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TAXONOMY, ONTOGENY AND PALEOECOLOGY OF TWO SPECIES OF *HARBINIA* TSAO, 1959 (CRUSTACEA, OSTRACODA) FROM THE SANTANA FORMATION, LOWER CRETACEOUS, NORTHEASTERN BRAZIL

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ABSTRACT—The Araripe Basin is the most extensive interior basin in northeastern Brazil, comprising areas of Ceará, Piauí and Pernambuco states. The Santana Formation, attributed to the Aptian–?lower Albian age of the basin, is subdivided into two members, Crato and Romualdo, which bear an abundant fossil record of plant fragments, arthropods and vertebrates, especially 3D-preserved fishes. The present study focuses on the taxonomy, ontogeny and paleoecology of two ostracode species from the Romualdo Member and the top section of the Crato Member (Ipubi layers), *Harbinia salitrensis* (Krömmelbein and Weber, 1971) emend. and *H. alta* new species. The ontogenetic series for both species are illustrated, except for the A-8 instar; *H. salitrensis* is also redescribed. The present work is also the first to produce quantitative information about the paleoecology of the Santana Formation based on ostracode populations. The results obtained from analyses of the population age-structure of both species, in addition to dominance (Simpson) and diversity index (Shannon) values, corroborated previous data on the studied sequence. According to these results, the strata were deposited in a limnic, low-to-moderate energy environment with salinity levels varying from oligohaline to mesohaline. The new data indicate the possibility of these environments also being hypersaline.

INTRODUCTION

THE PRESENT work focuses on the taxonomy, ontogeny and paleoecology of two species of *Harbinia* Tsao, 1959 (as emended by Hou, 1984) found in samples from the Romualdo and Crato members in the Santana Formation during the Lower Cretaceous in the Araripe Basin. Most of the *Harbinia* species from Brazilian basins lack proper characterization, and one of the main objectives of the present work is to fill this gap. With regard to paleoenvironmental and paleoecological aspects, several works carried out in the Araripe Basin, particularly in the Santana Formation (Arai and Coimbra, 1989; Assine, 1992, 1994, 2007; Berthou et al., 1994; Coimbra et al., 2002), relied exclusively on qualitative rather than quantitative observations of ostracode faunas. The present work is the first to use ecological indices and population age-structure studies of ostracodes to attain quantitative data about the paleoenvironments of the Santana Formation.

Araripe is the most extensive interior basin in northeastern Brazil, located close to the boundaries of Ceará, Piauí and Pernambuco states (Ponte and Appi, 1990; Assine, 1992) (Fig. 1). The assemblages preserved in the Santana Formation represent one of the best-known Lagerstätten in the world, with an abundant fossil record that includes plant fragments, arthropods and vertebrates, especially 3D-preserved fishes (Ponte and Appi, 1990; Maisey, 1991; Martill and Wilby, 1993; Carvalho and Santos, 2005; Fara et al., 2005).

The lithostratigraphy of the Araripe Basin comprises five geologically distinct depositional events. The basal Paleozoic section is considered a remainder of Silurian sedimentation which linked several basins in the region (Beurlen, 1962; Ponte and Ponte Filho, 1996). From the Late Jurassic onward, four successive stages of tectonic development are identifiable: pre-rift, rift, post-rift I and post-rift II (Assine, 2007) (Fig. 2). Therefore, most of the geological history of the basin can be associated with the fragmentation of Gondwana and the consequent opening of the South Atlantic Ocean (Castro and Castelo Branco, 1999; Kellner, 2002).

The Santana Formation is deposited in the post-rift I sequence and dated as late Aptian–?early Albian according to previous works with palynomorphs (Regali et al., 1974; Pons et al., 1990; Regali, 1990; Coimbra et al., 2002; Assine, 2007). Its lower section, the Crato Member, is characterized by carbonate shale interbedded with laminated limestone and bituminous layers, which are frequently calcified due to the remarkable amount of ostracode carapaces. The Ipubi layers, a very thick, although discontinuous, set of gypsum evaporite, lie above the Crato Member (Assine, 2007; Martill, 2007). The upper section of the formation is composed of the Romualdo Member, a set of shales, marls and limestones with sandstone lenses and local conglomeratic levels. The Romualdo Member also commonly appears interfingered with the Crato Member in areas where Ipubi layers are absent (Assine, 2007).

The basal strata of the Romualdo Member contain an extensive amount of non-marine fossils, such as freshwater ostracodes (Berthou et al., 1990). The top of the unit is characterized by levels with calcareous concretions that contain 3D-preserved macrofossils (Fara et al., 2005). The paleoenvironments are interpreted as lacustrine, later becoming fluvio-lacustrine and possibly transitional (Berthou et al., 1994; Coimbra et al., 2002; Assine, 2007). A transgressive marine system was formed later, with its apex at the top of the Romualdo Member, as evidenced by the presence of ecozone *Subtilisphaera* spp. (Arai and Coimbra, 1989; Kellner, 2002; Heimhofer and Hochuli, 2010).

Harbinia is a common genus in the Cretaceous sediments of several basins (Tsao, 1959; Krömmelbein and Weber, 1971; Guan et al., 1978; Coimbra et al., 2002; Ramos et al., 2006; Do Carmo et al., 2004; Do Carmo et al., 2008). This genus is

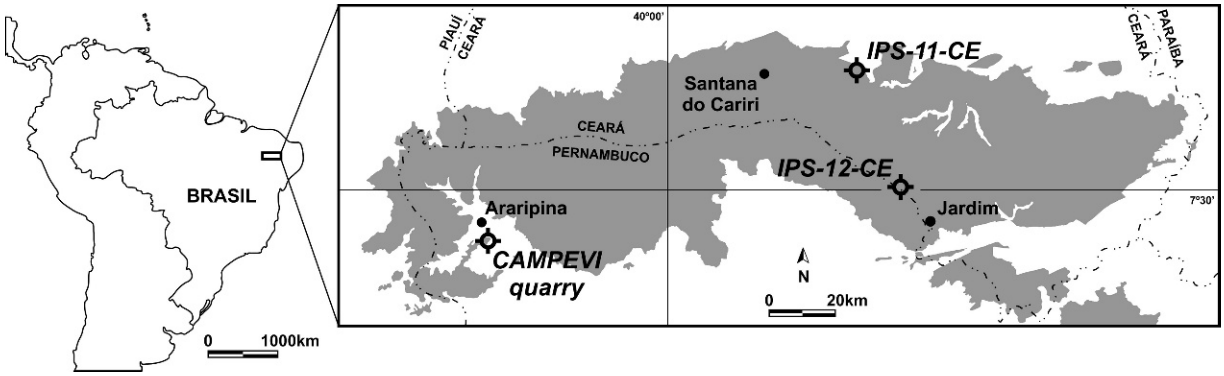

FIGURE 1—The Araripe Basin, northeastern Brazil, containing the locations of IPS-11-CE, IPS-12-CE and CAMPEVI quarry (modified from Assine, 2007).

