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Anomalous seafloor mounds in the northern Natal Valley, southwest Indian Ocean: Implications for the East African Rift System

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ABSTRACT

The Natal Valley (southwest Indian Ocean) has a complicated and protracted opening history, as has the surrounding southwest Indian Ocean. Recently collected multibeam swath bathymetry and 3.5 kHz seismic data from the Natal Valley reveal anomalous seafloor mounds in the northern Natal Valley. The significance, of these domes, as recorders of the geological history of the Natal Valley and SE African Margin has been overlooked with little attempt made to identify their origin, evolution or tectonic significance. This paper aims to describe these features from a morphological perspective and to use their occurrence as a means to better understand the geological and oceanographic evolution of this basin. The seafloor mounds are distinct in both shallow seismic and morphological character from the surrounding seafloor of the Natal Valley. Between 25 km and 31 km long, and 16 km and 18 km wide, these features rise some 400 m above the sedimentary deposits that have filled in the Natal Valley. Such macro-scale features have not previously been described from the Natal Valley or from other passive margins globally. They are not the result of bottom water circulation, salt tectonics; rather, igneous activity is favoured as the origin for these anomalous seafloor features. We propose a hypothesis that the anomalous seafloor mounds observed in the Natal Valley are related to igneous activity associated with the EARS. The complicated opening history and antecedent geology, coupled with the southward propagation of the East African Rift System creates a unique setting where continental rift associated features have been developed in a marine setting.

1. Introduction

The geological evolution of the ocean basins is reflected in the shape and form of the deep seafloor (Cochran, 1981; Dietz, 1963; Goff and Jordan, 1988; Norton and Sclater, 1979). This typically comprises a variety of features that range in horizontal scales from the micro (10^{-3} km) to basin-scale (10^4 km) level. At the macro scale (10 km and above), seafloor features are usually determined by the nature of the basin margins (passive vs. active), the location of oceanic ridges (including past spreading centres and abyssal hills) (cf. Goff et al., 1997; Leinweber and Jokat, 2011a,b), fracture zones (Cochran, 1981; Courtillot et al., 1999), and sediment input to the basin over time.

With respect to the shape and form of the deep seafloor, morphological characteristics may vary with the type of feature encountered. Parameters such as the height to width ratio, length to width ratio, slope angle and flatness are useful measures for the morphological comparison of different features. Furthermore, these parameters are suggestive of general formative processes related to the origin of seafloor features (Das et al., 2007; Kodagali, 1989; Mukhopadhyay and Batiza, 1994; Mukhopadhyay and Khadge, 1990; Smith, 1988).

This paper describes a series of macro scale (ca. 30 km) seafloor mounds in the Natal Valley, southwest Indian Ocean (SWIO). The Natal Valley has a complicated and protracted opening history, during the Jurassic and Cretaceous, which is reflected in the mixture of rifting, shearing and drifting of the margin, coupled with episodic submarine volcanism. The adjacent African continent, too, has a long tectonic and seismic history. Following the break-up of Gondwana (Watkeys, 2006), the East African Rift System (hereafter EARS) is by far the most dominant active feature on the continent (Chorowicz, 2005). The EARS represents a 3000 km long discrete intracontinental rift zone initiated some 30 Ma ago between the Nubian and Somalian plates (Calais et al., 2006). EARS rift kinematics have resulted in the development of two micro-plates, the northern Victoria plate, and southern Rovuma Plate, with a possible third micro-plate, Lwandle, developing further south (Calais et al., 2006; Stamps et al., 2008) through the interaction of several rift segments comprising the EARS (Koehn et al., 2008). The East African Rift is comparable in size to the West Antarctic Rift, and far more accessible as it lacks the ice cover of the West Antarctic Rift (Fig. 1, insets, lower right). Since the initiation of the EARS in the Afar region (NE Africa), rift propagation has been southward (Burke, 1996), developing

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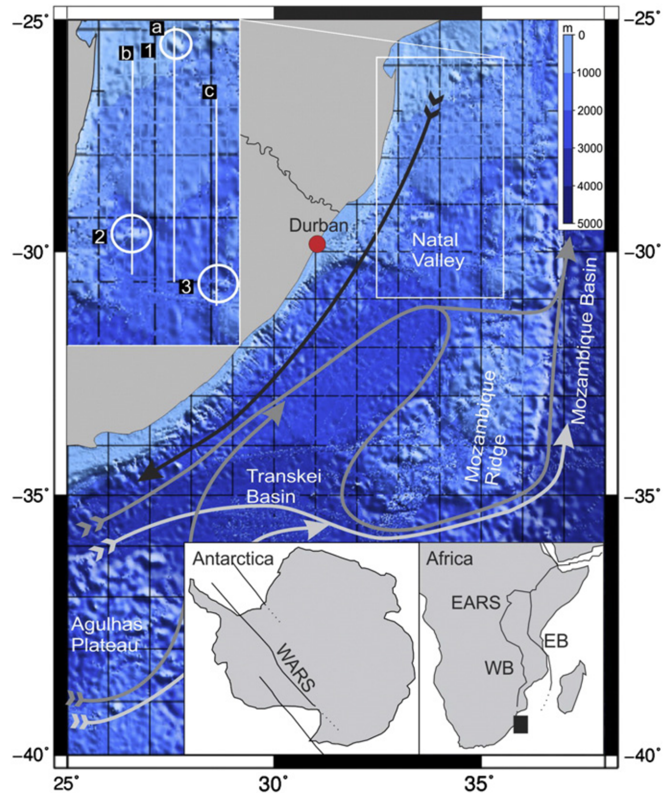

