APTIAN MICROFOSSILS FROM THE SOUTHWEST PORTION OF THE ARARIPE BASIN, PERNAMBUCO STATE, NORTHEASTERN BRAZIL

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ABSTRACT – Known worldwide for the excellent preservation of its fossils, the Araripe Basin, located between the states of Ceará, Piauí, and Pernambuco, has been the target of hundreds of studies on micropaleontology over the last few decades. However, papers focusing on this basin within the Pernambuco State are scarce. In the present work, microfossils (especially ostracods) recovered from samples of the well AR-TR-3-PE drilled in the city of Trindade were studied. The recovered ostracod assemblage is typically Aptian, as follows: *Neuquenocypris* cf. *N. berthoui* Colin & Dépêche, *Pattersoncypris micropapillosa* Bate, *Pattersoncypris* sp., *Damonella grandiensis* Tomé *et al.*, and *Theriosynoecum silvai* (Silva). These ostracods were associated with other fossil groups, such as benthic foraminifera (*Bathysiphon*? sp., *Rhizammina* sp., and *Psammosphaera*? sp.), seeds, gastropods, bivalves, and fish teeth. Overall, this mixohaline association suggests a transitional paleoenvironment to the Aptian interval in the southwest portion of the Araripe Basin.

Keywords: Early Cretaceous, ostracods, foraminifera, paleoecology.

RESUMO – Conhecida mundialmente pela excelente preservação de seus fósseis, a Bacia do Araripe, que está contida em parte dos estados do Ceará, Piauí e Pernambuco, foi estudada em centenas de trabalhos micropaleontológicos nas últimas décadas. Contudo, poucos deles tiveram sua área de estudo no Estado de Pernambuco. No presente trabalho foram investigados microfósseis, especialmente ostracodes, provenientes de amostras do poço AR-TR-3-PE perfurado no município de Trindade. A fauna de ostracodes recuperada é tipicamente Aptiana, composta de *Neuquenocypris* cf. *N. berthoui* Colin & Dépêche, *Pattersoncypris micropapillosa* Bate, *Pattersoncypris* sp., *Damonella grandiensis* Tomé *et al.* e *Theriosynoecum silvai* (Silva). Esses ostracodes estão associados a outros grupos fósseis, como foraminíferos bentônicos (*Bathysiphon*? sp., *Rhizammina* sp. e *Psammosphaera*? sp.), sementes, gastrópodes, bivalves e dentes de peixes. Essa associação faunística mixohalina sugere um paleoambiente transicional durante o Aptiano na porção sudoeste da Bacia do Araripe.

Palavras-chave: Eocretáceo, ostracodes, foraminíferos, paleoecologia.

INTRODUCTION

The Araripe Basin is known worldwide for the richness and diversity of its fossiliferous content, in particular insects, amphibians, crustaceans, fishes, pterosaurs, plants, and microfossils, most extraordinarily well-preserved. The most diversified and abundant fossil record is precisely that from the Santana Group, which became known by two Konservat-Lagerstätten (*e.g.*, Mabesoone & Tinoco, 1973; Maisey, 1991; Kellner & Campos, 1999; Kellner, 2002; Fara *et al.*, 2005; Osés *et al.*, 2016, 2017).

Among the microfossils, the ostracods have been gaining more and more importance in paleoecological and biostratigraphic studies on Early Cretaceous deposits from basins of the interior northeastern of Brazil (Arai & Coimbra, 1990; Arai & Assine, 2020; Melo *et al.*, 2020; Araripe *et al.*, 2022; Tomé *et al.*, 2022; Fauth *et al.*, 2023; Guzmán *et al.*, 2023). Their wide ecological distribution in the most varied environments (marine and non-marine aquatic and, more rarely, terrestrial), combined with their rapid biological evolution, make them widely applied as paleoenvironmental, paleoclimatic, and biostratigraphic indicators (Smith & Horne, 2002; Rodriguez-Lazzaro & Ruiz-Muñoz, 2012).

The record of the Alagoas Stage in the Araripe Basin, recently attributed exclusively to the Aptian (Arai & Assine, 2020; Melo *et al.*, 2020; Fauth *et al.*, 2023; Guzmán *et al.*, 2023), corresponds to the Post-Rift Sequence I of the basin. This sequence encompasses the Santana Group, which consists, from bottom to top, of the Barbalha, Crato, Ipubi and Romualdo formations (Assine *et al.*, 2014).

Despite being a "school basin", the micropaleontology in the portion of the Araripe Basin located in the Pernambuco State is still poorly developed. Therefore, this work not only contributes to the micropaleontological knowledge on the Araripe Basin, but also adds paleoenvironmental and paleogeographic interpretations for the Santana Group based on ostracods and other associated microfossils.

GEOLOGICAL SETTING

The Araripe Basin is located in the northeast Brazil, covering partially the states of Ceará, Pernambuco, and Piauí, extending over an area of approximately 9,000 km². Tectonically, it lies on Precambrian crystalline terrains of the Borborema Province, south of the Patos Lineament in the Transverse Zone (Brito Neves *et al.*, 2000). The shape of this basin stands out in the landscape due to the Chapada do Araripe, a geomorphologically elongated feature, with a preferably flat top with a small slope in the EW direction and limited by erosive and steep cliffs (Assine, 1992, 2007; Assine *et al.*, 2014; Morales & Assine, 2015).

The geological history of this basin is linked to the events that promoted the rifting of Gondwana, culminating in the opening of the South Atlantic Ocean during the Mesozoic (Matos, 1992; Ponte & Ponte Filho, 1996; Maisey, 2000; Assine, 2007; Assine *et al.*, 2014; Custódio *et al.*, 2017). The Mesozoic sedimentary succession of the Araripe Basin is divided into three tectono-stratigraphic stages: the early rift, rift climax and post-rift (see Ponte & Asmus, 1976; Chang *et al.*, 1992; Kuchle & Scherer, 2010; Scherer *et al.*, 2014). The Santana Group was deposited during Post-Rift Sequence I. The lithostratigraphy of the Santana Group consists of the following units from the base to the top: Barbalha, Crato, Ipubi, and Romualdo formations (Assine *et al.*, 2014).

MATERIAL AND METHODS

The samples used in this study come from the well AR-TR-3-PE, which was drilled by the Fundação Nacional de Saúde (**FUNASA**), in the Municipality of Trindade (7º41'08.5''S; 40º15''02.7''W), and donated to the Applied Micropaleontology Laboratory, Geology Department, Universidade Federal de Pernambuco (**UFPE**).

Thirty-six cutting samples were recovered each three meters from a 108 m depth interval, spanning the Crato, Ipubi, and Romualdo formations (Figure 1). As the rock samples were partially to completely pulverized, their assignment to each of the Santana Group formations was based on the percentage of each lithology (Figure 2).

The Crato Formation is represented by limestone and marl, and was observed between 108 (bottom) and 90 m. It is overlaid by the Ipubi Formation, characterized by intercalations of evaporite and marl between 90–69 m. Finally, the marls, claystones, and shales of the Romualdo Formation were observed in the 69–12 m interval. A Cenozoic cover composed of medium to coarse-grained quartz arenite overlies the Santana Group from the depth of 12 m onwards.

