northwest to west trending structures in the western Otway, and result from the influence of pre-existing structural grain on a dominantly north-south oriented extension direction during the Early Cretaceous (Cooper and Hill, 1997; Miller et al., 2002). Early Cretaceous Crayfish Group sediments have not been intersected by wells in the Torquay Sub-basin, but are inferred at depth through correlations with the onshore Otway Basin and troughs to the west. High amplitude reflections at the base of the sequence are characteristically similar to the organic-rich Casterton Formation (e.g., around Sawpit 1). The presence of the Casterton Formation at the base of the succession would imply early initiation of the rifts in the Torquay Sub-basin. In addition to growth in the Crayfish Sequence associated with southern margin extension, syn-rift geometries are also interpreted in the volcaniclastic Eumeralla Sequence. Similar to the nearby Shipwreck Trough, this interval in the Torquay Sub-basin is interpreted as a rift transition phase, suggesting the influence of the far-field stresses related to the fragmentation of eastern Gondwana.

Cenomanian uplift was focused east of the Sorell-Purrembete Trend (see Cooper and Hill, 1997 for location) and in the Otway Ranges where up to 3.5km of uplift occurred. Sediments from *P. pannosus* to *N. senectus* age are not present in the Torquay Sub-basin (Cooper and Hill, 1997). Post-rift deposition was interrupted by inversion that dominated from Late Cretaceous to Recent times. The influence of Late Cretaceous extension is interpreted as minimal in this region (e.g., Shipwreck/Sherbrook sequences) and may have been hindered by an underlying Proterozoic/Paleozoic basement trend (Miller et al., 2002). While clear syn-rift geometries are observed in the offshore Otway Basin in the Late Cretaceous, the Torquay Sub-basin has only minor NW-SE trending extension faults on the Snail Terrace (Cooper and Hill, 1997). Seismic data also suggest growth adjacent the margin fault to the west (and other minor faults to the east), so this interval may also be partially in a rift transition phase. Uplift during the Miocene-Pliocene, created the large NW trending inversion anticlines which have been targets of previous exploration wells.

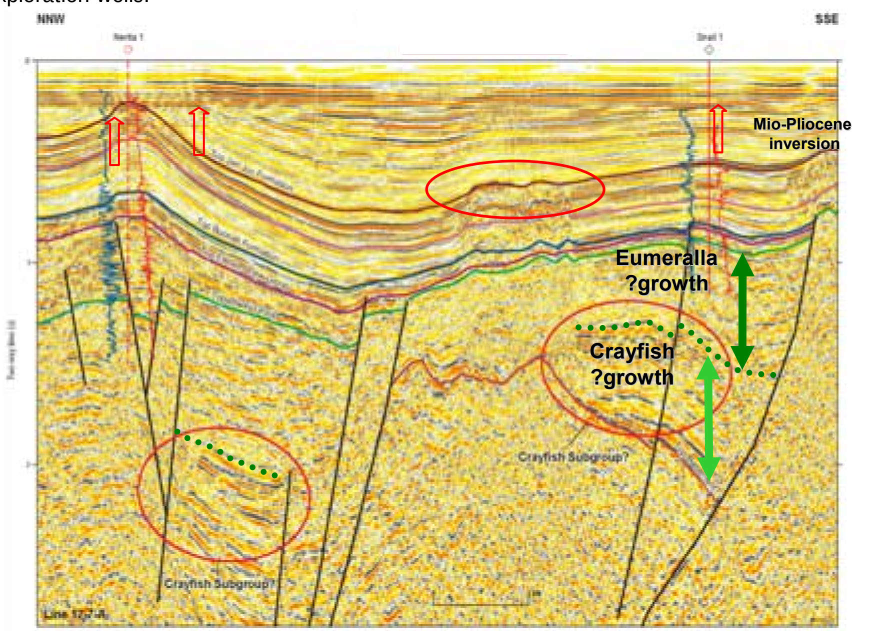


Figure 53. Seismic line 12-7A across the Torquay Sub-basin showing extension (syn-rift) geometries in Crayfish and Eumeralla sequences and Miocene inversion structures (modified from ITR, 2004).

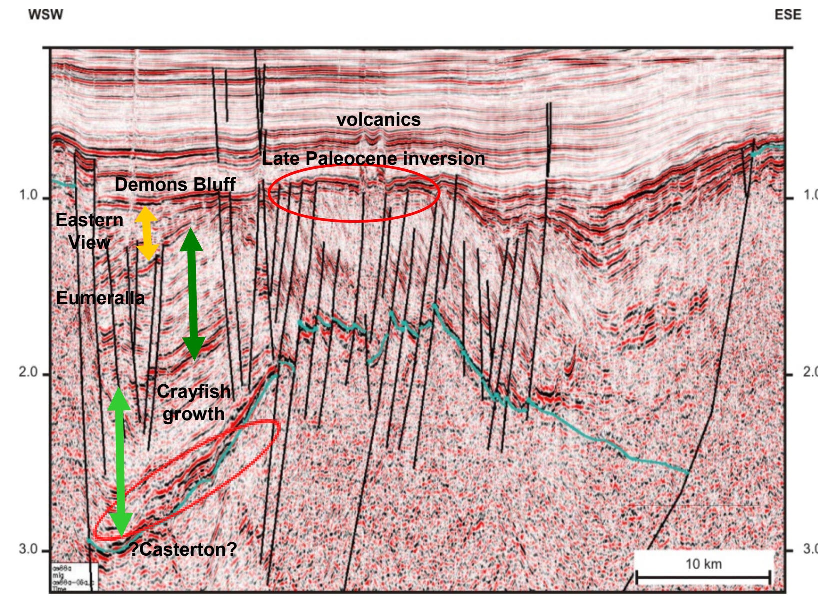
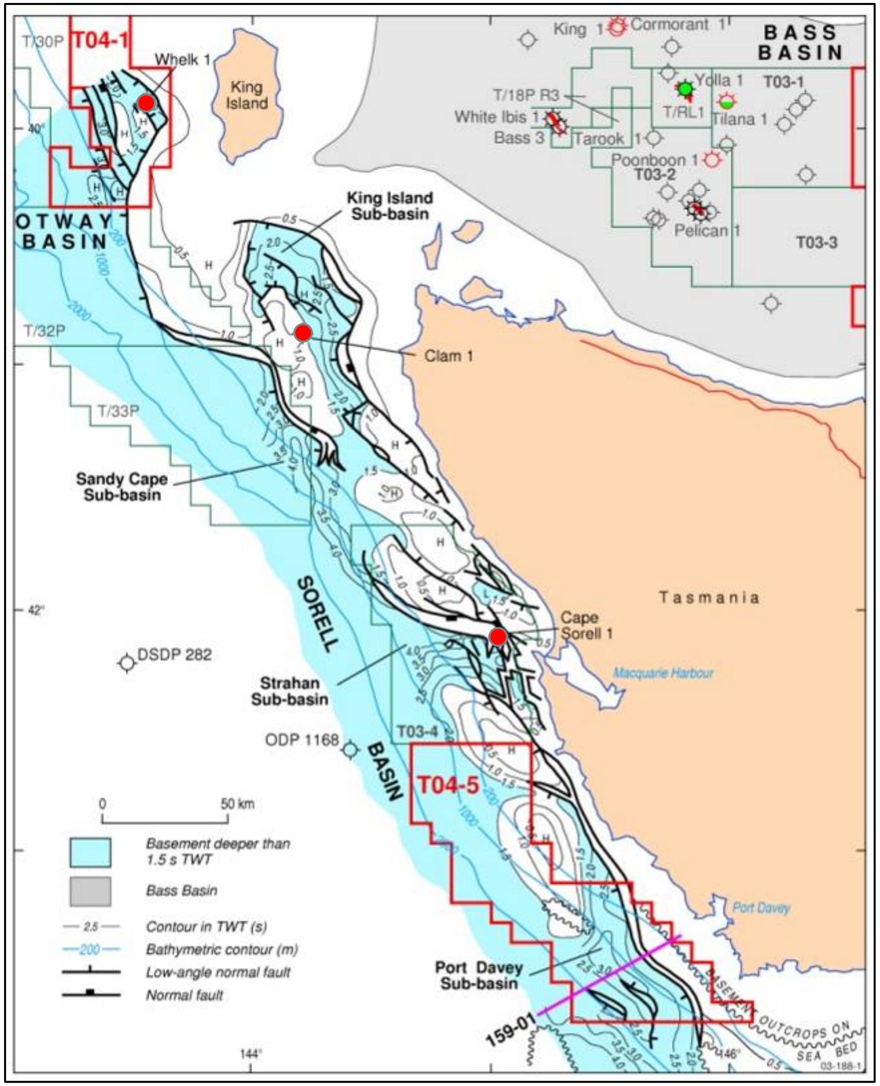


Figure 54. Seismic line OS88A-06 across the Snail Terrace showing the presence of high amplitude reflections near the base of the rift which have been inferred to be the Casterton Formation. The sections also show evidence of Late Cretaceous faulting on the Snail Terrace (probably associated with Cenomanian uplift and collapse) that is unconformably overlain by sediments of the Late Eocene Demons Bluff Formation. There is also evidence of syn-tectonic growth against the major boundary fault within the Eastern View Formation.



Basin Summary – Sorell Basin

The NW trending Sorell Basin is located on the transitional boundary between the Delamerian and Lachlan Fold Belt terranes. The boundary between the Otway and Sorell basins is poorly defined and the basins are thought to be largely continuous (Moore et al., 2000), particularly between the Sandy Cape Sub-basin and the Shipwreck Trough. The Sorell Basin contains Early Cretaceous to Recent mostly non-marine sediments (fluvial and red beds), overlain by younger post-rift paralic and shallow marine siliciclastics and carbonates.

Rigorous mapping of the basin structure is precluded by limited seismic datasets – particularly the areas lying between the King Island and Strahan sub-basins, and south of the Strahan Sub-basin. Well data is also limited to two depocentres – the King Island (Clam-1) and Strahan (Cape Sorell-1) sub-basins. Clam-1 is located over a shallow basement fault block and intersected a thinned updip succession from an adjacent half graben. Cape Sorell-1 is located near a basin-bounding fault and intersected coarse clastic alluvium probably associated with the fault scarp.

The Sorell Basin is composed of seven depocentres (King Island, Sandy Cape, Strahan, Port Davey, Toogee and two unnamed sub-basins) along the western Tasmanian margin (Exon et al., 1997). Geometry of the narrow, relatively deep depocentres is controlled by transtensional fault systems from Cretaceous to Paleocene and left-lateral strike slip from Early-mid Eocene. Southward propagation of seafloor spreading resulted in collapse of the margin with thick prograding Paleocene sequences to the north (Otway) and prograding Eocene sequences to the south (Sorell Basin and South Tasman Rise; Hill et al., 1997). Continued movement of the transform plate margin along western Tasmania, culminated in final separation and clearance of the Australian and Antarctic plates at 33.5 Ma (Exon et al., 2001).

Figure 55. Tectonic elements of the Sorell Basin along the western margin of Tasmania. (ITR, 2004)

Basin Summary – King Island Sub-basin (Sorell Basin)

The King Island Sub-basin is an elongate, isolated half graben that underlies the continental shelf south of King Island (see Sorell Basin summary for location). Seismic data suggests minor growth during the Early Cretaceous Otway Sequence was followed by significant extension during deposition of the Shipwreck and Sherbrook supersequences – similar to the age of growth packages observed in the offshore Otway Basin. Volcanic intrusions are interpreted in the lower part of the Shipwreck Supersequence. An inversion anticline occurs within the hanging wall succession. Significant erosion of the Sherbrook Supersequence is interpreted over this feature at the base of the Wangerrip Supersequence. Limited biostratigraphy at Clam-1 indicates a short hiatus at the boundary and highlights the local nature of the uplift. Timing of the uplift and erosion is interpreted as Latest Cretaceous to Paleocene similar to the southwest plunging folds on the Prawn Platform to the north. Uplift of the west Tasmanian margin is supported by apatite fission track analysis indicating cooling, possibly due to uplift and erosion (O'Sullivan and Kohn, 1997). This uplift is near the timing of rapid erosion in Victoria Land and the Transantarctic Mountains and onset of seafloor spreading off SW Tasmania (55 Ma; Davey and Brancolini, 1995; Hill and Exon, 2004). The flat-lying Wangerrip and upper Sherbrook supersequences are cut-out by a single canyon adjacent the boundary fault to the east, similar to incision in the Sorell Basin (see later). The Nirranda Supersequence progrades into limited accommodation to the SW.

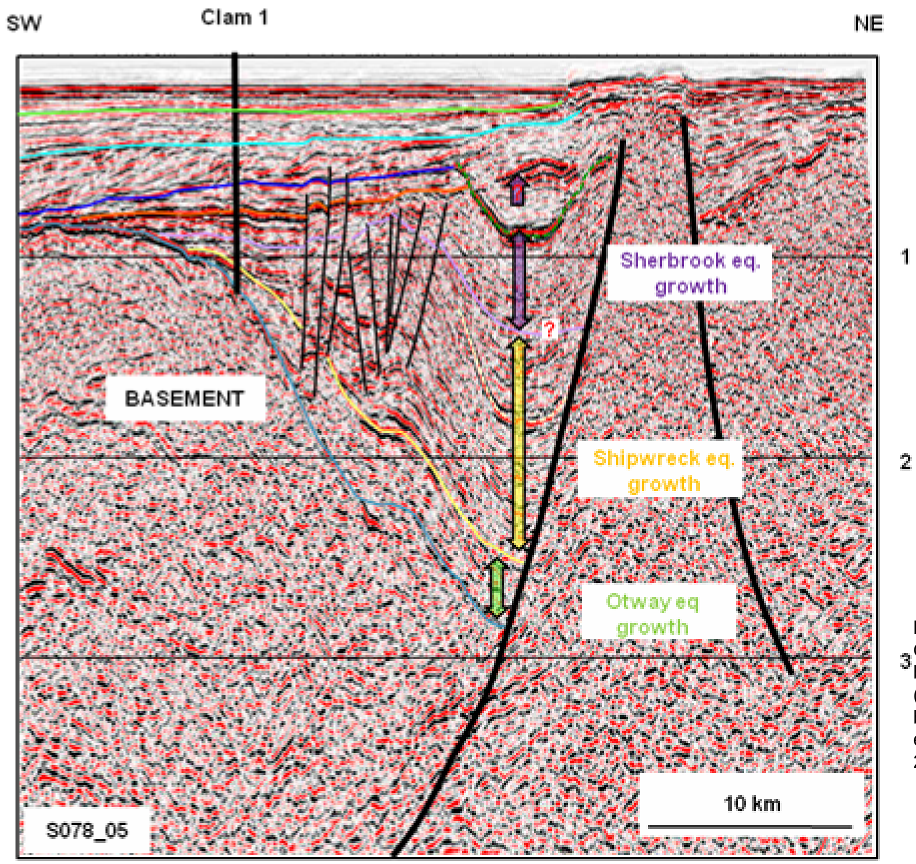
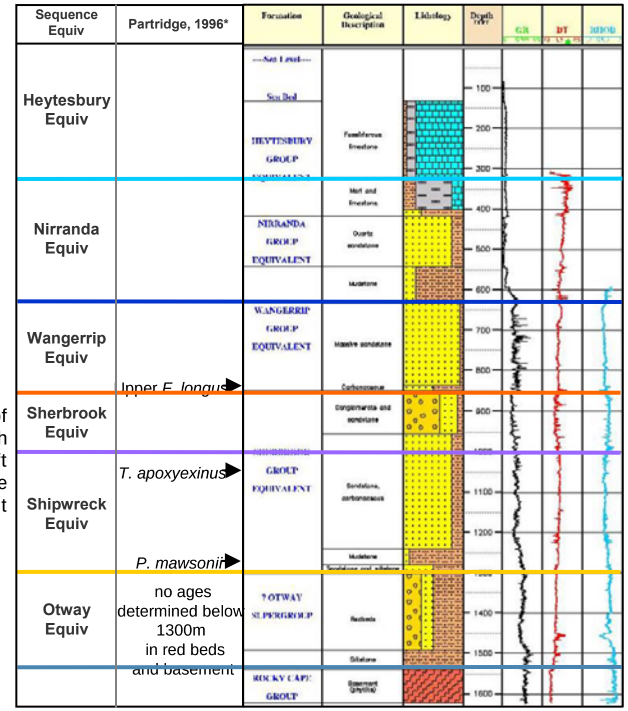


Figure 56 (left). Interpretation of Geoscience Australia line 78-05 through Clam-1, showing evidence of syn-rift growth during deposition of the Shipwreck and Sherbrook equivalent supersequences

Figure 57 (right). Well logs for Clam-1 showing the most recent biostratigraphic work of Partridge (1996). Approximate sequence boundaries and supersequence equivalents (after Krassay et al., 2004) are also shown.



Basin Summary – Strahan Sub-basin (Sorell Basin)

The Strahan Sub-basin has the greatest density of seismic data along the western Tasmanian margin and a single well that intersects the upper part of the Late Cretaceous. The section below the well is interpreted to contain Early and Late Cretaceous non-marine sediments. Seismic data suggests the margin has experienced multiple magmatic episodes, although the lack of good stratigraphic controls prohibits a good spatial and temporal understanding of these events. Oil shows and hydrocarbon seeps have been interpreted in the Strahan Sub-basin by Boreham et al (2002) and O'Brien et al (2004). There is no evidence of an active petroleum system in the other depocentres of the Sorell Basin.

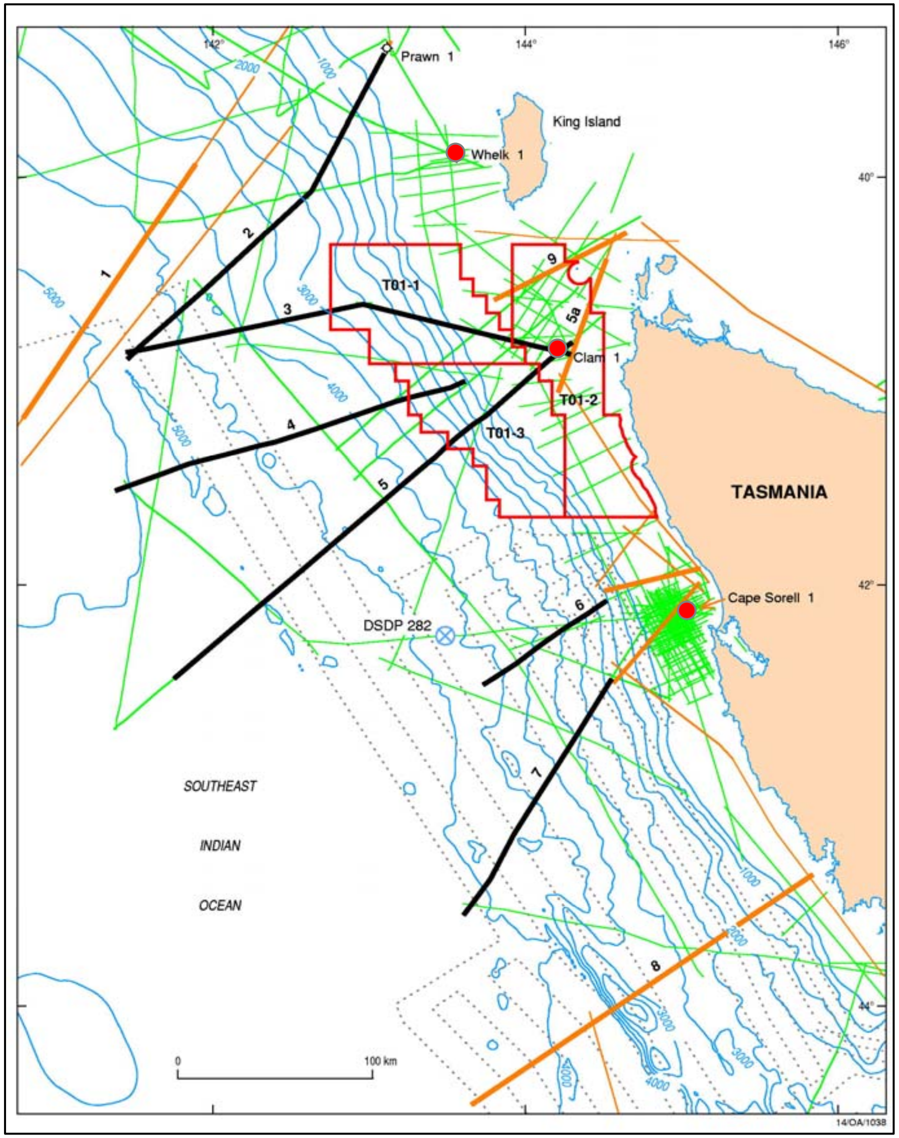


Figure 58 (left). Regional bathymetry and seismic line location map of the Sorell Basin (from ITR, 2001).

