The effect of flexural isostasy on delta architecture: implications for the Mungaroo Formation

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SUMMARY

The fluvio-deltaic Triassic Mungaroo Formation, North West Shelf (NWS) of Australia, hosts vast resources of hydrocarbons. However, the mechanisms that generated its 4-6 km monotonous infill architecture (colloquially known as layer cake stratigraphy) remain elusive. The vertical fluctuation between fluvial and shallow marine deposits indicates that accommodation was created simultaneously with deposition. This seems to suggest that the stratigraphic style of the Mungaroo formation was significantly controlled by the isostatic compensation of the sediment load. To test this we use a basin and landscape dynamics model, BADLANDS that combines fluvio-deltaic processes (erosion and sedimentation) with flexural isostasy. To drive our simulations we use dimensions, gradient, water discharge and sediment flux from seismic and scaling relationships extracted from the Mungaroo Formation and different lithospheric elastic thickness (*Te)* to account for the effect of dissimilar lithospheric rigidities and flexural isostasy. Results show an increase in delta size and decrease in sediment thickness as the lithospheric elastic thickness increases. These models help explain how thick deltaic sequences can be generated in a lithosphere with low *Te* values. Future research will focus on comparing the synthetic stratigraphy extracted from the models with the stratigraphic record. This study provides a valuable quantitative approach for understanding how the isostatic compensation of the sediment load can control the architecture of fluvio-deltaic deposits, which has implications for reservoir modelling.

Key words: flexural isostasy, accommodation, delta, basin infilling, architecture.

INTRODUCTION

The fluvio-deltaic Triassic (Carnian-Norian) Mungaroo Formation, NWS (Fig. 1) exhibits a 4-6 km (Fig. 2) thick monotonous infill architecture that fluctuates vertically between delta front and alluvial plain deposits, with an overall transgressive trend (Fig. 3). Previous research has proposed that these vertical fluctuations were produced by a series of third and possibly fourth order duration regressive-transgressive cycles related to variations in relative sea-level, sediment supply and/or climate (Adamson et al., 2013). An additional factor that may have contributed to create such a cyclic pattern is the isostatic compensation of the sediment load.

Previous modeling of the Mississippi delta shows that sediment-driven isostatic adjustments can take place at high-frequency time-scales ($<10^6$ yr, Blum et al., 2008; Blum et al., 2013). Blum et al., (2008) showed that sediment volumes removed onshore and deposited offshore were sufficient to induce >12 m of uplift in the valley center, and >9 m along valley margins, followed by subsidence of the same magnitude. The flexural effects were predicted to extend, and affect stratal architecture, >150 km from the valley margin along the Gulf of Mexico coast. Blum's study concluded that cyclical uplift and subsidence should amplify valley incision and filling, whereas spatial patterns of uplift and subsidence should play a key role in the development of valley fill architecture, as well as along strike stratal variation. Furthermore, Blum et al., (2013) argue the role of isostatic compensation of the sediment load should be particularly relevant for large river systems, which deliver significant volumes of sediment to basins, such as in the case of the Mungaroo delta (Longley et al., 2000; Adamson et al., 2013). Other numerical modeling studies have concluded that the contribution of isostatic compensation of the sediment load must be accounted for when estimating the effect of relative sea-level changes to fluvio-deltaic architecture (Reynolds et al., 1991; Driscoll and Karner, 1994).

We consider that the effect of the isostatic compensation of the sediment load in the accumulation of the Mungaroo Formation is a significant factor, especially because no high-frequency eustatic and/or global climatic cycles are observed during the Triassic. Eustatic levels in the Triassic exhibit a progressive transgression that began in the latest Permian, which then peaks in the Anisiane-Ladinian boundary interval, followed by a regression to the Late Norian (Ogg, 2012). High-frequency global climatic cycles have not been observed in the Upper Triassic, only a long-term cooling trend after the onset of the Carnian Pluvial Event (Preto et al., 2010). Climatic conditions were cooler and increased rainfall has been documented in many continental regions (Ogg et al., 2016), including in the Mungaroo Formation (Ratcliffe et al., 2010).