After detailed description of the lithology, 60 g from each sample were weighed on analytical balance, and subsequently immersed in water for 24 h. Then, the samples were washed under running water through 500, 250, 180, 63 μm sieves and the different fractions oven-dried at 60ºC for 24 h. All microfossils from the fractions 500, 250, 180 and 63 μm of each sample were picked under binocular stereomicroscope Zeiss Stemi 305 and the best representative specimens of each species examined in a Scanning Electron Microscope (**SEM**) Phenom XL at the Applied Micropaleontology Laboratory, UFPE.

RESULTS AND DISCUSSION

A typically Aptian ostracod assemblage (according to the proposal of Guzmán *et al.*, 2023), consisting of *Neuquenocypris* cf. *N. berthoui* Colin & Dépêche, 1997, *Pattersoncypris micropapillosa* Bate, 1972, *Pattersoncypris* sp., *Damonella grandiensis* Tomé *et al.*, 2014 and *Theriosynoecum silvai*? (Silva, 1978) was obtained. They were associated with other fossil groups, such as benthic foraminifera, seeds, gastropods, bivalves, fish teeth, and an indeterminate ostracod. The stratigraphic distribution and abundance of these microfossils are shown in Figure 2.
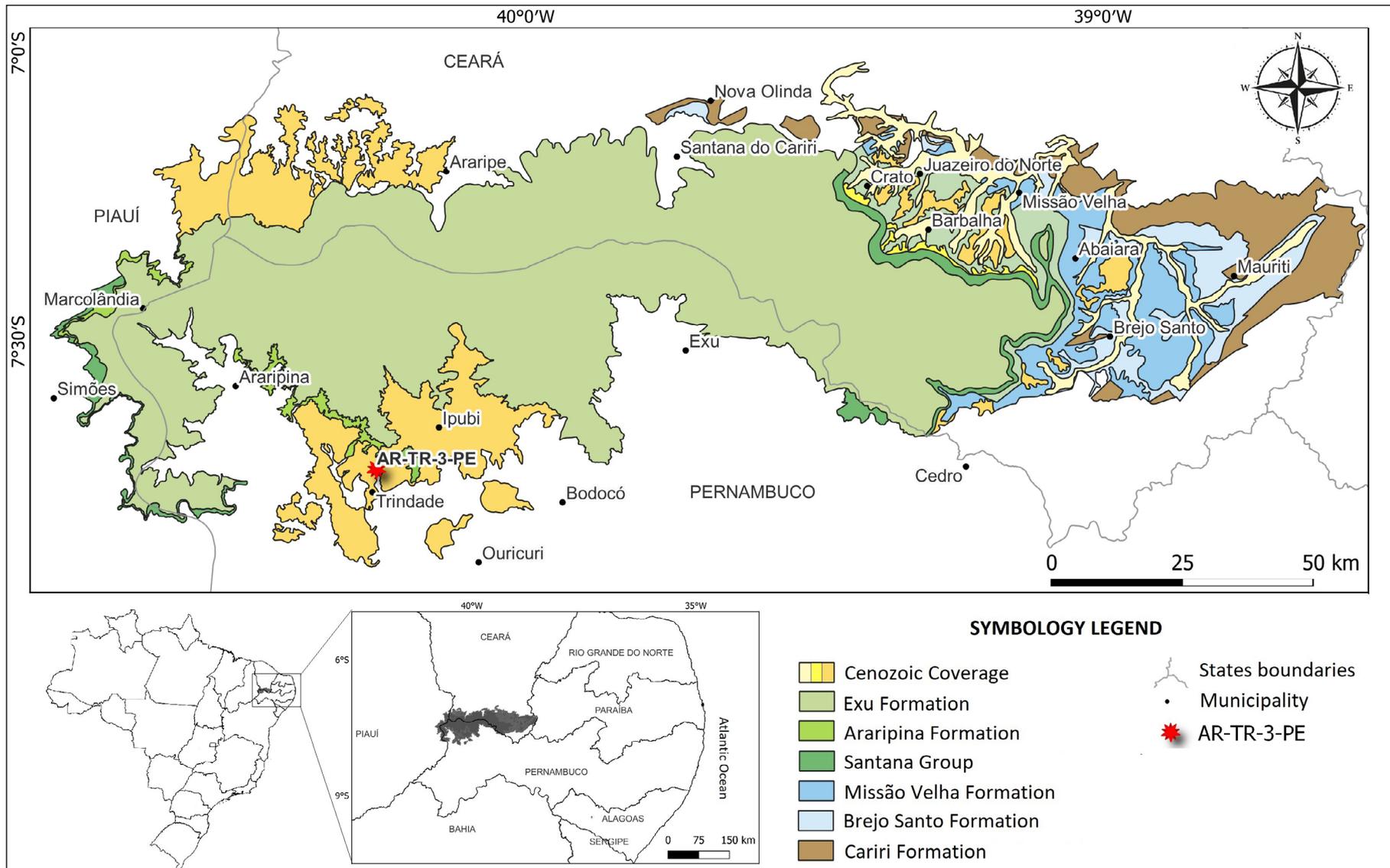
Figure 1. Geological map of the Araripe Basin, with the location of the AR-TR-3-PE well. Modified from Guzmán *et al*. (2023), shapefile from GEOSGB.
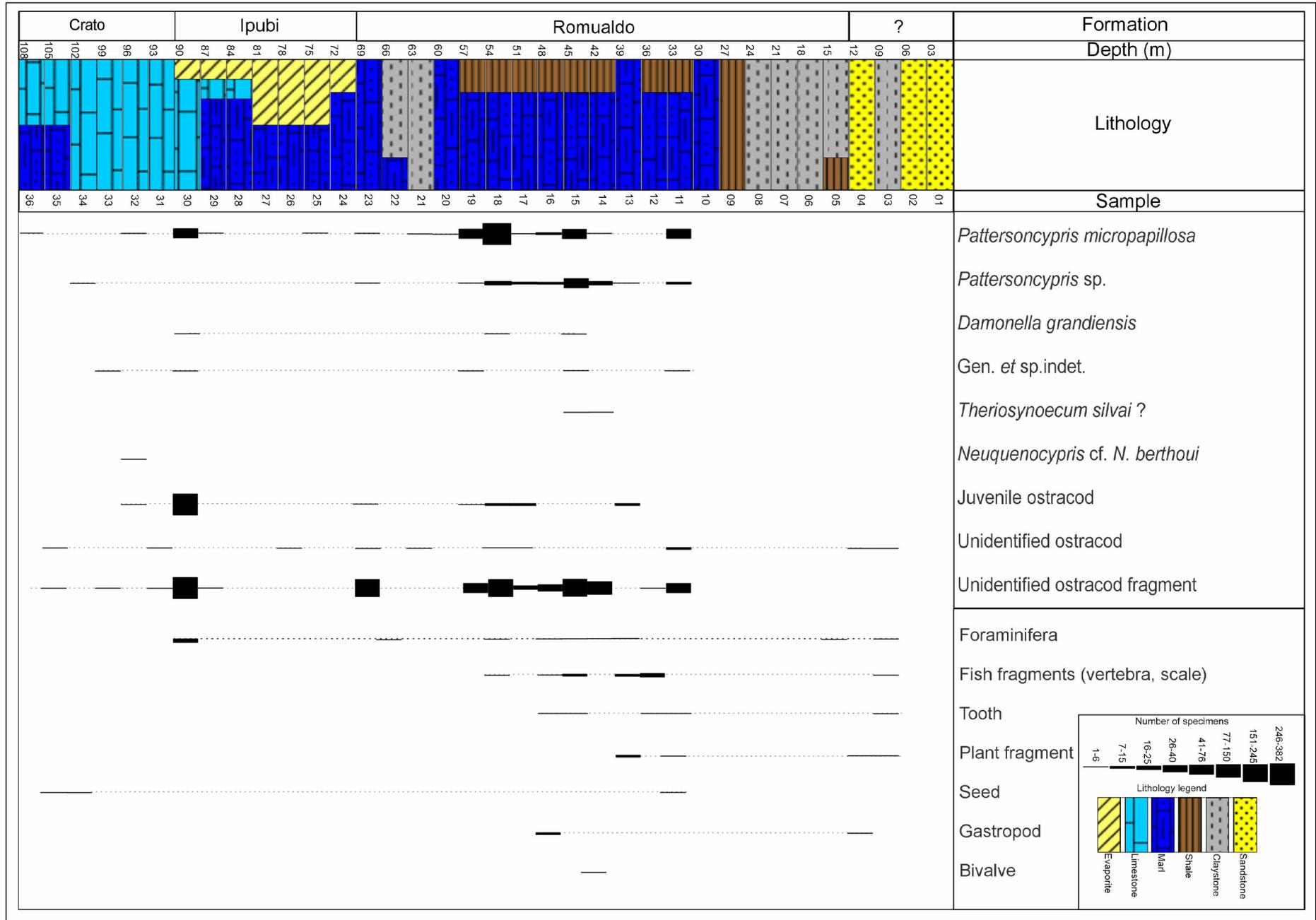
Figure 2. Stratigraphical range and abundance of the ostracod species recovered from the well AR-TR-3-PE, Santana Group, Araripe Basin.

