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Ostracoda and foraminifera from Paleocene (Olinda well), Paraíba Basin, Brazilian Northeast

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ABSTRACT

Paleocene ostracods and planktonic foraminifera from the Maria Farinha Formation, Paraíba Basin, are herein presented. Eleven ostracod species were identified in the genera *Cytherella* Jones, *Cytherelloidea* Alexander, *Eocytheropteron* Alexander, *Semicytherura* Wagner, *Paracosta* Siddiqui, *Buntonia* Howe, *Soudanella* Apostolescu, *Leguminocythereis* Howe and, probably, *Pataviella* Liebau. The planktonic foraminifera are represented by the genera *Guembelitria* Cushman, *Parvularugoglobigerina* Hofker, *Woodringina* Loeblich and Tappan, *Heterohelix* Ehrenberg, *Zeauvigerina* Finlay, *Muricohedbergella* Huber and Leckie, and *Praemurica* Olsson, Hemleben, Berggren and Liu. The ostracods and foraminifera analyzed indicate an inner shelf paleoenvironment for the studied section. Blooms of *Guembelitria* spp., which indicate either shallow environments or upwelling zones, were also recorded reinforcing previous paleoenvironmental interpretations based on other fossil groups for this basin.

Key words: Brazil, ostracods, Paleocene, Paraíba Basin, foraminifera.

INTRODUCTION

The Paraíba Basin, located in northeastern Brazilian, is well known for its remarkable paleontological content, and by a rather continuous and exposed record of the Cretaceous-Paleogene (K-Pg) boundary. The Upper Cretaceous (Maastrichtian) deposits of this basin constitute the Gramame Formation, while the Paleogene ones are included in the Maria Farinha Formation. The Gramame Formation is characterized by deposits of both calcareous marl and marl without siliciclastic influence deposited in a high energy shallow platform environment under low to moderate action of periodic storms. The overlying Maria Farinha Formation is composed also of calcareous marl, as well as marls with more siliciclastic influence (see Barbosa et al. 2006 and references therein).

The interval between the end of Cretaceous and the beginning of Paleogene was characterized

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by several catastrophic events that caused the extinction of a significant part of the biota and the emergence of new lineages. Many hypotheses have been proposed as the main triggers of those changes. According to one of them, the impact of an asteroid would have been the causal factor of the mass extinctions (Alvarez et al. 1980). In another hypothesis, proposed by Courtillot et al. (1986), the extinction would have been caused by the intense volcanism in Deccan, India (the so-called Deccan traps), which caused huge continental flows of basalt (CFB) associated with the large igneous regions. More recently Keller et al. (2003) and Keller (2014) sustained that these changes in the Earth were caused by several events acting simultaneously.

According to Birch et al. (2016), the coherence of terrestrial and marine proxy data is especially strong with regard to warming beginning near 65.9–66.0 Ma, a peak of warming from 65.8 to 65.6 Ma, and cooling immediately before the K–Pg, and the authors interpret these as climate shifts of global extent. Based on paleontological data, Ashrof and Stinnesbeck (1989), suggested important climatic changes from tropical to subtropical conditions during the Maastrichtian to a subtropical to temperate conditions during the Paleocene in the Paraíba Basin. Oxygen isotope data corroborate this interpretation, showing a slight increase of temperature during the Cretaceous-Paleogene transition, followed by a slight temperature decrease in the Paraíba Basin (Nascimento et al. 2011). The Paleogene deposits of the Paraíba Basin are interpreted as shallow marine environments connected with a regressive event (lowstand system tract) (e.g., Mabesoone et al. 1991, Barbosa et al. 2003, 2006, Fauth et al. 2005, Córdoba et al. 2007). This event is interpreted as a regression forced by the combination of eustatic sea level fall (Haq 2014) and local rising tectonic processes (Barbosa et al. 2003). Due to the regression, the strata of the Maria Farinha Formation were preserved only in a narrow belt along the coast.

The Maria Farinha Formation holds abundant and well-preserved microfossil assemblages, including calcareous nannofossils, foraminifers, palynomorphs and ostracods. The first study on Paleogene ostracods of the Paraíba Basin was carried out by Tinoco (1967), who reported the occurrence of the marine genera *Cytherella* Jones, *Costa* Neviani, *Cytheretta* Muller, *Bairdia* M'Coy, *Monoceratina* Roth, *Cytheropteron* Sars, *Pontocythere* Dubowsky and *Paracypris* Sars. Stinnesbeck and Reyment (1988) reported that the ostracod assemblages in the Maria Farinha Formation contain rare but well-preserved *Brachycythere* sp., *Dahomeya* sp. and *Soudanella laciniosa* Apostolescu 1961. A more comprehensive study, carried out by Fauth et al. (2005), reported abundant and diverse ostracod assemblages composed of 17 species, with three of them described as new. According to Fauth (2002), the Paleocene ostracod fauna has strong affinities with north, central and southern of South America, and west, north and central Africa.

The Maastrichtian and Paleogene sections in the Paraíba Basin are well characterized by planktonic foraminifer studies (Mabesoone et al. 1968, Tinoco 1967, 1976, 1977, 1978, Tinoco and Siqueira 1976). Subsequently, biostratigraphic and paleoenvironmental studies were intensified (Albertão et al. 1994, Stinnesbeck and Keller 1995, Koutsoukos 1996, 2006, Gertsch et al. 2013), mainly in the K-Pg boundary sequence of the Poty quarry, where the uppermost Maastrichtian *Plummerita hantkeninoides* Zone (CF1) was identified. In the Paleocene, the upper Pα, P1a/P1b and P1c zones were identified, above a biostratigraphic gap at the base, which was recognized by the absence of the *Guembelitria cretacea* Zone (P0) and the basal part of Pα (Koutsoukos 1996, 2006), which may extend up to the top of *Plummerita hantkeninoides* Zone (CF1) according to the studies of Gertsch et al. (2013).

The main purpose of this article is to present the microfossil assemblages (Foraminifera and Ostracoda) from the Olinda well, Paraíba Basin, in order to contribute to the taxonomic, stratigraphic and paleoenvironmental knowledge of the Maria Farinha Formation, and provide additional data on the geological evolution of this basin in the Paleocene.

STUDY AREA AND GEOLOGICAL SETTING

The geological evolution of eastern Brazilian sedimentary basins is related to the breakup of the western Gondwana supercontinent and development of the South Atlantic Ocean in the Late Jurassic–Early Cretaceous (Cainelli and Mohriak 1999, Mohriak et al. 2008). The onshore and offshore areas of the Paraíba Basin comprise approximately 7600 km^2 and 31400 km^2, respectively, extending to the isobath of 3000 m. The south limit of this basin in the coastal zone is the Pernambuco Shear Zone (ZCPE), and the north limit is the Patos Shear Zone (ZCPA) (Fig. 1).

The tectonism that originated and shaped the Paraíba Basin generated two depocenters that split the basin into the Olinda Sub-basin and the Alhandra/Miriri Sub-basin. The first one is bordered in the south by the Pernambuco Shear Zone (ZCPE), and in the north with the Alhandra/Miriri Sub-basin by the Goiania High. The Alhandra/Miriri is limited in the north by the Mamanguape Fault (Mabesoone and Alheiros 1988, 1993, Barbosa et al. 2003).

The evolution of the Olinda Sub-basin is characterized by three tectonic phases. The first phase is represented by the opening and emergence of a rift (NW-SE) in the distal portion of the sub-basin. Subsequently, a distensive phase (NE-SW) was set up with the formation of valleys and filled by clastic wedges. Finally, in the third phase (Paleogene), the NW-SE structures were reactivated, influencing the limestone deposits.

The sedimentary deposits of the Paraíba Basin consist of a continental-transitional sequence (Beberibe and Itamaracá formations) including the Coniacian?-Campanian interval, a marine sequence (Itamaracá, Gramame and Maria Farinha formations) deposited in the Campanian-Paleocene (Lima Filho et al. 1998, Barbosa et al. 2003), a restricted reef-lagoon (Tambaba Formation), corresponding to the Eocene (Correia Filho et al. 2015), and finally the continental siliciclastic sequence (Miocene-Recent) represented by the Barreiras Formation and recent deposits.