abundant in the south Atlantic marginal basins, specially through the lower Alagoas Stage in Brazil (late Aptian–?early Albian). It plays an important role in dating both marginal and inland Brazilian basins (Biozone O11) (Schaller, 1969; Moura, 1987) and their African counterparts (Biozone AS11) (Coimbra et al., 2002; Do Carmo et al., 2008).

MATERIALS AND METHODS

Five samples from three different sites in the Araripe Basin were studied in the present work. Samples MP-1075, MP-1076, MP-1089 and MP-1109 came from project Santana II, which was carried out in the Araripe Basin by the Brazilian Geological Survey (CPRM) (Scheid et al., 1978). The two wells selected, IPS-11-CE (446610 E–9206760 N UTM) and IPS-12-CE (459760 E–9171760 N UTM), were drilled, respectively, in the cities of Santana do Cariri and Jardim, Ceará State. Sample MP-931 was collected in an outcrop at the CAMPEVI quarry (0338526 E–9143785 N UTM) in the city of Araripina, Pernambuco State (Fig. 3).

The core cylinder samples analyzed came mostly from the Romualdo Member (MP-1075, MP-1076 and MP-1089). MP-1109, collected in IPS-11-CE, came from the Ipubi layers in the top section of the Crato Member, which is comprised of dark gray to black laminated marl levels. MP-1075 consists of dark gray micaceous siltstone levels, while MP-1076 and MP-1089 come from dark gray micaceous to muddy siltstones. Additional field work was performed in the CAMPEVI quarry of Araripina, Pernambuco in 2007; the resulting sample, MP-931, is also from the Romualdo Member and consists of dark gray to black shale (Table 1).

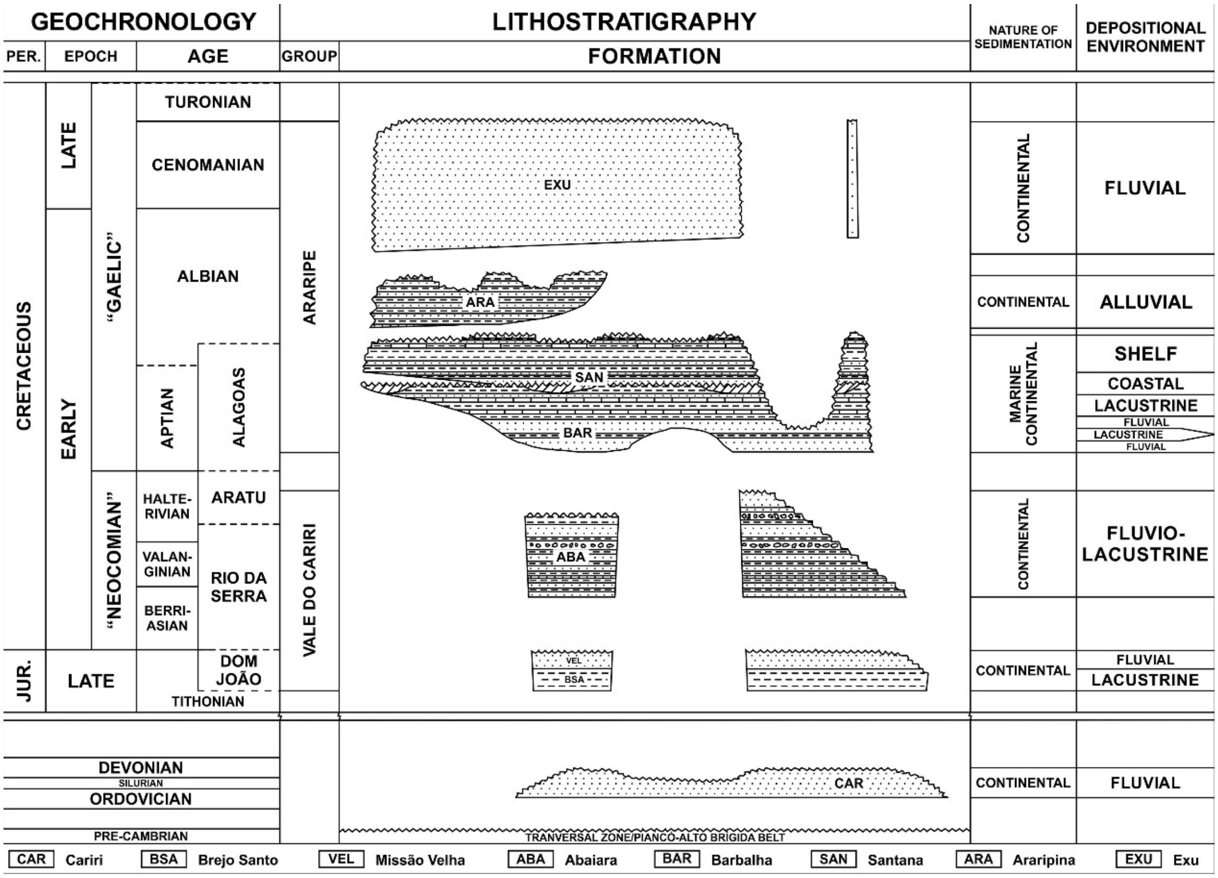

FIGURE 2—Stratigraphical chart of the Araripe Basin, northeastern Brazil (modified from Assine, 2007).

