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Maturity of central Madagascar's landscape — Low-temperature thermochronological constraints

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ABSTRACT

Low-temperature thermochronological data from two profiles across central Madagascar give apatite fission track and apatite (U–Th)/He ages ranging between 258 Ma and 176 Ma and from 239 Ma to 48 Ma, respectively. Thermal models derived from these data, as well as modelling of basement denudation and the sedimentary record, indicate that first order topography of central Madagascar developed mainly due to flexural uplift during Mesozoic times. This was in response to successive erosion and depositional loading associated with the sedimentation in the Morondava and Majunga basins, both of which are now exposed along the western margin of Madagascar. Our data suggest that the eastern margin of the island had a similar denudation history and was probably at a similar topographic level before the late Cretaceous break-up of Madagascar and the India/Seychelles block. Cretaceous normal faulting, without major amounts of denudation, led to the development of the present east coast topography defined by a tectonically juvenile escarpment. In the centre of the island Cenozoic tectonics and volcanism has had a minor and localised influence on the landscape of central Madagascar.

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1. Introduction

Extensional tectonics tends to control the formation of continental interior topography. This occurs via the successive interplay between faulting, denudation and sedimentation and the feedback from these processes (e.g., Nichols and Daily, 1989; Beaumont et al., 1999). This is certainly the case for dispersed components of Gondwana where the presently observed physiographies along the margins of these continents mostly reflect the internal rifting and subsequent passive margin formation that resulted from Gondwana break-up. Madagascar is one such Gondwana relic. Within Gondwana it was located between Africa and India and only came to define a separate landmass in the Cretaceous when successive phases of rifting isolated it first from Africa and then from India (Fig. 1).

The onset of extension within Gondwana began in the Late Carboniferous and is documented via the deposition of a number of intracontinental basins (e.g., Catuneanu et al., 2005). One of the more significant of these is the Karoo basin which onlaps both the southeastern margin of Africa and the western margin of Madagascar. The deposition of these rocks preceded actual rifting by at least 100 Ma, which in the India–Africa–Antarctica sector of Gondwana was manifested first in the Jurassic by the opening of the Somali basin between East Africa, and Madagascar–India/Seychelles and concurrent opening of the Mozambique Basin and the Riiser–Larsen Sea between East Africa and Antarctica. Madagascar was subsequently separated from the India/Sychelles block in the Late Cretaceous (e.g., Salman and Abdula, 1995; Storey et al., 1995). During these rift and drift episodes passive margins formed around Madagascar. Extensive sedimentation continued in the relics of the Karoo basin along the western margin of the island (Figs. 1 and 2) while subordinate deposition occurred in the younger basins found along the eastern coast (Besairie and Collignon, 1972). These basins were fed with detritus from their exhumed basement hinterlands.

The erosion of these basement rocks controls their vertical velocity through the upper part of the crust (<5 km). This can be quantified by low-temperature thermochronological dating methods such as fission track and (U–Th)/He dating of apatite (e.g., Farley et al., 1996; Gallagher et al., 1998). From the Malagasy basement rocks numerous of apatite fission track ages have been published (Emmel et al., 2004, 2006a, 2006b, 2008; Seward et al., 2004; Jöns et al., 2009; Schreurs et al., 2011). These studies typically report ages between ca. 460 Ma and 70 Ma (Fig. 2c) and indicate that periods of basement exhumation occurred between the onset of rifting within Gondwana (Late Carboniferous) and the final separation of Madagascar from India (Late Cretaceous). Post-Cretaceous cooling was restricted to temperatures less than ca. 60 °C—a range below the sensitivity of apatite fission track thermochronology. Cooling below 60 °C can be constrained by apatite (U–Th)/He

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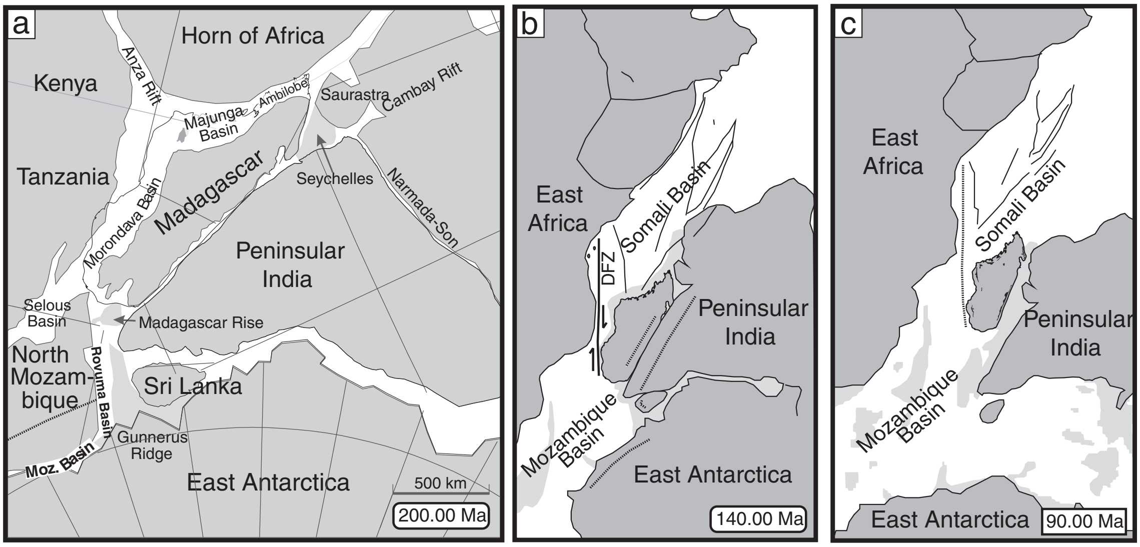

Fig. 1. a) Madagascar had a central position within central Gondwana at ca. 200 Ma (after Reeves et al., 2002). b and c) Gondwana break up 140 Ma and 90 Ma (after de Wit, 2003) with locations of high elevated continental margins (b, dashed lines) and Cretaceous volcanic rocks in Madagascar (c, block dots).

thermochronology, a methodology that, prior to the present study, has not been applied in Madagascar.

