The Equatorial Atlantic and the South Atlantic Margins: Cretaceous twins, but so different at birth.

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Abstract

During the last two decades many authors have focused on geodynamics models to explain the South Atlantic Conjugate margin. Three main segments have been described within the South Atlantic Margin: South, Central and Northeast. Poliphasic rifting evolution, with variable time-dependent thermal structure controlled variations in volcanic activity from one segment to another and exhumation of the middle and lower crust in hyper-extended segments. The mantle plume model responsible for the opening of South and Central Atlantic has been questioned, and a non plume origin of magmatism at some segments in the South Atlantic conjugate margin became accepted. On the other hand, geodynamics models for the Equatorial Atlantic are not as well developed. Attempts to consider the Equatorial margin as a twin sister of the South Atlantic margin may lead to wrong predictions in oil exploration. Completely different at birth, the Equatorial Atlantic evolved from a transform margin to an oblique-passive margin during early “rifting” and early drifting stages. The entire Equatorial region of the South Atlantic behaved as a global-scale accommodation zone linking the evolving Central and Southern Atlantic ocean basins. This project explores the importance of a major pre-rift shear zone to the Atlantic opening: The Transbrasilian Lineament and its continuation in Africa -Trans-Saharan Lineament (TB-TS belt), as well as the Borborema Horse Tail. They were formed during the amalgamation of the Western Gondwana around 600 million years ago. These features are major rheological boundaries. Lithospheric keels and the roots of thick, stable Proterozoic cratons (West African Craton/São Luiz Craton) worked as anchors, preventing and postponing the lithospheric rupture that would linked South and Central Atlantic rifting. The deformation rates during rupture were very high with no evidence of rift-related volcanic activity documented in South Atlantic basins with a quite different time dependent thermal structure.

Introduction

The Equatorial Atlantic transform margin (Figure 1) formed in response to motion along continental transforms linking the South Atlantic oceanic spreading to Central Atlantic spreading centers (Matos, 2000,2004).

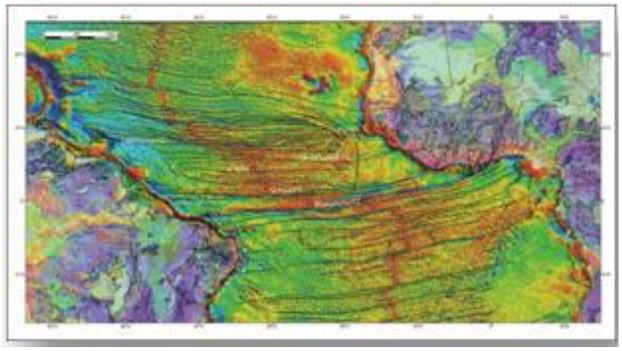

Figure 1. *Equatorial Atlantic, Free-air gravity with isostatic correction Sandwell and Smith (2014) with Onshore Geology in South America and Africa (USGS) and GeTechstructural interpretation modified in study areas by Casey, 2014.*

Divergent margins have been the subject of research on geodynamics models, mainly for petroleum plays predictions, especially along the South, Central and North Atlantic conjugate margins (Mohriak et al., 2013). Huge pre-salt discoveries were among the most important in the past decade and draw attention of geoscientists worldwide. Traditional geodynamic models were challenged by data acquired in search for deeper targets. Magma poor and magma dominated segments of the South Atlantic conjugate margins were identified, as well as rifting in hyper-extended continental crust (Blaich et al., 2011, Caixeta et al, 2014). Three main segments have been described within the South Atlantic Margin: South (south of the Walvis Ridge), Central and Northeast. The Tristan da Cunha plume in the central province introduced a huge volume of magmatism but its influence on the rifting process along the whole margin was questioned by Blaich et al. (2011) as well as the mantle plume model by Oreiro et al. (2005). Rifting was polyphasic with variable volcanic activities at different segments of the South Atlantic Margin, which led to variable time-dependent thermal structure with exhumation of the middle and lower crust in some segments. Figure 2 illustrates a plate reconstruction at 126 Ma (Barremian), when sea-floor spreading was taking place at the southern segment of the South Atlantic, and rifting was propagating northward, up to the Borborema horse tail (Pernambuco lineament), where deformation could not cross this feature with a deep lithospheric root (Matos, 2004).

