SBGf41199

FROM OBLIQUE RIFTING TO A TRANSFORM MARGIN: THE OPENING OF THE EQUATORIAL ATLANTIC

Renato M. Darros de Matos

PETROBRAS S/A - E &P- RN-CE, Brazil

ABSTRACT

From oblique rifting to a transform margin, what do we really know about that?
The integrated analysis of the Brazilian and African equatorial basins provided important insights regarding the process of continental fragmentation through the activation of transform faults. A quite dynamic ruptural process produced an unique segment among the Circum-Atlantic basins, which can not be adequately explained by conventional extensional processes, such as passive or active rifting, or by mechanisms such as pure-shear or simple-shear, typical of divergent margins. Even though shearing signatures and pull apart features are easily recognized throughout the margin, their magnitude and rift architecture vary significantly accordingly with the distance from the main transform faults, generating significant differences in the thermal evolution, basin architecture, tectonic subsidence, facies distribution and uplift history.

INTRODUCTION

The Equatorial Atlantic provide a very good example of an ancient transform margin with a quite long history of transform movements, leading to the development of very complex sedimentary basins on each side of the Equatorial Atlantic, characterized by multiple subsidence phases and associated structural styles. The Brazilian side encompasses a series of offshore basins, from east to west, the Potiguar, Ceará, Barreirinhas, Pará-Maranhão and Foz do Amazonas, some of which extend to onshore region, as for example, the Potiguar and Barreirinhas basins. Among them, there are three aborted rifts: (1) the onshore Potiguar graben, (2) the Marajó basin (Mexiana, Limoeiro and Gurupá grabens) and (3) Gurupi Graben System (São Luís, Bragança Viseu and Ilha Nova grabens, Figure 1). The African margin consists of a series of open marine basins that make up the northern part of the Gulf of Guinea (Figure 1), with a wide variety of mostly offshore basins, named, from west to east: The Sierra Leone-Liberia, Côte-D'Ivoire-Ghana (Tano-Salt Pond-Accra-Keta basins), the Dohomey Embayment (Togo-Benin-Western Nigeria basins) and Benue Trough/Niger Delta. The entire region was developed under the kinematic influence of the St Paul, Romanche and Chain Fractures Zones, with a special influence of the Romanche Fracture zone, which kept a much longer history of transform movements between the Côte d'Ivoire-Ghana margin and the abyssal plain of the Gulf of Ghinea.

GEODYNAMIC MECHANISMS

The equatorial splitting evolved during the Albian-Cenomanian interval, through a multi-stage basin development, that is better understood if considering the kinematic and dynamic controls on the chronologic activation of transform faults, the emplacement of oceanic crust and the onset of drifting between Africa and South America. The geodynamic evolution on the Equatorial Atlantic is addressed by recognizing tectonic stages that predates, are synchronous or postdate the activation of transform faults in the Equatorial Atlantic (Table 1).
Pre-Transform /Pre-Transtension: Represented by Jurassic and early Cretaceous (pre-Barremian) sediments that predate the main stretching phase in the Equatorial Atlantic, preserved as rift sediments in the Marajó and Onshore Potiguar basins, related to the opening of the Central and Southern Atlantic, respectively; Pre-Transform /Syn-Transtension The fragmentation process started as diffuse magmatic and sedimentary events, that began in Late Barremian time, with the initiation of lithospheric stretching in the equatorial Atlantic, triggered by the onset of transtensional deformation, climaxed during the Aptian, when an almost instantaneous extension was responsible for the widespread fracturing of the Equatorial Atlantic, generating a series of NW-SE trending en-echelon precursory basins, with no evidence of volcanic margins or the widespread development of typical syn-rift basins, as expected in orthogonal extensional regimes. Even though these sediments have been assigned as representative of a syn-rift stage, major deviations from a classical rift architecture were observed, as the lack of true tilted half-grabens, controlled by planar/listric faults, and divergent syn-rift seismic pattern.
Syn-Transform: The Albian-Cenomanian interval recorded a diachronous transition from transtensional (shallow) deformations to deep-seated deformational processes, represented by the activation of transform faults, and the emplacement of oceanic crust, defining the lithospheric boundary between Africa and South America. The boundary geometry was controlled by an array of transform faults that provided a network of right oversteps, that evolved to major releasing and restraining transform segments, kinematically controlled by the oblique divergent movement of Africa and Brazil. A regional rotational strain regime, kinematically controlled, produced complex structural patterns, characterized

