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The rate of oceanic detachment faulting at Atlantis Bank, SW Indian Ridge

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ABSTRACT

The rates of slip on oceanic detachment faults and how those rates compare to sea-floor spreading rates constitute fundamental data required to constrain how oceanic core-complexes form and their role during crustal accretion. We combine sea-surface magnetic data, with the magnetic polarity of shallow-core samples and Pb/U SHRIMP ages of igneous zircon to determine the time-averaged half-spreading rate during oceanic detachment faulting at Atlantis Bank, 100 km south of the ultraslow-spreading Southwest Indian Ridge (SWIR). The Pb/U zircon ages correlate well with the magnetic ages and so highlight that magmatic accretion and faulting were coeval for over 2 Myr, creating and exposing a >1.5-km-thick layer of gabbro for >35 km parallel-to-spreading. We use bivariate linear regression of distance–age data and forward modeling of magnetic anomaly data to calculate a half-spreading rate during detachment faulting of 14.1+1.8/−1.5 km/Myr (95% confidence limits). When integrated with regional constraints on spreading history, we note that detachment faulting coincided with a short-lived regional increase in the full-spreading rate along the SWIR and, for the ridge segment containing Atlantis Bank, spreading was highly asymmetric with ~80% of plate-motion accommodated by detachment faulting. Consequently, the detachment fault effectively formed the plate-boundary at the surface in this spreading segment. Highly asymmetric spreading was confined to the spreading segment containing Atlantis Bank and to the duration of detachment faulting. So the ridge segment containing Atlantis Bank migrated northward relative to its symmetrically spreading eastern neighbour, such that the intervening non-transform discontinuity shortened. We suggest that the highly asymmetric spreading may be a characteristic feature of oceanic detachment faulting, an inference supported by more poorly constrained half-spreading rates determined at several other oceanic core-complexes.

1. Introduction

At slow- and ultraslow-spreading mid-ocean ridges large offset (>10 km) normal fault systems, referred to as oceanic detachment faults, expose gabbro and peridotite at the sea-floor in domal massifs termed ‘oceanic core-complexes’ (Cann et al., 1997; Blackman et al., 1998; Tucholke et al., 1998; Escartin et al., 2003; Searle et al., 2003; Smith et al., 2006). Active oceanic detachment faults root in the axial valley of these mid-ocean ridges so slip on these faults may accommodate a significant component of sea-floor spreading, such that these faults can be considered an integral part of the plate-boundary system (Fig. 1). Although many authors have assumed symmetric sea-floor spreading rates during detachment faulting (Tucholke et al., 2001, 1998; Escartin et al., 2003; Buck et al., 2005); there is evidence for both short- and long-lived asymmetric spreading rates at slow- and ultraslow-spreading mid-ocean ridges (Allerton et al., 2000; Hosford et al., 2003). To test the assumption of symmetric spreading during slip on oceanic detachment faults and improve our understanding of the dynamics and conditions that form these fault systems, accurate determinations of half-spreading rates during detachment faulting are needed. To date, slip-rates on these faults have been inferred solely from the interpretation of sea-surface magnetic anomaly data. However, magnetic anomalies are often unclear over oceanic core-complexes, most likely because core-complexes expose sometimes weakly magnetic lower crustal and mantle rocks rather than basalt. Consequently, the few spreading rates determined have been poorly constrained (Schulz et al., 1988; Searle et al., 2003). Recently, radiometric dating techniques have been used for the first time to accurately date oceanic crust across an oceanic core-complex (John et al., 2004; Schwartz et al., 2005), and the opportunity now exists to use these data to provide independent constraints on half-spreading rates during detachment faulting. Here we combine Pb/U ages from igneous zircon with detailed magnetic data from the Atlantis Bank oceanic core-complex, on the SWIR, to determine the half-spreading rate during detachment faulting. We argue that this spreading rate approximately corresponds to the rate of slip on this oceanic detachment fault (Fig. 1), as intrusion of the exposed gabbros, cooling through the Curie temperature and denudation during detachment faulting were synchronous or

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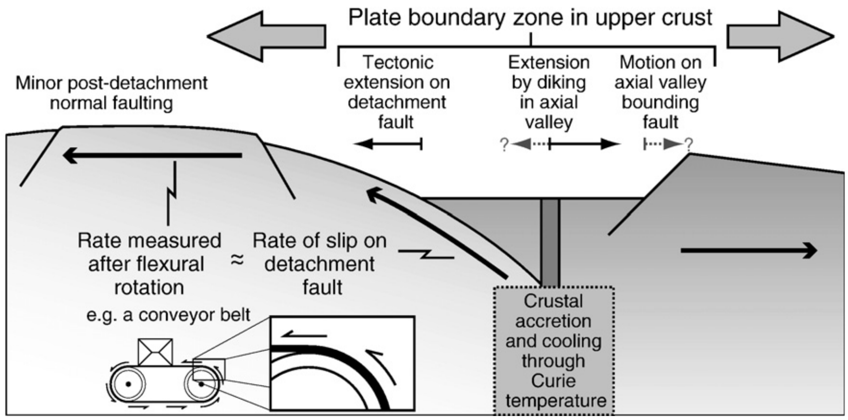

Fig. 1. The accommodation of sea-floor spreading in the upper crust during detachment faulting. Flexural rotation following denudation on the detachment fault suggests that half-spreading rates determined by magnetic data and absolute ages over a detachment fault will record the original time-averaged rate of slip along the detachment fault prior to rotation.

occurred very rapidly (Dick et al., 2000; Natland and Dick, 2002; John et al., 2004; Miranda, 2006; Coogan et al., 2007). Flexural rotation of the footwall to the detachment fault (Buck, 1988) means that the horizontal half-spreading rate approximates the original rate of slip on the dipping fault system (Fig. 1). We also use regional magnetic data from the surrounding region to place this rate of detachment faulting in a broader plate tectonic context.

