MOZAMBIQUE PASSIVE MARGIN AND ITS UNDERSTANDING ON FORMATION PROCESS DUE TO THE GONDWANA BREAKUP

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Abstract

In recent years, many studies have been carried out at Mozambique passive margin to understand the geotectonic history of this margin and its relation with the processes that were in force during the Gondwana Breakup and its implication for the generation of petroleum system.
It is known two types of Passive Margin: Volcanic Passive Margin characterized by extrusive basalts and igneous rock underplating and significant uplift during the time of breakup, where large volume of igneous rocks was produced in a short period of time, often associated with LIPs. Magma-poor Margin characterized by lack evidence of thermal activity, but with strong distensive deformation during the time of breakup. The formation process of this two type of margin are closely related to Passive and Active-rifting endmembers models which in the first one the major process is consider to be mechanical stretching caused by distensive forces while the second one the continental rift is trigger by the mantle plume activity.

In the case of Gondwana Break up is thought to be a result of mantle plume activity by the upwelling of Bouvet mantle plume around 183 Ma, which the irradiation was mainly controlled by the basement structure forming triple junction (Okavango, Lebombo and Limpopo-Angoche dyke swarms). The emplacement of Angoche dyke around 170 Ma marked the end of the Rift I mostly controlled by magmatism and then the rift jumped to start Rift II stage along the Beira High structure (thought to be a remain continental fragment left behind by Antarctica block during continental drift) mainly magma poor with a strong distensive deformation leading to the final disintegration of Gondwana and the onset of oceanic crust around 155 Ma Know until now along the Mozambique Passive Margin.

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1. Introduction

Volcanic Passive Margins (MPV) was formed as a result of continental fragmentation associated with volcanic eruptions during the Pre-rift and /or Syn-rift stages of continental breakup, producing a large volume of igneous rocks in a short period of time (Menzies et al, 2002). They are often associated with the Large Igneous Provinces (LIP) characterized by numerous dykes and igneous intrusion in the continental crust (Eldholm and Montader, 1981; Allen and Allen, 2005; Geoffroy, 2005 and Franke, 2013).

Recent studies (eg. Eagles and Köning, 2008; Reeves, 2009; Mahanjane, 2012; Reeves and Mahanjane, 2013; Mahanjane, 2014; Reeves et al., 2016) shows that Mozambique Passive Margin was exposed to several magmatic stages during its evolution started with the emplacement of Lebombo dyke swarm in the initial phase and Angoche dyke swarm in the final phase of the stage I of the Gondwana Breakup, whereby the Mozambique passive margin reflects an environment of intensive volcanic activity with massive deposition of basaltic magmas and a silicate in minority, thus suggesting volcanic nature for this margin.

2. General Concepts of Passive Margins

Two types of Passive Margin was proposed: Volcanic Passive Margin characterized by extrusive basalts and igneous underplating and significant uplift during the time of breakup. In this process the large volume of igneous rocks is produced in a short period of time, which is often associated with LIPs (Large Igneous Province) and Magma-poor Margin characterized by lack evidence of thermal activity, but with strong distensive deformation during the time of breakup.

So to explain the formation process of these two types of passive margins two End-member models of rifting were proposed (Menzies et al., 2002; Allen and Allen, 2005; Geoffroy, 2005 and Franke, 2013):

2.1. Passive Rifting

The deformation is related to mechanical stretching of the continental lithosphere by distensive forces, followed by uplift and magmatism associated with passive ascension and accretion of the magma in the crust. In this model volcanic activity is considered as a secondary process as late consequence of lithosphere dynamical stretching (Figure 1a) and the (mechanical) subsidence controlled by fault during syn-rift, as an isostatic response to continental crust elongation.

