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Denudation history and landscape evolution of the northern East-Brazilian continental margin from apatite fission-track thermochronology

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A B S T R A C T

We reconstruct the history of denudation and landscape evolution of the northern East- Brazilian continental margin using apatite fission-track thermochronology and thermal history modeling. This part of the Brazilian Atlantic margin is morphologically characterized by inland and coastal plateaus surrounding a wide low-lying inland region, the Sertaneja Depression. The apatite fission track ages and mean track lengths vary from 39 ± 4 to 350 ± 57 Ma and from 10.0 ± 0.3 to 14.2 ± 0.2 μm, respectively, implying a protracted history of spatially variable denudation since the Permian at relatively low rates (<50 m My^{-1}). The Sertaneja Depression and inland plateaus record Permian-Early Jurassic (300–180 Ma) denudation that precedes rifting of the margin by > 60 Myrs. In contrast, the coastal regions record up to 2.5 km of Late Jurassic-Early Cretaceous (150–120 Ma) denudation, coeval with rifting of the margin. The samples from elevated coastal regions, the Borborema Plateau and the Mantiqueira Range, record cooling from temperatures above 120 °C since the Late Cretaceous extending to the Cenozoic. We interpret this denudation as related to post-rift uplift of these parts of the margin, possibly resulting from compressional stresses transmitted from the Andes and/or magmatism at that time. Several samples from these areas also record accelerated Neogene (<30 Ma) cooling, which may record landscape response to a change from a tropical to a more erosive semi-arid climate during this time. The inferred denudation history is consistent with the offshore sedimentary record, but not with evolutionary scenarios inferred from the recognition of “planation surfaces” on the margin. The denudation history of the northeastern Brazilian margin implies a control of pre-, syn- and post-rift tectonic and climatic events on landscape evolution.

1. Introduction

Rifted-margin escarpments are major geomorphic features that separate high-elevation interior plateaus from low-lying coastal plains along numerous rifted continental margins worldwide. Our basic understanding of rifted-margin escarpment evolution has greatly improved over the last two decades as extensive datasets on their long-term denudation became available. Such datasets were collated using primarily apatite fission-track (AFT) thermochronology (e.g., Dumitru et al., 1991; Gallagher et al., 1994; Brown et al., 2002; Gunnell et al., 2003). At the same time, numerical models of landscape evolution led to the recognition that rifted-margin escarpments are long-lived erosional features associated with km-scale long-wavelength uplift of the margin and its continental interior (e.g., Gilchrist and Summerfield, 1990; Kooi and Beaumont, 1994; Tucker and Slingerland, 1994; van der Beek and Braun, 1999; Sacek et al., 2012); this prediction was shown to be consistent with available AFT datasets (van der Beek et al., 1999, 2002). However,

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the mechanisms of the uplift remain disputed: magmatic underplating associated with extensive syn-break-up magmatism (Lister et al., 1991; Gallagher et al., 1994), isostatic support by buoyant hot mantle (Nyblade and Sleep, 2003; Hasterok and Chapman, 2007), dynamic support by mantle flow (Lithgow-Bertelloni and Silver, 1998; Braun, 2010), and transmission of plate-boundary forces (Cobbold et al., 2007; Cloetingh et al., 2008) have all been proposed as viable mechanisms. Similarly, the timing of uplift has been variably interpreted as pre-, syn- or post-break-up; although the denudation record of some rifted-margin escarpments can be explained without invoking post-rift uplift (e.g., Brown et al., 2002; van der Beek et al., 1999, 2002), post-rift reactivation of major crustal shear-zones leading to localized uplift and denudation has been recognized on several margins (Harman et al., 1998; Raab et al., 2002; Cogné et al., 2011, 2012). Other researchers have interpreted the geomorphic record of high-elevation rifted margins in terms of significant and widespread post-rift uplift (e.g., Japsen et al., 2009, 2012a and references therein). Finally, the flexural isostatic response to onshore denudation and offshore sedimentation may also have contributed to the history of vertical motions at rifted continental margins (Pazzaglia and Gardner, 1994).

The margins surrounding the South Atlantic have been the focus of considerable attention in the debate on the origin and evolution of rifted-margin escarpments (e.g., Gilchrist and Summerfield, 1990; Gallagher and Brown, 1999; Brown et al., 2000). The South Atlantic margins are characterized by voluminous igneous activity coincident with the break-up between South America and Africa (Hawkesworth et al., 1992), but also by more localized magmatism at 80 and 50–40 Ma (Misuzaki et al., 1992, 2002). Several authors have explored the links between this magmatism, the uplift and denudation history of the onshore continental margin, and the sedimentary record of the adjacent passive-margin basins (e.g., Chang et al., 1992). The patterns of uplift and denudation along the South Atlantic margins also appear to be controlled by syn- and post-rift reactivation of major pre-existing structures formed during a long Proterozoic history of plate assembly (Gallagher et al., 1994; Harman et al., 1998; Gallagher and Brown, 1999; Raab et al., 2002; Cobbold et al., 2007; Cogné et al., 2011, 2012).