Fig. 1. The south-west Indian Ocean (The GEBCO_08 Grid, version 20091120), showing notable basin features. The black arrow shows passage of the Agulhas Current, the dark-grey arrow shows the NADW pathways, while the light grey arrows describe the route of the AABW. The study area (white box), offshore of Durban (red circle), is enlarged showing the location of the mounds. The mounds are identified as follows: 1 — northernmost, 2 — southwestern and 3 — southeastern. N–S transects (a, b and c) through the northern Natal Valley are depicted by white lines.
West Antarctic Rift System (WARS) inset modified after Schmidt and Rowley (1986).

two distinct southern extensions, the older eastern branch and younger western branch (Ebinger, 1989; Ruppel, 1995; Wolfeden et al., 2004). Both of these branches avoid the Archean cratons, taking advantage of Proterozoic orogenic belts which represent preferential avenues for rift propagation (Morley, 1999). The possible seaward extension of the eastern branch of the EARS was discussed by Mougenot et al. (1986). These workers suggested that the eastern branch joins up with the submerged Cretaceous age grabens (located on the Tanzanian continental shelf) associated with the drift of Madagascar away from Africa. There is renewed interest in this area, particularly in the vicinity of the Kerimbas Graben in the northern Mozambique Channel. Similarly, we discuss the possible southward extension of the western branch (southern Malawi Rift) into the Natal Valley.

The Natal Valley Mounds were partly documented previously (cf. Goodlad, 1986; Martin, 1984); however the significance of the mounds was not recognised at that time and were considered non-descript basement outcrop within the Natal Valley. Their significance as recorders of the geological history of the Natal Valley and SE African margin has been over-looked with little attempt made to identify their origin, evolution and tectonic significance. This paper aims to describe these features from a morphological and shallow seismic perspective and to use their occurrence as a means to better understand the geological and/or oceanographic evolution of this basin.

1.1. Previous bathymetric work

As in all other basins, early work in the Natal Valley relied heavily on high frequency seismic echo-character to describe the bathymetry and shallow sub-bottom characteristics of the seafloor (cf. Dingle and Camden-Smith, 1979; Dingle et al., 1978; Kolla et al., 1980). The primary focus of this was to establish the acoustic stratigraphy and magnetic character of the Natal Valley. The bathymetric and seismic data sets were of sufficiently high resolution to resolve basin-scale features but insufficient to resolve the scale and complexity of complicated seafloor features that are easily revealed with modern multibeam and high resolution seismic tools. With the introduction of multibeam swath bathymetry systems to scientific research (in conjunction with high frequency seismic systems); our capacity to document and describe the deep-sea floor at far higher resolutions has been greatly increased. Compared to Dingle et al. (1978), Goodlad (1986) and Martin (1984) were able to resolve significantly more of the Natal Valley, providing 20 m interval bathymetry charts, and seismic reflection profiles (with 10, 40, 300 cubic inch air-guns). Seismic coverage was such that the majority of the seafloor mounds were inadvertently missed, while the 20 m interval bathymetric charts could not resolve the complex seafloor in sufficient detail. Present technologies and techniques allow data to be acquired at far higher resolutions. The recent acquisition of multibeam swath bathymetry and high frequency seismic data in the Natal Valley is testament to this (cf. Wiles et al., 2013). It is from the perspective of increased resolution in both bathymetry and seismic data that we re-investigate aspects of the Natal Valley seafloor and shallow subsurface geomorphology.

2. Regional setting

2.1. Geology and physiography

The Natal Valley is a N–S orientated basin located in the SWIO (Fig. 1). Bound to the west by the south-eastern margin of southern Africa and to the east by the Mozambique Ridge, the Natal Valley shoals north from the deep Transkei Basin toward the extensive coastal plains of southern Mozambique (Dingle et al., 1978; Goodlad, 1986). Although both floored by an oceanic crust, the northern and the southern Natal Valley (Fig. 1) are the product of two distinct spreading centres. The former was created ca. 183–158 Ma (Leinweber and Jokat, 2011a) while the latter opened ca. 138.9–130.3 Ma (Leinweber and Jokat, 2011b). By 90 Ma spreading within the Natal Valley had ceased (Ben Avraham et al., 1993; Martin and Hartnady, 1986).

The western continental margin boundary of the Natal Valley exhibits a narrow, 4–15 km wide, coast-parallel shelf (Dingle and Robson, 1985; Green, 2011a,b). Departure from the narrow shelf is observed offshore of the Zambezi, Limpopo and Tugela rivers where sedimentary cones prograde into the Natal Valley (Dingle et al., 1978). Over the past 65 Ma, sediment input into the Natal Valley has been estimated at ca. 23 m^3/km^2/year; the Limpopo and Tugela rivers delivering the bulk of sediment to the basin which amounts to the deposition of approximately 800 m of sediment in the basin (Flemming, 1980; Partridge and Maud, 2000).

2.2. Oceanography

Bottom water (a deep current in contact with the seafloor) circulation within the Natal Valley is dominated by the equatorward flowing North Atlantic Deep Water (NADW). The passage of NADW (ca. 1.2×10^6 m^3 s^{-1}) into the Natal Valley is controlled by two, likely contemporaneous, systems (Fig. 1). The South Atlantic Current (SAC) facilitates the first (southern) pathway, transporting NADW around the southern tip of Africa. The NADW core then bifurcates; one branch (depth of 2000–3500 m, salinity of 34.83%) continuing northeastward into the Natal Valley via the Agulhas and Transkei basins respectively. The second branch continues east beneath the meandering Agulhas Return Current (Toole and Warren, 1993).

The second (northern) NADW pathway flows along the continental slope, at depths between 2000 and 2500 m as it rounds the African