ARTICLE IN PRESS
EPSL:14146
Earth and Planetary Science Letters ••• (••••) •••–•••
Contents lists available at ScienceDirect
Earth and Planetary Science Letters
www.elsevier.com/locate/epsl

Shear velocity structure of the crust and upper mantle of Madagascar derived from surface wave tomography

Martin J. Pratt [a,*], Michael E. Wysession [a], Ghassan Aleqabi [a], Douglas A. Wiens [a], Andrew A. Nyblade [b], Patrick Shore [a], Gérard Rambolamanana [c], Fenitra Andriampenomanana [c], Tsiriandrimanana Rakotondraibe [c], Robert D. Tucker [d], Guilhem Barruol [e], Elisa Rindraharisaona [f]

[a] *Washington University in St. Louis, MO, USA*
[b] *Pennsylvania State University, State College, PA, USA*
[c] *Institut Observatoire et Geophysique d'Antananarivo, Madagascar*
[d] *University of Maryland, College Park, MD, USA*
[e] *Laboratoire GéoSciences Réunion, Université de la Réunion, Institut de Physique du Globe de Paris, UMR CNRS 7154, Université Paris Diderot, F-97744 Saint Denis, France*
[f] *Deutsches GeoForschungsZentrum (GFZ), Germany*

A R T I C L E I N F O

Article history:
Received 16 July 2016
Received in revised form 15 October 2016
Accepted 21 October 2016
Available online xxxx
Editor: P. Shearer

Keywords:
surface wave
ambient noise
tomography
Madagascar
intraplate volcanism

A B S T R A C T

The crust and upper mantle of the Madagascar continental fragment remained largely unexplored until a series of recent broadband seismic experiments. An island-wide deployment of broadband seismic instruments has allowed the first study of phase velocity variations, derived from surface waves, across the entire island. Late Cenozoic alkaline intraplate volcanism has occurred in three separate regions of Madagascar (north, central and southwest), with the north and central volcanism active until <1 Ma, but the sources of which remains uncertain. Combined analysis of three complementary surface wave methods (ambient noise, Rayleigh wave cross-correlations, and two-plane-wave) illuminate the upper mantle down to depths of 150 km. The phase-velocity measurements from the three methods for periods of 8–182 s are combined at each node and interpolated to generate the first 3-D shear-velocity model for sub-Madagascar velocity structure. Shallow (upper 10 km) low-shear-velocity regions correlate well with sedimentary basins along the west coast. Upper mantle low-shear-velocity zones that extend to at least 150 km deep underlie the north and central regions of recent alkali magmatism. These anomalies appear distinct at depths <100 km, suggesting that any connection between the zones lies at depths greater than the resolution of surface-wave tomography. An additional low-shear velocity anomaly is also identified at depths 50–150 km beneath the southwest region of intraplate volcanism. We interpret these three low-velocity regions as upwelling asthenosphere beneath the island, producing high-elevation topography and relatively low-volume magmatism.

1. Introduction

Though Madagascar is a large island with a geologic history extending far back into the Archean (Collins, 2006; Tucker et al., 2011), its crust and mantle structure have been largely unexplored by seismic methods until now. Despite recent surface geologic mapping, culminating in the high-resolution geologic map of Roig et al. (2012), the lack of subsurface observations has prevented an accurate interpretation of the geologic and tectonic histories of the region. For example, prior to the current studies, the crustal thickness of the island had only been inferred from a gravity survey (Fourno and Roussel, 1994) and more recently by receiver function techniques applied at the few permanent seismic stations (Rindraharisaona et al., 2013).