by conjugate strike-slip fault systems, with associated normal and reverse faults, not evenly distributed in the Equatorial branch, characteristic of wrench tectonics. The resultant deformation was partitioned into domains dominated by pure-shear or wrench dominated transtension and/or transpression. The term wrench is used here to characterize kinematically an overall tectonic regime (as used by Milnes, 1994), instead of a dynamic meaning as developed by Anderson (1942). The Barreirinhas (Tano in Africa) and Mundaú-Potiguar (Keta-Togo-Benin in Africa) segments of the Equatorial margins evolved under pure shear-dominated transtension, characterized by broad regions dominated by extension, limited by discrete shear zones, recognized on conventional seismic data as discrete oblique faults, and flower-structures. In the Pará-Maranhão (Côte-d´Ivoire) and East Potiguar (Benue) basins deformation evolved through wrench-dominated transtension, where the divergent movement was accommodated by relatively narrow zones, accounting for most of the slip between Africa and Brazil. A large transpressive belt was developed in the Piauí-Camocim-Acaraú (Accra) basins as the result of an overall shortening and uplift around a left overstep of this dextral transform system. This segment evolved under wrench dominated transpression, generating major oblique/strike slip faults, en echelon folds and shale ridges (Zalan and Warme, 1985).

Syn-Transform / Passive Transform Margin: Local tectonics and magmatism played a key role in the “post-break-up” subsidence. The resultant basin architecture, facies distribution and subsidence history for any particular basin vary significantly according to its paleo-geographic position and to its proximity with active transform faults. The dynamic juxtaposition of continental crust against oceanic crust or spreading centers on the opposite side of a transform fault causes diachronous deformations, recorded on the sedimentary record as important unconformities, either amplified or not by syncronous eustatic sea level variations.

Post- Transform - Passive Margin: A typical passive margin environment is only reached after the thermal effect of any spreading center nearby is finished; and the tectonic influence of a fracture zone / transform fault became a minor control on the available space generated by the thermal cooling of the lithosphere and sea level variations. The subsidence curves of transform margin segments indicate a flattening of the tectonic component of the total subsidence during the post-transform stage, with the exception of the Amazon Cone and the Niger Delta, which were affected by large sedimentary input associated with deltas that prograded from the platform toward deep-water frontiers.

CONCLUSIONS

Conventional extensional processes can not truly explain the kinematics and rift geometry of the Equatorial South Atlantic basins. The commonly accepted causal processes for rifting, such as passive/active or diffuse/discrete rifting can not accommodate the South Atlantic equatorial data set. Accepted pure-shear or simple-shear rift mechanisms typical of divergent margins can not be promptly used when modeling basins generated as a response of major transform motions along a continental scale plate boundary. Even though shearing signatures and pull apart features are easily recognized throughout the margin, their magnitude and rift architecture varies significantly accordingly with the distance from the main transform faults, generating significant differences in the thermal evolution, basin architecture, tectonic subsidence, facies distribution and uplift history.

The tectonic evolution of the Equatorial Atlantic is better understood if considering the main events that predate, are synchronous or postdate the activation of transform faults, the emplacement of oceanic crust and the onset of drifting of Africa and South America. Deformation partitioning as a function of the coaxiality of the progressive deformation in the Equatorial Atlantic led to characterize basins segments dominated by transtension or transpression. Some segments of the Equatorial margin evolved under pure shear-dominated transtension, while some segments experienced wrench-dominated transtension or transpression.

REFERENCES

Anderson, E. M., 1942. The Dynamics of Faulting and Dyke Formation with Application to Britain. Oliver & Boyd, Edinburgh.

Azevedo, R. P. de 1991. Tectonic Evolution of Brazilian Equatorial Continental Margin Basins, Ph.D. thesis, Imperial College, London , 455p.

Mascle, J., Lohmann, P., and Clift, P., 1997. Development of a passive transform margin: Côte d`Ivoire-Ghana transform margin - ODP Leg 159 preliminary results. Geo-Marine Letters, 17, 4-11.

Matos, R. M. D. de, 1992. The Northeast Brazilian Rift System. Tectonics*, v. 11 (4), 766-791.*

Milnes, A. G., 1994. Aspects of `strike-slip´ or wrench tectonics - an introductory discussion. Norsk Geologisk Tidsskrift, 74, 129-133.

Zalan, P.V., & Warme, J. E. 1985. Tectonics and sedimentation of the Piauí-Camocim sub-basin, offshore Northeastern Brazil. Petrobrás-Cenpes, Ciência Técnica Petróleo, seção exploração de petróleo*, v. 17, 71p.*

ACKNOWLEDGMENTS

I would like to thank PETROBRAS for permission to publish this work.

GEODYNAMIC EVOLUTION OF THE EQUATORIAL ATLANTIC

STAGE	KINEMATIC / DYNAMIC	EVENTS	AGE	PHASE
PRE - TRANSFORM	PRE-TRANSTENSION	Rifts in the Central and in the Southern Atlantic (Marajó and Potiguar grabens, respectively)	PRE-BARREMIAN	PRE - STRETCHING
	SYN-TRANSTENSION	Transtensional conditions created a series of NW-SE trending enechelon depo-centers throughout the Equatorial domain	BARREMIAN TO APTIAN	STRETCHING
SYN - TRANSFORM	PURE-SHEAR DOMINATED TRANSTENSION	Deformation characterized by broad regions dominated by extension, limited by discrete shear zones	ALBIAN TO CENOMANIAN	WRENCH
	WRENCH DOMINATED TRANSTENSION	The divergent movement was accommodated by relatively narrow zones, accounting for most of the the slip between Africa and Brazil		
	WRENCH DOMINATED TRANSPRESSION	A large transpressive belt (Piauí-Acaraú and Accra basins) as the result of an overall shortening and up-lift around a restraining bend of the Equatorial Atl.		
	PASSIVE TRANSFORM MARGIN	Oceanic-continental contact through an active Transform Fault	CENOMANIAN TO RECENT	DRIFT
POST - TRANSFORM	PASSIVE MARGIIN	Almost continuous sedimen-tation as the result of cooling-thermal contraction of the lithosphere		