The Maria Farinha Formation overlies the Gramame Formation and is underlain by an erosional contact (Albertão and Martins 1996). It was deposited in a deep-middle neritic environment, and its lithology changes from limestone in the base to siliciclastic (shales) in the upper portion. According to Barbosa et al. (2006) this lithostratigraphic unit is restricted to the Olinda Sub-basin (south part of the Paraíba Basin) due to the tectonically forced regression that influenced the deposition in the Paleocene in the north Alhandra/Miriri Sub-basin.

MATERIALS AND METHODS

The studied material consists of 16 samples collected along a stratigraphical interval of 8.05 m of the Olinda well. This core was drilled by the Universidade Federal de Pernambuco (UFPE) near the Poty quarry, in Olinda City, Pernambuco State (UTM 0296669E 9116303N) (Fig. 1). In the lower portion, it consists mostly of limestone and, in the upper, the incidence of siliciclastic rocks is higher. For this study, samples were chosen from the Paleocene, which was correlated using the distribution of the ostracod fauna of Fauth et al. (2005) and the international foraminiferal biostratigraphical framework by Gradstein et al. (2012).

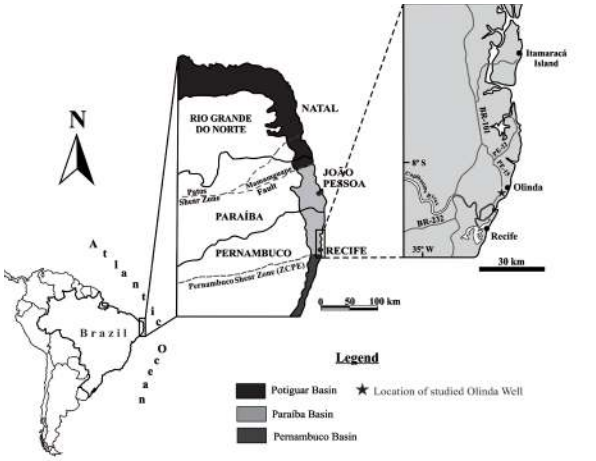

Figure 1 - The Paraíba Basin, showing the position of the studied well in Olinda city, Pernambuco State, Brazil (modified from Barbosa et al. 2003 and Gertsch et al. 2013).

The analyzed section (39.15 m-31.35 m) is represented by limestone with lithologic variations. In the base of the section (38.15m-38.05m), grayish conglomeratic limestone predominates and show the presence of bioturbation, sparse sedimentary structures and intraclasts. Near to the base (38.97 m), there is a thin clay layer. In the middle (38.05 m-33.96 m) beige marl predominates and contain in the lower to middle part dark clay layers (37.1 m, 37.0 m, 36.7 m and 35.5 m), and in the middle to upper part the occurrence of convolution (post-depositional processes, slumps?) sparse intraclasts and bioclasts. The top of the section presents interspersed layers of grayish marly limestone and dark gray marl. There are records of sedimentary structures and intraclasts. At 33.1 m depth is a rich layer of bioclasts. Bioturbation was registered along all the section.

The samples were prepared according to the usual techniques for calcareous microfossils, which consist basically in an overnight soaking in hydrogen peroxide P.A. (H_2O_2), washing over a 0.062 mm sieve and H_2O_2 under heat for 2 hours. Afterwards, the samples were split into three meshes (0.250, 0.180 and 0.062 mm) and dried at 60°C. All ostracods and foraminifera from the three fractions were picked. Whenever necessary, the specimens were cleaned in ultrasonic baths for a few minutes before being imaged under a scanning electron microscope (SEM). The figured specimens are deposited at the collections of the Departamento de Geologia, Universidade Federal de Pernambuco, under the prefix DGEO-CTG-UFPE followed by their respective catalogue numbers.

SYSTEMATIC PALEONTOLOGY

OSTRACODS

Taxonomy follows the classification by Horne (2005). For the species in open nomenclature a brief description is included. The following abbreviations and conventions are employed: L: length, H: height, W: width; very small (<0.400 mm), small (0.400-0.500mm), medium (0.510-0.700 mm), large (0.710-0.900 mm), very large (>0.900 mm); C: carapace, RV: right view, LV: left view, DV: dorsal view. All measurements are in millimeters (mm).

Class Ostracoda Latreille 1802
Subclass Podocopa Sars 1866
Order Platycopida Sars 1866
Suborder Platycopina Sars 1866
Superfamily Cytherelloidea Sars 1866
Family Cytherellidae Sars 1866

Genus *Cytherella* Jones 1849

Cytherella piacabucuensis Neufville 1973
Figure 2, a

1973 Cytherella piacabucuensis Neufville, pp. 38-41, Pl. 6.1, Figs. 3a-b, Pl. 6.2, Figs. 1a-b.

1979 *Cytherella piacabucuensis*. Neufville, p. 137-138, Pl. 1, Figs. 3a-d.

1990 *Cytherella piacabucuensis*. Bassiouni and Luger, p. 777-778, Pl. 1, Figs. 7-12.

2005 *Cytherella piacabucuensis.* Fauth et al., p. 286, 288, 289 and 290, Pl. 4, Figs. 1-4.

Material: Eight C.

