Mentelle Basin – tectonic evolution controlled by of the combined extensional history of the Southwestern and Southern Australian margins

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SUMMARY

New geophysical data acquired by Geoscience Australia during the Southwest Margins 2D seismic survey in 2008-09 has been used to interpret the tectonic and depositional history of the Mentelle Basin. The Mentelle Basin is a large, potentially prospective frontier basin located between the Yallingup Shelf and the Naturaliste Plateau, offshore southwestern Australia. It comprises several intermediate water-depth (500–2000 m) depocentres in the east (eastern Mentelle Basin) and a large ultra deep-water (2000–4000 m) depocentre in the west (western Mentelle Basin).

Interpretation of the new data suggests that initial rifting in the Mentelle Basin occurred in the Early Permian as part of the Perth Basin extensional system. This was followed by Late Permian to Early Jurassic thermal subsidence. Half graben with Permo-Triassic fill are mapped in the eastern Mentelle Basin. The main depositional phase in the western Mentelle Basin is interpreted to correlate with Mid-Jurassic to Early Cretaceous extension in the Perth Basin and on the southern margin. Structural interpretation of the new dataset indicates that in the northern part of the western Mentelle Basin, major structures are trending north–south, similar to the Perth Basin, whereas in the south most structures are trending northeast–southwest, which is consistent with the orientation of the extensional basins on the southern margin. The proximity of the southern margin rift system not only affected the structure of the Mentelle Basin but also resulted in major fault reactivation, inversion and margin collapse in the Eocene corresponding to the onset of fast spreading in the Southern Ocean.

Key words: Mentelle Basin, structure, tectonic history.

INTRODUCTION

The Mentelle Basin is a large sedimentary basin (36,000 km^2) located about 150 km to the west of Cape Leeuwin. It lies beneath the continental slope of the southwest Australian margin and the Naturaliste Trough – a bathymetric saddle separating the margin from the Naturaliste Plateau (Figure 1).

The intermediate water-depth (500–2000 m) eastern Mentelle Basin lies beneath the outer part of the Yallingup Shelf, while the ultra deep-water (2000–4000 m) western Mentelle Basin is underpinned by highly extended continental crust (Johnston et al., 2010) of uncertain origin.

The Mentelle Basin forms part of an extensional rift system on Australia's southwestern margin that developed during the Paleozoic to Mesozoic breakup of eastern Gondwana. It has been suggested that the basin formed close to the triple junction between the Indian, Australian and Antarctic plates (Borissova, 2002) and therefore structurally represents a transition between the Perth Basin to the north and the southern margin basins to the south (Bradshaw et al, 2003).

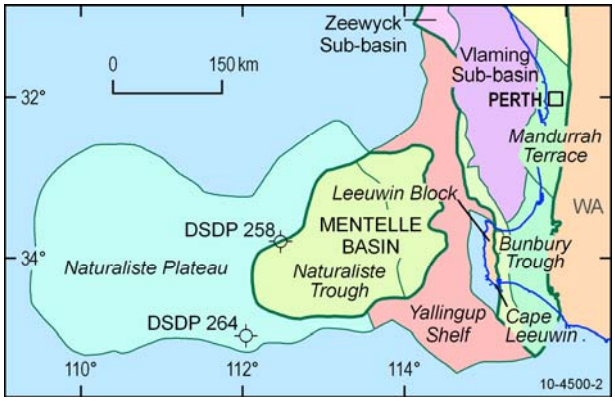

Figure 1. Location and regional geological setting of the Mentelle Basin

Until recently very limited data was available for the Mentelle Basin and its structure remained poorly understood. Acquisition of regional seismic and potential field data by Geoscience Australia in 2004 and 2008–09 enabled mapping of the main structures, which has led to a better geological understanding of this remote basin.

REGIONAL SETTING

The Pinjarra and Albany–Fraser orogens make up the basement terrane of the southwestern part of Australia. The Albany–Fraser Orogen comprises a series of Paleoproterozoic to Mesoproterozoic belts that strike parallel to the southern border of the Archean Yilgarn Craton (Myers et al, 1996). The Pinjarra Orogen stretches along the western margin of the

Yilgarn Craton and was emplaced by oblique collision at 550–500 Ma during the assembly of Gondwana (Myers, 1990). Plate reconstructions of the southwestern Australian margin by Fitzsimons (2003) show that these terranes extend offshore beneath sedimentary basins along Australia's southern and southwestern margins.