To investigate the role of isostatic compensation of the sediment load on delta architecture, we use a parallel basin and landscape dynamics model, BADLANDS, (acronym for BAsin anD LANdscape DynamicS) that combines fluvio-deltaic processes (erosion, sedimentation, diffusion) with flexure. Isostatic compensation of this load here is computed by flexural compensation (Watts, 1978). Our modeling approach allows investigating how as the delta evolves through time the sediment load increases generating a deflection in the lithosphere and thus creating accommodation. Our hypothesis is that the extent, thickness and stratigraphy of the delta would differ depending on the rigidity of the lithosphere, a parameter expressed as the lithospheric elastic thickness (*Te*). This first stage of this research shows an increase in delta size and decrease in sediment thickness as the lithospheric elastic thickness increases. These models help explain how thick deltaic sequences can be generated in a lithosphere with low *Te* values.

METHODS AND PRELIMINARY RESULTS

Our modeling approach allows investigating how as the delta evolves through time the sediment load increases generating a deflection in the lithosphere creating additional accommodation, and therefore changes in sea-level. Our approach is to create a series of simulations were sediment is transported by channel flow and linear diffusion processes to generate a delta. To test the effect of flexural isostasy we keep all parameters constant and systematically increase *Te* in different runs. The *Te* values we use are based on ranges from global published datasets. To drive the sediment transport component of our simulations we use dimensions, gradient, water discharge and sediment flux from seismic and scaling relationships extracted from the Mungaroo Formation. The model setup consists of a gently sloping rectangular grid with dimensions similar to the basin containing the Mungaroo Formation (700x350 km) and a gradient (1E-4) extracted from seismic data. Water and sediment discharge were estimated using published channel depth-discharge scaling regressions derived from Quaternary rivers (Blum et al., 2013); channel depth values needed for the regression were extracted from borehole data from the Mungaroo Formation. Estimated water and sediment discharge are in the range of large wet-tropical deltas, which is consistent with the proposed continental-scale of the Mungaroo system. Results show an increase in delta size and decrease in sediment thickness as the lithospheric elastic thickness increases. These models help explain how thick deltaic sequences can be generated in a lithosphere with low *Te* values (Fig. 4).

CONCLUSIONS

In this paper we investigate the role the isostatic compensation of the sediment load on delta architecture by conducting a series of numerical models where we keep all parameters constant and systematically increase *Te* in different runs. Results show an increase in delta size and a decrease in sediment thickness as the rigidity of the lithosphere increases. Relatively similar results have been obtained based on 1D models. Reynolds et al., (1991), showed that the manner in which flexure distributes accommodation space is a function of lithospheric rigidities: higher rigidities partition space laterally producing wide shelves, whereas lower rigidities partition space vertically forming narrow shelves.

We recognize that the flexural strength of the lithosphere can also be affected by lithospheric cooling, which in turn would create accommodation space and affect stratigraphic patterns, this is not accounted for in our simulations. This effect is particularly important for the case of the Mungaroo Formation, where thermal subsidence was a primary factor controlling the formation of this sag-basin. Future thermo-mechanical models would account for this effect. This study provides a valuable quantitative approach for understanding how the isostatic compensation of the sediment load can control the architecture of fluvio-deltaic deposits, which has implications for reservoir modelling.

