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Age of Seychelles–India break-up

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ABSTRACT

Many continental flood basalt provinces are spatially and temporally linked with continental break-up. Establishing the relative timing of the two events is a key step in determining their causal relationship. Here we investigate the example of the Deccan Traps and the separation of India and the Seychelles. Whilst there has been a growing consensus as to the age of the main phase of the Deccan emplacement (65.5±1 Ma, chron 29r), the age of the rifting has remained unclear. We resolve this issue through detailed seafloor magnetic anomaly modeling (supported by wide-angle and reflection seismic results) of the north Seychelles and conjugate Laxmi Ridge/Gop Rift margins, and geochemistry and $^{40}Ar/^{39}Ar$ geochronology of rocks from the north Seychelles margin. We show that syn-rift volcanics offshore the Seychelles Islands in the form of seaward-dipping reflectors were most likely erupted during chron 28n, and the first organized seafloor spreading at the Carlsberg Ridge also initiated during this chron at 63.4 Ma. The severing of the Seychelles occurred by a south-eastward ridge propagation that was completed by the start of chron 27n (~62 Ma). A brief, pre-28r phase of seafloor spreading occurred in the Gop Rift, possibly as early as 31r–32n (~71 Ma). Initial extension at the margin therefore preceded or was contemporaneous with the Deccan emplacement, and separation of the Seychelles was achieved less than 3.5 Ma afterwards. This is the shortest time interval between flood basalt emplacement and break-up yet reported for any continental flood basalt-rifted margin pair. A contributing factor to the apparently short interval in the Deccan case may be that rifting occurred by a ridge jump into already thinned continental lithosphere. However, we conclude that external plate-boundary forces, rather than the impact of a mantle plume, were largely responsible for the rifting of the Seychelles from India.

1. Introduction

The emplacement of continental flood basalt provinces is often associated with continental break-up (Morgan, 1983). Establishing the relative timing of the two phenomena provides an important constraint on the dynamic relationship between them. For example, models in which the rifting results from uplift above the thermal anomaly responsible for the flood basalts (active rifting, (Richards et al., 1989; Campbell and Griffiths, 1990)) predict that the flood basalt volcanism would significantly pre-date break-up. According to Hill (1991) the time lapse between flood basalt emplacement and break-up depends on the initial thermal structure of the lithosphere, with periods of 10–20 Ma expected for "normal" 200 km thick lithosphere. Alternatively, models in which the extension is due to regional tectonics (passive rifting, (White and McKenzie, 1989)) predict contemporaneous flood basalt volcanism and break-up. Establishing which of the models is correct has important implications for plate-tectonics: in the active rifting model, mantle plumes play a strong, if not dominant, role in continental break-up and hence changes in plate motions, whereas in the passive rifting model plate-boundary forces are more significant.

Whilst technical developments in the dating of onshore flood basalt provinces have greatly improved our knowledge of the timing of their emplacement, constraining the age of the associated rifting is generally more difficult. The main reason for this is that much of the rifting-associated volcanic products lie offshore, often buried beneath thick sedimentary piles that form as the continental margins mature (Coffin and Eldholm, 1994). Consequently, few continental margins have been directly sampled beyond the shelf edge and typically the precise age of the syn-rift and early post-rift volcanism is poorly known. Identifying seafloor spreading magnetic anomalies adjacent to rifted continental margins is therefore commonly the only way to determine the age of continental break-up. However, along many rifted margins, magnetic interpretations are hampered by features such as edge effect anomalies (between juxtaposed weakly magnetized continental and strongly magnetized oceanic crusts), the presence of transitional crust (that has neither continental nor oceanic characteristics and may include exhumed mantle), and bodies formed by syn-rift or early post-rift magmatism near the continent–

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ocean boundary. Perhaps the best-known example of the latter effect is the East Coast Magnetic Anomaly (ECMA) that borders much of the North American Atlantic margin. This anomaly has been shown to correlate with seaward-dipping reflectors (SDRs) and hence has been interpreted as due to the emplacement of large thicknesses of late rift stage or early drift stage igneous material onto thinned continental crust (Keen and Potter, 1995). Therefore because of the likelihood of magmatic signatures unrelated to organized seafloor spreading, it is only possible to determine accurately the age of the first oceanic crust where additional constraints, such as from seismic data, exist. It is also preferable to study both sides of a conjugate margin pair in tandem, to resolve further interpretational ambiguities and determine more accurately when plate separation occurred.