Systematic paleontology

The adopted suprageneric classification follows Horne *et al.* (2002). Detailed synonymic list and known stratigraphic and geographic distribution of the recorded taxa is available in Guzmán *et al.* (2022). The illustrated specimens are deposited in the micropaleontological collection of the LMA-UFPE (Laboratório de Micropaleontologia Aplicada – Universidade Federal de Pernambuco) under the curatorial numbers LMA-00430 to LMA-00436. Abbreviations: **L** = length; **H** = height; **W** = width.

Class OSTRACODA Latreille, 1802
Subclass PODOCOPA Sars, 1866
Order PODOCOPIDA Sars, 1866
Suborder CYPRIDOCOPINA Jones, 1901
Superfamily CYPRIDOIDEA Baird, 1845
Family ILYOCYPRIDIDAE Kaufmann, 1900

Neuquenocypris Musacchio, 1973

Neuquenocypris cf. *N. berthoui* Colin & Dépêche, 1997
(Figure 3A–C)

Illustrated specimen. LMA-00430. L = 910 µm, H = 540 µm, W = 394 µm. Sample 32.
Material. One poorly preserved juvenile carapace.
Occurrence. Sample 32; Crato Formation.
Remarks. The specimen recovered in the present study shows the main diagnostic features of *Neuquenocypris berthoui* Colin & Dépêche, 1997, such as subtrapezoidal outline in lateral view, straight dorsal margin, slightly concave ventral margin, small marginal denticles and spines (Colin & Dépêche, 1997, fig. 2: 1–3, 4). However, due to the poor preservation of our material, it was not possible to observe other features of this species, such as the conspicuous conic spines present on the surface of each valve and the anterodorsal sulci. Our material also differs from *Neuquenocypris* cf. *N. berthoui* in the general outline. The specimen illustrated by Colin & Dépêche (1997, fig. 6: 10) presents a subrectangular outline and less pronounced anterior cardinal angle.

Family CYPRIDIDAE Baird, 1845

Pattersoncypris Bate, 1972

Pattersoncypris micropapillosa Bate, 1972
(Figure 3D–F)

Illustrated specimen. LMA-00431. L = 1112 µm, H = 771 µm, W = 589 µm. Sample 18.
Material. 645 specimens, including adults and juveniles.
Occurrence. Samples 11, 14–21, 23, 25, 29-30, 32, and 36; Crato, Ipubi and Romualdo formations.
Remarks. This species is very abundant in the studied well, recording specimens of all instars. Preservation varied, with specimens broken, fractured, and recrystallized to calcite and/or substituted for pyrite. According to Guzmán *et al.*

(2023), *Pattersoncypris micropapillosa* is the appropriate taxon to characterize the Biozone OST-011 (Alagoas Local Stage = Aptian) because it is abundant, has wide geographic distribution, and calibration with foraminifer biozones.

Pattersoncypris sp.
(Figure 3G–I)

Illustrated specimen. LMA-00432. L = 961 µm, H = 576 µm, W = 462 µm. Sample 15.
Material. 124 specimens, including adults and juveniles.
Occurrence. Samples 11, 13–19, 23, and 34; Crato and Romualdo formations.
Remarks. These specimens are not well-preserved as the *Pattersoncypris micropapillosa* ones and some specimens are recrystallized to calcite and/or substituted for pyrite. Its anterodorsal margin is similar to *Pattersoncypris sinuata* Krömmelbein & Weber, 1971, but the general outline of *Pattersoncypris* sp. is subtrapezoidal and elongated in lateral view. The anterior margin is supracurvate, while in *P. sinuata* it is equicurvate. The posterodorsal margin of *P. sinuata* is more inclined backwards, with less marked posterior cardinal angle. Additionally, *Pattersoncypris* sp. has the posterior cardinal angle marked and visible on both valves; the ventral margin is sinuous on the left valve; in *P. sinuata* the ventral margin is straight. In dorsal view, *Pattersoncypris* sp. has a biconvex and wider carapace when compared to *P. sinuata*. Probably, our material is a new species of the genus *Pattersoncypris*.

Family CANDONIDAE Kaufmann, 1900

Damonella Anderson, 1966

Damonella grandiensis Tomé *et al.*, 2014
(Figure 3J–L)

Illustrated specimen. LMA-00433. L = 666 µm, H = 379 µm, W = 307 µm. Sample 30.
Material. Nine specimens were recovered. Relatively well-preserved and mostly found in the 180 µm fraction.
Occurrence. Samples 15, 18, and 30; Ipubi and Romualdo formations.

Gen. et sp. indet.
(Figure 3M–O)

Illustrated specimen. LMA-00434. L = 587 µm, H = 282 µm, W = 217 µm. Sample 15.
Material. Fourteen specimens.
Occurrence. Samples 11, 15, 19, 30, and 33; Crato, Ipubi and Romualdo formations.
Remarks. A similar morphotype was recorded by Do Carmo *et al.* (2013) in the Potiguar Basin, Brazilian Northeast, named as *Paracypria? elongata*. The attribution of this material in the genus *Paracypria* Sars, 1910 is problematic since the inclusion of the fossil specimens in this genus

Figure 3. Ostracods. **A-C**, *Neuquenocypris* cf. *N. berthoui* Colin & Dépêche, 1997 (LMA-00430); **A**, right view; **B**, left view; **C**, dorsal view. **D–F**, *Pattersoncypris micropapillosa* Bate, 1972 (LMA-00431); **D**, right view; **E**, left view; **F**, dorsal view. **G–I**, *Pattersoncypris* sp. (LMA-00432); **G**, right view; **H**, left view; **I**, dorsal view. **J-L**, *Damonella grandiensis* Tomé *et al.*, 2014 (LMA-00433); **J**, right view; **K**, left view; **L**, dorsal view. **M–O**, gen. et sp. indet. (LMA-00434); **M**, right view; **N**, left view; **O**, dorsal view. **P–R**, *Theriosynoecum silvai*? Silva, 1978 (LMA-00435); **P**, right view; **Q**, left view; **R**, dorsal view. **S–U**: *Theriosynoecum silvai*? Silva, 1978 (LMA-00436); **S**, right view; **T**, left view; **U**, dorsal view. Scale bars = 100 μm.

remains controversial due to poor preservation of internal morphology, as pointed by Do Carmo *et al.* (2013). Extant species of the genus *Paracypria* are identified based on soft parts (see Hiruta & Kakui, 2016). It is probably a new taxon, not described here due to the small number of specimens and their poor preservation. In addition, all recovered carapaces were articulated, not allowing examination of their internal features.

