Multiphase Deformation of the Northern Carnarvon Basin

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SUMMARY

The Northern Carnarvon Basin has experienced multiple phase of deformation, most likely starting in the Lower Palaeozoic and continuing to the present day. The widespread availability of public domain 2D and 3D seismic data sets over large parts of the basin allows mapping of structures at different stratigraphic levels in considerable detail, which in turn enables spatial relationships between structures of different ages to be established. Permian rifting established the fundamental underlying architecture of the basin and created the accommodation space for the accumulation of thick sequences of Triassic sediments. NE-SW trending structures were reactivated under E-W extension, starting in the latest Triassic, but the onset and magnitude of rifting is variable across the basin. The initial phase of rifting ended in the Middle Jurassic, but subsequent reactivation is variable, both spatially and temporally. Upper Jurassic to Lower Cretaceous reactivation is most evident in the easternmost and westernmost parts of the basin, and may be associated with a change in stress regime. A particularly short lived and enigmatic episode of extension occurs in the Exmouth sub-basin, associated with significant uplift and erosion. The Valanginian unconformity marks the end of most rift related activity, although minor fault reactivation occurs into the Albian. Upper Cretaceous to Recent compressional structures form at different times in different parts of the basin.

Key words: Northern Carnarvon Basin, extension, rifting, uplift, erosion

INTRODUCTION

The Northern Carnarvon Basin is a prolific hydrocarbon province and this has been extensively studied, not only in terms of hydrocarbon prospectivity, but also in terms of the structural, stratigraphic, sedimentological and geodyanimc evolution of the continental margin. The north-west margin of Australia is however somewhat unusual in that while it is broadly associated with the break up of Gondwana, this part of the margin has been located on the margin of the supercontinent throughout much of its history, and the repeated rifting of microcontinental fragments from that margin is invoked to explain its evolution. This is in contrast to the western and southern margins of Australia which are dominated by break-up events associated with separation of large continental block – Greater India and Australia respectively.

The widespread availability of public domain seismic data makes it relatively easy to study the evolution of the margin on a regional scale. This has enabled compilation maps of key stratigraphic intervals covering large parts of the Northern Carnarvon Basin and adjacent parts of the Roebuck Basin that shed further light on the structural and stratigraphic evolution of this important hydrocarbon province

Lower Palaeozoic to Recent evolution of the Northern Carnarvon Basin

Lower Palaeozoic
The oldest sediments intersected by wells in the Northern Carnarvon Basin are Early Carboniferous in age (the Moogooree Limestone in the Kybra-1 well; McHarg et al., 2018). However, seismic sections show a thick sequence of sediment below this, possibly extending as far back as the Silurian or Devonian (by analogy with similar sequences in the Merlinleigh (Southern Carnarvon) and Canning Basins). These sequences accumulated adjacent to the NNE trending Sholl Island Fault. This possibly represents an early phase of extension, analogous to similar events in the Petrel and Canning Basins, resulting in the formation of a series of relatively narrow NW to N-S trending basins during the Devonian and Lower Carboniferous. Upper Carboniferous, Permian and Triassic sediments passively infilled remnant rift related topography associated with the Sholl Island Fault.

By contrast, NE-SW trending faults on the southern margin of the Dampier and Beagle sub-basins contain thinner sequences of Permian sediments that are strongly rotated and separated by an angular unconformity from overlying Triassic sediments. This clearly represents a distinct phase of Permian extension, presumably related to that which resulted in extreme thinning of the crust beneath the Exmouth Plateau. It is this event that set up the fundamental NE-SW trend of the Northern West Shelf basins, but the interaction with the older N to NW trending basins is still to be resolved.

Triassic

The Locker Shale represents a major transgression that marked the start of the post-rift sequence following the end of Permian extension, in the Northern Carnarvon Basin at least. In addition to its stratigraphic significance, and source rock potential, it also forms a major detachment surface which controls the geometry of a number of younger Mesozoic faults. The Mungaroo Formation is widely regarded as a post rift sequence that filled the considerable accommodation space created by thermal subsidence resulting from extreme Permian extension, but subsidence and sediment supply must have been carefully balanced to maintain the relatively constant water depths represented by the thick sequence of fluvio-deltaic deposits.