2.2.Active Rifting

The deformation of the continental lithosphere is associated to the thermal process, characterized by the implantation of the mantle plume and its interaction with the base of continental lithosphere, causing the gradual narrowing of the continental lithosphere and subsequent uplift, both as isostatic response to the stretching up to rift (Menzies et al., 2002 and Allen and Allen, 2005) (Figure 1b). According to Geoffroy (2005), two stages can be distinguished in this model: (1) Contemporary basaltic flow stage, associated with a small crustal distension; and (2) Fragmentation stage associated with Volcanic Passive Margin formation.

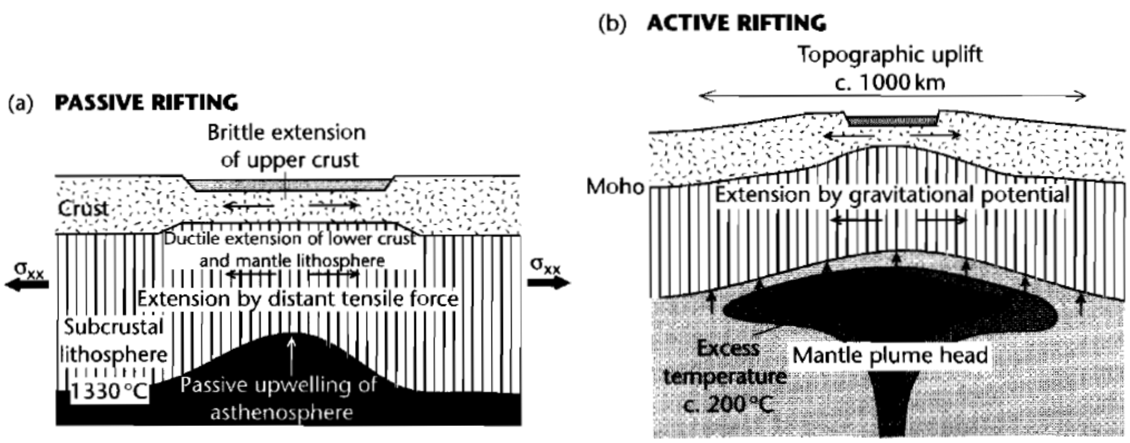

Figure 1. Schematic sketch of Two End-member models of Continental extension that try to explain the formation of Passive Margins. a) Passive Rifting related to mechanical stretching of continental lithosphere and b) Active Rifting related to thermal process that cause stretching of the continental lithosphere (Allen and Allen, 2005).

3. Mozambique Passive Margin

Mozambique Passive Margin is bounded to the north by the Limpopo-Angoche dykes swarms and the Lebombo monocline to the west extending to South Africa (Reeves et al. 2016) (Figure 2). The Limpopo-Angoche and Lebombo dyke swarms mark the boundary between the Precambrian rocks (Mozambique Belt) and the archaic rocks from the Zimbabwe and Kaapvaal Craton, respectively.