2. Regional setting

Atlantis Bank (Fig. 2) is a well-studied oceanic core-complex located on the Antarctic Plate ~100 km south of the axial valley of the ultraslow-spreading SW Indian Ridge (Fig. 2c inset), between the Atlantis II Transform fault (~57°05′E) and a fracture zone associated with a non-transform discontinuity at ~57°40′E (Dick et al., 1991). At Atlantis Bank, detachment faulting exposed relatively evolved gabbros and subsidiary peridotite for at least 35 km parallel-to-spreading (Dick et al., 2000; Matsumoto et al., 2002). Extensive high-temperature crystal plastic textures are observed in gabbros from ODP Hole 735B (Dick et al., 2000) and from the surface of Atlantis Bank (Miranda, 2006), suggesting that deformation was synchronous with or immediately followed gabbro emplacement. Fluid inclusion data from the upper 500 m of core recovered in ODP Hole 735B suggest that intrusion and cooling of gabbros occurred only 1.5–2 km below the sea-floor (Vanko and Stakes,

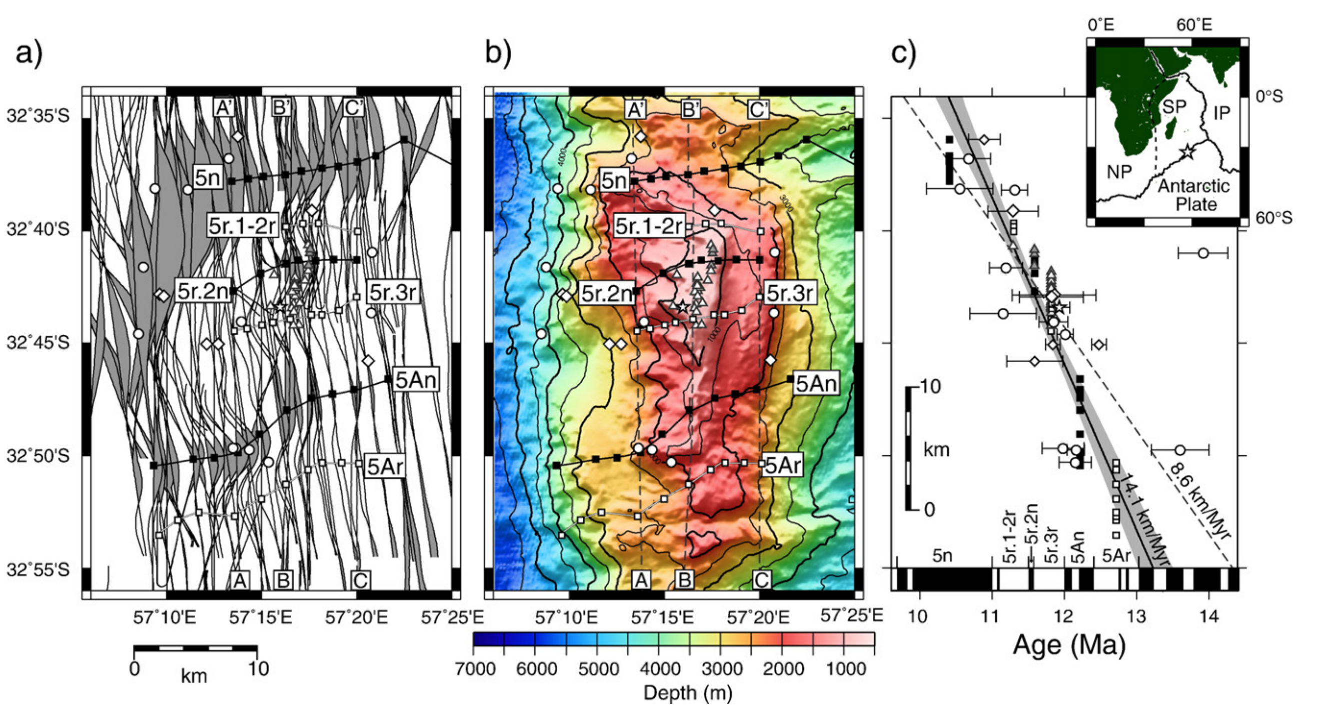

Fig. 2. a) Crustal magnetization plotted along ship tracks over Atlantis Bank. Hand picked isochrons are also plotted: Normal polarity isochrons — thick black lines and reverse polarity isochrons — black and white lines. Also shown are the location of submersible samples (circles), dredge samples (diamonds) and ODP Hole 735B (star) that were dated using the U/Pb method (John et al., 2004; Schwartz et al., 2005). Grey triangles show the location of shallow drill cores whose magnetic polarities were presented by Allerton and Tivey (2001): Solid triangles — normal polarity, open triangles — reverse polarity. b) Shaded bathymetry of Atlantis Bank: symbols as in (a), plus thin black lines — 500 m contours, dashed black lines — profiles used in Fig. 3. c) Latitude versus age for the samples and for the isochrons at the same scale. Symbols are the same as for (a) with the exception of the magnetic data, which are plotted as squares (filled for normal chrons, open for reversed chrons). Also shown are the best-fit bivariate linear regression (thin solid black line), the 95% confidence limits on that line (grey shading), and the average half-spreading rate of 8.6 km/Myr since 20 Ma. Age error bars are only shown for the Pb/U zircon ages. The magnetic polarity timescale is shown as a black and white panel at the bottom and provides an indication of errors for the magnetic ages. Location error for each point is <2 km. Inset shows the location of Atlantis Bank (star): SP — Somalian Plate, NP — Nubian Plate, IP — Indian Plate (after Horner-Johnson et al., 2005).