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The extent of continental crust beneath the Seychelles

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ABSTRACT

The granitic islands of the Seychelles Plateau have long been recognised to overlie continental crust, isolated from Madagascar and India during the formation of the Indian Ocean. However, to date the extent of continental crust beneath the Seychelles region remains unknown. This is particularly true beneath the Mascarene Basin between the Seychelles Plateau and Madagascar and beneath the Amirante Arc. Constraining the size and shape of the Seychelles continental fragment is needed for accurate plate reconstructions of the breakup of Gondwana and has implications for the processes of continental breakup in general. Here we present new estimates of crustal thickness and V_P/V_S from H–κ stacking of receiver functions from a year long deployment of seismic stations across the Seychelles covering the topographic plateau, the Amirante Ridge and the northern Mascarene Basin. These results, combined with gravity modelling of historical ship track data, confirm that continental crust is present beneath the Seychelles Plateau. This is ~30–33 km thick, but with a relatively high velocity lower crustal layer. This layer thins southwards from ~10 km to ~1 km over a distance of ~50 km, which is consistent with the Seychelles being at the edge of the Deccan plume prior to its separation from India. In contrast, the majority of the Seychelles Islands away from the topographic plateau show no direct evidence for continental crust. The exception to this is the island of Desroche on the northern Amirante Ridge, where thicker low density crust, consistent with a block of continental material is present. We suggest that the northern Amirantes are likely continental in nature and that small fragments of continental material are a common feature of plume affected continental breakup.

1. Introduction

Small slivers of continental crust, or 'microcontinents' are found in most of the Earth's oceans. Their identification is relatively straight-forward, differing from typical oceanic crust by having thicker crust, lower seismic velocities and lacking seafloor-spreading magnetic lineations (Carlson et al., 1980; Nur and Ben-Avraham, 1982). One of the best examples of a microcontinent is the Seychelles Plateau with its series of granitic islands, located in the Indian Ocean. These spectacular granitic outcrops were first noted as unusual by Darwin (1839) and later cited by Wegener (1924) as evidence for continental drift. Additionally, recent studies have shown that the Indian Ocean may contain many small fragments of continental crust isolated during the complex breakup of Madagascar–Seychelles–India (Minshull et al., 2008; Torsvik et al., 2013). In this study we present estimates of crustal thickness and the ratio of V_P to V_S derived from receiver functions across the Seychelles covering the topographic plateau, the Amirante Ridge and the northern Mascarene Basin. These results combined with an analysis of gravity data, show for the first time the extent of continental crust in this region.

2. The Seychelles microcontinent

The Seychelles are made up of 115 islands, the majority of which are small coral atolls, but 41 have a granitic composition, and are found around the main islands of Mahé and Praslin (Fig. 1). The granites are similar petrologically, geochemically and in age to the granites found on Madagascar and north–west India, and were likely formed in an Andean arc-like setting ~750 Ma (Tucker et al., 2001; Ashwal et al., 2002). The Seychelles granites are thought to have been emplaced in two main stages, with the grey granites of Mahé being slightly older than the pink Praslin granites (Weis and Deutsch, 1984). The Seychelles granites are cut by numerous doleritic dykes with predominantly WNW–ESE trends which were emplaced in two stages, one in the Precambrian and