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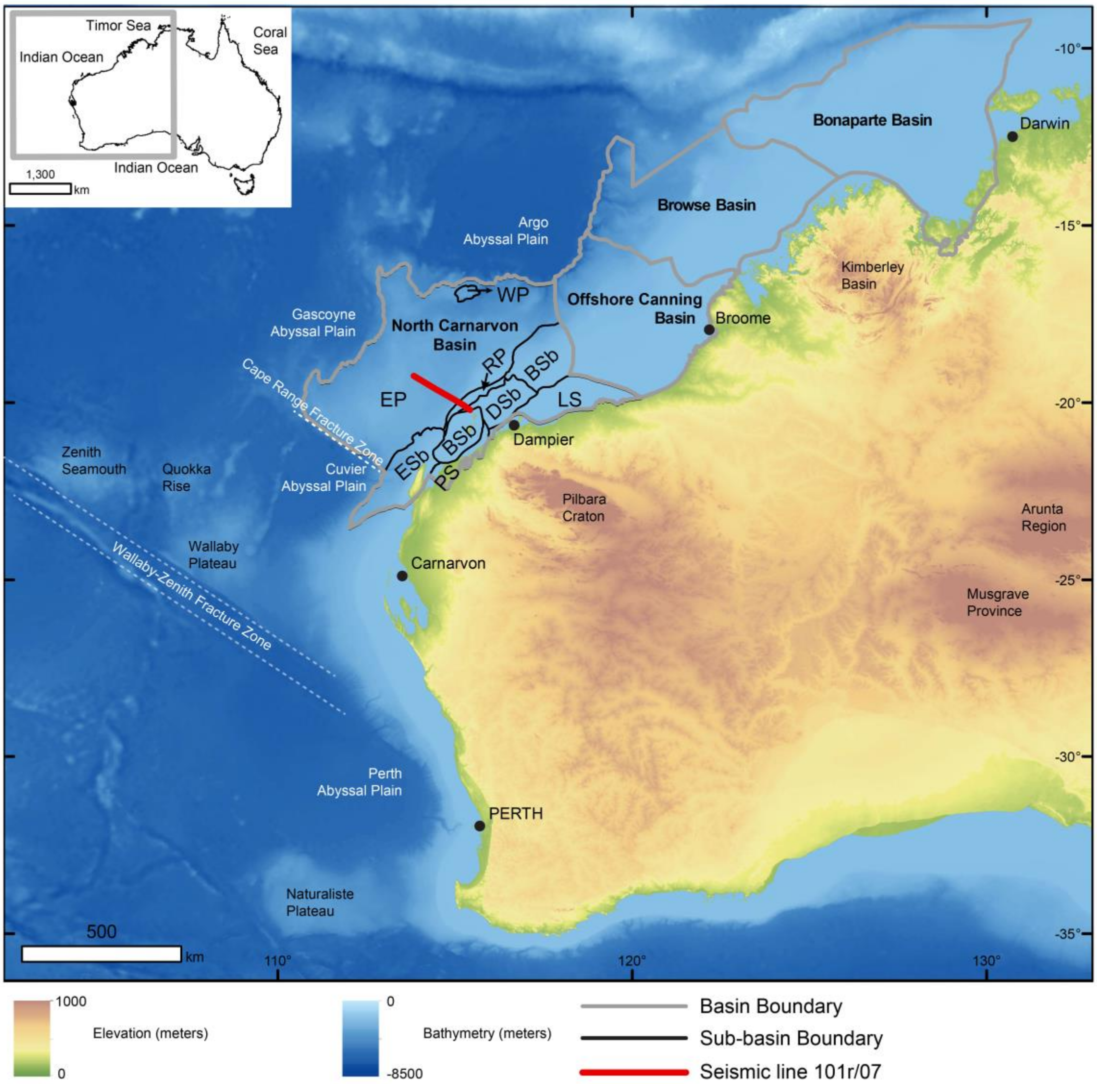

Figure 1. Map of showing the location of the North West Shelf of Australia as well as topography, bathymetry with major bathymetric elements and main basin subdivisions. Elevation data are based on the 2009 Australian Bathymetry and Topography grid (Geoscience Australia). EP=Exmouth Plateau, WP=Wombat Plateau, RP=Rankin Platform, BSb= Beagle Sub-basin, DSb=Dampier Sub-basin, BSb=Barrow Sub-basin, LS= Lambert Shelf, PS=Peedamullah Shelf. Rectangle on inset shows the location of the area within Australia.