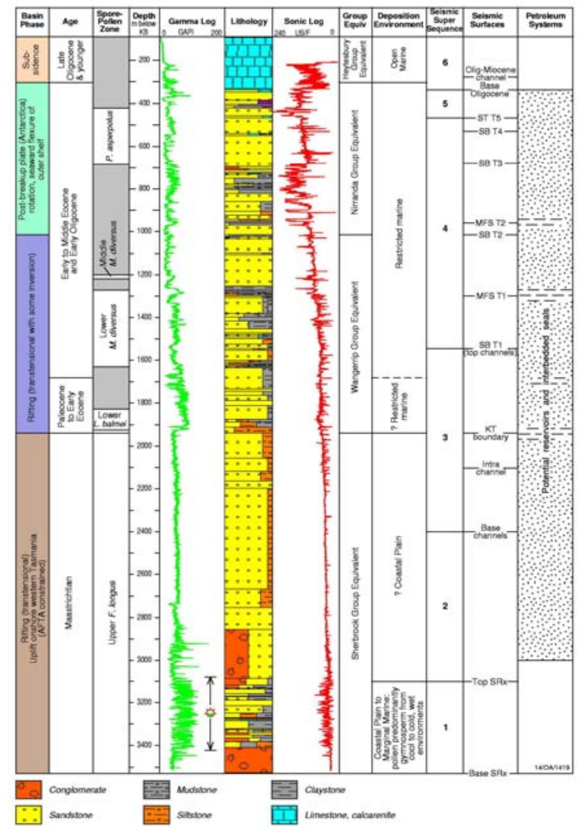


Figure 59 (right). Well logs for Cape Sorell-1 showing stratigraphy, spore/pollen picks (MacPhail, 2003), formation equivalents and mapped horizons (modified from Boreham et al., 2002).

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Basin Summary – Strahan Sub-basin (Sorell Basin)

The Strahan Sub-basin is bounded to the east by steep, northwest-trending faults and to the north by steep east-west-trending faults. Both fault sets were active in the Late Cretaceous (and possibly earlier) as indicated by syn-depositional growth into the boundary faults. Approximately north-south extension between Australia and Antarctica and differential extension between the western and eastern Otway Basin resulted in left lateral transtension along the west Tasmanian margin in the Late Cretaceous (Miller et al., 2002). In this tectonic setting, the Strahan Basin developed as a pull-apart basin filled with ?Early and Late Cretaceous sediments. Syn-inversion deposition, folding and incision are observed in the Paleocene at the same time as incision occurs elsewhere along the Otway-Sorell margin. The Tertiary interval is dominated by SSW-SW progradation of fine clastics and carbonates. The thick progradational succession in the Eocene and younger succession represents the progressive collapse of the margin.

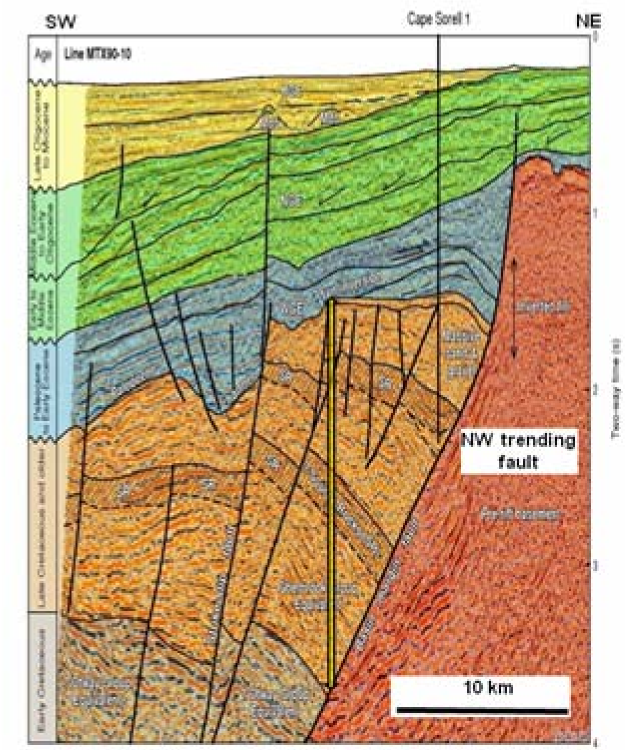
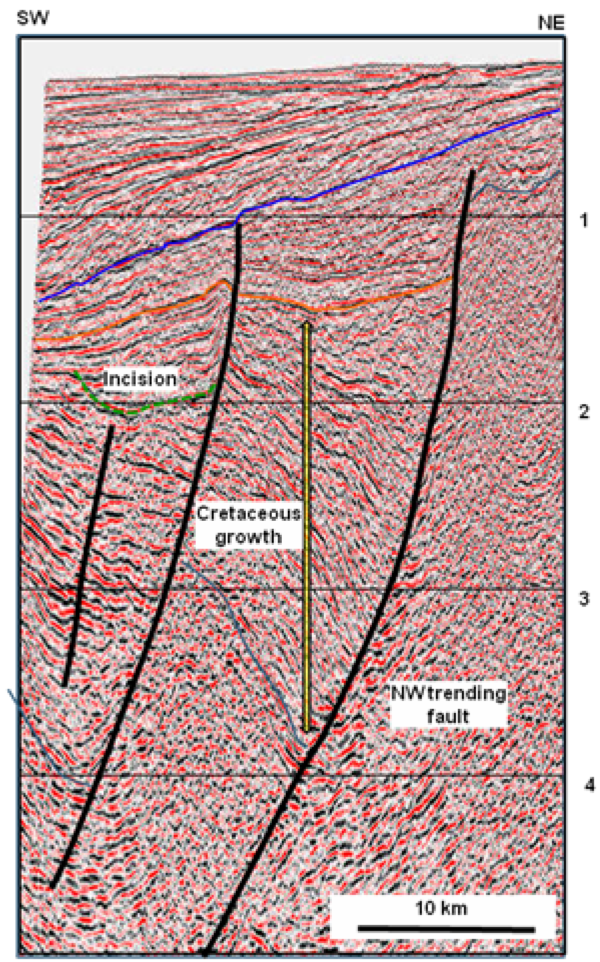


Figure 60 (above). Maxus line MTX90-10 crossing Cape Sorell-1 which intersected upper Late Cretaceous with the section below TD interpreted to contain Early and Late Cretaceous non-marine sediments. Early Cretaceous sediments (Otway Group equivalent) may be present at the base of the rifted sequence (ITR, 2003).



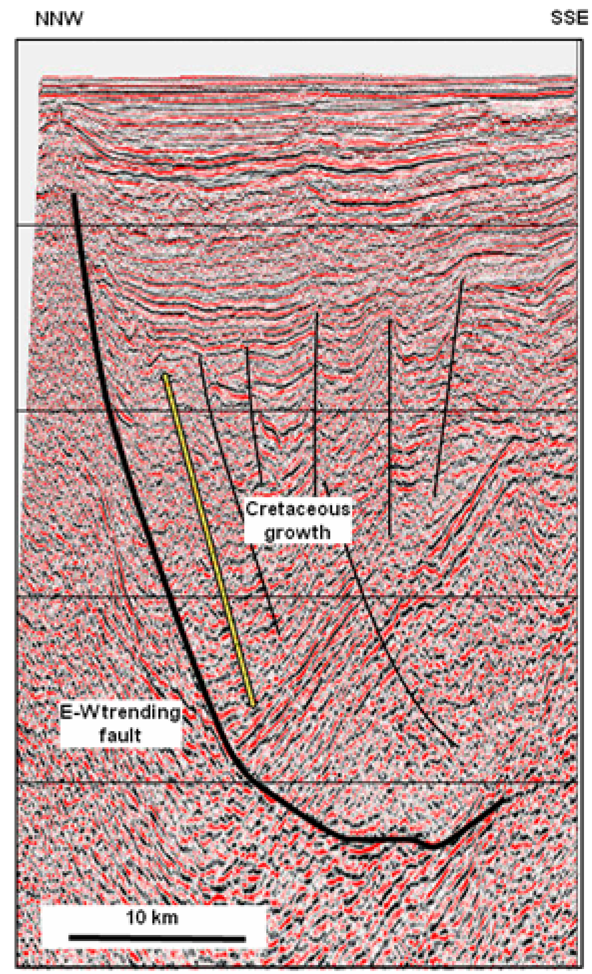


Figure 61 and 62. Interpreted seismic sections MTX90-16 (right) MTX90-13 (far right).

Basin Summary – Bass Basin

The Bass Basin is an Early Cretaceous to Tertiary intracratonic basin that developed over Neoproterozoic mobile belts and the accreted Palaeozoic terranes of the Lachlan Fold Belt. The basin depocentres have a graben and half graben structural style and are bounded by northwest-striking normal faults (Figure 63). Two sub-basins are recognised based on structural style in the eastern and western Bass Basin – the Durroon Sub-basin and Cape Wickham Sub-basin, respectively.

In the Cape Wickham Sub-basin, the southwestern margin of the basin is characterised by a structural ramp (rift shoulder; Figure 64) that dips basinward, while the northwestern margin is generally bounded by a steep (almost vertical) fault that has been focus of reactivation during mid-Miocene compression. This fault is more clearly imaged in the far northwestern corner of the basin near Konkon-1 and Toolka-1A (Figure 63). The northwestern margin of the basin is heavily affected by volcanic intrusions and extrusions.

The western Bass Basin is also characterised by a distinctive intra-basin horst block that is offset along-strike across the Yolla Accommodation Zone (Blevin et al., 2003). This structurally complex area was first described by Etheridge et al (1985) as a series of northwest-trending deep half graben offset by major northeast-trending transfer faults. The near-vertical transfer faults described by Etheridge et al (1985) served to strongly compartmentalise the depocentres. The model was updated by SRK Consulting (2001) who attributed the structural style of the basin to the fabric and rheology of the underlying basement terranes. Subsequent seismic mapping has modified the rigourous orthogonal fault blocks depicted by Etheridge et al (1985) but there are clearly abrupt along-strike offsets of intrabasin structures which are linked to the underlying basement fabric.

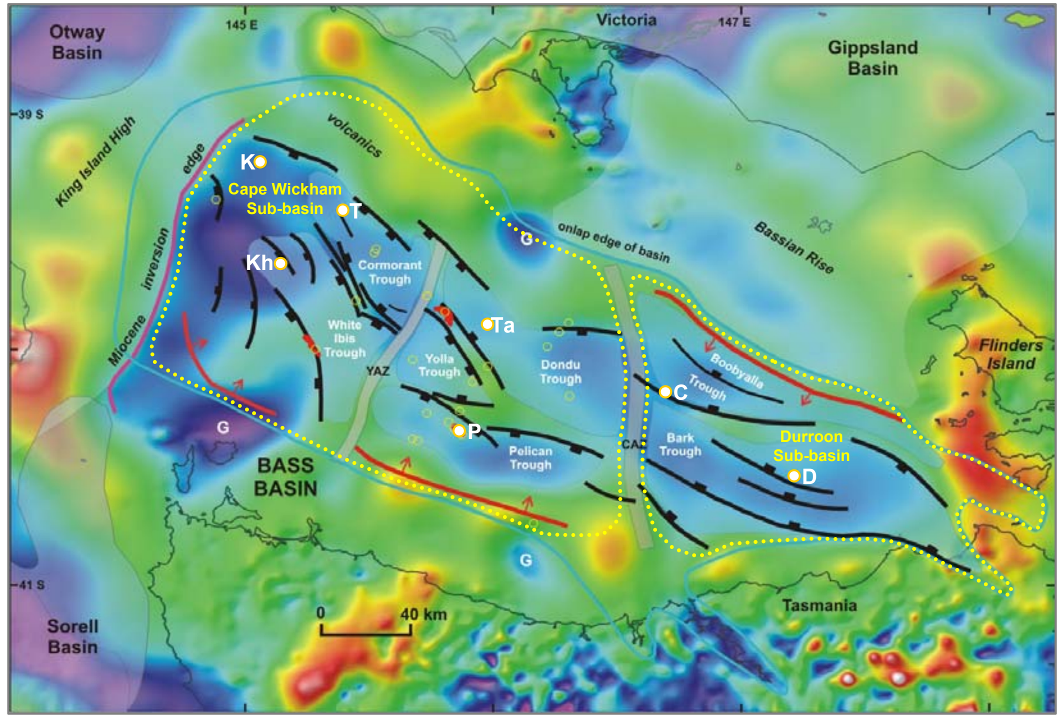


Figure 63. Free-air gravity image overlain by major faults as mapped by Blevin et al (2005). Wells that are discussed in this basin summary are highlighted on this figure a shown: K=Konkon-1, T=Toolka-1A, Kh=Koorkah-1, Ta=Tilana-1, P=Pelican-5, C=Chat-1 and D=Durroon-1.

Three phases of extension are recognised in the western Bass Basin based on seismic stratigraphy (megasequences) and limited well intersections (Blevin et al., 2003, 2005). The nature and extent of these megasequences will be discussed in subsequent pages. The focus of Extension-3 is best observed in the Yolla and Pelican troughs.

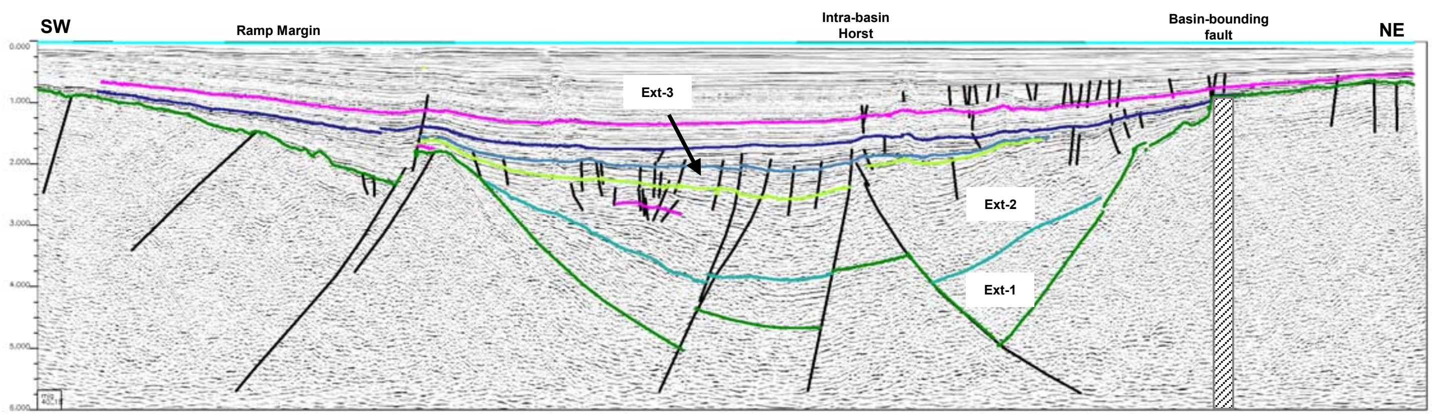


Figure 64. Geoscience Australia seismic line 40-18 showing the structural style of the western Bass Basin (Cape Wickham Sub-basin). The main tectonostratigraphic units related to extension are also shown (Ext-1, -2 and -3).

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Tectonostratigraphy – Bass Basin

Rifting in the Bass Basin did not progress to breakup and the basin remained within the basement ridge that extends unbroken between mainland Victoria and Tasmania. As such, there is no 'breakup event' recorded in the basin, although its location at the junction between the Southern Ocean and the Tasman Sea meant that the basin has undergone multiple periods of deformation (Figure 65).

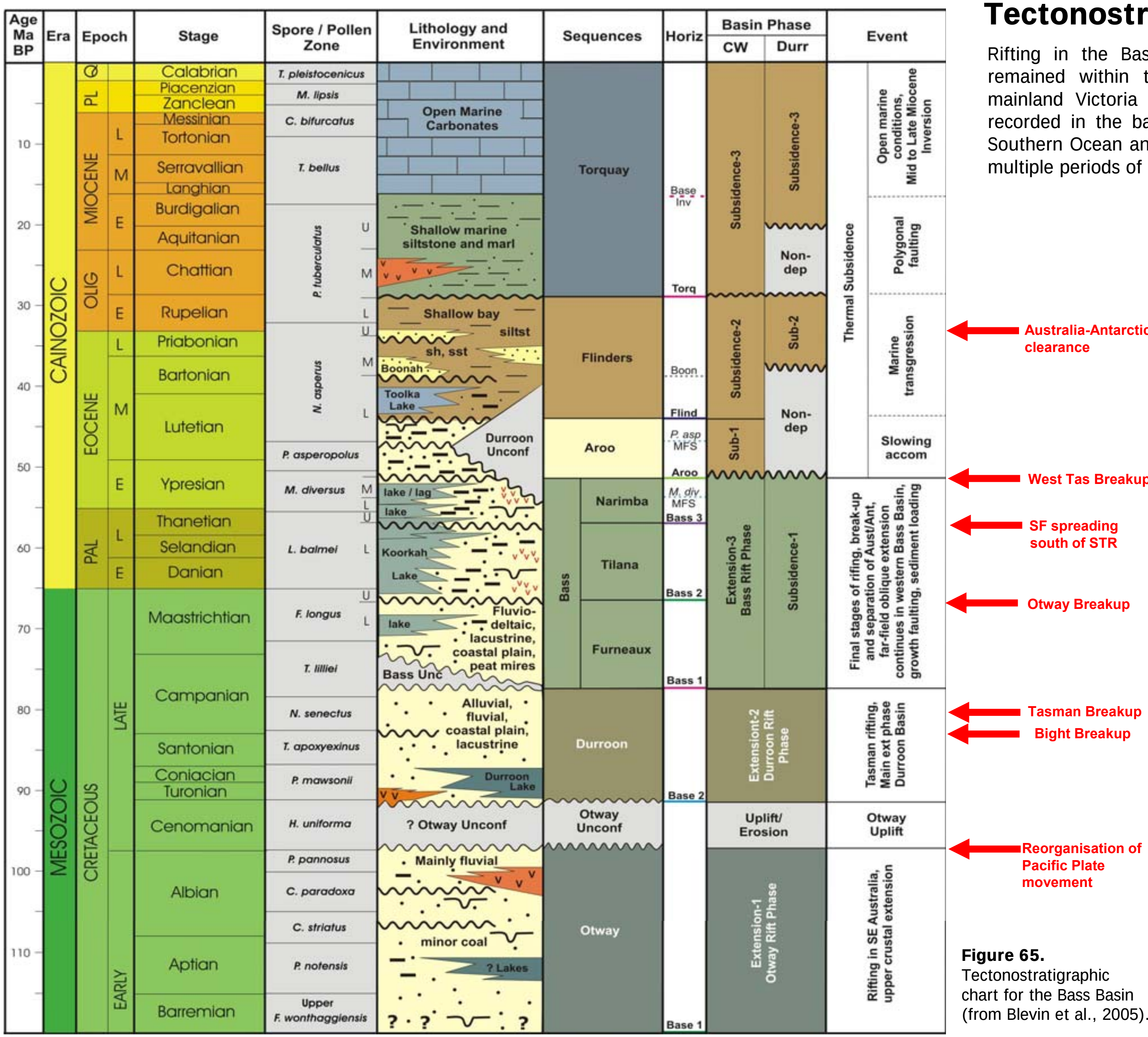

Figure 65. Tectonostratigraphic chart for the Bass Basin (from Blevin et al., 2005).

Some periods of extension associated with the main periods of Southern Margin and Tasman rifting resulted in pervasive upper crustal extension in the Bass Basin. The associated megasequences show clear syn-rift geometries, although age control is poor due to a lack of deep well intersections.

A key event reflected in the accommodation history of the Bass Basin is breakup in the nearby Otway Basin at approximately 67 Ma. From this time onwards, tectonic stresses that affected the basin became more far-field and resulted in selective movement on faults/fault sets of particular orientations, rather than the pervasive effect of events that occurred earlier. The Furneaux Sequence shows more significant growth in the Pelican and Cormorant troughs, while appearing to have thinner and more sag-like geometries elsewhere. The Tilana and Narimba sequences show localised growth on major bounding and intra-basin faults.

The accommodation history of this strongly compartmentalised basin is clearly complex and differs from area-to-area within a given period of time. As such, it is difficult to assign a single Basin Phase that accurately covers all aspects of the accommodation history. As the Bass Basin did not progress to breakup and remained subjected to stresses directly due to rifting and prolonged fragmentation (albeit waning through time), these events have been consolidated into a single Basin Phase (Extension-3).

Further complexity in defining Basin Phases is observed in the Otway Megasequence and this is discussed in subsequent pages.

