

# Crustal Architecture and nature of the crystalline basement of Campos Rifted Margin (Southeast Brazil)

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### Abstract

The Campos rifted continental margin formed during the breakup of Gondwana in the Early Cretaceous. Its underlying crystalline basement is assumed to be the Cabo Frio Tectonic Domain (CFTD), a Paleoproterozoic terrane of the Ribeira Belt. We investigate the nature and architecture of this crustal basement using new geophysical data.

Our results suggest the existence of four different rifted margin crustal domains: 1) a Proximal Rifted Domain (PRD); 2) a crustal Necking Zone (NZ); 3) a Hyper-extended Domain (HED); 4) an Embryonic Oceanic Domain (EOD). The PRD is characterized by a bipartite basement with an upper unreflective, massive and faulted layer below volcanic and synrift depocenters, and a lower reflective, foliated crust with a low-angle/west-dipping thrust fault system. The NZ is characterized by a wide crustal necking and positive magnetic anomalies. The presence of syn-rift basalts at the NZ implies that crustal extension was accompanied by magmatism. The HED exhibits a 130 km wide poorly reflective thin crust, with planar normal faults underlying a large sag basin. The EOD displays a two layered oceanic crust thickening seawards, with seaward dipping reflectors and a large volcanic center on top of sub-parallel reflectors, and faults reaching the Moho.

We propose that the PRD and NZ domains

represent the offshore prolongation of the CFTD, with extension and volcanism increasing oceanwards. We suggest that the larger thickness of ductile lower-crust relative to the thinner brittle upper-crust inherited from the CFTD probably exerted a first-order control on deformation, which along with the temporal variations of volcanism, produced the observed crustal structure. The distal margin architecture implies an initial magmalimited breakup followed by steady-state seafloor spreading.



## Modes of extension and oceanization: an example from the magma-poor Brazilian/African margins

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#### Abstract

In the last decades it has been shown that at some margins the thinned continental crust abruptly transitions to magmatic oceanic crust, while others, the so-called magma-poor margins, present a wide continent-ocean transition, COT, consisting of serpentinised mantle before magmatic oceanic crust occurs. These COTs form wide belts of exhumed mantle bordering many sectors of the world's oceans and are potential areas of intense serpentinite-based hydrothermal activity at low temperatures and hence hydrogen and methane production during break-up.

Here we use numerical modeling to explore the links between margin architecture, continental strength and type of COT. We show that although the ultraslow velocities that reign during magma-poor margin extension inhibit, to some extent, mantle melting, this does not directly translate into the formation of a wide COT with serpentinised and exhumed mantle. In places where the pre-rift weak lower crust generates extremely wide margins, the weak lower crust prevents faults to reach the mantle and bring water to serpentinise it. Instead melting of the mantle starts much earlier than serpentinisation, resulting in an abrupt transition to magmatic oceanic crust after break-up.

The magma-poor margins of the central South Atlantic segment are an excellent testing ground for this conceptual template. Our results suggest that, as the conjugate margin width increases southwards, the COT changes from a wide area of exhumed and serpentinized mantle at the Camamu-Gabon Basin to a sharp transition of mostly magmatic oceanic crust in the North Santos-South Kwanza basin. Our results suggest that magma-poor margins do not necessarily undergo a mantle exhumation phase before magmatic oceanic accretion.



# Evidence for the Paleoproterozoic/Cambrian Angolan Belt in the SE Brazilian Margin – New Data from Offshore Basement Drill Core

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#### Abstract

The onshore basement of Campos and Santos Basins is dividedin two tectonic terranes: the Oriental Terrane, (OT) and Cabo Frio Tectonic Domain (CFTD), involved in the Neoproterozoic-Eo-Paleozoic Brasilianoorogenic event. The tectonic grain left behind by these eventsexerted critical influence on the localization of the Early Cretaceous rifting of the South Atlantic Continental Margin. A recent well drill coreat 100 km SW offshore from Cabo Frio town reached basement rocksat 4343 m, yielding useful geological information to the tectonic evolution of this part of the margin and its African counterpart.

The drilled basement rock is acalc-alkaline orthogneiss. New U-Pbdata from the zircon cores yield crystallization agesfrom 1.98 to 1.96 Ga. Thin metamorphic rims in some crystalspresentages of ca. 500 Ma.These precise agesand the lithotypescorrelatewell with onshore orthogneissesof theCFTD. The OTplutonic/orthoderived metamorphic units, outcropping in a much wider area, are younger.