Superfamily CYTHEROIDEA Baird, 1850
Family LIMNOCYTHERIDAE Klie, 1934

Theriosynoecum Branson, 1936

Theriosynoecum silvai? (Silva, 1978) emend.
Do Carmo *et al.*, 2004
(Figure 3P–U)

Illustrated specimens. LMA-00435. L = 562 µm, H = 313 µm, W = 251 µm; LMA-00436. L = 845 µm, H = 530 µm, W = 450 µm. Sample 14.
Material. Six carapaces, probably juveniles.
Occurrence. Samples 14 and 15; Romualdo Formation.
Remarks. Our material is very similar to the illustrated specimens of Do Carmo *et al.*, (2004). However, we prefer to keep this taxon in doubt, considering that several morphological and taxonomic questions about the specimens attributed to *Theriosynoecum silvai* were highlighted by Coimbra & Petró (2023), reinforcing the importance of a review of this species. Our material is scarce, poorly preserved, and probably composed only of juveniles, which did not allow this review to be developed.

Associated fossil groups

In addition to ostracods, other fossil groups were also recorded in the samples studied (Figure 4). A total of 39 specimens of benthic foraminifera were found at samples 03, 05, 14–16, 18, 22 and 30, in the Crato, Ipubi, and Romualdo formations. Despite their poor preservation, it was possible to recognize at least three genera: *Bathysiphon*? sp. (Figure 4A), *Rhizammina* sp. (Figure 4B), and *Psammosphaera*? sp. (Figure 4C).

The benthic infaunal foraminifera *Bathysiphon* and *Rhizammina* suggest poorly oxygenated conditions in a neritic middle-upper bathyal environment (Jones & Charnock, 1985; Kaminski & Kuhnt, 1995; Kaminski *et al.*, 1995; Gradstein *et al.*, 1999). In other portions of the Araripe Basin, they occur frequently associated with other genera (Melo *et al.*, 2020; Guzmán *et al.*, 2023). The specimens of these genera in the analyzed samples are sporadic and scarce, but they reinforce the hypothesis of a marine influence in the Araripe Basin during the Aptian.

Five fish teeth with good preservation were found in samples 03, 11, 12, 15, and 16 (Figure 4D), and one dark brown to black seed was found in the sample 33 (Romualdo Formation). Although fragile and broken, the seed's morphology reveals similarity to Caryophyllaceae (Figure 4E).

Six internal mold fragments of gastropods were found in samples 04 and 16 (Figure 4F). Lastly, one bivalve specimen was recovered in sample 14 (Romualdo Formation) that, despite the abrasion marks, revealed perceptible growth lines (Figure 4G). The abundance and stratigraphic distribution of these groups throughout the well are represented in Figure 2.

Paleoenvironmental inferences

The Santana Group is composed of fluvial to bayhead delta and coastal to marine deposits, including (from base to top) the Barbalha, Crato, Ipubi and Romualdo formations (Assine *et al.*, 2014; Custódio *et al.*, 2017; Varejão *et al.*, 2019, 2021a, b; Melo *et al.*, 2020; Guzmán *et al.*, 2023). The Barbalha Formation was not recovered in well AR-TR-3-PE and is therefore not discussed in this study.

The base of the well (samples 36 to 31), corresponding to the Crato Formation, is composed of laminated limestone and marl (Figure 2). This carbonate succession is in accordance with the interpretation of low energy lacustrine systems (Assine, 1990, 1992). According to Neumann *et al.* (2003), the lacustrine system was relatively shallow, closed meromictic, which evolved in a paleoequatorial zone under warm and semiarid climates. Some authors also suggested that there was an intermittent connection of the Crato lagoon with the sea, perhaps through restricted channels, inferred by the presence of certain marine fish, which could have entered the lagoon for reproduction and nursery (Brito, 2007; Brito & Yabumoto, 2011). This idea is reinforced by the record of foraminiferal linings in the same formation (Arai, 2012; Goldberg *et al.*, 2019). The occurrence of dinocysts and typical marine ichnotaxa at the base of the unit, as well as the record of both benthonic and planktonic foraminifera by Varejão *et al.* (2019) and Guzmán *et al.* (2023), respectively, reinforce this paleoenvironmental interpretation. All these records indicate a marine influence during the late Aptian, described by Varejão *et al.* (2019) as short marine incursions during the deposition of the Crato formation.

In the samples herein analyzed the microfossils recovered from the Crato Formation consist of the limnic and mixohaline ostracods *Neuquenocypris* cf. *N. berthoui*, *Pattersoncypris micropapillosa* and *Pattersoncypris* sp., gen. et sp. indet., undetermined ostracod fragments and seeds, as seen in Figures 2 and 5. The association is neither rich nor abundant, and due to the lack of typically marine fossils, there is no evidence of marine influence for the Crato Formation in the study area. When taking into consideration the distribution of this assemblage in other parts of the Araripe Basin, it is worth noting that *P. micropapillosa* and *Neuquenocypris berthoui* were also reported by several authors (see Guzmán *et al.*, 2023 and references therein). Furthermore, they found these species associated with other ostracod species and marine and mixohaline benthic foraminifera. It is crucial to highlight that our results are based on a small portion of the Crato Formation (*ca.* 18 m), composed basically by limestone and marl, and probably reflect the lagoonal part of this formation.

