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Microbial mediation in invertebrate trace fossil preservation in Sousa Basin (Early Cretaceous), Brazil

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ABSTRACT

Well-preserved invertebrate and vertebrate trace fossils commonly occur in reddish, fine to very fine-grained sandstone and mudstone bedsets of the Antenor Navarro and Sousa formations in the Sousa Basin, referring to an Early Cretaceous pull-apart basin in northeastern Brazil, related to the South Atlantic opening. Palaeoenvironments are understood as oxidizing terrestrial (alluvial fans and meandering rivers with extensive floodplains or perennial flooded areas), under hot and humid palaeoclimates punctuated by drought episodes. The ichnodiversity is low but trace fossils are abundant in the invertebrate ichnoassemblages analyzed in this paper. The ichnoassemblages are composed mainly of shallow endostratal traces. Repichnia and Fodinichnia behaviours are represented by *Aulichnites* isp., *Palaeophycus* isp., ?*Arenicolites* isp., *Planolites* isp., *Taenidium* isp. and *Phycodes* isp. and are a taphonomic challenge in terms of their production and preservation, particularly considering its palaeoenvironment. Field observations and collected samples reveal common presence of microbially induced sedimentary structures associated to these traces. Biofilms and thin microbial mats seem to produce the adequate conditions of nutrient supply, moisture and substrate biostabilization to allow trace makers' survival and taphonomically enhance the preservation of the invertebrate trace fossils in an unstable and even sometimes inhospitable environment.

1. Introduction

The preservation of invertebrate continental trace fossils has not been extensively evaluated, particularly the ones occurring in oxidizing, ephemeral, high to moderate energy fluvial and lacustrine systems. Usually, such trace fossil preservation is considered to be controlled by grain size, sediment consistency and humidity of the substrate, but not by its biosedimentological aspects. However, Fernández and Pazos (2013) showed that biostabilization by microbial mats and biofilms also play an important role in the preservation of such traces.

The Sousa Basin is well-known by its terrestrial trace fossils (Leonardi, 1989; Carvalho and Leonardi, 1992; Carvalho, 2004), along with exquisitely preserved primary sedimentary structures (such as ripple marks, raindrop imprints and mudcracks). Carvalho et al. (2013) stressed the importance of microbial mats and biofilms for enhancing the preservation potential of vertebrate trace fossils (footprints and dinosaur tracks) at this basin.

Biofilms, as a way of substrate stabilisation, may entrap sedimentary grains by the interwoven cyanobacterial filaments, also protected by the mucous-rich cyanobacterial cover (EPS – Exopolysaccharide) against flowage frictional forces; or by its sealing through denser biofilm or microbial mat (Noffke et al., 2001).

This study describes epistratal invertebrate trace fossils in the Sousa Basin and points out to the role of biofilms or microbial mats in their preservation.

2. The Sousa Basin

Throughout most of the Early Cretaceous, South America was still connected to Africa as part of Gondwana. At that time in northeastern Brazil, an area of hundreds of square kilometers, with ephemeral to perennial rivers and shallow lakes constituted common palaeoenvironments.

The Sousa Basin (Fig. 1) is part of a wide sedimentary basin complex in the Borborema Province (Matos, 1992; Medeiros, 2008),

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also known as the "interior basins of Northeast Brazil" (Ponte, 1992), which are pull-apart basins (Matos, 1992) originated during the breakup of Gondwana in the Early Cretaceous (Françolin and Cobbold, 1994; Mabesoone, 1994; Valença et al., 2003; Castro et al., 2007). Roesner et al. (2011) revealed Devonian strata in subsurface (well drillings), which can be understood as an unknown remnant Palaeozoic basin and as part of its basement.

Along the faulted borders of these pull-apart basins, deposition consisted of alluvial fan systems and distally characterised braided fluvial lithofacies (Mabesoone et al., 1979). In the central region of the basins, meandering fluvial systems were established with a wide floodplain laterally associated with perennial to temporary lakes (Fig. 2).

The lithofacies, sedimentary structures and stratal geometries of the Antenor Navarro (lower) and Rio Piranhas (upper) formations are interpreted as fan-delta, alluvial fan and braided fluvial palaeoenvironments (Fig. 3). In the Sousa Formation, the reddish laminated mudstones, which are thinly interbedded with siltstones and very fine cross-laminated sandstones in extensive tabular beds, are interpreted as floodplains with ponds and swampy areas. These pass laterally and stratigraphical upwardly into reddish mudstones interpreted as lacustrine (perennial/temporary) palaeoenvironments (Leonardi, 1989; Machado et al., 1990; Carvalho and Leonardi, 1992; Garcia and Wilbert, 1994; Da Rosa and Garcia, 2000). These Early Cretaceous rocks are strong reddish coloured, typical sediments in oxidizing terrestrial environments.

3. Sedimentary palaeoenvironments and stratigraphy

The main lithologies in the Sousa Basin are terrigenous clastics, including breccias and conglomerates, sandstones, siltstones, mudstones, marls and shales grouped into three lithostratigraphic units: Antenor Navarro, Sousa, and Rio Piranhas formations, all belonging to the Rio do Peixe Group and reaching a thickness of up to 2870 m (Mabesoone, 1972; Mabesoone and Campanha, 1973).

