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Evolution of detached listric fault systems in the Ceduna Delta, Bight Basin: Insights from 3D seismic data

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SUMMARY

Deformation of the Cretaceous Ceduna Delta system is dominated by gravitationally driven listric extensional faults. They were initiated as strongly listric faults during deposition of the Cenomanian White Pointer deltaic sequence, coincident with the final stages of rifting and break up between Australia and Antarctica. The faults were progressively reactivated during deposition of the post break up Santonian to Maastrichtian Hammerhead deltaic sequence, propagating upwards as relatively planar sequences associated with narrow zones of downward converging secondary faults.

Individual faults segments maintain a characteristic curved geometry in map view which link together to form relatively long continuous NW-SE trending faults which rotate to a NNW orientation in the west of the study area (towards the break of slope at the edge of the delta top). Previously unrecognised N-S trending faults that are confined to the lower part of the sequence control some of the segmentation of the NW-SE trending faults.

Understanding the evolution of these fault systems will help to better define the risks associated with Cretaceous plays in this highly prospective frontier petroleum province.

Key words: Bight Basin, Ceduna, delta, fault

INTRODUCTION AND REGIONAL SETTING

The Bight Basin, considered by many to be a frontier petroleum province, evolved through several phases of extension and thermal subsidence during the Middle Jurassic to Late Cretaceous, related to rifting, breakup and the commencement of sea floor spreading between Australia and Antarctica (Totterdell and Bradshaw, 2004).

The Bight Basin contains four main depocenters: the Ceduna, Duntroon, Eyre and Recherche sub-basins (Bradshaw et al., 2003; Totterdell and Krassay, 2003). The largest and most prospective of these depocenters, the Ceduna Sub-basin (Figure 1), comprises two large prograding delta systems, the Cenomanian White Pointer and the Campanian-Masstrichtian Hammerhead supersequences, the deposition and deformation of which was controlled by the interaction of differential sediment loading and continental breakup during the Late Cretaceous (Ball et al, 2013; Espurt et al., 2009).

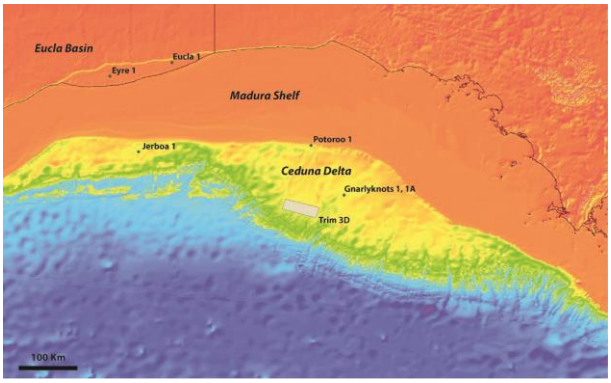

Figure 1. Location of the Ceduna Delta and Trim 3D seismic dataset.

Established fault trends in the Ceduna Sub-Basin are E-W to NW-SE (Teasdale et al., 2003, Totterdell and Bradshaw, 2004) and are attributed to gravitational extension associated with shale mobilisation in the Late Cretaceous. Rapid sediment deposition during the Cretaceous facilitated gravity driven fault growth to form the main Ceduna Basin depocentres (Totterdell and Bradshaw, 2004).

Although relatively unexplored, the Ceduna Sub-basin is thought to hold significant hydrocarbon potential, with companies having recently acquired significant exploration acreage in the area.