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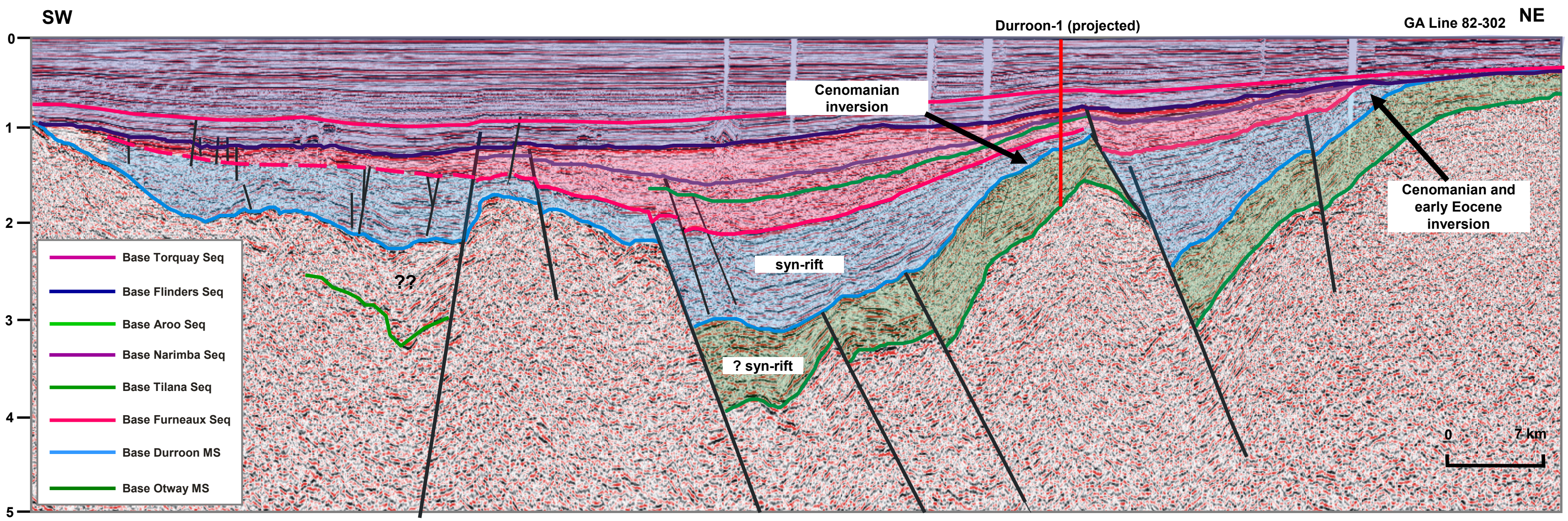
Basin Summary – Durroon Sub-basin

The Durroon Sub-basin (eastern Bass Basin) is characterised by domino-style fault blocks bounded by northeast-dipping planar faults (Figure 66). Some inversion has occurred on the northern and eastern margins of the sub-basin – probably during the Cenomanian and again in the mid-Eocene prior to the deposition of the Flinders Sequence. Durroon-1 and Chat-1 provide the only stratigraphic control on the deeper succession in the entire Bass Basin. The oldest sediments penetrated in the Bass Basin belong to the basal Otway Megasequence intersected at Durroon-1. The Otway Megasequence contains volcanogenic sediments and is age equivalent to the Eumeralla Megasequence (Krassay et al., 2004) in the nearby Otway Basin. The structural nature of this sequence in the Bass Basin is somewhat unclear due to limited stratigraphic control and the uncertainty encountered when mapping between structurally compartmentalised depocentres. In the Durroon Sub-basin, this megasequence has a overall sag geometry although seismic data indicates minor growth on faults near Chat-1 (Blevin et al., 2003). There is no evidence in the Durroon Sub-basin of a deeper pre-Otway Megasequence that would be age equivalent to the syn-rift Crayfish Group in the Otway Basin (Late Jurassic to late Barremian).

In the Otway Basin, the Eumeralla Megasequence (age equivalent of the Otway Megasequence in the Bass Basin) is generally characterised by a sag geometry (Krassay et al., 2004; Norvick and Smith, 2001). However, significant syn-rift growth on faults is observed during Eumeralla deposition in the Torquay Sub-basin (Cooper and Hill, 1997; this study) and the Shipwreck Trough (Krassay et al., 2004; Palmowski et al., 2004; this study) of the eastern Otway Basin. Similarly, Power et al (2004) also interpret active syn-rift growth on some faults in the Gippsland Basin during deposition of the Upper Strzlecki Group (mostly in the western Gippsland Basin), while other areas of the basin experienced sag deposition.

Across the Southern Margin, the collective evidence does not support a model of pervasive, margin-scale rifting during the Aptian-Albian period (ie., Eumeralla/Otway/Upper Strzlecki megasequences). However, evidence of active faulting during this timeframe appears to be confined to the eastern Otway, western Gippsland and possibly the western Bass Basin. This scenario would suggest a component of movement centered along and near the boundary between the Delamerian and Lachlan fold belts. Given the distribution and possible nature of such tectonism, it is proposed that the Aptian to Albian be considered a 'Rift Transition Phase' in basins which support evidence of active faulting. Clearly, better well data to constrain the age and nature of the deep lying syn-rift sections in the Cape Wickham Sub-basin will help to resolve these issues.

Figure 66. Geoscience Australia seismic line 82-302 from the Durroon Sub-basin (western Bass Basin) showing megasequences mapped



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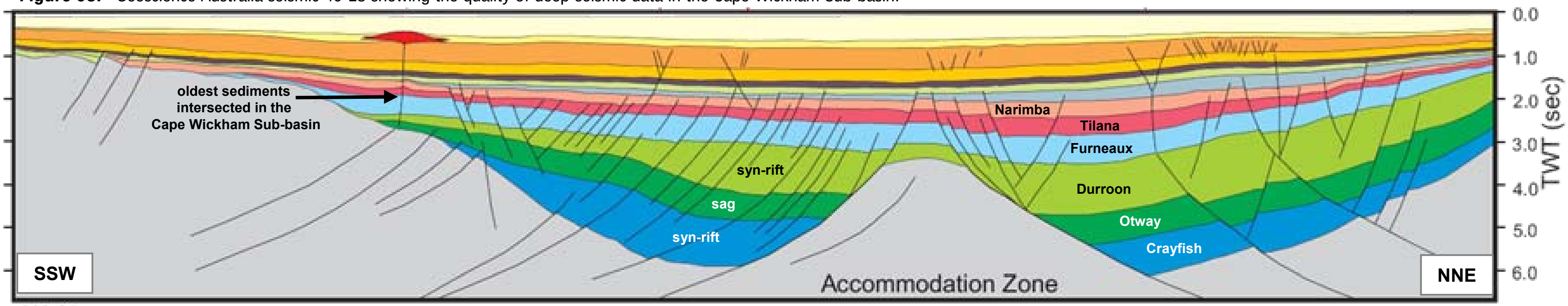
Basin Summary – Cape Wickham Sub-basin

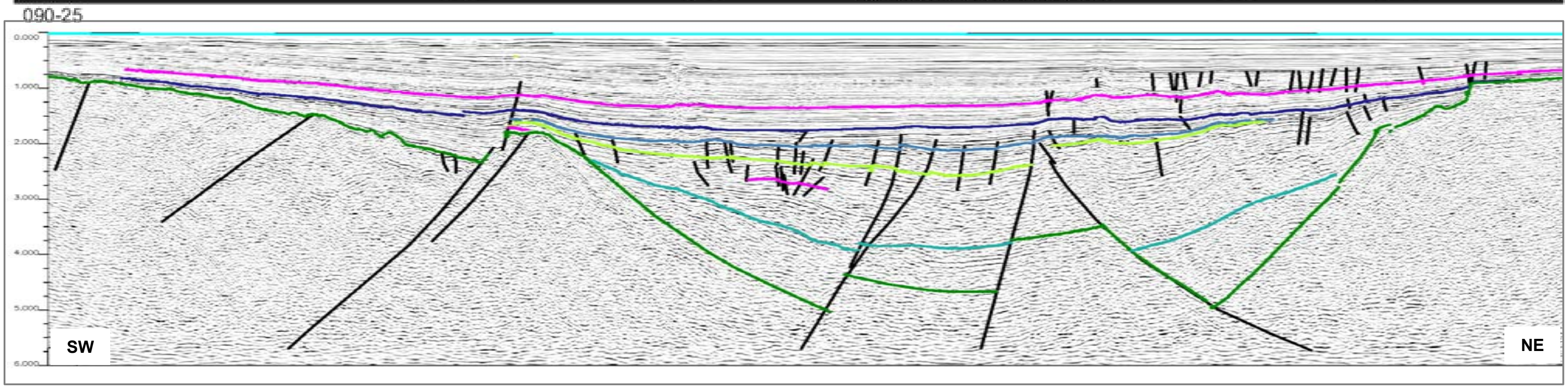
Cummings et al (2004) published a new structural interpretation of the deep basin succession in the Bass Basin based on concepts developed from Geoscience Australia deep seismic lines in the western basin (Survey 90; Cape Wickham Sub-basin). Here, Cummings et al (2004) interpreted the presence of a deep syn-rift section which they infer from its geometry to be age equivalent to the syn-rift Crayfish Group (roughly Berriasian to mid-Barremian; Figure 67). Overlying this syn-rift package, is the sag phase Otway Sequence – which is intersected in Durroon-1 and is 'Eumeralla' equivalent (mid-Barremian to late Albian). Cummings et al (2004) propose that the Crayfish Sequence that is interpreted in the Cape Wickham Sub-basin is not present in the Durroon Sub-basin, where deposition began with sag phase Otway Sequence. The Turonian to mid-Campanian Durroon Sequence is also interpreted in the Cape Wickham Sub-basin where it shows divergent geometries into extensional faults – and this is consistent with observed geometries in the Durroon Sub-basin.

The model presented by Cummings et al (2004) is a viable alternative interpretation of the deeper succession than presented in Blevin et al (2003; Figure 68). The model as presented relies strongly on seismic definition of megasequence units and correlation of events to the Otway Basin. Sediments as old as the Crayfish Group have not been interpreted by previous studies, while the oldest sediment intersected in the Cape Wickham Sub-basin is Late Maastrichtian in age (Koorkah-1) – some 70Ma years younger than the basal Crayfish Group. The correlation of basin phases between the Bass and Otway basins should also consider that extensional growth is observed in the Torquay Sub-basin (Cooper and Hill, 1997) and the Shipwreck Trough (Krassay et al., 2004) during the Albian-Aptian time. These areas are due west of the Cape Wickham Sub-basin, thus extension may have occurred in the western Bass Basin during this time.

Figure 67. Interpretation of Geoscience Australia seismic line 90-25 from the Cape Wickham Sub-basin by Cummings et al (2004) showing the deep syn-rift Crayfish Sequence.

Figure 68. Geoscience Australia seismic 40-18 showing the quality of deep-seismic data in the Cape Wickham Sub-basin.





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Basin Summary – Cape Wickham Sub-basin

The western Bass Basin has a graben and half graben structural style with a distinct intra-basin horst block that has been interpreted to be an structural accommodation zone (Cummings et al., 2004). Stratigraphic control is variable across the basin and mapping of the deeper section is difficult due to the strong compartmentalisation of the depocentres, along-strike offsets and variable data quality. However, deeper wells such as Pelican-5, Tilana-1 and Koorkah-1 provide regional ties to the Late Cretaceous and Early Paleocene successions (Figure 69). Blevin et al (2003, 2005) interpreted that variable growth was observed between the segmented depocentres, thus no single seismic section or well tie is wholly representative of the accommodation history of the Bass Basin.

The deep succession that onlaps the White Ibis-1 fault block shows significant growth within the Durroon/Otway, Furneaux and Narimba sequences (Figure 70). This indicates periods of active extension from the ?early or Mid-Cretaceous to latest Paleocene time. The Aroo Sequence shows increased thickness against selected faults on the northern margin of the basin and within the Pelican Trough. The large Miocene inversion anticline at Cormorant-1 is the largest structure in the Bass Basin (Figure 70) with contraction coevel with deformation in the Otway and Gippsland basins.

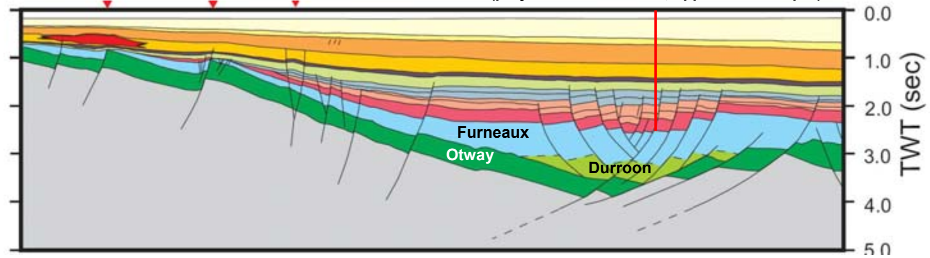
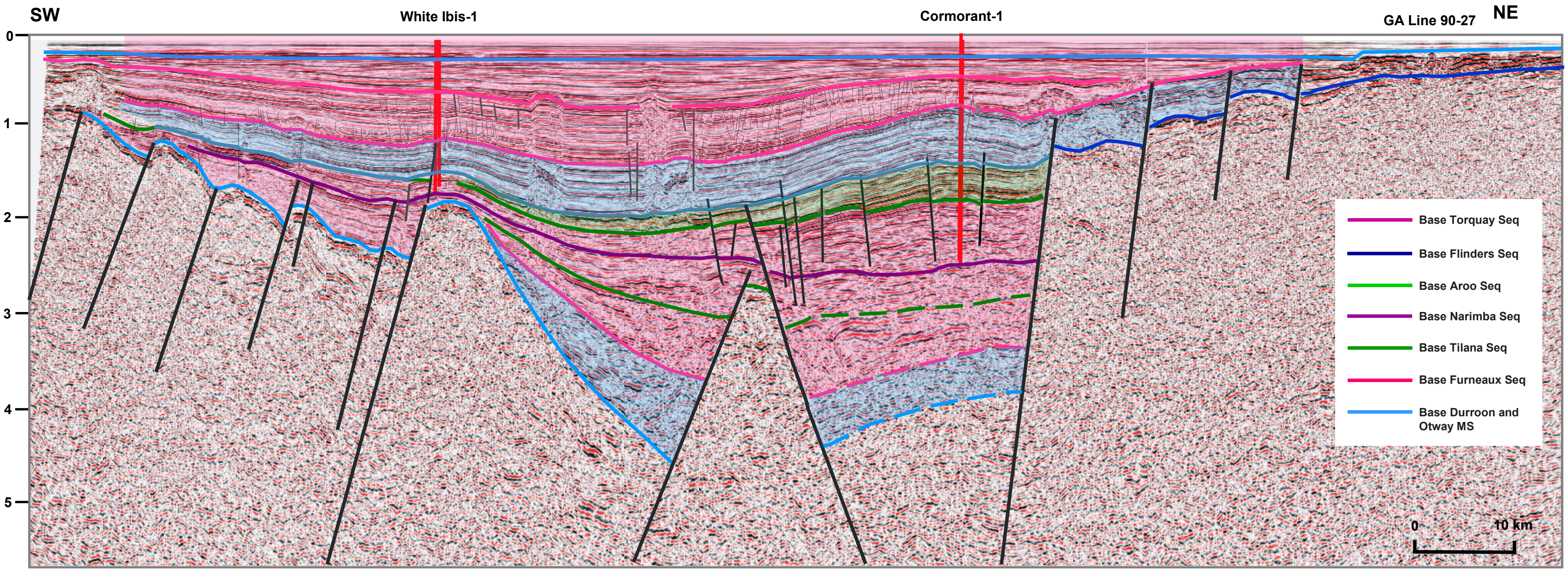


Figure 69. Geoseismic section across the Pelican Trough showing growth within the Furneaux Sequence (from Cummings, et al., 2004). The Otway succession interpreted by Cummings et al (2004) could be a much older succession of pre-rift rocks that outcrop onshore.

Figure 70. Geoscience Australia seismic line 90-27 across the western Bass Basin (Cape Wickham Sub-basin) showing megasequences mapped by Blevin et al (2003, 2005).



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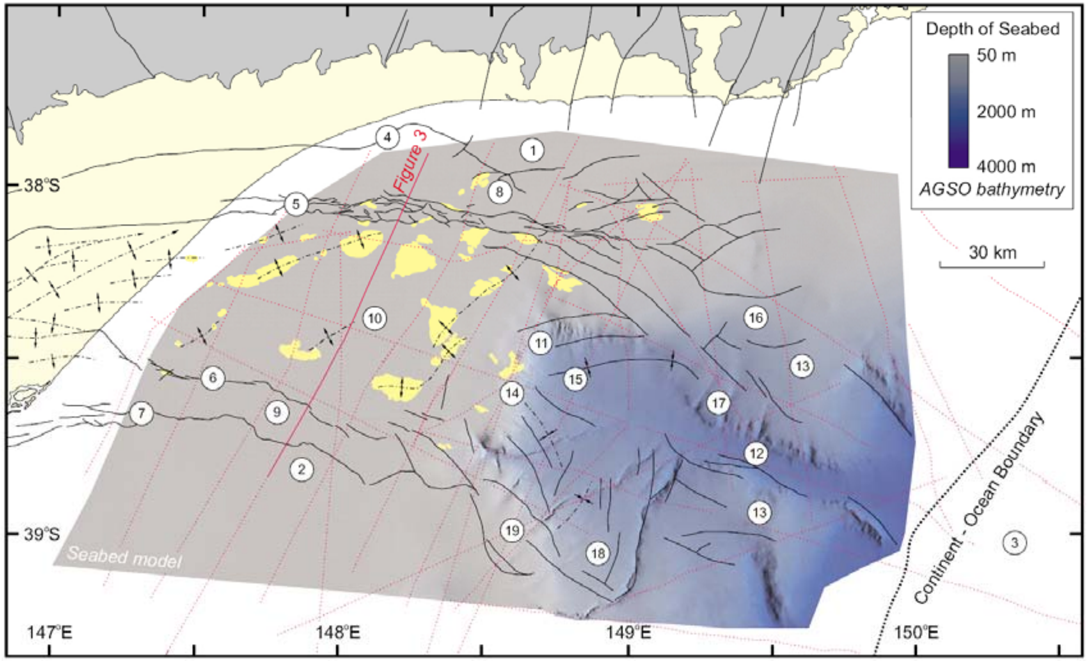
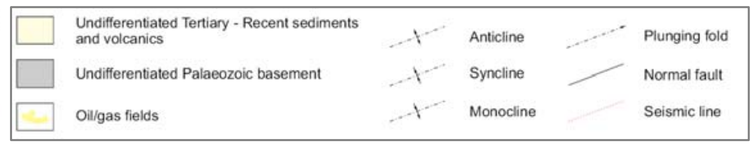


Basin Summary – Gippsland Basin

The Gippsland Basin is located along Australia's eastern margin and was strongly affected by rifting in eastern Gondwana and breakup in the adjacent Tasman Sea. However, evidence of Late Jurassic extension suggests that initial development of the rift basin was linked to tectonic events involved in Southern Margin rifting. Power et al (2001) interpreted and depth converted more than 4000km of 2D seismic and generated 15 regional horizon maps from Palaeozoic to Late Tertiary to develop a 3D model for evolution of the Gippsland Basin. This work undertook a more detailed mapping approach than the previous work of Willcox et al (1992) and used reprocessed Geoscience Australia deep seismic data.

Power et al (2001) identified two rift phases and related megasequences: 1) Early Cretaceous Strzlecki Megasequence (Strz1 and Strz2); and 2) Middle Cretaceous Emperor and Golden Beach (combined) Megasequence – shown as units 11/12/13 and 10, respectively, on Figure 72.

Figure 71. Bathymetry map of the Gippsland Basin overlain by major faults (key shown below; from Power et al., 2001).