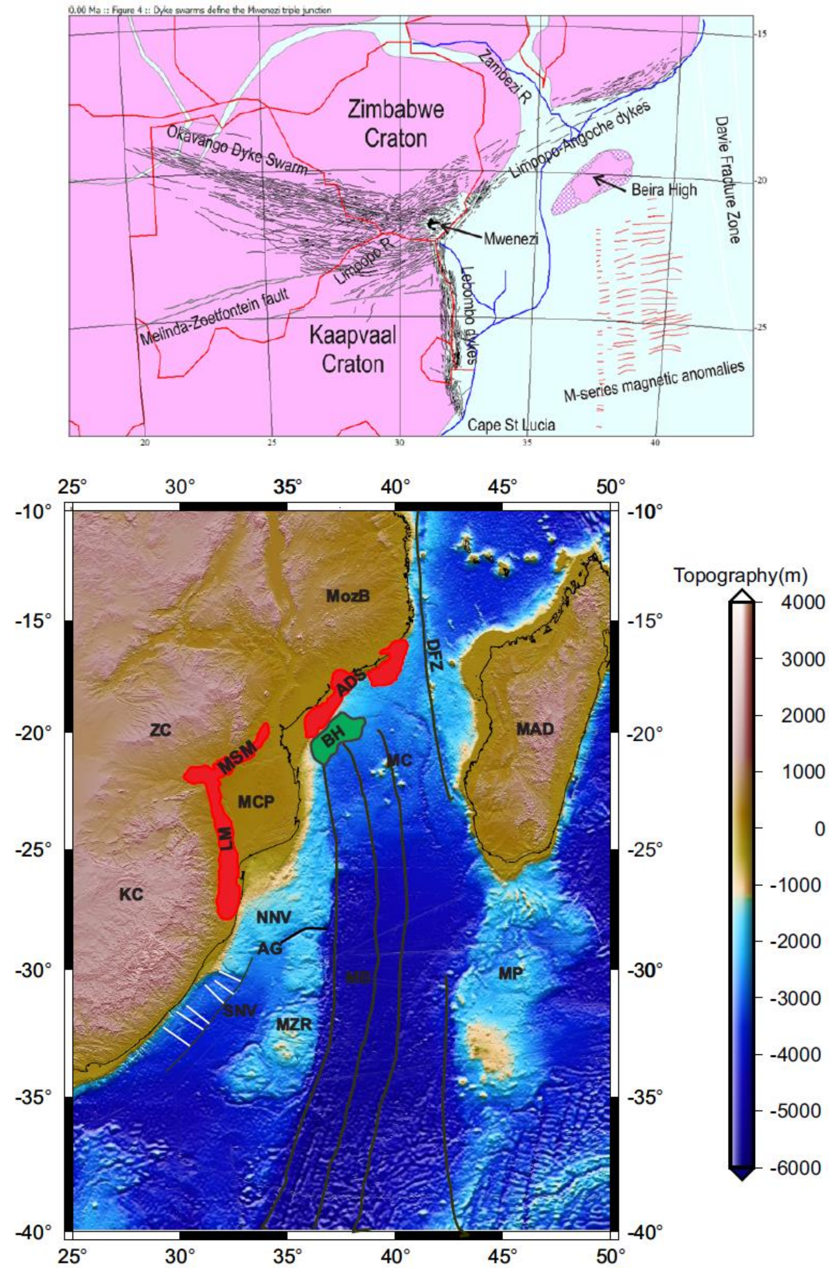

Figura 2. Top: Map of the Mozambique Passive Continental Margin (map taken from Reeves et al., 2016). Bottom: Topography map showing the tectonic overview of the Mozambique Passive Margin and major tectonic provinces. Abbreviations: **MozB-** Mozambique Mobile Belt; **ZC-** Zimbabwe Craton; **KC-** Kaapval Craton; **MCP-** Mozambique Coastal Plain; **MC-** Mozambique Channel; **BH-** Beira High; **NNV** and **SNV-** Northern and Southern Natal Valley; **AG-** Ariel Graben; **MZR-** Mozambique Ridge, **MB-** Mozambique Basin, **ADS-** Angoche Dyke Swarm; **LM-** Lebombo Monocline (or Lebombo Dyke Swarm); **MSM-** Mateke-Sabi Monocline **MP-** Madagascar Plateau and **MAD-** Madagascar.

3.1.Gondwana Breakup

Mozambique Passive Margin was formed by the open of Indian Ocean in Later Jurassic caused by the breakup of Gondwana in West (Africa, South America) and East (Antartica, Madagascar, India, Sri Lanka, Seychelles). The rifting period was accompanied by the massive volcanism, which gave rise to the Karoo continental flood basalt (183 Ma) in the Eastern African margin (Elliot et al., 1985 quoted by Riley and Knight, 2001; Svensen et al., 2012; and Elliot et al., 2000), and Ferrar continental flood basalt (180 Ma) in the Antarctica leading to the final disintegration and drifting between Western Gondwana and Eastern Gondwana, and development of the transform fault zone in the east Davie Fracture Zone (DFZ) and in the west Lebombo-Explora Fracture Zone (LEFZ) (Reeves and Mahanjane, 2013 and Reeves et al., 2016) (Figure 3).