The Ipubi Formation is represented in the studied material by the interval between the samples 30 and 24 and consists
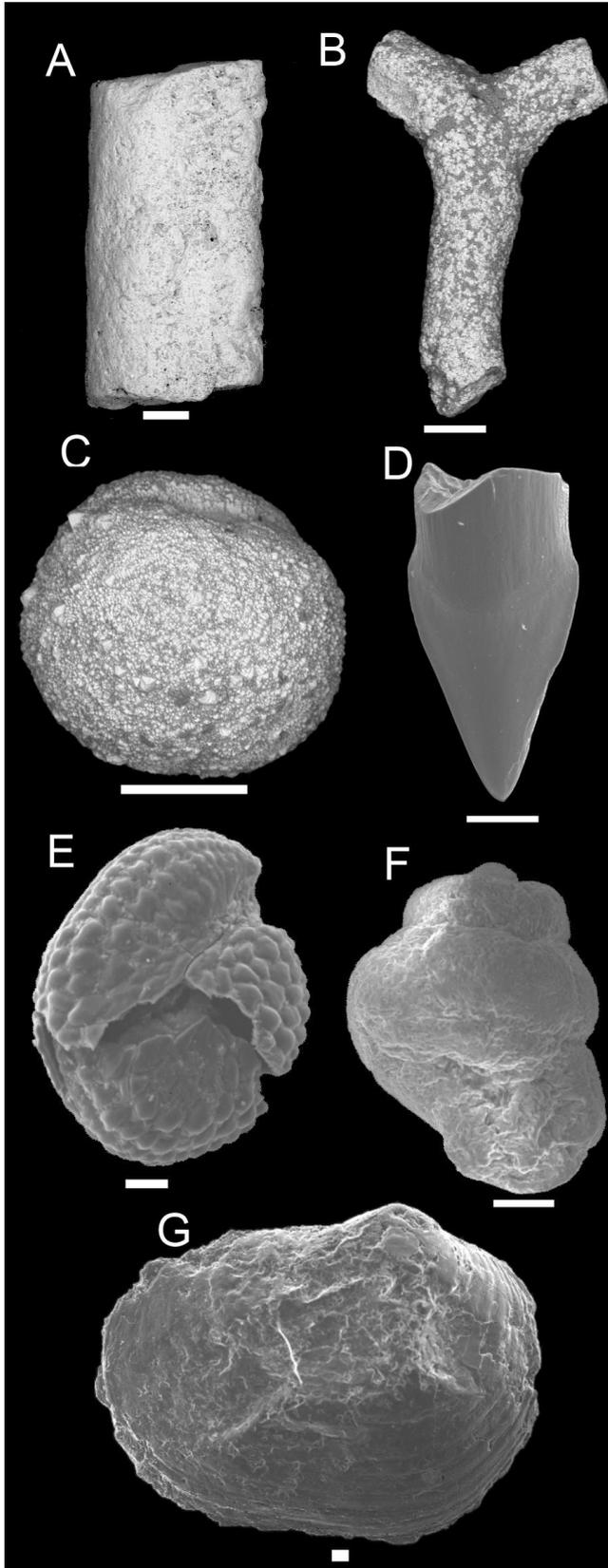
Figure 4. Associated fossil groups. **A**, *Bathysiphon*? sp.; **B**, *Rhizammina* sp.; **C**, *Psammosphaera*? sp.; **D**, fish teeth; **E**, seed; **F**, gastropod; **G**, bivalve. Scale bars = 100 μm.

of evaporite, limestone and marl (Figure 2). This formation is concentrated on the western border of the basin, where it is laterally continuous. In its eastern portion, the evaporite levels, largely gypsum, do not extend laterally and occur intercalated with green and black shales, thin fine sandy layers, and laminated limestone (Menor *et al.*, 1993; Assine, 2007; Fabin *et al.*, 2018; Fambrini *et al.*, 2020).

Based on the microfossils association recovered in our study, it is possible to divide the Ipubi Formation into two intervals. The first one, between approximately 90 to 87 m (sample 30), was deposited under marine influence, as demonstrated by the presence of foraminifera (Figure 2). This abrupt environmental change might have caused the death of the ostracod fauna, represented by the massive occurrence of articulated adults of *Pattersoncypris micropapillosa*, rare adults of *Damonella grandiensis* (all articulated), rare articulated adults of gen. et sp. indet., many juvenile non-identified ostracods, and numerous non-identifiable ostracod fragments. The high number of fragmented articulated carapaces and the high rate of juvenile over adult ostracod carapaces could be indicative that these fragments and adult ostracods are allochthonous components transported from high energy environments and deposited in low energy ones (Figure 5). Alternatively, at least one ostracod mortality event might have happened in response to the abrupt salinity change. The second interval in Ipubi Formation, between 87–69 m (samples 29 to 24), has a much larger percentage of evaporite, reinforcing once again the increase of salinity and showing that not much of life could prosper in this environment. In this interval, only one adult of *P. micropapillosa* and two unidentified ostracods were recovered.

The interval corresponding to the Ipubi Formation presents species recovered in other parts of the Araripe Basin. Guzmán *et al.* (2023) recorded, near the municipalities of Crato and Santana do Cariri, *Damonella grandiensis* and *Pattersoncypris micropapillosa*, at the northeastern and southeastern portions of the basin (both in the Ipubi and Romualdo formations). They also found mixohaline ostracods and a high diversity of both planktonic and benthic foraminifera associated. The presence of *D. grandiensis* in the well 1-PS-11-CE was recorded by Tomé *et al.* (2014), and Coimbra *et al.* (2002) reporting some species present in this work, such as *P. micropapillosa*, *D. grandiensis* (= Ostracod 207), and *Theriosynoecum silvai*.

The top of the Santana Group is represented by the Romualdo Formation, which, according to Custódio *et al.* (2017), comprises a transgressive–regressive cycle with a depositional dip towards southeast, decreasing in thickness towards northwest, with its source areas located at the northern side of the basin. To the east of the basin, the facies associations recorded indicate a deepening-upward sequence on a mixed siliciclastic-carbonate marine ramp (Melo *et al.*, 2020; Guzmán *et al.*, 2023), whereas to the western the facies indicate a rocky-protected lagoon (Varejão *et al.*, 2019). This
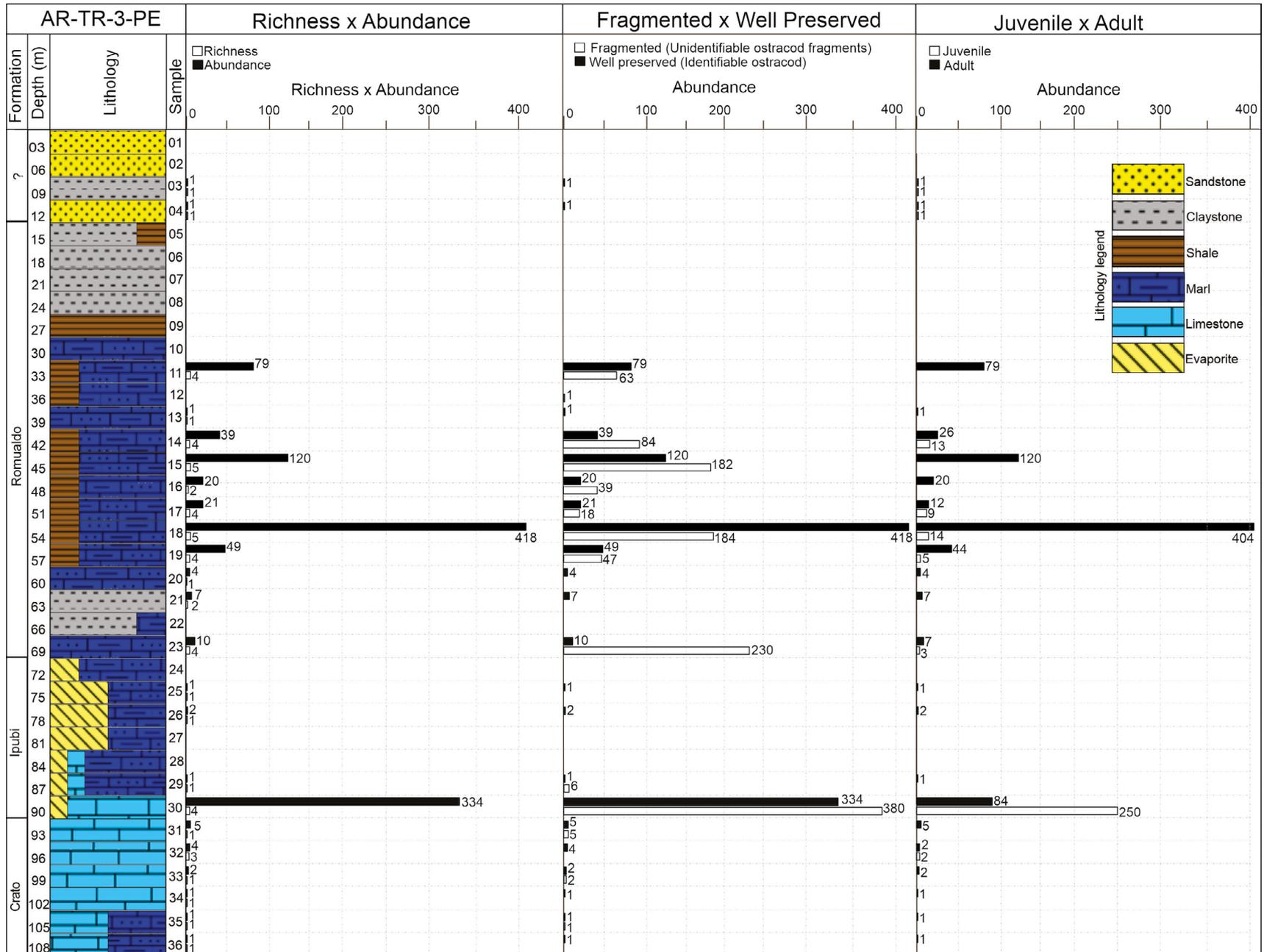
Figure 5. Lithological profile of the well AR-TR-3-PE associated with the taphonomic parameters analyzed for this study.

