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How to identify oceanic crust—Evidence for a complex break-up in the Mozambique Channel, off East Africa

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ABSTRACT

The identification of oceanic crust at rifted margins plays a crucial role in academic research understanding rifting mechanisms and the architecture of continent–ocean boundaries, and is also important for hydrocarbon exploration extending into deeper water. In this paper, we provide a workflow for the determination of the crustal nature in the Mozambique Channel, east of Davie Ridge, by presenting a compilation of several geophysical attributes of oceanic crust at divergent margins. Previous reconstructions locate the Davie Ridge at the trace of a transform fault, along which Madagascar drifted to the south during the breakup of Gondwana. This implies a sharp transition from continental to oceanic crust seaward of Davie Ridge.

Using new multichannel seismic profiles offshore northern Mozambique, we are able to identify distinct portions of stretched basement east of Davie Ridge. Two phases of deformation affecting the basement are observed, with the initial phase resulting in the formation of rotated fault blocks bounded by listric faults. Half-grabens are filled with wedge-shaped, syn-extensional sediments overlain by a prominent unconformity that northward merges with the top of highly reflective, mildly deformed basement, interpreted as oceanic crust. The second phase of deformation is associated with wrench faulting and probably correlates with the southward drift of Madagascar, which implies that the preceding phase affected basement generated or modified prior to the opening of the West Somali Basin. We conclude that the basement is unlikely to consist of normal oceanic crust and suggest that the first extensional phase corresponds to rifting between Madagascar and Africa. We find evidence for a wide area affected by strike–slip deformation, in contrast to the earlier proposed major single transform fault in the vicinity of Davie Ridge and suggest that the Mozambique Channel area to the north of Madagascar may be classified as an oblique rather than sheared margin.

1. Introduction

Much effort has been made in recent years to delineate the boundary between continental and oceanic crust at both magma-poor and volcanic rifted margins. However, due to a lack of good-quality geophysical datasets, sheared continental margins have been much less well studied. The delineation of continent–ocean transitions (COT) plays an essential role in academic research investigating plate tectonic models, rifting mechanisms and ocean formation. Furthermore, it is also crucial for hydrocarbon exploration that moves further offshore and relies on understanding the COT to locate potential source and reservoir rocks and to effectively model heat flow and maturity.

Sheared margins are expected to consist of sharp transitions from continental to oceanic crust (e.g., Bird, 2001). Although the COT at sheared margins is generally considered easy to delineate, the COT offshore Mozambique and Madagascar has not yet been conclusively interpreted.

This study presents a structural interpretation of new offshore multichannel seismic (MCS) data integrated with potential field data and seismic velocity information from an OBS station, located seaward of Davie Ridge in the Mozambique Channel (Fig. 1). The Davie Ridge has been hypothesized to represent the morphological expression of the southward drift of Madagascar from the Middle Jurassic to the Early Cretaceous following Gondwana breakup (e.g., Coffin and Rabinowitz, 1987; Heirtzler and Burroughs, 1971; Rabinowitz et al., 1983; Segoufin and Patriat, 1980). In the Mozambique Channel, an abrupt change from continental to oceanic crust to the east of Davie Ridge has previously been interpreted, mainly based on reflection seismic and potential field datasets (e.g., Coffin and Rabinowitz, 1987; Mascle et al., 1987). Here we challenge this interpretation that is widespread in the literature.

We examined the basement structure to the east of Davie Ridge using a set of N–S and E–W trending seismic profiles. Distinct portions

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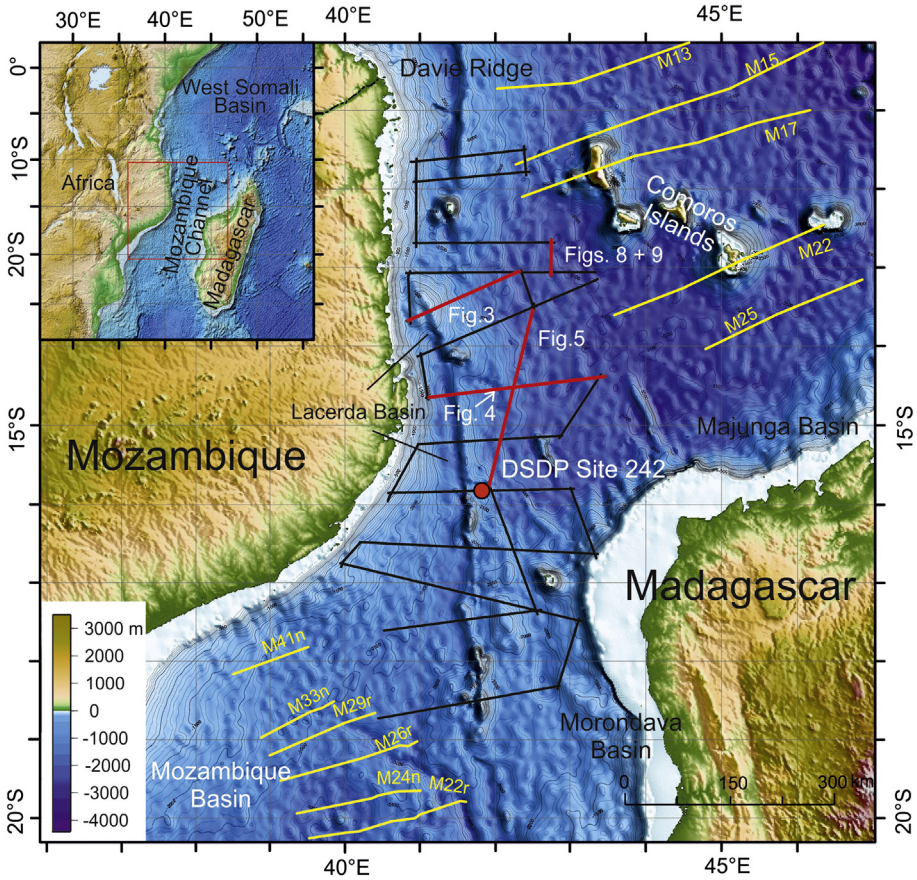

