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Research paper

# Tracking the paleogene India-Arabia plate boundary

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A B S T R A C T

The location of the India-Arabia plate boundary prior to the formation of the Sheba ridge in the Gulf of Aden is a matter of debate. A seismic dataset crossing the Owen Fracture Zone, the Owen Basin, and the Oman Margin was acquired to track the past locations of the India-Arabia plate boundary. We highlight the composite age of the Owen Basin basement, made of Paleocene oceanic crust drilled on its eastern part, and composed of pre-Maastrichtian continental and oceanic crust overlaid by ophiolites emplaced in Early Paleocene on its western side. A major fossil transform fault system crossing the Owen Basin juxtaposed these two slivers of lithosphere of different ages, and controlled the uplift of marginal ridges along the Oman Margin. This transform system deactivated ~40 Myrs ago, coeval with the onset of ultra-slow spreading at the Carlsberg Ridge. The transform boundary then jumped to the edge of the present-day Owen Ridge during the Late Eocene-Oligocene period, before seafloor spreading began at the Sheba Ridge. This migration of the plate boundary involved the transfer of a part of the Indian oceanic lithosphere formed at the Carlsberg Ridge to Arabia. This Late Eocene-Oligocene tectonic episode at the India-Arabia plate boundary is synchronous with a global plate reorganization event corresponding to geological events at the Zagros and Himalaya belts. The Owen Ridge uplifted later, in Late Miocene times, and is unrelated to any major migration of the India-Arabia boundary.



## 1. Introduction

The Zagros and Himalaya mountain belts are the most prominent reliefs built by continental collision. They respectively result from Arabia and India collision with Eurasia. It has been suggested that convergence motion at mountain belts induced most of the plate reorganization events in the Indian Ocean during the Cenozoic (Molnar et al., 1993; Patriat et al., 2008; Hatzfeld and Molnar, 2010). Although critical for paleogeographic reconstructions (Cande et al., 2010; Gibbons et al., 2013, 2015), the way transform motion between Arabia and India was accommodated since its inception ~90 Myrs ago remains poorly understood. Similar to the Andrew-Bain transform in the SW Indian Ocean (Ligi et al., 2002; Sclater et al., 2005), the India-Arabia plate-boundary is a case of long-lived transform that has been active since the Late Cretaceous. It thus provides a good case study to investigate the role of major kinematic events over the structural evolution and the successive migration of a long-lived transform system.

The present-day India-Arabia plate boundary is a 800-km-long strike-slip fault known as the Owen Fracture Zone (OFZ hereafter) (Fig. 1; DeMets et al., 2010; Fournier et al., 2011). The OFZ runs along the Owen–Murray Ridge system, a series of prominent bathymetric highs located between 60°E–62°E that currently isolate the Owen Basin to the west from the Indus turbidite system to the east. The OFZ differs from the Owen Transform (i.e., the India/Somalia boundary), which offsets the Carlsberg and Sheba Ridges over 250 km (Fig. 1). The OFZ sensu stricto (i.e. the present-day active trace) is Plio-Pleistocene in age (3–6 Ma) according to kinematic and structural studies (Fournier et al., 2008a,b; 2011; Rodriguez et al., 2011, 2013b; 2014b). This age drastically contrasts with the age of the India-Arabia relative motion, assumed to begin at ~84–92 Ma in most reconstructions, i.e., the age of ~N–S opening of the Mascarenes Basin between Madagascar and the India–Seychelles block (Besse and Courtillot, 1988; Bernard and Munschy, 2000; Seton et al., 2012 and references herein). It raises the question of the location and the structure of the pre-Pliocene

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India-Arabia plate boundary.

According to magnetic anomalies recorded in the Arabian Sea (Sheba and Carlsberg Ridges; Merkouriev and DeMets, 2006; Fournier et al., 2010), the India-Arabia plate boundary ran along the Owen–Murray Ridge since at least ~20 Ma, possibly accommodating about 80 km of relative motion (Chamot-Rooke et al., 2009). Strike-slip tectonics prior to the emplacement of the OFZ is inferred on the basis of the identification of a fracture zone immediately to the east of the Owen Ridge and the fanning configuration of Miocene sediments at the top of the ridge (Rodriguez et al., 2014a). The Plio-Pleistocene OFZ observed on the seafloor is the latest stage of structural evolution of this strike-slip system, older Miocene traces being buried under the Indus fan (Rodriguez et al., 2011, 2014a,b).

Conflicting views have been proposed with regards to the location of the India-Arabia boundary prior to the onset of seafloor spreading in the Gulf of Aden in the Early Miocene (Fig. 2) (Whitmarsh, 1979; Mountain and Prell, 1990; Edwards et al., 2000; Royer et al., 2002). Whitmarsh (1979) and Gaina et al. (2015) postulated that the India-Arabia plate boundary remained close to its present-day location since Late Cretaceous times, whereas Mountain and Prell (1990) proposed that Paleogene strike-slip motion took place at the edge of the Oman margin. Paleogeographic reconstructions based on magnetic anomalies also suggest the plate boundary was located in the Owen Basin during Paleogene (Royer et al., 2002). Although critical to unravel the past locations of the India-Arabia plate boundary, the structure of the Owen Basin has been scarcely documented, with preliminary works by Mountain and Prell (1990) and Barton et al. (1990).