On the South American margin of the South Atlantic, most thermochronology studies have focused on southeastern Brazil (Gallagher et al., 1994, 1995; Gallagher and Brown, 1999; Jelinek et al., 2003; Tello et al., 2003; Hackspacher et al., 2007; Hiruma et al., 2010; Cogné et al., 2011, 2012), where the rifted-margin escarpment is most clearly expressed. In contrast, the uplift and denudation history of the margin further to the north (Figs. 1 and 2) have not been studied in much detail until recently. Harman et al. (1998) used AFT data to constrain denudation in the cratonic interior and margin of northeastern Brazil. Cupertino (2000; see also Magnavita et al., 2012) presented a thermochronological study of the Recôncavo and Camamu Basins and the adjacent host rocks, but mostly focused on the implications for petroleum prospects in these basins. Turner et al. (2008) and Morais Neto et al. (2009) have worked on the Sergipe-Alagoas continental margin and Borborema Province, respectively. However, these studies have focused on relatively restricted areas and only the latter two studies explicitly linked the denudational history inferred from thermochronology data to rifted-margin development. In a recent paper, Japsen et al. (2012b) present new AFT data from the northeastern Brazilian margin and infer a complex post-rift history of repeated burial and exhumation. In contrast to the margins of southeastern Brazil and southwestern Africa, neither the northeastern Brazilian margin nor its African conjugate in Gabon and Congo is characterized by a well-developed escarpment. These peculiarities make this part of the Brazilian margin of interest for the study of long-term landscape evolution and its potential links with rifted-margin development.

Here we present an extensive AFT database that constrains the morphotectonic evolution of the northern East-Brazilian margin. We use inverse modeling of AFT ages and track-length distributions to establish the timing and magnitude of major cooling events and quantify the associated denudation. The data density is sufficient to develop a synoptic view of denudation patterns through space and time on the margin. We discuss the results in terms of the mechanisms responsible for the present-day topography and their relation to Pangaea break-up. Our data indicate a protracted history of landscape development on the northern East-Brazilian margin, on which pre- and post-rift events had at least as much influence as syn-rift uplift and denudation.

2. The Northern East-Brazilian margin

2.1. Geomorphic setting

The study area covers the northern half of the East-Brazilian margin, between 8° and 21°S (Fig. 1). Toward the south, the study area encompasses the Mantiqueira Range, which is characterized by high topographic relief (elevations reaching up to 2000 m) located close to the coastline, with the drainage divide and the mountain front running sub-parallel to the present-day coastline.

The continental margin in northeastern Brazil does not exhibit such high elevations near the coastline, but is characterized by two coastal plateaus, the Borborema Plateau to the northeast and the Conquista-Jequitinhonha Plateau to the southwest, which rise from the coastal plain to elevations of ~1200 m and 400–800 m, respectively (Fig. 1). A third plateau, the Diamantina Plateau, is located inland and is characterized by a low-relief summit surface at elevations of ~1500–2000 m. The Diamantina Plateau is bordered to the east by a conspicuously straight, north-south oriented escarpment located 300–400 km inland and incised by the headwaters of the Itapicuru and the Jacuípe-Paraguaçu rivers (Fig. 1). These three plateaus surround a widespread low-lying area known as the Sertaneja Depression. Although the escarpments are locally developed on more resistant lithologies, there is no direct relationship between the bedrock geology (cf. next section) and the occurrence of the plateaus as they cut across rocks of different ages (mainly Proterozoic). The plateau surfaces have been interpreted as uplifted "peneplains" (*sensu* King, 1967), which would have recorded extensive Cenozoic uplift (e.g., Peulvast et al., 2008; Japsen et al., 2012b).

The drainage system of northeast Brazil consists mainly of WNW-ESE flowing rivers. The largest catchment is that of the São Francisco River, which drains the Diamantina Plateau and a large part of the São Francisco Craton (cf. below) before crossing the Sertaneja Depression on a southeasterly course to the Atlantic. The São Francisco is a long-lived river system, which has evolved since mid-Cretaceous times (Potter, 1997); its present-day course has been suggested to result from Early Cenozoic capture of the northeast-flowing Parnaíba River (cf. Karner and Driscoll, 1999). Other major rivers present in the study area with a similar trend are the Jequitinhonha, Doce, Almada, Contas, Paraguaçu, Jacuípe, Itapicuru, Vaza-Barris, and Sergipe Rivers (Fig. 1). Similar to the plateaus, the structural control on the river systems is variable; for instance, rivers cut across the Mesozoic Recôncavo-Tucano-Jatobá rift system (cf. Section 2.3) in the Sertaneja Depression, although the São Francisco, Vaza-Barris, and Itapicuru partly follow the segment boundaries in this rift system. Similarly, some rivers (Jequitinhonha, Contas, Paraguaçu) cut into the Diamantina and Conquista-Jequitinhonha plateaus, whereas the larger Doce and São Francisco flow around the Mantiqueira Range and Diamantina Plateau, respectively.