Fig. 1. Base map of the study area in the Mozambique Channel showing the location of the geophysical profiles acquired during RV Sonne cruise SO231 (black lines). Red dot marks the location of DSDP Leg 25 Site 242 at the eastern flank of Davie Ridge (Simpson and Schlich, 1974). Magnetic lineations in the West Somali Basin are shown according to Rabinowitz et al. (1983). Magnetic lineations in the Mozambique Basin are taken from Leinweber et al. (2013). Locations of reflection seismic profiles shown in Figs. 3, 4, 5, 8 and 9 are indicated by red lines. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

of highly stretched basement more than ~100 km east of the Davie Ridge are identified, in an area that previously was consistently considered as oceanic (e.g., Coffin and Rabinowitz, 1987; Mascle et al., 1987; Segoufin and Patriat, 1980). We observe half-grabens, filled with wedge-shaped, syn-extensional sediments above rotated basement fault blocks. The area has been affected by a second phase of deformation, associated with wrench faulting that we connect with southward drift of Madagascar.

We present a compilation of several geophysical properties of oceanic crust at divergent margin settings that contributes to a reliable differentiation of oceanic crust from continental or exhumed mantle domains. By application of the presented "workflow", we discuss the possibility that the observed rotated basement fault blocks represent extended oceanic crust, but we conclude that this is unlikely the case. Our main arguments against oceanic basement are 1) the estimated large crustal thicknesses prior to deformation of ca. 9 km, 2) top basement velocities of ~6.6 km/s, 3) a first deformational (extensional) event occurring prior to the formation of oceanic crust in the West Somali Basin and 4) the lack of any distinct spreading anomalies in the data. Based on these new findings, we discuss implications for the formation of the Mozambique Channel.

2. Geological setting

The Davie Ridge traverses the Mozambique Channel in a N–S direction, extending from the northern coast of Mozambique to the southwestern coast of Madagascar (Fig. 1). It is widespread in the literature that the Davie Ridge is located at the trace of a fossil transform fault that was active during the Middle Jurassic (~165 Ma) and Early Cretaceous (~120 Ma) (e.g., Bassias, 1992; Coffin and Rabinowitz, 1987; Mascle et al., 1987). This transform fault is interpreted to result from the relative motion of Africa and Madagascar, where Madagascar moved from its original position in the Gondwana supercontinent, adjacent to the coasts of Tanzania, Somalia and Kenya to its present position (e.g., Bassias, 1992; Coffin and Rabinowitz, 1987, 1988; Heirtzler and Burroughs, 1971; Rabinowitz et al., 1983; Scrutton, 1978; Segoufin and Patriat, 1980).

Prior to break-up of East (Madagascar, India, Antarctica and Australia) and West (South America and Africa) Gondwana in the Middle Jurassic (Gaina et al., 2013), polyphase Karoo rifting between Madagascar and East Africa occurred. According to Schandelmeier et al. (2004), rifting happened during three successive tectonic stages. The first phase of rifting (Permian) was accompanied by a significant sinistral transtensional component. After a short transtensional period in the latest Permian (second stage), NW–SE directed extension (third stage) prevailed during the Triassic. During evolution of the Mozambique Channel, intracontinental basins on the continental side of the Davie Ridge were generated that display prominent extensional and compressional structures (Mahanjane, 2014).

The Davie Ridge separates the Mozambique Basin from the West Somali Basin, both basins being formed during N–S to NNW–SSE oriented breakup of East and West Gondwana (Gaina et al., 2015; Fig. 1). Nevertheless, the timing of oceanic spreading based on the interpretation of magnetic anomalies in the West Somali Basin is still subject of considerable discussion. This is mainly due to the fact that, if present, the earliest oceanic crust formed in the Jurassic Magnetic Quiet zone, with very few, if any, distinct seafloor spreading anomalies. Gaina et al. (2013) and Gaina et al. (2015) suggest the presence of magnetic anomaly

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