The Deccan traps and the separation of India and the Seychelles are one of the best-known examples of a spatially and temporally linked continental flood basalt province and continental rift event. There has been much debate in the literature concerning the age of the Deccan. Some authors propose that magmatism lasted from about 69 to 63 Ma ((Pande, 2002), chron 31r to 28n, according to the timescale of Gradstein et al. (2005) that we use throughout this paper) whilst others propose much shorter durations, such as 66 to 64 Ma (chron 30n to 29n, (Courtillot and Renne, 2003)). However, the debate has largely focused on the significance of small-volume early and late stage volcanics, and there is a general consensus that the main tholeiitic eruption happened rapidly at 65.5± 1 Ma (mostly in 29r). In comparison, dating the lithospheric extension is poorly resolved. Working onshore, Hooper (1990) mapped feeder dyke orientations within the Western Ghats and concluded that flood basalt volcanism preceded significant extension. This interpretation, however, was rejected by Kent et al. (1992). Exploration wells off Kutch and Bombay are unable to provide a chronology of events as they do not penetrate pre-Deccan strata, but the available data suggest that there was significant subsidence, and therefore extension, before 60 Ma (Whiting et al., 1994). Working further offshore, previous workers have identified the oldest seafloor spreading magnetic anomaly in the Arabian Sea to be either 27n (62.0 Ma, (Schlich, 1982; Miles et al., 1998)), 28n (64.1 Ma, (Norton and Sclater, 1979; Naini and Talwani, 1982; Miles and Roest, 1993; Chaubey et al., 1998; Chaubey et al., 2002; Royer et al., 2002)), 29n (65.1 Ma, (McKenzie and Sclater, 1971; Malod et al., 1997)), 31n (68.7 Ma, (Todal and Edholm,