While the Mungaroo Formation represents a thick and relatively continuous sequence in the Exmouth Plateau, where Permian extension and subsequent subsidence was at its greatest, a widespread unconformity is recognised around the basin margins (the TR20 sequence boundary of Marshall & Lang, 2013). This is equated with the Fitzroy movement in the Canning Basin. While there is some evidence of compressional structures forming in the Canning Bain at this time, the equivalent unconformity in the Browse Basin represents the end of a period of extension that continues from the Carboniferous into the Lower Triassic. Complex intra-Triassic unconformities are also evident in the outer parts of the Roebuck Basin, but the nature of the structures associated with those unconformities are unclear. There is little evidence of compression at this time in the Northern Carnarvon Basin. The significance of the Fitzroy Movement is still to be resolved.

Latest Triassic to Middle Jurassic

Mesozoic extension resumed in the uppermost Triassic, during deposition of the Brigadier Formation, in the western part of the Exmouth Plateau and in the Exmouth sub-basin (Jitmahantakul & McClay, 2013). In the Beagle sub-basin, extension appears to post-date deposition of the Brigadier Formation and is of much less magnitude. Extensional faults across the Exmouth Plateau and Roebuck basins have a very uniform NNE strike, implying that they formed under a ENE oriented extension regime. However, the underlying Permian structures have clearly influenced the architecture of the basins that subsequently formed. The location & orientation of the Barrow sub-basin is controlled by the NNE oriented Sholl Island Fault and Mesozoic extension was orthogonal to this. The Dampier and Exmouth sub-basins follow the trend of the underlying NE striking Permian faults resulting in oblique extension manifest by the en-echelon faults of the Rankin trend on the northern margin of the Dampier Sub-basin, and the en-echelon pattern of rift border faults on the faults western margin of the Exmouth sub-basin. It is interesting to note that ENE-oriented extension is at odds with the NE oriented extension observed in the Browse Basin that culminated in the separation of Argoland from that part of the margin. This suggests that Argoland separation was a localised event and that extension in the Carnarvon and Roebuck Basins was controlled by stresses associated with development of the western margin of Australia.