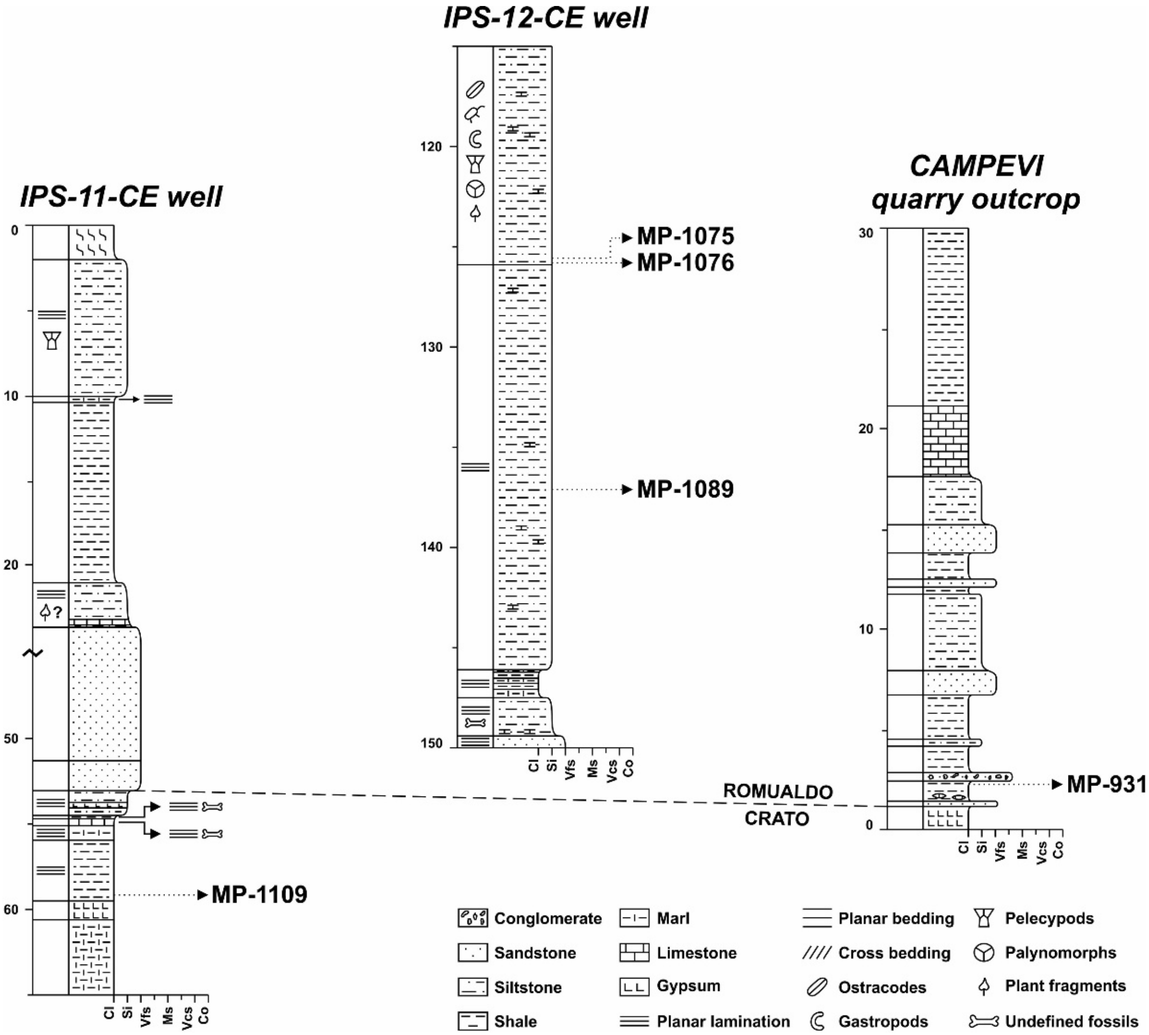

FIGURE 3—Lithology of the studied wells, IPS-11-CE and IPS-12-CE, and the CAMPEVI quarry outcrop, Santana Formation, Araripe Basin, northeastern Brazil.

Forty grams were prepared for each of the following four samples: MP-931, MP-1076, MP-1089 and MP-1109. Only 38.4 g of MP-1075 (not used for the ecological index but only for population age-structure studies) was prepared due to size restraints. The samples were initially treated with 30% hydrogen peroxide (H_2O_2) for 72 hours and then neutralized by the addition of 92% ethanol. Next, they were washed in tap water in a set of sieves with 630, 250, 160 and 80 μm pores. After washing, the remaining sediments were dried in a kiln at 90°C and then screened using a stereoscopic microscope.

The morphological terminology for taxonomical studies followed Kesling (1951), Lüttig (1962) and Do Carmo et al. (2008). The paleoecological analysis was divided into two subsections: the population age-structure study and the quantitative evaluation of diversity. The first was based on Whatley (1983, 1988) and Boomer (2003). The second was conducted using two ecological indices commonly used in the scientific literature: the Simpson (Simpson, 1949), and the Shannon (Whittaker, 1972).

SYSTEMATIC PALEONTOLOGY

Type-material is housed at the Museum of Geosciences, Laboratory of Micropaleontology, Research Collection, Institute of Geosciences, University of Brasília (Brasília, Brazil) with the prefix CP. Several genera and species were recovered from the

TABLE 1—Characterization of samples, Araripe Basin, northeastern Brazil.

Sample	Well/outcrop	Level (m)	Lithology
MP-931	CAMPEVI quarry	Surface	Dark gray to black shale, with millimeter-sized sub-horizontal sets, containing centimeter-sized calcareous nodules, rounded to sub-rounded and white or beige colored. Fossil content rich in ostracodes, phytoclasts, bivalves and gastropods.
MP-1075	IPS-12-CE	125.56	Dark gray micaceous siltstone. Fossil content including ostracodes gastropods, bivalves, palynomorphs and plant fragments.
MP-1076	IPS-12-CE	125.79	Dark gray micaceous siltstone and muddy siltstone, with calcareous layers and thin micaceous or pyritized levels. Fossil preservation represented by leaf impressions.
MP-1089	IPS-12-CE	137.11	
MP-1109	IPS-11-CE	59.15	Dark gray to black laminated marl.