According to Reeves et al. (2016), it can be seen that the evolution of the East African passive margin was associated to the initial movement of rift in the NE-SW orientation (between 188-170 Ma), which led to the Gondwana separation into East and West. The Karoo geometry (300-200 Ma proposed by de Wit, 2003) suggests a possible continuation or reactivation of the Karoo rift as the first step in whole Gondwana disruption and then the Bouvet mantle plume activity as second step which was important to the successful rupture. On the other hand, the hypothesis more often suggested as the key of Gondwana disruption is the Karoo (Bouvet) mantle plume activity as the main process that irradiated in three directions around 183 ± 1 Ma (Figure 3) (Cox, 1992; Riley and Knight 2001; Klausen 2009; Hastie et al. 2014). The reality shows that the evolution was accompanied by intense magmatism in the Southern Africa and Antarctica regions, associated with the emplacement of Karoo and Ferrar volcanic provinces by extrusion of dyke swarms in the Mwenezi triple junction which gave rise to the so-called Karoo Igneous Provinces largest LIP formed in Gondwana (Klausen 2009; Reeves, 2009; Reeves and Mahanjane, 2013).

And so far, the arguments, paleogeographic reconstruction models and the results of the seismic interpretation (reflection and refraction) indicate that the Gondwana breakup process obeyed two main stages of rifting (Cox, 1992; Mahanjane, 2012; Leinweber et al., 2013). ***The Rift I*** related to the development of the first Karoo rift that ends along the Zambezi coast with the emplacement of the Angoche dykes, around 170 Ma (age proposed by Reeves, 2000). ***The Rift II*** developed the rift II located along the eastern edge of the Beira High (Mahanjane, 2012). This rift was mainly magma-poor, with a strong distensive deformation, giving rise to the final disintegration of Gondwana and the beginning of the first oceanic crust known until now, at approximately 155 Ma (obtained by M26 magnetic anomalies), suggested by Jokat et al. (2003) and Köning and Jokat (2010). So, this margin are associated to the active rifting, i.e. related to the extension of the continental lithosphere triggered by the underplating of mantle plume leading to Gondwana Breakup.