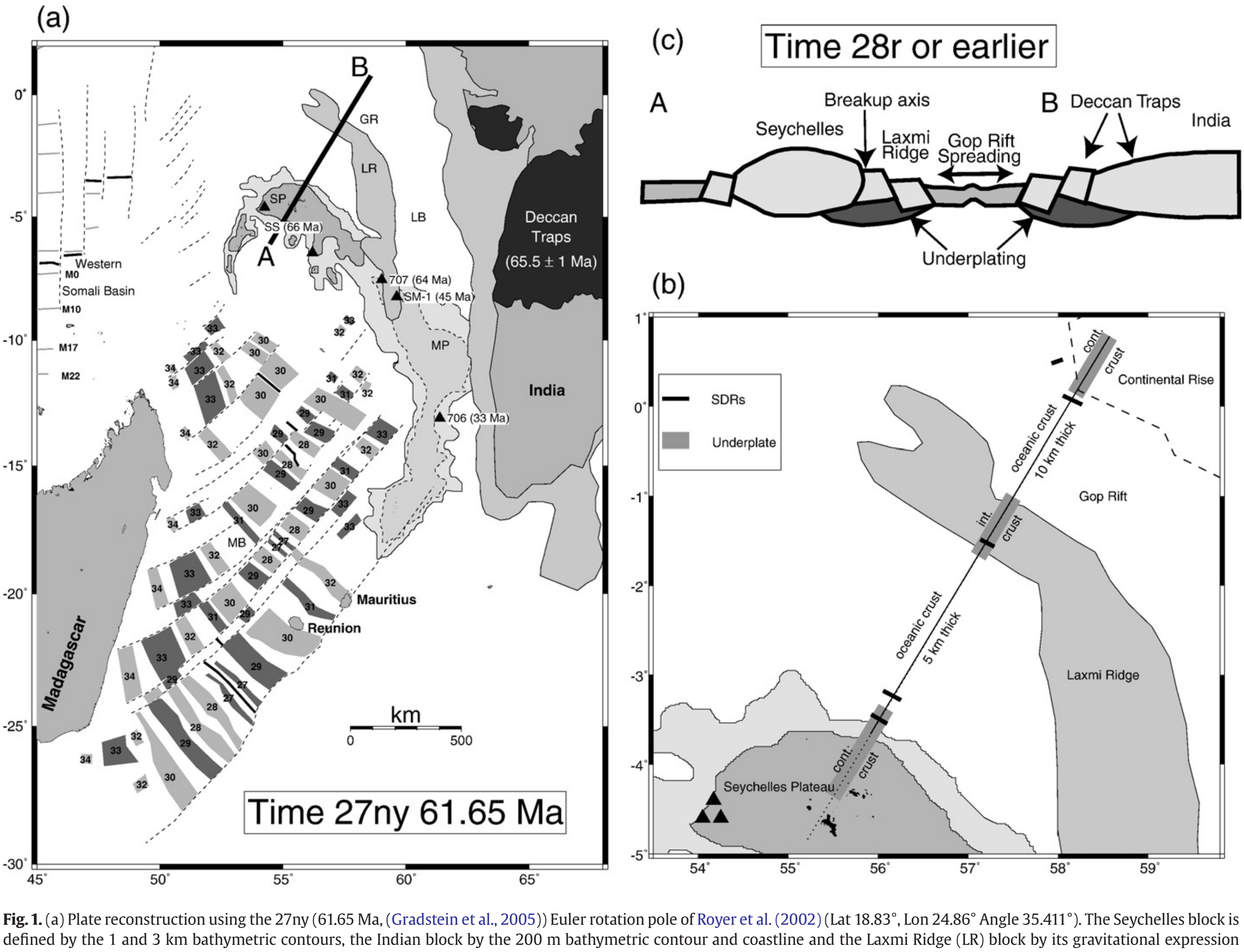

Fig. 1. (a) Plate reconstruction using the 27ny (61.65 Ma, (Gradstein et al., 2005)) Euler rotation pole of Royer et al. (2002) (Lat 18.83°, Lon 24.86° Angle 35.411°). The Seychelles block is defined by the 1 and 3 km bathymetric contours, the Indian block by the 200 m bathymetric contour and coastline and the Laxmi Ridge (LR) block by its gravitational expression (Miles and Roest, 1993). In the reconstruction shown the Seychelles block is held fixed and the Indian and Laxmi Ridge (LR) continental blocks (maintained in their present-day relative positions) are rotated back towards it. Also shown are published seafloor spreading anomalies (numbered) and fossil ridges (fine black lines) in the Mascarene Basin (MB) and in Western Somali Basin (Bernard and Munschy, 2000; Cochran, 1988; Chaubey et al., 1998). The Mascarene plateau (MP) is shown dashed as most if not all of it formed after 27ny as part of the Réunion plume trail. Triangles mark drill holes with the ages of recovered volcanics in brackets. SP Seychelles Plateau; LR, Laxmi Ridge, GR, Gop Rift; LB, Laxmi Basin. The cross-section A–B shown in c) is marked with the bold line. (b) Reconstruction detail and summary of seismic results (Minshull et al., in press; Collier et al., in preparation). Areas interpreted as continental (cont.), intermediate (int.) and oceanic crust are marked, together with seaward-dipping reflectors (SDRs) and regions of high seismic velocity material that we interpret as magmatic underplate. The dashed line marks the southern limit of the Indian continental rise (Malod et al., 1997). Additional SDRs west of our transect on the Indian side are from Gaedicke et al. (2002). (c) Cartoon of the plate kinematics following the opening of the Gop Rift but prior to the severing of the Seychelles.