DATA SET AND STUDY AREA

Most previous studies of the listric fault systems associated with the Ceduna Delta have focussed on the 2D survey acquired in 2000 that covers most of the delta top. While the 4km line spacing provides an excellent overview of regional fault patterns, the 2006 Trim 3D survey, covering an area of about 1200 km^2 on the south west edge of the delta (Figure 1) provides much higher resolution information that reveals the presence of previously unrecognised fault trends and allows the growth and linkage of individual faults to be studied in much greater detail. The survey is situated c. 50 km WSW of the

Gnarlyknots 1A well which was used to tie the interpretation to stratigraphic markers

STRUCTURAL STYLE

Within the 3D seismic survey faults follow the regional NW-SE trend, although NNW trending fault segments are more apparent to the west, and appear to be more prominent at deeper structural levels. In map view the faults show curved traces typical of listric faults and are clearly made up of individual coalesced segments 15-20km in length (Figure 2). In their upper part faults are associated with secondary fault arrays that converge downwards towards the base of the upper Hammerhead sequence. These define hangingwall grabens that are noticeably more linear than the master faults. Also of interest are previously unrecognised N-S trending faults that are highly oblique to the regional trend and confined to the Cenomanian White Pointer sequence, and the lower part of the overlying Turonian to Santonian Tiger sequence.

In cross section the faults are strongly listric in the Cenomanian White Pointer sequence, curving to parallelism with the Late Albian Blue Whale Shale, where they detach (Figure 3). Well developed rollover anticlines and syn-extesnional wedges are developed in hangingwalls. Most propagate up into the Hammerhead sequence where they have more planar geometries, the fault tips having achieved their maximum dip during the initial stage of growth. Consequently narrow arrays of downwards converging faults develop; rather than more typical rollovers and crestal collapse structures.

Rotated Cretaceous sequences are truncated by an unconformity at the base of the Eocene Dugong Formation, but most of the NW-SE trending faults show minor late stage reactivation.

STRUCTURAL EVOLUTION

It is evident both from thickness variations and from the presence of syn-extensional wedges in the White Pointer Formation that rapid fault growth commenced during the Cenomanian, establishing most elements of the present day structural architecture at this time. Most NW and NNW trending fault segments can be correlated from the White Pointer into the Hammerhead sequences and show growth in both intervals. The N-S trending faults are not present within the Hammerhead sequence, and although they are relatively straight in map view, they are strongly listric and also detach onto the Blue Whale Shale. They initiated in the Late Albian or Early Cenomanian, slightly before their NW-trending counterparts, constraining lateral propagation of these slightly younger faults, and thus controlling some elements of later fault segmentation.

Isopach maps indicate that growth continued from the Cenomanian into the Turonian, during deposition of the lower parts of the Tiger Formation, and was followed by a period of relative quiescence during the Coniacian. Growth resumed on just one set of NW-SE trending faults during deposition of the lower part of the Hammerhead sequence (Santonian, Figure 4), and was localised on NNW trending faults in the west of the area during the middle part of the Hammerhead deposition (~ Campanian), with the majority of faults only being fully reactivated during the Maastrichtian (upper part of the Hammerhead). The progressive reactivation of differently oriented faults in different parts of the survey area may reflect localised loading associated with progradation of individual delta lobes.

SUMMARY AND CONCLUSIONS

The previously unrecognised N-S trending faults are, in cross section, virtually indistinguishable in style from the better-recognised NW-trending listric faults, which may explain why they have not previously been identified in the more extensive 2D seismic surveys. They are likely influenced by the underlying rift architecture, which in turn may reflect deeper basement structures or terrane sutures within the Gawler Craton, and may indicate gravity sliding and subsidence to the west during the Albian to Cenomanian, just prior to onset of the main SW-directed faulting.

The main faults in the Trim 3D survey area are similar to those described elsewhere in the delta system. This study shows the importance of the early phase of rapid fault growth during the Cenomanian in establishing the architecture of the fault system. There appear to be no new faults developed during the development of the Hammerhead Delta; instead reactivation of older faults appears to be more closely related to the progradation of individual delta lobes. Understanding the reactivation of these faults may have important implications for understanding trap integrity and fluid migration during the evolution of Cretaceous petroleum systems.