Similar rocks to those drilled in this segment of the Brazilian Margin crops out at the Angolan Belt, which is the African correlative of theCFTD. Our data corroborates that the CFTD is a much larger tectonic unit, comprising the basement of the Campos basin and at least most of the northernSantos basin, as well as the Angolan conjugatedmargin. The Cambrian-Ordovician continental collisional suture zone, between OT and CFTD, marks a lithospheric scale discontinuity. The CFTD presents a NW-SE structural fabric orthogonal to the OT. This deeper divergent inheritance could have favored the strain partitioningand consequent increase in obliquity of the rift along this segment of the Brazilian Margin.



### Dividing the South American continental plate to fit Gondwana reconstruction: a model based on continental geology

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#### Abstract

The South American (SA) and African (AF) conjugated margins may show an obvious fit, however many reconstructions leave gaps and overlaps. Reassembling rigid plates is not an effective task when dealing with the misfits, since the intraplate deformation cannot be measured. To solve this problem, plate reconstruction models started using the method of breaking the continents into several rigid blocks, considering intraplate deformation along their boundaries. But these limits are most of the time defined regardless of the geological/tectonic features of the SA continent. The aim here is to propose a block subdivision for the SA continental plate from the point of view of geology and tectonic inheritance and not only plate reconstruction. To define block limits, we consider the main continental structures and tectonic pre-Neoproterozoic domains: cratons. Neoproterozoic-Cambrian mobile belts, Paleozoic-Mesozoic intracratonic basins. post-Jurassic sedimentary basins and the pre-Andean terranes. Some of these continental structures in between these domains accommodated part of the tectonic forces responsible for the West Gondwana break-up in the Lower Cretaceous and the subsequent

Atlantic opening. One of these structures is the Transbrasiliano lineament, ca. 630 Ma, reactivated several times through the Phanerozoic. We propose a subdivision model for the SA continent that best agrees with the geological inheritance. The blocks boundaries were tested for plate reconstruction implications, especially for piercing points correlation for both Atlantic sides. The rotation poles were visually defined using plate reconstruction software. The African blocks were already stablished by Colin Reeves. This method keeps intraplate deformation tied to the real possibilities of pre-opening fit, correlating geological features of both Atlantic sides, especially in the sectors with hyperextended margins.



# The Early Cretaceous Skeleton Coast Dyke Swarm: Multiple dyke generations related to South Atlantic rifting

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### Abstract

This paper presents a correlation between the conjugate margins of Northwest Namibia and Santa Catarina, Southern Brazil based on structural evidence and the timing of break-up related magmatism. We suggest that the majority of the dykes of the Skeleton Coast (Namibia) and of the Florianopolis (Brazil) Dyke Swarms were emplaced during the initial rifting prior to the final break-up of Gondwana.

However, field observations and structural evidence suggests that a significant number of dykes were emplaced during later tectonic events under differing stress regimes. In Namibia, this hypothesis is supported by geochemical results which show that the earlier, predominantly NNW trending, basalt to andesitic basalt dykes are enriched in Light Rare Earth Elements (LREE), whilst later ENE trending dykes typically display REE patterns similar to E-MORB.

The conditions of regional stress active during the emplacement of the dykes of the Skeleton Coast

Dyke Swarm (SCDS) have been estimated using the principles of kinematic analysis and through the identification of asymmetrical features, such as zigzags, en echelon dykes and bridges between dyke segments.

Three dykes generations were recognised in the SCDS: 1) NNW-SSE dykes associated with normal ENE-WSW extension; 2) ENE-WSW dykes with a sinistral component indicating NW-SE extension; & 3) N80W to N45W trending dykes with sinistral or dextral components, depending on their orientation, related to NNE-SSW extension.

Multiple dyke generations have been recognised within the Florianopolis Dyke Swarm (FDS), but the principal direction of the SCDS and FDS is equivalent when South America is restored to its pre-break-up position.

Offshore structures within the conjugate Walvis-Pelotas basins show similarities with the dyke directions, where NW-SE trending structures can be observed truncating earlier NNW trending faults.