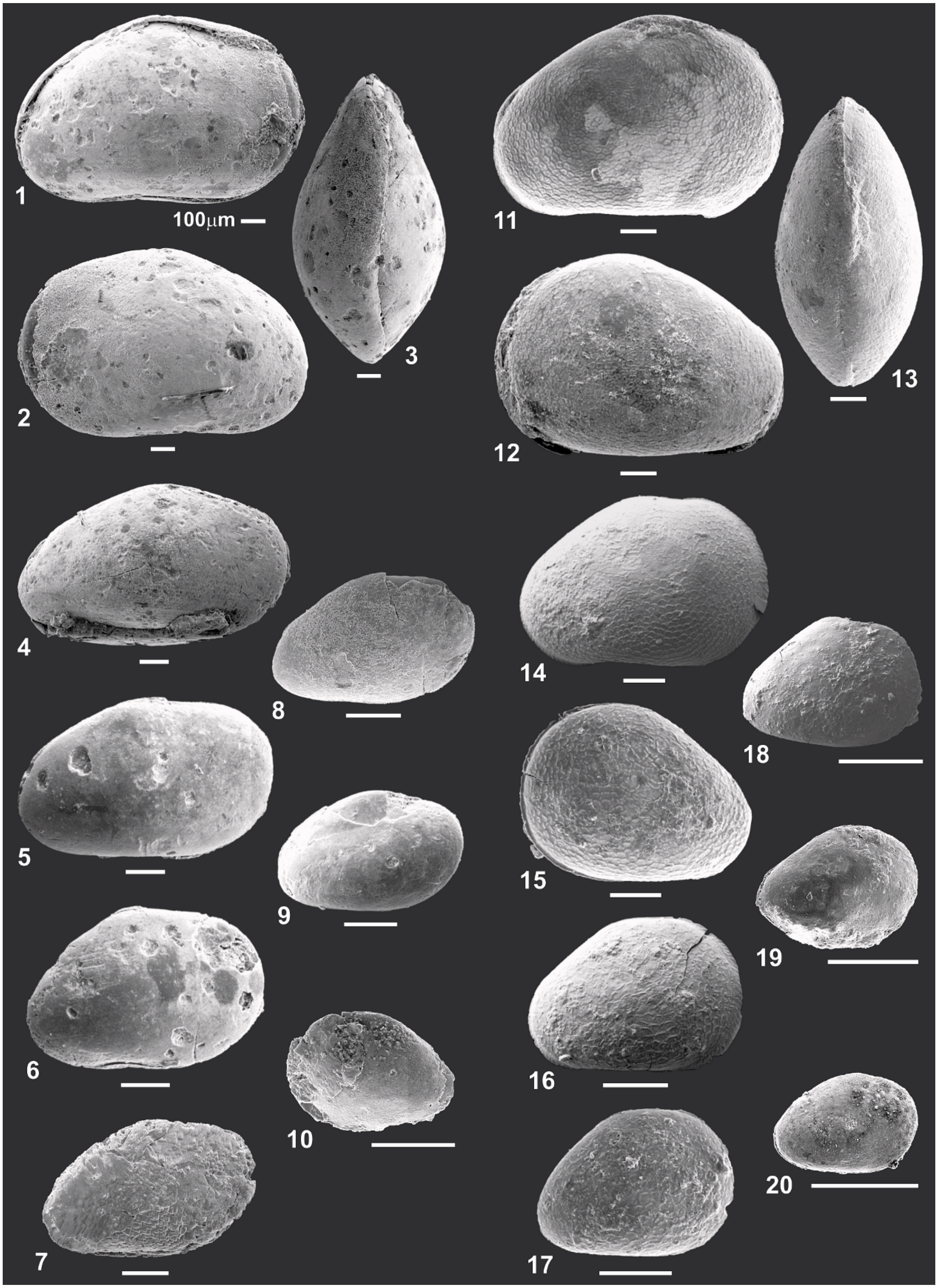

FIGURE 4—Species from genus *Harbinia* Tsao, 1959 (as emended by Hou, 1984). *1–10*, *Harbinia salitrensis* (Krömmelbein and Weber, 1971): *1–3*, adult (CP-581), right (RV), left (LV) and dorsal (DV) views; *4*, juvenile A–1 (CP-589), RV; *5*, juvenile A–2 (CP-403), RV; *6*, juvenile A–3 (CP-419), RV; *7*, juvenile A–4 (CP-590), RV; *8*, juvenile A–5 (CP-591), RV; *9*, juvenile A–6 (CP-420), RV; *10*, juvenile A–7 (CP-613), LV; *11–20*, *Harbinia alta* n. sp.: *11–13*, adult (CP-584), RV, LV and DV; *14*, juvenile A–1 (CP-423), RV; *15*, juvenile A–2 (CP-586), LV; *16*, juvenile A–3 (CP-426), RV; *17*, juvenile A–4 (CP-587), RV; *18*, juvenile A–5 (CP-427), RV; *19*, juvenile A–6 (CP-614), RV; *20*, juvenile A–7 (CP-612), RV.

TABLE 2—Illustrated material of *Harbinia salitrensis* (Krömmelbein and Weber, 1971), Romualdo Member, Santana Formation, Araripe Basin, northeastern Brazil.

Specimen	Sample	Instar	Length (mm)	Height (mm)	Width (mm)
CP-581	MP-1076	Adult	1.23	0.82	0.67
CP-589	MP-1076	A-1	0.94	0.56	0.47
CP-403	MP-1076	A-2	0.65	0.42	0.34
CP-419	MP-1076	A-3	0.51	0.34	0.24
CP-590	MP-1076	A-4	0.46	0.30	0.21
CP-591	MP-1076	A-5	0.39	0.25	0.19
CP-420	MP-1076	A-6	0.34	0.23	0.21
CP-613	MP-1076	A-7	0.21	0.16	0.08

analyzed samples. Two species from the genus *Harbinia* Tsao, 1959 emended Hou, 1984 were selected for the present work due to their abundance and exceptional preservation: *Harbinia alta* n. sp. and *H. salitrensis* (Krömmelbein and Weber, 1971). The suprageneric taxonomy followed the works of Bate (1972) and Liebau (2005) and the generic identification followed Do Carmo et al. (2008). Further discussion about its taxonomical implications, which some authors consider to be a necessity, is beyond the scope of the present work. Instead, this study is focused solely on describing the previously mentioned species.

Subclass OSTRACODA Latreille, 1802
Superorder PODOCOPOMORPHA Kozur, 1972
Order PODOCOPIDA Sars, 1866
Suborder CYPRIDOCOPINA Jones, 1901
Superfamily CYPRIDOIDEA Baird, 1845
Family CYPRIDIDAE Kaufmann, 1900
Subfamily CYPRIDINAE Baird, 1845
Genus HARBINIA Tsao, 1959

HARBINIA SALITRENSIS (Krömmelbein and Weber, 1971)
Figure 4.11–4.20

1971 *Hourcqia angulata salitrensis* KRÖMMELBEIN AND WEBER, p. 81, p. 6, figure 26a–26c; DÉPÊCHE, BERTHOU AND CAMPOS, 1990, p. 297, pl. 3, figure 14.

