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Eastern Indian Ocean microcontinent formation driven by plate motion changes

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ABSTRACT

The roles of plate tectonic or mantle dynamic forces in rupturing continental lithosphere remain controversial. Particularly enigmatic is the rifting of microcontinents from mature continental rifted margins, with plume-driven thermal weakening commonly inferred to facilitate calving. However, a role for plate tectonic reorganisations has also been suggested. Here, we show that a combination of plate tectonic reorganisation and plume-driven thermal weakening were required to calve the Batavia and Gulden Draak microcontinents in the Cretaceous Indian Ocean. We reconstruct the evolution of these two microcontinents using constraints from new paleontological samples, $^{40}Ar/^{39}Ar$ ages, and geophysical data. Calving from India occurred at 101–104 Ma, coinciding with the onset of a dramatic change in Indian plate motion. Critically, Kerguelen plume volcanism does not appear to have directly triggered calving. Rather, it is likely that plume-related thermal weakening of the Indian passive margin preconditioned it for microcontinent formation but calving was triggered by changes in plate tectonic boundary forces.

1. Introduction

The plume model for microcontinent formation (Müller et al., 2001), where microcontinent calving is driven by plume induced thermal weakening of continental crust is characterised by: 1) proximity to a mantle plume; 2) rifting from a <25 Myr old passive continental margin; 3) typically minor volcanism post-microcontinent formation; and 4) a prolonged period of asymmetric seafloor spreading following microcontinent formation. However, more recent studies suggest that mechanisms such as; changing external plate boundary forces (Collier et al., 2008; Gaina et al., 2009), underplating (Yamasaki and Gernigon, 2010), inherited structures (Van Wijk and Blackman, 2005; Koehn et al., 2007; Van Wijk et al., 2008) and intra-continental strike-slip motions (Nemcok et al., 2016) can also play a dominant or strong role in driving microcontinent formation.

In 2011, the Batavia and Gulden Draak microcontinents were discovered in the historically sparsely sampled eastern Indian Ocean at the western boundary of the Perth Abyssal Plain (PAP; Fig. 1; Williams et al., 2013b). These microcontinents are unique, both because they are the only surviving remnants of the now-destroyed or highly deformed Greater India margin, and because they provide us with an opportunity to test existing models of microcontinent formation against new observations.

Dredged rock samples from four sites on the Batavia and Gulden Draak microcontinents (Fig. 1) reveal these two submarine plateaus to be composed of a granulite facies basement, including pelitic paragneiss and mafic orthogneiss, with inferred Cambrian granite intrusions (Kobler, 2012; Whittaker et al., 2013a; Gardner et al., 2015). Boulders and cobbles of felsic gneiss with Mesoproterozoic and Cambrian protolith ages sampled from the western margin of the Gulden Draak microcontinent likely reflect a complex basement to variable sedimentary and volcanic rocks (Gardner et al., 2015).

The continental basement rocks reveal that the microcontinents shared a tectonic history with India, Australia and Antarctica be-

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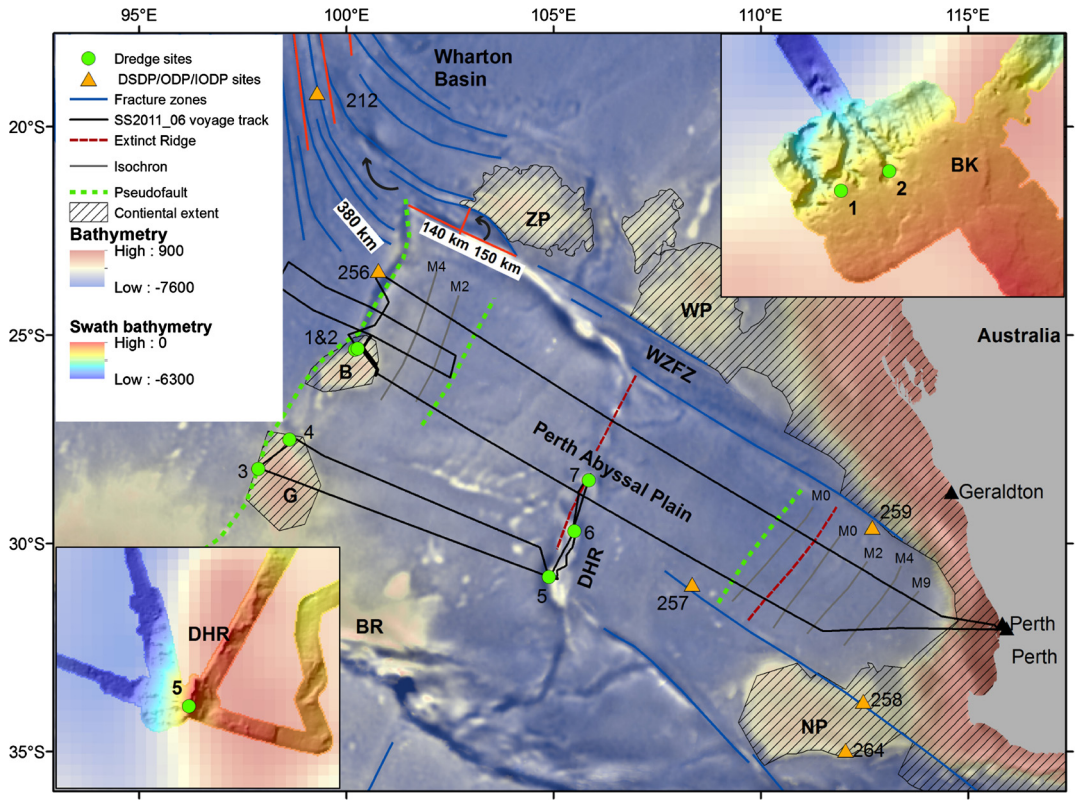

