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Neogene siliciclastic deposition and climate variability on a carbonate margin: Australian Northwest Shelf

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ABSTRACT

The Bare Formation represents a unique episode of Neogene siliciclastic deposition on the carbonate-dominated Australian Northwest Shelf (NWS). Seismic interpretation coupled with age control from International Ocean Discovery Program (IODP) Expedition 356 Sites U1462, U1463 and U1464 allow us to constrain the timing of siliciclastic deposition and the associated sedimentary processes. The Bare Formation is preceded by middle to late Miocene shelf exposure and karstification (~12 Ma). Elongate sandbars deposits with small lobate deltas developed during the late Miocene. Fluvial deposition increased markedly in the Zanclean (5.3–3.6 Ma), resulting in development of a large wave dominated delta, with evidence of channels, comprising the thickest component of the Bare Formation. Siliciclastic input decreased in the Piacenzian (3.6–2.58 Ma), leading to margin retreat and final termination in the early Pleistocene (~2.39 Ma). The results correlate with regional climate and sedimentary records from Sites U1463 and U1464, which indicate an arid middle to late Miocene on the NWS, followed by a humid interval in the Zanclean and a return to arid conditions during the Piacenzian. We suggest that fluctuation of surface runoff patterns in the continental hinterland was the primary control on Bare Formation evolution. Sedimentary and climate transitions are linked to reorganization of Indian Ocean paleoceanography, accompanying northward migration of the Australian continent and progressive restriction of the Indonesian Throughflow.

1. Introduction

In the Neogene period, dramatic changes in tectonic and climatic patterns affected ocean currents, sea level, and sedimentation on continental margins (Fig. 1). The modern-day configuration of continents and island arcs developed during this time, through tectonic orogeny in the Andean and Eurasian belts, formation of backarc basins along the Pacific margin, and the northward movement of the Australian plate (Potter and Szatmari, 2015). Modern oceanic gateways were established by the closure of the Paratethys Ocean (18–12 Ma; Rögl, 1997), closure of the Isthmus of Panama (~3 Ma; O'Dea et al., 2016) and by the constriction of the Indonesian gateway in the Indo-Pacific (5–2 Ma; Cane and Molnar, 2001; Gallagher et al., 2009). In the Mediterranean Basin, restriction of the Strait of Gibraltar in the late Miocene resulted in the Messinian salinity crisis and desiccation of the Mediterranean Sea (~6 Ma; Rouchy and Caruso, 2006). As a result of this tectonic reconfiguration, global oceans and climate were profoundly modified. The global warm period of the Middle Miocene Climatic Optimum (17–14 Ma) ended when expansion of the Antarctic Circumpolar Current and ice-sheet expansion on the Antarctic continent lowered global temperatures in the middle and late Miocene (Gulick et al., 2017; Shevenell et al., 2004; Zachos et al., 2008). What followed was the establishment of a cooling period in the late Miocene, marked by the decline of atmospheric CO_2 levels and enhanced aridity and seasonality in subtropical areas (Herbert et al., 2016). Global temperatures and sea level only rebounded during the Pliocene warm period (5–3 Ma), succeeded by a return to cooling conditions after 3 Ma (Fedorov et al., 2013; Sniderman et al., 2016; Karas et al., 2017).

These Neogene tectonic and climatic transitions affected sedimentation on continental margins. Rapid erosion and sedimentation occurred during the early to middle Miocene (24–11 Ma) in Southeast Asia, linked to the intensification of seasonal precipitation (i.e., monsoon development) and rock uplift, particularly during the Middle Miocene Climatic Optimum, when erosion rates were high across