The Antenor Navarro Formation is the basal lithostratigraphic unit in the Sousa Basin, overlaying a disconformity of unnamed Devonian rocks (Roesner et al., 2011), and overlaid conformably in a gradational lithostratigraphic contact with the Sousa Formation. Its thickness in outcrops is around 100 m. Lithologically the unit is characterised typically by coarse arkoses and conglomeratic lithic sandstones with trough-cross beddings, whose palaeocurrents point to the South and Southeast (Lima Filho, 2002). Trace fossils occur in more fine-grained sediments (e.g. Serrote do Letreiro locality, here described for invertebrate trace fossils), and the overall palaeoenvironment is understood as braided rivers in distal alluvial fans.

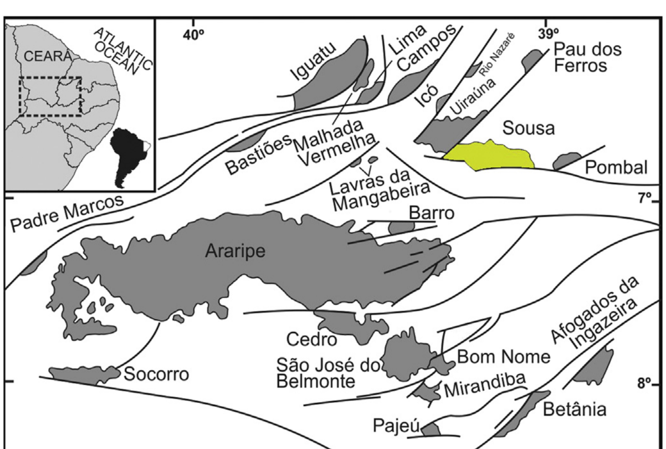

Fig. 1. Distribution of the Cretaceous basins of Northeastern Brazil in the context of Borborema Province and location area of the Sousa Basin.

The deposits of the Sousa Formation typically crop out expressively in the centre of the basin, where conformably overlays the Antenor Navarro Formation, with a mean thickness of around 800 m. Lithologically, the deposits are characterised mostly by reddish and greenish/grayish microclastics (mudstones, calciferous' mudstones or "marls"). This succession is interbedded with fine to coarse-grained, immature sandstone beds (some of them calciferous). These deposits frequently show horizontal- and cross-laminations, symmetrical and asymmetrical ripple marks, mudcracks, raindrop imprints and convolute laminations. The Sousa Formation is the most fossiliferous unit of the Sousa Basin (six localities herein described for invertebrate trace fossils), and the palaeoenvironment is understood as a perennial shallow lake, and in some instances, as an ephemeral lake transitioning to a fluvial floodplain (Carvalho and Leonardi, 1992).

Deposits of the Rio Piranhas Formation crop out at the southern border of the Sousa Basin, being characterised mostly by poorly to very poorly sorted, immature, very coarse-grained sandstones (arkoses and lithic sandstones) and conglomerates, deposited in alluvial fans related to the tectonic activity of the Malta Fault; their thickness is estimated in 300 m in outcrops and palaeocurrents pointing to the North (Lima Filho, 2002). This unity is devoided of fossils, and is located at the top of the lithostratigraphic column.

In terms of depositional systems, these three lithostratigraphic units seem to be part of a tract of alluvial fan–fluvial–lacustrine facies, deposited in the Sousa Basin during Berriasian–early Barremian times. Supported by the lithofacies and palaeocurrent data, alluvial fans must have operated from both, northern and southern borders (Antenor Navarro and Rio Piranhas formations). There are coarse-grained clastics that become finer towards the basin's centre (Antenor Navarro Formation). Braided rivers distally pass the basin through meandering channels and shallow lakes (Sousa Formation). Climatic fluctuations during the depositional history of the basin would be responsible for drought episodes of variable duration in a more humid overall context. This is evident by the immaturity of the sands of the Antenor Navarro and Rio Piranhas formations, and the presence of mudcracks, raindrop imprints and calciferous mudstones in the Sousa Formation. In this complex taphonomic setting, trace fossil preservation is enhanced towards the centre of the basin, in lower energy depositional facies, where moisture is more constant, thus allowing biofilms and microbial mats to easily proliferate.

4. Palaeontology

The existence of a diverse vertebrate ichnofauna, consisting of footprints and tracks of theropods, sauropods and ornithopods is one of the most striking aspects of the Sousa Basin. Invertebrate trace fossils such as trails and burrows produced by arthropods, molluscs and annelids are also common (Carvalho, 2004). Despite the strong reddish colour, typical of sediments in oxidising terrestrial palaeoenvironments, thin beds of greenish shales, mudstones, and siltstones marls are also present, thus allowing body fossils. These fossils are ostracods, conchostracans, plant fragments, palynomorphs, and fish scales. The large-sized conchostracan *Palaeolimnadiopsis reali* (up to 3.5 cm in length), which has been described from some lacustrine facies of Sousa Basin, refers to optimum ecological conditions for these species. Conchostracan lived in alkaline ephemeral lakes, with a large amount of nutrients including ions such as calcium and phosphorus (Carvalho, 1993, 2000a, 2004). A warm and wet palaeoclimate was pointed out by Carvalho et al. (2013), based on the palynological assemblage, a