Fig. 1. SS2011_06 voyage track and dredge locations over predicted satellite bathymetry (Sandwell et al., 2014). Roughly N–S oriented red lines trace post-100 Ma reorganisation trend of fracture zones (FZ; Matthews et al., 2012). Where the curved blue FZ meet the red lines marks when spreading reorganisation ceased. See text for explanation of labelled distances. BK – Batavia microcontinent; BR – Broken Ridge; DHR – Dirck Hartog Ridge; G – Gulden Draak microcontinent; NP – Naturaliste Plateau; WP – Wallaby Plateau; WZFZ – Wallaby-Zenith Fracture Zone; ZP – Zenith Plateau. Insets: zoom-ins of dredge sites DR1, DR2 (right) and DR5 (left) overlain on swath bathymetry from voyage SS2011_06. Map created using ArcGIS version 10.1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

fore the disintegration of East Gondwana (Gardner et al., 2015). The microcontinents, attached to Greater India, initially separated from Australia/Antarctica, specifically from the Naturaliste Plateau (Australia) and Bruce Rise (Antarctica) region, during the Early Cretaceous (∼137–136 Ma), followed by formation of ∼1600 km of seafloor in the PAP and Enderby Basin (Gibbons et al., 2012). The Kerguelen plume heavily affected this region during this period, with many voluminous volcanic outpourings over a wide region (see Figs. 3 and 4), including the formation of the Southern Kerguelen Plateau from ∼110–118 Ma and the Central Kerguelen Plateau at ∼100 Ma. At ∼95–105 Ma, a significant, possibly global, change in plate boundary configurations occurred (Matthews et al., 2012). Regionally, India changed motion from northwestward to northward forming the striking, curved fracture zones joining the PAP to the Wharton Basin (Fig. 1).

The Batavia and Gulden Draak microcontinents adhere to the plume-driven model for microcontinent formation in some respects; they formed proximally (within ∼400 km) to the Kerguelen plume (Whittaker et al., 2013b), and formation was followed by an extended period of asymmetric spreading, which occurred in the Ninetyeast Ridge region with Antarctic crust periodically transferred onto the Indian plate until ∼43 Ma (Krishna et al., 2012). However, the Kerguelen plume was located proximally to the Greater India passive margin from at least 133 Ma, meaning that suitable conditions for thermal weakening and microcontinent calving likely existed for >25 Myr before calving actually occurred. Further, a dramatic change in Indian plate motion occurred from ∼105 Ma (Matthews et al., 2012) providing a viable alternative trigger. Here, we investigate the unique geological history of the Batavia and Gulden Draak microcontinents in the context of regional tectonics and magmatism to gain new insights into the key drivers of microcontinent calving.

2. Methods

2.1. $^{40}Ar/^{39}Ar$ analytical technique

Fresh plagioclase (gabbro; DR5–56) and sanidine (trachyte; DR4–6) grains were separated from the 150–215 μm fractions using a Frantz isodynamic magnetic separator and were hand-picked grain-by-grain under a binocular stereomicroscope. Feldspar grains were further leached using diluted HF (2N) for 5 min and thoroughly rinsed in distilled water and loaded in an aluminium disc, along with unrelated samples. The disc was irradiated for 40 hrs and included a series of fully inter-calibrated biotite GA1550 standards (Renne et al., 1998) for which ages of 99.74 Ma (±0.10% Renne et al., 2011) was used. The discs were Cd-shielded (to minimize undesirable nuclear interference reactions) and irradiated in central position in the Oregon State University nuclear reactor (USA). The mean J-value computed from standard grains within the small pits range from 0.011351 (±0.1%) to 0.011312 (±0.1%).

Mass discrimination was monitored regularly through the analysis using an automated air pipette and provided mean values of 0.99465 (±0.03%) and 0.994051 (±0.03%) per Dalton (atomic mass unit) relative to an air ratio of 298.56 ± 0.31 (Lee et al., 2006). The correction factors for interfering isotopes were $(^{39}Ar/^{37}Ar)_{Ca} = 7.6 \times 10^{-4}$ (±1.2%), $(^{36}Ar/^{37}Ar)_{Ca} = 2.7 \times 10^{-4}$ (±0.7%) and $(^{40}Ar/^{39}Ar)_{K} = 7.3 \times 10^{-4}$ (±10%). The $^{40}Ar/^{39}Ar$ analyses were performed at the Western Australian Argon Isotope Facility at Curtin University. Plagioclase and sanidine crystal populations (a few mg each) were step-heated using a continuous 100 W