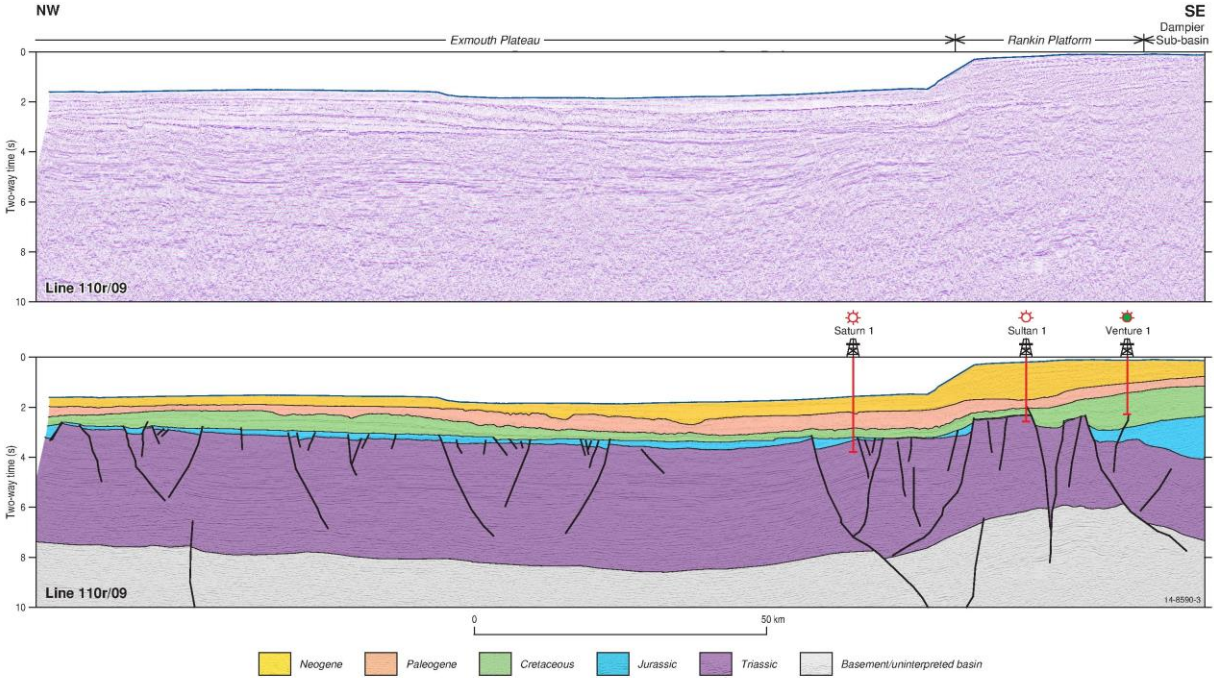

Figure 2. Composite seismic profile (lines 128/08 and 101r/09) across the Exmouth Plateau, Rankin Platform and Dampier Sub-basin. Notice how in the Exmouth plateau the Triassic sequence (Mungaroo Delta) has a gentle-dipping reflectors with no synsedimentary deformation and lack of extensive basement faulting and graben and/or half-graben formation. Interpretation by Geoscience Australia.

