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Research paper

Quantification of architectural variability and controls in an Upper Oligocene to Lower Miocene carbonate ramp, Browse Basin, Australia

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A B S T R A C T

Integration of seismic geomorphology and trajectory analysis of the Oligocene through Lower Miocene distally-steepened carbonate ramp system in the subsurface Browse Basin of the Northwest Shelf of Australia introduces a new way to parameterize carbonate slope channel systems and their stability, and sheds light on how basinward sediment transport is influenced by allogenic and autogenic controls. Seismic geomorphologic analysis identified large-scale prograding clinoforms with an extensive slope channel system and slope angles of up to 12°. Clinoforms have an average slope angle of 8°, a height of ∼500 m, and prograded 9 km during the Upper Oligocene through the Lower Miocene. Relative sea level changes overprinted the effect of intermediate-scale and small-scale antecedent topography, and determined progradation, aggradation and slope angles of the system. We introduce cumulative channel cross sectional area (CCCSA) as the product of number of slope channels, slope channel depth, and slope channel width. CCCSA quantifies the capability of the slope channel system to transport sediment basinward and highlights phases of autogenic slope system re-organization in response to changes in relative sea level. Abruptly increasing values of CCCSA correlate with slope sediment bypass through the incision of new slope channels during system re-organization phases at slope angles of 10°. Thus, we propose that CCCSA can be used as a proxy for slope system stability. Incision of new slope channels into the ramp margin created strike-parallel variability of the ramp margin trajectory. Our seismically-derived relative sea level curve and subsidence rates of 9–30 m/Myr indicate a good preservation of the subsidence and sea level signal in the data.

1. Introduction

Clinoforms are one type of record of the spatial and temporal evolution of sedimentary systems. Their evolution is controlled by a complex interplay between tectonics, eustasy, sediment supply, antecedent topography and climate (Henriksen et al., 2011). The combined signal of allogenic and autogenic controlling processes is preserved as a physical response in the sedimentary system architecture. It is this complex interplay of processes that defines the sedimentary packaging, and thus where and how much sediment is deposited and preserved in the stratigraphic record. This direct feedback between controls and the system response enables geoscientists to solve the inverse problem of extracting paleoenvironmental conditions from the rock record (Dalrymple, 2010). The quantification of system architecture, therefore, can provide a better understanding of the individual signals of allogenic and autogenic controls.

Geomorphometry is the quantitative description of landforms, their processes, geometries and sediments at the Earth's surface. It is used to derive parameters about slope and curvature and to extract information about morphometric features (Pike et al., 2009; Pike, 2000). In modern depositional environments, geomorphometry is used to quantitatively describe and understand sedimentologic feedbacks. Seismic geomorphology is the application of this approach to extract geomorphic insights using dominantly 3D seismic data. The petroleum industry extensively uses 3D seismic data to identify geobodies, such as channels, mounds etc., and to identify prospective drilling targets (Posamentier et al., 2007).

The well imaged subsurface clinoforms of the Oligocene – Miocene carbonate ramp system of the Australian North West Shelf (NWS) were previously studied to investigate their evolution and controls in the Carnarvon Basin (e.g. Cathro and Austin, 2001; Cathro et al., 2003). Research on the evolution of the overlying Middle – Late Miocene carbonate shelf in the adjacent Browse Basin utilized high-resolution seismic geomorphology, lithological information from well logs,

Abbreviations: NWS, North West Shelf; SS, Seismic sequence; SB, Sequence boundary; DL, Dip line; IDA, Individual dip line aggradation; IDP, Individual dip line progradation; SAA, System average aggradation; SAP, System average progradation; m/Myr, Meters per million years; Ma, Million years ago; CCCSA, Cumulative channel cross sectional area