About 5000 km of seismic lines crossing the Owen Basin, the Owen Ridge, and the OFZ were acquired (Fig. 3 a,b). Seismic lines are tied with the DSDP and ODP drillings available in the area to define the stratigraphic framework of the basin and the age of the deformation episodes. The objective of this study is to locate and describe the structure of the India-Arabia plate boundary prior to Miocene, with a particular emphasis over the Paleogene period, i.e., the period of separation of Arabia from Africa (McQuarrie et al., 2003).

## 2. Material and methods

The dataset presented in this study was acquired onboard the BHO Beautemps-Beaupré (a ship of the French Naval Hydrographic and Oceanographic Service) during the OWEN and OWEN-2 surveys in 2009 and 2012, respectively. Seismic reflection profiles were acquired using the high-speed (10 knots) seismic device designed by GENAVIR. The source consists in two GI air-guns (one 105/105 c.i. and one 45/45 c.i.) fired every 10 s at 160 bars in harmonic mode, resulting in frequencies ranging from 15 to 120 Hz. The receiver is a 24-channel, 600-m-long seismic streamer, allowing a common mid-point spacing of 6.25 m and a sub-surface penetration of about 2 s two-way travel time (TWT). The processing consisted of geometry setting, water-velocity normal move-out, stacking, water-velocity f-k domain post-stack time migration, bandpass filtering and automatic gain control. All profiles are displayed with a vertical exaggeration of 8 at the seafloor. Reflectors picked on seismic profiles have been selected on the basis of seismic discontinuities that either reflect lithological changes, stratigraphic hiatuses or

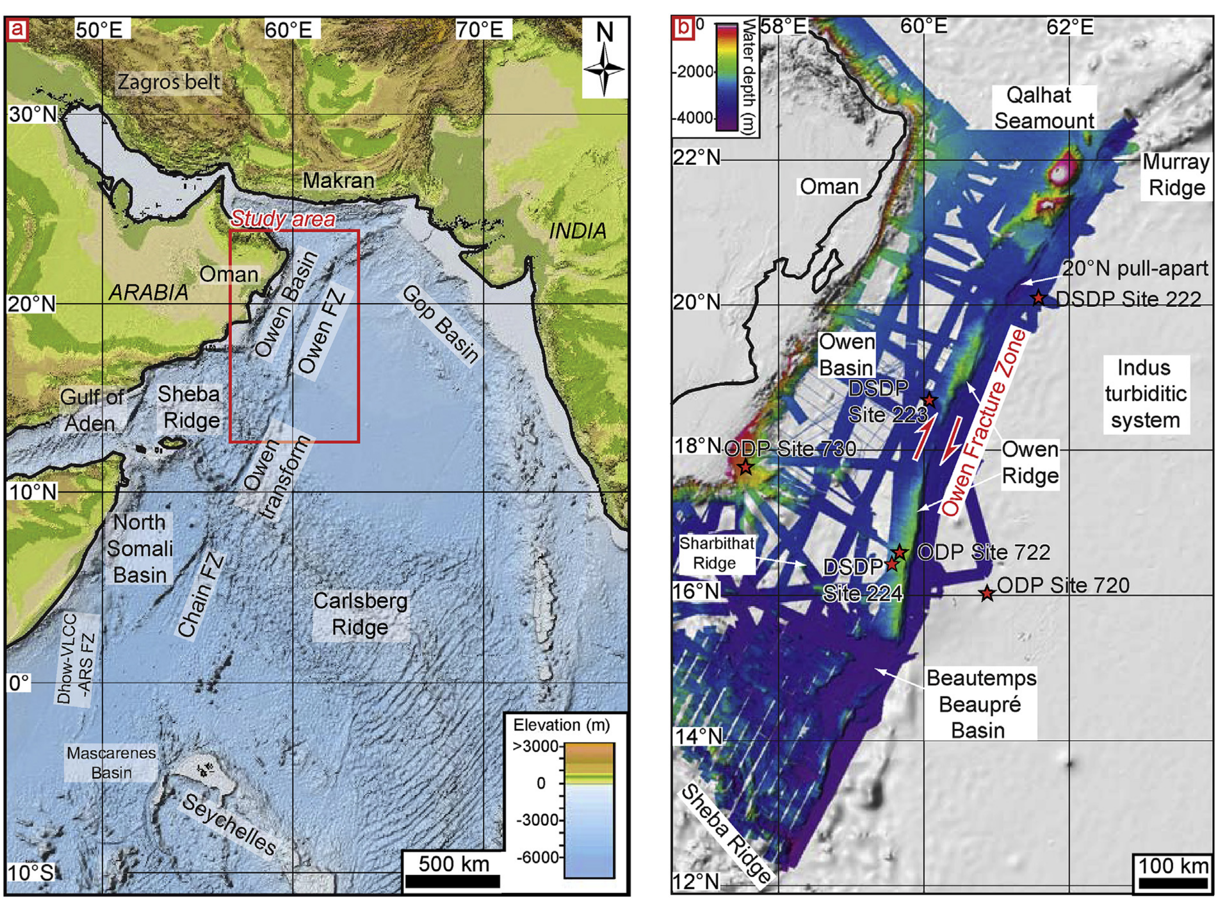


**Fig. 1.** a) General map of the western Indian Ocean (FZ: Fracture Zone); b) Multibeam bathymetry of the Owen Basin, compiled with SRTM topography at 30 (Becker et al., 2009).