Table 1. Geodynamic evolution of the Equatorial Atlantic considering events that predate, are synchronous or posdate the activation of trasnform faults.

Sixth International Congress of the Brazilian Geophysical Society

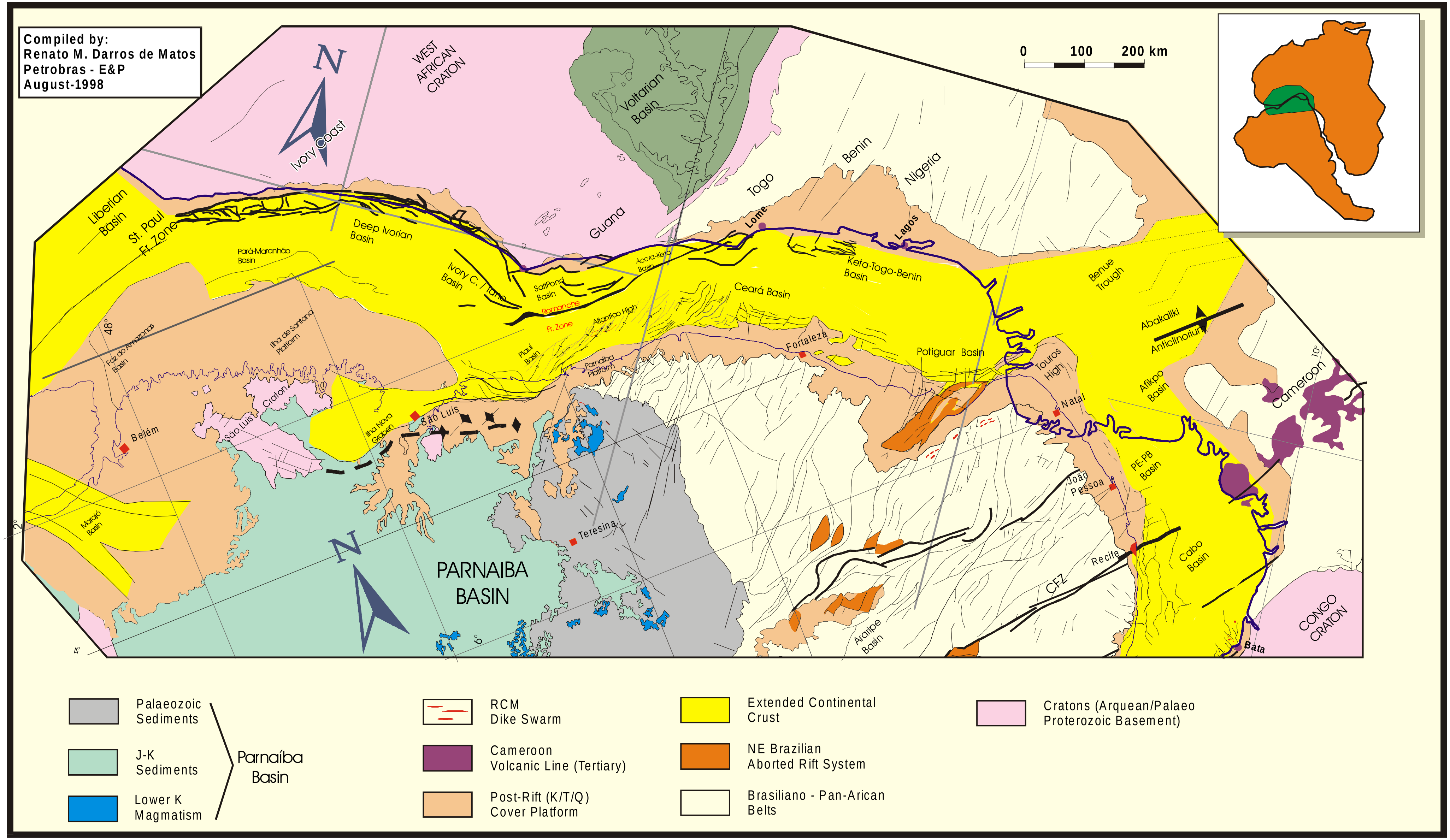

Figure 1. Aptian pre-drift reconstruction: palaeogeography and spatial distribution of basins in the Equatorial South Atlantic.