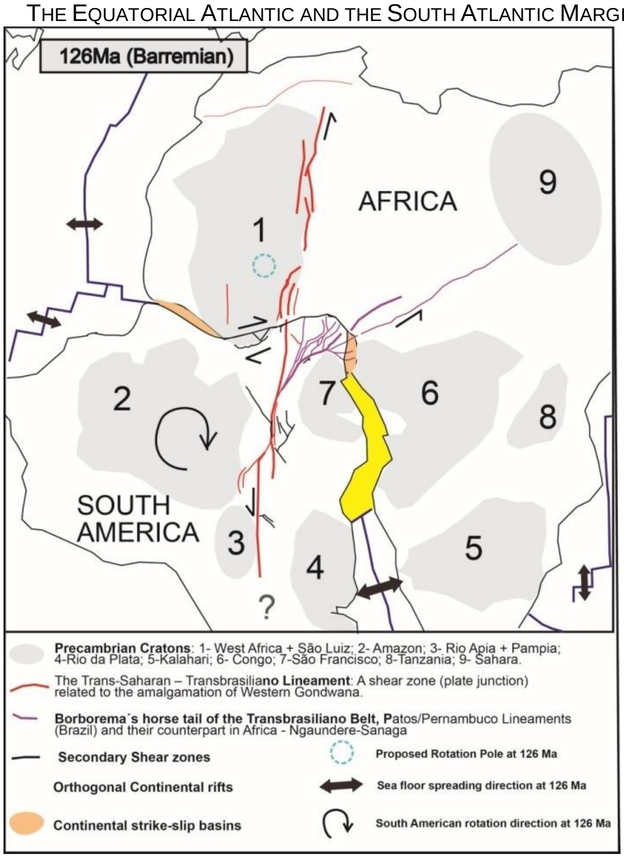

Figure 2. *Schematic figure based on Norton´s reconstruction at 126Ma.The TB-TS Belt is a major lithospheric feature, with + 4000 km long Proterozoic wrench shear zone.*

Matos (1992) has described how extensional deformation propagated further north of the Pernambuco Lineament (Borborema´s horse tail) giving birth to a series of intracontinental rift basins, named Northeastern Brazilian Intracontinental basins (NBRS). Kuchle et al. (2011) findings corroborate Matos (1992,1999) proposed model that the Dom João Stage (Brotas Group -Late Jurassic) would represent an early rifting stage in Northeast Brazil.

The Proterozoic Heritage

Figure 2 illustrates the distribution of Proterozoic cratons in the Western Gondwana and a major feature, named TB-TS belt: The Transbrasilian Lineament and its continuation in Africa -Trans-Saharan Lineament. This is at least a 4000 km long dextral wrench shear zone. Another key feature is the horse tail of this mega-shear zone, defined by the Borborema Province, named as a Transversal Zone, by Matos (2000,2004). The TB-TS belt was developed during the collision of the West Africa/São Luiz Craton against the Congo-São Franscisco Craton during the Brasiliano orogeny. The Borborema Province (Brazil) is correlated with the Nigerian Province (Africa). The TB-TS belt includes the Hoggar belt, which splays into the Kandi fault zone in Benin and corresponds to the Sobral Pedro II fault in Brazil, north of the Transbrasiliano lineament.

The Transbrasiliano Lineament was reactivated several times and geophysical evidence shows that it is a major lithospheric discontinuity (Chamani, 2011). The Transbrasiliano Lineament displays evidences of reactivations and progressive deformation under anomalous stress field related to the shear in Equatorial Atlantic transform margin. Fairhead & Maus (2003) proposed a left lateral movement at the TBL right before and during the opening of the South Atlantic. A comprehensive stress-inversion analysis performed by Ibanez et al. (2017) at outcrops of the Aptian-Albian sequences in the Grajaú sub-basin in the Parnaiba Basin located westward of the TB-TS belt indicates a multidirectional extensional regime under a transcurrent/transpressional stress state related to the complex kinematic evolution of the Equatorial Atlantic transform margin.

Rheological challenges to rift propagation

Active rifting zones during the Barremian are marked in yellow and transtensional areas are marked in orange in Figure 2. At that time the lithospheric boundaries of African and South American continents were not defined yet. The clockwise rotation of South America with respect to Africa was initiated at the opening of South Atlantic to the south of Walvis Ridge with a pivot point between Demerara and Guinea platforms discussed and modeled by Casey et al. (2015). It is conceivable that the fabric of the TB-TS belt, a previous right lateral wrench shear zone, was reactivated as left lateral shear zone, accommodating a dominating transcurrent - transpressional stress state.

The location of the Proterozoic Cratons (thicker, older and colder lithosphere) and the fold belts would have control the opening of the Equatorial Atlantic until a brand new, “lithospheric, plate scale shear zone” would link the tip of Central Atlantic to the northernmost tip of the South Atlantic. The entire Equatorial Atlantic behaved as a global-scale accommodation zone linking the Central and Southern Atlantic. Lithospheric keels of the thick and stable Proterozoic cratons served as anchors, preventing and postponing the residual Gondwanan rupture.

Remarkable differences are observed between adjacent basins of the Equatorial Atlantic. Deformation partitioning occurred along the Equatorial Margin because of the coaxiality of the progressive deformation. Diachronous deformation occurred as a function of the degree of obliquity of each basin at a specific time. The mode of deformation was directly related to the rate of deformation. Rapid rupture occurred when the stress buildup overcomes the resistance of the lithospheric anchors and there was no time for crustal thinning to occur.

The evidence for this model is observed in the Pernambuco-Paraiba basins (The Transversal Zone), where a narrow lithospheric “neck” quickly developed over 5–6 Ma. The result is an absence of a broad crustal transition zone - a very narrow margin. Volcanic rift margin with hyper-extended zoneswas developed just to the south, in the Sergipe Alagoas basin (Caixeta et al., 2014) to mechanically balance the Equatorial movement.

Conclusions

While a single mantle plume triggered the final fragmentation process of Western Gondwana opening the South Atlantic, Proterozoic heritage controlled the deformation during continental scale fracture propagation northward of the Walvis Ridge. Once this fracture propagation met the TB-TS belt´s horse tail (Figures 2) the deformation was locked until a development of the lithospheric shear zone without the influence of a mantle plume.

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