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Earth structure and instrumental seismicity of Madagascar: Implications on the seismotectonics

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ABSTRACT

The aim of this study is to improve the knowledge of the seismotectonics of Madagascar. We first investigate the structure of the Earth beneath Madagascar through the joint inversion of receiver functions and Rayleigh wave group velocities. Then we use the obtained velocity models to relocate local earthquakes in order to analyse the distribution of seismicity. Finally, we use structural models and earthquake coordinates to compute focal mechanisms.

Our retrieved Earth structure models confirm a thin lithosphere beneath Madagascar when compared to the nearby East African Rift. The High Plateau in the Central region coincides with the thinnest lithosphere over the slowest asthenosphere. Our results are in good agreement with the gravity anomalies and likely confirm a localised asthenospheric upwelling beneath the central part of Madagascar. The surface expression of the asthenospheric upwelling consists in a horst–graben structure. The moderate seismicity is localised along pre-existing structures reflecting an E-W extension that is mostly accommodated in the lower crust.

1. Introduction

Madagascar is located about 1000 km from the East African Rift (EAR) and more than 2000 km from the mid-ocean Indian ridges. It is the site of a moderate historical and instrumental seismic activity as reported by Bertil and Regnoult (1998) and Poisson (1924, 1930). The largest earthquakes that occurred between 1897 and 2010 took place on November 3rd, 1897 in Itasy (intensity VIII on the Mercalli scale); September 14th, 1932 in Mantasoa (intensity VII); March 29th, 1943 near the west coast (intensity VII, with body wave magnitude estimated to be 6.0); April 16th, 1955 in Itasy (intensity VII); November 10th, 1955 in Alaotra (intensity VII) and April 21st, 1991 in Famoizamkova (body wave magnitude 5.8). The seismic activity (Fig. 1) delineates several prominent geological structures trending both N and NW (Bertil and Regnoult, 1998; Kusky et al., 2007; Rakotondraompiana et al., 1999). The most active areas are the rift valleys of Alaotra, Ankay and Anjafy (Figs. 1 and 2), the volcanic regions of Ankaratra and Itasy, Mahajanga and Morondava basins, the east coast, Ranontsara faults, the region of Nosy Be, Famoizankova and Itremo (Figs. 1 and 2) (Andrianirina, 1994; Fourno, 1990; Fourno and Roussel, 1993, 1994; Rakotondrainibe, 1977; Rambolamanana, 1989).

The recent tectonics of these structures and the related seismicity are still under debate and no direct observation of earthquake related faulting has ever been established in Madagascar. Different interpretations on the origins of the seismicity were proposed: (1) as the reactivation of pre-existing zones of weakness in the crust related to the pan-African orogenesis, and break-up of Madagascar with Africa and the Indian continent (Bertil and Regnoult, 1998; Fourno and Roussel, 1994); (2) as the result of a bulge of thermal origin affecting the lithosphere (Bertil and Regnoult, 1998; Rambolamanana, 1989). More recent studies (Kusky et al., 2007; Stamps et al., 2008) based on field observations, focal solutions and GPS argue that Madagascar and the Madagascar ridge are within the diffuse Lwandle–Somalia plate boundary which makes the south-eastern part of the African plate considerably more fragmented by likely plume-related uplift and diffuse extensional boundaries.

The first study of the crustal structure in Madagascar is that of Rakotondrainibe (1977) that used short period seismic data recorded in 1975–1977, and proposed an average crustal thickness of 36 km for the central highlands. Considering global models, the crustal thickness beneath Madagascar varies from 25 to 35 km in the 3SMAC model (Nataf and Ricard, 1996) and from 36 to 45 km in the CRUST2 model (Bassin et al., 2000). Based on simultaneous inversion of hypocentral parameters and velocity structure, Rambolamanana et al. (1997) suggested a crustal thickness of 42 km in the central part of Madagascar. Using gravimetric data, Rakotondraompiana et al. (1999) proposed that the crustal thickness in Madagascar is