# Gradient based Investigation overnortheastern Brazil and its conjugate western AfricanMargin

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### Abstract

We investigated conjugate margins of northeastern Brazil and western Africa using gradient-based approach. Gravity gradients estimated from highresolution satellite gravity data (~ 1 min resolution) from radar altimetry replicates the regional features of both the conjugate margins.Enhanced images such as tilt and theta derived from gravity gradients correlated using the angles between their gradient directions to map the geomorphological features of different types. This demarcates crustal Continental-Oceanic Boundaries [COBs] with good precision over both regions, mostly consistent with previous results. In similar way, we estimated the magnetic gradients from EMAG2 (~2 min resolution) and subsequently, tilt and theta magnetic images and correlation between them, but were unable to distinguish crustal types, attributedto lower resolution and very distinct magnetic source signatures in comparison to gravity anomalies.Magnetic anomalies demarcate the possible magnetic intrusions but lacks appearance of spreading-related linear anomalies. In general these anomalies are associated to oldest oceanic crust over the conjugate margins, where the COB is placed.

We undertook conjugate margin transectsorthogonal to the extensional rift axis tointerpret the gravity anomalies, its gradients and correlation images. These transects include Sergipe-Alagoas, Jacuipe, and Camamu basins in northeastern Brazilian margin, and Gabon basin in West African side. COB deduced from correlation angles over northeastern Brazilian margin is mostly uniform and consistent except Camamu basin, whereas, COB over Gabon basin is relatively wide compared to its conjugate Camamu basin. Moreover, transitional crust over Camamubasin has distinct M-reflector below rifted extensional margin from available seismic lines, representative of extremely shallow Moho discontinuity, which hinders itspossible demarcation. Gabon margin exactly matches with recent COB estimation from plate reconstruction studies.



# Depth-dependent lithospheric thinning: an evaluationusing geodynamic models of rifted margins

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#### Abstract

Geological and geophysical observations support geological models of diachronous evolution of rifted margins. That diachronous evolution is also supported by recent kinematic and geodynamic models of lithospheric extension. However, there is still a debate regarding depth-dependent extension/thinning of the lithosphere as a mechanism leading to those margins, notably on how the observed fault-restored extension in the upper crust is usually less than that calculated from crustal thickness estimates or from subsidence models. An evaluation of a continuous spatial and temporal evolution concerning depth-dependency of the lithospheric thinning is difficult to achieve by only using data from natural systems due to the lack of observations that constrain crustal and mantle thinning at different stages between pre-rift extension and lithospheric breakup. Thus, to obtain a continuous portrait, we use geodynamic models comparable to observed rifted margins - with varying widths and asymmetry - to extract thinning profiles at several stages of rifting. We evaluate the spatial and temporal evolution of the ratio of upper to lower crustal thinning (CRUSTAL DDT) and of crustal thinning to mantle thinning (LITHOS DDT) from those models. Our results support that CRUSTAL DDT may be overestimated because of the difficulty in recognizing distributed deformation, and polyphase and detachment faulting in seismic data. More importantly, our results support that LITHOS DDT is likely to predominate at stages of rift evolution because crustal and mantle thinning distributions are not always spatially coincident, and at times are not even balanced by an equal magnitude of thinning in two-dimensions. Understanding both DDT and pure-/simple-shear variations across space and time has a major impact in unravelling uplift/subsidence and thermal histories of rifted margins, therefore in assessing their petroleum systems.



## New evolutionary model for Brasiliano/Panafrican orogenic system in the southern Brazilian continental margin.

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#### Abstract

The influence of basement structures and the role of fractures zones regarding the evolution of continental margin basins is an issue with many key questions still to be answered. The study area covers the onshore basement in the southern portion of the Santos Basin, limited to the south by the Florianópolis Fracture Zone. The abrupt change in the orientation of Brazilian coast in the vicinity of the Luis Alves Terrane is remarkable. To the north rifting occurred parallel to the trend of Ribeira Orogenic Belt, in contrast to oblique to the main tectonic boundaries within the study area.

The aim of this work is the correlation of onshore and offshore structures and the hierarchization of Pre-Cambrian crustal scale shear zones that may have been reactivated during the evolution of the continental margin.

The integration of geological and geophysical data, (airborne magnetics and gravimetric) allowed the proposal of a new geodynamic model highlighting the sutures zones and their prolongation towards the Santos Basin. It was possible to identify important structural lineaments and crustal limits, in both onshore and offshore areas. The results suggest that the suture between the Pre-Cambrian blocks is composed by the Itajaí-Perimbó Shear Zone, a transpressive shear zone; the Palmital Shear Zone, a transcurrent and traversal shear zone; and the Icapara and Serra Negra shear zones, a frontal thrust. The oblique collision between the blocks would have occurred with the development of a dextral transpression in the Itajaí Perimbó Shear Zone, a sinistral transcurrence represented by the Palmital Shear Zone a frontal thrust, represented by the Icapara and Serra Negra Shear Zones.