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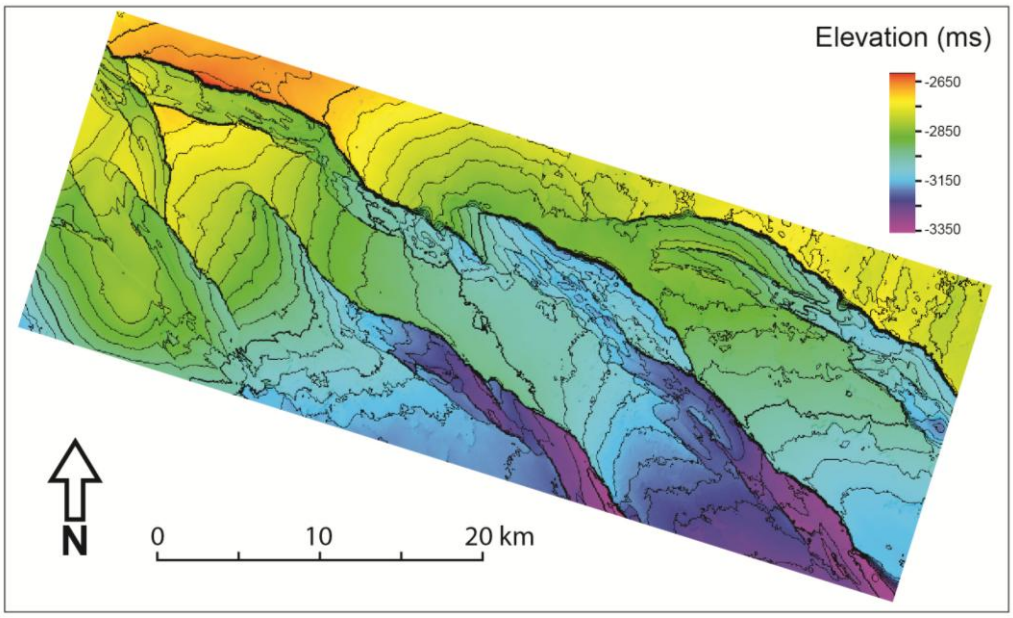

Figure 2. Map view of fault pattern, showing linkage of curved faults (Campanian horizon).