corroborates a low-gradient ramp marine environment model that deepens to the eastern portion of the Araripe Basin (Melo *et al.*, 2020).

In the studied section, the Romualdo Formation is represented by the sample interval between 23 to 05 and can be divided in two parts (Figures 2, 5). The first one is from 69 to 30 m depth, where most of the microfossils were recovered. The collected specimens are *Pattersoncypris micropapillosa*, *Pattersoncypris* sp., *Damonella grandiensis*, gen. et sp. indet., *Theriosynoecum silvai*?, non-identified juveniles, ostracod fragments, benthic foraminifera, fish teeth, seeds, gastropods and one bivalve. The greatest richness and abundance, as well better preservation, occur specifically in samples when there is a mix of shale (25%) and marl (75%). In the second interval (30 to 15 m), the lithology generally consists of marl, shale and clay, in which neither ostracods nor benthic foraminifera were recovered. Similarly to another localities (see Tomé *et al.*, 2022; Araripe *et al.*, 2022; Guzmán *et al.*, 2023), this interval of the Romualdo Formation also records a marine ingression in the Araripe Basin.

Guzmán *et al.* (2023) studied the Romualdo Formation from sections close to the municipalities of Abaiara and Jardim, as well as from the 2-AR-SR-1A-CE well close to the municipality of Crato, all in the Ceará State. They recovered the mixohaline ostracods *Pattersoncypris micropapillosa* and *Damonella grandiensis*. In addition, an abundant and diverse assemblage of benthic and planktonic foraminifera were recorded, including the benthic genera *Bathysiphon* and *Rhizammina*, also reported in our study.

The conspicuous abundance of *Pattersoncypris micropapillosa* throughout the Santana Group, associated with the presence of *Damonella grandiensis* and the ostracod assemblage mentioned above, allows to place the studied section in the *P. micropapillosa* Biozone (OST-011), *sensu* Guzmán *et al.* (2023).

CONCLUSIONS

The data presented in this work shows the occurrence of only three ostracod species in the Crato Formation: *Neuquenocypris* cf. *N. berthoui*, *Pattersoncypris micropapillosa*, and *Pattersoncypris* sp. It was not possible to observe marine influence in this formation based on calcareous microfossils. In the Ipubi Formation both mixohaline ostracods and benthic foraminifera were recorded, and the taphonomic signature suggested catastrophic death, probably due to the onset of marine influence and salinity increase. In the Romualdo Formation deposits, the marine influence is clear, as previously indicated by several studies. The whole microfossil assemblages recorded in this work suggest that the Aptian marine ingression that flooded the interior basins of northeastern Brazil also reached the southwestern part of the Araripe Basin, setting up a transitional environment in the study area.

REFERENCES

Arai, M. 2012. Evidência micropaleontológica da ingressão marinha aptiana (pré-evaporítica) na Bacia do Araripe, Nordeste do Brasil. *In*: CONGRESSO BRASILEIRO DE GEOLOGIA, 46, 2012. *Resumos*, p. 1.

Arai, M. & Assine, M.L. 2020. Chronostratigraphic constraints and paleoenvironmental interpretation of the Romualdo Formation (Santana Group, Araripe Basin, Northeastern Brazil) based on palynology. *Cretaceous Research*, **116**:104610. *doi:10.1016/j.cretres.2020.104610*

Arai, M. & Coimbra, J. 1990. Análise paleoecológica do registro das primeiras ingressões marinhas na Formação Santana (Cretáceo Inferior da Chapada do Araripe). *In*: SIMPÓSIO SOBRE A BACIA DO ARARIPE E BACIAS INTERIORES DO NORDESTE, 1, 1990. *Resumos*, Crato, p. 225–239.

Araripe, R.C. *et al.* 2022. Upper Aptian–lower Albian of the southern-central Araripe Basin, Brazil: Microbiostratigraphic and paleoecological inferences. *Journal of South American Earth Sciences*. **116**:103814. *doi:10.1016/j.jsames.2022.103814*

Assine, M.L. 1990. *Sedimentação e Tectônica da Bacia do Araripe, Nordeste do Brasil*. Programa de Pós-Graduação em Geociências e Meio Ambiente, Universidade Estadual de São Paulo, M.Sc. thesis, 124 p.

Assine, M.L. 1992. Análise estratigráfica da Bacia do Araripe, Nordeste do Brasil. *Revista Brasileira de Geociências*, **22**:289–300. *doi:10.25249/0375-7536.1992289300*

Assine, M.L. 2007. Bacia do Araripe. *Boletim de Geociências da Petrobrás*, **15**:371–389.

Assine, M.L.; Perinotto, J.A.J.; Custódio, M.A.; Neumann, V.H.; Varejão, F.G. & Mescolotti, P.C. 2014. Sequências deposicionais do Andar Alagoas da Bacia do Araripe, Nordeste do Brasil. *Boletim de Geociências da Petrobras*, **22**:3–28.

Brito, P.M. 2007. The Crato Formation fish fauna. *In*: D.M. Martill; G. Bechly & R.F. Loveridge (eds.) *The Crato Fossil Beds of Brazil: Window into an Ancient World*, Cambridge University Press, p. 429–443.

