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Episodic sea-floor spreading in the Southern Red Sea

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ABSTRACT

The Red Sea represents the most spectacular example of a juvenile ocean basin on the modern Earth. Synthesis of regional aeromagnetic data, gravity data, seismic refraction data coupled with structural mapping from the Farasan Islands suggest that the opening of the Red Sea is complex and episodic. Modeling of magnetic and gravity data constrained by seismic refraction data reveals the Arabian Shelf is underlain by oceanic and transitional crust and that mafic diking and intrusions are focused at the continental–transitional crust boundary. This relationship is interpreted to indicate that early Miocene diking along the Arabian Escarpment heralded termination of oceanic basin formation and a shift in the locus of extension focused from a central mid-ocean ridge spreading center to the continental–transitional crust zone. Uplift along the Arabian Escarpment caused erosion and Middle to Late Miocene sedimentation of the Farasan Bank onto existing oceanic crust, suggesting that the extensive sedimentary banks of the southern Red Sea are not passive margins. Re-initiation of spreading occurred at ca 5 Ma. Pliocene to Pleistocene Shelf reef systems (Farasan Islands), developed on the flanks of the spreading ridge, are extensively overprinted by normal faults, suggesting that not all crustal extension is accommodated by active spreading.

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1. Introduction

The Red Sea represents the modern example of a juvenile crust that has recently undergone the transition from continental rifting, characterized by crustal attenuation, to active mid-ocean ridge spreading (Bosworth et al., 2005; Lazar et al., 2012) (Fig. 1). There is a consensus that the axial trough of the Red Sea formed by mid-ocean ridge began at ca 5 Ma (e.g., Axen et al., 2001; Chu and Gordon, 1998; Pallister et al., 2010). However, an intriguing problem concerning the evolution of the Red Sea is whether it formed during one-stage (e.g. Bosworth et al., 2005) or two-stage spreading as proposed by several early researchers (e.g., Brown and Girdler, 1982; Girdler and Styles, 1974; Hall, 1989).

Tectonic models based on geological data are dominated by single stage rift models involving protracted stretching of continental crust followed by sea floor spreading at ca 5 Ma, and include both asymmetric (e.g., Dixon et al., 1989; Voggenreiter et al., 1988; Wernicke, 1985) and symmetrical extension models (e.g., Berhe, 1986; Bohannon and Eittreim, 1991; Martinez and Cochran, 1988). These models suggest that the Miocene sedimentary shelves (known as the Farasan and Dahlak Banks) (Fig. 1) of the southern Red Sea represent passive margins underlain by attenuated continental lithosphere. However, these models are not supported by reconstructions of the Red Sea by Sultan et al. (1992), which suggest that much of the Red Sea substrate may be entirely oceanic crust. Further, the composition and architecture of the crust that lies on either side of the spreading ridge beneath the Miocene marine sedimentary shelves show geophysical affinities to oceanic crust (e.g., Brown and Girdler, 1982; Gettings et al., 1986; Hall, 1989; Mechie et al., 1986).

Magnetic profiles in the southern Red Sea were used by Hall (1989) to interpret the presence of Oligocene oceanic crust (Fig. 2). However, the validity of magnetic stripes to interpret the onset of ocean floor spreading has been called into question in recent literature by the recognition that magnetic stripes during the transition from rift to drift can form as a result of dense magma intrusion into stretched transitional crust (e.g., Bronner et al., 2011). That said, documented examples of magnetic striping in transitional crust show evidence for one or two magnetic stripes associated transitional crust, suggesting that such striping must occur immediately before the onset of ocean spreading (Bridges et al., 2012). These relatively recent observations could be used to support assertions by Voggenreiter et al. (1988) that many of the magnetic anomalies interpreted by Hall (1989) where sourced from linear mafic intrusions parallel to the rift.

We combine high resolution aeromagnetic data with regional Bouguer gravity, seismic refraction data from the Farasan Bank, and field structural mapping from the Farasan Islands to constrain the evolution of the southern Red Sea since the Oligocene. In particular, using