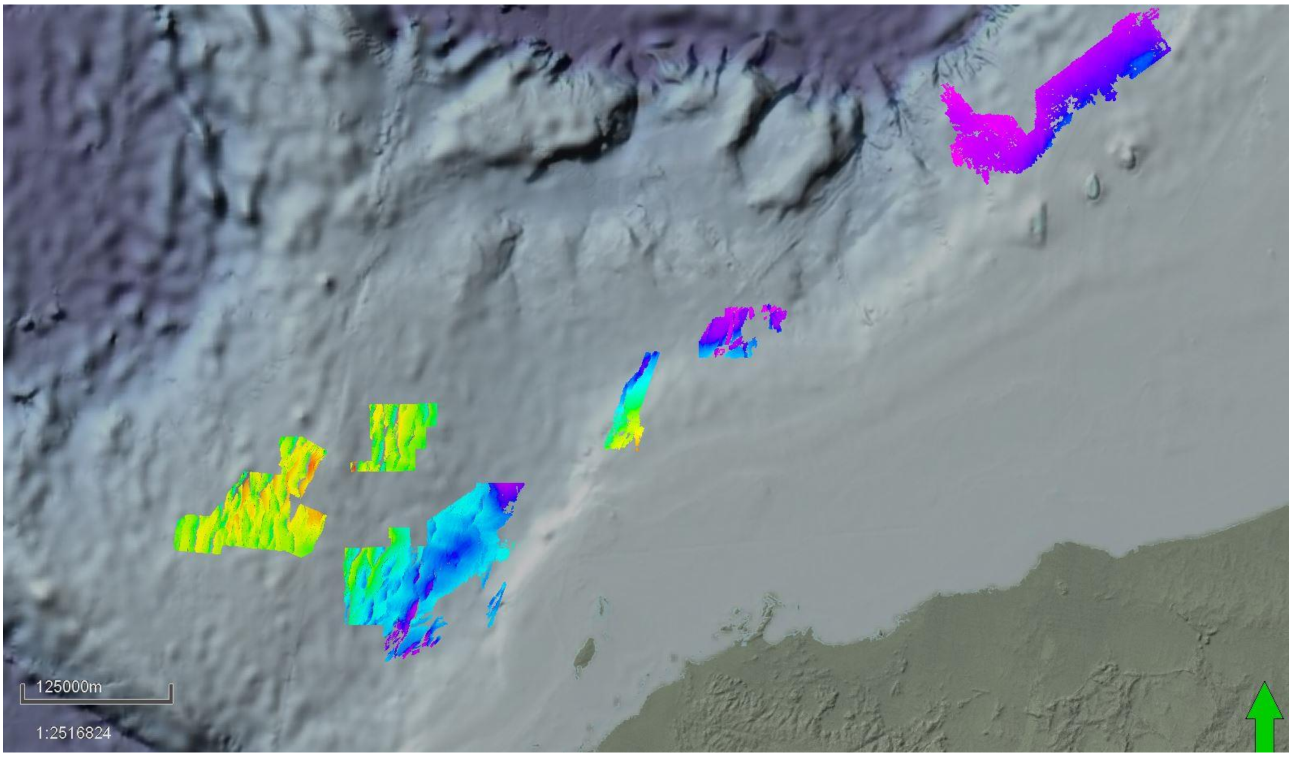

Figure 1: Partial map of the Top of the Mungaroo Formation extending from the Carnarvon Basin into the Roebuck Basin. Note the greater throw on faults and erosion of fault block crests in the western part of the Exmouth Plateau and the erosion truncation on the northern flank of the Exmouth and Barrow sub-basins

Uplift on the flanks of the Exmouth and Dampier sub-basins resulted in erosion of the pre-extensional Mungaroo Formatuion. There was also significant uplift of rotated fault blocks further outboard in the Exmouth Plateau. As sediment supply at this time was mainly from the east, the Exmouth Plateaus was sediment-starved, resulting in underfilling of half graben, condensed sequences and erosion of fault block crests (Rohead-O'Brien & Elders, 2018). Thicker sequences to the east show much less evidence of fault control on sediment distribution.

Upper Jurassic to Lowermost Cretaceous

The early Oxfordian unconformity (JB40 of Marshall & Lang, 2013) marks the end of the initial phase of extension. Further rotation of fault block occurred in the Exmouth Plateau prior to the deposition of Upper Jurassic sediments (Rohead-O'Brien & Elders, 2018), but in the Exmouth sub-basin, Upper Jurassic and Lowermost Cretaceous sediments have the appearance of post-rift sequences (Black et al, 2017). Likewise Berriasian sediments of the Barrow Group in the southern part of the Exmouth Plateau also appear to be unaffected by active faulting, although reactivation of extensional faults becomes more apparent in the westernmost parts of the Exmouth Plateau. The influx of Berriasian sediments from the south marks a major change in sediment supply, associated with uplift to the south, in the vicinity of the northern Perth Basin, possibly related to plume activity preceding the separation of Greater India from Australia (Rohrman, 2015).

Within the Exmouth sub-basin a significant phase of extensional faulting occurs after deposition of the Berriasian sediments of the Barrow Group, but prior to the formation of the Valanginian unconformity, a period of less than at least 5 million years, and possibly even less than one million years. This very short lived period of extension was also associated with uplift and erosion of Berriasian and Tithonian sediments. Some of this uplift maybe associated with igneous activity, but it also appears to reflect a broader tilting of the basin. Again, the tectonic significance of this event is still to be established.

Lowermost Cretaceous to Recent

The Valanginian unconformity coincides with the formation of oceanic crust associated with initiation of the separation of Greater India from Australia. Uplift and erosion of the Exmouth sub-basin provided a secondary source of sediments for the Zeepard Formation (or Upper Barrow Delta) which filled in the depositional topography of the lower delta (Barrow Group *sensu stricto*) as well as the most of the remnant rift topography of the Exmouth Plateau. Further minor extensional faulting disrupts this sequence prior to regional transgression that resulted in deposition of the Muderong Shale towards the end of the Lower Cretaceous.