1972 *Pattersoncypris angulata salitrensis* (KRÖMMELBEIN AND WEBER); BATE, p. 381, figure 11c, 11d, 11f.

1990 *Pattersoncypris* cf. *angulata salitrensis* (KRÖMMELBEIN AND WEBER); SILVA-TELLES JR. AND VIANA, p. 321, figure 2.8.

2006 *Harbinia salitrensis* (KRÖMMELBEIN AND WEBER); RAMOS, ROSSETTI AND PAZ, p. 345, figure 4Q–4T; DO CARMO, WHATLEY, QUEIROZ NETO AND COIMBRA, 2008, p. 795, figure 6.8.

Holotype.—Initially housed at the Federal Institute for Geosciences and Natural Resources (BGR) in Hannover, Germany under the designation BfB no. 7798 (Krömmelbein and Weber, 1971); currently, housed at the Senckenberg Museum, Frankfurt am Main, Germany.

Diagnosis.—Original: a large species of *Hourcqia angulata* (carapace size approximately 1.1 mm) with the following characteristics: very compact and high carapace; from dorsal view, thick and fusiform. Dorsal margin slopes backwards; slightly sealed posterior end. Posterior end begins at a more elevated and noticeably more angulated point than in *Ho. a. symmetrica.* Ventral margin slightly concave (Krömmelbein and Weber, 1971). Emended: large-sized carapace, subovate in lateral view; greatest height at median region. Slightly infracurvate posterior end. Rounded posterior cardinal angle, visible only in the right valve. Ventral margin slightly concave. External surface smooth. From dorsal view, widely fusiform.

Material.—CP-403, CP-419, CP-420, CP-581, CP-589, CP-590 and CP-591 (carapaces) (Table 2); upper Aptian, lower Cretaceous; Romualdo Member, Santana Formation, Araripe Basin.

Description.—Carapace subtriangular in lateral view with greatest height at the median and greatest length along the ventro-median region. Left valve larger than the right, overlapping it along the free margin, most extensively in the antero-dorsal and postero-dorsal regions. Dorsal margin slightly convex, with a small hump close to the antero-dorsal margin; hinge line sub-straight; posterior cardinal angle visible only in the right valve. Ventral margin nearly straight. Anterior end rounded; posterior end slightly infracurvate. External surface smooth in adults and juveniles in A–7, A–6

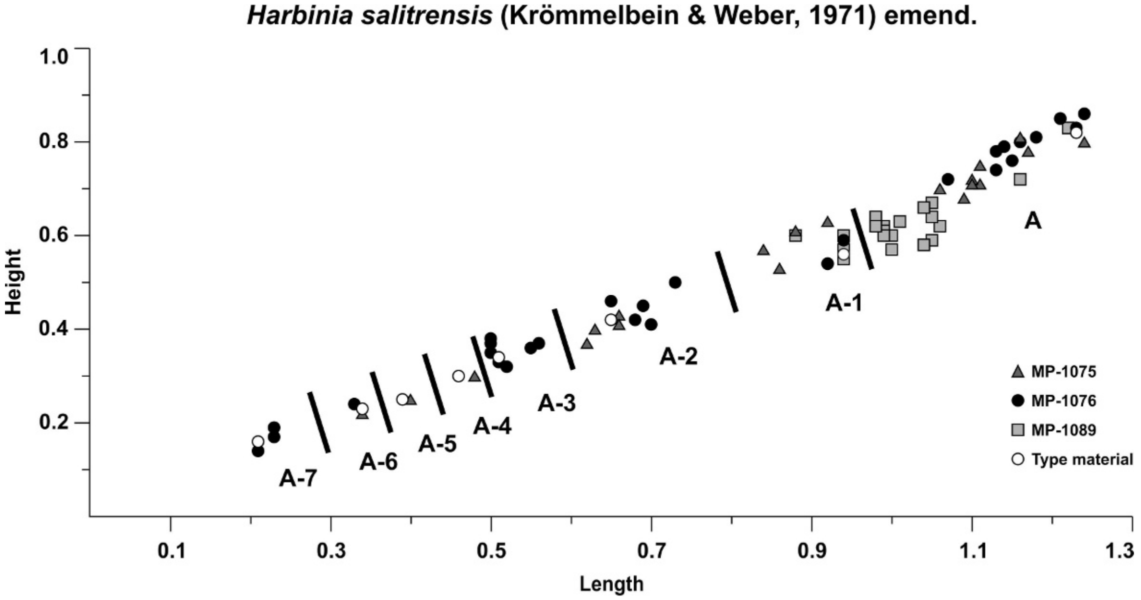

FIGURE 5—Instar size distribution for *Harbinia salitrensis* (Krömmelbein and Weber, 1971), Romualdo Member, Santana Formation, Araripe Basin, northeastern Brazil.

TABLE 3—Illustrated material of *Harbinia alta* n. sp., Romualdo and Crato members, Santana Formation, Araripe Basin, northeastern Brazil. Abbreviation: - =not measured.

Specimen	Sample	Instar	Length (mm)	Height (mm)	Width (mm)
CP-584	MP-931	Adult	0.84	0.59	0.43
CP-423	MP-931	A-1	0.60	0.41	-
CP-586	MP-931	A-2	0.46	0.35	-
CP-426	MP-931	A-3	0.36	0.26	-
CP-587	MP-931	A-4	0.29	0.22	-
CP-427	MP-931	A-5	0.22	0.18	-
CP-614	MP-1109	A-6	0.18	0.15	0.08
CP-612	MP-1109	A-7	0.14	0.10	0.06

and from A–3 to A–1 instars; not fully observable in A–4 and A–5 individuals. From dorsal view, broadly fusiform with the greatest width at the postero-median region. Juveniles from A–7 to A–1 vary from a subtriangular (A-7 to A-3) to subovate (A-2 and A-1) shape with an overlap area that is progressively more preeminent while still less apparent than in adults.

Occurrence.—Codó Formation, São Luís-Grajaú Basin (Ramos et al., 2006). Brazil, Araripe Basin, Santana Formation, Aptian (Krömmelbein and Weber, 1971); possibly also in the Aptian of the Congo, Gabon and Angola basins (Bate, 1999). In the present work, Romualdo Member, Araripe Basin in the samples MP-1075, MP-1076 and MP-1089, well IPS-12-CE, city of Jardim, Ceará State, Brazil.