### Paired seaward dipping reflector sequence of Antarctica -Mozambique: and Nambia-South America lessons on how seaward dipping reflectors may form

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### Abstract

The paired SDR sequences of South America and West Africa and the AntarticaExplora wedge and the Lembombo monocline in Mozambique provide good field outcrop evidence and high resolution seismic imaging to better understand the formation of seaward dipping reflectors and the observed rapid subsidence of subaerial lavas. Seismic observations from Brazil indicate the lavas can be up to 18 km thick with no observable faulting. Multiple unconformities have been observed in the seismic data and outcrops of the Lembombovolcanics indicating short-lived vertical movements occurred during lava eruptions. Dyking is very important in the Lebombo monocline with up to 40% extension observed in the middle of the SDRs, and evidence that dykes are injected during the lava eruption. Previous models of SDR formation have involved faulting of SDR sequence and crustal loading by the magma pile to produce subsidence. Undoubtedly these two processes occur but they fail to explain the large amounts of rapid

subsidence visible in the Pelotas Basin The best explanation for these observations involves a processes of multiple collapse of laterally-migrating lensoid magma chambers. The removal of material from the lensoid-shaped magma chamber causes downward collapse of the overlying lavas and the magma is taken to surface by important diking, which cannot be imaged on seismic data as the dikes are generally less than 10 m wide.



### Seaward Dipping Reflectors in NE Brazil and North Gabon, a matching pair: implications for petroleum exploration

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#### Abstract

A conjugate matching pair of Seaward Dipping Reflector sequences (SDRs) have been identified in North Gabon and the Jacuipe-Sergipe-Alagoas basins. Both SDR zones are unusually narrow (20-40 km) and thin (4 km) with low angle dips ( $10^{\circ}$ ) compared to the most major SDR provinces. This implies a short eruption period of probably less than 1 million years during rifting. Sub-marine pillow basalts at the top of the SDRs have been dated in the deepwater Sergipe Basin at  $104.8 \pm 2$  Ma (Caixeta et al. 2014). A matching pair of grabens with highly reflective closely spaced reflectors have been mapped on each conjugate margin, which areprobably Albian in age and situated at the landward edge of the seaward dipping reflectors. This allows a very precise correlation across the margins to position South America in relation to Africa near the end of rifting. Seismic data indicates that shallow water Late Albian carbonates rest on top of the SDRs. This indicates that even the present day outer shelf (>2000m water depth) was maintained near to sea level until the latest Albian. Salt is present to the west in the shallow Sergipe-Alagoas Basin. However, there is a notable absence of salt in the deepwaterSDR province which indicates suggests that either crust was probably not

present at the time of salt deposition or the area was a volcanic high at this time. Rapid subsidence in the Latest Albian and Cenomanian would have created a restricted marine basin with volcanic nutrients which would befavourable for source rock development on both margins.

Ref. Caixeta, J.M. Ferreira, T.S. Machado Jr. D.L., Teixeira, J.L., and Romeiro, M.A.T. 2014. Albian rift systems in the Northeastern Brazilian margin: An example of rifting in hyperextended continental crust. AAPG Search and Discovery Article #30378



## The Guarapari Shear Zone: A possible link between South America and West Africa Neoproterozoic continental margins

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### Abstract

The southeastern coast of Espirito Santo State, Brazil, shows an abruptly change in the regional foliation from NE to E-W trends. This variation is well marked by a myloniticfabric in Ediacaran paragneisses and is related to the Guarapari Shear Zone (GSZ): a shearzone with a foliation pattern that dips steeply to SSE and contains gently plunging stretching lineation to ESE. Kinematic indicators S/C shear rotated as bands, porphyroclasts and pressure shadows indicates dextral shear sensein a transpressive tectonics.

The stablished regional deformation history for this segment of Ribeira-Araçuaí Belts do not consider the occurrence of GSZ, however, integrated tectonics models based in structural studies reveals that GSZ had an important role in the tectonic evolution through this section of West Gondwana.

Located parallel to the south boundary of São Francisco Craton, the Guarapari Shear Zone was an arc-arc transform fault that contributed to approaching of São Francisco and Congo microplates during the pre-collisional and collisional phases of Late Neoproterozoic RibeiraAraçuaí-West Congo Orogen System. Also, paleogeographic reconstructions and correlations between basement rocks of South America and Africa continental margins in this segment of Atlantic Ocean suggests the possible lateral continuity of Guarapari Shear Zone along the Luanda Shear Zone in the African counterpart.