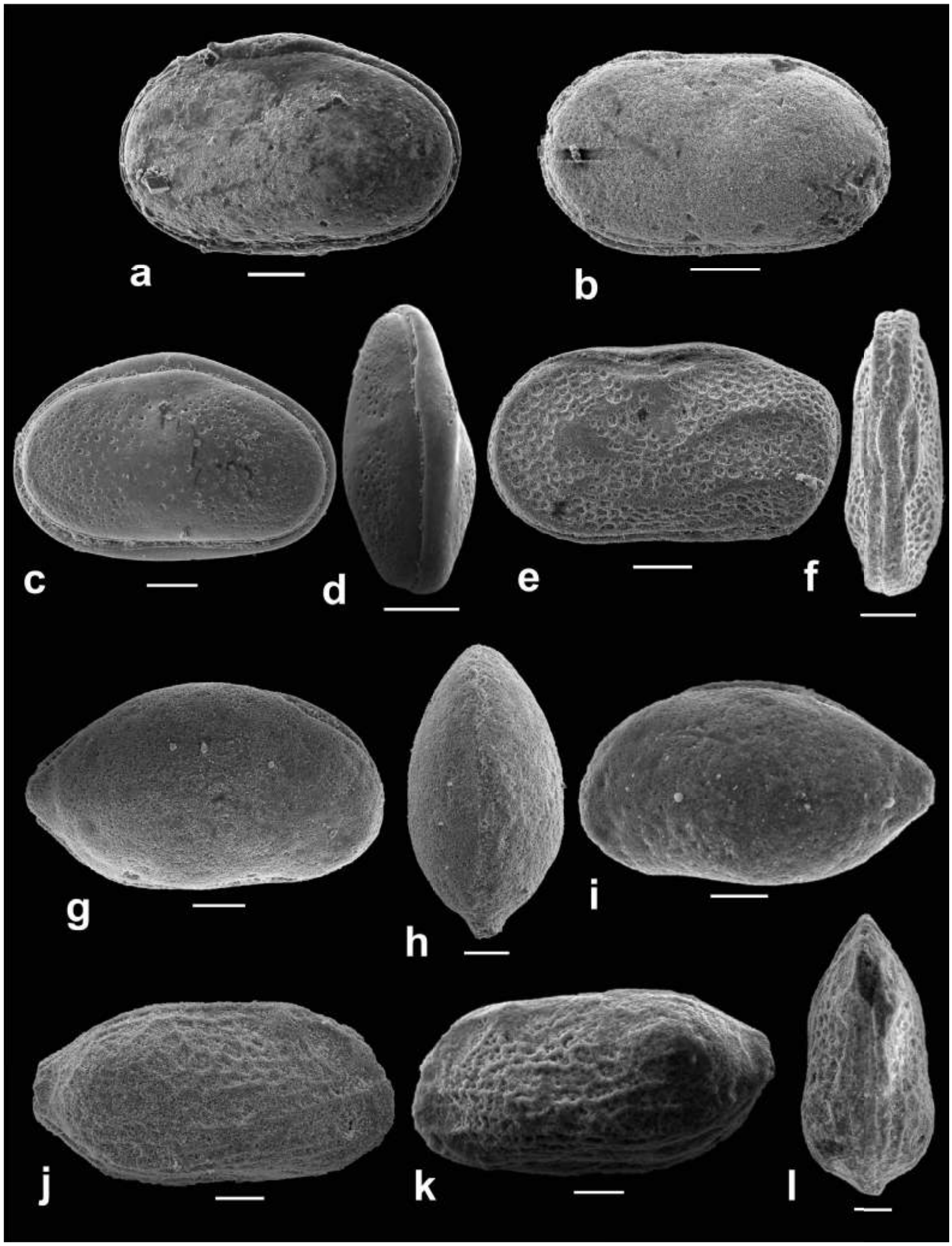

Figure 2 - Scanning electron micrographs of ostracods from Paleocene, Maria Farinha Formation, Paraíba Basin. **a**. *Cytherella piacabucuensis* Neufville, 1973, C, LV, DGEO-CTG-UFPE-1432. **b**. *Cytherella* sp. 1, C, LV, DGEO-CTG-UFPE-1410. **c-d**. *Cytherella* sp. 2, **c**, C, LV, DGEO-CTG-UFPE-1411; **d**, same specimen DV. **e-f**. *Cytherelloidea* sp., **e**, C, LV, DGEO-CTG-UFPE-1412; **f**, C, DV DGEO-CTG-UFPE-1413. **g-i**. *Eocytheropteron* sp., **g**, C, RV, DGEO-CTG-UFPE-1414; **h**, C, DV, DGEO-CTG-UFPE-1415; **i**, C, LV, DGEO-CTG-UFPE-1416. **j-l**. *Semicytherura* sp., **j**, C, male, RV, DGEO-CTG-UFPE-1417; **k**, same specimen, LV; **l**, C, male, DV, DGEO-CTG-UFPE-1418. Scale bars: a-f=100 μm; g-l=50 μm.

Illustrated material: DGEO-CTG-UFPE-1432: C, LV, L: 0.630; H: 0.409.

Occurrence: Olinda well, 35.25 m, 37.35 m.

Stratigraphic distribution: Middle Paleocene–lower Eocene of Egypt (Bassiouni and Luger 1990), Danian of the Sergipe-Alagoas Basin, Brazilian northeast (Neufville 1973, 1979) and Paleocene of the Paraíba Basin (Fauth et al. 2005 and this work).

Remarks: *Cytherella piacabucuensis* is a good stratigraphic marker for Paleogene strata in Brazilian and African Basins.

Cytherella sp. 1

Figure 2, b

Material: Two C.

Illustrated material: DGEO-CTG-UFPE-1410: C, LV, L: 0.550; H: 0.320.

Short description: Medium-sized carapace; sub-rectangular in lateral view. RV overlaps the LV symmetrically along all margins. Anterior margin somewhat asymmetrically rounded; posterior margin less broadly rounded than the anterior. Dorsal and ventral margins almost straight and subparallel. Maximum height in the anterior third of the carapace. Surface entirely covered by small punctuations.

Stratigraphic distribution: Paleocene of the Paraíba Basin (this work).

Occurrence: Olinda well, 32.25 m, 34.65 m.

Remarks: Fauth et al. (2005) recorded a similar species in the Maastrichtian of Poty quarry, Paraíba Basin (*Cytherella* sp. 2, p. 290-291, Figs. 4.11-12). The species recorded herein differs mainly by the dorsal outline, which is straighter, and the whole punctuated surface. *Cytherella harmoniensis* Bold 1960, recorded in Eocene of Trinidad, is bigger and more ovate.

Cytherella sp. 2

Figure 2, c-d

Material: Two C.

Illustrated material: DGEO-CTG-UFPE-1411: C, LV and DV, L: 0.660; H: 0.424; W: 0.275.

Short description: Medium-sized carapace; sub-ovoid in lateral view. RV strongly overlapping the LV along all margins. Anterior and posterior margins asymmetrically rounded; posterior end narrower. Dorsal margin arched, ventral margin almost straight. Maximum height and width at the mid region. A depressed region is present in the mid-dorsal part of the carapace. Surface punctuated, more densely in the anterior and posterior regions. The size of the pits decreases towards the periphery of the carapace.

Stratigraphic distribution: Paleocene of the Paraíba Basin (this work).

Occurrence: Olinda well, 38.85-39.15 m.

Remarks: This species differs from other *Cytherella* species recorded in the Paraíba Basin in the more angular posterodorsal outline, in the punctuation pattern and in the stronger overlap of the RV, along all margins. *Cytherella piacabucuensis* Neufville 1973, recorded in the Middle Paleocene of Egypt (Bassiouni and Luger 1990), Danian of Sergipe-Alagoas Basin (Neufville 1973, 1979) and Danian of the Paraíba Basin (Fauth et al. 2005) differs mainly in the more symmetrically rounded outline and lack of ornamentation.

Genus *Cytherelloidea* Alexander 1929

Cytherelloidea sp.

Figure 2, e-f

Material: Three C.

Illustrated material: DGEO-CTG-UFPE-1412: C, LV, L: 0.622; H: 0.351 DGEO-CTG-UFPE-1413: C, DV. L: 0.524; W: 0.181.

Short description: Medium-sized carapace; laterally compressed; subrectangular in lateral view. RV larger than LV, overlapping it strongly in the dorsal and posteroventral regions; dorsal margin sloping gently backwards; ventral margin almost straight. Posterior margin obliquely truncate; anterior margin broadly rounded, gently denticulate. Maximum height just behind the middle portion; greatest width at the posterior third. External surface strongly pitted, presence of an antero-marginal ridge and two longitudinal ridges: a very sinuous medium ridge, running from the posterior region to the middle one; a shorter ventrolateral ridge, from the posterior to the medium region. Stratigraphic distribution: Paleocene of the Paraíba Basin (this work).

Occurrence: Olinda well, 36.15 m.

Remarks: This species is similar to *Cytherelloidea* sp. aff. *C. keiji* Mckenzie 1967 from the Paleocene of Senegal (Diop et al. 1982), but presents two median ridges. Compared with *Cytherelloidea keiji* Mckenzie 1967, recorded firstly in Recent deposits, the Brazilian specimens are shorter, with median ridges more sinuous and dorsal margin slightly concave. It is worthy to be mentioned that Malz (1981) reassigned *C. keiji* to *Keijcyoidea* Malz, a genus proposed on Paleocene material from the Emperor Seamounts Ridge, in the Pacific Ocean. Bergue and Coimbra (2002) recorded the genus *Keijcyoidea* in Holocene deposits from Brazilian equatorial shelf. Therefore, *Cytherelloidea* sp. possibly constitutes the first fossil species of *Keijcyoidea* recorded in Brazil.

Order Podocopida Sars 1866
Suborder Cytherocopina Baird 1850
Superfamily Cytheroidea Baird 1850
Family Cytheruridae G.W. Müller 1894

Genus *Eocytheropteron* Alexander 1933

Eocytheropteron sp.
Figure 2, g-i

Material: Five C.

Illustrated material: DGEO-CTG-UFPE-1414, C, RV. L: 0.328; H: 0.189. DGEO-CTG-UFPE-1415, C, DV. L: 0.327; W: 0.173; DGEO-CTG-UFPE-1416, C, LV. L: 0.317; H: 0.188.

Short description: Carapace very small, subtrapezoidal in lateral view, egg-shaped in dorsal view, short caudal process, without wing-like lateral expansions. LV overlapping the RV conspicuously along all margins, except the dorsal one, where this pattern is inverted. Maximum height just behind the middle portion; greatest width at the middle. Surface smooth.

Stratigraphical distribution: Paleocene of the Paraíba Basin (this work).

Occurrence: Olinda well, 35.55 m, 36.45 m, 37.35 m.