Remarks.—*Harbinia salitrensis* is redescribed due to a lack of detailed figuration in the original work by Krömmelbein and Weber (1971) and an incomplete, and possibly inaccurate, description, considering that the holotype was deformed by diagenetic processes. A single A–1 specimen covered with pyrite presented a slightly rounded, striated outer surface, also likely due to diagenesis. Because the specimens identified as *Pattersoncypris angulata salitrensis* in Bate (1999, p. 289) were insufficiently illustrated, they could not be reviewed properly. In the present work, therefore, this occurrence is considered dubious. The ontogenetic series was recovered, except for the A–8 instar. Thus, the specimen originally described as an adult is, in fact, from the A–2 instar. A study on the size distribution of instars was also made, which is presented here for the first time (Fig. 5). The results were similar to those of Bate (1972) and Smith (2000) for *H. micropapillosa* (Bate, 1972) in which seven and eight instars were identified, respectively.

HARBINIA ALTA new species
Figure 4.1–4.10

1971 *Hourcqia angulata angulata* Krömmelbein and Weber; VIANA, BRITO AND SILVA-TELLES JR., 1989, p. 216, figure 2a–2c; DÉPÊCHE, BERTHOU AND CAMPOS, 1990, pl. 1, figures 1, 2; SILVA-TELLES JR. AND VIANA, 1990, p. 320, figure 3.3.

2006 *Harbinia angulata* (KRÖMMELBEIN AND WEBER); RAMOS, ROSSETTI AND PAZ, p. 343, figure 4E–4H.

Diagnosis.—Middle-sized carapace, subtriangular to subovate in lateral view. Antero-dorsal hump well developed. External surface covered by small angular reticulation, tightly distributed and somewhat parallel to the margins. Anterior end of the right valve with a striated flange, which overlaps the left valve along the free margin.

Description.—Carapace subtriangular in lateral view, with greatest height at the antero-median region and greatest length along the ventro-median region. Left valve larger than the right, overlapping it along the antero- and postero-dorsal margins; right valve overlapping the left along the anterior end and the central and postero-ventral margins. Dorsal margin slightly convex with a pronounced hump close to the antero-dorsal margin; hinge line straight, obliquely inclined to the posterior end; cardinal angle visible on both valves. Ventral margin substraight. Anterior end rounded. Posterior end slightly supracurvate. External surface covered with rows of reticulation that are densely packed and somewhat parallel to the margins. From dorsal view, elliptical to fusiform, with greatest width at the postero-median region. Juveniles from A–5 to A–1 subtriangular, with an overlap area that is progressively more preeminent but still less apparent than in adults. Ornamentation varying from smooth (A-7) to reticular (A-4 to A-2) to adult pattern (A-1).

Etymology.—Based on the well-developed dorsal hump, which gives the species a higher height/length ratio compared with other species of *Harbinia*.

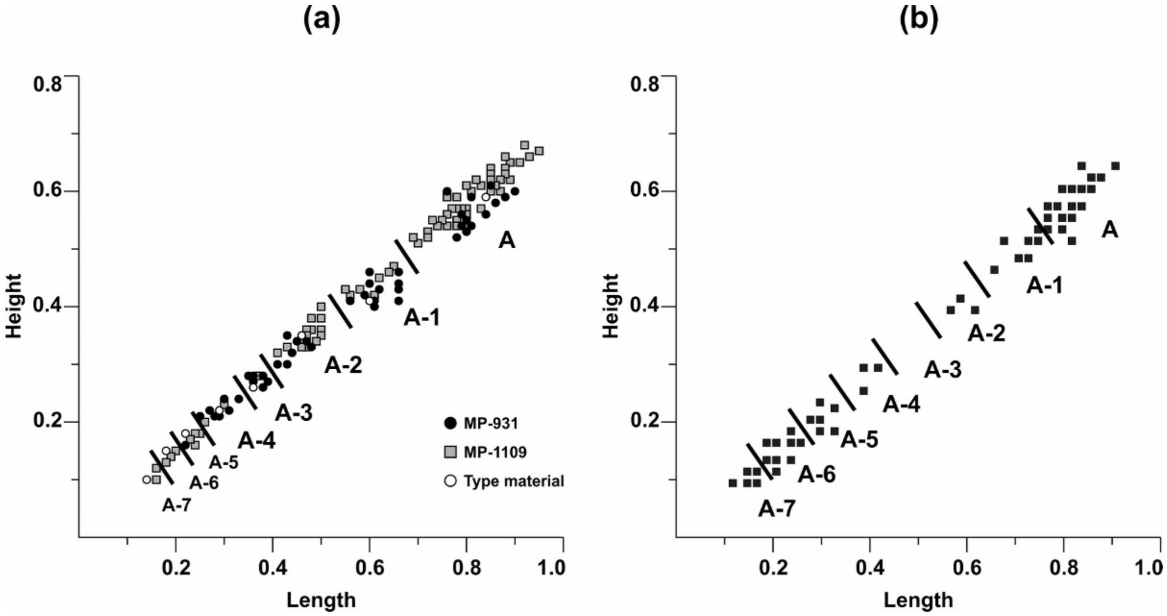

FIGURE 6—Instar size distribution for (a) *Harbinia alta* n. sp., Crato (Ipubi layers) and Romualdo members, Santana Formation, Araripe Basin, northeastern Brazil, compared with (b) *H. alta*, Romualdo member, in Viana et al. (1989).