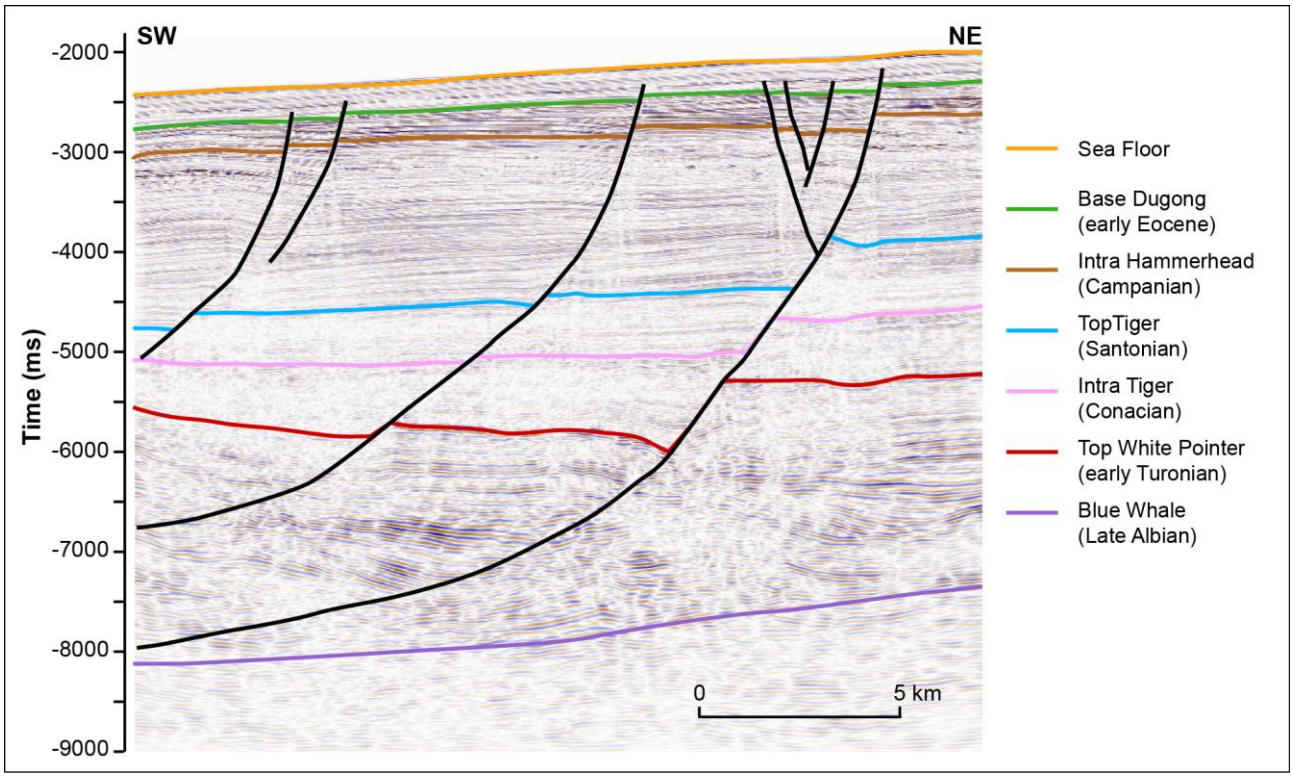

Figure 3. Seismic section showing listric faults detaching within the Late Albian Blue Whale Shale.

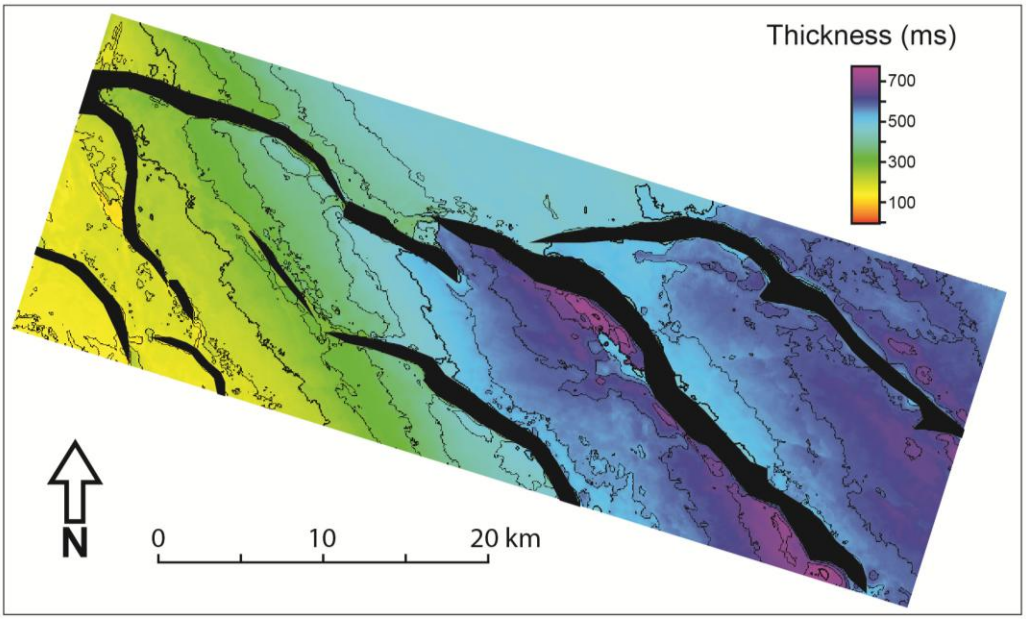

Figure 4. Isopach map of the lower part of the Hammerhead sequence, showing localised growth on the central fault.