Brito, P.M. & Yabumoto, Y. 2011. An updated review of the fish faunas from the Crato and Santana formations in Brazil, a close relationship to the Tethys fauna. *Bulletin of the Kitakyushu Museum of Natural History and Human History, Series A (Natural History)*, **9**:107–136. *doi:10.34522/kmnh.9.0_107*

Brito Neves, B.B.; Santos, E.J. & Van Schmus, W.R. 2000. Tectonic history of the Borborema province, northeastern Brazil. *In*: U.G. Cordani; E.J. Milani; A. Thomas Filho & A.D. Campos (eds.) *Tectonic Evolution of South America*, DNPM, p. 151–182

Chang, H.K.; Kowsmann, R.O.; Figueiredo, A.M.F. & Bender, A.A. 1992. Tectonics and stratigraphy of the East Brazil Rift system: an overview. *Tectonophysics*, **213**:97–138. *doi:10.1016/0040-1951(92)90253-3*

Coimbra, J.C.; Arai, M. & Carreño, A.L. 2002. Biostratigraphy of Lower Cretaceous microfossils from the Araripe Basin, northeastern Brazil. *Geobios*, **35**:687–698. *doi:10.1016/S0016-6995(02)00082-7*

Coimbra, J.C. & Petró, S.M. 2023. The critical role of accurate fossil identification: the case of the ostracods of the Codó Formation, NE Brazil. *Revista Brasileira de Paleontologia*, **26**:241–255. *doi:10.4072/rbp.2023.4.01*

Colin, J.P. & Dépêche, F. 1997. Faunes d'ostracods lacustres des bassins intra-cratoniques d'âge albo-aptien en Afrique de l'Ouest (Cameroun, Tchad) et au Brésil: considérations d'ordre paléoécologique et paléobiogéographique. *Africa Geoscience Review*, **4**:431–450.

Custódio, M.A.; Quaglio, F.; Warren, L.V.; Simões, M.G.; Fürsich, F.T.; Perinotto, J.A.J. & Assine, M.L. 2017. The transgressive-regressive cycle of the Romualdo Formation (Araripe Basin): Sedimentary archive of the Early Cretaceous marine ingression in the interior of Northeast Brazil. *Sedimentary Geology*, **359**:1–15. *doi:10.1016/j.sedgeo.2017.07.010*

Do Carmo, D.A.; Coimbra, J.C.; Whatley, R.C.; Antonietto, L.S. & Citon, R.T.P. 2013. Taxonomy of limnic Ostracoda (Crustacea) from the Alagamar Formation, middle–upper Aptian, Potiguar Basin, northeastern Brazil. *Journal of Paleontology*, **87**:1–104. *doi:10.1666/11-108R.1*

Do Carmo, D.A.; Rafael, R.M.L.; Vilhena, R.M. & Tomassi, H.Z. 2004. Redescrição de *Theriosynoecum silvai* e *Darwinula martinsi*, Membro Crato (Formação Santana), Cretáceo Inferior, Bacia do Araripe, NE, Brasil. *Revista Brasileira de Paleontologia*, **7**:151–158. *doi:10.4072/rbp.2004.2.07*

Fabin, C.E.; Correia Filho, O.J.; Alencar, M.L.; Barbosa, J.A.; Miranda, T.S.; Neumann, V.H.M.L.; Gomes, I.F. & Santana, F.R. 2018. Stratigraphic Relations of the Ipubi Formation, Siliciclastic-Evaporitic Succession of the Araripe Basin. *Anais da Academia Brasileira de Ciências*, **90**:2049–2071. *doi:10.1590/0001-3765201820170526*

Fambrini, G.L.; Silvestre, D.C.; Barreto Junior, A.M. & Silva-Filho, W.F. 2020. Estratigrafia da Bacia do Araripe: estado da arte, revisão crítica e resultados novos. *Geologia USP Série Científica*, **20**:169–212. *doi:10.11606/issn.2316-9095.v20-163467*

Fara, E.; Saraiva, A.Á.F.; Campos, D.A.; Moreira, J. K. R.; Siebra, D.C. & Kellner, A.W.A. 2005. Controlled excavations in the Romualdo Member of the Santana Formation (Early Cretaceous, Araripe Basin, northeastern Brazil): stratigraphic, palaeoenvironmental and palaeoecological implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **218**:145–160. *doi:10.1016/j.palaeo.2004.12.012*

Fauth, G. *et al.* 2023. Early Aptian marine incursions in the interior of northeastern Brazil following the Gondwana breakup. *Scientific Reports*, **13**:6728. *doi:10.1038/s41598-023-32967-w*

Goldberg, K.; Premaor, E.; Bardola, T. & Souza, P.A. 2019. Aptian marine ingression in the Araripe Basin: Implications for paleogeographic reconstruction and evaporite accumulation. *Marine and Petroleum Geology*, **107**:214–221. *doi:10.1016/j.marpetgeo.2019.05.011*

Gradstein, F.M.; Kaminski, M.A. & Agterberg, F.P. 1999. Biostratigraphy and paleoceanography of the Cretaceous seaway between Norway and Greenland. *Earth-Science Reviews*, **46**:27–98. *doi:10.1016/S0012-8252(99)00018-5*

Guzmán, J.; Piovesan, E.K.; Melo, R.M.; Almeida-Lima, D.; Sousa, A.J. & Neumann, V.H.M.L. 2022. Aptian ostracods from the Santana Group, Araripe Basin, Brazil. *Revue de Micropaléontologie*, **77**:100694. *doi:10.11606/issn.2316-9095.v20-163467*

Guzmán, J.; Piovesan E.K.; Melo, R.M.; Almeida-Lima, D.; Sousa, A.J.S. & Neumann, V.H.M.L. 2023. Ostracoda and foraminifera biostratigraphy and palaeoenvironmental evolution of the Aptian Santana Group, post-rift of the Araripe Basin, Brazil. *Gondwana Research*, **124**:18–38. *doi:10.1016/j.gr.2023.06.014*

Hiruta, S.F. & Kakui, K. 2016. Three new brackish water thalassocypridine species (Crustacea: Ostracoda: Paracyprididae) from the Ryukyu Islands, southwestern Japan. *Zootaxa*, **4169**:515–539. *doi:10.11646/zootaxa.4169.3.6*

Horne, D.J.; Cohen, A. & Martens, K. 2002. Taxonomy, Morphology and Biology of Quaternary and Living Ostracoda. *In*: J.A. Holmes & A. Chivas (eds.) *The Ostracoda: Applications in Quaternary Research. American Geophysical Union, Geophysical Monograph Series*, Vol. 131, American Geophysical Union, p. 5–36. *doi:10.1029/131GM02*

Jones, R. & Charnock, M. 1985. Morphogroups of agglutinating foraminifera. Their life positions and feeding habits and potential applicability in (paleo)ecological studies. *Revue de Paleobiologie,* **4**:311–320.

Kaminski, M.A.; Boersma, A.; Tyszka, J. & Holbourn, A.E.L. 1995. Response of deep- water agglutinated foraminifera to dysoxic conditions in the California Borderland basins. *In*: M.A. Kaminski; S. Geroch & M.A. Gasifski (eds.) *Proceedings 4th International Workshop on Agglutinated Foraminifera 1993*, Vol. 3, Grzybowski Foundation Special Publication, p. 131–140.

Kaminski, M.A. & Kuhnt, W. 1995. Tubular agglutinated foraminifera as indicators of organic carbon flux. *In*: M.A. Kaminski; S. Geroch & M.A. Gasifski (eds.) *Proceedings 4th International Workshop on Agglutinated Foraminifera 1993*, Vol. 3, Grzybowski Foundation Special Publication, p. 141–144.

