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Rift brittle deformation of SE-Brazilian continental margin: Kinematic analysis of onshore structures relative to the transfer and accommodation zones of southern Campos Basin

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ABSTRACT

High-resolution drone-supported mapping and traditional field work were used to refine the hierarchy and kinematics of rift-related faults in the basement rocks and Early Cretaceous mafic dikes onshore of the Campos Basin, SE-Brazil. Two sets of structures were identified. The most significant fault set is NE-SW oriented with predominantly normal displacement. At mesoscale, this fault set is arranged in a rhombic pattern, interpreted here as a breached relay ramp system. The rhombic pattern is a penetrative fabric from the thin-section to regional scale. The second-order set of structures is an E-W/ESE-WNW system of normal faults with sinistral component. These E-W structures are oriented parallel with regional intrabasinal transfer zones associated with the earliest stages of Campos Basin's rift system. The crosscutting relationship between the two fault sets and tholeiitic dikes implies that the NE-SW fault set is the older feature, but remained active until the final stages of rifting in this region as the second-order fault set is older than the tholeiitic dikes. Paleostresses estimated from fault slip inversion method indicated that extension was originally NW-SE, with formation of the E-W transfer, followed by ESE-WNW oblique opening associated with a relay ramp system and related accommodation zones.

1. Introduction

Over the geological time, rift systems evolve from an embryonic stage of intracontinental deformation into restricted seaways, and in their mature stages form continental rifted margins. As the rifted margins evolve, less deformed regions are left along the margins, whereas the axis of rifting migrates progressively basinward as oceanic spreading centers initiate (McKenzie, 1978; Wernicke, 1981; Lister et al., 1986; Sawyer et al., 2007; Reston and Pérez-Gussinyé, 2007; Rosenbaum et al., 2008). However, few traces of these initial stages are preserved in the proximal continental crust and only detailed field observations are able to unravel their geological record. Along the Southeastern Brazilian Margin, onshore brittle structures in basement rocks shed light on the early stages of opening of the South Atlantic opening. Despite much study of the area (Mello et al., 2002; Valente et al., 2005; Stanton and Schmitt, 2007; Motoki et al., 2011; Souza, 2011; Ashby, 2013; Almeida et al., 2013), a real challenge remains regarding the connection between the structural record of the basins offshore and the early extensional deformation structures in the onshore upper continental crust. Since many studies have concentrated on the offshore record of the successive extensional deformation stages (Almeida, 1976; Nürnberg and Müller, 1991; Cainelli and Mohriak, 1999; Heine et al., 2013), the geology of the early rifting stages remains almost unstudied.

In this study, a multi-scale structural analysis of a specific region in the southeastern Brazilian margin, allowed us to unravel the structural record that can be related to an early rift phase imprinted in the basement rocks close to the city of Cabo Frio, SE-Brazil. The

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region is particularly remarkable for its location at the western continuation of an intrabasinal E-W to ESE-WNW accommodation zone that separates the Meso-Cenozoic marginal Campos and Santos basins, site of the most important Brazilian oil accumulations.

The main goal of this study is to untangle a complex arrangement of brittle structures related to multiple deformation events in a quite limited area. These structural patterns are key to fill the knowledge gap of the Campos and Santos basins early stages of rifting and of similar rifted margins elsewhere. The hierarchical refinement of the structural framework in the area was obtained by high resolution mapping techniques based on drone survey, combined with classic field work. The relationship between the Early Cretaceous tholeiitic dikes and brittle structures was the temporal cornerstone for definition of structural features related to the early South Atlantic opening deformation.

The study identified a major NE-SW normal fault set – clearly related to the main rift faults of the adjacent to the southern part of Campos basin – and its relationship to the E-W/ESE-WNW oblique-slip faults: a subordinate transfer fault set. As the E-W/ESE-WNW fault set became inactive before the tholeiitic dike emplacement, the NE-SW fault set continued to evolve, as shown by its mutual crosscutting relationship with the same dikes. Examining further the geometrical arrangements and kinematics of those geological features, relevant insights about the rifting stage of this marginal basin were achieved.

2. Geological setting

The Brazilian basement of the southeastern continental margin is characterized by high-grade metamorphic rocks from the Ribeira Orogenic Belt (Figs. 1 and 2). This deeply eroded orogen evolved from the Neoproterozoic to the Cambrian through a succession of accretionary and collisional episodes attributed to the Brasiliano-Pan African tectonic events (Brito Neves et al., 1999; Heilbron et al., 2000; De Wit et al., 2008). The Ribeira Orogen's structural framework is defined by a complex NE-SW trending arrangement of amalgamated terranes, ductile shear zones and magmatic intrusions (Schmitt et al., 2008, 2016).