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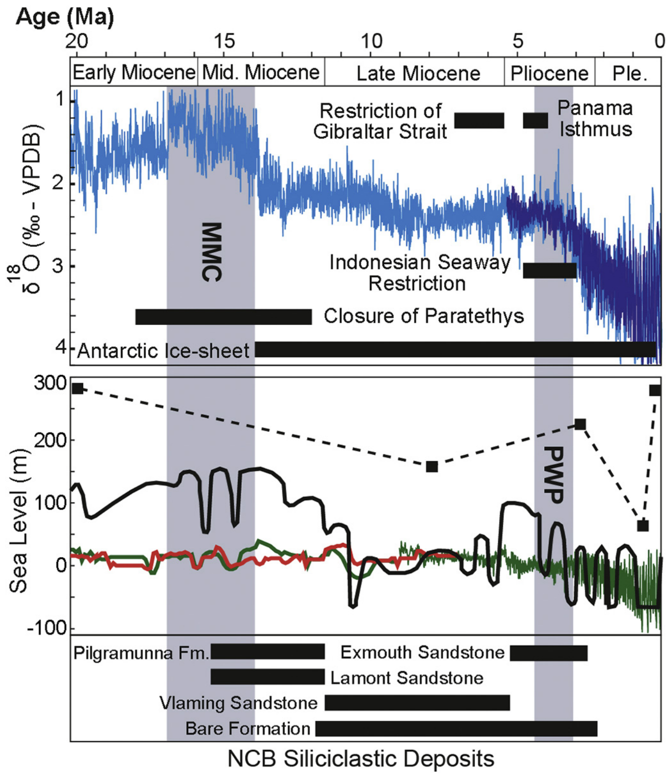

Fig. 1. Ages of Neogene global events compared with $\delta^{18}O$ benthic isotope records (blue line - De Vleeschouwer et al., 2017; purple - Lisiecki and Raymo, 2005), sea-level curves (red – Kominz et al., 2008; green – Miller et al., 2011; black – Haq et al., 1987) and inundation records of Australia based on paleoshorelines (dashed black line; Heine et al., 2010). Approximate age ranges of other Neogene siliciclastic deposits of the NWS are also shown and were extracted from the Australian Stratigraphic Unit Database (Geoscience Australia, 2017; Kelman et al., 2013). LR04 is adjusted to ‰ - VPDB, parts per thousand, Vienna Peedee Belemnite. MMC - Middle Miocene Climatic Optimum; PWP - Pliocene Warm Period. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

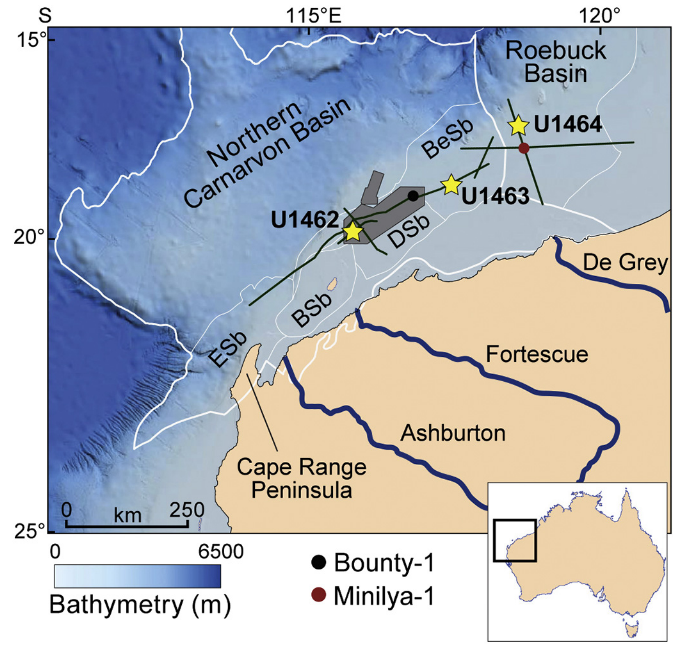

Fig. 2. Bathymetric map of Western Australia showing boundaries of offshore sedimentary basins, IODP Expedition 356 sites used in this study and modern river systems (modified after Gallagher et al., 2017b). Gray polygon delineates available 3D seismic coverage and green lines the 2D seismic lines used. Esb – Exmouth Sub-basin; BSb – Barrow Sub-basin; DSb – Dampier Sub-basin; BeSb – Beagle Sub-basin.