One of the more unusual aspects of Madagascan geology is the occurrence of several episodes of Cenozoic volcanism in the central (Itasy/Ankaratra) and northern regions (Nosy Be/Massif D'Ambre) of the island (Emerick and Duncan, 1982; Nougier et al., 1986; Tucker and Conrad, 2008) (Fig. 1). These two regions have been

* Corresponding author.
E-mail address: martin@seismo.wustl.edu (M.J. Pratt).

http://dx.doi.org/10.1016/j.epsl.2016.10.041

Please cite this article in press as: Pratt, M.J., et al. Shear velocity structure of the crust and upper mantle of Madagascar derived from surface wave tomography. Earth Planet. Sci. Lett. (2016), http://dx.doi.org/10.1016/j.epsl.2016.10.041

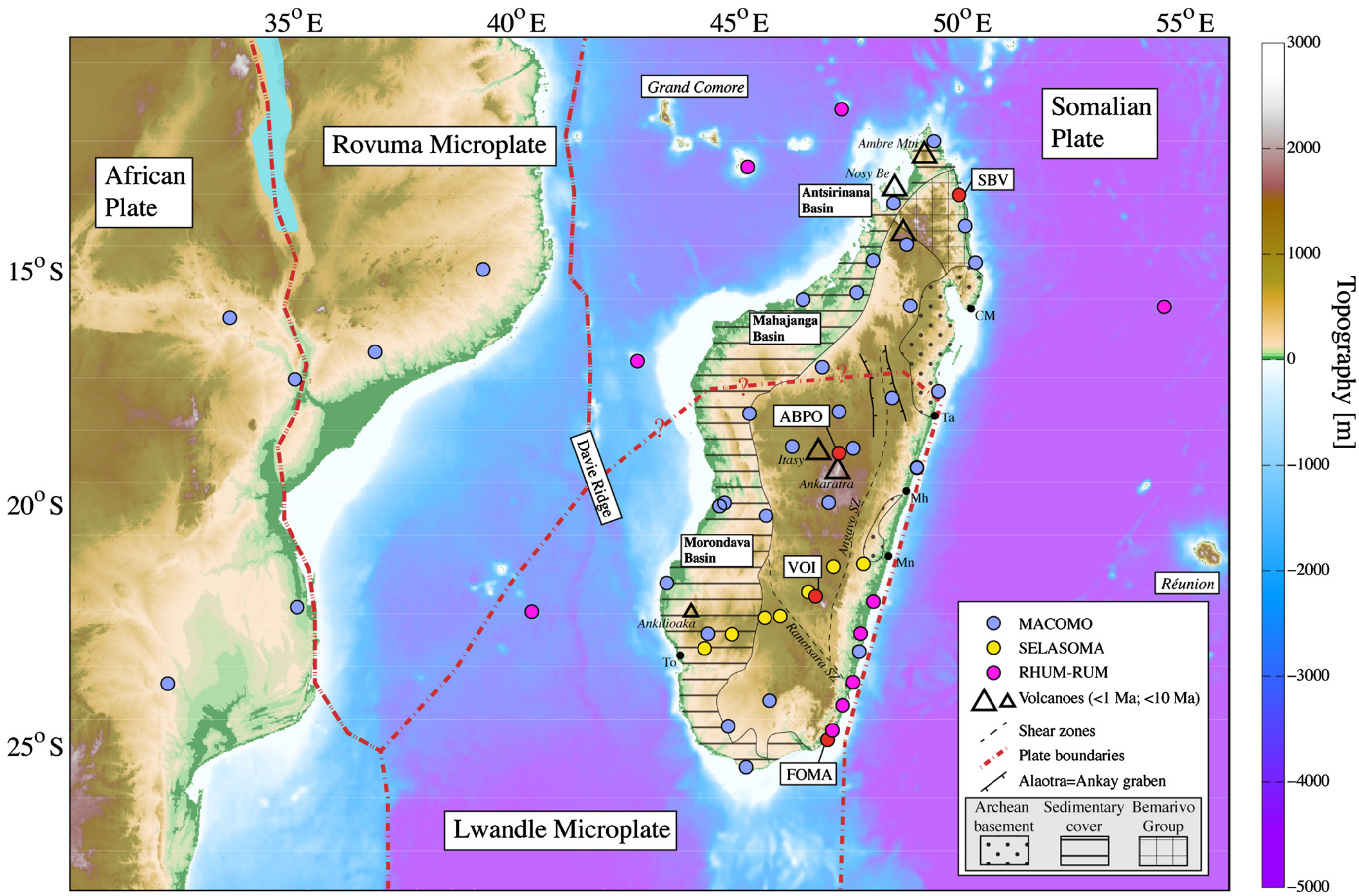

Fig. 1. Topographic map of the Madagascar/Mozambique region. Simplified geology for Madagascar is adapted from Roig et al. (2012), showing Precambrian metamorphic terranes consisting of Archean cratonic fragments, the Bemarivo Group, and the untextured Antananarivo Group. Phanerozoic sediments cover much of the west of Madagascar. Cenozoic volcanic areas are as marked, as are Precambrian shear zones and the post-Miocene Alaotra–Ankay graben structure. Initials are place names referred to in the text: A – Antananarivo, CM – Cap Masoala, Mh – Mahanoro, Mn – Mananjary, Ta – Tamatave, To – Toliara. Station locations are shown for the MACOMO, RHUM-RUM, and SELASOMA seismic projects used in this study. Known active hotspots currently lie beneath Grande Comore and Réunion. The Davie ridge is an inferred transform fault controlling the relative movement of Madagascar with respect to Africa during the Mesozoic. Plate boundaries are after Stamps et al. (2015). Elevation and bathymetry are from ETOPO1 (Amante and Eakins, 2009). (For interpretation of the colors in this figure, the reader is referred to the web version of this article.)

referred to in the literature as the Northern Madagascar Alkaline Province (NMAP) and the Central Madagascar Alkaline Province (CMAP). A third outcrop of late Cenozoic volcanism was also identified in the southwestern part of the island by Bardintzeff et al. (2010), which we will refer to as the SMAP. Several ideas have previously been put forward to explain this anomalous volcanic activity (Emerick and Duncan, 1982; Nougier et al., 1986). However, without the imaging provided by broadband seismological investigations, hypotheses concerning the origin of this magmatic activity could not be tested. It was in the context of this challenge that the seismic imaging presented here was carried out through the 2-year deployment of an island-wide network of 26 broadband seismometer