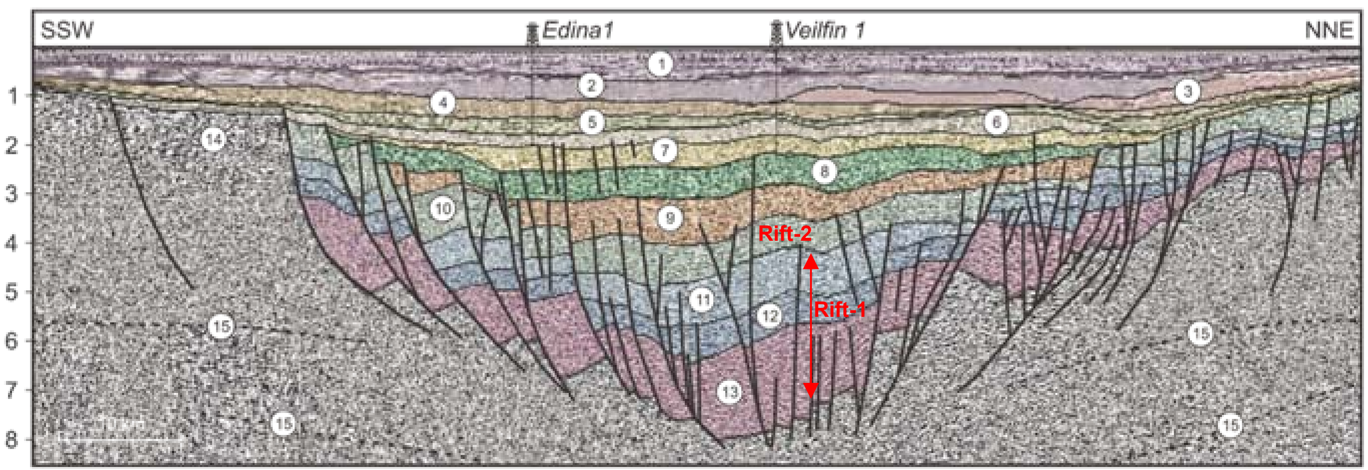


Figure 72. Interpreted seismic line across the Gippsland Basin showing the major megasequences mapped (key to numbers and the stratigraphic key shown below relate to a stratigraphic column shown on Figure 73 on the following page; from Power et al., 2001).

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Basin Summary – Gippsland Basin

Mapping of the Early Cretaceous rift phase (Strzlecki Megasequence) indicates the main Early Cretaceous depocentres were the Central Deep (CD), Eastern Graben (EG), Northern Graben (NG), Southern Graben (SG) and SE Strzlecki Graben System (SGS; Figure 74; Power et al., 2001). The Middle Cretaceous rift phase obliquely reactivated the underlying Early Cretaceous and basement structures with deposition largely confined within the Foster (FFS) and Rosedale (RFS) fault systems. The Rosedale Fault System was a major feature during this period, while the greatest amount of extension probably occurred through the Eastern to Southern graben. The well control used in this study is not specified (Power et al., 2001).

Based on the seismic cross-section published by Power et al (2001; previous Figure 72), it would appear that extensional geometries within the Early Cretaceous rift succession are best developed in Strz1 (Berriasian to Hauterivian) and Strz2b (Aptian to early Albian). The intervening section (Strz2a; Barremian to earliest Aptian) appears to be more continuous in thickness across the basin thinning only onto the basin margins – thus may be more sag or ‘waning rift’ related.

Power et al (2001) do not mention Late Jurassic involvement in the offshore rift development, as most evidence of these older sediments is known from onshore well intersections. However, this does not preclude the occurrence of Late Jurassic sediments within the basal section of Strz1.

The Middle Cretaceous rift phase (Emperor and Golden Beach; Turonian to mid-Campanian) is chronostratigraphically equivalent to Durroon Rift Phase in the Bass Basin, and was related to extension in eastern Gondwana prior to breakup in the Tasman Sea.

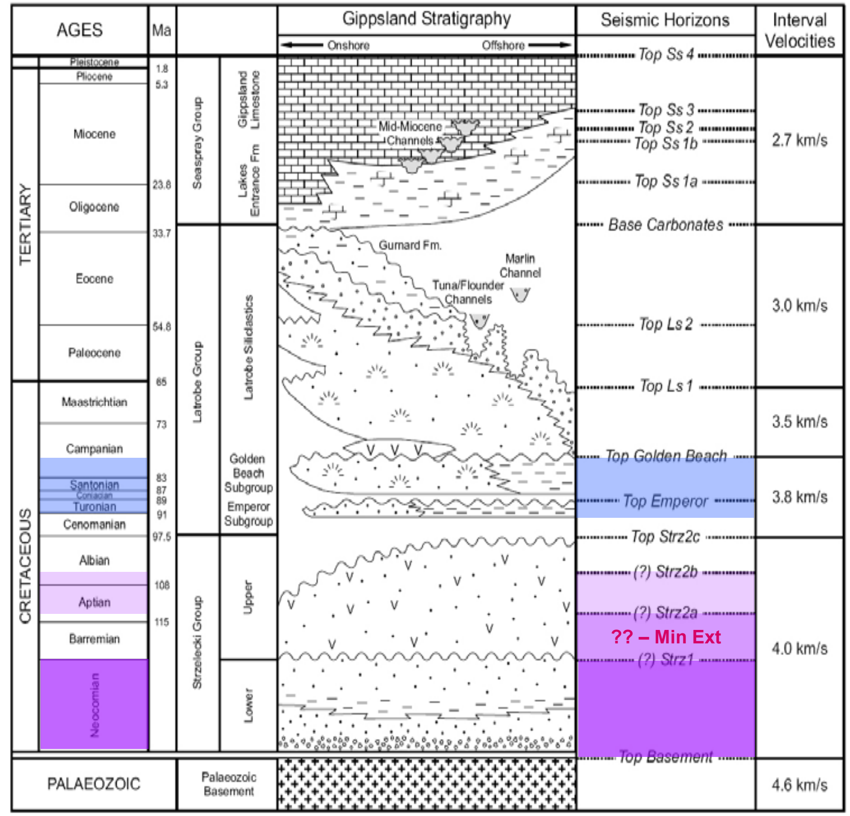


Figure 73. Stratigraphic column and mapped horizons in the Gippsland Basin study of Power et al (2001).

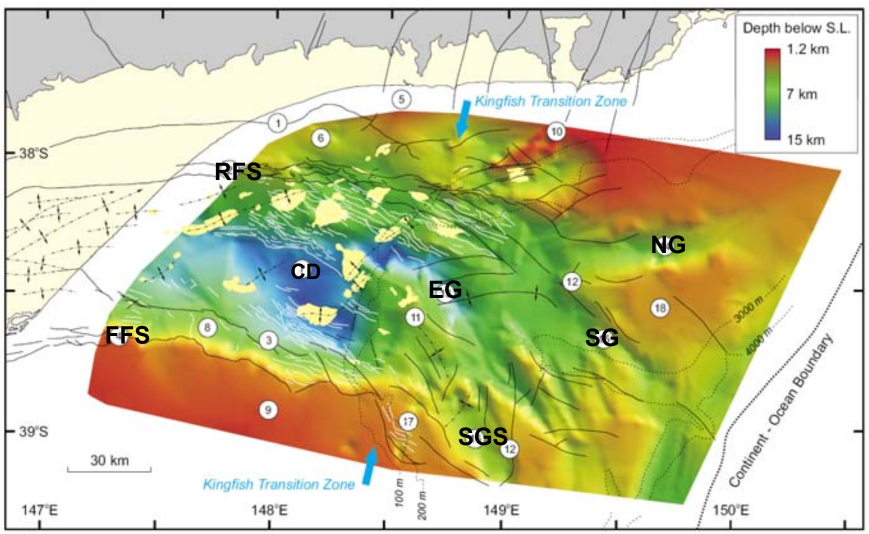
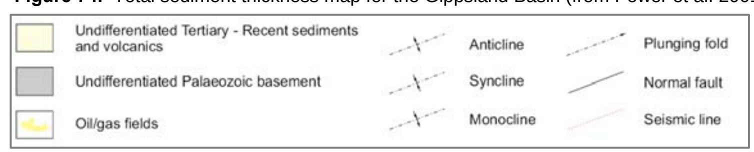


Figure 74. Total sediment thickness map for the Gippsland Basin (from Power et al. 2001).



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Basin Summary – Gippsland Basin

Geosec™ restoration was undertaken on a 2D slice from the 3D model derived from the regional mapping (Power et al., 2001). A detachment surface interpreted by Willcox et al (1992) was also tested by the restorations. The modeled restoration resulted in (brittle) extension factors of 16% (Strz1), 6% (Strz2a) and 5% (Strz2b). The amount of extension during Strz2c is unclear as the top of this unit is strongly affected by erosion.

Earlier observations of the appearance of less active extension (possibly sag geometries) during deposition of Strz2a sequence are highlighted in the restorations. Even though extension is estimated at 6%, this occurred through minor/moderate offset of faults across the basin. In contrast, extension during deposition of Strz2b was less (5%), and the offset is primarily along the Rosedale Fault Zone and faults within the Central Deep.

Rift phase Strz1 correlates closely with the timing of extension in the onshore Otway Basin and parts of the offshore basin. Sediments of this age have not been penetrated in the Bass Basin, but Cummings et al (2004) have inferred their presence from seismic data in the western part of the basin.

The latter part of Rift Phase 1 (Strz2b) is more ambiguous, as observed in the Shipwreck Trough, Torquay Sub-basin and the Bass Basin. In those areas, some evidence of fault movement is observed, but, in general, does not support a margin-scale extensional event during the Aptian-Albian period. However, the focus of observed Aptian-Albian movement appears to centre on a ‘corridor’ extending from the western Gippsland to the western edge of the Shipwreck Trough – and possibly extends into the western Bass Basin.

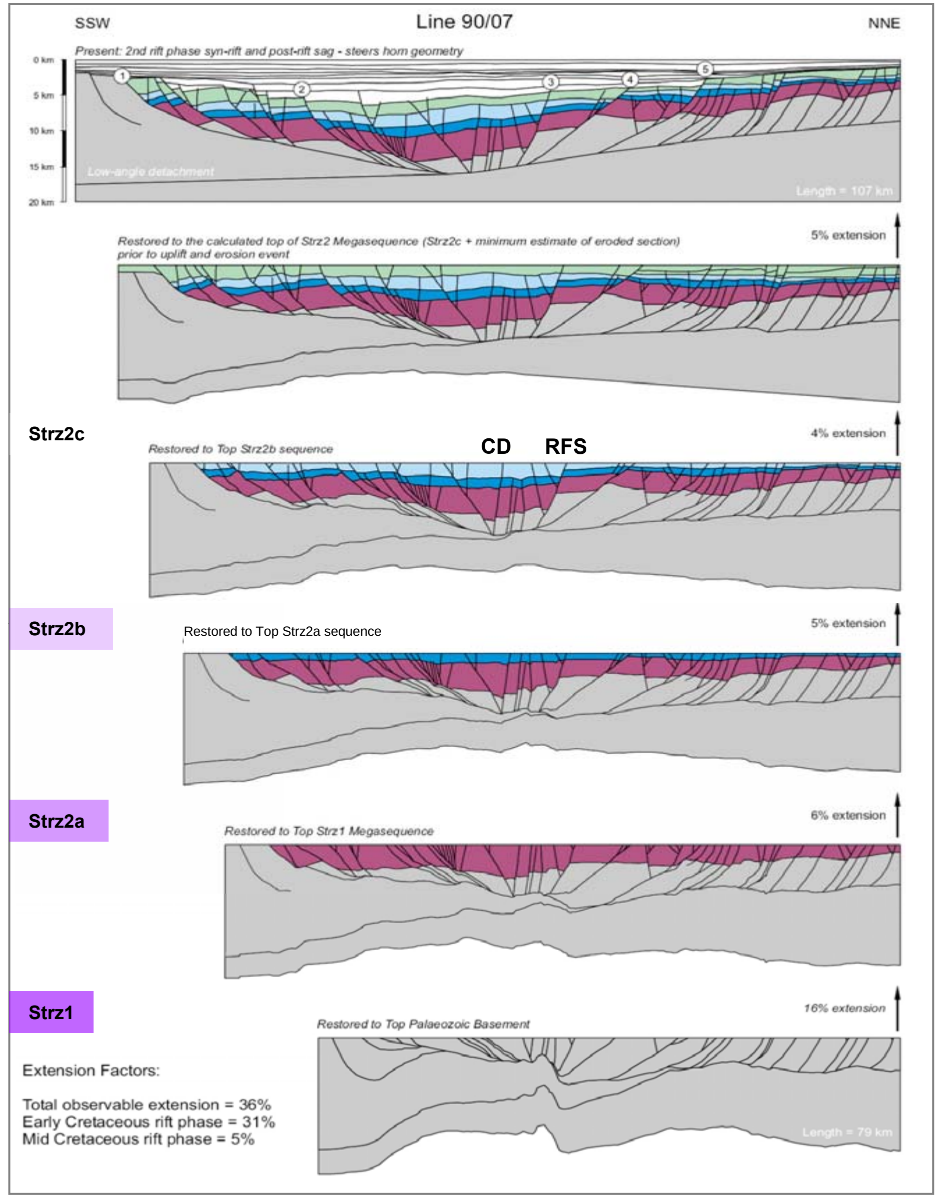
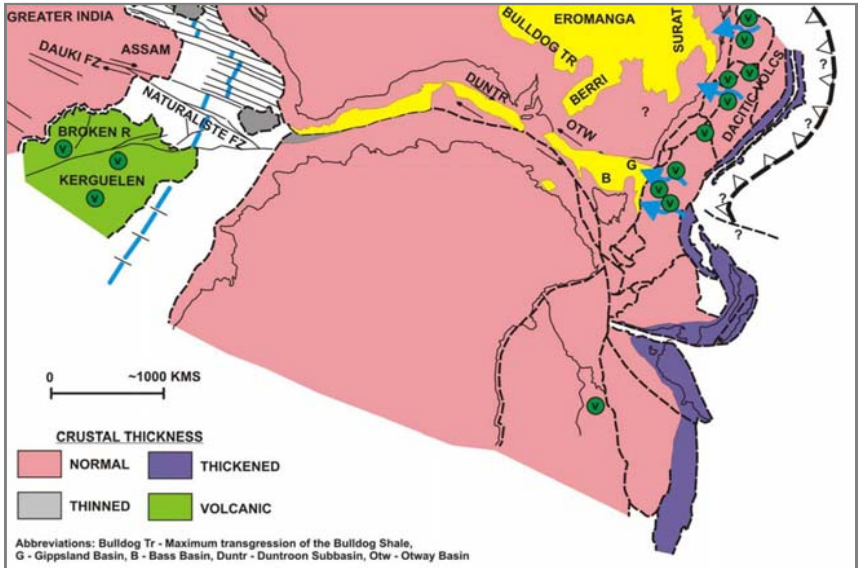
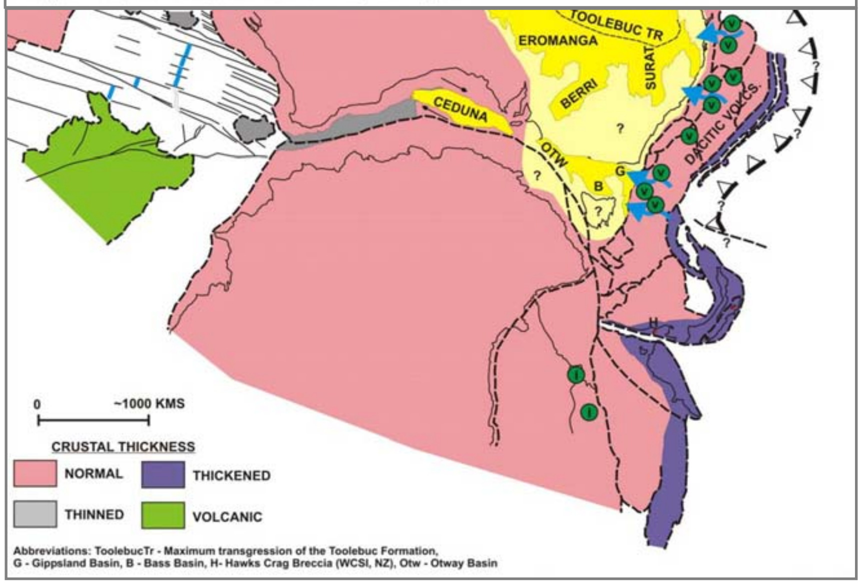


Figure 75. Geosec™ restorations based on regional mapping of the Gippsland Basin (from Power et al., 2001). The locations of the Central Deep (CD) nd Rosedale Fault System (RFS) are noted.





Volcaniclastic Sedimentation

Aptian-Albian age, non-marine sediments in the Gippsland, Otway and Bass basins characteristically contain a high percentage of rock fragments derived from contemporaneous volcanism (Gleadow and Duddy, 1981). These volcaniclastic facies are dominantly dacitic and reflect the magma composition of the principal source which is presumed to be a magmatic complex to the east or northeast of these basins. Lesser amounts of basaltic to rhyolitic fragments are also present in these facies. Near the basin margins, the volcanogenic influence is less pronounced and alluvial fans comprising quartz-rich sandstones and conglomerates were derived from the surrounding Paleozoic rocks (Woollands and Wong, 2001).

In the Gippsland Basin, the onset of volcanic sediment input began in the early Barremian (130 Ma) as recorded within basal sediments of the Upper Strzlecki Group (onshore Wonthaggi Formation). Norvick (2005) records the main period of volcaniclastic input in the Gippsland Basin as 130 to 110 Ma (Barremian to mid-Albian; base *C. hughesii* to base *C. striatus*). To the west in the Otway Basin, volcanogenic sediments occur within the Eumeralla Formation with deposition lasting from the mid-Barremian (123 Ma) to the mid-to-Late Albian (110 Ma). The onset of volcanic input in the offshore Bass Basin is less constrained due to limited well intersections, with Dunroon-1 indicates the onset of volcaniclastic sedimentation in approximately mid-Barremian time (Otway Group). Near Cape Portland, located in northeastern Tasmania, Early Cretaceous age volcanogenic sediments have also been recorded. To the north, volcaniclastic sediments are first observed in Late Aptian (115 Ma) age sediments of the Murray Basin (Norvick, 2005), with sediments of similar age and composition known to occur in the Clarence-Morton, Surat, Styx and Great Artesian basins. Late Albian age volcaniclastics are recorded in sediments as far west as the Duntroon Sub-basin (Smith and Donaldson, 1995).

Fission track analysis on detrital zircon, sphene and apatite from the volcanogenic sandstones indicates that volcanism was contemporaneous or nearly contemporaneous with deposition of the volcanogenic sediments (Gleadow and Duddy, 1981). However, despite the volume of volcanic detritus, no undisturbed airfall tuffs are known and only relatively minor *in situ* igneous rocks have been intersected in the southeastern basins (Woollands and Wong, 2001). Palaeocurrent data precludes an intra-rift volcanic source for the sediment (Felton, 1992), as does the absence of interbedded volcanic rocks within these units. Collectively, this evidence suggests the basins lie outside the zone of blast surge, and that more distal deposited (tuffs) were either very thin, re-worked/destroyed or currently not recognised within the sedimentary succession. Deposition of the volcanic material occurred via fluvial transport from east to west.

Figure 76 (upper left). Plate tectonic reconstructions for the Late Aptian (110Ma) from Norvick (2005).

Figure 77 (left). Plate tectonic reconstructions for the Late Albian (100Ma) from Norvick (2005).

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Volcaniclastic Sedimentation

Bryan et al (1997) have suggested the Early Cretaceous inundation of volcanogenic sediments in the southeastern basins may have been sourced from a north-south-trending rift system that existed off the eastern margin of Australia from approximately 125 to 120 Ma (Figure 78; Mortimer et al., 2005. The Whitsundays Volcanic Province (WVP) and nearby onshore exposures in Queensland (Proserpine Volcanics) are remnants of this system which was estimated to have been 900 km long and 100 km wide with a calculated production of approximately $>1.4\times10^6$ km^3 of volcaniclastic sediments (Bryan et al., 1997). Overall, the volcanic belt probably stretched along the length of the east Australian margin over a distance of more than 2500 km (Bryan et al., 1997). Intrusive activity (mainly granites) was coeval with volcanic activity from approximately 132 to 95 Ma. The main period of magmatic activity occurred from 120 to 105 Ma (Bryan et al., 1997) with explosive volcanism dominant over the period 120 to 115 Ma. Rocks of the WVP consists of dacitic to rhyolitic lithic ignimbrites, with intercalated surge, fallout, lag breccias and phreatomagmatic deposits (Bryan et al., 1997). Basalt lavas are uncommon in the WVP but more volumetrically abundant in mainland exposures (Bryan et al., 1997). Bryan et al (1997) also argue against Early Cretaceous volcanism being related to back arc extension, instead favouring an association with Tasman breakup.

The massive influx of sediment sourced from Early Cretaceous magmatic activity significantly influenced depositional environments in the southeastern basins. Duddy (2003) describe the Eumeralla Formation (Otway Basin) as consisting of multi-story complex channel deposits with extensive overbank and localised lacustrine facies (including coals). These facies developed within major fluvial systems that occupied belts 10s of kms wide. Overall, periods of high sediment influx were probably related to volcanic episodes and basin subsidence rates only just kept up with the fluctuating, but high rate of sediment supply.