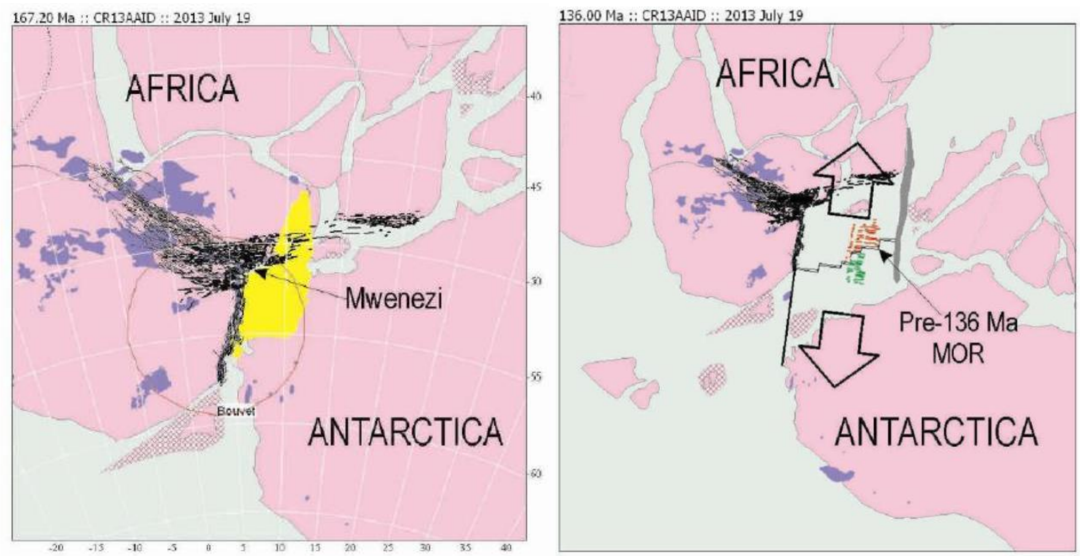

Figure 3. Gondwana Break-up and formation of Mozambique Passive Margin. Left: location of Bouvet/Karoo mantle plume (in red circle) irradiated in three directions, and gave rise to the Gondwana Breakup. Right: showing the segments N-S along Lebombo-Explora Fracture Zone and NW-SE of Limpopo-Angoche, which defined the initial movement of Antarctica block (Reeves and Mahanjane, 2013).

The active rifting model is the most acceptable explanation based on evidence of Leinweber et al. (2013), proposed the model of Mozambique Passive Margin based in interpretation of wide angle and reflection seismic data and magnetic anomaly, where they observed in the Continent-Ocean Transition Zone (COT) SDR which reflect a emplacement of massive subaerial basaltic lava flow and presence of High Velocity Lower Crust (HVLC) related to the accretion of igneous rocks to the base of continental lithosphere, therefore concluding that the Mozambique Continental Margin belongs to the volcanic-type margin (Figure 4).

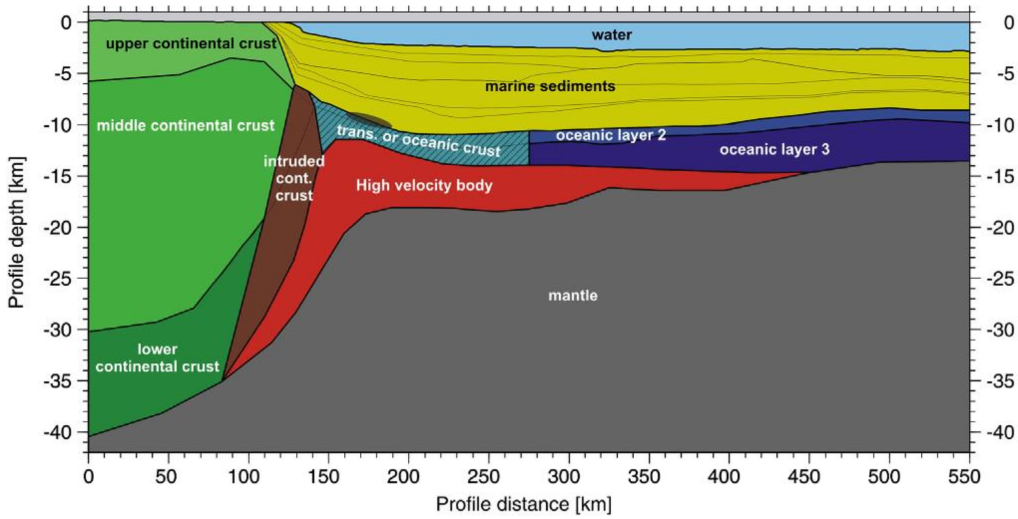

Figure 4. Model showing the crustal structure of the Mozambique Passive Margin, which was identified the presence of SDR in the proposed Continent-Ocean transition zone (Leinweber et al., 2013).

3.2.Karoo Igneous Province

According Riley and Knight (2001), the initiation of this magmatism is linked to the Bouvet mantle plume beneath southern Africa at 183±1 Ma which gave arise to the Gondwana break-up and subsequent seafloor spreading (Figure 5).

There Jurassic magmatism in Gondwana formed the most voluminous outpouring of continental volcanic rocks on Earth during the Phanerozoic, where during the Early-Middle Jurassic, over three million km^3 of dominantly basalt and lesser extent rhyolite were erupted onto continent during a short episode 3-4 Ma, during the initial stages of Gondwana breakup, which gave rise to the Karoo Igneous Province (Riley and Knight, 2001).

