Tectonophysics 699 (2017) 1–15

Contents lists available at ScienceDirect

Tectonophysics

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

Stress variability in the Parnaíba Basin, Brazil, during Cretaceous rifting

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ARTICLE INFO

Article history:
Received 13 April 2016
Received in revised form 24 December 2016
Accepted 17 January 2017
Available online 19 January 2017

Keywords:
Stress variability
Equatorial Atlantic
Transform margin
Faults and fractures
Fluid inclusion
Morphostructural

ABSTRACT

The Cretaceous section of the Parnaíba Basin, designated as Grajaú Basin, represents an intracontinental half-graben formed during the Early Cretaceous due to the separation between the South American and African continents during the final dispersal of Western Gondwana. Here, through a synergetic approach between fluid inclusion planes (FIPs), outcropping geologic structures, borehole breakouts and remote sensing data, we elucidate in different scales the main structural features and their kinematic indicators. Normal faults strike mainly NNE–SSW and WNW–ESE, while deformation bands and extension joints trend to NW–SE and NE–SW, and FIPs to NE–SW and WNW–ESE. In addition, normal fault-generated scarps border geomorphological units and constitute dense zones of deformation bands and fluidization. Microthermometric FIP analyses suggest this fracturing event occurred at shallow basin levels, at temperatures below 50 °C. Furthermore, joints, bands and FIPs present mutually cross-cutting relationships, thus indicating contemporaneity. The numerical inversions applied to striated faults, non-striated faults, joints, deformation bands and FIPs suggest the occurrence of an extensional event characterized by variable direction of extension (σ_3) trending from NW–SE to WNW–ESE or NE–SE to NNE-SSW. This event probably started in the Albian during the final Gondwana fragmentation stages. The quasi-perpendicular σ_3 trend could be caused by one or all of the following phenomena: a) stress ratio *R* values obtained (<0.4) indicate the possibility of radial extension ($\sigma_2 \approx \sigma_3$), perhaps in response to the deformation partitioning due to kinematic simple-shearing constraints along the Equatorial Atlantic transform margin; b) along the WNW-oriented release normal faults, the local extension (NNE–SSW) switch positions in relation to the regional extension (WNW–ESE) by rotating 90°; c) influence of the pre-existing structures on the regional stress field. Thus, the spatial and temporal relationships between Cretaceous fault activity, stress field and the development of the geomorphological features in the Grajaú Basin contribute to understanding of the Brazilian Equatorial margin geodynamics.

1. Introduction

The stress tensor within a rock volume can be visualized as the sum of several individual tensors, each one representing a genetic component of tectonic, gravitational, thermal, fluid or diagenetic origin (Caputo, 2005). All of them are combined at each moment and at each individual point to produce a single stress state according to common stress superposition rules (Ramsay, 1967). The tectonic component of the regional stress field is basically induced by plate motion, which generates a first order stress field (Zoback, 1992). Alternatively, in complex plate motion cases, a number of distinct remote tectonic forces (i.e. different tectonic genetic components) may be merged into the regional stress field, together with second- or third-order tectonic stress systems induced by local structures, anisotropies or heterogeneities (e.g., Heidbach et al., 2007). As a result, actual complex stress fields, strongly varying in both space and time, are developed (Liesa and Simón, 2009).

Stress variability in space and time is particularly intricate in the case of intracontinental rift basins, as revealed by paleostress studies carried out in the Rhine Graben (Plenefisch and Bonjer, 1997), Bristol Channel Basin (Caputo and Hancock, 1999), Recôncavo–Tucano Rift (Destro et al., 2003), Dead Sea Rift (Lunina et al., 2005) and Barguzin Rift (Lunina and Gladkov, 2007). Although the Cretaceous section of the Parnaíba Basin can be classified as an intracontinental rift basin (Góes and Rossetti, 2001), Matos (2004) prefers to classify it as a nonconventional rift because of the influence of transform faults in their evolution.

Transform boundaries are developed due to offsets in the rift axis (Le Pichon and Hayes, 1971). They are characterized by a steep, fault-controlled continental slope bordering a marginal plateau or a wide continental shelf. Most passive margins are orthogonal to seafloor-

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http://dx.doi.org/10.1016/j.tecto.2017.01.014
0040-1951/© 2017 Published by Elsevier B.V.

spreading, but some of them (like in most of the Equatorial Atlantic) are oblique to crustal motion. Indeed, large-scale lateral movements controlled early Equatorial Atlantic development stages (Matos, 2000, 2004). This progressive deformation led to a stack of complex structures on a regional scale, thus defining anomalous local stress fields changing through space and time. Nevertheless, a model of stress evolution during Cretaceous times for the Parnaíba Basin is still required, bearing in mind the framework of the Equatorial Atlantic margin kinematics.

In the present paper, based on the complementary analysis of fluid inclusion planes (FIPs), outcropping geologic structures, borehole breakouts and remote sensing data, we elucidate in different scales the main structural features and their kinematic indicators in the Itapecuru River region, Southeastern Parnaíba Basin (Fig. 1). Based on fault-slip, non-striated fault, joints, deformation bands and FIPs analysis, the kinematic and paleostress evolution has been unravelled. The interpretation of deformation bands and microthermometric data combined with structural and geomorphological mapping also facilitated a general conclusion on the morphostructural evolution of the investigated site. It is important to point out that the tectonic deformation of the Cretaceous section of the Parnaiba Basin has not been studied in detail so far. Therefore, results obtained in the present research can shed light on the Cenozoic evolution of topography in the context of continental margin development.