Remarks: *Eocytheroteron* sp. differs from *E. trapezoidalis* Carbonnel 1990, from the Paleocene of Niger, by the smaller size and smooth surface. Furthermore, *E. trapezoidalis* presents the caudal process more projected upward and acuminated. In the Upper Cretaceous from the Potiguar Basin, Piovesan et al. (2014) recorded two species of *Eocytheropteron*, both differing significantly from the species here recorded, especially in size, outline and ornamentation.

Genus *Semicytherura* Wagner 1957

Semicytherura sp.
Figure 2, j-l

Material: Two C.

Illustrated material: DGEO-CTG-UFPE-1417, C; DV; L: 0.395, H: 0.202, W: 0.178; DGEO-CTG-UFPE-1418, C; LV; L: 0.364, H: 0.189.

Short description: Carapace very small, subrectangular and elongate in lateral view; LV overlaps the RV in dorsal and posteroventral regions. Dorsal margin almost straight, ventral margin with small concavity in the mid-length. Anterior margin nearly rounded, posterior margin subtriangular, with a truncated caudal process slightly above the mid-height. Maximum width at posterior third. Anterior region very compressed. Surface with small and irregular reticula and weak

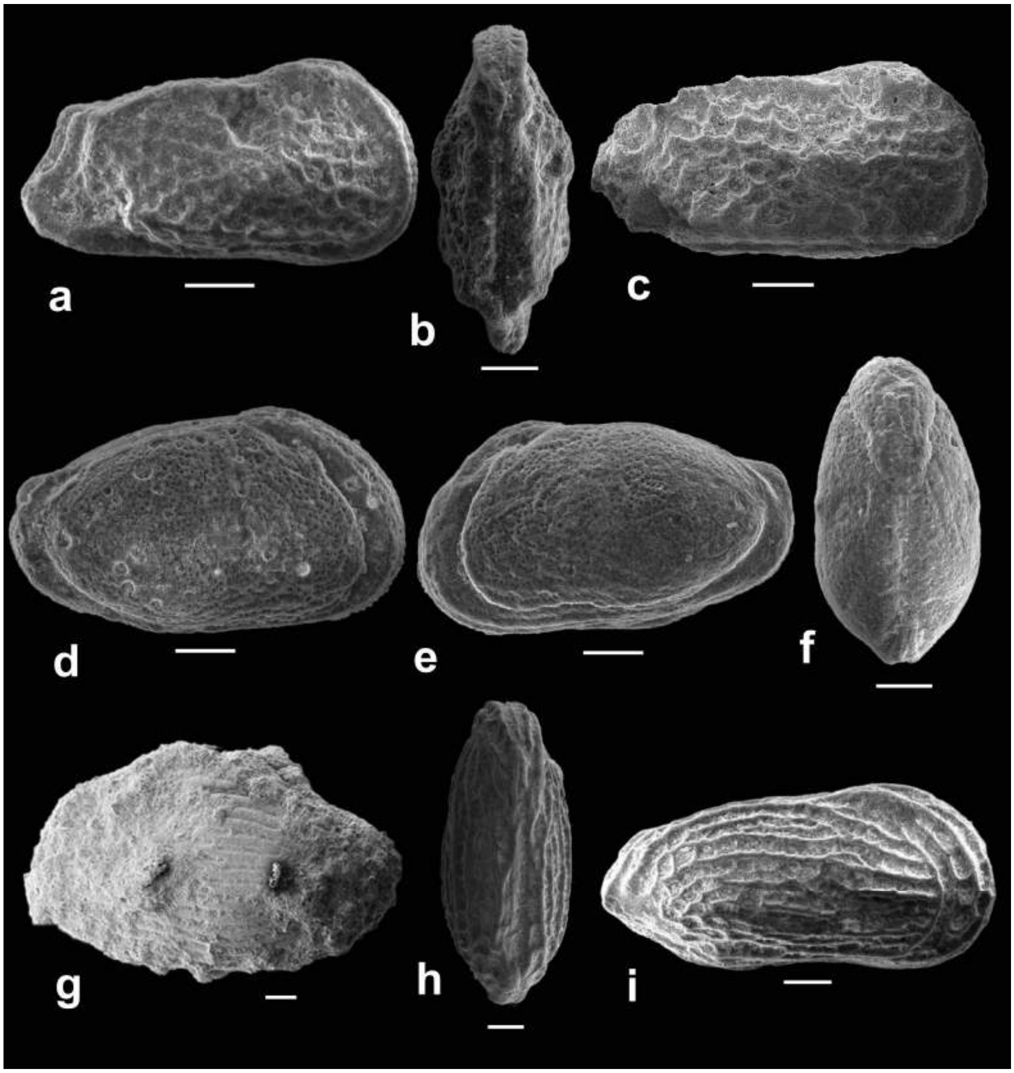

Figure 3 - Scanning electron micrographs of ostracods from the Paleocene, Maria Farinha Formation, Paraíba Basin. **a-b**. *Pataviella*? sp., **a**, C, RV, ULVG 11473, DGEO-CTG-UFPE-1419; **b**, same specimen, DV. **c**. *Paracosta recifeiensis* Fauth et al. 2005, C, RV, DGEO-CTG-UFPE-1420. **d-f**. *Buntonia* sp., **d**, C, RV, DGEO-CTG-UFPE-1421; **e**, C, LV, DGEO-CTG-UFPE-1422; **f**, C, DV, DGEO-CTG-UFPE-1423**. g**. *Soudanella lacioniosa* Apostolescu 1961, C, female, LV, lost specimen. **h-i**. *Leguminocythereis* sp., **h**, C, male, DV, DGEO-CTG-UFPE-1424; **i**, same specimen, RV. Scale bars = 100 μm.

ribs in ventral and dorsal regions. Eye tubercles pronounced.

Stratigraphical distribution: Paleocene of the Paraíba Basin (this work).

Occurrence: Olinda well, 36.45 m, 37.35 m.

Remarks: This species resembles *Semicytherura musacchioi* Piovesan, Cabral and Colin 2014, recorded in the Santonian–Campanian of the Potiguar Basin (Piovesan et al. 2014), but has a more rounded anterior outline, weaker reticula and the maximum width at the posterior third.

Family Hemicytheridae Puri 1953

Genus *Pataviella* Liebau 1991

Pataviella? sp.
Figure 3, a-b

Material: Five C.

Illustrated material: DGEO-CTG-UFPE-1419, C, RV and DV, L: 0.585; H: 0.308, W: 0.273.

Short description: Medium-sized carapace, subrectangular in lateral view. LV overlaps the RV more conspicuously in the posterodorsal and anterodorsal margins. Dorsal outline slightly convex, ventral margin, straight to concave at the mid. Anterior outline obliquely rounded and posterior subtriangular caudate. Anteromarginal denticles very small. Surface reticulated, with a conspicuous rib that runs from post-ocular sulcus to the posterior region; another strong rib is alate and subparallel to the ventral margin. Eye tubercles conspicuous; subcentral tubercle well-developed.

Stratigraphical distribution: Paleocene of the Paraíba Basin (this work).

Occurrence: Olinda well, 36.15 m, 36.45 m, 37.35 m.

Remarks: This taxon is tentatively assigned to *Pataviella* Liebau 1991, but has the dorsal rib less convex and more elongated shape. The most similar species is *P. mbeganendouri* Sarr 1999, recorded in Paleocene strata of Senegal. The African species differs in the posterior outline, which is more rounded, and the more robust and convex dorsal rib.

Family Trachyleberididae Sylvester-Bradley 1948

Genus *Paracosta* Siddiqui 1971

Paracosta recifeiensis Fauth et al. 2005
Figure 3, c

2005 *Paracosta recifeiensis* Fauth et al., p. 295-296, Pl. 5, Figs. 10,13,14, Pl. 6, Figs. 1-3.

Material: One C.

Illustrated material: DGEO-CTG-UFPE-1420, C; RV; L: 0.660, H: 0.320.

Stratigraphical distribution: Lower Danian of the Paraíba Basin (Fauth et al. 2005), Paleocene (this work).

Occurrence: Olinda well, 36.15 m.