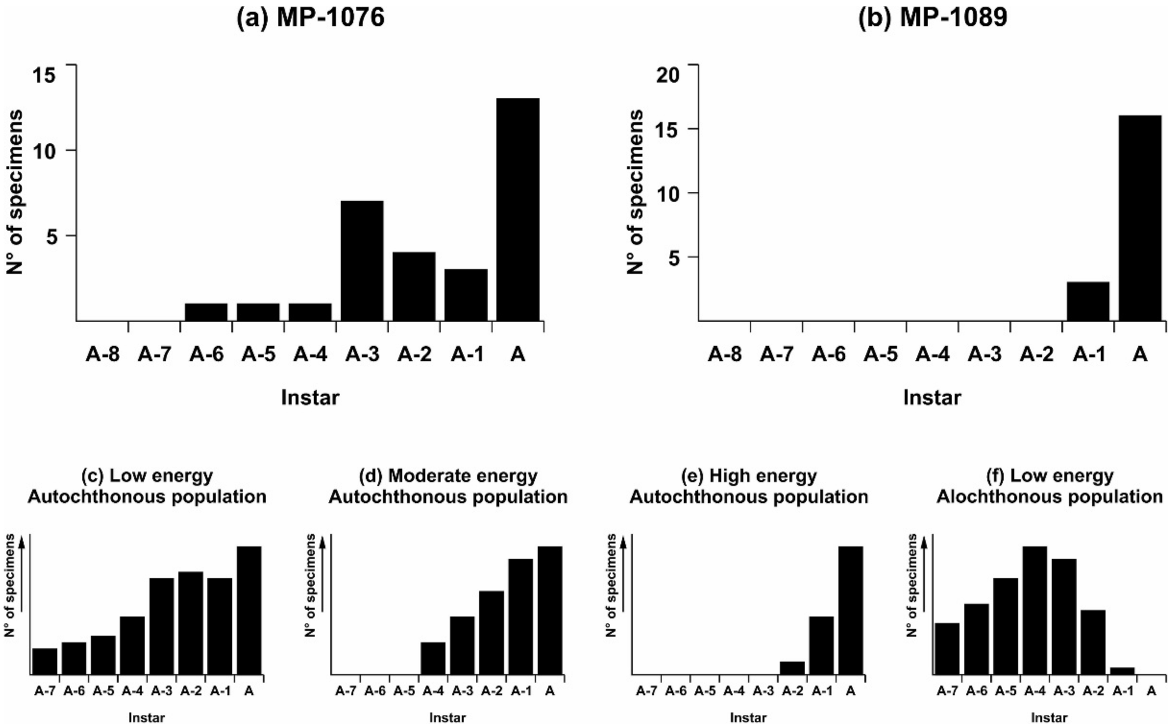

FIGURE 7—Population age-structure in samples MP-1076 (a) and MP-1089 (b), Romualdo Member, Santana Formation, Araripe Basin, northeastern Brazil, compared with possible interpretations (c–f) (Whatley, 1983, 1988; Boomer et al., 2003).

Types.—CP-584 (carapace), holotype; CP-423, CP-426, CP-427, CP-587 (right valve) and CP-586 (left valve) (Table 3), paratypes; upper Aptian, lower Cretaceous; Romualdo Member, Santana Formation, Araripe Basin.

Occurrence.—Brazil: Pará-Maranhão Basin, Codó Formation, late Aptian (Ramos et al., 2006; Soares et al., 2007). Araripe Basin, Santana Formation, Crato and Romualdo members (Viana et al., 1989; Silva-Telles Jr. and Viana, 1990), ?Aptian–?Albian (Regali, 1990; Coimbra et al., 2002). In the present work, Ipubi layers, Crato Member, Araripe Basin, in the sample MP-1109, IPS-11-CE well, city of Crato, Ceará State, Brazil; and Romualdo Member, Araripe Basin, in the sample MP-931, CAMPEVI quarry, city of Araripina, Pernambuco State, Brazil.

Remarks.—Variations in ornamentation from younger to older instars of *Harbinia alta* are assumed by the authors to be a consequence of the morphological development from larval instars to the Adult instar. The overlapping pattern for *H. alta* differs from other species of *Harbinia*, in which the left valve overlaps the whole free margin of the right one. In *H. alta*, the right valve also overlaps the left one, at the anterior end and between the postero-ventral margin and the posterior end (Fig. 4.1–4.3). *Harbinia alta* presents a reticulated ornamentation pattern similar to those of *H. symmetrica* (Krömmelbein and Weber, 1971) and *H. angulata* (Krömmelbein and Weber, 1971). They, however, diverge on the height/length ratio (greater in *H. symmetrica*) and position of the greatest height (more anterior in *H. alta*). Specimens identified and illustrated as *Hourcqia angulata angulata* in Viana et al. (1989), Dépêche et al. (1990) and Silva-Telles Jr and Viana (1990) also belong to *H. alta*. Compared with those in Krömmelbein and Weber (1971), they present different height/length ratios and ornamentation patterns (papillose rather than reticulate). Specimens of *H. angulata* identified by Ramos et al. (2006) also belong to *H. alta*. Herein, an ontogenetic series of the species is presented (except for the A–8 instar) along with a graphic of instar size distributions from Viana et al. (1989) for

TABLE 4—Abundance, dominance and diversity of species per sample, Crato (Ipubi layers) and Romualdo members, Santana Formation, Araripe Basin, northeastern Brazil.

Sample (Member)	Species identified	Number of specimens	Simpson index/λ	Shannon index/H′
MP-931 (Romualdo)	*Darwinula martinsi*? Silva, 1978 emend.	7	0.91	0.21
	Harbinia alta n. sp.	2075		
	Ilyocyprimorpha sp. 1	3		
	Gen. et sp. indet. 1	92		
MP-1076 (Romualdo)	*Harbinia salitrensis* (Krömmelbein and Weber, 1971) emend.	51	0.86	0.3
	Talicypridea? sp.2	1		
	Gen. et sp. indet. 1	3		
MP-1089 (Romualdo)	*Harbinia salitrensis* (Krömmelbein and Weber, 1971) emend.	50	1	0
MP-1109 (Crato)	*Darwinula martinsi*? Silva, 1978 emend.	1	1	0.01
	Darwinula? sp1	3		
	Harbinia alta n. sp.	5,314		
	Talicypridea? sp.1	1		
	Gen. et sp. indet. 1	1		

comparison (Fig. 6). The results obtained are similar to those of *H. micropapillosa* in Bate (1972) and Smith (2000), where seven and eight instars were identified, respectively.

PALEOECOLOGY

The paleoecological analysis in the present work is focused on population age-structure studies and the quantitative evaluation of diversity. The main objective is to access paleoenvironmental conditions during the late Aptian–?early Albian of the Araripe Basin.

Differentiation between allochthonous and autochthonous populations can be useful for determining paleoenvironmental characteristics. Carapaces from different ostracode instars possess unique hydrodynamic properties based on shape, size and weight; consequently, the differential transport of these carapaces allows energy levels for paleoenvironments to be evaluated. When different instars from a species are preserved in a fossil assemblage, four types of population age-structures can be identified, according to Whatley (1983, 1988) and Boomer et al. (2003) (Fig. 7c–7f).