2. Geological setting

The Parnaíba Basin is an intracratonic feature located in north-eastern Brazil. It occupies an area of approximately 600,000 km^2 and contains a sedimentary pile up to 4000 m thick in the depocenter. This large, sag-type cratonic basin is filled by Ordovician to Cretaceous sediments, mostly of marine provenance, but also by fluvio-deltaic, desertic deposits and basaltic flows (Pedreira da Silva et al., 2003). The Cretaceous portion of this basin, also called the Grajaú Basin by Góes and Rossetti (2001), formed in response to a broad uplift that occurred in

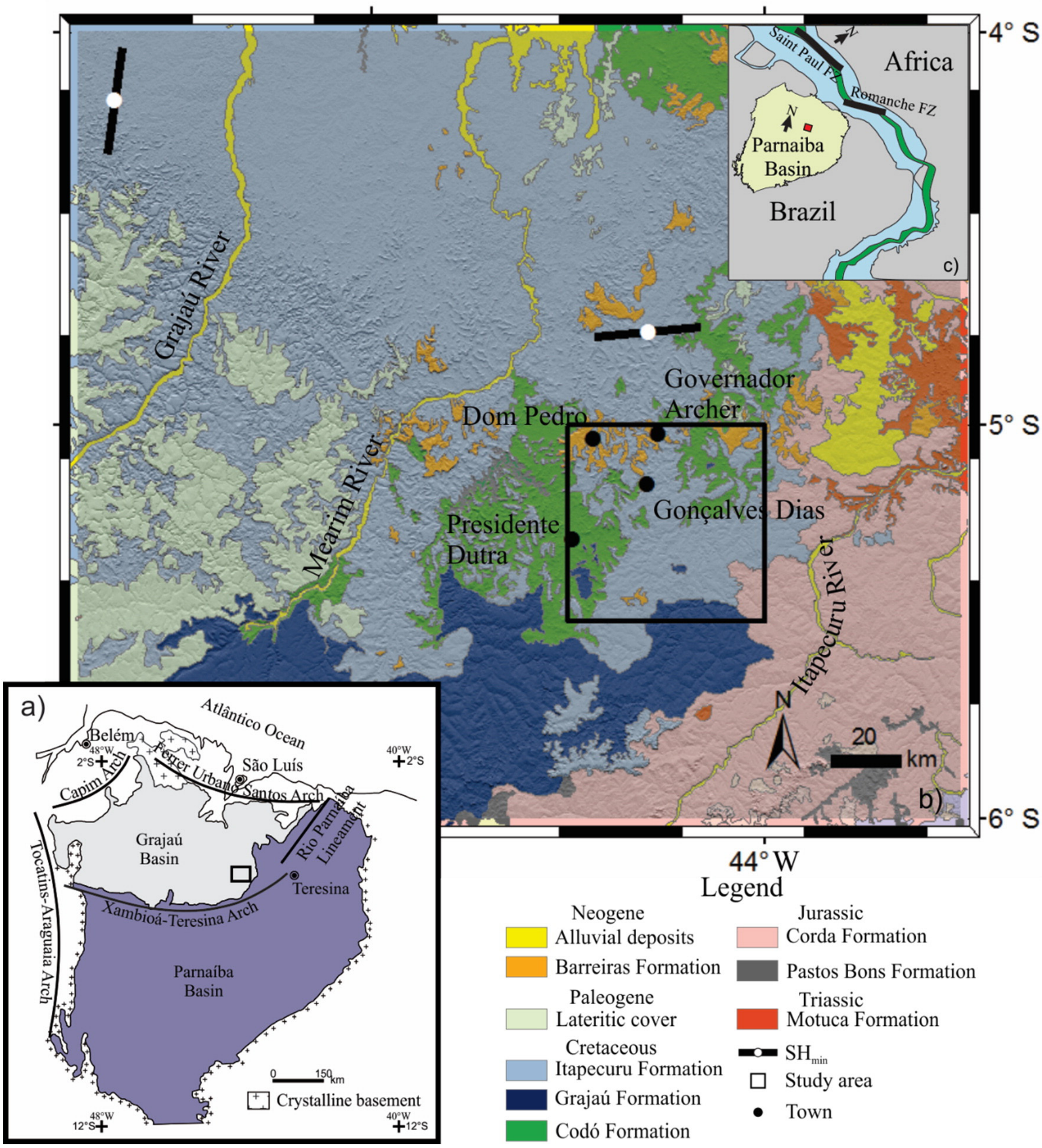

Fig. 1. Location map of the study area in the (a) Parnaíba Basin, Maranhão State, Brazil. Geological map after CPRM (2004); (b) Parnaíba sedimentary province (modified from Góes, 1995); (c) paleogeographic reconstruction of Africa and Brazil during Albian times with early sea-floor spreading and the onset of transform movements (modified from Matos, 2004).