locations, complemented by six seismometers deployed in neighboring Mozambique as part of the MACOMO (MAdagascar COmores MOzambique) experiment (Wysession et al., 2011). The experiment was simultaneously accompanied by the German SELASOMA seismic deployment of twenty-seven broadband stations along a SW–NE profile in the south of Madagascar (Tilmann et al., 2012) and by terrestrial deployments of ten broadband stations in the frame of the RHUM-RUM experiment; five along the SE coast of Madagascar and five in the surrounding Eparses Islands (Barruol and Sigloch, 2012).

Previous broadband seismological work within Madagascar was carried out using four permanent broadband seismometer stations at ABPO (GSN), FOMA (GEOSCOPE), SBV and VOI (GEOFON) (Rindraharisaona et al., 2013). Small deployments of short-period seismometers were also carried out by researchers from the University of Antananarivo, through these short-period sensors were only sensitive to local seismicity in the Itasy and Ankaratra region (e.g. Rindraharisaona et al., 2013), and were not able to resolve deep and large-scale structures. The global model Crust1.0 (Laske et al., 2013) includes a representation of Madagascar with a 1° parameterization that varies between a maximum crustal thickness of ∼42 km along the backbone of the island, where the topography is highest, to a minimum crustal thickness of ∼30 km along the western coast. This model improved upon crustal-thickness models that were based on gravity studies, which suggested crustal-thickness variations of 25–35 km (Rakotondraompiana et al., 1999). Upper mantle observations beneath Madagascar had previously only been constrained by receiver-function and teleseismic surface-wave shear-velocity inversions for each of the four permanent stations (Rindraharisaona et al., 2013), which also concluded that the Madagascan lithosphere is relatively thin compared with East Africa, and that the lowest asthenospheric shear velocities lie beneath some of the highest topography around the central Itasy region.

In this study, we utilize an island-wide deployment of seismometers that is able to explore the crust and upper mantle seismic velocities of Madagascar using phase velocity measurements derived from both ambient noise and teleseismic surface wave analyses, providing good structural resolution to depths of up to 200 km. Resolving below this depth will require a subse-

Please cite this article in press as: Pratt, M.J., et al. Shear velocity structure of the crust and upper mantle of Madagascar derived from surface wave tomography. Earth Planet. Sci. Lett. (2016), http://dx.doi.org/10.1016/j.epsl.2016.10.041