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Geomorphic development of the escarpment of the Eritrean margin, southern Red Sea from combined apatite fission-track and (U–Th)/He thermochronometry

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Abstract

Apatite (U–Th)/He and fission-track thermochronometers are combined to constrain models of denudation and escarpment development of the high elevation Eritrean margin along the southern Red Sea. (U–Th)/He ages have been determined for apatites from two coast-perpendicular transects that were previously used for apatite fission-track analysis [E. Abbate, M.L. Balestrieri, G. Bigazzi, Morphostructural development of the Eritrean rift flank (southern Red Sea) inferred from apatite fission track analysis, J. Geophys. Res., 107, B11, doi: 10.1029/2001JB001009, (2002)]. In central Eritrea near Asmara, He ages increase from c. 7 Ma at the coast to 152 Ma on the plateau along a transect. Further south, He ages from the margin border to the base of the escarpment span a narrower range (7 to 12 Ma). One sample from the top of a marginal high (2950 m) yields older ages (22–43 Ma). Forward modeling suggests that the He age distribution across the margin should allow scarp retreat and downwearing mechanisms to be distinguished in the case of a margin formed in the last twenty million years. The distribution of He ages suggests that the escarpment evolved by downwearing and that post-break up erosion of the escarpment was facilitated by in situ excavation rather than parallel retreat. This implies the existence of an inland drainage divide located seaward of the present day escarpment rim. We envisage that the inland divide formed during or immediately after continent break up, and that the eastern marginal belt represents a remnant of the apex structure. The short distance between the eastern marginal belt and the rim (c. 10 km) represents the total retreat of the escarpment. Comparison of the measured He ages from the coastal plain with those predicted from forward modelling indicates that the main phase of post-break up erosion started at about 15 Ma, closer to the initiation of seafloor spreading in the Red Sea than was thought previously.

Keywords: escarpment; denudation; passive margin; thermochronology; (U–Th)/He dating; fission tracks

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1. Introduction

The continental margins bordering the Red Sea are among the youngest in the world forming in response to continental rifting that commenced during the earliest Miocene [2]. The Eritrean continental margin along the southern Red Sea is morphologically typical of high-elevation rifted margins. A steep escarpment separates a low elevation coastal plain from a high elevation plateau that reaches altitudes of more than 2500 m. Escarpments are the most prominent geomorphological feature generated during continental break up and how they evolve provides constraints on the roles of tectonics and erosion in the formation of passive margins, and on the supply of sediments to hydrocarbon-bearing reservoirs.

Conflicting models have been proposed for the generation of escarpments at high elevation passive margins (Fig. 1a). They differ in the nature of rift tectonics, the spatial distribution of the amount of post-break up erosion across the margin and the position of the drainage divide prior to break up. In the downwarp or monocline model [3,4], the margin is formed by long wavelength flexure of the lithosphere and the post-break up margin topography is characterised by a broad monocline. The amount of erosion is limited as indicated by the preservation of the pre-rift land surface on hilltops across the coastal plain and on the plateau [4,5]. In the other two models, rifting is accommodated by normal faulting that creates a steep escarpment at the new continental margin. Pre-break topography plays a fundamental role on subsequent margin evolution [6]. If the pre-rift topography was flat a new drainage divide coincident with the head of the escarpment is created and the system evolves by parallel scarp retreat. If the pre-rift topography included an inland drainage divide less than approximately 100 km from the rift, the plateau seaward of this original divide rapidly degrades by downwearing and a new escarpment is created at the drainage divide [6–9]. In the plateau degradation, or downwearing, model the area between the inland divide and the coast is incised rapidly by seaward flowing rivers. In the escarpment retreat model,

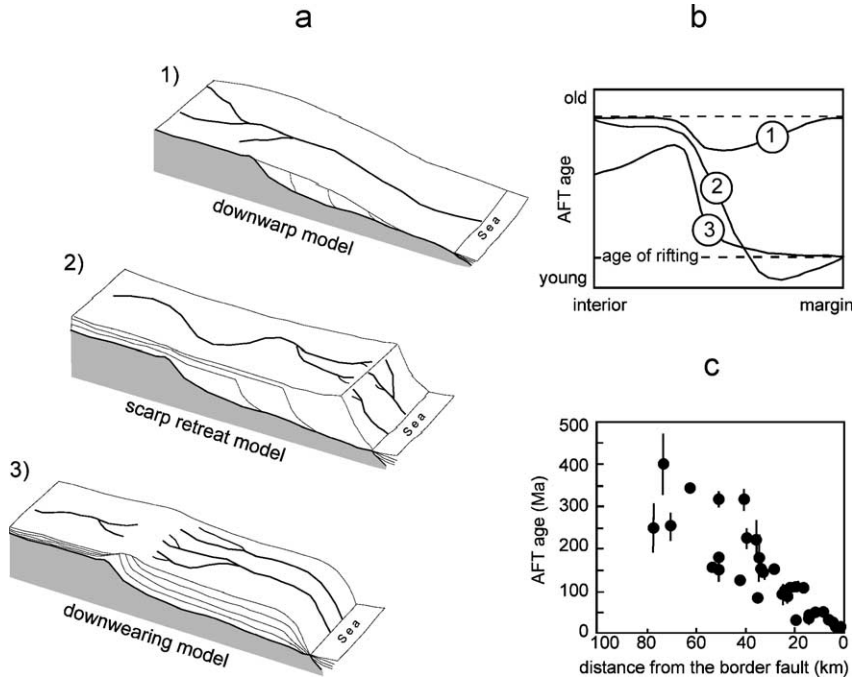

Fig. 1. (a) Block-diagrams showing the three prevailing models developed for the evolution of escarpments at high-elevation passive margins, the thick lines on the sections represent the present-day topography while the thin lines indicate the cover removed at various time steps. (b) Distinct patterns of AFT ages across passive margins generated by the three models, redrawn from [10]. (c) Plot of AFT ages versus distance from the border fault for all the four transects sampled for AFT analysis along the Eritrean margin [1].