Remarks: This species is typical from Danian of the Paraíba Basin (Fauth et al. 2005). The only specimen recorded is probably a juvenile, due to its smaller size compared to the holotype.

Subfamily Buntoniinae Apostolescu 1961

Genus *Buntonia* Howe 1935

Buntonia sp.
Figure 3, d-f

Material: Three C.

Illustrated material: DGEO-CTG-UFPE-1421, C, RV. L: 0.684; H: 0.375; DGEO-CTG-UFPE-1422, C; LV; L: 0.672, H: 0.383; DGEO-CTG-UFPE-1423, C; DV; L: 0.580, W: 0.300.

Short description: Medium-sized carapace, subrectangular to ovoid, in lateral view. LV overlaps the RV in posterodorsal, dorsal and anterodorsal margins. Dorsal margin almost straight, ventral margin rather convex. Anterior outline obliquely rounded; posterior angular. Strongly ovoid in dorsal view. The anterior, posterior and ventral regions compressed. Anteromarginal rib very developed. Surface covered with small puncutations, except in the compressed regions.

Stratigraphical distribution: Paleocene of the Paraíba Basin (this work).

Occurrence: Olinda well, 36.15 m, 37.35 m.

Remarks: The genus *Buntonia* Howe is very common in the Paleocene of African basins (e.g., Apostolescu 1961, 1963, Reyment 1963, Foster et al. 1983, Okosun 1987, Carbonnel et al. 1990, Sarr 1999) and South America (e.g., Bertels 1973, Ceolin et al. 2011). This species differs from others by its rounded posterior outline and strong anteromarginal rib clearly seen in dorsal view. Compared to *Buntonia tichittensis* Apostolescu 1961, from the Paleocene of Senegal, our species is bigger, the punctuation is less prominent and the anterodorsal sulcus absent. Probably, it is a new species, but the scarcity and poor preservation of the material prevents its description.

Genus *Soudanella* Apostolescu 1961

Soudanella laciniosa Apostolescu 1961
Figure 3, g

1961 *Soudanella laciniosa laciniosa* n. g. n. sub. sp. Apostolescu, p. 809, Pl. 6, Figs. 124-126; Pl. 7, Fig. 136; Pl. 16, Figs. 304-306.

1973 *Soudenella* [sic] *laciniosa triangulata* Apostolescu. Neufville, p. 96-98, Pl. 6.11, Figs. 1 a-b.

1979 *Soudanella laciniosa* Apostolescu. Neufville, p. 153-154, Pl. 6, Figs. 1 a-b.

1991 *Soudanella laciniosa* Apostolescu. Reyment and Aranki, p. 24, Pl. 2, Figs. 1a-b, 2a-b, 3a-b.

1998 *Soudanella* cf. *S. laciniosa laciniosa* Apostolescu. Colin et al., p. 311, Pl. 3, Fig. 28.

2005 *Soudanella laciniosa* Apostolescu. Fauth et al., p. 299-301, Pl. 8, Figs. 1-6.

Material: Three C (two broken).

Illustrated material: C, LV. L: 1.361; H: 0.862 (lost).

Stratigraphical distribution: Paleocene of Nigeria (Reyment 1963, Foster et al. 1983, Okosun 1987); Paleocene-Eocene of Senegal (Apostolescu 1961, Diop et al. 1982) and Togo (Damotte 1982, Carbonnel and Johnson 1989); Upper Paleocene of Benin (Carbonnel and Oyede 1991) and Mali (Colin et al. 1998); Danian of the Sergipe-Alagoas (Neufville 1973, 1979) and Paraíba basins, Brazil (Fauth et al. 2005).

Occurrence: Olinda well, 35.25 m, 35.55 m, 39.15 m.

Remarks: The genus *Soudanella* Apostolescu is a remarkable taxon that appears in the Paleocene of some African and South American basins. In Brazil, *S. laciniosa* is a Danian bioestratigraphical marker in the some Brazilian basins, including the Paraíba Basin.

Subfamily Campylocytherinae Puri 1960

Genus *Leguminocythereis* Howe 1936
Leguminocythereis sp.
Figure 3, h-i

Material: Four C.

Illustrated material: DGEO-CTG-UFPE-1424, C, DV and RV. L: 0.868; H: 0.409, W: 0.394.

Short description: Carapace large, subrectangular and elongate in lateral view. LV overlaps the RV along all margins, mainly in the anterodorsal and posterodorsal margins. Dorsal margin almost straight, ventral margin with a concavity at the middle part. Anterior outline broadly rounded and posterior subtriangular. Anteromarginal rib present. Surface reticulated and with well-developed longitudinal ribs. Anterior region with three ribs, parallel to the anterior margin; intercostal region coarsely reticulated.

Stratigraphical distribution: Paleocene of the Paraíba Basin (this work).

Occurrence: Olinda well, 37.05 m, 37.35 m.

Remarks: This species is similar to *Leguminocythereis senegalensis* Apostolescu 1961, firstly recorded in Eocene of Senegal and later in the Paleocene-Eocene of Nigeria (Reyment

1963, Okosun 1987). The Brazilian species has a more acuminate and elongate posterior region and presents three ribs in the anterior region.

PLANKTONIC FORAMINIFERA

Suprageneric classification follows chiefly Loeblich and Tappan (1988), modified by Sen Gupta (1999). Additional literature adopted are Ellis and Messina (1940), Bolli (1957), Nederbragt (1991), Koutsoukos (1996, 2014), Olsson et al. (1999) Premoli Silva and Verga (2004), Huber (2006) and Portal CHRONOS (http://portal.chronos.org). The synonymic list is simplified and contain the most important species recorded for this work.

Class Foraminiferida d'Orbigny 1826
Order Globigerinina Delage and He'rouard 1896
Superfamily Heterohelicacea Cushman 1927
Family Guembelitriidae Montanaro Gallitelli 1957

Genus *Guembelitria* Cushman 1933
Guembelitria cretacea Cushman 1933
Figure 4, a-b

1940 *Guembelitria cretacea* Cushman 1933, vol. 9, Pl. 2, 132, p. 37-38, Pl. 4, Figs. 12a-b apud Ellis and Messina.

1999 *Guembelitria cretacea* Cushman. Olsson et al., p. 79, 80, Pl. 13, Fig. 3.

2004 *Guembelitria cretacea* Cushman. Premoli Silva and Verga, p. 154, Pl. 57, Figs. 1-6.

2014 *Guembelitria cretacea* Cushman. Koutsoukos, p. 115, Figs. 6.1-6.6.

Material: 19 specimens.

Illustrated material: DGEO-CTG-UFPE-1425.

Occurrence: Olinda well, 38.25 m, 39.15 m.

Stratigraphical distribution (in the studied well): Lower Paleocene.

Remarks: In the studied specimens, although mostly fragmented, it was possible to observe the trisserial arrangement of the chambers, a feature that defines the genus. Wall structure microperforate and surface texture often characterized by blunt pore mounds. The specimens show notable intermediate morphological variation, related to the height/diameter ratio of tests. Specimens with a short-spire are common at the depth 39.15 m. According to Olsson et al. (1999), *Guembelitria besbesi* Salaj 1986 is short-spired, being typical from lowest Paleocene. However, the present authors considered this feature as a morphological variation of *G. cretacea*. These variable forms occur in shallow platforms of Upper Maastrichtian and Lower Paleocene.

Guembelitria spp.
(Not figured)

Material: 22 specimens.

Stratigraphical distribution (in the studied well): Lower Paleocene.

Occurrence: Olinda well, 38.25 m, 39.15 m.

Remarks: A group of specimens showed morphological features that allowed include it in a *Guembelitria* genus. Due to the bad preservation and/or absence of diagnostic morphological features, it was not possible to determine the species.

Genus *Parvularugoglobigerina* Hofker 1978

Parvularugoglobigerina? spp.
Figure 4, c-e

Material: Seven specimens.

Illustrated material: DGEO-CTG-UFPE-1426.

Stratigraphical distribution (in the studied well): Lower Paleocene.

Occurrence: Olinda well, 36.45 m, 39.15 m.