The Aptian to Albian period of basin evolution is one of the most interesting periods in the development of the Southern Margin basins. During this time, there is no clear evidence of pervasive extension across the Southern Margin basins, and the Gippsland, Otway and Bass basins have been interpreted to have undergone a 'Rift Transition Phase'. That is, extensional stress are still active (although somewhat abated) as part of the overall tectonic setting of the margin, but appear to only control movement on faults of certain orientations. For this reason, the Aptian-Albian succession has been described as 'syn-rift' by some authors (e.g., O'Brien et al., 1994) and 'thermal subsidence/sag' by others (e.g., Krassay et al., 2004). Fault activity during the Aptian-Albian seems to have been focused in the Shipwreck Trough, possible the Torquay Sub-basin and in the western Bass Basin. Power et al (2001) also notes movement on selective faults during deposition of the Upper Strzlecki Group in the Gippsland Basin. Collectively, this suggests that fault activity was confined to the basins that overlie the eastern foldbelt terranes, with strain focused on or near terranes that underlie the western margin of Tasmania and its extension northward into the continent (Stavely Terrane).

The thickness of the Aptian-Albian succession (Eumeralla Formation) in the Otway Basin suggests rapid or high rates of subsidence in parts of the basin (i.e., the present-day onshore Otway Basin and the 'Inner Basin' of the Duntroon Sub-basin). Differential sediment loading/subsidence across the basin has probably resulted in the reactivation of some faults at the basin margin and this movement could be misconstrued in some cases as 'active mechanical extension', rather than loading.

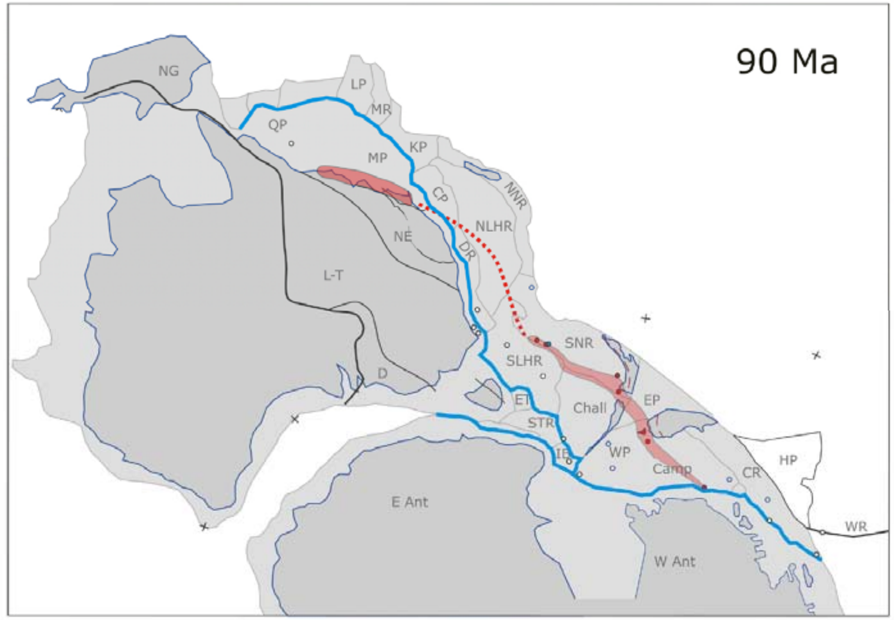

Figure 78: Plate tectonic reconstructions and volcanic terranes in the Tasman Sea region (from Mortimer et al., 2005). The caption from Mortimer et al (2005) described this figure as: an 'untightened' reconstruction of the continental blocks of Australia, Zealandia and Antarctica showing possible along-strike correlation between the Median Batholith of New Zealand and Early Cretaceous Whitsunday Province of Queensland (Tulloch et al., 2005). Ocean basins have been closed but no attempt has been made to unstretch continental crust beneath Cretaceous sedimentary basins or beneath Cretaceous core complexes. Reconstruction is based on Gaina et al (1998) and Sutherland (1999). Thick lines show the places where the major Tasman Sea and Southern Ocean oceanic crust spreading eventually took place, and circles are restored locations of offshore samples and islands. Geographic/bathymetric features: NG=New Guinea, QP=Queensland Plateau, MP=Marion Plateau, LP=Louisiade Plateau, MR=Mellish Rise, KP=Kenn Plateau, CP=Chesterfield Plateau, DR=Dampier Ridge, LHR=Lord Howe Rise (N & S), NR=Norfolk Ridge (N & S), CR=Chatham Rise, HP=Hikurangi Plateau, WR=Wishbone Ridge, Ant=Antarctica (W & E). Geological features: D=Delamerian Orogen, L-T=Lachlan-Thomson Orogen, NE=New England Orogen, EP=Eastern Province, WP=Western Province.

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Igneous Rocks in the Bass Basin

Igneous intrusions and extrusions are common across the Bass Basin with their presence noted in both well intersections and seismic data. Seismic data indicate that the younger volcanic episodes were more prevalent in the Cape Wickham Sub-basin, and that igneous rocks form some component of the basement rocks.

Regional magnetic data is generally low resolution over the offshore basin. However, correlations with seismic data suggests an abundance of volcanic rocks occur along the northern and western margins of the basin towards mainland Victoria and the Bassian Rise (Figure 79 and 80). Onshore outcrop and well intersections suggest these are Tertiary volcanic rocks. Several large, highly magnetic bodies are also imaged along the axis of the Bass Basin near Aroo-1 and Squid-1. Both wells intersected volcanic rocks and seismic data indicates numerous intrasedimentary volcanic features in this area such sills, dykes and possible flows. However, the large features evident on the magnetic data lie at much greater depths.

Higher resolution magnetic data in the onshore and nearshore areas off northwestern Tasmania indicate the presence of northeast-trending, linear, strongly magnetic features associated with the Arthur Lineament that extend towards the Bass Basin. A large granite (G) is surrounded by dyke swarms west of the Arthur Lineament.

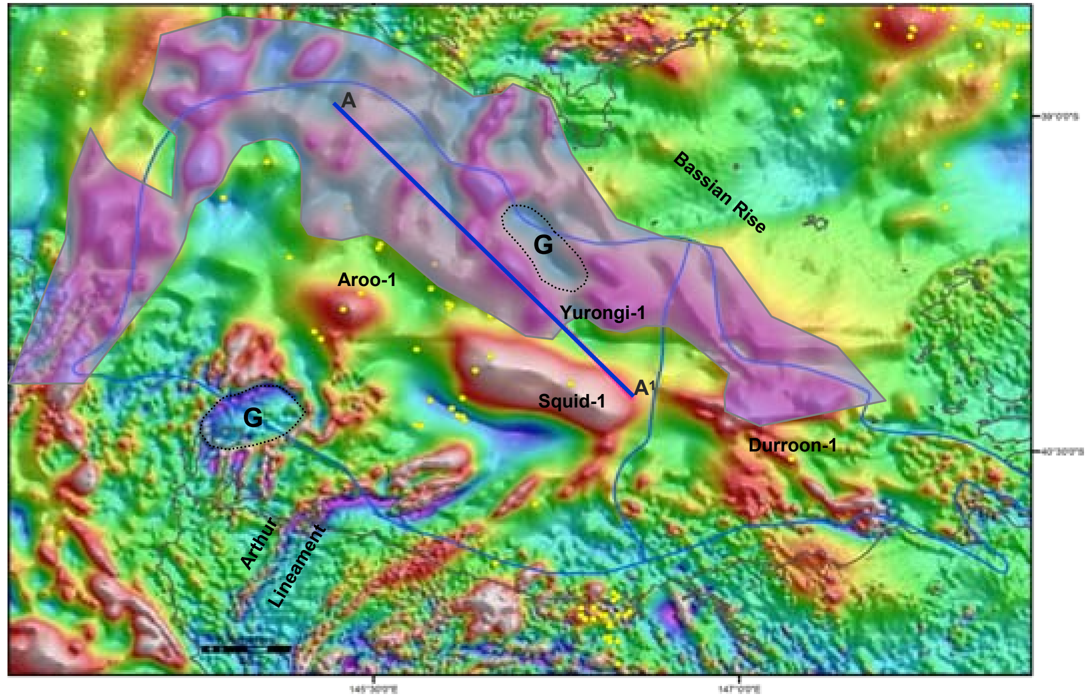
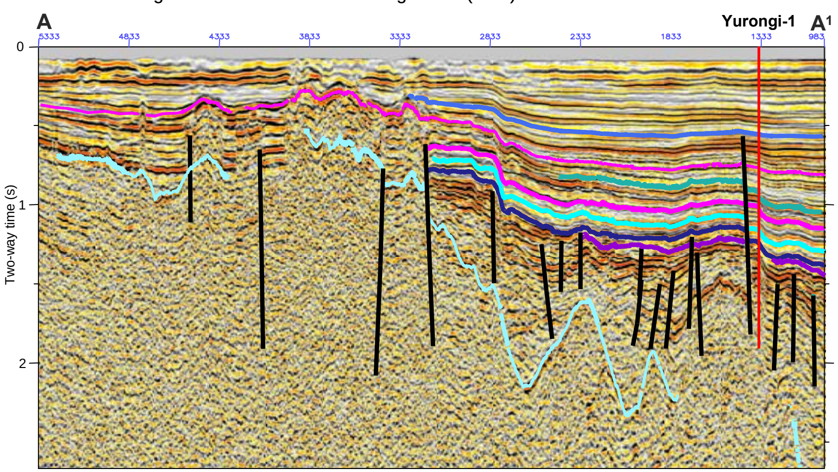


Figure 79. TMI image supplied by Geoscience Australia overlain by basin boundary (line blue line) and well locations. The location of the seismic section shown in Figure 80 is indicated by the bold blue line.

Figure 80. Geoscience Australia seismic line 40-16 along the northern margin of the Bass Basin showing the occurrence of Eocene and younger volcanic intrusions. This seismic line cross the magnetic anomalies shown on Figure 81 (A-A1).



In northeastern Tasmania, west/northwest-trending linear magnetic features extend into the Durroon Sub-basin and underlie the Durroon-1 well location. Durroon-1 intersected volcanic rocks at the Top of the Otway Megasequence (Base Durroon Megasequence). These rocks are undated but may be related to the onset of Tasman rifting, or associated with later intrusions during the Eocene to Miocene. The magnetic ridge observed near the Durroon-1 well is probably associated with the mid- Jurassic dolerites that occur across Tasmania and have been correlated with the onset of Southern Margin extension.

Further integration of magnetic and other datasets is required to fully understand the source, nature and association of the different magnetic bodies underlying the Bass Basin. Given the prevalence of intrasedimentary magmatic features in the basin and their influence on hydrocarbon prospectivity, this integration would help to understand risks associated with maturity, reservoir degradation and the seal potential of sills (e.g., Trefoil-1).

Volcanic Rocks in the Bass Basin (Chat-1)

A subset of the magmatic rocks in the Bass Basin were studied as part of a Geoscience Australia graduate rotation program during late 2003 (Dance et al., 2004; Dunlap, 2003; Figure 81). The study sought to identify intrusive and extrusive igneous rocks that have been intersected in wells, and to understand the age, petrographic characteristics and geochemical composition of these rocks. The study ultimately aimed to a basic framework for the spatial and temporal relationships of different rock suites, and to constrain the nature of volcanic events and their magmatic origin. Compositional analysis of the samples indicate an intra-plate setting for the volcanism (A. Lambeck, pers comm).

Argon-argon ($^{40}Ar/^{39}Ar$) dating of selected samples was carried out under a collaborative arrangement with the Research School of Earth Sciences (RSES) at the Australian National University (Dunlap, 2003). Potential samples were screened for potassium content and purity on the ion microprobe at the RSES. Plagioclase from volcanic rocks at Aroo-1, Koorkah-1 and Tilana-1 were analysed, while biotite from Yolla-1 and whole rock analyses of Chat-1 were also carried out. All mineral samples had >90 purity, while the whole rock samples from Chat-1 were cleaned of most altered material through untrasonication (Dunlap, 2003).

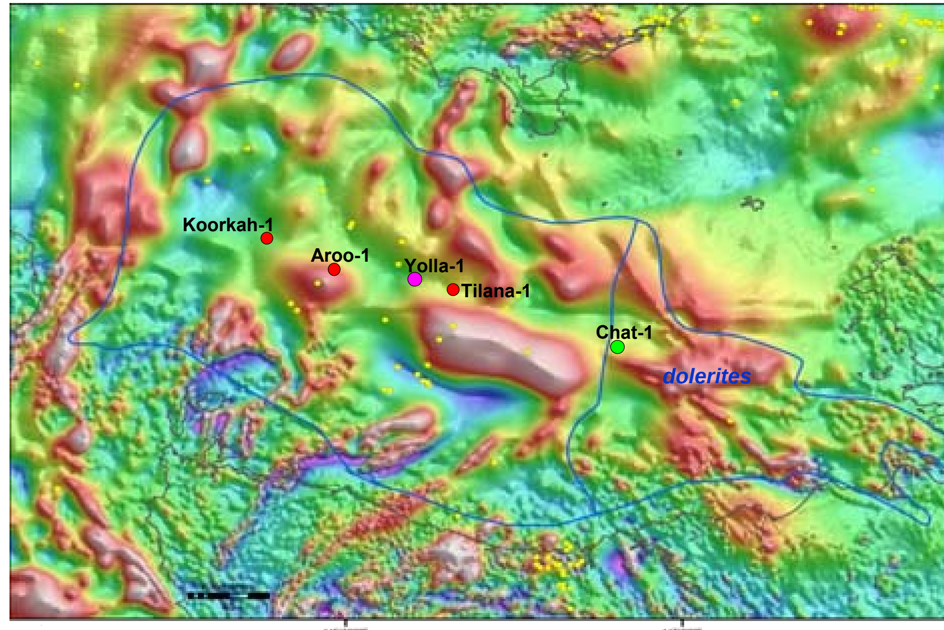
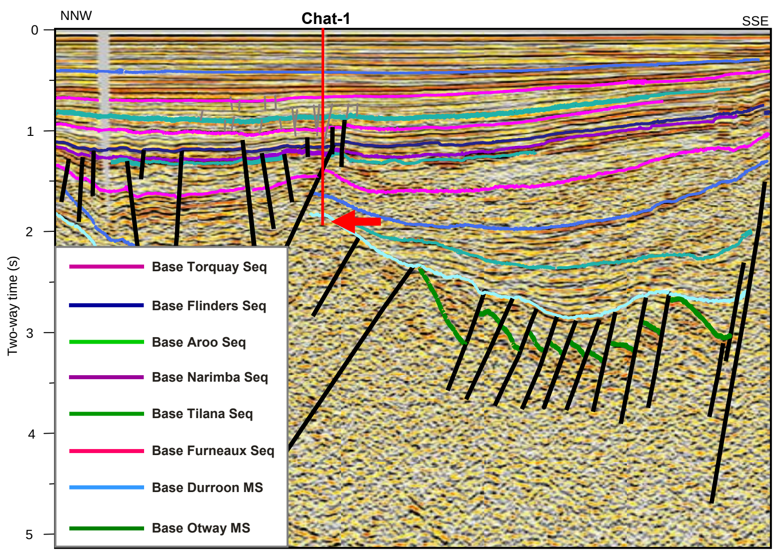


Figure 81. TMI image supplied by Geoscience Australia overlain by basin boundary (line blue line) and well locations. The location of the seismic section shown in Figure 80 is indicated by the bold blue line.

Figure 82. Geoscience Australia seismic line across the Chat-1 well in the Durroon Sub-basin.



Dating of the rock samples yielded the following ages (listed from oldest to youngest; Dunlap, 2003):

- Chat-1 (3030m): >167 Ma for the eruption age
- Aroo-1 (3596.91m): 63-73 Ma
- Koorkah-1 (2098-2128m): 32-40 Ma
- Yolla-1 (2597-2624m): 24.2 Ma (some alteration of biotite is possible)
- Tilana-1 (2172-2193m): 17.9 Ma or possibly older than 22 Ma

Based on the limited samples alone, Dunlap (2003) suggested that at least two phases of volcanism are evident and possibly several more. The Chat-1 sample (>167 Ma) correlates well to the mid-Jurassic age of dolerites that are widespread across Tasmania. These dolerites are thought to signal the onset of rifting on the Southern Margin. The Chat-1 sample came from near total depth in the well (Figure 82) and, together with regional magnetic data (Figure 81), suggest that dolerites and volcanic rocks floor parts of the southern and eastern Bass Basin. Thin sections from Chat-1 indicate the rocks are heavily altered, porphyritic trachytic basalts (A. Lambeck and T. Dance, Geoscience Australia, pers. comm).

Comparison of the younger volcanic rocks with volcanic episodes quoted by Norvick (2005) and Hill and Moore (2001) indicate that the Yolla-1 and Tilana-1 samples are consistent with the ages of volcanics intersected in the Gippsland Basin, while samples from Aroo-1 and Koorkah-1 are more consistent with the timing of volcanic episodes in the Otway, western Tasmanian margin, the South Tasman Rise and East Tasman Plateau.

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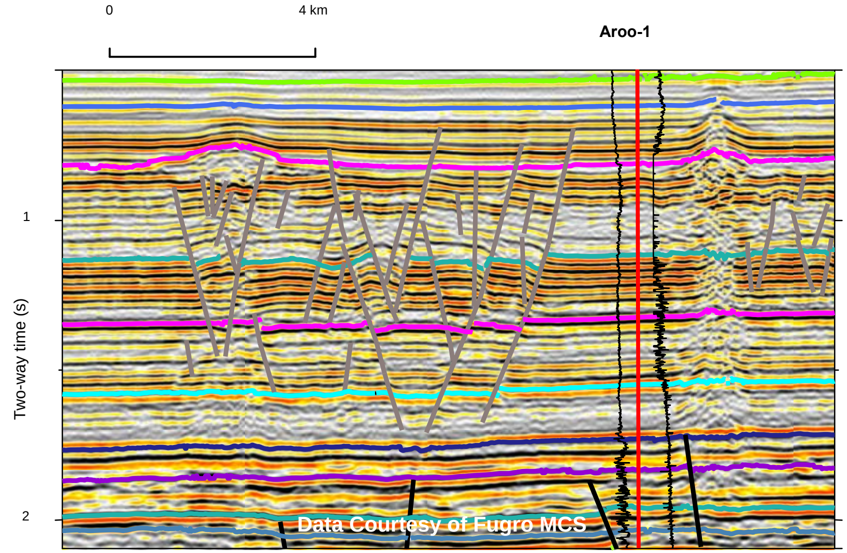
Volcanic Rocks in the Bass Basin (Aroo-1)

Aroo-1 was drilled over an intra-basin horst block and intersected approximately 500m of moderately weathered basalts near TD (Figures 83 and 84). There are no preserved spore/pollen in the sandstones interlayered with the basalts, but the overlying rocks are Early Paleocene in age (lower *L. balmei zone*). The volcanic rocks were dated as 63-73 Ma or Late Cretaceous to Early Paleocene. This is consistent with the age of the sedimentary succession and also with their original description as 'basaltic flows'. This volcanic episode is coeval with breakup in nearby the Otway Basin (67 Ma; Krassay et al., 2004).

Although younger volcanic rocks were not intersected in the shallower section at Aroo-1 (Figure 83), seismic data clearly shows the area has been affected by subsequent volcanic intrusions and extrusions (Figure 85). These younger events are probably similar to those rocks encountered in Tilana-1 and Yolla-1 which are latest Oligocene to Early Miocene in age. In some instances, the volcanic or fluid vents observed on seismic data near Aroo-1 appear to intrude or deform overburden rocks of Late Miocene and younger age. These are the youngest volcanic events observed in the basin. Thin section descriptions indicate the volcanic rocks at Aroo-1 are principally feldspathic porphyritic trachytic basalts (A. Lambeck and T. Dance, Geoscience Australia, pers. comm.).



