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LETTER TO THE EDITOR

Comments on paper by M. Arai "Aptian/Albian (Early Cretaceous) paleogeography of the South Atlantic: a paleontological perspective"

Discussão do artigo "Aptian/Albian (Early Cretaceous) paleogeography of the South Atlantic: a paleontological perspective" de M. Arai

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The paleogeographic reconstruction of the Brazilian sedimentary basins during the Albian-Aptian interval has been a controversial issue for over a decade. The tectonic dynamics, as well as the stratigraphy, sedimentology and paleontology of those basins are closely related to the origin and evolution of the South Atlantic Ocean. The indisputable concept of northward rifting propagation during the Gondwana break-up is primarily based on the sea-floor spreading pattern of magnetic stripes, and several geodynamic reconstructions have been proposed to explain plate rotation and accommodation of the associated intracontinental deformation (e.g. Le Pichon & Hayes 1971, Rabinowitz & LaBrecque 1979, Eagles 2007, Torsvik *et al.* 2009, Moulin *et al.* 2010). The opening direction of the South Atlantic ocean is believed to have followed the northward rifting, and formerly evoked scenarios reconstructed the marine ingression from the north towards the interior NE Brazil solely after the break-up reached the equatorial Brazilian margin in the Cenomanian (Dingle 1999) or even earlier during the Albian (Dias-Brito 2000, Azevedo 2004).

Based on paleontological data, Arai (2014) recently proposed a distinct scenario in which the earliest marine ingression in the Brazilian marginal basin would have taken place during the late Aptian "under the domain of waters coming from north through the Tethys Sea (Central Atlantic)". According to Arai's model, "Tethyan waters could reach the basins of the Brazilian continental margin via the seaway then existing in the present-day region of northeastern Brazil". The proposed paleogeographic reconstruction comprises several elongated, shallow, branched gulf-like tongues connecting the Western Tethys with interior (Parnaíba, Araripe, Recôncavo, Tucano, São Francisco and Parecis), marginal equatorial (Ceará and Potiguar) and also marginal eastern Brazilian basins (Almada, Espírito Santo, Campos and Santos) (see Arai 2014, Fig. 2, p. 342).

Attempts to reconstruct the Late Aptian to Early Albian South Atlantic Ocean paleogeography are critical to understand the paleoenvironmental changes tied to the Gondwana break-up. This issue is tricky, and a rich discussion on possible scenarios of marine ingression in the NE Brazilian basins is indeed very welcome. By considering this, we suggest that several data on distinct areas of Geology (i.e., sedimentology, structural geology, stratigraphy and paleontology) should not be overlooked when aiming a more precise paleogeographic scenario. Our purpose in this comment is to take part of this discussion and highlight that a multidisciplinary approach must be addressed in order to confirm or refute the paleogeographic model proposed by Arai (2014). In our opinion, an integrated paleogeographic reconstruction must be based on

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1. the number of Tethyan *versus* austral fossil representatives and their accurate stratigraphic occurrence,
2. the precise timing of the first marine ingression in the continent interior,
3. the basin-filling pattern and stratigraphic architecture of the depositional sequences,
4. paleocurrents and other paleogeographic indicators, and
5. the continental paleotopography and paleodrainage.

The model proposed by Arai (2014) is mainly based on dinocyst fossils (Arai 1999, 2011), as well as other micro and macrofossil evidences (forams, radiolarians, molluscs, echinoids, crustaceans, fishes and pleurodiran turtles) from literature. A very important point is that several of these macrofossils were not formally described or even properly illustrated in available scientific venues. In fact, some of them (especially molluscs) were firstly identified more than three decades ago and, thus, require a profound systematic revision.

Nevertheless, as pointed out by Arai (2014), the Late Aptian to Early Albian marine ingression in the Araripe Basin is long-established (Beurlen 1962, Beurlen 1971a, Beurlen 1971b, Mabesoone & Tinoco 1973, Coimbra et al. 2002), as indicated by the presence of echinoids (Beurlen 1966, Manso & Hessel 2012), as well as microfossils, such as dinoflagellates (Arai & Coimbra 1990, Coimbra *et al.* 2002). On the other hand, the Tethyan affinity is undoubtedly assumed by the author based on the occurrence of members of the *Subtilisphaera* ecozone recorded in the São Luís, Ceará, Parnaíba and Araripe basins. Apart of *Subtilisphaerea*, most of fossils mentioned in Arai's contribution typify marine occurrences only, meaning that they are not necessarily of exclusive Tethyan affinity. The total dominance of distinct species of *Subtilisphaera* is more abundantly recorded and with higher species richness in Tethyan-related deposits. For this reason, the genus is a paleobiogeographic proxy for Aptian deposits in the model. Indeed, a northern influence in the fauna as early as in the Aptian seems to us quite plausible. The main issue regarding the overall subject is the direction of the marine ingression in all of those basins, and the presence of fossils of Tethyan affinity solely is not reliable to confirm the distribution pattern of the hypothesized seaway. Other data are needed in order to understand how the marine connections had evolved.