Initial northeast–southwest extension between Greater India and Western Australia and the formation of north–south trending depocentres in the inboard part of the Perth Basin occurred in the Permo-Triassic. In the Early to Middle Triassic this rifting was accompanied by northwest–southeast transpression and shortening (Harris, 1994). Sag sedimentation in the Late Triassic followed this initial oblique rifting. In the latest Triassic to Early Jurassic rifting resumed in a west-northwest to east-southeast direction (Harris, 1994).

The most significant rifting episode on the southwestern margin occurred during northwest–southeast extension preceding breakup. The southwestern and southern margins of Australia are two arms of a triple junction that formed during the final stages of fragmentation of Gondwana (Norvick and Smith, 2001; Direen et al, 2007). From the Middle Jurassic onwards, extension occurred within the continental rift systems between Greater India and Australia (western margin), Australia and Antarctica (southern margin) as well as between India and Antarctica (Norvick and Smith, 2001).

Breakup between Greater India and southwestern Australia occurred in the Valanginian (Crostella and Backhouse, 2000), while breakup between southern Australia and Antarctica started much later, in the Santonian (Sayers et al, 2001, Totterdell et al, 2000). On the southern margin there was a long period of slow spreading followed by fast spreading that stated in the mid-Eocene (Tikku and Cande, 1999).

The main regional tectonic events on the southwestern and southern Australian margins therefore include:

- Early Permian northeast–southwest extension on the western Australian margin.
- Middle Jurassic to Early Cretaceous northwest–southeast extension on the western Australian margin and the onset of northwest–southeast extension on the southern Australian margin.
- Valanginian to Hauterivian breakup between Greater India and Australia
- Turonian to Santonian breakup between Australia and Antarctica with the onset of slow spreading.
- Middle Eocene onset of fast spreading in the Southern Ocean.

STRUCTURAL ELEMENTS

The Mentelle Basin can be divided into two key structural domains with distinctly different fault and depocentre geometries: the western and eastern Mentelle Basin (Figure 2). Major faults in the eastern Mentelle Basin strike predominantly north–northwest to north–northeast. Several mapped depocentres containing up to 7–9 km of sediments have been interpreted as remnants of Permo-Trassic half-graben (Figure 3), which were mostly eroded at the onset of the Mid-Jurassic rifting. The differences in structural architecture of the individual depocentres possibly reflect heterogeneity in the structural grain of the basement combined with the varying influence of Permian and mid-Jurassic to Early Cretaceous extension.

In the western Mentelle Basin fault orientations and depocentre geometries are similar to those in the eastern Mentelle Basin in the north, but change significantly in the south (Figure 2). The majority of faults in the south-western part of the Mentelle Basin strike northeast–southwest, with the major rift bounding faults dipping to the southeast. The depocentres of the western Mentelle Basin are interpreted as extensional half-graben structures formed during Mid-Jurassic to Early Cretaceous rifting (Figure 3). The depocentres are interlinked and contain up to 11 km of sediments. They have fairly simple geometries (Figure 3), but show signs of significant fault reactivation and inversion in the Cenozoic.

