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Post break-up tectonic inversion across the southwestern cape of South Africa: New insights from apatite and zircon fission track thermochronometry

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ABSTRACT

The south-west African margin is regarded as an example of a passive continental margin formed by continental rifting following a phase of lithospheric extension and thinning. Recent attention focused on this margin has included theoretical modelling studies of rift processes, plate kinematic studies of the opening geometry and timing, and empirical studies focused on documenting the crustal structure and offshore sedimentary record. Here, we examine the onshore geomorphic and tectonic response to rifting and breakup, with a specific focus on the SW Cape of South Africa. We present 75 new apatite and 8 new zircon fission track analyses from outcrop samples and onshore borehole profiles along the western margin of South Africa. The data are used to derive robust thermal histories that record two discrete phases of accelerated erosional cooling during the Early Cretaceous (150–130 Ma) and Late Cretaceous (100–80 Ma), respectively. Both periods of enhanced erosion are regional in extent, involved km-scale erosion, and extend well inland of the current escarpment zone, albeit with spatially variable intensity and style. The Late Cretaceous episode is also expressed more locally by tectonic reactivation and inversion of major faults causing km-scale differential displacement and erosion. The new AFT data do not exclude the possibility of modest surface uplift occurring during the Cenozoic, but they restrict the depth of regional Cenozoic erosion on the western margin to less than c. 1 km. The inferred pattern and chronology of erosion onshore is consistent with the key features and sediment accumulation patterns within the offshore Orange and Bredasdorp basins. It is suggested that the Late Cretaceous event was triggered by a combination of regional dynamic uplift augmented along the western margin and in the SW Cape by local tectonic forces arising from dextral displacement of the Falkland Plateau along the Falkland–Agulhas Fracture Zone.

1. Introduction

The widespread occurrence of prominent coast-parallel escarpments along high-elevation passive margins is a strong indication that significant relief is generated along the edge of separating continental plates as a consequence of rifting with examples being southern Africa, western India and southeastern Australia (e.g., Matmon et al., 2002; Ollier, 1985; Summerfield, 2000). However, despite numerous studies focusing on the geodynamic and geomorphic processes involved during continental rifting (e.g., Braun and Beaumont, 1989; Brune et al., 2014; Gilchrist and Summerfield, 1991; Huismans and Beaumont, 2011; Japsen et al., 2006; Kooi and Beaumont, 1994; Ollier, 1985; van der Beek and Braun, 1998), the precise nature of the relationship between rifting processes and the mechanisms responsible for creating and maintaining topography is not fully understood and remains controversial (e.g., Blenkinsop and Moore, 2013; Green et al., 2013; Japsen et al., 2006; Rouby et al., 2013).

The extent to which tectonic and geomorphic responses are transmitted away from the rift axis during continental rifting is largely controlled by the rheology of the lithosphere and degree of coupling with the convecting mantle (e.g., Brune et al., 2014; Huismans and Beaumont, 2011). In addition to this, although less well understood, is the important influence that pre-existing crustal-scale structures exert on the geometry and location of intercontinental rifting and on the style of crustal deformation (e.g., Autin et al., 2013; Corti et al., 2013; Gibson et al., 2013; Schumacher, 2002; Tommasi and Vauchez, 2001).

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This phenomenon has been particularly well documented within west, central and east Africa and north-eastern Brazil where 'Pan-African' (c. 500 Ma, Frimmel, 2000) aged structures have controlled the location of Early Cretaceous intracontinental rift basins and also their subsequent inversion during the Late Cretaceous (e.g., Brown et al., 2014; Cogné et al., 2011; Daly et al., 1989; Fairhead, 1988; Raab et al., 2002; Ring, 1994; Rosendahl, 1987; Unternehr et al., 1988).

Recent structural analyses of both the on and offshore regions of the South Atlantic margin in South Africa have indeed documented evidence for multiple episodes of tectonic inversion following the initial rift phases (e.g., Andreoli et al., 1996; Brandt et al., 2003, 2005; de Beer, 2012; Hirsch et al., 2010; Kounov et al., 2009; Viola et al., 2005, 2012). Along the western margin of South Africa, however, the lack of significant or widespread post-rift sedimentary stratigraphy preserved onshore (i.e., Late Mesozoic-Tertiary) hinders detailed investigation of the timing and magnitude of post break-up tectonic development of this region of the continent. Consequently, the spatial extent and timing of these periods of tectonic activity, and the nature of any related geomorphic response, remain poorly constrained.

The origin and evolution of high passive margin topography and the longevity of the South African interior plateau (Fig. 1) have been a subject of debate for decades (Burke and Gunnell, 2008; Gilchrist and Summerfield, 1991; Gilchrist et al., 1994; Japsen et al., 2012; Moore et al., 2009; Ollier and Pain, 1997; Partridge and Maud, 1987; Paul et al., 2014; van der Beek et al., 2002). Investigations aimed at understanding the mechanisms controlling the development of this topography have focussed on assessing numerical models of the mechanical and isostatic response of the lithosphere during thinning and rupture (e.g., Brune et al., 2014; Gilchrist and Summerfield, 1991; Huismans and Beaumont, 2011; Rouby et al., 2013; ten Brink and Stern, 1992) and of syn- and post-rift mantle driven dynamic uplift (e.g., Forte et al., 2010; Gurnis et al., 2000; Lithgow-Bertelloni and Silver, 1998; Moucha and Forte, 2011; Moucha et al., 2008; Nyblade and Robinson, 1994). One of the limitations of testing these models is the paucity of useful empirical observations of the magnitude and chronology of surface uplift. One approach to resolving this limitation is constraining the timing and magnitude of major erosional events that have occurred across a particular margin using suitable empirical data, and using this information to unravel the geomorphic development of the margin.