The paleogeographic map depicted in the proposed model uses landmass distributions by Scotese (2001) and previous reconstructions by Arai (2007, 2011). The branched pattern of the seaway is based on modern contours of the Araripe, Jatobá, Tucano, Recôncavo, Almada, Potiguar, São Francisco and São Luís basins. One should note that the modern limits of those basins do not represent their original paleogeographic configurations, neither the area of the interior sea during Aptian/Albian times (Braun 1966), because the basins are solely the sedimentary record preserved after uplift and intense denudation during the Cenozoic (Peulvast *et al.* 2008, Japsen *et al.* 2012).

The proposed reconstruction includes a seaway branch connecting the São Francisco basin and the Western Tethys to the north. This assumption is based on the presence of radiolarians and sponge spicules in thin chert levels interbedded in aeolian sandstones of the Três Barras Formation (Sgarbi 2000), Areado Group (Kattah 1991, Pessagno & Dias-Brito 1996, Dias-Brito *et al.* 1999). This succession would represent a single, quite unusual occurrence of a deep marine deposit in a thick (~200 m) continental sedimentary succession. In fact, Sgarbi (2000) stated: "how marine fossils are present in a continental sequence in central Brazil? It is a surprising geologic puzzle, with many and large paleogeographic implications, with interest for the geology of the Gondwana and the opening of the South Atlantic Ocean". Nearly 20 years after the first report of this occurrence, this conundrum persists, as no transitional layers that would potentially represent marine transgressive deposits over the continental interior is preserved between the radiolarian-rich chert and aeolian sandstones. Besides this controversial radiolarite occurrence, the proposed seaway is also not feasible taking into account that the radiolarians are associated with Pacific austral forms, typically found southerly to latitude 22°S (Dias-Brito *et al.* 1999).

The narrow seaway depicted in the paleogeographic model that connects the northwestern coast of the South America and the Parnaíba and São Francisco Basins through the Parecis Basin seems another farfetched assumption. The late Early Cretaceous deposits of the Parecis Basin are exclusively continental (Bahia 2006), ruling out a possible marine connection through the Parecis Basin.

The Araripe Basin is a critical area for the epicontinental paleogeographic seaway-model proposed by Arai (2014), because the basin is located in the most probable central route for the marine ingression of the Tethyan waters to the eastern-marginal Brazilian basins placed north of the Rio Grande Rise and the Walvis Ridge. According to the hypothetical paleogeographic scenario proposed by Arai (2014), the seawaters advanced towards the continental interior in a complete opposite direction of the contemporaneous flowing rivers of the Araripe and Tucano basins. Hundreds of paleocurrent data measured from distinct outcrops in the Aptian fluvial deposits of the Barbalha Formation, Araripe Basin (Assine 1994, Chagas *et al.* 2007, Scherer *et al.* 2015), and in the Marizal Formation, Tucano Basin (Rolim & Mabesoone 1982, Figueiredo *et al.* 2015), indicate a consistent paleoflow towards south and southeast. Considering that the sea transgressions are constrained by the continental drainage, the paleocurrents of Aptian fluvial deposits strongly suggest that the marine transgression advanced towards the continent throughout fluvial valleys, from the Recôncavo-Tucano basin back to the watersheds located at north and northwest (Assine 1994). Moreover, the stratigraphic architecture of the Araripe Basin indicates that the thicker marine successions are located in the eastern and southeastern portions of the basin, whereas in its western border marine strata rest directly over the basement (Assine 2007).

Our interpretation is also supported by the stratigraphic framework of Parnaíba/Grajaú and Potiguar basins. Towards the south of the Parnaíba Basin, marine facies of the Codó Formation laterally interbed with deltaic and fluvial facies of the Grajaú Formation (Rossetti *et al.* 2000, 2004). This pattern points to the existence of emerged lands to the south and southeast, which would have worked as sedimentary source-areas for the Aptian basins. In the east border, the Codó Formation includes marginal, lacustrine and evaporite facies association overlying directly the basement of the Cretaceous basin, composed of Triassic and Paleozoic rocks (Paz & Rossetti 2006), overlapping the basement towards the east. Therefore, this stratigraphic architecture suggests the existence of a drainage divide located between the Araripe and the Parnaíba basins.

The Aptian Alagamar Formation of the Potiguar Basin lacks paleocurrent data because it occurs only in subsurface. However, the stratigraphic architecture of the facies associations shows a proximal to distal transition towards the northeast in the basin. This onshore to offshore pattern observed in the Potiguar Basin indicates a continental paleodrainage distinct of that one outlined in the Araripe Basin. This implies a drainage divide between Potiguar and Araripe basins nearly following the Patos Lineament (Assine 1994).

All these data suggest a paleogeographic scenario in which the Parnaíba and Potiguar basins were set apart of each other and of the system formed by the Araripe, Tucano and Jatobá basins, configuring three distinct drainage basins in the northeast Brazil. In such paleocontinental hydrographic arrangement, the directions of marine ingression are expected to be upstream along contemporaneous river valleys, which means the existence of at least three distinct main directions of marine ingression towards the interior northeastern Brazil during Aptian times (Fig. 1).