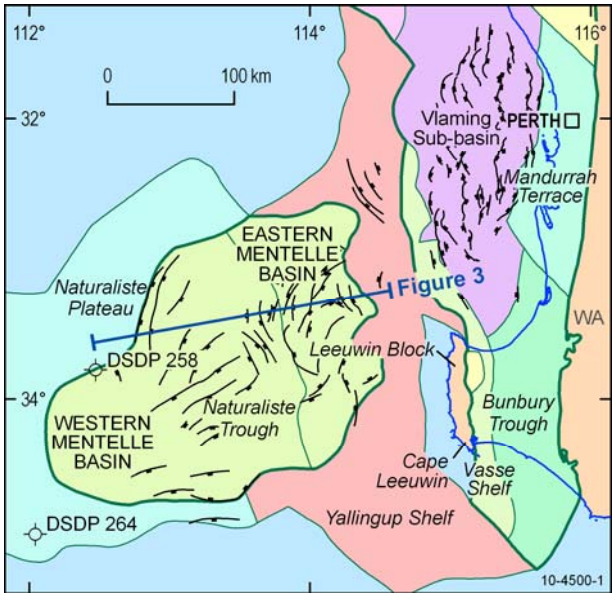

Figure 2. Structural elements of the southwest Australian margin

The presence of older half-graben on the flanks of the western Mentelle Basin (Figure 3) suggests that the Early Permian rifting affected the whole basin, although by the Mid-Jurassic most of the extension was mostly confined to the western Mentelle Basin. The distinct change in the fault and half-graben orientation in the western Mentelle Basin could be explained by the postulated triple junction between the Indian, Australian and Antarctic plates (Norvick and Smith, 2001). The rift structures in the south-western part of the basin are more consistent with the direction of extension between the Australian and Antarctic plates.

The change in fault orientations may also be related to the change in the structural grain of the basement. Rift structures often inherit structural grain from underlying basement (McClay et al, 2004) and therefore a change from the Pinjarra Orogen in the north to the Albany–Fraser Orogen in the south could have contributed to the structural change in the Mentelle basin.

Distribution and timing of fault reactivation and inversion in the western Mentelle Basin suggest that this event is regional in nature and occurred in the Mid-Eocene (I. Borissova et al, 2010). The only known significant regional event at this time is the onset of fast spreading on the southern Australian

margin and therefore it is the likely cause of fault reactivation and partial inversion in the Mentelle Basin. This demonstrates that the post-rift history of the Mentelle Basin continued to be linked to the tectonic events on the southern margin.

BASIN HISTORY

The Mentelle Basin has had a complex history of extension, volcanism and reactivation linked to tectonic events both on the southwestern and southern Australian margins. It began to form in the Early Permian, when rifting first started along the incipient plate boundary between Greater India and Australia. In the Triassic and Early Jurassic it was characterised predominantly by thermal subsidence. The Permo-Trassic succession in the eastern Mentelle Basin is up to 6 km thick (2500 ms two-way time).

In the Middle Jurassic, upper crustal extension resumed in the Perth and Mentelle basins and started on the southern margin. Middle Jurassic to Early Cretaceous extension produced a series of half graben that are mostly bounded by easterly dipping faults in the north, and by southeasterly dipping faults in the south. In the western Mentelle Basin, the Mid-Jurassic–Early Cretaceous succession is up to 9 km thick (3500 ms two-way time), and it is overlain by up to 2 km (1700 ms two-way time) of post-rift succession (Figure 3). In the eastern Mentelle Basin, Middle Jurassic to Early Cretaceous sediments appear to be largely eroded.

The Early Cretaceous (Valanginian to Hauterivian) breakup in the southern part of the Australian–Indian extensional terrain was accompanied by extensive volcanism on the Naturaliste Plateau (Coffin et al, 2002). Our study has shown that during this breakup the western Mentelle Basin also became a centre for magmatic activity, with the emplacement of up to 1 km (500 ms two-way time) of igneous rocks. In the eastern Mentelle Basin this volcanic episode is mostly represented by intrusive bodies, sills and dykes.

Following the breakup, deposition in the Mentelle Basin was dominated by thermal subsidence and gradual establishment of an open marine environment. A series of regional plate tectonic events in the Cretaceous, such as the breakup between India and Antarctica, the hotspot-related volcanism on the Kerguelen and Naturaliste plateaus (Coffin et al, 2002), and the breakup between Australia and Antarctica led to some fault reactivation and local volcanic activity, and produced regional unconformities in the Mentelle Basin. The onset of fast spreading in the Southern Ocean in the mid-Eocene correlates with margin collapse in the eastern Mentelle Basin and a significant inversion event in the western Mentelle Basin, accompanied by reactivation of many faults.