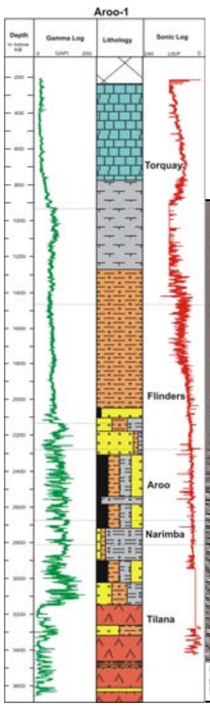
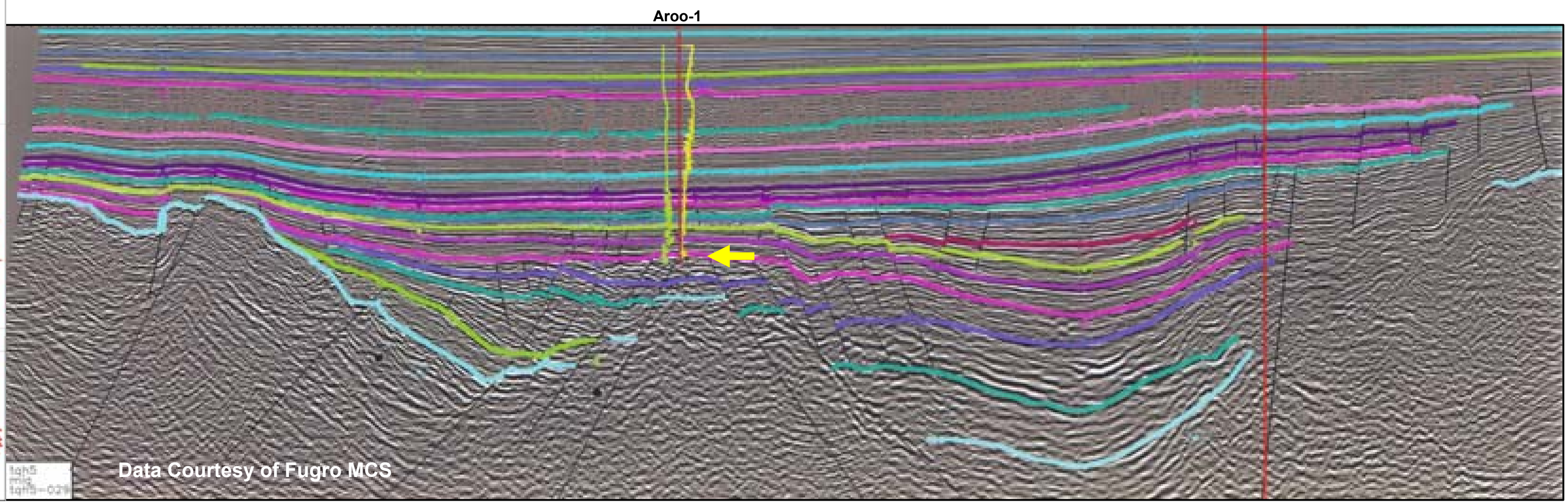


Figure 83 (left). Logs for the Aroo-1 well showing the thick volcanic section intersected near TD.

Figure 84 (below). Interpreted industry seismic line TQH5-29 across the Cape Wickham Sub-basin showing the location of the Aroo-1 over a prominent intra-basin horst.

Figure 85 (top right). Excerpt from the seismic line shown in Figure 84 showing the emplacement of intrusions (fluids) in the Oligocene and younger sections.



Magmatic Rocks in the Bass Basin (Koorkah-1)

Koorkah-1 intersected a 35m thick dolerite sill in Early Eocene age strata just below the Base Aroo Sequence boundary (Figure 87). The rock samples yielded an age of 32-40Ma (Late Eocene to Early Oligocene). The sill at Koorkah-1 is older (by approximately 14 Ma) than the latest Oligocene to mid-Miocene magmatic rocks that are observed elsewhere in the western Bass Basin, and also appear to be unrelated to the older basaltic flows seen around Aroo-1.

On the South Tasman Rise, Hill et al (2001) report widespread volcanism in the Eocene that resulted in a number of large isolated basaltic seamounts, 1-2km high, mainly in the L'Atalante Depression and the East Tasman Plateau (Cascade Seamount). This volcanic activity has been attributed to transit over the Balleny mantle plume with possible enhancement by regional tensile stress in the lithosphere associated with the onset of fast spreading (Hill et al., 2001).

While there is only minor evidence of younger intrusions/extrusions immediately around the Koorkah-1 well, there is some evidence of Eocene-age deformation and possible associated intrusions near Toolka-1 (Figures 87 and 88). The flattened seismic section suggests some localised deformation occurred during the Middle Eocene. The deformation is associated with a reactivated basement fault but may also have involved magmatic intrusions as suggested by the high amplitude and low frequency seismic character of the deformed rocks.

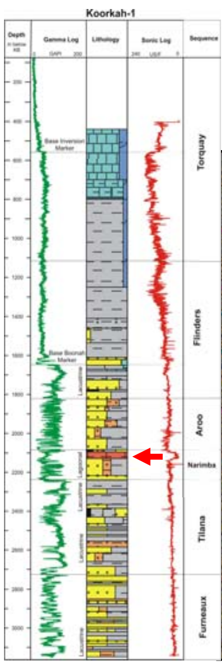
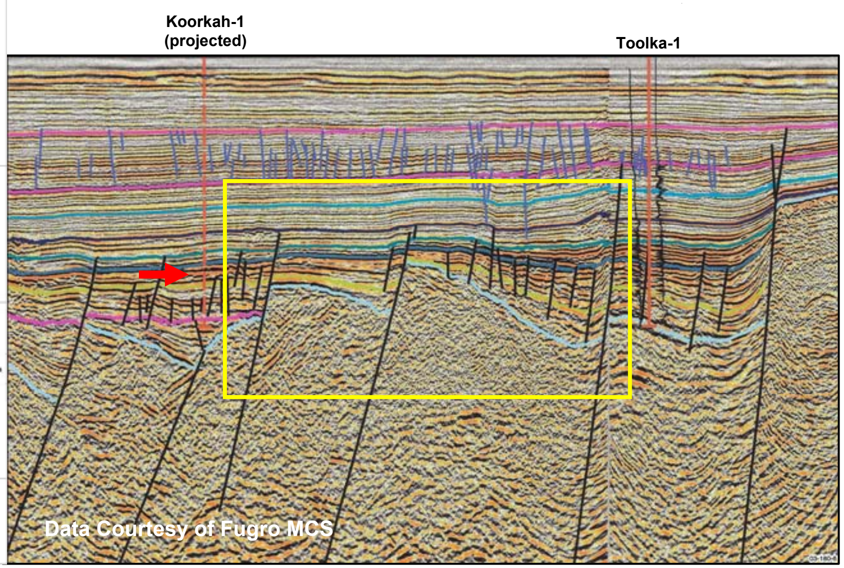


Figure 86 (left). Logs for the Koorkah-1 well showing the rocks that were dated by Geoscience Australia (red arrow).



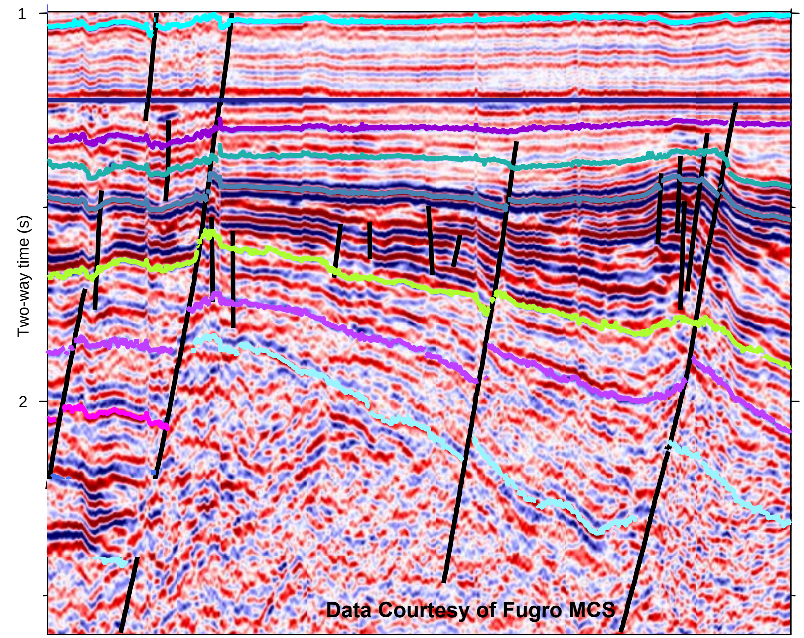


Figure 87 (left). Interpreted industry seismic line across the Cape Wickham Sub-basin showing the locations of the Koorkah-1 and Toolka-1 wells. The red arrow at Koorkah-1 indicates the stratigraphic level of the sill that was sampled and dated. The yellow box indicates the area of section shown in Figure 88.

Figure 88 (top right). Excerpt from the seismic line shown in Figure 88 showing the possible emplacement of intrusions associated with basement faults and Eocene deformation.

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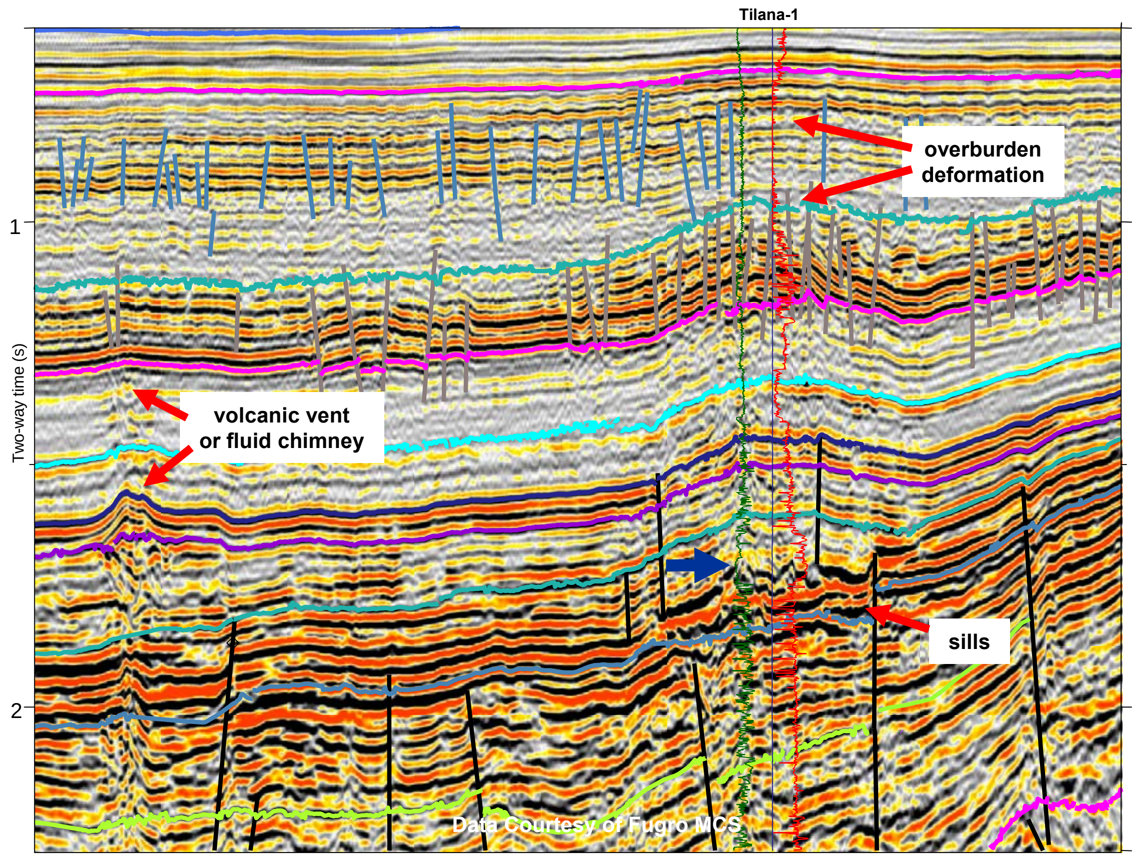
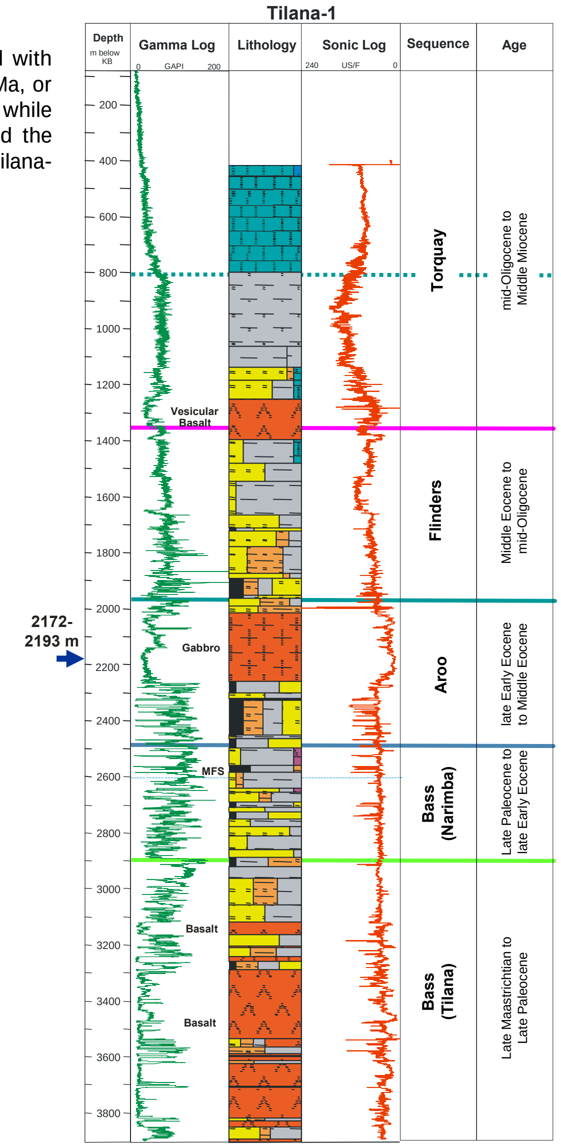
Magmatic Rocks in the Bass Basin (Tilana-1)

Intrusive (gabbros) and extrusive (vesicular basalts) magmatic rocks were intersected at Tilana-1. The sills and flows are associated with late Early Eocene to Middle Eocene age sediments (Aroo Sequence), although the sampled gabbro yielded an Early Miocene age (17.9 Ma, or older than 22 Ma; Dunlap, 2003). The sills intersected at Tilana-1 correlate to high amplitude, low frequency intervals on seismic data, while the broad uplift and faulting of the overburden rocks associated with the intrusion are also evident. Boreham et al (2003) identified the effect of localised heating (not related to geothermal gradient) in organic samples from Tilana-1, Flinders-1, Pipipa-1 and Squid-1. In Tilana-1, samples up to the Miocene stratigraphic level were heat affected. This is consistent with the age derived from the dating.

Figure 89 (below). Seismic line across the Tilana-1 well showing sills and other localised intrusions.

Figure 90 (right). Logs for Tilana-1 showing the magmatic rocks that were intersected and the sampled interval (blue arrow).





Conclusions, Synthesis Charts, Tectonic Events & Recommendations

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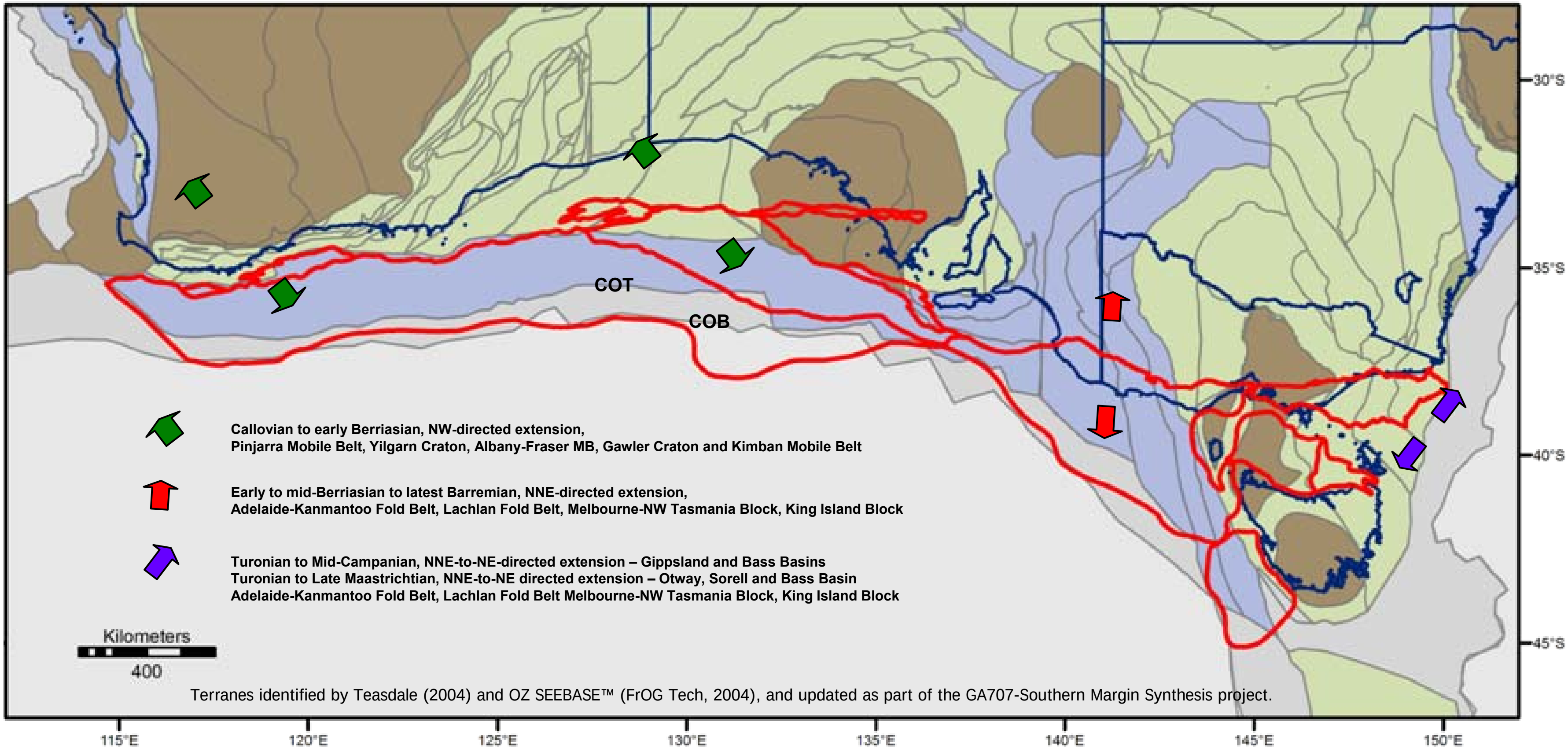
Conclusions

- The tectonostratigraphic synthesis of the Southern Margin Basins has identified three major rift phases and one transitional rift phase. While the entire Southern Rift System was the locus of crustal instability, the response to extensional stresses (rift basin formation) appears to have propagated from west to east. It can be argued that the mid-Callovian onset of extension in the Southern Margin has no clear expression (i.e., active faults) in the Otway, Bass and possibly the Gippsland basins.
- The basal lacustrine and volcanic sediments which floor the early rifts in the Otway and Gippsland basins are near age equivalent to the cessation of upper crustal extension in the Bight Basin. The subsequent onset of extension in the Otway and Gippsland appears to have responded to north-northeast-directed extensional stress – a shift from the earlier northwest-directed extension which affected the Bight Basin.
- The Rift Transition Phase (Aptian-Albian) is the most ambiguous of all phases, as the interpreted response and tectonostratigraphic record shows differential movement on selected fault/fault sets across the southeastern basins. However, this is a viable scenario given the documentation of fault movement along the western margin of Tasmania at this time.
- The Late Cretaceous Rift Phase affected the southeastern basins but was related to a convergence of stresses associated with the final separation, fragmentation and clearance between Australia and Antarctica, and rifting in the Tasman Sea. The continuation of fault activity in the western Bass Basin and along the west Tasmanian margin is attributed to far-field stresses associated with final clearance.