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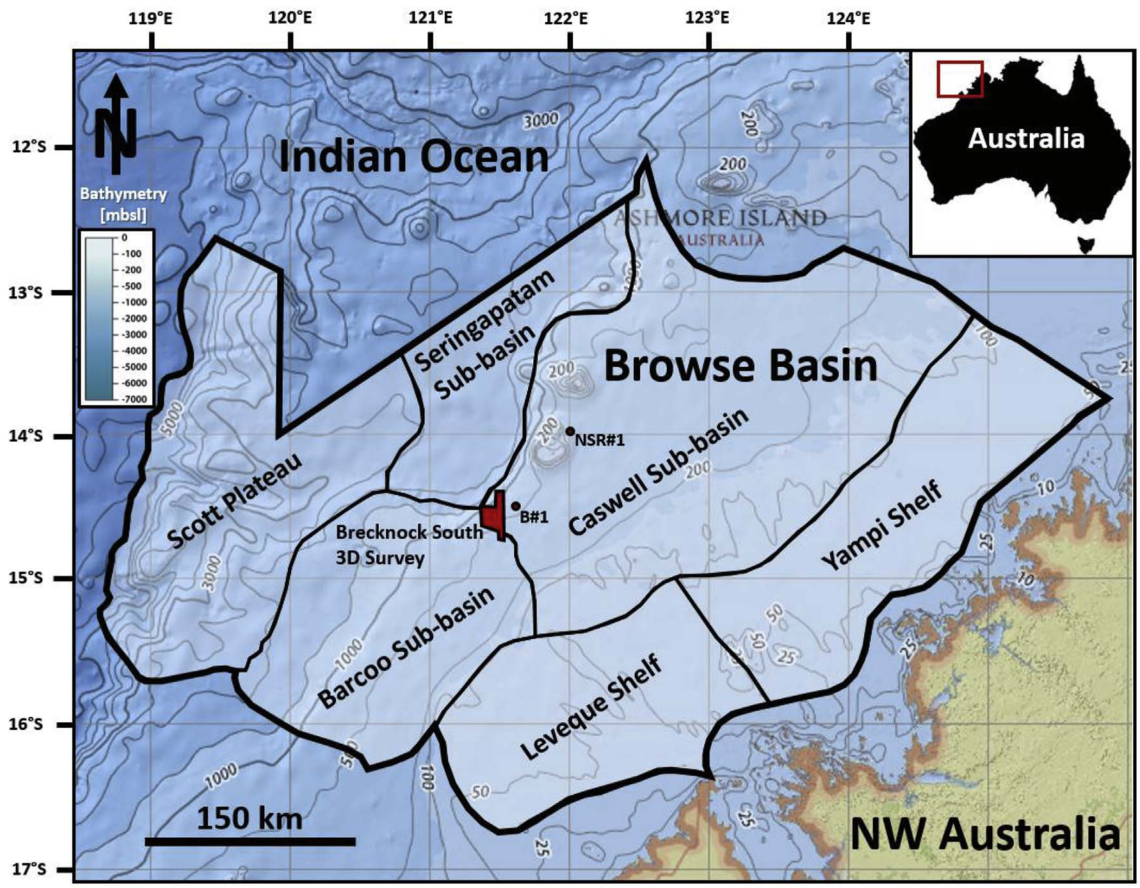

Fig. 1. Location of Browse Basin on the North West Shelf of Australia after Struckmeyer et al. (1998). Note the location of the Brecknock South 3D seismic survey at the intersection of the Caswell, Barcoo and Seringapatam sub-basins. Offset wells B#1 = Brecknock #1 and NSR#1 = North Scott Reef #1 provided well data for stratigraphic correlations (Rosleff-Soerensen et al., 2012; Woodside Energy, 2007). Regional bathymetric contours (GEBCO_2014) in meters below sea level (mbsl) are displayed on an ESRI National Geographic Basemap and indicate the present-day southwest-northeast strike of the shelf.

sidewall cores, ditch cuttings, stable isotope ($\delta^{18}O$, $\delta^{13}C$) data, and Rb/Sr age-dating methods to reconstruct the paleo-environmental changes in the Browse Basin during the Miocene (Rosleff-Soerensen et al., 2012).

This study presents novel techniques to quantitatively resolve geometries, along-strike variability, and to delineate paleoenvironmental signals of the Oligocene – Lower Miocene carbonate ramp system in the Browse Basin. Use of 3D seismic data allows for determination of lateral variability, thereby, reducing the lateral bias and uncertainty of 2D studies. Calculated 3D progradation and sedimentation rates are a better representation of the actual system behavior than their 2D counterparts. This study describes how we reconstructed the signals of tectonics and relative sea level from 3D seismic data. We quantify how relative sea level changes influenced progradation and aggradation in the system. Furthermore, we delineate the interaction between relative sea level and the slope system to show how lateral variability in the ramp margin trajectory evolves.

2. Geological setting

The Browse Basin (Fig. 1) is part of the Westralian Superbasin (Yeates et al., 1987) that comprises the Carnarvon, Canning, Browse and Bonaparte Basins (Stephenson and Cadman, 1994) on the Australian North West Shelf (NWS). A significant amount of fluvio-deltaic siliciclastic, passive margin sediments accumulated in the Browse Basin (Woodside Energy, 2007, 2008, 2009) during a prolonged period of little or no tectonic activity in the Cretaceous (Apthorpe, 1988). Basin sedimentation changed from siliciclastic to carbonate-dominated in the Eocene (Apthorpe, 1988; Stephenson and Cadman, 1994). During the Paleocene – Eocene (Fig. 2), the NWS of Australia migrated north from 40° S to 32° S, into climatic conditions more favorable for carbonate systems (McGowran et al., 2004). A non-tropical, heterozoan carbonate ramp developed during the Eocene-Oligocene, overlying Paleocene and older siliciclastic strata (Reuning et al., 2009; Rosleff-Soerensen et al., 2012). Foreland loading related to the collision of the Australian plate with the Banda Arc and development of the Timor Trough caused increased basement subsidence beginning in the late Oligocene, and resulting in minor structural deformation in the study area (Baillie et al., 1994; Kennard et al., 2003). The Australian NWS shifted farther north from 30°S to 25°S during the Oligocene-Miocene (McGowran et al., 2004), and a warm climatic optimum was reached by the Middle Miocene (Feary and James, 1995; Savin et al., 1985; Tripati et al., 2009).

The transition into a tropical photozoan rimmed shelf occurred at the time of transition from Early to Middle Miocene, and is associated with a eustatic sea level fall (Reuning et al., 2009). The Browse Basin Middle Miocene barrier reefs, patch reefs and atolls drowned during the Early Tortonian relative sea level rise associated with the collision of the Australian Plate with the Banda Arc (Baillie et al., 1994; Stephenson and Cadman, 1994; Willis, 1988). This drowning event initiated the transition to Late Miocene-Recent hemipelagic carbonate sedimentation