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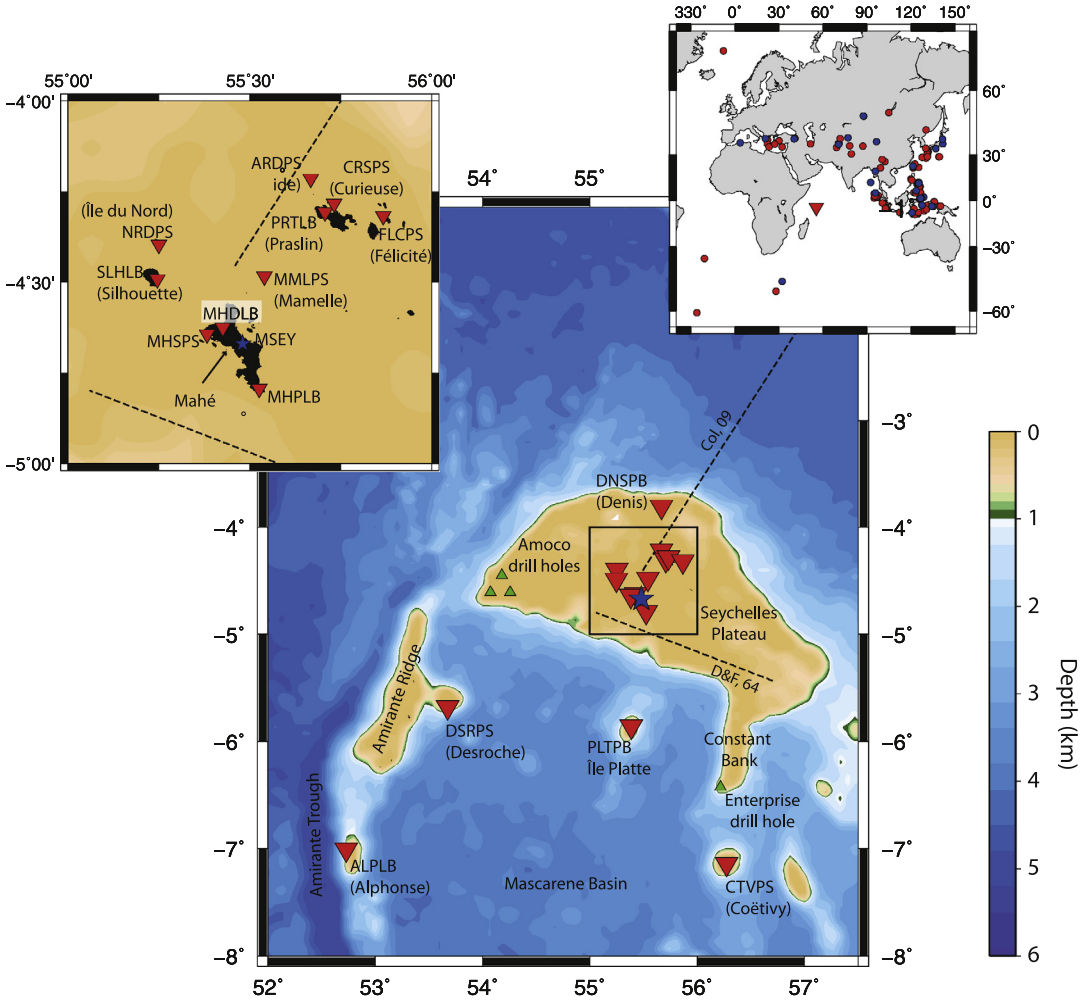

Fig. 1. Seismic stations used in the study. Inverted red triangles show seismic stations in our array, the blue star shows the permanent station MSEY, the dashed line shows the controlled source profile of Davies and Francis (1964) (D&F, 64) and Collier et al. (2009) (Col, 09). Also shown are the seismic events used in this study (top right) where red dots show events used at MSEY and blue dots show those used at the temporary seismic array. The inverted triangle shows the approximate location of the Seychelles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

one in the early Tertiary (Suwa et al., 1994). Other volcanics are found on the Seychelles, most spectacularly in the form of the islands of Silhouette and Île du Nord. These islands form alkaline igneous complexes, dated to 61–67 Ma (Dickin et al., 1986; Ganerod et al., 2011), similar in age to the second emplacement of doleritic dykes and likely linked with the Deccan Trap formation, when the Seychelles is thought to be positioned proximal to India (Collier et al., 2008).

Early refraction work determined the crustal thickness beneath the central part of the plateau to be 33 km with a typically continental velocity profile in the crust (Gaskell et al., 1958; Shor and Pollard, 1963; Davies and Francis, 1964; Francis et al., 1966; Francis and Shor, 1966; Matthews and Davies, 1966). More recent controlled source seismic data provide good constraints on the northernmost extent of continental crust beneath the Seychelles (Collier et al., 2009). Further constraints exist from hydrocarbon exploration during the 1980's when Amoco drilled three holes on the southwesternmost extent of the topographic plateau (Fig. 1). Drilling encountered Triassic/Jurassic sediments and showed evidence of hydrocarbons suggesting continental crust extends to the southwesternmost tip of the topographic plateau (Coakley, 1997; Franks et al., 2006). In the mid 1990's Enterprise also drilled a hole on Constant Bank, but this encountered thick volcanics and the crustal affinity remained unclear. Despite this work, the southern margin, including the nature of the crust beneath the enigmatic Amirante Ridge and the northern Mascarene Basin remains poorly known.

3. Data

A major onshore–offshore controlled source experiment was conducted in February 2003 to constrain the north Seychelles passive margin (Collier et al., 2009). This involved the deployment of 32 ocean bottom seismometers, 8 broadband and 18 short-period, three component seismometers on islands throughout the Seychelles. Following the controlled source experiment the land based stations were relocated to cover a broad region of the Seychelles microcontinent and were left recording for one year (see Hammond et al., 2005; Collier et al., 2009, for details). The majority of the stations were located on the granitic islands of Mahé and Praslin and their satellite islands. More distant sites were situated on coral islands on the northern edge of the Seychelles Plateau and along the Amirante Ridge and Mascarene Basin. Additionally this study uses data from a permanent seismic station (MSEY) on Mahé, the largest of the Seychelles islands (Fig. 1). The aperture of the resulting roughly triangular array was on the order of 500 km (Fig. 1).

During the period of deployment 239 earthquakes $>$ 5.8 Mb were recorded, of which 101 fell in to a suitable range for generating receiver functions (RF) (40°–90°).