Tectonophysics 685 (2016) 21–34

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Thermotectonic history of the southeastern Brazilian margin: Evidence from apatite fission track data of the offshore Santos Basin and continental basement

Christie Helouise Engelmann de Oliveira [a,*], Andréa Ritter Jelinek [a], Farid Chemale Jr. [b], José Antônio Cupertino [c]

[a] Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Brazil
[b] Universidade do Vale do Rio dos Sinos, Brazil
[c] PETROBRAS, Rio de Janeiro, Brazil

ARTICLE INFO

Article history:
Received 29 March 2016
Received in revised form 11 July 2016
Accepted 17 July 2016
Available online 20 July 2016

Keywords:
Southeastern Brazilian margin
Apatite fission track
Offshore Santos Basin
Basement

ABSTRACT

The Santos Basin is the largest offshore sedimentary basin in the southeastern Brazilian margin and originated by breakup of West Gondwana in the Early Cretaceous. We carried out a new thermochronological study by apatite fission track analysis from borehole samples of the Santos Basin and its continental basement to constrain the tectonic history of the southeastern Brazilian margin. Apatite fission track central ages of the basement and borehole samples vary from 21.0 ± 1.8 to 157.0 ± 35.0 Ma and from 6.5 ± 1.1 to 208.0 ± 11.0 Ma, respectively. From thermal modeling, the basement samples reached the maximum paleotemperatures during the final breakup of South America and Africa. The onshore basement and offshore basin record an early thermotectonic event during the Late Cretaceous linked to the uplift and denudation of the Serra do Mar and Serra da Mantiqueira. Maturation of the organic matter in the offshore basin is related with the progressive increase of the geothermal gradient due to burial. The thermal modeling indicates that the oil generation window started at 55–25 Ma. The basement samples experienced the final cooling during the Cenozoic, with an estimated amount of denudation linked to the sedimentary influx in the offshore basin. A rapid cooling during the Neogene becomes evident and it is linked to the reactivation along Precambrian shear zones and change of the Paraíba do Sul drainage system.

1. Introduction

The southeastern Brazilian margin constitutes part of the South Atlantic rift system originated by breakup of West Gondwana in the Early Cretaceous. The opening of the South Atlantic developed by diachronous rifting, which initiated in the south in the Late Triassic-Early Jurassic and propagated to the north along reactivated older tectonic lineaments (e.g., Meisling et al., 2001; Nürnberg and Müller, 1991; Torsvik et al., 2009). Initially, the divergent plate motion was E-W directed, but progressively changed to a NE-SW direction, with transtension along the eastern Brazilian margin (Macdonald et al., 2003; Rabinowitz and LaBrecque, 1979).

Breakup of the paleocontinent at 130 Ma was affected by widespread rifting and the impact of the volcanic activity of the Paraná-Etendeka province (e.g., Macdonald et al., 2003; Zalán et al., 1991). The plume-related volcanic activity caused the lifting of the crust, including the exposure of the Precambrian basement followed by erosion and deposition. Today, the southeastern Brazilian margin has a characteristic passive continental margin morphology with offshore sedimentary basins (Santos, Campos and Espírito Santo) separated from continental elevated region (Serra do Mar) by a relatively narrow coastal plain (Gallagher et al., 1994).

Thermochronological methods such as apatite fission track (AFT) have been used extensively to understand the development of rift margins, quantifying rates of surface and rock uplift, and providing timing and rates of movement along faults and shear zones (e.g., Gallagher and Brown, 1999; Jelinek et al., 2014; Raab et al., 2005). The earlier AFT studies in southeastern Brazil have been carried out on results of basement rocks and onshore Tertiary basins, and the data were interpreted in terms of denudation and movement along faults (Cogné et al., 2012; Franco-Magalhaes et al., 2010, 2014; Gallagher et al., 1994; Hackspacher et al., 2004; Hiruma et al., 2010; Karl et al., 2013; Tello Saenz et al., 2003).