Remarks: Due to the bad preservation and absence of diagnostic morphological features it was not possible to identify the specimens at specific level.

Genus *Woodringina* Loeblich and Tappan 1957

Woodringina hornerstownensis Olsson 1960
Figure 4, f-g

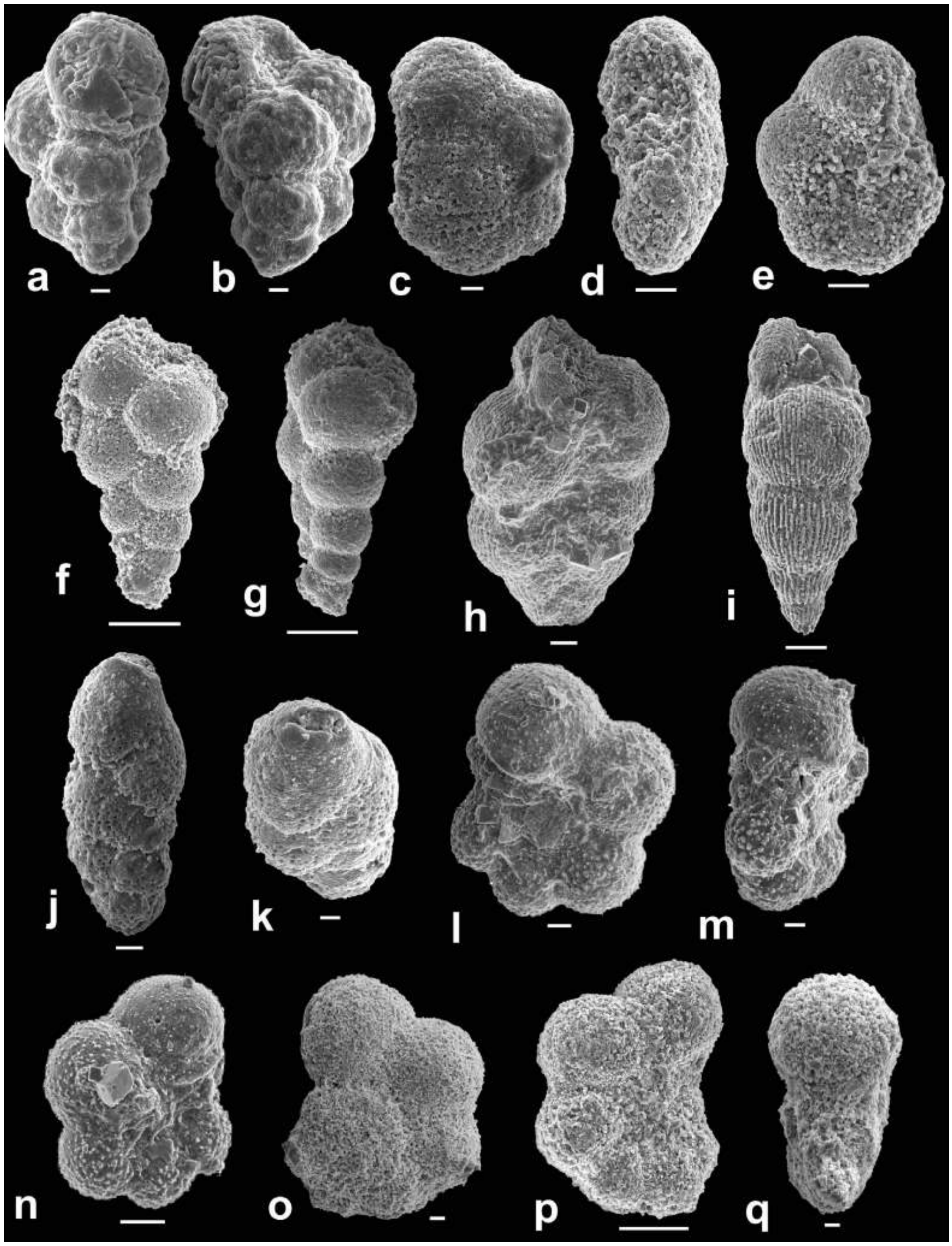

Figure 4 - Scanning electron micrographs of planktonic foraminifers from the Paleocene, Maria Farinha Formation, Paraíba Basin. **a-b**. *Guembelitria cretacea* Cushman 1983, **a**, lateral view; **b**, apertural view. **c-e**. *Parvularugoglobigerina*? sp., **c**, spiral view; **d**, lateral view; **e**, umbilical view. **f-g**. *Woodringina hornerstownensis* Olsson 1960, **f**, lateral view; **g**, apertural view. **h-i**. *Heterohelix* cf. *globulosa* (Ehrenberg 1840), **h**, lateral view; **i**, apertural view. **j-k**. *Zeauvigerina waiparaensis* (Jenkins 1965), **j**, lateral view; **k,** apertural view. **l-n**. *Muricohedbergella monmouthensis* (Olsson 1960), **l**, umbilical view; **m**, lateral apertural view; **n**. spiral view. **o-q**. *Praemurica* cf. *pseudoinconstans* (Blow 1979), **o**, spiral view; **p**, apertural view; **q**, umbilical view. Scale bars: a, b, c, k=10 µm; d, e, j, l, m, o, q=20 µm; F, g, i, n, p=50 µm; h=30 µm.

1960 *Woodringina hornerstownensis* Olsson, p. 29, Pl. 4, Figs. 18, 19.

1999 *Woodringina hornerstownensis* Olsson. Olsson et al., p. 87, 88, Fig. 34, Pl. 13, Figs. 4, 5; Pl. 68, Figs. 8-14.

2014 *Woodringina hornerstownensis* Olsson. Koutsoukos, p. 116, Figs. 6:16-6:24.

Material: One specimen.

Illustrated material: DGEO-CTG-UFPE-1427.

Stratigraphical distribution (in the studied well): Lower Paleocene.

Occurrence: Olinda well, 36.45 m.

Remarks: The examined specimens are small and elongated, showing the biserial portion of the test distinctly twisted, although in lesser degree than *Woodringina claytonensis* Loeblich and Tappan 1957. According to Olsson et al. (1999), *W. hornerstownensis* differs from *W. claytonensis* by the elongate tapering test and the almost straight sutures.

Woodringina? spp.
(Not figured)

Material: Five specimens.

Stratigraphical distribution (in the studied well): Lower Paleocene.

Occurrence: Olinda well, 36.45 m, 39.15 m.

Remarks: The specimens examined are broken in the initial portion of the test, hampering the identification at specific level, though in the studied material there are possibly more than one species.

Subfamily Heterohelicinae Cushman 1927

Genus *Heterohelix* Ehrenberg 1843
Heterohelix cf. *globulosa* (Ehrenberg 1840)
Figure 4, h-i

Material: One specimen.

Illustrated material: DGEO-CTG-UFPE-1428.

Stratigraphical distribution (in the studied well): Lower Paleocene.

Occurrence: Olinda well, 38.25 m, 40.05 m, 42.75 m, 44.55- 45.45 m, 47.25- 49.95 m.

Remarks: *Heterohelix globulosa* usually shows globular chambers that grow gradually, being covered by thin costae. According to Nederbragt (1991), *H. globulosa* shows variations in the size, robustness of ornamentation and depth of its chambers, and the overlap of the subsequent chambers. In the examined material, this morphological variation is clear, but due to the preservation the identification was not possible. The abundant presence of species belonging to the genus *Heterohelix* in the Paleocene has been reported by several authors (Arenillas et al. 2000, Peryt et al. 1993, Keller 2004, Barrera and Keller 1990, Liu and Olsson 1992). According to them *H. globulosa* dominated the populations of planktonic foraminifera of the upper Maastrichtian and occurs, although rare, until the P1a Zone, in lower Danian (*Parasubbotina pseudobulloides* Zone).

Genus *Zeauvigerina* Finlay 1939

Zeauvigerina waiparaensis (Jenkins 1965)
Figure 4, j-k

1965 *Chiloguembelina waiparaensis* Jenkins, p. 1095, Pl. 1, Figs. 1-6.