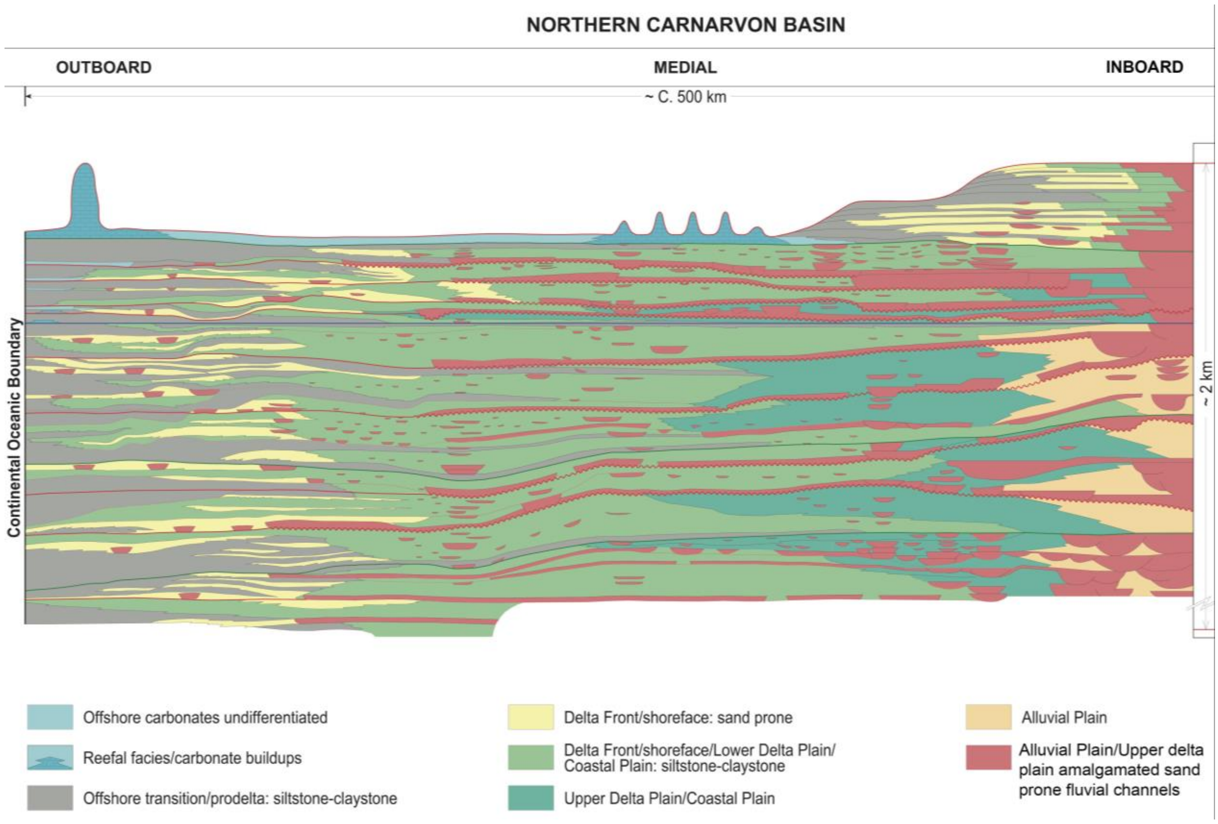

Figure 3. Schematic stratigraphic cross-section in depth across the Northern Carnarvon Basin with annotated conceptual geological interpretation of the stratigraphic architecture of the Mungaroo delta ranging from alluvial plain to delta front conditions. Notice the monotonous vertical variation of environments of deposition and limited fluctuations in base-level. After Adamson et al., (2013).

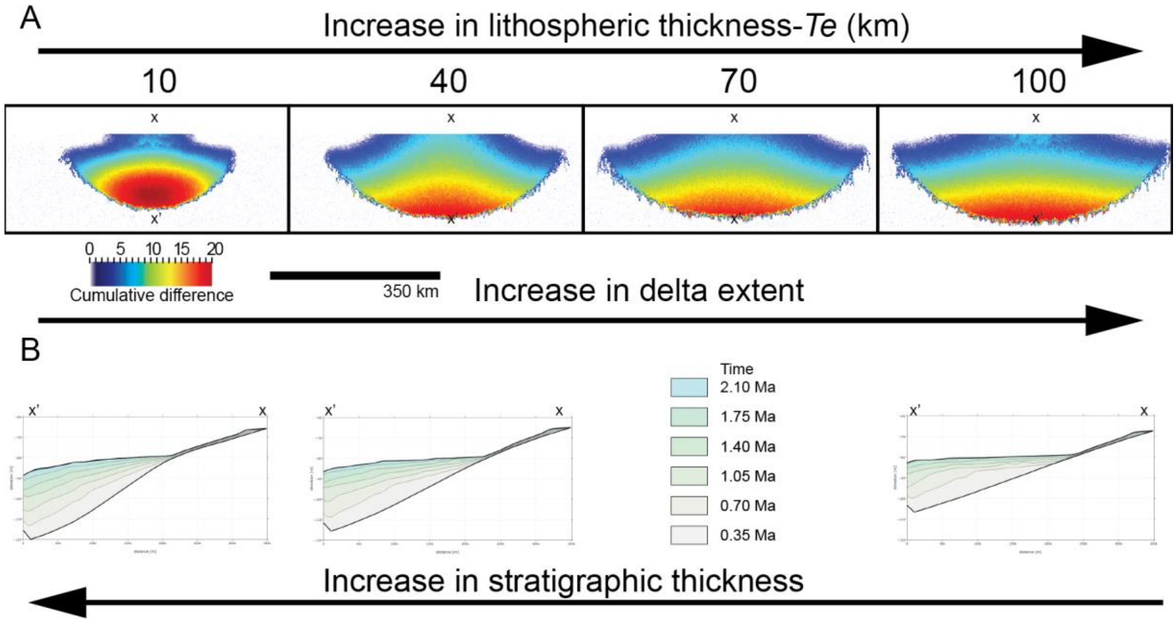

Figure 4. Results show an increase in delta size (A) and decrease in sediment thickness (B) as the lithospheric elastic thickness increases.