Eurasia, North America and Africa (Clift, 2010; Wan et al., 2009). In addition, analysis of seismic data reveals that consistent Neogene progradational/retrogradational patterns are observed in many sedimentary basins worldwide, involving: early Miocene transgression and aggradation, early to middle Miocene transgression, middle to late Miocene progradation and Plio-Pleistocene high-frequency progradation and transgression (Bartek et al., 1991).

The Australian continent was particularly affected by the Neogene reorganization of climate and tectonics. The northward movement of the Australian plate shifted the continent towards a warmer equatorial climate (Dicaprio et al., 2011). Variability in the southward-flowing Indonesian Throughflow (ITF) and the onset of the southward-flowing Leeuwin Current affected oceanic temperatures along the western margin of the continent, leading to the appearance of tropical carbonate platforms and reefs on the Australian Northwest Shelf (NWS; Gallagher et al., 2009, 2017b). Furthermore, dynamic topography models and paleoshoreline analysis indicate that Western Australia has undergone an anomalous tectonic tilting of the continent to the northeast since the Eocene, which resulted in inundation of the NWS (Dicaprio et al., 2011; Heine et al., 2010). International Ocean Discovery Program (IODP) Expedition 356 drilled seven sites on the Western Australian margin, including two sites in the Northern Carnarvon Basin (NCB), and one in the Roebuck Basin to study these processes (Fig. 2; Gallagher et al., 2017b). The continuous cores and well logs acquired during this expedition enhance our understanding of the Neogene paleoclimatic and paleoceanographic history of the NWS and of the Australian continent.

Sedimentation on the NWS has been dominated by carbonates since the Eocene, although a persistent minor siliciclastic component is also present (Hull and Griffiths, 2002; Cathro et al., 2003; Wallace et al., 2003; Moss et al., 2004). However, during the Neogene, deposits in the NCB contain a concentrated influx of siliciclastic sediments, which includes the late Miocene-Pliocene Bare Formation (Sanchez et al., 2012a; Sanchez et al., 2012b). The presence of the Bare Formation within a section that is otherwise dominated by carbonate sediments implies a change in erosional and sediment transport conditions on this continental margin. Previous studies have proposed different mechanisms of deposition of the Bare Formation. Sanchez et al. (2012a, 2012b) interpreted that siliciclastic deposition occurred by deltaic progradation over the carbonate shelf during the late Miocene long-term sea level fall. In contrast, Smith (2014), O'Callaghan (2014) and Gribben (2015) argued that the absence of recognizable fluvial channels in 3D seismic data, coupled with the along-strike orientation of the deposits, suggested instead a beach-barrier depositional system.

Expedition 356 Site U1462 in the Dampier sub-basin of the NCB, in addition to coring a record of Neogene carbonate deposition, cored the Bare Formation at a location where it is of late Miocene age (Fig. 3; Gallagher et al., 2017c). At that Site, siliciclastics comprise medium to coarse-grained quartz-sandstone interbedded with calcarenite and dolomite (Figs. 3 and 4). Above the siliciclastic deposits, carbonate deposition resumed in the Pliocene and has continued throughout the Quaternary at U1462C (Fig. 3; Gallagher et al., 2017c). These new lithological descriptions, biostratigraphic age data and downhole logs acquired by IODP Expedition 356, coupled with 3D seismic data, allow us to reevaluate the development and evolution of the Bare Formation, the events that triggered its initiation, termination and potential links to Neogene paleoclimatic and paleoceanographic events.

2. Regional setting

The NCB is bounded by the Roebuck and Canning Basins to the East, and the Southern Carnarvon Basin to the West and South (Fig. 2). It