This study provides new evidence that constrains the thermotectonic history of the Santos Basin with AFT data from onshore basement outcrops and offshore borehole samples (Fig. 1) from Drift stage (Fig. 2). The primary aim of this study is to establish the timing and magnitude of major cooling events and to quantify the associated denudation of the margin topography and the burial history of the offshore basin. The data are interpreted in the context of the regional tectonic setting and enhance the extensive thermochronometry data

* Corresponding author.
E-mail address: christie.oliveira10@gmail.com (C.H. Engelmann de Oliveira).

http://dx.doi.org/10.1016/j.tecto.2016.07.012
0040-1951/

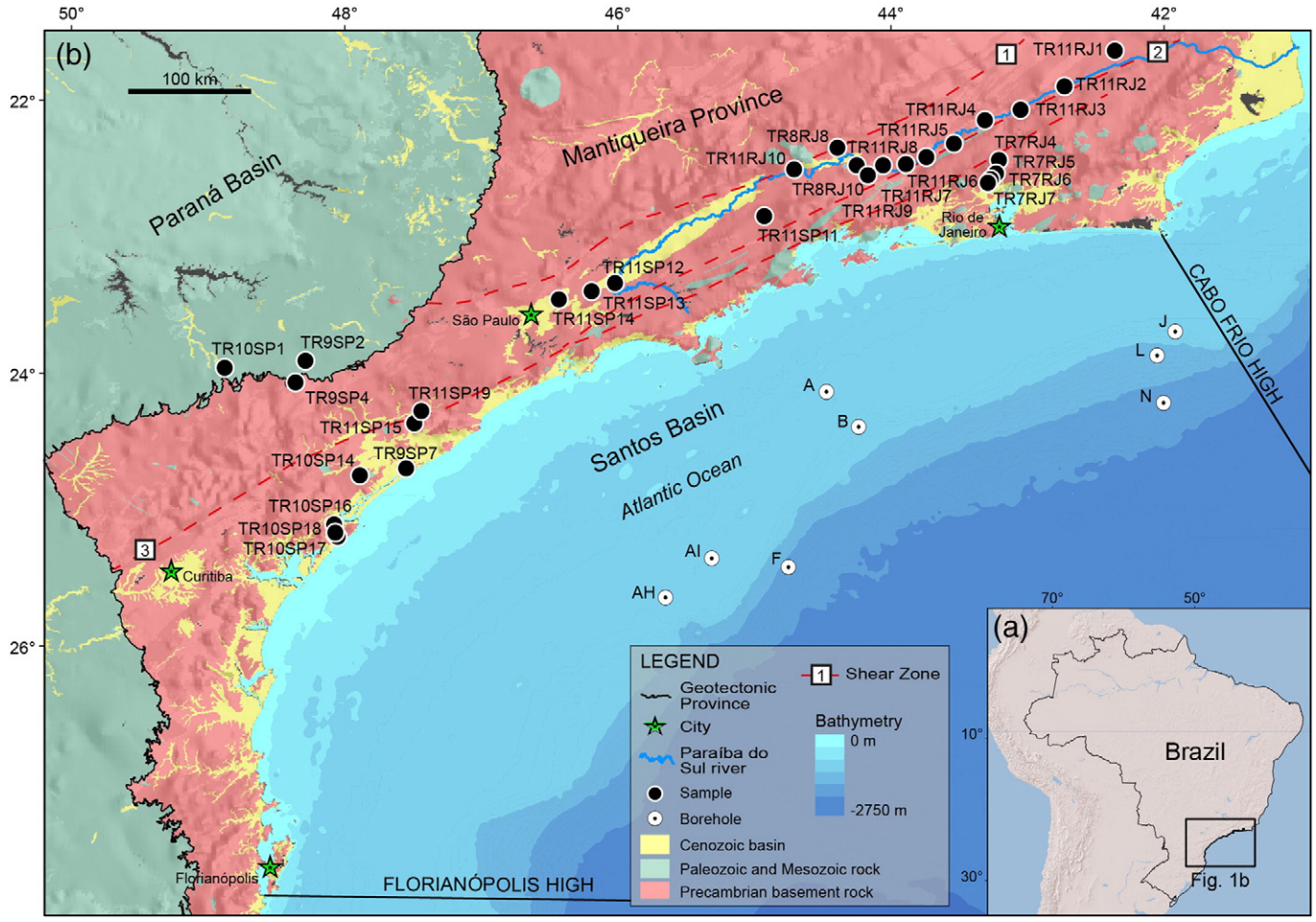

Fig. 1. Simplified geotectonic map of the southeastern Brazilian margin with location of samples. (a) General location. (b) Studied area. (1) Jundiuvira-Boquira-Rio Preto shear zone; (2) Além Paraíba shear zone; (3) Cubatão shear zone.

set across this region providing a thermotectonic history of the southeastern Brazilian margin. We show that AFT cooling ages are related to the continental breakup that led to the separation of South America and Africa and the quantitative thermal histories derived from the data provide the denudation rates, which have a significant effect on the evolution of the offshore basin and the maturation of the organic matter starting at 55–25 Ma.

2. Geological setting

The geology onshore of the Santos Basin is characterized by Precambrian-Cambrian basement provinces, predominantly granites and gneisses, formed during the Brasiliano/Pan-African orogeny (e.g., Brito Neves et al., 2014; Schmitt et al., 2008). The basement rocks are affected by Neoproterozoic NE-trending strike-slip shear zones and subordinated NW-oriented structures (Ebert et al., 1996; Heilbron et al., 2000). The assemblages are partially overlain by a sedimentary sequence of Ordovician to Jurassic siliciclastic and carbonate rocks of the Paraná Basin (Fig. 1). In the Early Cretaceous, synchronous with opening of the South Atlantic Ocean, basalt flows of the Paraná-Etendeka province covered the Paraná Basin (Zalán et al., 1991). Following continental breakup, a second magmatic episode occurred (80–50 Ma) producing alkaline intrusive bodies along the Cabo Frio High (Almeida et al., 1996; Moreira et al., 2006).