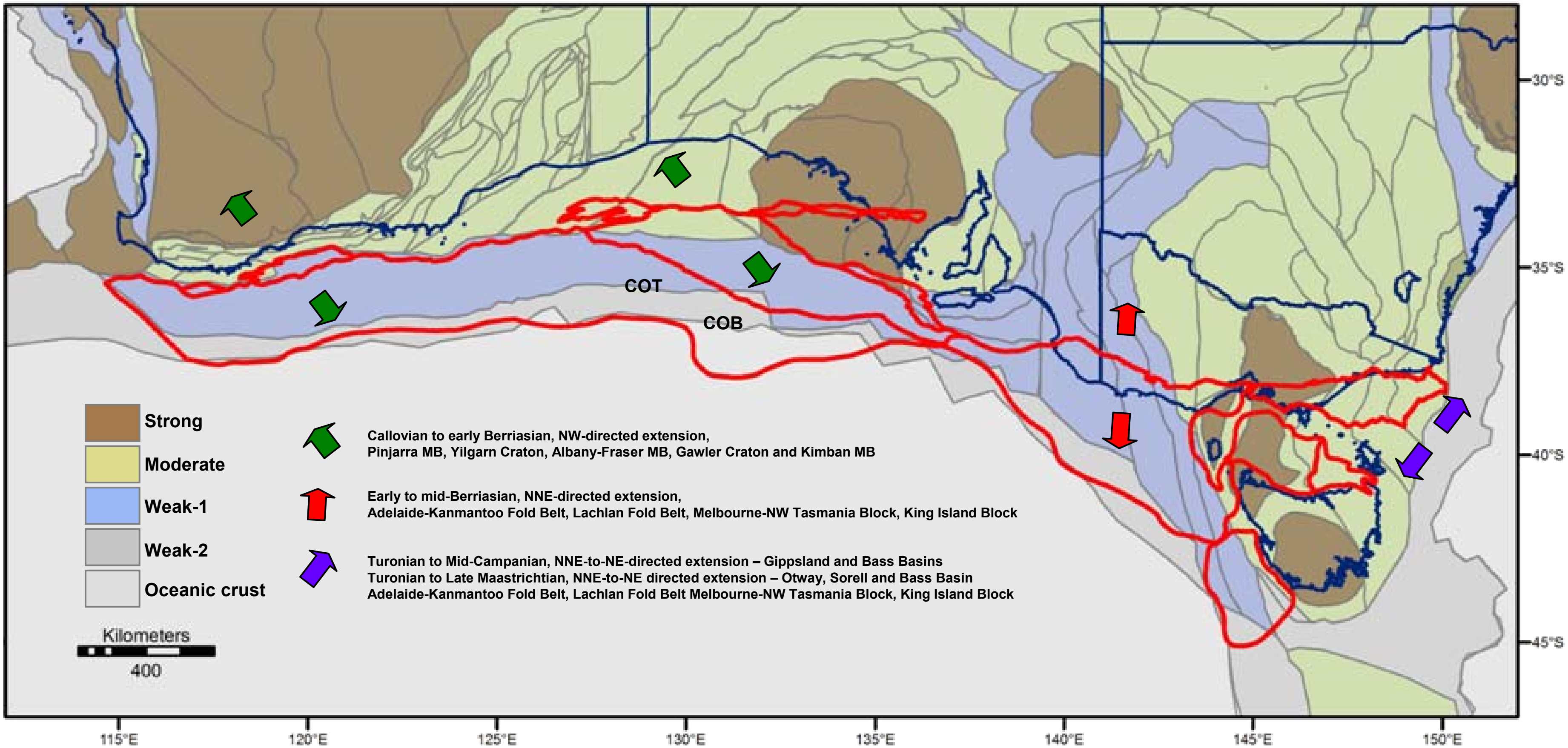


Terranes identified by Teasdale (2004) and OZ SEEBASE™ (FrOG Tech, 2004), and updated as part of the GA707-Southern Margin Synthesis project.

Terrane Rheology and Composition

The basement response to extensional stresses varied along the length of the Southern Rift System due to inherent basement properties of fabric and rheology. Lower crustal processes were also influential but these have not been included here (see Miller et al., 2002). While it is beyond the scope of this study to integrate basement response and tectonostratigraphy of the overlying basin, some simple observations can be stated. Northeast-to-northwest trending terrane boundaries and moderately strengthened crust responded to oblique stresses along the western Southern Margin, while the southern edge of the Gawler Craton (strong crust) formed the northeastern boundary of the Ceduna Sub-basin. In the east, terranes of the Adelaide-Kanmantoo Fold Belt underlie the Otway Basin, while terranes of the Lachlan Fold Belt underlie the Bass Strait Basins.

Terranes identified by Teasdale (2004) and OZ SEEBASE™ (FrOG Tech, 2004), and updated as part of the GA707-Southern Margin Synthesis project.



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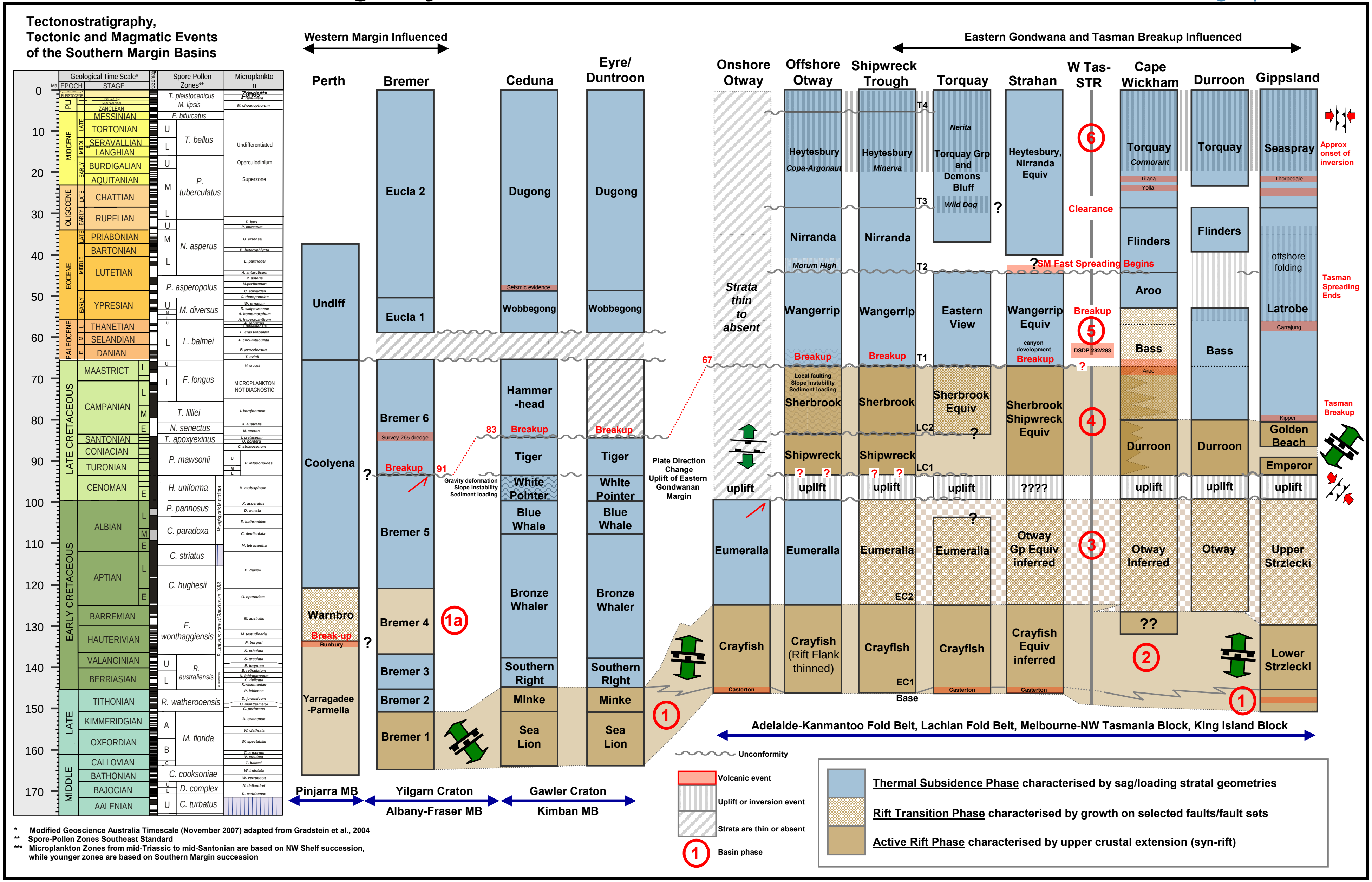
Australian Southern Margin Synthesis – GA707

Mesozoic to Recent Tectonostratigraphic Chart



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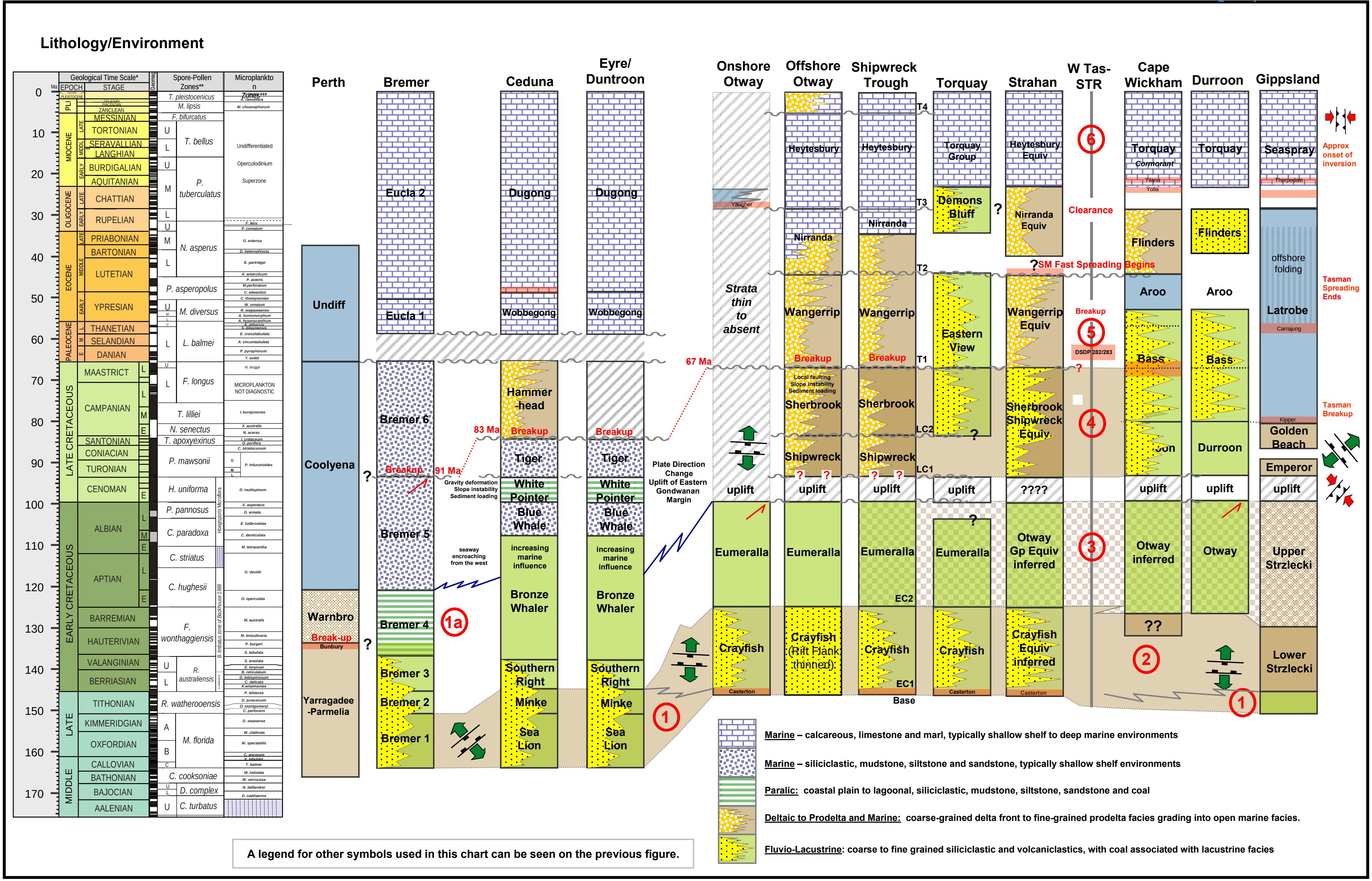
Australian Southern Margin Synthesis – GA707

Mesozoic to Recent Tectonostratigraphic Chart



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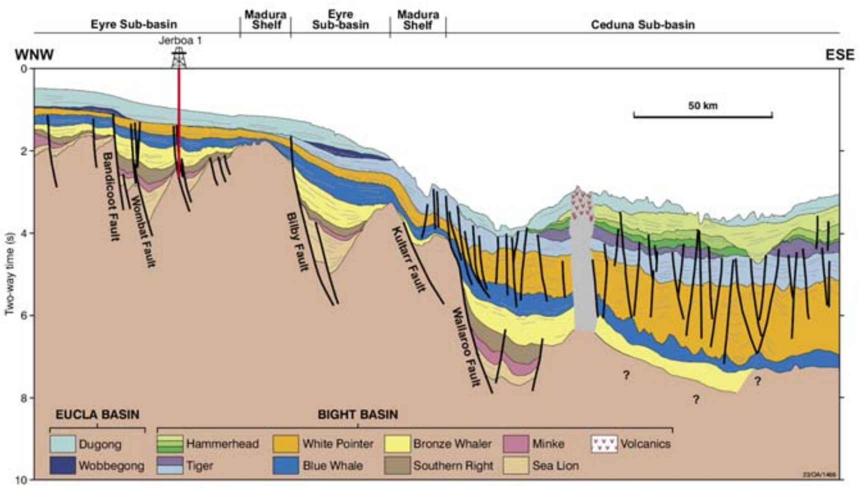
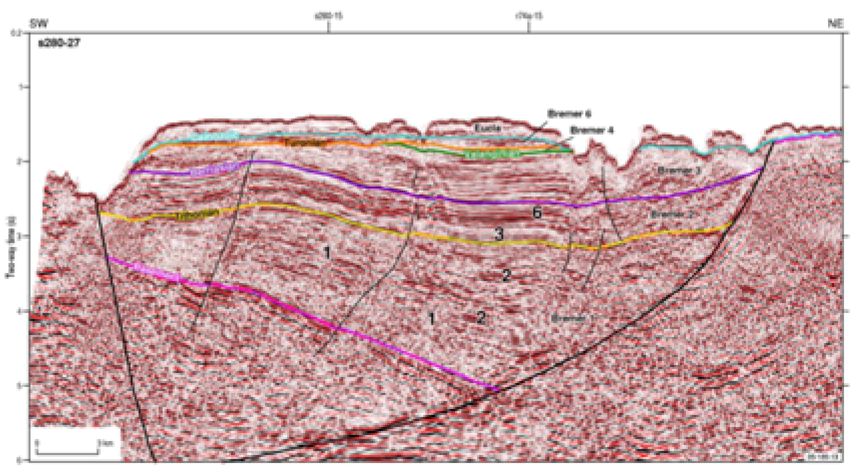
Phases 1 & 2: Late Jurassic – Early Cretaceous Extension





Middle Jurassic magmatism in areas along the Southern Margin has been attributed to mantle instability which preceded the onset of upper crustal extension in the Callovian (Stagg et al., 1990). This instability resulted in the widespread extrusion of dolerites across Tasmania and in the adjacent Bass Strait region, and also the basalts on Kangaroo Island east of the Bight Basin. Correlation of these magmatic rocks suggest they have close geochemical affinities (Farrand, 1995; Foden et al., 2002), while isotopic dating suggest basaltic eruptions occurred during the Bajocian and Bathonian (Farrand, 1995; Foden et al., 2002; Dance et al., 2004).

The onset of upper crustal extension in the eastern Bight Basin is reasonably well-constrained based on regional correlations with Jerboa-1 (Eyre Sub-basin), where the well intersected the upper part of the syn-rift wedge (?Callovian-Kimmeridgian Sea Lion and Tithonian-early Berriasian Minke supersequences; Totterdell et al., 2000). Similar age rocks were interpreted to lie in deeper half graben within the Duntroon Sub-basin, although the syn-rift facies themselves have not been intersected by drilling. In the Ceduna and Recherche sub-basins, half graben can be imaged on seismic data in some areas, and these structures have been correlated to structures in the Eyre Sub-basin (Totterdell et al., 2000; Bradshaw et al., 2003). In the eastern Bight Basin, the onset of extension has been interpreted as mid-Callovian (near base of *M. florida* zone) or possibly slightly older.

In the western Bight Basin, seismic and dredge sample correlations in the Bremer Sub-basin suggest the onset of rifting also began in the early Callovian based on results from four dredge samples (Bremer 1; Bradshaw, 2005). A lower confidence is given to the western Bight Basin results because of the nature of the samples and their approximate ties to seismic packages. In addition, it appears unclear whether these samples represent the base of the syn-rift succession. If the four samples yielded minimum ages, then it is possible that extension in the Bremer Sub-basin began as early as Bathonian. This would mean that rift onset was synchronous with extension in the Perth Basin (166 Ma, Yarragadee Formation).

Timing of the onset of upper crustal extension in the Otway and Gippsland basins is less clear because of uncertainty in the age and nature of the basal syn-rift sections – the Casterton and Lower Strzlecki formations, respectively. In the Otway Basin, the Casterton Formation overlies basement and its distribution is restricted to the early horst and graben fault system. Only minor growth is apparent into major bounding faults, and the unit varies in thickness from 26 to 500+m (Krassay et al., 2004). The age of the Casterton Formation has long been a contentious issue due to a wide range of isotopic dates (Mitchell et al., 1997) and the absence of decisive key palynological taxa (Sinclair and Monteil, 2004). Previous work indicates the formation ranges in age from Late Jurassic to Early Cretaceous. To further complicate matters, Mitchell et al (1997) suggest that the Casterton Formation is not a chronostratigraphic unit, with the 'Casterton' east of the Merino High being younger than 'Casterton' facies in the western Otway Basin. Recent work on the Casterton Formation at Sawpit-1 (western Otway Basin) by Sinclair and Monteil (2004) indicates a clear age of Valanginian based on a definitive presence of *G. mutabilis* dinoflagellate cysts.

Figure (top). Geoscience section across the Eyre and Ceduna Sub-basins (Bight Basin) showing evidence of Late Jurassic to earliest Cretaceous upper crustal extension (from Bradshaw et al., 2003).

Figure (bottom). Geoscience Australia seismic line S280-27 showing the divergent syn-rift character of the Middle to Late Jurassic succession (Callovian-Kimmeridgian; Bremer 1; from Bradshaw, 2005).

Phases 1 & 2: Late Jurassic to Early Cretaceous Extension

Clearly, more intersections and detailed work may resolve the age(s) of the Casterton Formation, and whether there is one continuous unit or if the 'Casterton' is a time-transgressive facies that signals the onset of rifting and therefore varies in age. Nonetheless, the absence of significant growth geometries observed within the Casterton Formation would indicate that upper crustal extension was still at an early stage of development.

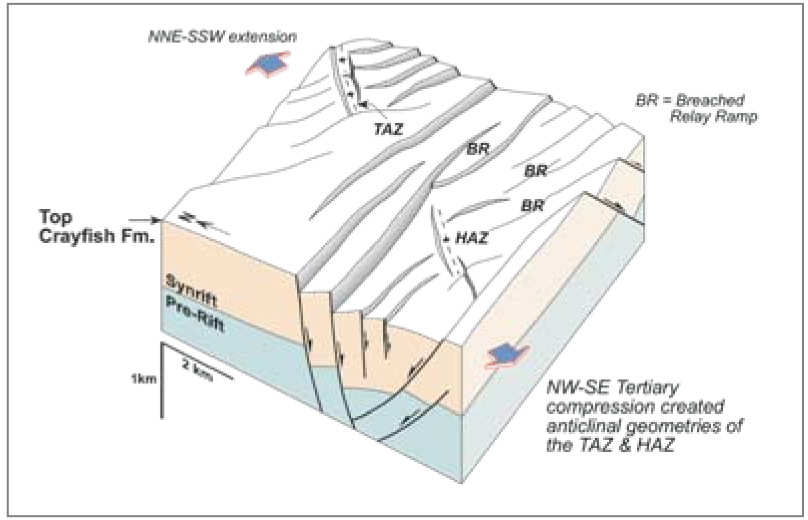
Based on the tectonostratigraphic framework established by Krassay et al (2004), significant growth on the early rift faults in the Otway Basin occurred during the 'post-Casterton' depositional phase of the Crayfish Supersequence (EC1 of Krassay et al., 2004). This would mean that growth occurred during Berriasian to Barremian time (*R. australiensis* to *F. wonthaggiensis* zones), and is thus not time equivalent to extension in the Bight Basin (i.e., the Sea Lion-Minke sequences which are older).

It is suggested here that deposition of the 'Casterton Formation' in the Otway Basin represents the early or far-field response to Bight Basin extension. In this scenario, once significant upper crustal extension ceased in the Bight Basin (early Berriasian), the focus of extension shifted to the Otway Basin with deposition of the Crayfish Supersequence (Berriasian to Barremian). This would imply that two progressive, but different phases of extension affected these basins.