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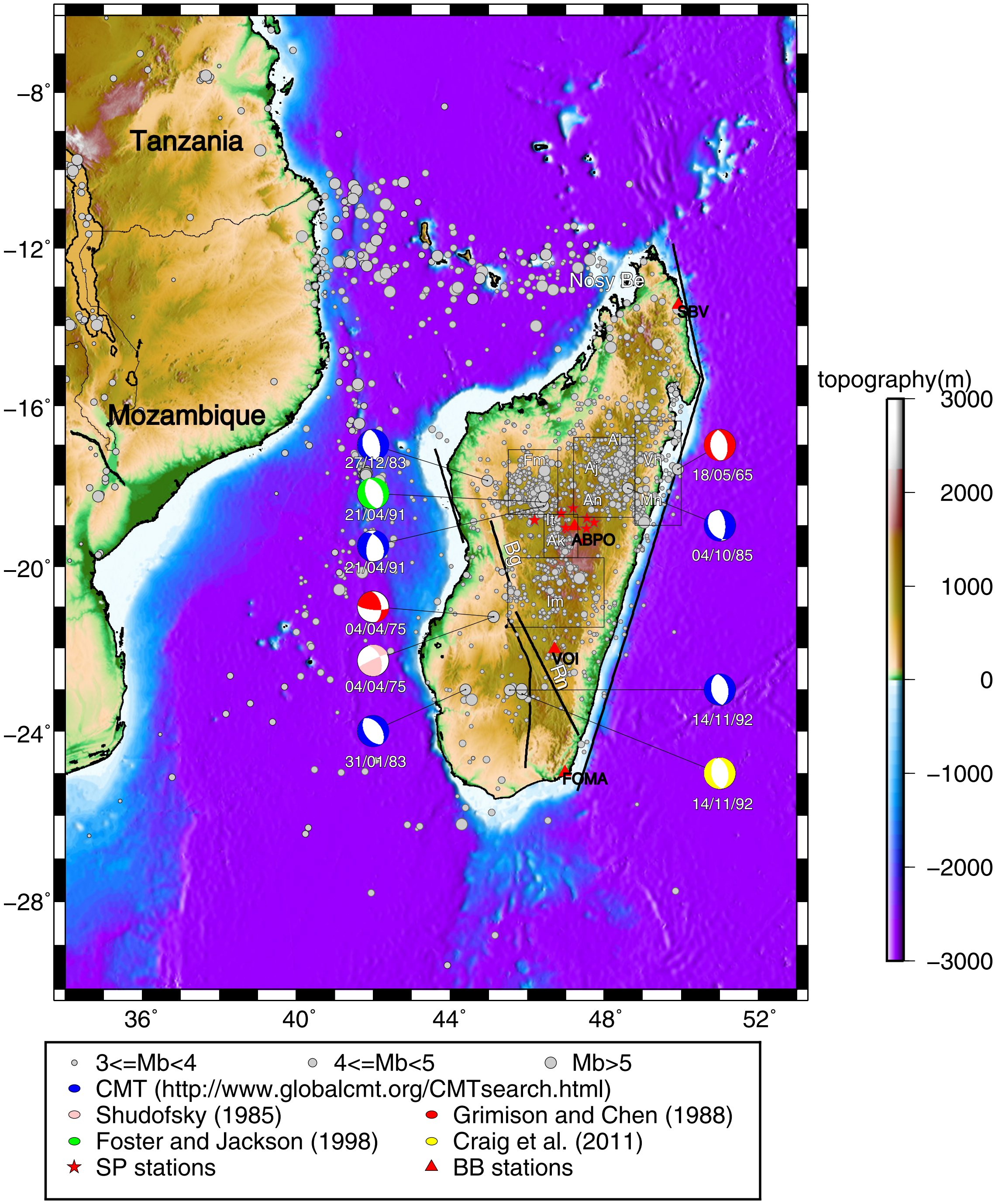

Fig. 1. Seismicity in Madagascar between 1990 and 2011, located by the Institute and Observatory of Geophysic Antanananarivo (IOGA). Focal mechanisms shown here are taken from literature. Rectangles enclose the different seismic zones analysed in this study. Vh = Vohibory, Mh = Mahatsara, Al = Alaotra, Aj = Anjafy, An = Ankay, Fm = Famoizankova, It = Itasy, Ak = Ankaratra, Im = Itremo, Bg = Bongolava, Rn = Ranotsara.

between 25 km and 35 km, with lithospheric thicknesses ranging from 62 to 90 km in the central part of the island. The result obtained by Pasyanos and Nyblade (2007) using fundamental mode surface waves over a broadband period range is similar to the model in 3SMAC. The receiver function inversion in Rai et al. (2009) shows a crustal thickness of 38 ± 1.5 km beneath the seismic station ABPO (in the central part of Madagascar).

Focal mechanism solutions play an important role in tectonic interpretation. However, only a limited number of focal solutions are available for Madagascar (Table 1). In 1985, Shudofsky (1985) determined the source mechanisms of one event in the south-western part of Madagascar using Rayleigh-wave inversion and body-wave modelling techniques and found a thrust fault with strike, dip and slip of 95°, 75° and 43°, respectively (event of April 4th, 1975). Grimison and Chen (1988) calculated focal mechanisms at the Davie-Ridge and in Madagascar by inverting the waveform and the absolute amplitude of P and SH waves. They suggested a normal fault striking N-S (event of May 18th, 1965) and a strike-slip faulting with a thrusting component striking NW (event of April 4th, 1975) in the eastern coast and the southwestern part of Madagascar, respectively. The focal