Extensional and compressional stress events operated during the post-breakup development of several onshore Tertiary basins (São Paulo, Taubaté, Resende and Volta Redonda) along the Serra da Mantiqueira and Serra do Mar ranges (Cobbold et al., 2001). The deposition of these basins occurred at ca. 48 Ma (Riccomini et al., 2004), but according Cogné et al. (2012) could be as old as Paleocene. Offshore, seismic and stratigraphic studies (e.g., Contreras et al., 2010; Modica and Brush, 2004) show that the southeastern Brazilian margin is typically of a passive margin, but underwent tectonic reactivation during the Late Cretaceous, Paleogene and Neogene (e.g., Cobbold et al., 2001).

In this context, the Santos Basin is the largest offshore sedimentary basin in the southeastern Brazilian margin developed on a tectonic framework of NNE–SSW direction approximately parallel to the coast line (Fig. 1). The basin is limited by the Florianópolis High in the south and the Cabo Frio High in the north (Moreira et al., 2007).

The development of the Santos Basin included the five major development stages (Fig. 2) of pre-rift (150–138 Ma), rift (ca. 138–123 Ma), post-rift (ca. 123–113 Ma), drift I (113–66 Ma) and drift II (66–0 Ma) (modified after Moreira et al., 2007). The rift structures are mainly NE–SW trending, represented by normal faults bounding horsts and grabens, locally intruded by syn- and post-rift magmatic rocks. The post-rift phase is characterized by diminishing activity of large faults and a regional unconformity that bevels the topography at 117 Ma. This unconformity separates continental lacustrine sediments from sediments of transitional to marine environments (Mohriak et al., 2008).

The initiation of the drift phase is marked by the cessation of rifting and the transition from continental to oceanic conditions. The drift I sequences are characterized by salt deposition (Ariri Formation), which was restricted to a short time span at 113 Ma. The salt layer extends