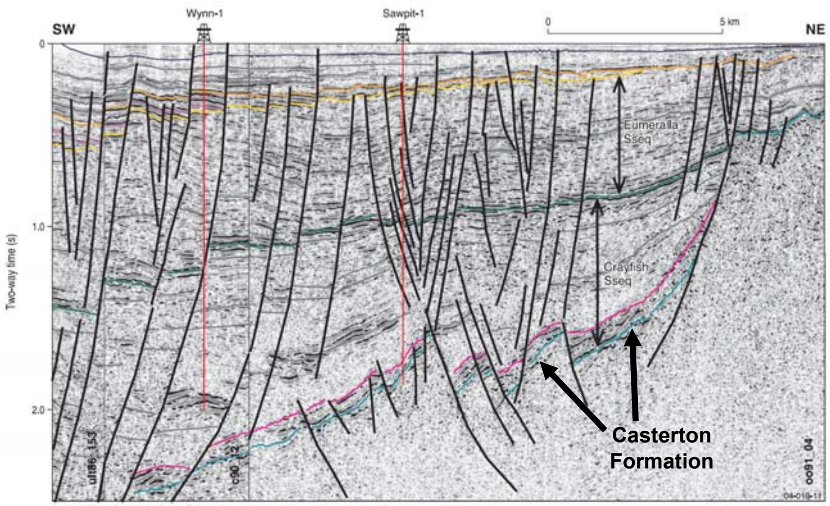
This scenario is also supported by the disparity between the extensional stress directions that have been interpreted during early rifting in the Otway and Bight basins. While the Bight Basin was affected by northwest/southeast-directed extensional stresses (e.g., Stagg and Willcox, 1990; Totterdell et al., 2000), the Otway Basin appears to have formed under a north-northeast/south-southwest-directed stress regime (e.g., Chantraprasert et al., 2001; Krassay et al., 2004). Regional stress in both basins was oblique to the underlying basement fabric and this is reflected in fault trends and offsets across accommodation zones that are sub-parallel to the interpreted extensional direction (e.g., Chantraprasert et al., 2001). There is also clearly some element of basement (or deeper) control on the apparent partitioning of the regional stress regime. This is probably related to the transition between the Gawler Craton-Kimban Mobile Belt (Bight Basin) and the Adelaide-Kanmantoo Fold Belt (western Otway Basin).

A similar situation may also have occurred in the Gippsland Basin, with volcanics of the lowermost Lower Strzlecki Formation signaling the proximity of rifting, rather than the onset of significant upper crustal extension. Similar to the Casterton Formation of the Otway Basin, the interpreted Jurassic part of the Strzlecki Formation is rarely penetrated onshore and poorly imaged in the deeper initial rift basins offshore. Indeed, Power et al (2001) interpreted the onset of rifting in the Gippsland Basin as Neocomian, not Jurassic.

Extension in the western Bight Basin (Bremer Sub-basin; Bremer 1 unit) ceased in the Kimmeridgian-Tithonian – approximately 5Ma earlier than in the eastern Bight Basin (O'Leary et al., 2005). The cessation of extension is confidently constrained by only two samples which came from the overlying sag section, while several more samples from other dredge sites are unresolved whether they originated from the Bremer-1 (syn-rift) or Bremer-2 (sag) stratigraphic units. O'Leary et al (2005) concluded that Bremer-2 was deposited during a time of diminished growth on bounding faults in the eastern Bight Basin. Alternatively, the poor spatial constraint of these rocks could mean that they originated from Bremer-1 (syn-rift) and that extension in the Bremer Sub-basin ceased in the earliest Berriasian – a timeframe that is more consistent with the Perth and eastern Bight basins.



3D block diagram showing the evolution of the Penola Trough structures during the late syn-rift extension phase (Otway Supergroup) in the Otway Basin (from Chantraprasert et al., 2001). This interpretation suggests NNE-SSW extension in the western Otway Basin.



Seismic section across the Penola Trough show the syn-rift Crayfish Supersequence (from Krassay et al., 2004). The volcanic Casteron Formation can be observed as the base of the syn-rift section.

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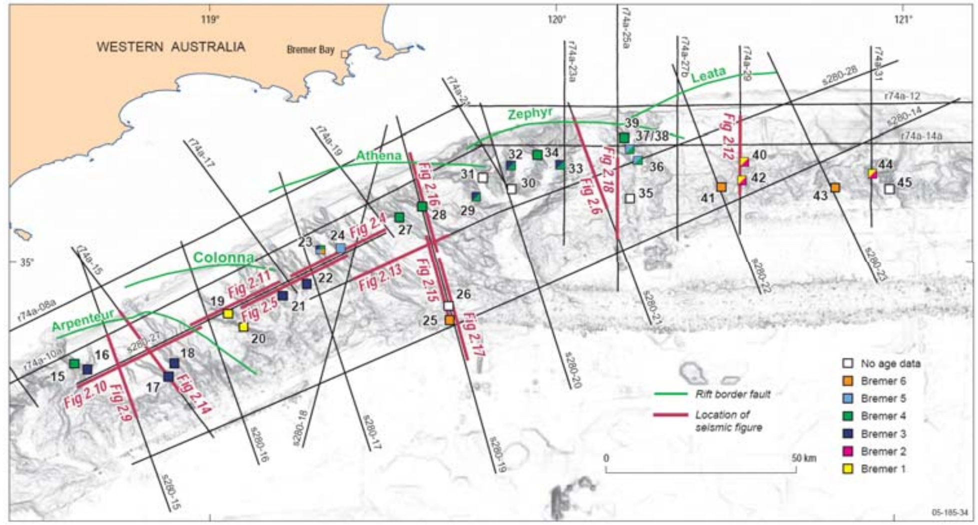
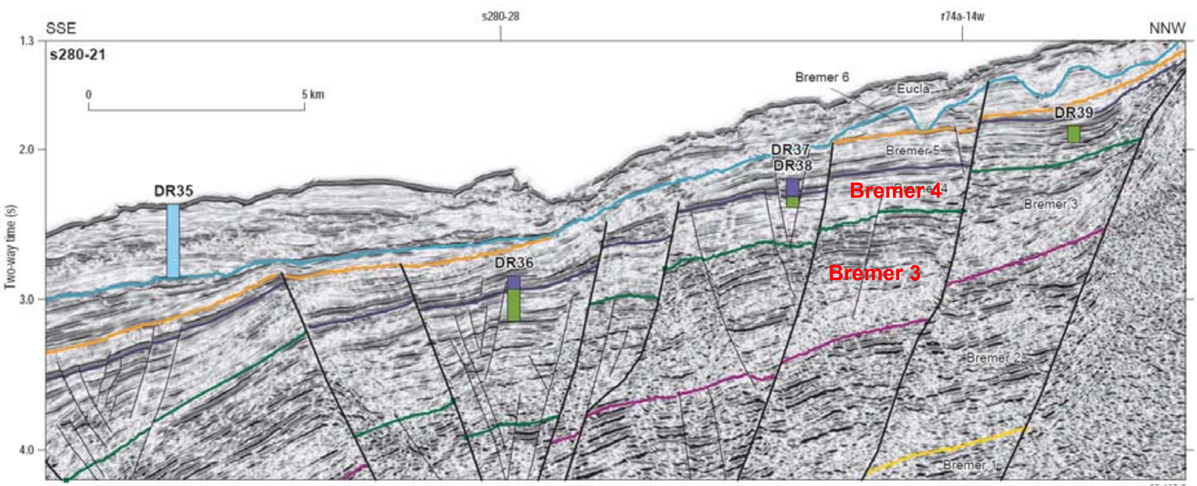
Phase 1a: Mid-Valanginian to Late Aptian Extension

Mid-Valanginian to Late Aptian extension (Phase 1a) was identified on seismic data in the Bremer Sub-basin (eastern Bight Basin) and correlated to stratigraphic unit Bremer-4 (O'Leary et al., 2005). The age of this event is well constrained by dredge samples and confident ties to seismic data. O'Leary et al (2004) described Bremer-4 unit as a 'parallel, sheet-like fill', although the 'upper part of Bremer 4 forms a divergent wedge geometry in the hanging wall blocks of the Arpenteur, Colonna and Leata depocenters'. Uplift and large anticlines were also formed in the eastern and western parts of the basin (Nicholson and Ryan, 2005)

Evidence of active extension during this time period has not been observed in the eastern Bight basins, although breakup and the onset of seafloor spreading in the Perth Basin was coeval with the onset of Bremer-4 deposition (mid-Valanginian). It is likely that deposition of Bremer-4 resulted from the influence of transtensional stresses associated with the onset of seafloor spreading on the southwestern margin. This event was unrelated to fault movement observed in some of the eastern basins during this time period.



Summary of stratigraphic units at sampled at Survey 265 dredge sites in the Bremer Sub-basin overlain on a high-resolution bathymetry image (from O'Leary et al., 2005).



Geoscience Australia seismic line S280-21 showing the nature of Bremer-4 (Extension-2) package in the Bremer Sub-basin (from O'Leary et al., 2005).

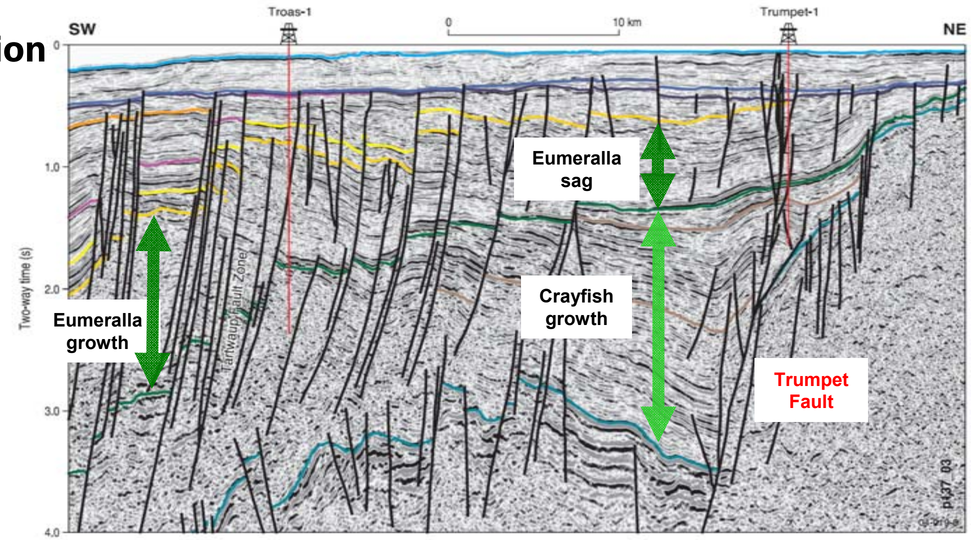
Phase 3: Albian-Aptian Post-Rift and Rift Transition

An extended period of subsidence and accelerated subsidence followed the early Berriasian cessation of upper crustal extension in the Bight Basin (Totterdell et al., 2000). Likewise, the onshore Otway Basin and much of the offshore basin experienced sag conditions after the cessation of upper crustal extension in the latest Barremian (Krassay et al., 2004). Norvick and Smith (2001) describe the Aptian-Albian as a post-rift phase in the southern and southeastern basins.

However, it remains clear that some tectonic activity continued in various parts of the eastern basins during the Aptian to Albian period (Otway Sequence/Bass Basin, Eumeralla Supersequence/Shipwreck Trough and Torquay Sub-basin and Upper Strzlecki Sequence/Gippsland Basin). In these areas, syn-tectonic growth on selected faults/fault sets is observed, with 5% extension modeled in the Gippsland Basin (Power et al., 2001) and sag with minor faulting described from Geosec™ restorations by Palmowski et al. (2004) in the western offshore Otway Basin. The Eumeralla Supersequence is up to 2300m thick in well intersections and estimated to reach up to 4500m in the Shipwreck Trough (based on calculated seismic velocities; this study) The Aptian-Albian was also a period of prolific volcanic eruptions to the east and input of volcaniclastic sediments into the eastern basins (Mortimer et al., 2005).

Observations of active fault movement appear to cluster in the eastern Otway Basin (Palmowski et al., 2004; Krassay et al., 2004; this study), Torquay Sub-basin (Cooper and Hill, 1997; this study), possibly the western Bass Basin (Blevin et al., 2005; this study), and in the western Gippsland Basin (Power et al., 2001). Other workers (e.g., Cockshell et al., 1995; Morton et al., 1995; O'Brien et al., 1994) describe deposition of the Eumeralla Formation in the Otway Basin as an uppermost syn-rift sequence deposited during a slower, second rifting phase where fault activity was reduced in the onshore basin, but continued offshore. To the east, the New Zealand margin entered an extensional phase around 120 Ma (mid-Aptian) following the end of subduction and Rangitata metamorphism (Norvick and Smith, 2001). Some extension continued in New Zealand during the Albian.

Collectively, the observed evidence does not support a period of pervasive upper crustal extension across the southeastern basins during the Aptian-Albian. The areas that appear to have been active mostly overlie terranes of the Lachlan Fold Belt and easternmost Delamarian crust. These terranes and the boundary between them continued to be tectonically active as a major strike/slip system along the west Tasmanian margin until the Eocene – indicating this was a zone of weakness that was important during the separation and final fragmentation of the Australian and Antarctic plates. It is feasible that episodic transtensional movement along this system resulted in localised fault movement (Shipwreck Trough) and far-field stresses in nearby areas (Torquay Sub-basin, western Bass and Gippsland basin) during the Aptian-Albian period.



Geoscience Australia seismic line 137-03 showing the sag nature of the Eumeralla Supersequence inboard of the Tartwaup Fault Zone, and the growth that occurs within the same section outboard of the fault system (modified after Krassay et al., 2004).

Part of the difficulty in resolving the nature of the Aptian-Albian event is that only the upper part of the succession is intersected in the offshore Otway and Gippsland basins, thus much of the correlation is seismic-based. In the western Bass Basin and Strahan Sub-basin where Eumeralla and Crayfish equivalent units have been interpreted to lie at depth (Cummings et al., 2004; Boreham et al., 2002), the oldest sediments intersected are Maastrichtian in age.

For these reasons, Phase 3 is best described as 'Post-Rift' (sag) in basins where no evidence of fault movement (extension) is present such as the Bight Basin and onshore Otway Basin. Areas that show evidence of growth on selected faults are described as 'Rift Transition Phase', with movement attributed to localised extensional, transtensional and far-field stresses.

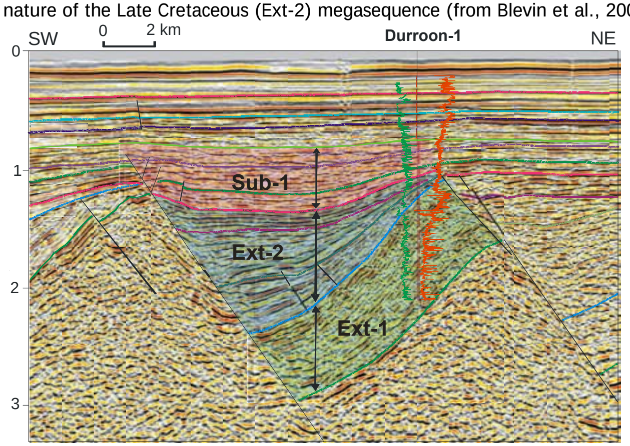
While it is out-of-scope for the current study, further work (synthesis) to incorporate plate-scale kinematics of eastern Gondwana during this period will help to resolve the uncertainty of the 'Rift Transition Phase' period in eastern Australia. Also, more detailed work on the wells used in the Geosec ™ models of the Gippsland (Power et al., 2001) and Otway basins (Palmowski et al., 2001) would help to understand the confidence of these correlations at a detailed level. 2D/3D structural modeling restorations modeling could also help in the Torquay Sub-basin, although such work in the Bass Basin could be inhibited by a lack of chronostratigraphic control on the deeper syntectonic section.

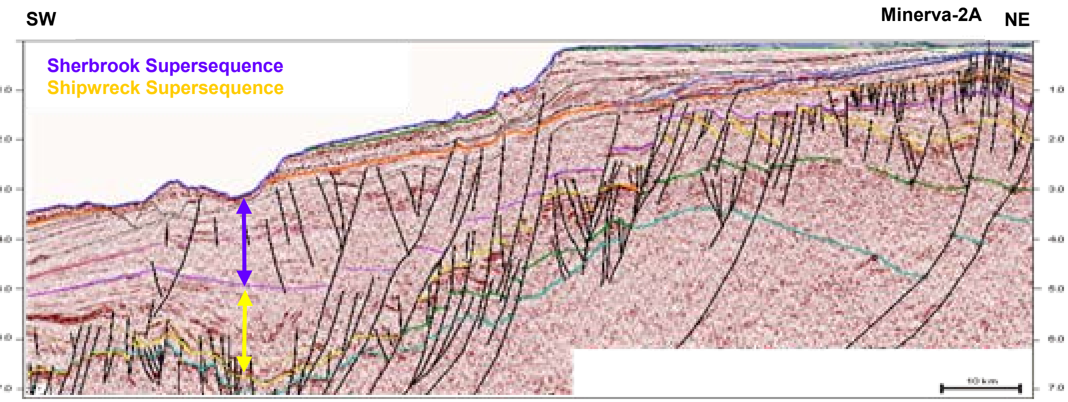
Phase 4: Late Cretaceous Extension

The Late Cretaceous Extension (Phase 4) is well documented in the offshore Otway Basin where the Shipwreck and Sherbrook supersequences were deposited seaward of the Mussel-Tartwaup fault zone as the locus of extension moved outboard of the early rift basins (e.g., Krassay et al., 2004). Here, growth sections in excess of 3000m thick are observed in the offshore basin. Extension occurred in two phases – 1) Turonian to latest Santonian (Shipwreck); and 2) Campanian to late Maastrichtian (Sherbrook). The boundary between these two phases coincides with breakup outboard of the Ceduna and Recherche sub-basins (approximately 83 Ma; Sayers et al., 2001). Overall, the amount of observed growth decreases upward in the younger Sherbrook Supersequence. Extension direction is interpreted to be north-south and driven by the later stages of Southern Margin rifting. The end of rifting in the offshore Otway Basin is marked by breakup and the onset of seafloor spreading at 67 Ma (Krassay et al., 2004). Previous authors have interpreted breakup off the Otway Basin as Cenomanian (Boult and Hibburt, 2002;) or mid-Eocene (43 Ma; Norvick and Smith, 2001).

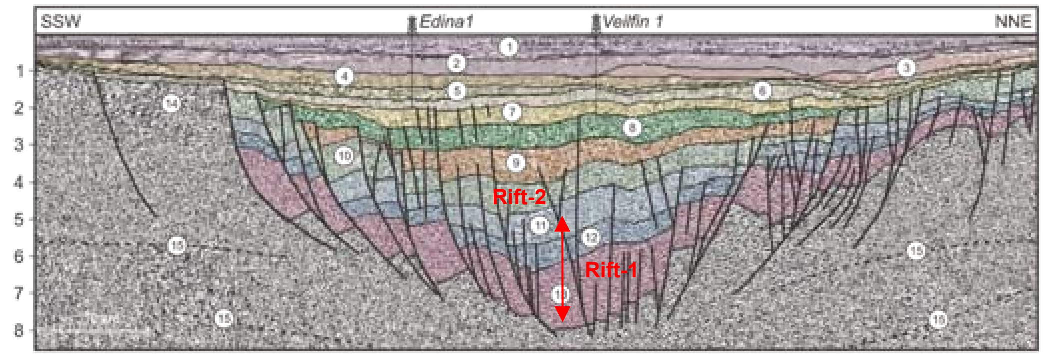
In the Gippsland and Bass basins, Late Cretaceous extension is also well documented, e.g. at Durroon-1, where the event is recorded by strata with clear divergent geometries in the initial rift phase followed by decreasing extension in the later stages (Ext-2). In the Gippsland Basin, the two pulses of rifting are recorded as the Emperor (early stage) and Golden Beach (later stage) events. Many of the stratigraphic charts of the basin (e.g., Norvick and Smith, 2001) shown an unconformity between these two stages, but it is likely that deposition was continuous within the deeper half graben.

Interpreted seismic line across the eastern Durroon Sub-basin showing the syn-tectonic nature of the Late Cretaceous (Ext-2) megasequence (from Blevin et al., 2005).





Geoscience Australia seismic line 137-09 across the Nelson Sub-basin showing interpreted syn-rift growth during deposition of the the Shipwreck and Sherbrook supersequences (from Krassay et al., 2004).



Interpreted seismic line across the Gippsland Basin showing the major megasequences mapped (from Powers et al., 2001). A key to the numbered stratigraphic units are shown in Power et al (2001) and later in this report.

Extension in the Gippsland and eastern Bass Basin occurred from the Turonian to mid-Campanian and was driven by rifting in the Tasman Sea to the east. A northeast-oriented extension direction has been interpreted. Breakup in the Tasman Sea was approximately coeval with breakup off the Ceduna Sub-basin – 80-83 Ma (early Campanian). The cessation of extension in the Bass and Gippsland was slightly later, as the spreading ridge propagated north from the initial ridge.

While the early phase of the Late Cretaceous Extension event is coincident in the southeastern basins (Turonian to mid-Campanian), the stresses are associated the final stages of separation between Australian and Antarctica (Otway/Bass) and breakup of eastern Gondwana (Bass/Gippsland). Tasman Sea breakup was rapid and post-rift subsidence commenced in the mid-Campanian, while the prolonged fragmentation and clearance between Australia and Antarctica meant that extensional stresses continued to affect the western Bass Basin until the Early Eocene. During this period, continued extensional and transtensional movement is observed on selected faults/fault sets (Rift Transition Phase).

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