The majority of the fission track data, with ages >70 Ma, indicate that the Malagasy landscape is, in a general sense, relatively old. However, Madagascar remains tectonically active and the impact of Cenozoic events on Madagascar's landscape remains a point of active discussion (e.g., Bertil and Regnoult, 1998; Kusky et al., 2007, 2010; Gunnell and Harbor, 2008; Schreurs et al., 2011). It is known for example that Madagascar is undergoing active extension in the north-central highlands (Alaotra–Ankay Graben: Kusky et al., 2010). Recent volcanic activity is also widespread as is ongoing seismicity. These features argue in favour of a young topography (Bertil and Regnoult, 1998; Bardintzeff et al., 2010; Kusky et al., 2010), which may be reflected in cooling below the sensitivity of the apatite fission track system.

In order to test the impact of post-Cretaceous tectonics on the Malagasy landscape, we double dated basement samples using apatite fission track and (U–Th)/He thermochronology. The combination of both methods allowed us to improve the modelled thermal and denudation histories. Assuming a close relationship between surface processes and characteristics (Pike, 2000), the present topography can be compared with estimated topographies during the geological past. Here, we test the impact of flexural response to basin formation along the western margin of the island. We used the amounts of basement denudation obtained from modelled cooling histories combined with the amount of sedimentary load (from seismic data)

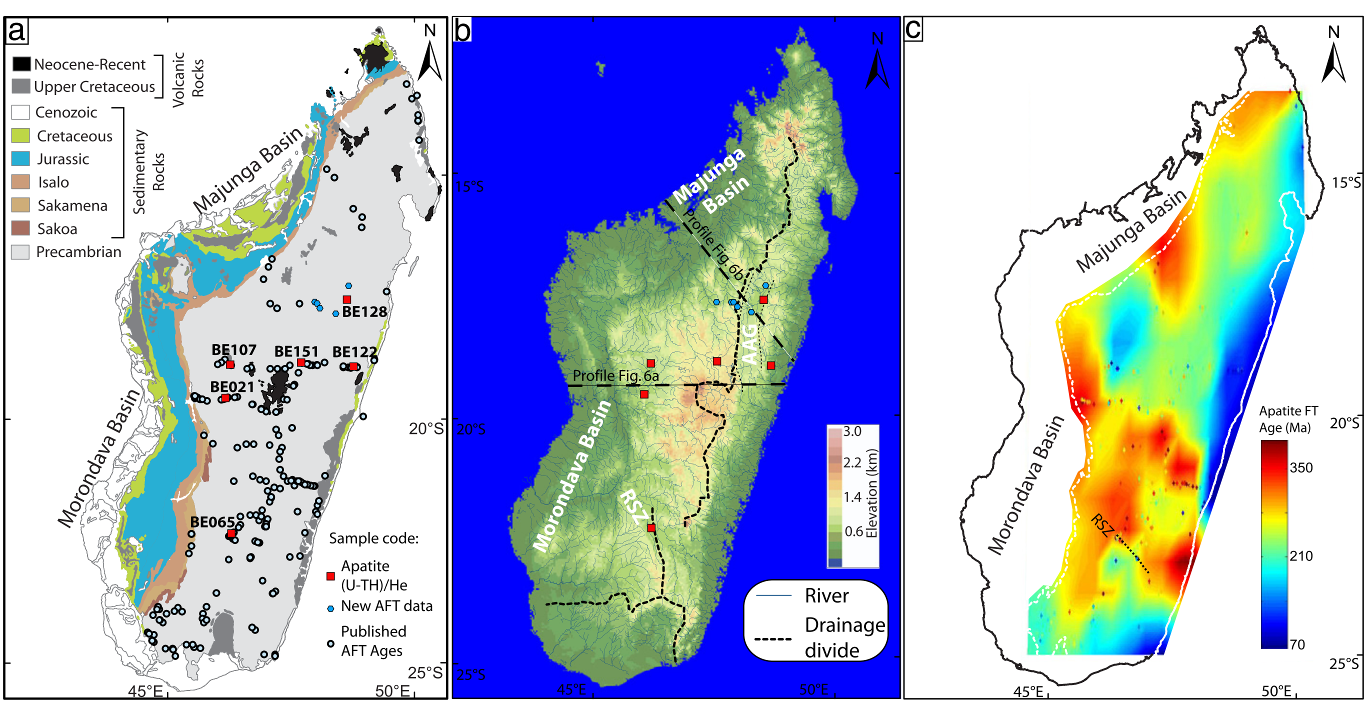

Fig. 2. a) Simplified geological map of Madagascar with locations of the new dated (U–Th)/He samples, new and published apatite fission track data. b) Topograhic and hydrographic map of Madagascar. AAG: Alaotra–Ankay Graben; RSZ: Ranotsara Shear Zone. c) Interpolated apatite fission track age distribution map (data given in supplementary data S1).

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