Kellner, A.W.A. 2002. Membro Romualdo da Formação Santana, Chapada do Araripe, CE: um dos mais importantes depósitos fossilíferos do Cretáceo brasileiro. *In*: C. Schobbenhaus; D.A. Campos; E.T. Queiroz; M. Winge & M. Berbert-Born (eds.) *Sítios Geológicos e Paleontológicos do Brasil*, DNPM, p. 121–130.

Kellner, A.W.A. & Campos, D.A. 1999. Vertebrate paleontology in Brazil — a review. *Episodes*, **22**:238–251. *doi:10.18814/epiiugs/1999/v22i3/012*

Krömmelbein, K. & Weber, R. 1971. Ostracoden des "Nordost-Brasilianischen Wealden". *Geologisches Jahrbuch*, **115**:1–93.

Kuchle, J. & Scherer, C.M.S. 2010. Sismoestratigrafia de bacias rifte: Técnicas, métodos e sua aplicação na Bacia do Recôncavo. *Boletim de Geociências da Petrobras*, **18**:179–206.

Mabesoone, J.M. & Tinoco, I.M. 1973. Palaeoecology of the Aptian Santana formation (northeastern Brazil). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **14**:97–118. *doi:10.1016/0031-0182(73)90006-0*

Maisey, J.G. 1991. *Santana Fossils: An Illustrated Atlas*. Neptune City, T.F.H. Publications 459 p.

Maisey, J.G. 2000. Continental break up and the distribution of fishes of Western Gondwana during the Early Cretaceous. *Cretaceous Research*, **21**:281–314. *doi:10.1006/cres.1999.0195*

Matos, R.M.D. 1992. The northeast Brazilian rift system. *Tectonics*, **11**:766791. *doi:10.1029/91TC03092*

Melo, R.M.; Guzmán, J.; Almeida-Lima, D.; Piovesan, E.K.; Neumann, V.H.M.L. & Sousa, A.J. 2020. New marine data and age accuracy of the Romualdo Formation, Araripe Basin, Brazil. *Scientific Reports*, **10**:15779. *doi:10.1038/s41598-020-72789-8*

Menor, E.A.; Cavalcanti, V.M.M. & Sena, R.B. 1993. Os eventos evaporíticos da Formação Santana, Bacia do Araripe, Nordeste do Brasil. *Revista de Geologia*, **6**:93–104.

Morales, N. & Assine, M.L. 2015. Chapada do Araripe: A Highland Oasis Incrusted into the Semi-arid Region of Northeastern Brazil. *In*: B. Vieira; A. Salgado & L. Santos (eds.) *Landscapes and Landforms of Brazil. World Geomorphological Landscapes*, Springer, p. 231–242. *doi:10.1007/978-94-017-8023-0_21*

Neumann, V.H.M.L.; Borrego, A.G.; Cabrera, L. & Dino, R. 2003. Organic matter composition and distribution through the Aptian-Albian lacustrine sequences of the Araripe Basin, northeastern Brazil. *International Journal of Coal Geology*, **54**:21–40. *doi:10.1016/S0166-5162(03)00018-1*

Osés, G. L. *et al.*, 2016. Deciphering the preservation of fossil insects: a case study from the Crato Member, Early Cretaceous of Brazil. *Peer J*, **4**:e2756. *doi:10.7717/peerj.2756*

Osés, G.L. *et al.* 2017. Deciphering pyritization-kerogenization gradient for fish soft-tissue preservation. *Scientific Reports*, **7**:1468. *doi:10.1038/s41598-017-01563-0*

Ponte, F.C. & Asmus, F.C. 1976. The Brazilian marginal basins: current state of knowledge. *Anais da Academia Brasileira de Ciências*, **48**:215–239.

Ponte, F.C. & Ponte Filho, F.C. 1996. *Estrutura Geológica e Evolução Tectônica da Bacia do Araripe (technical report)*. Recife, DNPM, 68 p.

Rodriguez-Lazaro, J. & Ruiz-Muñoz, F. 2012. A General Introduction to Ostracods: Morphology, Distribution, Fossil Record and Applications. *In*: D.J. Horne; J.A. Holmes; J. Rodriguez-Lazaro & F.A. Viehberg (eds.) *Developments in Quaternary Sciences*, Vol. 17, Elsevier, p. 1–14. *doi:10.1016/B978-0-444-53636-5.00001-9*

Scherer, C.M.S.; Sá, E.F.J.; Córdoba, V.C.; Sousa, D.C.; Aquino, M.M. & Cardoso, F.M.C. 2014. Tectono-stratigraphic evolution of the Upper Jurassic-Neocomian rift succession, Araripe Basin, Northeast Brazil. *Journal of South American Earth Sciences*, **49**:106–122. *doi:10.1016/j.jsames.2013.10.007*

Smith, A.J. & Horne, D.J. 2002. Ecology of Marine, Marginal Marine and Nonmarine Ostracodes. *In*: J.A. Holmes & A.R. Chivas (eds.) *The Ostracoda: Applications, Quaternary Research*, , American Geophysical Union, p. 37–64. *doi:10.1029/131GM03*

Tomé, M.E.; Araripe, R.; Oliveira, D.; Barreto, A.M.F.; Prado, L.; Pedrosa, F.; Pereira, P.; Nascimento, L.R. & Ng, C. 2022. Early Cretaceous Ostracoda (Crustacea) from south-central Araripe Basin, Brazil, with descriptions of seven new species. *Zootaxa*, **5159**:535–557. *doi:10.11646/zootaxa.5159.4.4*

Tomé, M.E.; Lima Filho, M.F. & Neumann, V.M.L. 2014. Taxonomic studies of non-marine ostracods in the lower cretaceous (Aptian-lower Albian) of post-rift sequence from Jatobá and Araripe basins (Northeast Brazil): Stratigraphic implications. *Cretaceous Research*, **48**:153–176. *doi:10.1016/j.cretres.2013.12.007*

Varejão, F.G.; Fürsich, F.T.; Warren, L.V.; Matos, S.A.; Rodrigues, M.G.; Assine, M.L.; Sales, A.M.F. & Simões, M.G. 2019. Microbialite fields developed in a protected rocky coastline: The shallow carbonate ramp of the Aptian Romualdo Formation (Araripe Basin, NE Brazil). *Sedimentary Geology*, **389**:103–120. *doi:10.1016/j.sedgeo.2019.06.003*

Varejão, F.G.; Silva, V.R.; Assine, M.L.; Warren, L.V.; Matos, S.A.; Rodrigues, M.G.; Fürsich, F.T. & Simões, M.G. 2021a. Marine or freshwater? Accessing the paleoenvironmental parameters of the Caldas Bed, a key marker bed in the Crato Formation (Araripe Basin, NE Brazil). *Brazilian Journal of Geology*, **51**:e2020009. *doi:10.1111/sed.12846*

Varejão, F.G.; Warren, L.V.; Simões, M.G.; Buatois, L.A.; Mángano, M.G.; Bahniuk Rumbelsperger, A.M. & Assine, M.L. 2021b. Mixed siliciclastic–carbonate sedimentation in an evolving epicontinental sea: Aptian record of marginal marine settings in the interior basins of north-eastern Brazil. *Sedimentology*, **68**:2125–2164. *doi:10.1111/sed.12846*