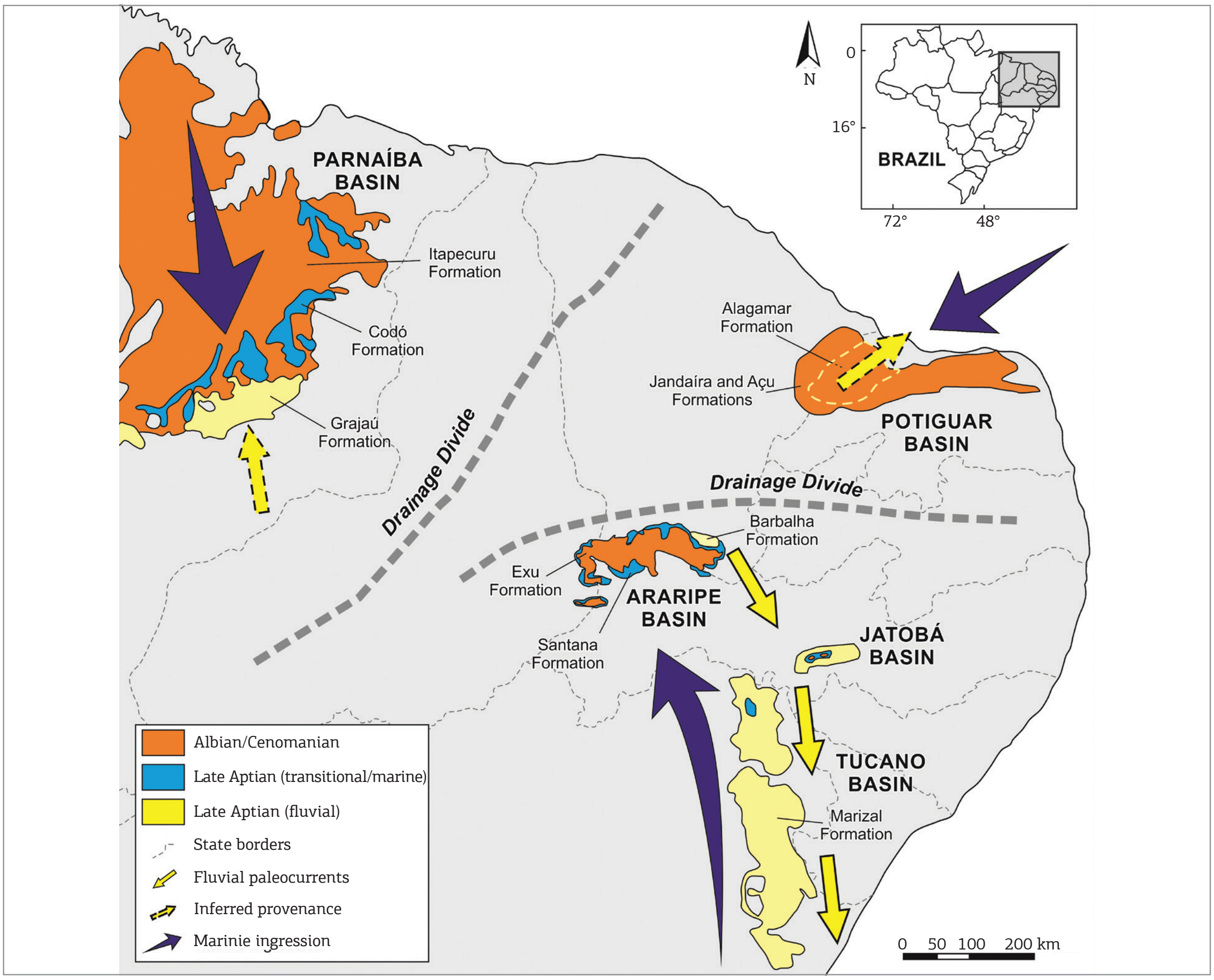

Figure 1. Paleogeographic scenario of Northeast Brazil during Aptian times based on paleocurrents of fluvial deposits as well as on the architecture of facies associations of coeval stratigraphic units. Note the drainage divides resulted from the three drainage basins, and the probable path of marine ingressions upstream along fluvial valleys (based on Assine 1994). Inferred sediment provenance is based on lateral facies changes and grain-size distribution.

By considering all data we have mentioned above, we emphasize that the paleogeographic model proposed by Arai (2014) includes important paleontological data, and is a good starting point to discussions. However, it needs a reappraisal. Unfortunately, the seaways depicted in his model cannot be regarded as accurate paths of marine ingression in the interior of Brazil during the Aptian/Albian time lapse. Indeed, a reliable paleogeographic model still seems far from being achieved. The discussion remains open and more multi-proxy studies are required to improve our understanding of one of the episodes that pinpoints the Gondwana rifting and opening of the South Atlantic Ocean.

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