This Igneous Province is located in southern Africa and continues into east Antarctica is the largest Gondwana Volcanic Provinces, consisting of thick sequences of volcanic rocks. Tholeiitic basalts are dominated, but in the Lebombo-Mwenezi area rhyolitic ignimbrites are the principal rock type. The Dronning Maud Land magmatic province of east Antarctica consists of mafic dykes, sills and lava flows and alkaline intrusions (Riley and Knight, 2001).

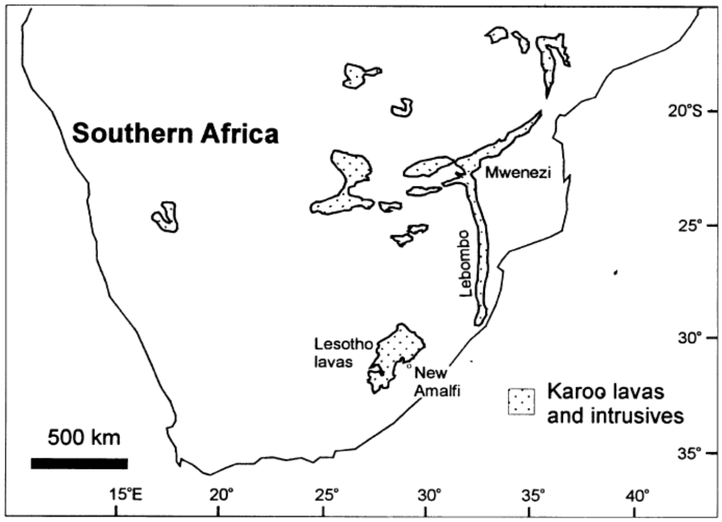

Figure 5. Map of Southern Africa showing the distribution of Karoo Igneous Province. Left: The Bouvet mantle Plume (in red circle) beneath the southern Africa at 183 Ma irradiated magma in a triple direction, the same age gave to the Gondwana break-up (Reeves, 2016) and Right: Distribution of Karoo igneous Province in southern Africa (Riley and Knight, 2001).

4. Conclusion

Passive Continental Margin represents the major part in the world and have been attracted many attention of many researcher because they are natural laboratory to study paleogeographic reconstruction and host of several mineral resources.

Mozambique Passive Margin is not an exception, so many studies related to paleogeographic reconstruction have been done because this margin is the key where Gondwana starts to break in different blocks considered to be a volcanic passive margin The Formation of Mozambique Passive Margin is related to the Gondwana Breakup that was triggered by the Karoo/Bouvet mantle plume around 183 Ma. And the presence of Karoo Igneous Province are strong evidence of the mantle plume activity that was produced in very short period of time 3-4 Ma large volume of igneous rocks.

The most agreed hypothesis for the Gondwana breakup is related to the upwelling of the Karoo (Bouvet) mantle plume that irradiated in three directions around 183 ± 1 Ma and emplaced Okavango, Lebombo and Limpopo-Angoche dyke swarm, which the basement mainly controlled the distribution and orientation of this dykes swarms in a three direction.

As a result of intense magmatism one of the largest LIP of Gondwana was formed called Karoo Igneous province that was emplaced huge amount of igneous rocks in a very short period of time of 3-4 Ma.

Although, several studies have been done along the Mozambique Passive Margin contributing to the understanding of the geotectonic history and the relation between the evolution of continental margin and Gondwana breakup, which is also very important for the study of the existence of hydrocarbon reservoirs, many aspects related to the evolution of this margin remain unclear, such as the crustal structure underneath Mozambique Coastal Plain, the origin and crustal structural of the tectonic features known as Beira High and Mozambique Ridge located in the Mozambique Channel and Mozambique Basin, respectively, the relation between Gondwana breakup and evolution of this margin and also the understanding of petroleum system formation, which the source rock characteristics is still unknown.

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