CONCLUSIONS

Interpretation of the new seismic data from the recent Geoscience Australia surveys has resulted in a better understanding of the structural and depositional histories of the Mentelle Basin. The new interpretation has confirmed that the basin's history is closely linked to tectonic events both on the western and southern Australian margins, which is clearly reflected in its structure. For the first time it has been shown that Permian rifted basins may have spread as far west as the Naturaliste Plateau. The focus of extension migrated from the Yallingup Shelf in the Permian to the western Mentelle Basin in the Mid-Jurassic–Early Cretaceous. Potential field modelling results (Johnston et al., 2010) suggest that this part of the Mentelle Basin is underpinned by highly extended crust.

The study also highlights a possible influence of the basement terrane underpinning the basin on initial orientation of the extensional faults.

Until recently, the Perth Basin margin has been classified as a non-volcanic rifted margin in comparison to the Gascoyne and Cuvier segments of the west Australian margin that are considered to represent typical volcanic rifted margins (Symonds, et al, 1998). The presence of an up to 1 km thick breakup related volcanic unit across the whole western Mentelle Basin suggests that the southwestern Australian margin may also be described as a volcanic rifted margin segment.

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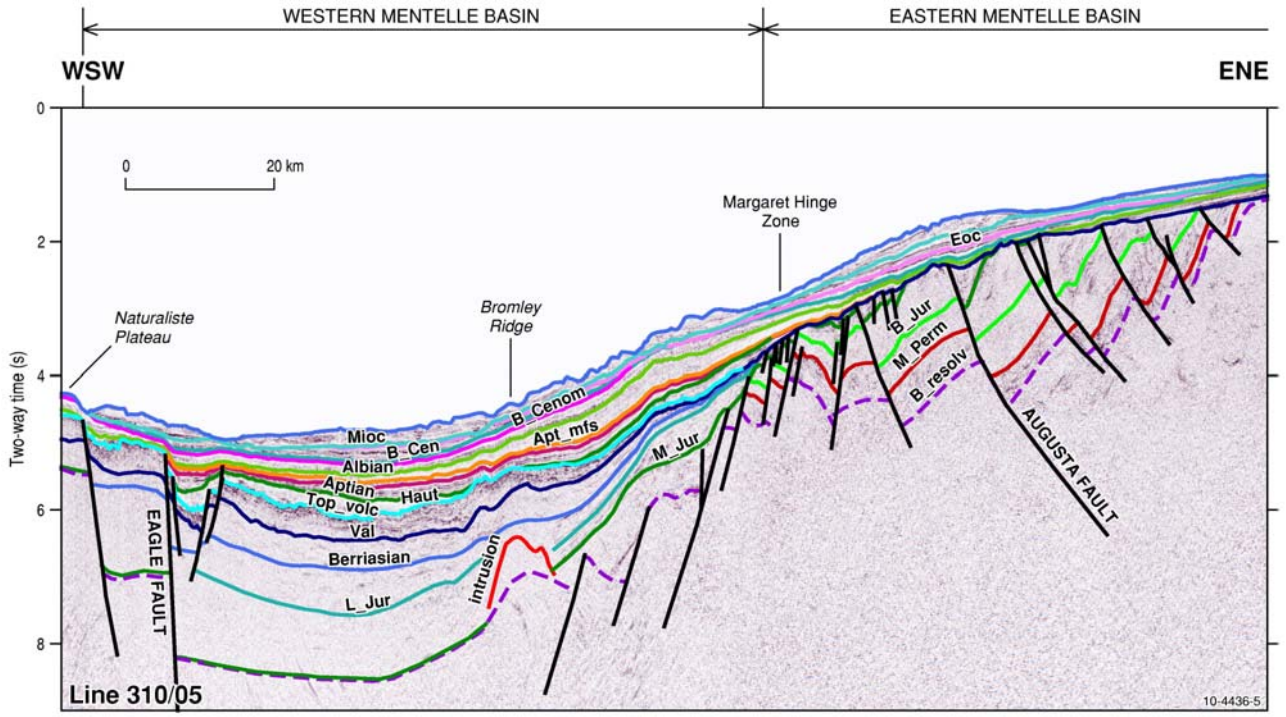

Figure 3. Geoscience Australia seismic line GA 310/05 across the Mentelle Basin showing interpreted supersequences. Refer to Figure 2 for location of seismic line