Many indices have been proposed to access diversity in paleoenvironments (Simpson, 1949; Whittaker, 1972, 1977; Krebs, 1989; Clarke and Warwick, 2001). In this work, the Simpson and Shannon indices are used. The Simpson, or dominance, index (λ) (Simpson, 1949) can be expressed by the following formula:

$$\lambda = \sum_{i=1}^{S} \frac{n_i(n_i-1)}{N(N-1)}$$

where "n_i" is the number of individuals of "i" species, and "N" is the total number of all individuals counted. The Simpson index represents the probability of two randomly selected individuals in the habitat belonging to the same species.

The Shannon index (H′), sometimes referred to as the Shannon-Wiener or Shannon-Weaver (Krebs, 1989), associates the number of species with its evenness. It has probably been the most widely used index in community ecology for comparing diversity between various habitats (Clarke and Warwick, 2001). The following equation is used to calculate it:

$$H' = \sum_{i=1}^{S} p_i \ \ln \ p_i$$

where "S" is the total number of species and "p_i" is the frequency of the "i"th species.

All the instars from Adult to A–7, both for *Harbinia salitrensis* and *H. alta* n. sp., are present in the studied material. Both samples in which *H. alta* occurs, MP-931 (Romualdo Member) and MP-1109 (Ipubi layers), despite low diversity, yielded countless well-preserved and recoverable specimens. Thus, population age-structures are not easily recognizable because measuring all individuals (height and length) is fundamental to identify their life stage. Limnic, low to moderate energy paleoenvironments are inferred from the occurrence of *H. salitrensis* in MP-1076, which was considered autochthonous (Fig. 7a). In MP-1089, high energy levels may also be possible (Fig. 7b), but the population age-structure observed could actually result from diagenetic processes because approximately 12 internal casts of smaller juvenile carapaces, probably from the A–3 and A–4 stages, were identified. Such an age-structure would be typical of moderate environmental energy levels.

The studied samples presented assemblages dominated by either *Harbinia alta* (MP-931 and MP-1109) or *H. salitrensis* (MP-1076 and MP-1089) without co-occurrence. The values for the Simpson index ranged between 0.86 and 1.00 (Table 4). Such high dominance situations, as suggested by Hudson (1990) and Boomer et al. (2003), indicate overall stressed environments, possibly brackish to hypersaline waters, where opportunistic species become abundant. The same can be inferred, also according to these authors, from the low diversity levels indicated by the Shannon values, which ranged from 0.00 to 0.30 on the studied samples.

DISCUSSION

Harbinia salitrensis was associated with well-established limnic paleoenvironments in the Araripe (Silva-Telles Jr and Viana, 1990) and Pará-Maranhão (Ramos et al., 2006) basins. In particular, populations shown by Ramos et al. (2006) tended to be small and non-dominant. These approaches were not corroborated by Bate (1999), who reports abundant and strongly dominant populations of this species inhabiting salinity-stressed paleoenvironments in the African basins of Angola, Congo and Gabon. The present results from the Araripe Basin are in comformity with Bate (1999). Therefore, *H. salitrensis* can be considered a euryhaline species, occurring in a wide range of salinities, until becoming dominant in mixohaline environments.

Harbinia alta n. sp. inhabits strata in the Santana Formation with paleosalinities ranging from hypersaline (Ipubi layers) to mixohaline (Romualdo Member) in the Araripe Basin and under similar environmental conditions in the Pará-Maranhão basin (Ramos et al., 2006). Considering these approaches to paleoecology, *H. alta* could also be considered euryhaline. Assine (2007) made an extensive review of the Ipubi layers; the unity, traditionally considered a sterile, continuum gypsum layer, also presents fossil-rich marl and shale deposits. The occurrence of *H. alta* was strongly associated with these strata (where it represented the virtual totality of the ostracodes recovered) but also with more suitable, although still stressed, environments in the basal section of the Romualdo Member.

The dominance of *Harbinia micropapillosa* in strata of the Romualdo Member is usually related to mixohaline lacustrine to lagoonal paleoenvironments, sustained by pulsative marine ingressions that prevented the development of highly diverse ostracode faunas (Arai and Coimbra, 1989; Coimbra et al., 2002). Some species of *Harbinia* constitute monospecific assemblages under dysoxic environmental conditions in the Crato and Romualdo members and in the adjacent Barbalha Formation (Viana et al., 1989; Dépeche et al., 1990; Berthou et al., 1994). Both approaches are considered by Silva-Telles Jr and Viana (1990), although they state that such high population densities, as observed in some strata of both formations, must be supported by high levels of water-dissolved oxygen.

The results obtained from the Simpson and Shannon calculations for *Harbinia alta* and *H. salitrensis*, along with the population-age structures of *H. salitrensis*, allowed the interpretations made by previous authors about the paleoecology of the Santana Formation upper sections to be quantified. According to the present data, the dominance, diversity and environmental energy levels are in conformation with a general paleoenvironment that comprises lacustrine to lagoonal systems composed by shallow water bodies with relatively common periods of hypoxia. These environments would favor the massive occurrence of species tolerant to high salinity variations, as is the case for *H. alta* and *H. salitrensis*.

CONCLUSIONS

Two ostracode species from the Araripe basin, *Harbinia salitrensis* (Krömmelbein and Weber, 1971) and *H. alta* n. sp., had their ontogenetic series (except for the A–8 instar) recovered, illustrated and characterized. Additionally, *H. salitrensis* was redescribed. Both species are relevant to biostratigraphical, paleozoogeographical and paleoecological studies on the Alagoas Stage in Brazil. Therefore, providing accurate taxonomical analyses for both is of main importance. Studies on the Aptian–Albian zonation of western Africa basins may also be improved because occurrences of *H. salitrensis* have been recorded in the Congo, Angola and Gabon basins.

Results on the study of population age-structure and ecological indices of *Harbinia salitrensis* and *H. alta* quantify and sustain previous interpretations of the Ipubi layers and basal Romualdo Member paleoenvironments. Coimbra et al. (2002) and Assine (2007), based on micropaleontological and lithostratigraphic data, state that these strata were mainly deposited in lacustrine/lagoonal systems characteristic of the Brazilian lower Alagoas Stage. This interpretation is confirmed by the data from the present work, which show low to medium environmental energy levels, specific high dominance and low diversity of the studied samples from the Santana Formation.

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