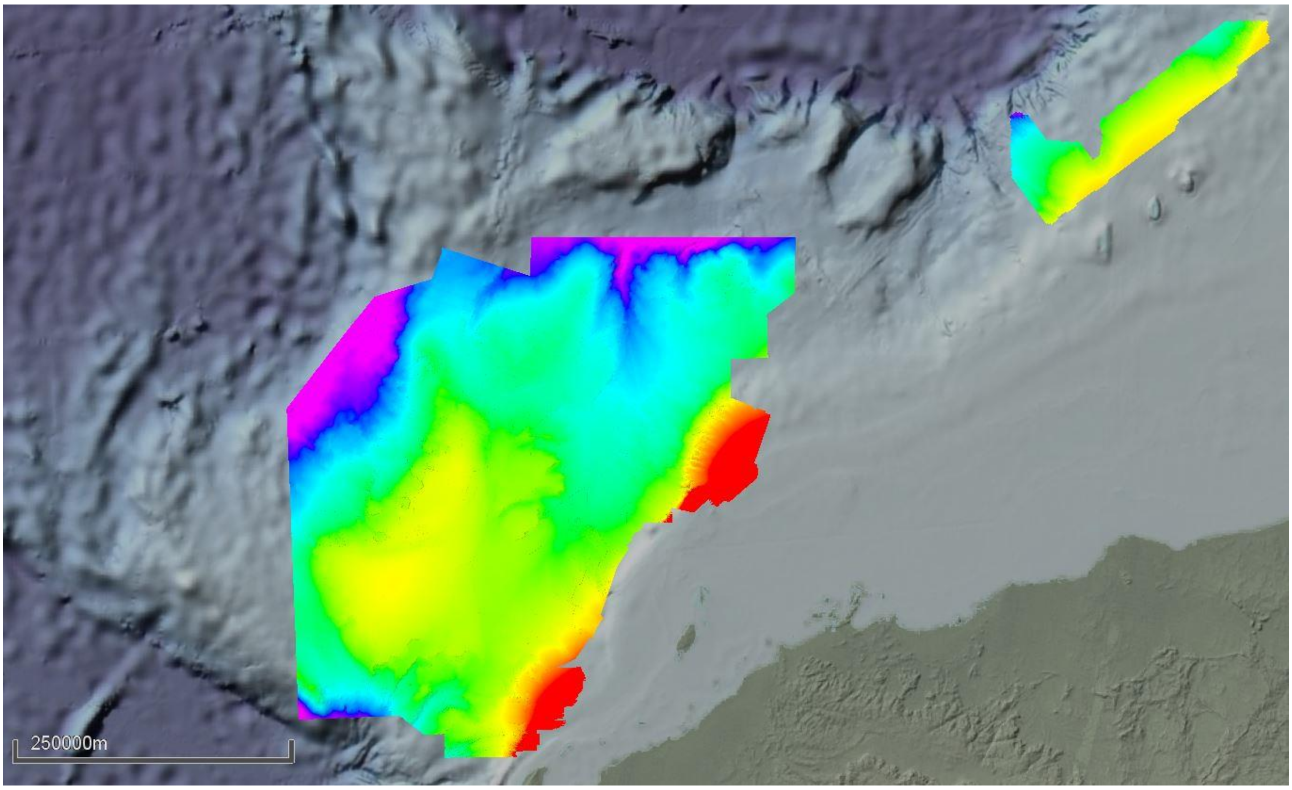

Figure 2: Map od the seabed showing the Exmouth Arch, associated slumps and collapse of the shelf edge

Although now part of a passive margin, compressional deformation has subsequently affected the margin. Large scale folds such as the Cape Range Anticline and the Novarra Arch were probably initiated in the Upper Cretaceous. However, the Exmouth anticline appears to be a younger feature that possibly initiated as recently as the Oligocene, and continues to grow at the present day. There is not a direct relationship between these large scale anticlines and the underlying rift structures, so they do not represent basin inversion *sensu stricto*, and there is some evidence to suggest that the Exmouth Arch is detached from underlying structures.

CONCLUSIONS

Although complex, the history of the Northern Carnarvon Basin can be unravelled due to the availability of extensive datasets that are a result of the extensive exploration activity, the enlightened rules that make such data publically available and the role of Geoscience Australia in providing ready access to it. While there is no such thing as a "typical" passive margin, the North West Shelf, and the Northern Carnarvon Basin in particular, are particularly unusual in the sense that they have experienced repeated rift events as well as younger compressional deformation. The variable distribution and timing of those events even with in the Carnarvon Basin highlight the fact that some of the general "truths" that are applied to the whole of the North West Shelf need to be critically examined. By examining in detail the variations in timing and intensity of different events along the margin, the tectonic events and geodynamic processes responsible for its evolution can be better understood.

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