1994 *Zeauvigerina waiparaensis* (Jenkins) Huber and Boersma, p. 278, Pl. 1, Figs. 4a-c, Pl. 2, Figs. 10a-b (form prolate).

1999 *Zeauvigerina waiparaensis* (Jenkins). Olsson et al., p. 97, 98, Pl. 71, Figs. 6-8 (prolate shape).

Material: One specimen.

Illustrated material: DGEO-CTG-UFPE-1429.

Stratigraphical distribution (in the studied well): Lower Paleocene.

Occurrence: Olinda well, 39.15 m.

Remarks: Only one specimen was recovered from the analyzed material. The species is characterized by a small test with weakly inflated chambers increasing slowly and irregularly in size. It shows four or even seven pairs of chambers in the biserial phase, generally followed by one or two chambers above the previous pair becoming almost uniserial. According to Olsson et al. (1999), the studies about *Zeauvigerina* showed disagreement about the generic classification, since it presents similarities with benthic and planktonic forms. Finlay (1939) found similarities between *Zeauvigerina teauria* Finlay 1939 and the *Guembelina* (=*Chiloguembelina*) genus, indicating that it is a planktonic genus.

Superfamily Rotaliporacea Sigal 1958
Family Herbergellidae Loeblich and Tappan 1961
Subfamily Hedbergellinae Loeblich and Tappan 1961

Genus *Muricohedbergella* Huber and Leckie 2011

Muricohedbergella monmouthensis (Olsson 1960)
Figure 4, l-n

1960 *Globorotalia monmouthensis* Olsson, p. 47, pl. 9, Figs. 22-24.

1999 *Hedbergella monmouthensis* (Olsson). Olsson et al. p. 35-37, Fig. 15, Pl. 31, Figs. 1-15.

2004 *Muricohedbergella monmouthensis* (Olsson). Premoli-Silva and Verga, p. 167, Pl. 97, Figs. 1-4; p. 260, Pl. 30, Figs. 9-10.

Material: Three specimens.

Illustrated material: DGEO-CTG-UFPE-1430.

Stratigraphical distribution (in the studied well): Lower Paleocene.

Occurrence: Olinda well, 37.35-39.15 m, 43.65 m.

Remarks: *Muricohedbergella monmouthensis* is characterized by test very low trochospiral, nearly planispiral in appearance. Wall calcareous, finely perforate, covered with short, minute spines. Chambers inflated, globular with five, occasionally six, chambers of the final whorl increase rather rapidly in size. Aperture a low arch with a distinct lip. It differs from *Mu. holmdelensis* (Olsson 1964) because it presents more globular to subglobular chambers, while *Mu. holmdelensis* has ovate and compressed chambers. According to Olsson et al. (1999), only two species of *Hedbergella* (realocated in *Muricohedbergella* by Huber and Leckie 2011) cross the K-Pg boundary, *Mu. monmouthensis* and *Mu. holmdelensis*, both surviving up to the P0 zone.

Family Truncorotaloididae Loeblich and Tappan 1961

Genus *Praemurica* Olsson Hemleben, Berggren and Liu 1992

Praemurica cf. *pseudoinconstans* (Blow 1979)
Figure 4, o-q

Material: Two specimens.

Illustrated material: DGEO-CTG-UFPE-1431.

Stratigraphical distribution (in the studied well): Lower Paleocene.

Occurrence: Olinda well, 36.45 m.

Remarks: The studied specimens are scarce, small (<125 µm) and resemble *P. pseudoinconstans.* According to Olsson et al. (1999), the first chambers of this species increase gradually in size, while the terminal ones increase abruptly; the last chamber slightly offsets towards the umbilicus in some specimens. Aperture is a high rounded arch, bordered by a narrow lip broadening towards umbilicus. It differs from *Praemurica taurica* by the moderately inflated chambers, which increase more abruptly in size in the last whorl. However, the smooth texture raises doubts about its identification.

RESULTS AND DISCUSSION

A total of 11 species of ostracods and nine planktonic foraminifera were identified in the Paleocene deposits of the Olinda well, Paraíba Basin. From the 16 analyzed samples, only 12 contained ostracod specimens and six, foraminifera. The stratigraphic distribution of the species is illustrated in Figure 5.

Most of the ostracod material was identified only at genus level, due to the poor preservation and scarcity of specimens. Despite the low abundance and preservational constraints, the following genera

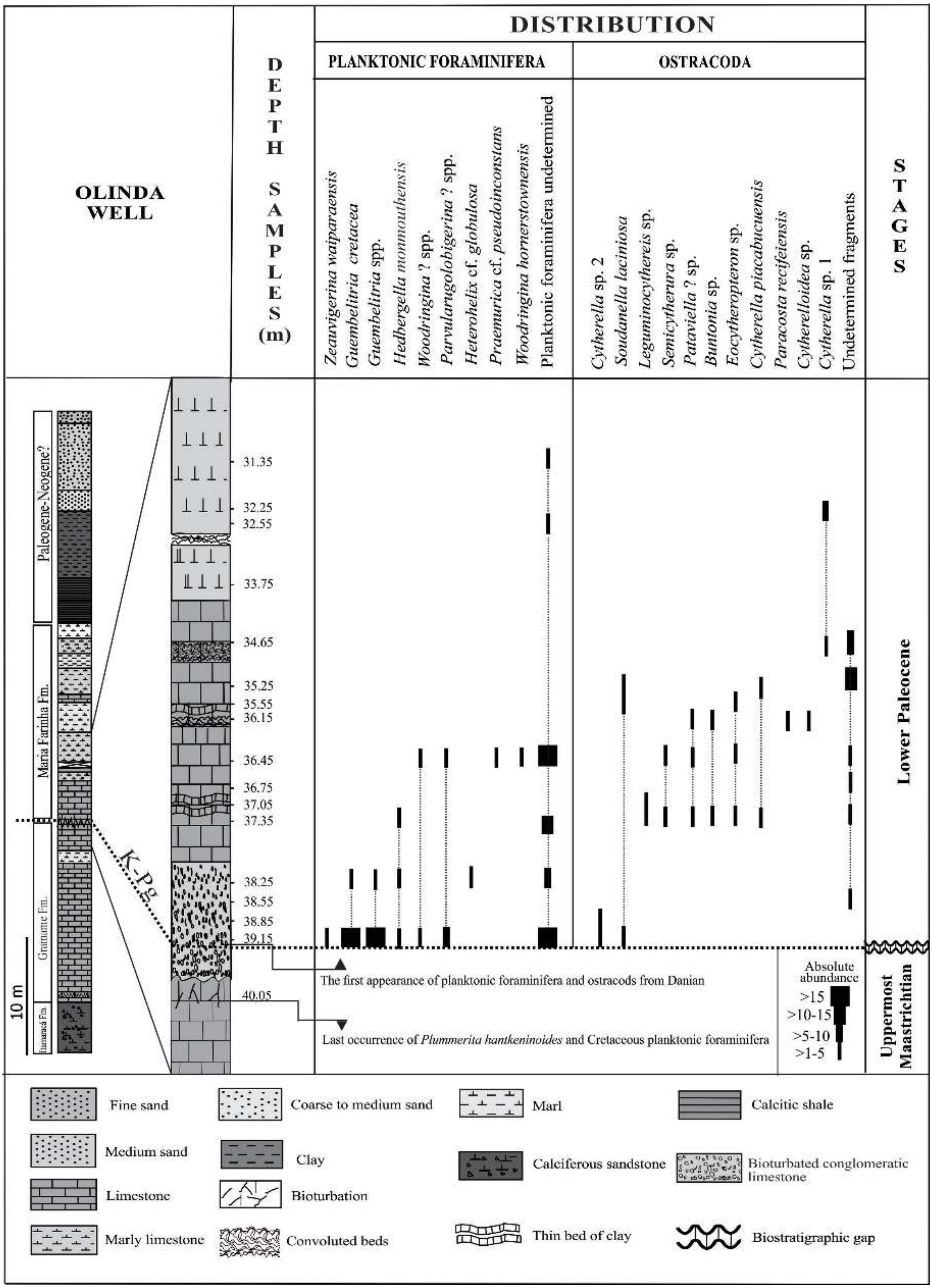

Figure 5 - Stratigraphic distribution of ostracods and planktonic foraminifera in the Olinda well, Paraíba Basin.

were identified: *Cytherella* (3 spp.), *Cytherelloidea* (1 sp.), *Eocytheropteron* (1 sp.), *Semicytherura* (1 sp.), *Pataviella*? (1 sp.), *Paracosta* (1 sp.), *Buntonia* (1 sp.), *Soudanella* (1 sp.) and *Leguminocythereis* (1 sp.).