This complex configuration is subdivided into four terranes (Heilbron et al., 2000; Trouw et al., 2000): the Occidental Terrane, the Paraíba do Sul Klippe, the Oriental Terrane and Cabo Frio Tectonic Domain (CFTD) (Fig. 2) The study area is located within the CFTD which includes Neoproterozoic metasedimentary rocks tectonically interleaved with Paleoproterozoic orthogneisses (Schmitt et al., 2008) (Fig. 2). The domain is characterized by NW–SE oriented penetrative ductile structures (Schmitt et al., 2004, 2008), i.e. orthogonal to the rest of the Ribeira Belt, which is mainly NE–SW oriented (Heilbron et al., 2000). The CFTD collided with the Ribeira Belt at ca. 530-490 Ma producing an

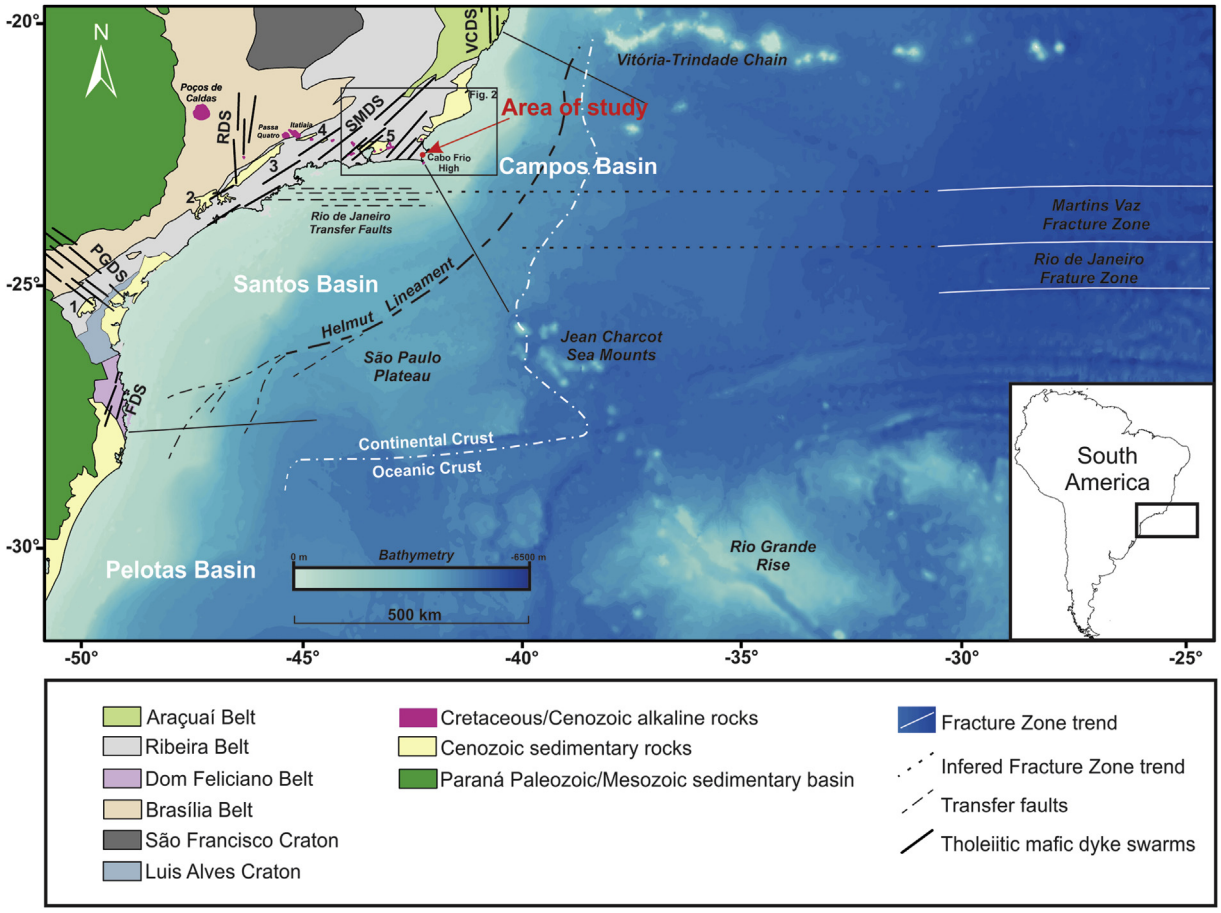

Fig. 1. The Southeastern Brazilian margin and its main geological features: the orogenic belts, cratons and the Paraná sedimentary basin (after Hasui, 2010); dike swarms (after Almeida et al., 2013); Cenozoic continental sedimentary basins and alkaline rocks (after Zalán and Oliveira, 2005), transfer zones, continent-ocean boundary (after Alves et al., 2006; Dehler et al., 2016) and the Cabo Frio High (after Fetter, 2009). FDS – Florianopolis Dike Swarm. PGDS – Ponta Grossa Dike Swarm. RDS – Resende Dike Swarm. SMDS – Serra do Mar Dike Swarm. VCDS – Vitória-Colatina Dike Swarm. 1 – Curitiba Basin. 2 – São Paulo Basin. 3 – Taubaté Basin. 4 – Resende Basin. 5 – Guanabara Graben. Note the area of study indicated by the arrow. The black line rectangle displays Fig. 2.