Apatite fission track (AFT) analysis has been used extensively as a means of extracting low temperature (c. 60–110 ± 10 °C) thermal history information from rocks as they cool through the upper 3–5 km of the crust (Brown et al., 1994; Donelick et al., 2005; Gallagher et al., 1998; Lisker et al., 2009). As such, the technique has proved effective in providing constraints on the magnitude and timing of crustal denudation of the onshore regions of various rifted and continental margins where stratigraphic evidence is limited or unavailable (Gunnell et al., 2003; Japsen et al., 2006; Menzies et al., 1997; Pedersen et al., 2012). The technique has also been successfully applied to resolve the structural style of rift-margin mountains by documenting structural displacements across basement faults (e.g., Cogné et al., 2011; Foster and Gleadow, 1992; John and Foster, 1993; Redfield et al., 2005; Seward et al., 2004; Tremblay et al., 2013).

In this paper, we present new AFT and zircon fission track (ZFT) analysis data from outcrop and borehole samples. We use these data

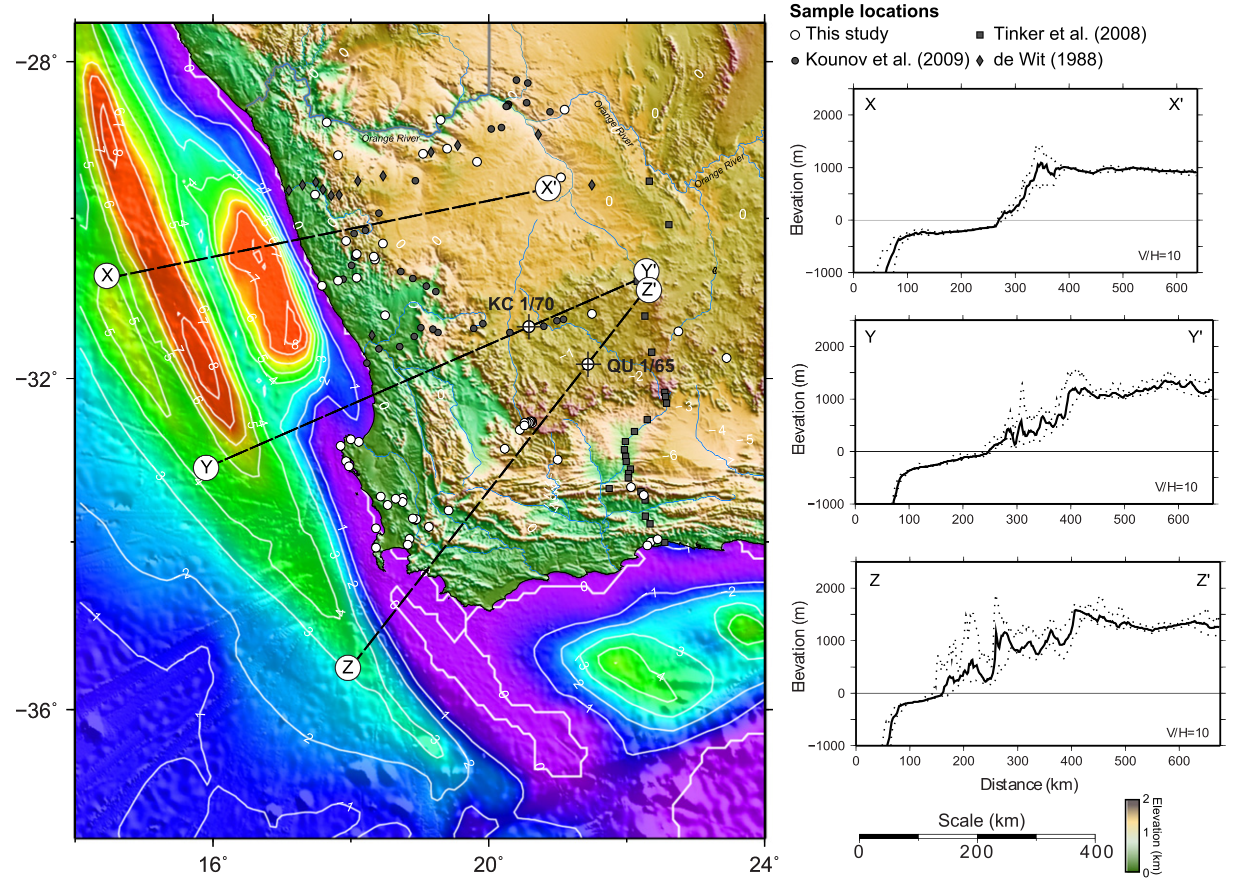

Fig. 1. Map illustrating the topography of southwestern Africa, sediment thickness in offshore basins and sample locations of regional AFT data. Regions of equal sediment thickness (data are from Rouby et al., 2009) in the offshore region are highlighted by white isopach lines and single numbers (in km). For alternative sediment thickness maps see Rouby et al. (2009) and Maystrenko et al. (2013). Three representative topographic sections across the margin are shown on the right. Elevations within 20 km of the line of section were projected. Solid line represents the mean elevation within the 40 km wide swath at 10 km windows projected onto the section while dashed lines represent the maximum and minimum values. See Supplementary material 1 (Fig. A1) for complimentary gravity and aeromagnetic maps of the region.