The Poty quarry bears more diverse and abundant ostracod assemblages compared with the Olinda well (Fauth et al. 2005). The species shared are *Cytherella piacabucuensis*, *Soudanella laciniosa* and *Paracosta recifeiensis.* The genera *Cytherelloidea*, *Eocytheropteron*, *Semicytherura, Buntonia*, *Leguminocythereis* and, probably, *Pataviella* are recorded for the first time in the Paraíba Basin. With the exception of the presumed occurrence of *Pataviella*, all the remaining genera had already been recorded in the Upper Cretaceous of the Potiguar and Sergipe basins (Neufville 1973, Delicio et al. 2000, Viviers et al. 2000, Piovesan et al. 2014). If confirmed, the record of *Pataviella*, also present in Paleocene of Senegal, would reinforce the similarities between the ostracofauna of the Brazilian northeast basins and the east African ones, as summarized by Fauth (2002).

The Paleocene planktonic foraminifera were identified as *Guembelitria cretacea, Guembelitria* spp., *Parvularugoglobigerina*? spp., *Woodringina hornerstownensis*, *Woodringina*? spp., *Heterohelix* cf. *globulosa, Zeauvigerina waiparaensis, Muricohedbergella monmouthensis* and *Praemurica* cf. *pseudoinconstans.* With the exception of *Zeauvigerina waiparaensis* and *Praemurica* cf. *pseudoinconstans*, the other foraminifer taxa had already been reported for the Paraíba Basin (e.g., Koutsoukos 1996, 2006, Gertsch et al. 2013). *Zeauvigerina waiparaensis* occurs from the Maastrichtian (*Abathomphalus mayaroensis* Zone) to the late Paleocene, presenting abundance levels at the base of the Danian. Similar to the species of *Guembelitria*, *Z. waiparaensis* survived the K-Pg extinction (e.g., Huber and Boersma 1994, Pardo and Keller 2008). Another important species in this interval is *Praemurica pseudoinconstans,* characteristic of the Pα zone (upper part) and of the P1a subzone (basal part of the P1 zone) as already observed by Berggren and Pearson (2005) and Koutsoukos (2014).

In the lower part of the Olinda well (39.15-38.25 m) the ostracod assemblages are very poorly preserved and composed of *Soudanella laciniosa* and *Cytherella* sp. 2 along with a more diversified assemblage of the foraminifera, constituted by *Zeauvigerina waiparaensis, Guembelitria cretacea, Heterohelix* cf. *globulosa* and some unidentified species of *Guembelitria, Muricohedbergella, Parvularugoglobigerina* and *Woodringina.* The association is marked by the abundance of *Guembelitria cretacea*, *Guembelitria* spp. and the occurrence of *Woodringina* spp. This interval probably corresponds to the lower part of the Pα Zone, in accordance with bioevents recorded by Koutsoukos (2014) in the Campos Basin. The first occurrence of *Soudanella laciniosa* is also suggestive of the base of the Paleocene (Fauth et al. 2005). The blooms of *Guembelitria* (20-30%) are related either to shallow water environments or upwelling events. In the Danian, where the P0-P1a zones are recorded, *Guembelitria* (10-20%) and *Z. waiparaensis* are dominant in the low diversifity associations (Pardo and Keller 2008). These blooms of *Guembelitria* are commonly associated with a high influx of nutrients or continental runoff, upwelling along continental margins, or volcanic entry (Pardo and Keller 2008). In the Paraíba Basin blooms of *Guembelitria* have been identified by Stinnesbeck and Keller (1995), Keller and Stinnesbeck (1996), Koutsoukos (1996) and Pardo and Keller (2008).

The presence of the ostracod *Soudanella laciniosa,* a dominantly neritic species in the Poty quarry (Rodrigues et al. 2014), reinforces the interpretation of a neritic environment at the base of the well. The isotopic data show a substantial decrease of SiO_2 and Al_2O_3, a pattern associated with reduction of the siliciclastic input. The $\delta^{18}O$

negative values in this interval suggest hotter seawater (Nascimento et al. 2011).

The superposed interval (38.25-37.35 m) is marked by the decline in the abundance of planktonic foraminifera, with only *Muricohedbergella monmouthensis* present. According to Olsson et al. (1999), Paleocene species of *Hedbergella,* realocated in *Muricohedbergella* by Huber and Leckie (2011), are limited to the P0 zone. Thus, the specimen of *Muricohedbergella monmouthensis* recorded in this section could be reworked. This hypothesis is reinforced by its coincident occurrence with *Woodringina*? spp. that, according to Olsson et al. (1999), are restricted to the younger Pα zone. A notable change in the assemblage composition, with a decrease in diversity and abundance of Paleogene taxa and increase of reworked taxa is observed. A conspicuous change in the assemblage composition is seen in the interval 37.35-35.25 m. From this level onwards, the ostracod diversity increases, in contrast to the planktonic foraminiferal diversity. The planktonic association in this range consists of *Praemurica* cf. *pseudoinconstans*, *Woodringina hornerstownensis*, *Parvularugoglobigerina*? spp., *Woodringina*? spp., and other unidentified specimens. In addition, the benthic foraminiferal association, represented mainly by *Gavelinella* and *Cibicidoides* (36.45 m and 35.55 m), also indicates a neritic environment. In the Poty quarry, Paraíba Basin, Koutsoukos (2006) reports the presence of *Gavelinella coonensis* and *Cibicidoides alleni* as indicative of a deep neritic environment. Another aspect of the ostracod fauna indicative of neritic environments is the presence of cytherurids (*Semicytherura* sp. and *Eocytheropteron* sp.). The Cytheruridae is a diverse and abundant family of marine/brackish water cytheracean Ostracoda (Ramos et al. 1999), and in the Mesozoic they seem to have been confined to shelfal depths, with many species also in marginal marine habitats (Ballent and Whatley 2009), a behavior that may have been extended to the Paleocene. Shallower waters in this interval could be inferred not only by the dominance of the benthic ostracods and reduction in plancktonic foraminifera, but also by the increase of SiO_2 and Al_2O_3 (Nascimento et al. 2011).

Above 34.65 m begins 5.10 m thick interval composed predominantly of limestone where occurs only rare benthic foraminifera, fragmented planktonic specimens and the ostracod *Cytherelloidea* sp. occur. This noteworthy reduction in abundance and richness of both ostracods and foraminifera results possibly from preservational conditions related to the lowstand system tract, as proposed by Nascimento et al. (2011), based in the high SiO_2 and Al_2O_3 content of the sediments.

CONCLUSIONS

Ostracods and foraminifera from the Olinda well seem to indicate environmental changes in the lower Paleocene of the Paraíba Basin. Nine planktonic foraminifer and eleven ostracod taxa were identified.

The lower Paleocene of Olinda Well can be subdivided in different faunal associations, probably related to changes in environmental conditions. The base of the well is characterized by blooms of *Guembelitria* spp., which constitutes important marker for shallow environments and upwelling zones in association with the ostracod *Soudanella laciniosa,* typical of neritic environments. The superimposed interval, in the median part of the studied well, presents associations indicative of shallower water based on the dominance of benthic foraminifera and cytherurid ostracods, associate with the reduction in the abundance of planktonic foraminifera. Finally, on the top of the section, the foraminifera and ostracods are rare and badly preserved, which could be related to the inception of the lowstand system tract.

The ostracod and foraminifera analyzed, therefore, permit the interpretation of neritic paleoenvironment in the studied section, corroborating previous palaeoenvironmental interpretations for the Paleocene of the Paraíba Basin based on other fossil groups and isotopic data.

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