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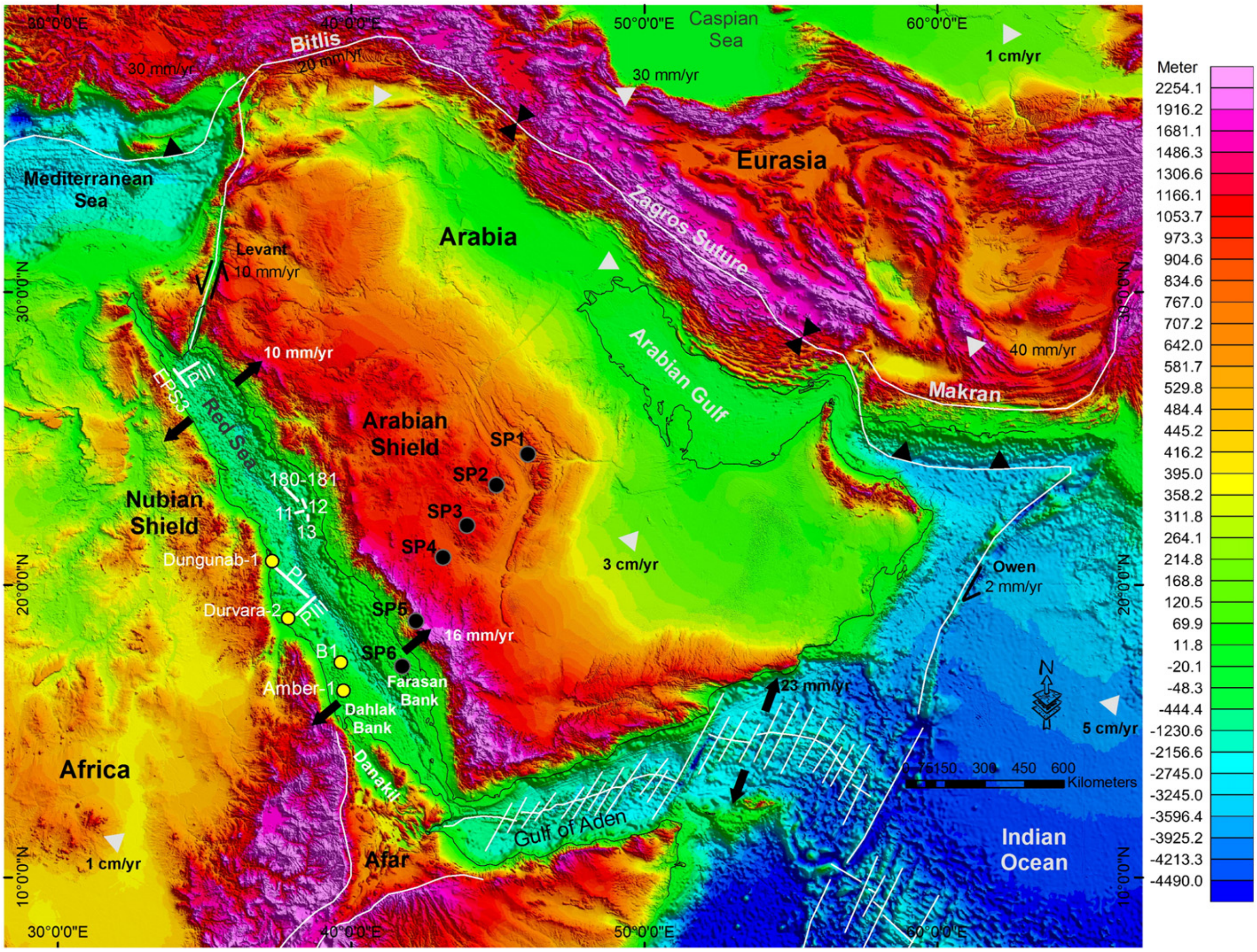

Fig. 1. Bathymetry and topography image after Becker et al. (2009) showing major Arabian plate boundaries and extension direction with residual velocities of the region after ArRajehi et al. (2010) and Bellahsen et al. (2003), wells, and seismic profiles locations at the Red Sea.

reprocessed and filtered magnetic data we address the nature of the basement under the Farasan Bank. The results show remarkable complexity including multiple episodes of mid-ocean ridge spreading, intervened by an episode of failed rifting and Miocene shelf sedimentation.

2. Data and analysis

Aeromagnetic data and Bouguer gravity data were collected by the Deputy Ministry of Minerals Resources of Saudi Arabia. Aeromagnetic

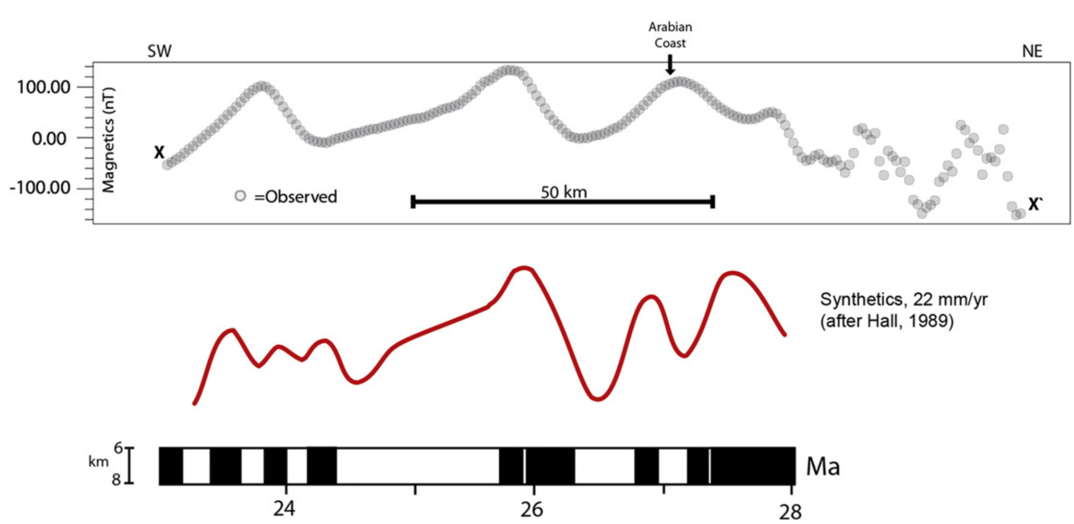

Fig. 2. Observed magnetic profile across the Arabian Shelf correlation with synthetic sea-floor spreading profile after Hall (1989). Location of the profile is showing in Fig. 4A.

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